THE WORLD AROUND US

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A
SURVEY OF SCIENCE

Distinguishing features of

I. THE WORLD AROUND US

Its underlying aim, the same as that recommended in the Thirty-first Yearbook. Read the preface beginning on page iii.

Its organization into large units of work, each developing a large concept. Note the unit titles beginning on page ix.

Its pupil foreword, establishing at the outset the general theme and point of view of the book. Read pages xv to xix inclusive.

(over)

Its unit and chapter approaches, consistently awakening desirable interests and points of view. Read pages 4, 5, and 6.

Its smoothly developed chapters, with uninterrupted learning periods. Glance through pages 8 to 26.

Its concise summaries, establishing firmly the desirable interests and points of view previously awakened. Turn to page 27.

Its questions and things to do, stimulating many vicarious experiences and actual contacts with scientific phenomena. Turn to pages 27, 28, and 29.

Its illustrations, assisting the pupil materially to arrive at the desired understandings. In examining the organization and content of the other chapters, note the unusual quality of the illustrations throughout the book.

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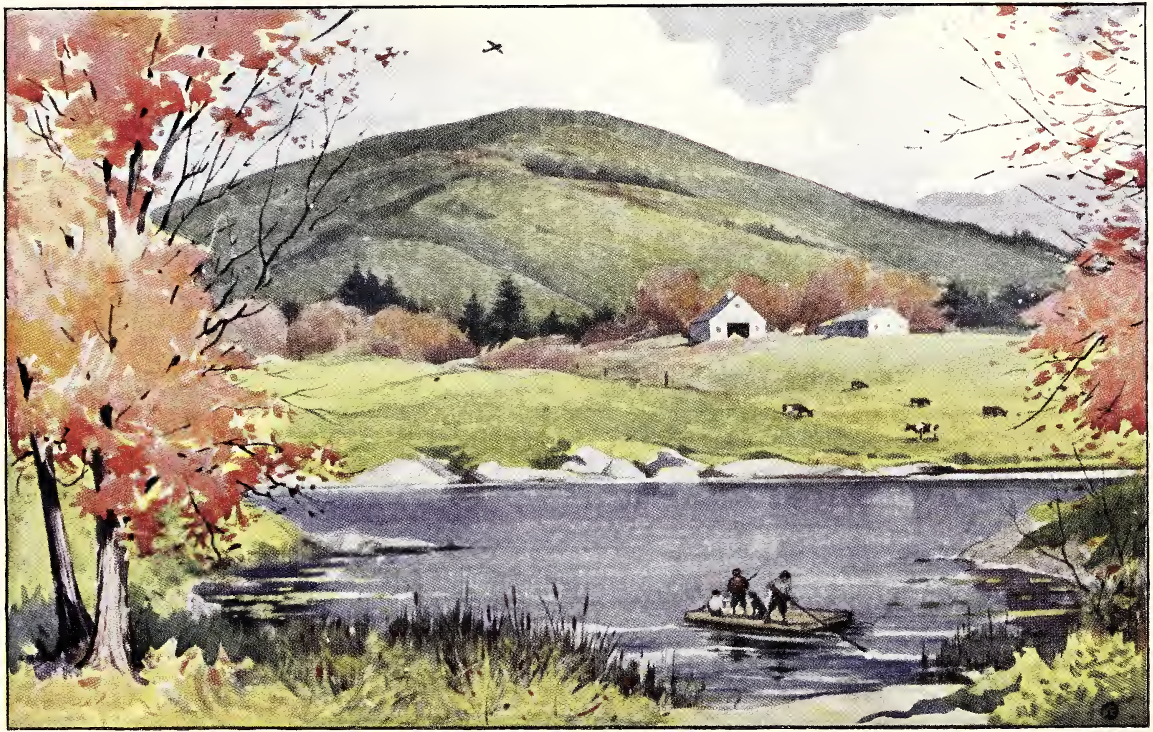

Sears Gallagher

Our Environment consists of All the Things around Us

A · SURVEY · OF · SCIENCE · I
FOR JUNIOR HIGH SCHOOLS

The World Around Us

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Preface

This series has been prepared for use in the junior-high-school grades. The books are equally appropriate for such use, whether or not the grades are incorporated in a junior-high-school organization.

The authors have been guided in this work by the recommendations set forth in the report "A Program for Teaching Science," in the Thirty-first Yearbook of the National Society for the Study of Education (1932), Part I. In this report it is recommended that: "The science courses of the seventh, eighth, and ninth grades should be considered as an integral part of the program of science instruction for the period of elementary and secondary education. The science of this level should, on the one hand, be built upon and comprehend the science of the first six grades; it should, on the other hand, serve as a basis for an orientation into the special sciences of the high school for those who are to continue beyond the ninth grade. Above all else, it must provide the most worth-while science experiences possible for the pupils on this level, and it must be in accord with the acceptable objectives of a liberal education for boys and girls of ages twelve to sixteen years."

In this report of the National Society for the Study of Education, there is a list of principles and generalizations which, taken collectively, define the major contributions of science to human welfare and to human interests. This list of principles and generalizations, with some additions and modifications, has been used for guidance in the selection of instructional material used in these books.

The present series constitutes A Survey of Science. It is an exploratory survey of the areas of scientific achievements defined by the important principles and generalizations. The series is designed to give to children an acquaintance with, and an ability to use, the products of scientific achievements that are interesting and important in the general, unspecialized intellectual and practical activities of educated laymen. The criteria set forth in the yearbook in the chapters on "The Objectives of Science Teaching in Relation to the Aim of Education," "The Psychology of Science Teaching," and "Science in the Seventh, Eighth, and Ninth Grades" have been carefully considered in the selection and organization of the instructional material used in these texts.

The point of view that is developed in this report of the National Society for the Study of Education and accepted in this series is that the aim of instruction in science is threefold:

1. To develop an understanding of, together with an ability and desire to use, those scientific attainments that may function in intellectual experiences most common to everybody.
2. To develop some understanding of, together with an ability and desire to use, some of the methods by means of which scientific attainments have been achieved.
3. To engender the scientific attitude of respect for truth and for scientific methods.

It may be expected that the attainment of this threefold aim will function in the lives of maturing youths and in their lives as adults as a continuous stimulation to wholesome intellectual endeavors and as a constant source of personal satisfaction due to an enriched appreciation.

For the attainment of this aim these books furnish a wealth of vicarious experiences and suggestions for actual contacts with challenging scientific phenomena. At the end of each chapter there are many carefully prepared aids to learning which take the form of direct experiences. These are arranged under the following heads: "Can You Answer these Questions?" "Questions for Discussion," and "Here are Some Things You May Want to Do."

These direct and vicarious experiences supplement each other in developing for the learner a continuous enlargement of understanding of important principles and generalizations, and serve to develop an increasing ability to use scientific methods of work.

The one theme that runs through these books is "Living things — including man — are dependent upon one another and upon the physical environment." The course develops an understanding of the ways in which this dependence functions. In the first book of the series emphasis is placed upon getting acquainted with the world around. The second book recognizes as a major theme the changes that are going on in living and nonliving things. In the third book the emphasis is upon control of physical and biological phenomena. These three features — acquaintance, change, and control — find recognition in each book, but the progress throughout the series is toward an increasingly intensive study of controls and an enlarged understanding of the extent to which man has broken the boundary of space and time in his efforts to attain a more satisfying adaptation to his environment and a fuller understanding of his place in the cosmos.

Experiences of exploration and adventure, similar to those associated with camp life, field work, club activities, and travel, have been used extensively in the writing. The experiences told in the text serve to enrich the activities associated with the recreational features which come normally into the lives of pupils of junior-high-school age and which constitute such an important part of their educational program. This is especially timely, since this generation of youth will have, as adults, larger opportunities for recreational activities than any preceding generation has ever enjoyed.

Throughout the series there is a continuous development of understanding of the positive aspects of health. These take the form of understanding the functioning of the normal and vigorous human body, to the end that the pupil may acquire a respect for his most precious possession. The needs for corrective measures in the control of health are recognized in the chapters that develop the procedures for control of bacterial and other forms of parasitic organisms that cause disease, and in the chapters that show the relations of foods to health. The field of health offers illustration of the manner in which science has contributed to the development of modern standards of living. The importance of sanitary measures and the penalties of ignorance in the form of illnesses with attendant losses to the community are well known. The science of sanitation has shown us how to protect crowded cities and rural communities from contagious diseases which, if uncontrolled, would be terribly destructive. Throughout the books may be seen a continuous development of scientific concepts that are functional in the thinking associated with personal and social adjustments.

The World Around Us is organized into relatively few teaching units, each of which is divided into conveniently arranged chapters. Each of these units develops understandings in some field of human interest. The instructional material of the unit is brought together because it belongs together for the development of an understanding of the problems associated with the unit.

In this first book the aim is to assist the learner in his progress toward the attainment of an acquaintance with, and an understanding of, the world of living things and their physical environment. Such an attainment is seen as one which associates meanings with observations. An obvious feature of each unit is, therefore, observations and their interpretations.

The objective of each unit is to attain understanding within the area suggested by the question with which the unit is introduced. The chapters within the units present an array of learning experiences that give to the learner an orientation within the field of the major objective. These experiences are presented and associated into a continuous development. There are no interruptions within the chapter with exercises or other forms of teaching devices. Reading the chapter gives to the pupil a composite picture of some situation that has in it rich potentialities for further study. The aids to learning at the end of each chapter guide the pupil to further learning through direct observation and experimentation.

Obviously, the aim of instruction in science is more than understanding. It is understanding, plus ability to attain further understanding through the use of scientific methods. Ability to use the scientific method may be expected to result from practice in the use of the scientific method, especially when applied within an interesting area.

Through the study of these units in science, pupils should gain in ability to do independent thinking in this large field. Success in thinking is conditioned upon a wealth of ideas and upon recognition by the learner of challenging problems. These units set up problem situations that, because of recognized interest and importance, really challenge boys and girls. The demands of a favorable learning situation have been met when such problems arise and when the learner may participate vicariously and directly in the experiences which develop the ideas for their solution.

In the preparation of the manuscript for this book the authors have received assistance from many sources. They are deeply indebted to their colleagues in Teachers College and New Rochelle and to experienced teachers who have been students in their courses. It is a pleasure to acknowledge especially the indebtedness to Mr. Arthur V. Linden of Teachers College for his constant and original work in bibliographical research and in adapting certain sections of materials for pupils' use, and to Mr. Herbert J. Arnold, formerly of Lincoln School and now of New Col-

lege, for invaluable assistance in developing outlines and for constructive criticism on many parts of the manuscript. Also to Mr. N. Eldred Bingham, now of Lincoln School, who has read all the manuscript and has assisted very substantially in the selection of materials for the bibliography. Mr. Merwin Milne Peake of the Elizabeth, New Jersey, schools has read all the manuscript and has offered suggestions especially relating to the exercise material included in the book. Mr. O. E. Underhill and Miss June M. Common have assisted in many ways.

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To the Readers of this Book

Have you ever read *Robinson Crusoe*? If so, you remember how he was shipwrecked and found himself on the shores of a strange land about which he knew nothing at all. Do you recall one of the first things he did? Let him tell you in his own words:

> My next work was to view the country, and seek a proper place for my habitation, and where to stow my goods to secure them from whatever might happen; where I was I yet knew not, whether on the continent or upon an island, whether inhabited or not inhabited, whether in danger of wild beasts or not. There was a hill not above a mile from me, which rose up very steep and high, and which seemed to overtop some other hills which lay as in a ridge from it northward; I took out one of the fowling pieces, and one of the pistols, and an horn of powder, and thus armed I travelled for discovery up to the top of that hill, where, after I had with great labor and difficulty got to the top, I saw my fate to my great affliction, *viz.* that I was in an island environed every way with the sea, no land to be seen, except some rocks which lay a great way off, and two small islands less than this, which lay about three leagues to the west.
>
> I found also that the island I was in was barren, and, as I saw good reason to believe, uninhabited, except by wild beasts, of whom, however, I saw none, yet I saw abundance of fowls, but knew not their kind, neither when I killed them could I tell what was fit for food, and what not; at my coming back, I shot at a great bird, which I saw sitting upon a tree on the side of a great wood. . . .

When Robinson Crusoe looked from the top of the hill, he was beginning a survey of his surroundings. You will remember that after he returned from the hill, he made many trips to the wrecked ship and brought ashore as large a supply of foods and other necessities as he possibly could to prepare himself for a long stay on the island.

The rest of his adventure you know if you have read this interesting story. After looking around him from the top of the hill, he knew that he would need to survey each part of the island quite carefully. In other words, he was wise enough to know that the more he knew about his surroundings, or his environment, the better he would be able to make proper preparations for the life he would probably have to live.

Although you are not wrecked on a desert island, it is still true that the more familiar you are with the world around you, that is, your environment, the more satisfactorily you can live.

Throughout your work in science you will find one word used time and time again. That word is *environment.* What does it mean? What relationship has it to the story of science we have just discussed?

Many people define the word as meaning their surroundings. If you asked them to explain this a little further, they would probably say that the environment is made up of many things, — the trees, the land, the water, the sky, people, houses, automobiles, — all the things which they feel, hear, and see around them.

As you read this book you will find, we think, that we too include all these things in our definition of the environment. But we hope you will find that we have tried to make the word mean more than just this, by including as a part of the environment all the forces which result from the relation of living and nonliving things to each other, and also the thoughts and beliefs which have come as the result of increased knowledge. Thus our definition of the environment includes three parts rather than one.

When we wrote this book, we tried to make a survey of the most important and interesting things in different environments. We called this book *The World Around Us.* We wanted to give you an opportunity to look over the field of science which explains the different types of environments, so that you might make preparations for more interesting and satisfactory living.

Science, as you know, is a large field. Thousands of men and women have worked in it for years and have made a record of their findings. When you go to the library again, ask the librarian to show you where the science books are. Look over a few of them, and see the many different things about which they tell you. You will find many books about living things, such as trees, plants, and flowers; birds, insects, fish, and other animals, including man himself. You will find books about nonliving things — the stars, the rocks and minerals of the earth, and the great bodies of water which cover the earth.

"Ah," you say, "science is the story of the things around us; the story of animals, of plants, of stars, of the rocks and the soil, and of the oceans!" Yes, all these things are part of the story of science. But there is more to the story.

Science is not only the story of the living and nonliving things which make up the earth, but also the story of how these things are related to one another. Differences in nonliving things make differences in living things, and, strange to say, differences in living things often make differences in nonliving things.

"Well," you say, "the story of science is a big one." Yes, it is, for we haven't included everything yet. There is still another part of the story, and a tremendously important one. It is the whole story of how people have changed their ways of living and thinking as a result of science.

Has science, then, changed thinking? Of course it has! The point of view we take in regard to many problems has become broader. For example, science, after first enabling us to travel and to send messages swiftly, has taught us to think more justly about people whose customs differ from ours.

Look at the way in which people live today as contrasted with life some hundreds of years ago. People today are healthier, and their foods and recreation are more varied. Life in general is in many ways more interesting today than it was even as recently as half a century ago. If you do not believe this, read some stories of life in the middle 1800's, not only in this country but abroad.

"But," you may say, "this is a tremendous story! Can I hope to learn it?" Our answer would be that no one can learn all of it. Not even the greatest scientists of today know all of it. You can, however, learn some extremely interesting parts of it.

These parts we have placed in three books which we have called A Survey of Science. The title of the first book is *The World Around Us.* In it we have tried to discuss with you a few of the simple things which make up the environment. In the second book, called *Our Changing World,* we have tried to explain some of the interesting changes which take place in the environment. In the third book, *Man's Control of his Environment,* we tell how man is able to control to a certain extent some of these changes as a result of his increased knowledge of the environment. In all three books we have tried to show how man's thinking and activities have changed as his knowledge has increased.

Now let us tell you a little more about *The World Around Us.* In it you will find pictures of life in different environments, and you will see how this life depends upon certain things in these various environments. We have tried to explain what these things — air, water, and soil — really are. We have tried to give answers to some very simple questions, such as What is water? What is air? What is rain? What is soil?

A little farther on in the book we have tried to explain certain forces in the environment which seem very simple. What, for example, is heat? How does it travel from place to place? What changes are those which the chemist calls chemical changes?

Finally we have tried to tell you something about the story of life itself. How does a tree grow? What happens when we breathe? Why do all of us have to eat? How does food help us to grow? In this part of the book you will see how air, water, soil, and sunshine combine to make life possible.

Has all the story of science been written? It certainly has not. While man has been able to record some parts of it, and reveal other parts so that much clearer thinking may be done, even the ablest scientists tell us that we are just beginning to learn the meaning of science and to realize its possibilities. Every day brings new achievements.

How far can man go? No one knows. The whole future lies ahead. Some of you who read these books will doubtless play an important part in pushing the boundaries of scientific knowledge still farther.

THE AUTHORS

A SURVEY OF SCIENCE

BOOK ONE

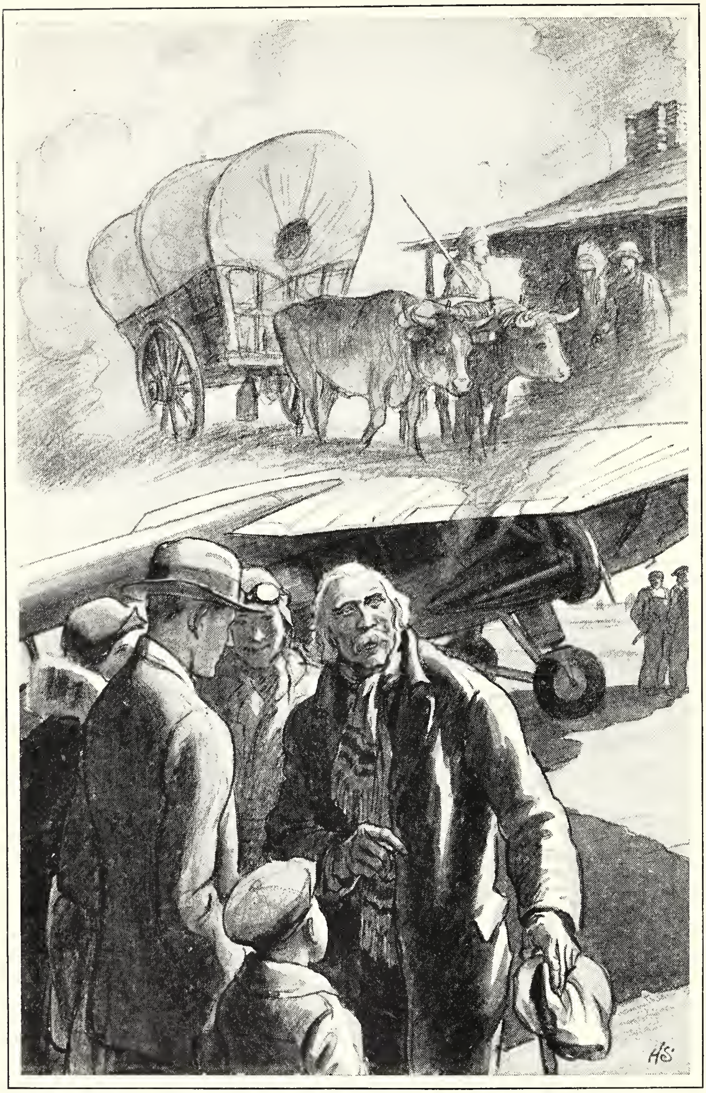

FIG. 1. Science has brought Many Changes in the Lives of People

UNIT I

What is Science?

Chapter I • What are Some of the Contributions of Science to Modern Living?

THIS is an age of science. Books, magazines, and newspapers are full of news about all sorts of everyday happenings in the world of science. If you should keep a list of what you read in science over the short space of a week or two, it might include any or even all of these:

Daily weather reports.
Stories of new records made in aviation.
Descriptions of new machines or improvements made on old machines.
Reports of flower shows, garden clubs, cattle shows, or state fairs.
Accounts of new discoveries in medicine.
Information about the stars, the planets, a coming eclipse, or possibly about a comet.
Historical sketches of important discoveries or the lives of prominent men such as Edison, Bell, Einstein, and others.

You might wish to make such a list or to save the clippings of what you read. Try it and you will probably find many things you will wish to save.

Perhaps you will not know whether all these things have to do with science. Perhaps you may want to ask some questions. Why are these things published? What have they to do with your own life? Why are people today so interested in science?

These questions may be more easily answered if one knows something about the story of science, what it is, and how it concerns each of us. We have tried to tell you a little of this story in the first unit of this book. After you have read it, see if you can answer the questions above.

Chapter I · What are Some of the Contributions of Science to Modern Living?

A. What has Science Done?

At the airport of a Middle Western town a group of curious people were crowded eagerly about an excited old man. No longer were they interested in the take-offs and landings of the planes about them. They forgot everything else as they listened to the old man's story.

For months he had been hearing about an airline between this town and the city on the river a hundred miles away. Well he knew that route by land, for as a young man he had carried goods hundreds of times over the forest cart paths and across the bridgeless streams to the "settlement" on the river. Five days and more it had taken him to make the journey, for the route he had been compelled to take was far from direct because of rapid streams and uncleared forests.

Recently he had been told that the airplanes which he had seen sailing so gracefully over the land were making the same trip in less than an hour. And so this morning he had journeyed by foot from his little home in the hills above the town to check for himself the stories about these strange new flying machines.

Today he had actually ridden in an airplane a hundred miles and back again, while it was yet morning. Proud and excited over his experiences, he was telling the visitors and airport employees about the times sixty years ago when he had made the trip between these same two places, at first in an oxcart and later with horses and wagon. This morning he had traveled by air! Finally breaking away from the curious crowd he shook his head and was heard to say to himself, "Five days in less than an hour! What next?"

"Five days in less than an hour! What next?"

But no one knows "what next" in a world of discovery and invention. Not a bit less remarkable than the recent progress in aviation are the finding of cures for diseases previously thought incurable, the discovery of methods of preparing more healthful and appetizing foods and ways of combining them into well-planned diets, the development of improved methods for transporting foods, the discovery of new planets and far-distant universes, and the invention and improvement of television. Within the last fifty years discoveries and inventions have been very numerous. Men of science are learning new things every day.

Most of the discoveries and inventions in science are comparatively recent

Most of the discoveries and inventions in science are comparatively recent. We think nothing today of picking up a telephone and calling our neighbors at the other end of town. On special occasions some of us have talked with relatives or friends at the other end of the continent. In the front pages of some of our telephone books you will find information telling you that you can talk to countries in Europe, South America, and even the Far East merely by calling the long-distance operator. Yet the telephone as such is only a little over fifty years old. When Alexander Graham Bell first succeeded in sending the human voice over a wire, his invention was looked upon as a novelty, sensational perhaps, but with little practical possibility. Now it is a part of everyday life.

In this age the airplane is so common that even a new flight across the Atlantic or the Pacific fails to create excitement. Yet the first flight of man in a motor-driven machine was made by one of the Wright brothers in 1903, a little over thirty years ago. That first flight lasted only a few seconds. Today endurance records are constantly being bettered.

These inventions, you may say, are fairly recent, but many of those around us must be much older; the locomotive, for example, or the steamboat or the automobile

SOME EVENTS IN THE HISTORY OF SCIENCE

1804	The first steam locomotive ran on rails
1807	Fulton began steamboat travel on the Hudson River with the *Clermont*
1824	Aspdin patented Portland cement
1834	McCormick patented his reaper
1844	Morse sent first telegram
1856	Bessemer announced a new process for making steel
1867	Lister announced a method of antiseptic surgery
1874	The first successful typewriter was put on sale
1876	Bell sent first telephone message
1877	Edison first reproduced spoken sound by the phonograph
1878	Edison introduced his carbon electric-light bulb
1882	The first commercial electrical power plant was placed in operation
1884	Parsons tested first model of his steam turbine
1885	Mergenthaler patented the linotype
1895	Four automobiles were produced in the United States
1901	Marconi sent and received the first wireless messages across the Atlantic Ocean
1903	Orville Wright flew the first motor-driven airplane
1905	The first motion-picture theater was opened in the United States
1907	De Forest patented the radio tube
1919	The first nonstop flight was made across the Atlantic Ocean from west to east
1924	First transcontinental day and night air-mail service was inaugurated
1927	Television first demonstrated between New York and Washington
1928	The first autogyro airplane was flown

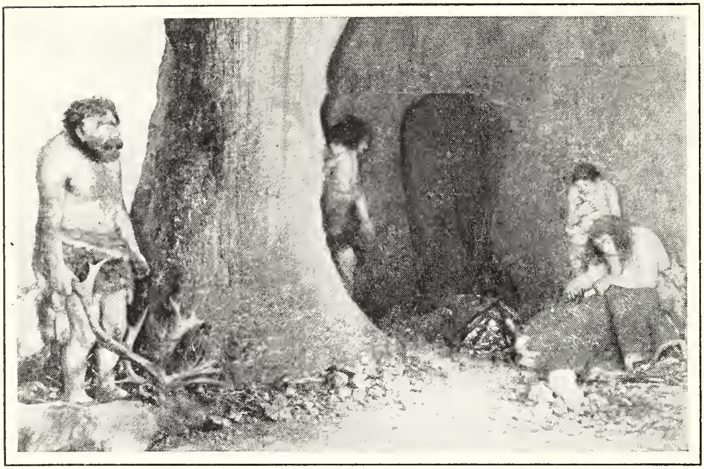

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Fig. 2. The Cave Man enjoyed Very Few of the Comforts which we have as the Result of Modern Science

or the typewriter. If you will refer to the list given on page 7, you will see that none of these is very old. True, they go back farther than the telephone or the airplane, but only a little. The first successful trip of a locomotive on rails was in 1804. Robert Fulton's *Clermont* first puffed its way slowly up the Hudson River in 1807. As late as 1895 only four automobiles had been produced in the United States, and the first successful typewriter was not put on sale until 1874.

The discoveries and inventions of science give us conditions for comfortable living

We look upon these and other inventions and discoveries as though they had been with us always. Yet most of them are less than a century old. This short space of a hundred years represents but a small fraction of the total life history of the human race. Although no one knows exactly how long man has been on the earth, from the evidence we now possess it seems certain that the story of mankind runs back many thousands of years. Consider the life of a family such as the one shown in Fig. 2. It is certain that for centuries such people lived in complete ignorance of many things we know today. More than this, they enjoyed very few of the comforts which have resulted from the work of scientists in comparatively recent times. They did not have the varied kinds of food, clothing, shelter, transportation, communication, or enjoyment that we have today.

Since man's ways of keeping records in that early period were inadequate or entirely lacking, he passed on to succeeding generations very little of the knowledge which he himself had gained. Our records are well kept, and a large part of our learning comes as a result of the knowledge passed on to us by those who have lived in previous generations. We can begin our discoveries where those of the men who came before us end.

B. What Part did Superstition and Fear play in the Days before the Growth of Science?

Away back in the dawn of history man knew very little about the natural forces which surrounded him. At some time during the long stretch of years in the past he had learned to use fire. At some other time he had learned to hollow out a log and take advantage of the streams and lakes for easier transportation and travel. Which of these did he learn first? No one really knows. Perhaps a period of a thousand years separated these two discoveries; perhaps a hundred thousand years. No one knows. Most of the phenomena of nature, however,— rain, lightning, day and night,— were just things that happened. Very little was known about them. Man had not discovered the laws which governed them.

Imagine yourself a cave man thousands of years ago. Your home is within the entrance to a gloomy cave under an overhanging mass of rock. You sit with your family huddled around a small smoky fire in the center of the floor.

The inky blackness of the night is broken slightly as a few ghostly rays of moonlight seep in through the opening of the cave. Suddenly even these are dimmed. The light of your fire throws strange, flickering shadows upon the walls. A feeling of uneasiness creeps over you. The air is still. You crawl to the opening of your cave and peer out. In the distance you see a flash of lightning as it touches the edge of a mass of black, wind-driven clouds. You hear faint rumbles of thunder. The wind which had died down rises again through the trees. A few drops of rain sprinkle the ground and rattle on its covering of dead leaves. The lightning becomes more vivid, the thunder louder and more continuous. You see the whirling clouds as they drive on, a tumbled black mass, blotting out the stars in their powerful sweep. Now the storm breaks in real earnest. Brilliant streaks of lightning flash across the sky. Terrific crashes of thunder blend in a deafening roar. Driven by the gale, torrents of water lash through the forest and rush down the mountain side. Trees above you are uprooted by the wind. A pine close by is shattered in a blinding, jagged blot of lightning. Trembling, you crawl back into your shelter to wait restlessly for dawn.

In primitive times man lived in constant fear of the natural forces of his environment

The next day you are still wondering about the night before. You ask someone, possibly an older member of the tribe, for an explanation of the terrific storm. He suggests one which you think is quite sensible. He reminds you that a few days ago you killed a deer in the neighboring forests. He points out that in your hurry to get home you forgot to make the customary offering to the favorite god of the tribe. The god became very angry at your neglect, the old man explains, and has shown you his power. You hurry to make a suitable offering. There are no more severe thunderstorms for several months, and you decide the advice of your neighbor was good. He is consulted more and more frequently about other natural phenomena.

The early magician was the "scientist" of the tribe

Perhaps all of you in the community of cave men decide that it would be a good thing if your neighbor would spend all his time in a new kind of work. He is to find ways for all of you to keep friendly with the gods who control your environment, and is to explain to you the strange things which are happening from day to day. Your neighbor is now given a special place in which to live. In order that he may not be disturbed, all sorts of rules and regulations are set up. None of the tribe is allowed to visit him except on special occasions. Certain ground is sacred to him alone. Here he is to meet with the gods for your benefit, and any trespassing will be an insult to the gods. Food and other necessities are to be given him. Soon your neighbor becomes the most powerful man in the tribe, feared by all because everyone thinks he confers with the gods.

Or perhaps your neighbor, being a little more clever than the rest of the tribe, decides for himself that it is much easier to spend his time in this new task than it is to work as the others do. Without any urging he begins to take to himself special powers and privileges which you in turn are glad for him to have.

In either case the result is the same. The first magician has begun his trade. Throughout the dim, dark pages of history you will find him practicing his secret ceremonies. He has not always been called a magician. He might be the medicine man, the soothsayer, the astrologer, or the witch doctor; but he has always been the wise man of his race, to whom everyone has gone in time of trouble and fear.

As his power increases, the wise man is asked more and more difficult questions. What is the sun? Why do we have day and night? Where does the rain come from? What causes heat and cold? Not knowing the true reasons in most cases, he invented more and more curious explanations for simple and natural phenomena. You have

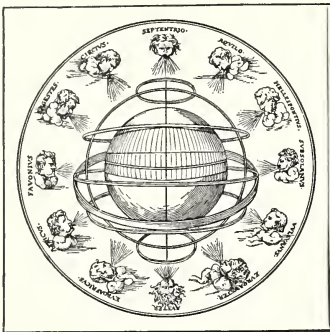

Fig. 3. The Ancients believed that these Gods were Responsible for the Winds

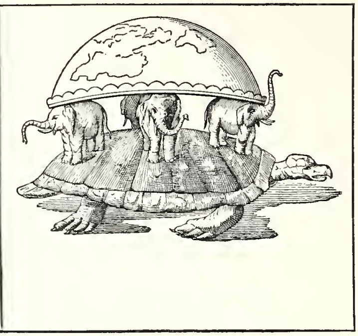

Fig. 4. Not so long ago, People believed that the World looked like This

read about many of these. The sun, to one tribe, was a polished plate of bright metal which was carried through the sky by a faithful god whose duty it was to see that the earth had heat and light. At the close of the day the plate was taken home and put away. While the group rested from their labors, night crept upon the earth. Many old maps of the world, such as the one in Fig. 3, show pictures of the wind gods with cheeks filled to bursting as they blew over the land and sea producing the winds which carried along the ships of ancient times. For a long time the earth itself was thought to be flat and saucer-shaped. Hence ships which failed to come back after a voyage were thought to have gone too far and plunged over the edge of the world. Fig. 4 pictures an early belief as to the shape of the earth, and how it was supported in space.

Primitive man explained his environment in terms of superstition

All these beliefs seem very foolish to us now, but they were matters of life and death then. Many people lost their lives or were horribly tortured because they dared to doubt some opinion expressed by the so-called wise men of the tribe or race.

It has been suggested that the men of early history were just as intelligent as we are. It is true that some of the races living thousands of years ago seem to have excelled us in certain arts, which we feel are the marks of superior intelligence. If you have read the story of the ancient Greeks, you know that in their sculpture, their buildings, their literature, their drama, and even in their form of government they set standards over two thousand years ago which command the respect and admiration of people today. As you see models of their beautiful buildings or the remains of their marvelous sculpture, and read their immortal dramas, you recognize that here was a people who in certain respects were possibly farther advanced than we are. Yet in spite of these brilliant achievements the Greeks were little superior to savage man in their understanding of many parts of their environment or the ways of controlling it. Some of the finest stories in Greek literature deal with the various gods, who, they believed, controlled the fate of mankind. Apollo, the god of the sun; Poseidon, the god of the sea; Zeus, the all-powerful father of gods and men — all these and a host of others were real beings to the ancient Greeks.

Even the Greeks with their comparatively high civilization knew little about the forces of their environment

They thought these gods controlled the environment and when displeased or angered could bring to the men on earth visible signs of displeasure in the form of terrific storms, earthquakes, thunder, lightning, and even failure of the crops. Since the gods were supposed to possess these powers, every effort was made to please them and to find out their wishes and desires. The help of the gods was usually sought when puzzling questions arose or important decisions had to be made. High on Mount Parnassus, at Delphi, stood a temple set apart as sacred to Apollo, the god of light. The Greeks believed that at certain times a priestess in this temple received from Apollo himself such advice and guidance as he wished to give to the people. This temple was but one of many sacred to the various gods. In all these dwelt ancient priests and priestesses who were supposed to be in direct communication with the gods and to get secret information and advice from them.

Here, then, we have a people highly advanced in culture and art and yet in many respects no further advanced than the savage primitive man. The environment of the Greeks was perhaps more favorable than that of primitive man, but their knowledge of the forces of that environment was in some respects just as limited. With the exception of a very few outstanding men they, like primitive man, depended upon superstition and magic for the explanation of things they did not understand.

What was true of the Greeks was also true of the Romans, and of other, comparatively modern civilizations. You can find examples of these superstitious beliefs even in the history of our own early American colonies, where witches, evil spirits, and other forms of monsters were honestly believed to roam the countryside.

If these civilized races had difficulty in understanding their environment, what must the life of man have been thousands of years before, when the environment was most unfavorable and the ways of living most rude?

C. Do Fear and Superstition play Any Part in Life Today?

Living in Africa and Australia — in fact, in certain parts of every continent today — there are people who still believe many of the same things that primitive man believed thousands of years ago. All their ways of living are colored by these beliefs. They hunt and cultivate the soil as did their ancestors before them. Their ways of worship have remained nearly the same for centuries. They

Fig. 5. The Lives of Many People today are ruled by Superstition

Here is a fakir tracing a horoscope in modern China

offer many of the same gifts and make many of the same sacrifices to their gods as did their ancestors in ancient days.

Science has caused many changes in what people believe. Our beliefs today are not the same as those of primitive man. He dared not question the advice offered him. To him his medicine man represented the gods. To question any statement of the medicine man, therefore, was to question the gods themselves. We do ask questions. We doubt things far more than did our primitive ancestors. We often hear people say: "I wonder if that's right?" "What do you know about this?" "Perhaps he's wrong." "What proof have you of that?" "I'll look it up." People today like to be sure of their facts before they decide. The beliefs of primitive man were based upon fear and superstition and not upon proved knowledge. We depend upon knowledge which has been tested and found true. We have watched the men and women of science and have seen the results of their work. We have confidence in their methods and follow their advice. While it is quite possible that the beliefs of primitive man might have been based upon the best information he had, this information was very limited. Today we have gathered a vast store of information which is used as a means of testing our beliefs.

Even today people hold many superstitious beliefs

In spite of the great change in beliefs which science has brought about, it has not succeeded in wiping out all fear and superstition. If you have ever been on a farm, you may have heard about a "mysterious way" in which horsehairs left in the watering trough turn into snakes. If you asked more about it, you were probably told that "horsehair snakes" were found in the watering trough at which the horses drink. Since they resemble horsehair, they must be hairs that have come to life. A careful study of these creatures proves that this explanation is entirely false. No one has ever succeeded in turning a horsehair into a snake.

Of course you have heard about the wonderful hoop snake. It can, so the story goes, put its tail in its mouth and roll off faster than a horse can run. Have you ever seen one? Do you know of anyone who really has? There are many such stories that are pure superstitions. They are started and carried along because a friend of someone has a friend who knows a man who did see something like it. There is no snake, nor any other animal, that travels by rolling along like a hoop.

There are countless other ideas of this kind. People have searched for water by carrying a forked willow twig in their hands, with the fork turned upward. When this twig, called a water witch, bent suddenly toward the ground, people thought they had come to the spot where water could be found and dug their well on that spot. There are no facts to support such a belief. It is true that no matter *where* you dig, you will find water, provided you dig deep enough.

Fig. 6. Even American Children are sometimes Superstitious

Do you believe any of these superstitions?

In stories of the West you may have read that rattlesnakes can be kept away from your bed if you merely run a rope made from horsehair around the place where you sleep. This was a common belief. One day someone decided to test it. Imagine his dismay when he saw the snake glide quietly and comfortably over the sacred rope!

Many of these things seem ridiculous to us now, but even yet many people are superstitious in some respects. Look at Fig. 6. Some people hesitate to walk under a ladder. Some believe they will have seven years of hard luck if they break a mirror. They may fear a Friday which falls on the thirteenth of the month. Many hotels of fourteen or more stories will not use the number thirteen for the thirteenth floor. Many people may turn back from a trip that they have planned if a black cat crosses their path as they start out. Some are afraid to handle a toad because they think toads cause warts. There is no evidence that any of these beliefs is true.

Perhaps you will say that no one believes in these things any more. If you are like most people, you will probably deny that *you* believe in superstitions, although you will admit your friends and neighbors do. You may be interested in making a collection of such beliefs. You may have heard of some, your friends may know of others, and older people in your own family or in the families of neighbors may be able to give you still others. It is wise to be careful how you ask for these, however, for many people still take their superstitions quite seriously. The following are the types of things you may find:

Superstitions about Lucky Days

Monday for wealth,
Tuesday for health,
Wednesday the best day of all;
Thursday for crosses,
Friday for losses,
Saturday, no luck at all.

PECULIAR CURES FOR ILLNESS

To cure a wart you must *steal* five beans or a bean for every wart, and tie them carefully up in paper, and carry them to a place where two roads cross, and then drop them and walk away, without ever once looking around. And then the warts will go away from you and come upon the hands of the person that picks up the beans.

You may laugh at some of the beliefs you find, for many of them seem so very silly. When we believe such superstitions, we are still following in the footsteps of the medicine man and the witch doctor. By so doing we are making far less intelligent use of our knowledge than primitive man did of his. He should not be held entirely responsible for beliefs which seem foolish to us now, for his knowledge was very limited. We, on the other hand, with the wealth of information science has gathered for us can test our beliefs by observation and experiment.

There is a far more serious thing, however, than a mere belief in certain silly superstitions. Every year hundreds of thousands of dollars are spent by people all over the world in their visits to palmists, astrologers, crystal-gazers, and other kinds of fortune-tellers. Like the old witch doctors of time long past, these modern fakers sell good-luck charms, secret spells to be repeated at midnight every third day, and a host of other mumbo jumbos which are taken seriously by thousands of people. In some cases these medicine men of today have an honest belief in their practices; in most they know full well that they are merely taking advantage of a public easily deceived. Their knowledge is not the result of scientific method, but represents the magic of the primitive magician handed down through time to a superstitious public.

The people who believe in such things today are trying to control natural forces, not by studying and experimenting, but by following a superstitious belief in some magic power stronger than the natural forces themselves. They try to build new natural laws from mere coincidence. The scientist accepts nothing as a law until it has been tested carefully for truthfulness.

Obviously it is clear from these illustrations that superstition, either in the dawn of history or today, whether in the very heart of uncivilized Africa or in the United States, makes slaves of those who are subject to its power. The people who still place their confidence in such things are refusing to benefit from the experiences of the countless men and women who have worked through the ages for a better understanding of our natural environment.

D. What does the Story of Science tell us about the Progress of Man?

The beliefs of people change as they gain new knowledge

The story of man's progress from the unquestioned beliefs of primitive man to the more sound beliefs of today is part of the story of the development of scientific thinking. Our beliefs began to change as we looked for and found more natural and reasonable explanations for some of the forces around us. We looked for better reasons because we found something wrong with the ones we had.

Again imagine yourself as the primitive cave man. You may believe many things, all of them the result of the training of the wise men. You believe that your tribe is the only race of people on earth. The earth itself, you have been told, extends only as far as a two days' journey from your village. One day a member of your tribe starts on a hunting trip and does not come back. After several weeks your medicine man tells you that this hunter has been killed by angry gods because he went into a part of the country sacred to the gods themselves. You, of course, believe the wise man and give the hunter up as lost.

Suddenly, one day months later, the hunter comes back.

He is not only safe and sound but has a wonderful story of strange people and new countries he found far from home. Have you as much faith in your so-called wise man now as you had before? Perhaps you feel that if the wise man is wrong this time, he has been wrong about some of the other things he has told you. Perhaps you decide that from now on you are going to try to find your own explanations for things that you do not understand. Perhaps you go further and decide that you will try to find evidence to support beliefs before you accept them as true. This is probably one of the ways by which man learned not to believe all he is told. As people seek evidence for their beliefs, the methods of science are substituted for practices based upon superstition. In your study of science you will learn to seek and to find evidence which supports your opinions. This is exactly what the scientist does. He seeks for evidence to support his beliefs, and he recognizes that truth cannot be changed simply by arguing about it. Beliefs that have been tested for truthfulness by careful observation and experiment, he says, must be substituted for beliefs based upon superstition.

The use of scientific methods has changed beliefs of long standing

The story of science is full of examples which illustrate how the use of scientific methods has changed beliefs of long standing. The story of an outstanding pioneer in scientific study may be found in the life of Galileo. As a young man Galileo was professor in the University of Pisa in Italy. About two thousand years before his time, Aristotle, a Greek, had taught that when two objects like two balls or two rocks were released and allowed to fall to the earth, the heavier object would fall faster. This was still accepted as true by many people, but Galileo wanted evidence to prove it. One day he carried two round weights, one of which was very much heavier than the other, to the top of the Leaning Tower of Pisa. He released the two balls at the same instant from

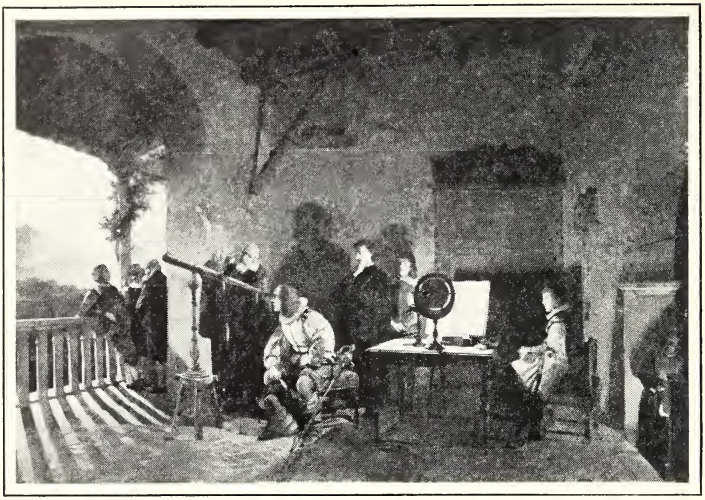

Fig. 7. Galileo was One of the First Men who tested Ideas to see if they were True

a window in the tower and found from observations that the balls fell at the same speed and struck the ground at the same time. Galileo demonstrated in this way that Aristotle was wrong. This simple experiment by Galileo in the year 1591 was one of the first to show that the way to learn the truth is to test ideas to see whether they really are so.

Not all the truths of science have been developed as easily as this of course. Herschel, an astronomer, began in 1788 the task of examining the whole of the heavens through his telescope. In order to do this he had to set his telescope in some three hundred thousand different positions. He worked at this task for many years and carefully recorded the results of his observations.

Another astronomer studied sun spots for a period of some thirty years. On every clear day he turned his telescope on the sun at sunrise. In thirty years he made about nine thousand observations.

Pasteur, who was one of the greatest benefactors of the world, learned by scientific study how to control some of the diseases that had been incurable up to his time. After five years of continuous work he discovered the means of preventing hydrophobia (the disease that develops from the bite of a mad dog).

Important discoveries were made by persons who wanted to know the truth —the scientists

One of the pioneers in experimenting with electricity was Faraday. In 1831 he discovered that a magnet may be used to produce a current in a coil of wire. At the time of its discovery the principle did not seem important, for no one saw any use for it. But today we know that without this discovery there could be no motors or dynamos, no telephone, telegraph, or radio. Faraday's discovery proved to be the basis for the age of electricity in which we live today.

Biologists, the scientists who are especially interested in living things, have studied plants and animals and have learned many things about life. They have used these facts in making us healthier, happier human beings. Many other illustrations of the achievements of science might be given. Each of them is part of the story of man's search for truth and of the way this truth has been used for the welfare of the world. Following the methods of experiment and observation scientists have been willing to work hard to discover the truth. Through knowledge of these facts we understand many of the things that were mysterious and terrifying to ancient people.

Almost everyone is a scientist in some respects. Almost everyone wants to know. In this respect children are scientific, for they are always wanting to know things. When you were very young and just beginning to be interested in the things around you, you asked three questions: "What is that?" "How does it work?" "Why?" You asked the same questions about many things, until your grown-up relatives very likely wished that there were

Fig. 8. **The Old Explorer, with his Dogs, spent Days in Traveling a Few Miles over the Snow and Ice**

A scientist studies the work of other people

no such words as *what, how,* and *why*. But you were acting like a real scientist, for you were asking questions about things in which you were interested. The trained scientist, of course, has learned many ways of finding out what he wants to know and of testing the truth of what he finds. He has learned to take advantage of the work of other people. He does not do over and over the work other people have completed, for the mere sake of repeating it. He has learned also to use the tools which other men have invented to help to control nature. A short half-century ago the true story of the lands of extreme heat and cold was familiar only to those who dared to travel and explore these unknown places. Exploration then meant terrific suffering and even loss of life. In their efforts to reach the north pole men struggled in intense cold for months over icebound wastes. Their ships were crushed beneath them. If they returned at all, they brought back in many instances only a story of hardships and failure. Today you have read and perhaps seen in the motion pictures the stories of adven-

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Fig. 9. The Modern Explorer, with his Airplane, travels Many Miles in a Few Hours

A scientist has learned to use tools

ture as told by modern explorers. They have crossed over the poles in airplanes and flown over the highest mountains. They have explored the interior of volcanoes and taken observations deep down in the oceans. From all these adventures they have brought us a wealth of new information. Those in charge of these expeditions have learned to take full advantage of the work of the many men who had perfected the airplane and other machinery used in exploration.

If you wish to see the difference between the old explorer and the new, look at Figs. 8 and 9. Which of these ways of transportation do you think the safest?

All this, then, is part of the story of science. In the first place, man has gained increasing knowledge of the forces in the environment. In the second place, he has been able through this knowledge to invent means by which he either uses these forces or adjusts himself to them. In addition to these two phases of science, however, there is a third and very important one. All these achievements have had a tremendous influence upon man's ways of thinking. He has studied previous knowledge, he has considered this knowledge in the light of his own findings, and he has then arrived at new ideas. These ideas have resulted in new inventions and discoveries, and these in turn have caused new thinking on the part of other men.

The third part of the story of science, then, deals with man's ways of thinking. There are men living today who have never invented anything new and yet may be called scientists in the real sense of the word. Why? Because they have thought about the discoveries and inventions of other men and have given new ideas to the world to think about.

The story of some of the achievements in science is told in this book. From your study of science you may learn the explanations of many things that you see. You may learn why these explanations may be accepted as true. As you go on with your study of science, you will seek more and more evidence. You will probably raise many questions in your study that are not answered in this book. Some will not be answered in any book. You may wish to seek the answers to these questions through the use of experiments and observations of your own.

In your study of science you will learn through reading about the work of others, and you will learn from your own experiments. In your textbook, in your school library, in the public library, and among your books at home you will find many interesting accounts of discoveries in the various fields of science. From your study you will gain in your understanding of the world in which you live. The story of science is a story of the interesting adventures of men and women. It is a story of man's progress from superstition toward intelligent understanding. Through the succeeding pages of this book some of the most important and entertaining of these adventures are described. More than this, suggestions and opportunities are offered to you of setting up some enjoyable and profitable adventures of your own.

Primitive peoples were victims of superstition and fear because of their lack of knowledge regarding the world about them. While some of these superstitions still exist, man has progressed tremendously towards better living, physical and mental, through a better understanding of his environment. Much of this increased knowledge has come through the use of science

Can You Answer these Questions?

1. Galileo used the experimental method to find the answer to a certain question. Aristotle had given an answer to this same question.

a. What is the evidence that Galileo's answer was correct and that Aristotle's answer was wrong?

b. What is the experimental method?

2. It is said that this is an age of science. What is meant by this statement?

3. (1) What part did superstition and fear play in the days before the growth of science? (2) Do superstition and fear play any part in life today?

Questions for Discussion

1. Could you use the experimental method to find out whether or not toads cause warts? Could you prove experimentally that the belief that horsehairs develop into "horsehair snakes" is a foolish one?

2. Some folks believe that finding a four-leaf clover brings good luck. Do you think this belief is supported by scientific evidence? Explain.

3. It is said that people today live more comfortable lives, physically as well as mentally. Can you give some examples of both, showing how we are living more comfortably than the people of a hundred years ago?

4. Is the experimental method the only safe method to use in finding answers to questions? What other methods are there?

5. How would you find answers to the following questions? If you would use an experimental method, describe the method.

a. Will a magnet pick up a piece of lead?

b. Do stars shine in the daytime?

c. Does a bee bite?

d. Why is a clear sky often blue in color?

e. What is the average monthly rainfall in your community?

f. How many people pass your house between the hours of 4 P.M. and 6 P.M. on the different days of the week? Do more people pass during any particular hours or on any one day of the week? How would you account for this?

6. Should you be suspicious of statements made by a person who never says, "I don't know"? Why?

7. It is said that knowledge drives away fear. Can you give an example of this?

Here are Some Things You May Want to Do

1. Start a class scrapbook in which to keep clippings and stories about superstitions of today. Add to this as you find more examples.

2. Read *The Story of Ab*, by Stanley Waterloo. This is a story about a boy who lived in a cave thousands of years ago. As you read it, compare his ways of living and thinking with your own. Make two lists, one showing the ways in which Ab did certain things, and the other the ways in which you would do the same things. If you care to, you might try to point out what you think science has had to do with the ways in which these things are now done.

3. Write a description of some experiment you have made or of one in which you have helped. Perhaps you would like to write up one which you have seen someone make. Write this as you would for someone else who had no idea of what the experiment was for, how it was done, or what the results were.

4. Read the story of the life of some scientist in whom you have been interested. Your librarian at school or in your community library will be glad to help you find it. As you read, try to decide what contribution the scientist made to the world and what effect his life has had upon our lives today. The results of your work might be presented to your class as a science talk.

5. You may want to read Van Loon's *Man the Miracle Maker*. In this book you will find the story of man's progress from the days of long ago. The pictures look just like those you might like to make.

6. You can probably put on a magic show and do some tricks that will illustrate how "magicians" fool the public. Such a book as R. F. Yates's *Boys' Playbook of Chemistry* may help you.

7. Would it not be interesting to make a study of several different races of more or less primitive people, such as the natives of Africa, the American Indians, the Hindus, the natives of ancient Greece, Egypt, Germany, and the British Isles, the Vikings, with respect to the following points?

a. Was there anyone in this race of people who supposedly predicted the future, conferred with the gods, read "signs" in the heavens, and so on?

b. If so, what title did this person bear, and what duties did he perform?

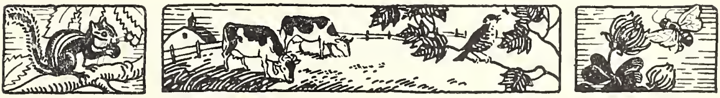
c. What was the importance of this person in the tribe or nation?

d. Does he still have influence today among this people? If so, what does this indicate about the progress made by this particular race?

Fig. 10. There are Living Things all around Us

UNIT II

What is the Relationship between Living Things and Where they Live?



Chapter II · How Many Different Kinds of Living Things are there and under What Conditions do they Live?

JOHN HENDRICKS spent a summer vacation with his aunt who lived in one of our large cities. When he returned to school in the fall, he had many things to tell his classmates. He had been to theaters, to several beaches, and to amusement parks. He had gone to many ball games and had even had a ball signed by the players on one of the big-league teams. You can imagine that John was a rather proud boy as he told of his experiences.

One afternoon in the science class John began to tell of some of the other places he had visited. He told about the zoo and the animals he had seen there — the lions, tigers, and elephants; the monkeys, bears, wolves, and giraffes; the parrots, the pelicans, and the snakes of every description. John could not name all the animals he had seen, but he knew he had been in dozens of houses and that each of them contained a great number of animals. He had been to the aquarium, too, and had seen many different kinds of water animals, from a small sea horse to a huge porpoise and a dignified penguin. On another day he had been to the botanical garden, where he had walked through glass houses filled with flowering plants of many hues.

When John finished his talk, Jim, another boy in the class, said enviously, "I'll bet you saw about every kind of plant and animal there is." But John's reply, "I guess so," was immediately questioned by some of the other boys in the class who were sure that John had not seen everything. An argument started immediately. Some of the boys took John's side, but others were against him. Finally the teacher ended the discussion. "Since this is a science class," he said, "we should try to settle the question in a scientific way. Arguing won't help. Is there any other way we can get the answer?"

Chapter II · How Many Different Kinds of Living Things are there and under What Conditions do they Live?

A. How Many Kinds of Living Things are there around Us?

Even our own back yard has numerous inhabitants

One late afternoon last summer we happened to be sitting idly in our back yard under an apple tree, thinking of nothing in particular. The sun was hot; the air still. A sprinkling of bright-colored flowers bloomed along the driveway. Bees and butterflies hovered around them, while a humming bird flitted about close by. A lone robin was pulling at a worm in the lawn near the poppy bed, apparently unaware of the cat just a few yards distant. As we glanced past the robin into the poppy bed, we were annoyed by the sight of the many weeds we saw there. Most certainly we had weeded that bed only last week

An airplane droned a mile above us, and a horsefly buzzed close by. From a curve on the state road came the sound of an automobile horn, followed by the shriek of brakes. Cars loaded with passengers had filled the roads since early morning.

As we sat on the bench, we began to think about the many, many living things in the scene before us. There were living things in the air and in the brook that ran near us. The ground was covered with them.

We thought of other familiar inhabitants of our dooryard. Ants and beetles were numerous. We remembered the fat old toad under the lilacs. We thought of the beetle larvæ around the grass roots. It occurred to us that the grass too was living. There was hardly a patch of bare ground to be seen. We thought of the excitement when the neighbor's dog chose to chase our cat.

Our thoughts strayed from our own yard to some other places close by. There was a vacant lot across the road; there were some apple trees in the garden next door. We thought of the beach and the lake where we had been swimming the day before, and the brook which trickled along through the meadow. Was the life in the meadow different from the life in our own yard? Was the life in the lake like that in the distant ocean? Do we know much about even our nearest neighbors? What, for instance, was that small green caterpillar dangling before our eyes? What was the name of the blue-black butterfly just balanced on the crimson poppy? We should really like to know, and this brought us back to John and Jim and the science class. Had John seen all there was to see, or had he just made a beginning? Was there any end to the curious creatures of the world? Suppose you too wanted to find answers to the following questions, which John and Jim's class finally decided to answer:

1. How many different kinds of living things are there in the world?
2. Is there any place on earth where there is no life?
3. Do different kinds of places have different kinds of life?

Suppose you had a class of thirty to forty interested people, how could you best get answers to these questions? Here is a suggestion: Suppose you should divide your group into as many committees of equal size as are necessary to visit certain selected areas in the neighborhood. These areas might be chosen from some such list as this:

A swamp
A vacant lot
A sand bank
A cow pasture
A forest
An open field
In the ground
A brook
A pond
The seashore
In an apple tree
A house
A barn
A park

After deciding upon your committees and the places each one is to visit, you can spend an afternoon or possibly more in the places chosen for observation. Lists

FIG. 11. If you were an Eskimo, you would live in a Snow House in Winter, and you would put on your Warmest Clothing

Courtesy of the American Museum of Natural History

can be made of all the living things found there. Some will surely find living things whose names they do not know. Specimens of these can be brought back or drawings made, so that some of these unknown creatures may be identified. At the end of the observation trips each committee can make a combined list of all the things each member has seen.

After your facts are collected, you will be ready to think about your observations and to discuss your findings.

B. What Effect do the Conditions in Any Place have upon the Types of Living Things found There?

If you were an Eskimo boy in the land of the midnight sun, your ways of living would be quite different from those in the United States. You would enjoy the long summer day, when you could fish and pick berries as long as you liked. The coming of darkness would not warn you to go home, because the day would last for several weeks. In summer your family would live in a tent as do the Indians to the south. You would certainly enjoy your summers.

But in winter things would not be so pleasant. Your family, like the animals around you, would have a hard time to keep warm and find enough food so that you would not starve. You would give up your summer home in a tent and move into an igloo made of blocks of earth or ice and snow. You would put on your warmest clothing, and your mother would sew you into it. Your father and mother would get in as large a supply of food and fuel as possible, all in preparation for the long, long night of bitter cold.

Eskimos must prepare for winter

If you lived in this region you would be familiar with living plants and animals far different from those you now know. In the summer you would like to watch the seals basking on the rocks. You would see hares and foxes. You might see a polar bear, walking noiselessly and sure-footedly on his padded hairy feet, trying to sneak up on a little northern fox; and if he were successful you would see him tear his victim to pieces with his sharp teeth and claws. At other times you might see him scooping a fish out of the water with his clever paws, or feeding on berries and other growing things that are able to grow because of the long hours of sunlight. Your father would have a spear or a bow and arrows to kill the polar bear, for it provides good meat and warm clothing.

There are many kinds of plant and animal life in the arctic regions

You might see many wild ducks and wild geese. Other kinds of birds too would come from farther south to eat berries, seeds, and insects and to rear their families. The foxes catch and eat both birds and rabbits, while the polar bear feeds upon all three, and upon seals and fish as well.

Even in the north you would observe in summer, as we did in our own back yard, that the earth is full of living things. You would notice the interdependence of these many different kinds of living things — how each depends for its food upon others, and how it in turn is hunted by other living creatures, probably larger and stronger.

With the coming of cold weather the animals change in many ways. Their fur grows thick and soft and warm. The hares that were brownish in color through the summer turn white in winter. The foxes that were bluish in summer are also white in winter. These little foxes bury ducks and hares in the snow for winter use. Many of the birds that nest in the north are able to migrate over long distances. When the cold weather comes and food is scarce, they fly south. Many of the fully developed insects die. These insects lay eggs before they die, however, and the life of the insect continues through the winter in the egg or in some other form. Many plants die after producing seed. These seeds grow again in the spring.

The forms of life in the Arctic depend upon one another

Life in the polar regions, except during the brief summer, is one continuous struggle with the cold. Plants cannot grow to any great height, for the period of growth is short. When plants are scarce, land animals must depend largely on other animals for food. The polar bear, a good swimmer and a skilled fisherman, gets most of his winter meals, when he is able to get any at all, from open places in the sea, where fish and seals are as abundant as in summer. The cold water of the sea does not worry him, for his warm, thick coat of fur protects him from the cold water as well as the cold air. The seals, with a thick layer of fat under their skin, seem quite comfortable as they slide through the icy water, seeking the fish on which they feed. The fish in turn eat smaller fish or other forms of animal life, and they feed upon the countless tiny water plants. Fortunately for seals and the polar bear there are always open places in the sea from which they may get their food. Even in the coldest arctic sea there is always a supply of fish and small water plants.

There are many different kinds of life in the polar regions. Many animals live and flourish in this environment. Their bodies are formed to meet conditions there. The difficul-

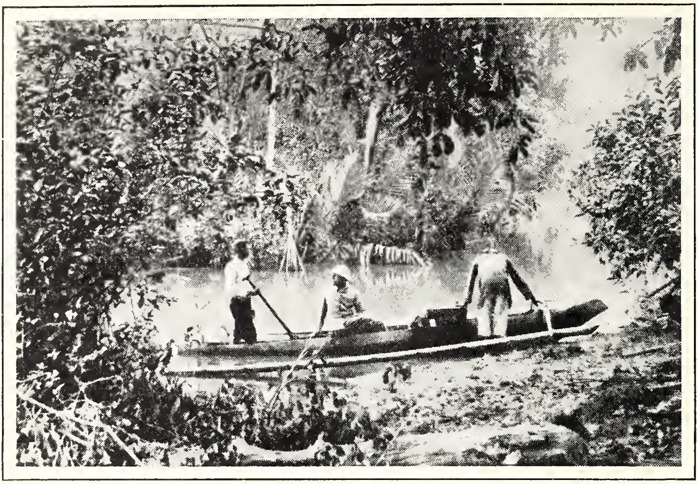


Fig. 12. The Tropical Forest is a Region of Dense Vegetation

ties of life in such a region do not affect them, for their habits and instincts have been developed to meet life in the north. Animals of the north belong to the north.

Let us see now what life is like in the tropics. Suppose we take a trip across the Atlantic Ocean to Africa, and up the Congo River into the forests and tropical jungles which extend almost across the continent near the equator. We shall probably have to use canoes for the last part of the trip, and we shall need to secure guides and helpers. Most of our clothing will be white, for white reflects the rays of the sun. In the tropics clothing is useful as a protection from the heat as well as from the millions of insects that live there.

As we paddle up the river beyond Leopoldville we sometimes brush against the lower branches of the trees that spread over the water on either side of the stream, sometimes forming a leafy arch above us. Vines twine around the trees and hang down almost to the water. Gayly colored parrots squawk as they fly from branch to branch, and

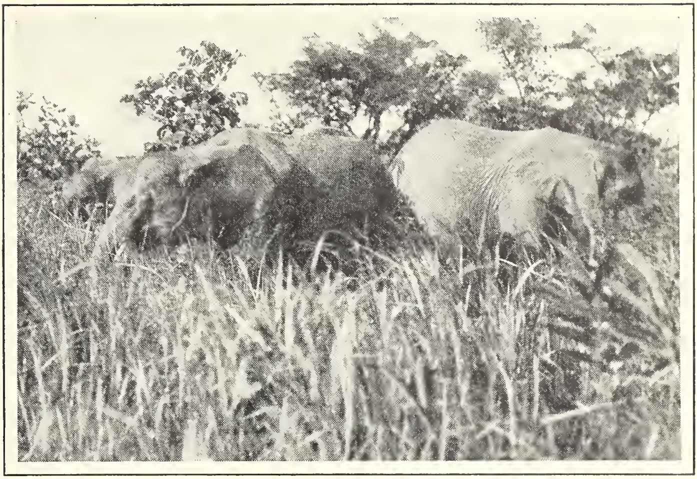


FIG. 13. How Many Ways do you see in which these Elephants are adapted to Life in the Jungle?

monkeys chatter far above us as we pass. There are snakes and countless insects that we do not see unless we look closely, because their colors are so much like those of the tree trunks and the leaves. There are crocodiles in the water and on the shores. A mother hippopotamus swims across the river ahead of us with a young one on her back. There is a herd of elephants, quite close to the river's edge. As long as they are still, it is difficult to see them, for their color is nearly like that of the tree trunks and the patches of dark shadow among the trees. Notice in Fig. 13 how well these animals blend into the surrounding landscape. Imagine how difficult it would be to see them from even a short distance. For similar reasons we do not see the spotted leopard hiding among the branches above.

The tropical forest is a region of dense vegetation and abundant animal life

If we could conceal ourselves among the grasses so that the elephants could not see, hear, or smell us, they might come down to the water. Then we could see them wade, and swim, with the tips of their trunks sticking up to supply them with air. The water cools them and helps to wash from their skin the troublesome flies and gnats that swarm in the jungle. It is easy for them to swim with their bodies almost completely under water, because their trunks, which really are their noses, may be held above water without much effort.

Growth goes on the year round in the tropics

In contrast to the small amount of plant life in the Far North, there is in the tropics a wealth of vegetation. Trees and vines of many kinds not only cover the ground, but extend for hundreds of feet into the air. Plant growth in the moist tropical climate of the Congo valley seems almost unlimited. There is no cold season, and growth goes on the year round. There is plenty of water, too,— almost too much for comfort sometimes,— for although there is no cold season in the tropics, there are two long rainy seasons. Under the hot tropical sun, plants grow very fast. There is so much competition among plants for a place in the sun that only tall or rapidly growing plants have a good chance to survive. These form a dense mass of leaves and branches, blended with brilliantly colored flowers blooming far above the forest floor. In these leaves and branches live many small animals, including frogs, tree porcupines, climbing cats, and innumerable insects and birds.

Abundant plant life means abundant animal life

Where there are many plants, there also are many animals. In the Arctic, where plant life is scarce, animals are scarce, especially on land. Land animals that live in the north for the most part have to eat other animals, and much of their food comes from the sea. But in the jungle many of the animals do not eat flesh at all; they live entirely on plants. An elephant, for example, never eats animal food. He grazes on young bamboo shoots and the tender leaves of trees. He digs up roots and tears down branches with his strong tusks. On cloudy or rainy days the elephant may risk grazing in the more open patches of grass. When he has eaten the choicest food in one place, he moves with his herd to another place where there is a new supply. Such a large animal must have a large supply of food. He cannot live in a region where there is not an abundance of plants to eat. The living things in the tropics, then, are all fitted in various ways to flourish in the tropics, just as truly as things of the Far North are fitted to live in a cold region.

The polar regions and the tropics represent two extreme types of environment. Each of them, however, has its own particular kind of plant and animal life. There are many other types of environment, and in each of them you will find plants and animals particularly fitted to live there. In fact, the forms of life are so varied that there are very few places on the earth's surface where some kind of life does not flourish.

In our temperate zone we do not have the extreme cold of the arctic region, nor the long periods of daylight and darkness. We do not have the extreme heat of the tropics, nor do we have a climate that is favorable for the growth of plants throughout the year. The climate of the temperate zone is intermediate between these two extremes. Our summers are too warm for the polar bear, and our winters are too cold for the elephant. In their place we find other types of living things, which are especially fitted to meet conditions in the temperate zone. In Fig. 14 is found an example of temperate-zone environment. Compare it with the pictures of the Arctic or the tropics. What differences do you find?

Before this country was settled by white men, great herds of bison roamed the prairies. During the summer, grass grew in great abundance, and food for the bison and for the many other forms of animal life was plentiful. The young of these animals were born in spring or early

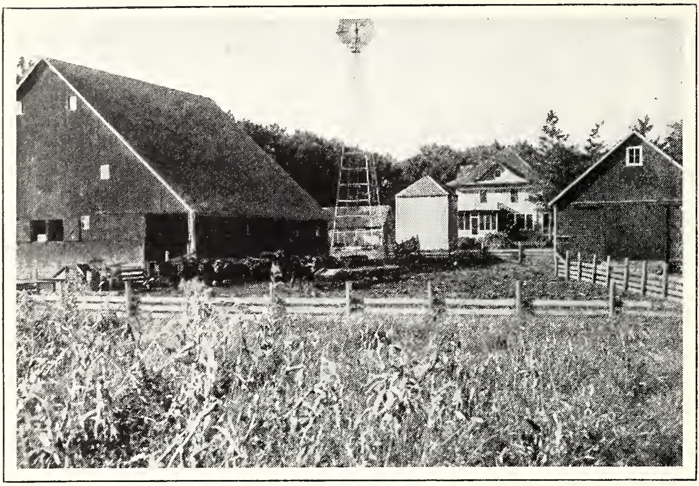


FIG. 14. Contrast this Environment with those pictured in Figs. 11 and 12

Courtesy of the United States Department of Agriculture

summer and grew rapidly during the season when food was easy to get. By the time winter came, these young animals were mature enough to endure the hardships of cold weather. With the approach of winter the herd migrated toward the south, where the grass, even though scarce, was nevertheless sufficient, since the bison could live through the winter partly on the food stored up in its body the previous summer. This is but one of many illustrations that might be given to show how living things are adapted to the climate in which they are found.

C. What Things are absolutely Necessary for Life of Any Sort?

There are living things of some kind in almost every part of the world. In some places they are numerous, and in some places they are few. Occasionally we find places where there seems to be no life at all. Why should this be so? What is lacking?

FIG. 15. Few Things are adapted to Live on the Desert

Water is necessary for life

In California there is a desert called Death Valley, where for most of the time the hot, dry sands cannot nourish even the hardiest of plants. In this case the only thing that is lacking for plant growth is water. In larger deserts, such as the Sahara, there are spots of green where trees and grasses grow. These spots are called oases. In every oasis there is a well or spring of fresh water. If you have ever traveled across the vast regions west of the Mississippi, and have seen those great stretches of grassy plains, you must have noticed that no trees are found except along the banks of occasional streams or rivers. Here they may grow in abundance.

In lands of the Far North and in the regions near the south pole there are no trees and but few green plants. The same is true on mountains, above a certain height. Can you guess the reason? It is not just the cold weather; it is also the lack of water. If you will look at Fig. 17, you will see that there is plenty of snow and ice; but the water in the soil cannot be used by plants, for it is frozen solid.

Warmth and sunlight are needed for growth

Water is necessary for the life of all growing plants. Along with water there must be enough warmth to keep the water liquid during at least part of the time. Some plants can live through long seasons of cold weather; but if they are to grow, there must be warm seasons between. But moisture and warmth are not enough. In spite of a warm room and plenty of water our house plants grow scrawny and one-sided in winter windows. Our lawns fail to flourish under large shade trees or in the shadow of tall buildings. Trees, where they grow close together, reach up high into the air. Sunlight is needed for plant growth.

Fig. 16. Death Valley in California is an American Desert

Good soil aids growth

Besides water and sunshine still another thing is needed, as any farmer or backyard gardener will tell us. That is good soil. An environment such as that shown in Fig. 18 lacks this necessary factor to plant life. In the soil are certain things which, in addition to water, plants need for their growth. If these things are not all present in the soil, in the form of mineral salts or as decayed leaves or other remains of living things, then the farmer or gardener must supply the ones that are lacking by using fertilizers or manure.

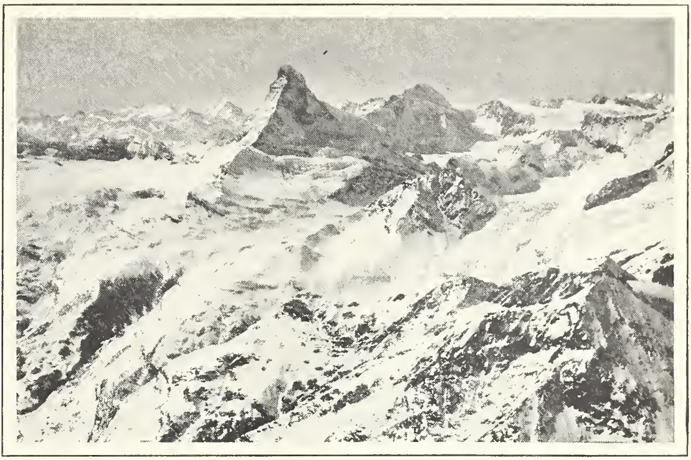


Fig. 17. The Desert of Ice is no More Hospitable than the Desert of Sand

Air is necessary for growth

There is one thing more that plants require. You might not think of it at first, perhaps, because it is present in abundance. It is everywhere on the earth, even in places where there are no plants. It cannot be seen or tasted or smelled or touched, but you can feel it when the wind is blowing. You know by this time that it is air. Neither plants nor animals can live without air. We can prove that plants need it just as much as animals do.

Factors of the environment are water, heat, light, soil, and air

The most obvious factors of the environment, then, are water, heat, light, soil, and air. These factors are present to a different extent in different places. On the mountain slope of solid rock ordinary plants cannot grow, for there is not enough soil. Yet this rocky surface is favorable for tiny plants called lichens. Some water is essential for all kinds of life, but the animals and plants of the desert cannot live in the swamps, nor can the animals and plants of the swamps live in the desert. Compare

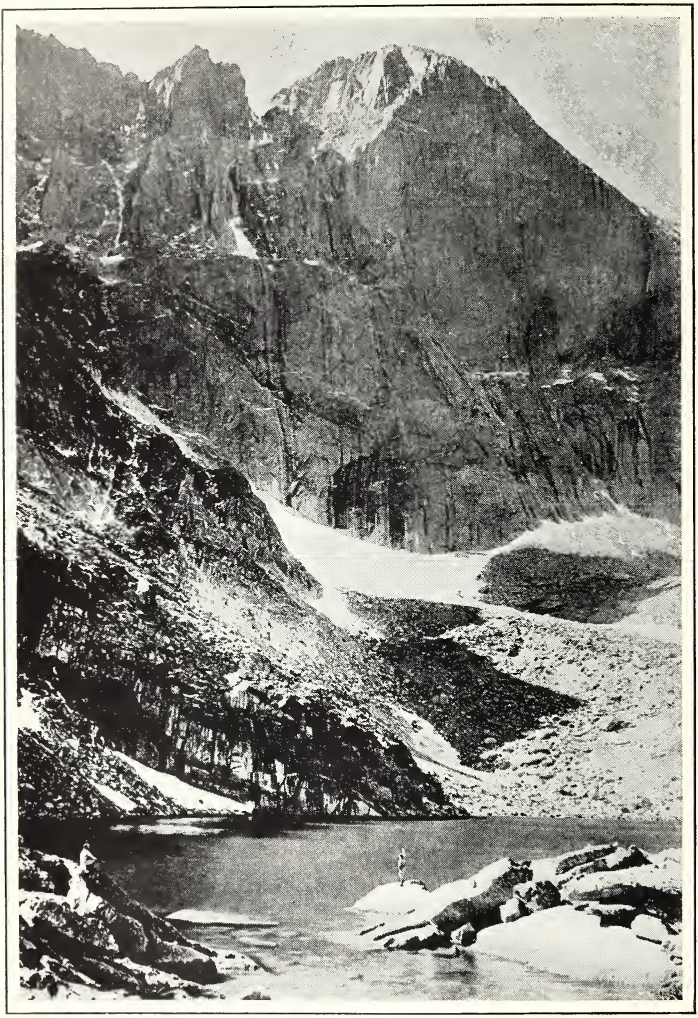


Fig. 18. Plants cannot grow on Solid Rock

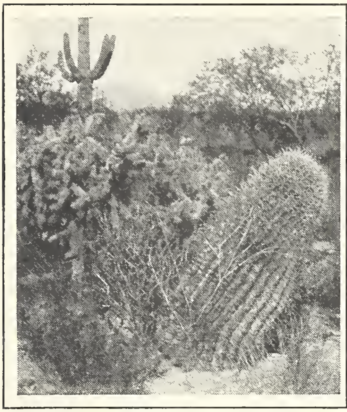


Fig. 19. Desert Plants can endure Drought for Long Periods of Time

Fig. 20. These Plants need an Abundant Supply of Water

Figs. 19 and 20, and you will see this very clearly. Air surrounds the earth, but if you have had experience in mountain-climbing above ten thousand feet, you know that there is not enough air at high altitudes for men to live in comfort. There are mountain goats that make their homes in high altitudes where men and other animals adapted to living at lower levels are very uncomfortable. Light is an essential factor for all green plants; but bright light destroys the life of fungus plants, such as bacteria, yeast, mold, and mushrooms.

Since water is necessary for life, the temperature must be warm enough to keep the water in liquid form at least part of the time. Water freezes at 32° F. and boils at 212° F. Very few plants will live and grow at temperatures below 40° F. There are many plants that can live for a short time at temperatures far below freezing, but growth ceases at these low temperatures and does not start again until warmer weather comes. Very few organisms, either plant or animal, can live and grow at temperatures above 113° F. Most animals and plants live and grow within a temperature range of 40° F. and 113° F. Some, like the plants and animals of the Arctic, are adapted to live at temperatures near the lower range, and others, like the plants and animals of the tropics, are adapted to live at temperatures nearer the higher range.

If conditions for life and growth are not favorable, plants and animals must die. Some birds migrate and thus avoid cold weather or seasons of scanty food supply. A few other animals do the same. But most animals and all plants must be fitted, or adapted, to their surroundings. Thus we find one type of animal that flies in the air and builds its nest in trees, and a very different type that lives in the water. The mushroom that grows in the dark cellar would die in the bright sunshine, and the green plant that grows in the bright sunshine would die in the dark cellar. The cactus that flourishes in the desert does not grow in the swamp, and the lily that grows in the swamp could not survive in the desert. Air and water, heat and cold, are not the only conditions to which various forms of life are adapted. Some plants can live only in dry, sandy soil, some only in swamps. Some animals eat only plant food, and some eat other animals. Some insects eat only a certain kind of plant. The list of plants and animals that depend for their life on some special conditions could be extended indefinitely.

You have seen that some animals and plants are adapted to such parts of their environment as the soil, the food supply, moisture, and temperature. Now let us see if there are any adaptations to light and color in the environment.

Many animals, especially birds, are particularly adapted to their environment in that they are protectively colored to match their surroundings. Have you ever been fortunate enough to see a mother nighthawk on her nest? Then you will remember that the color of her feathers so blended with the grayish rock, to which clung black lichens and withered mosses, that she was very difficult to see. In fact, she seemed to sense this fact, for she never moved until you were so near the nest that you might have stepped upon it, and then she fluttered away, uttering mournful cries.

In general, most female birds are of a dull color hard to see and very different from the often gayly colored male birds. If this were not so, the nesting mother birds would be too easily located by their numerous enemies. Then, too, the young of most animals are protectively colored. Have you ever seen a fawn, or baby deer? Its soft-brown spotted coat resembles a patch of ground spotted with the sunlight which filters through the trees of their forest home.

The stripes of the zebra and of the tiger so resemble the shadows cast in the long jungle-grass and in the forests where these animals live that they are very difficult to see. This enables the tiger to steal up on his intended victim the more easily, while it enables the zebra to escape his enemies.

Some animals, such as the polar bear, the snowy owl, and the ermine, are so adapted to their life in the arctic regions that their protective coloring changes with the changes in their surroundings from season to season. That is, they are white in winter to match the snow and ice, and brown in summer to match the color of the bare earth.

Usually, such birds as the grouse, prairie chicken, and nighthawk, which build open nests, are protectively colored, while the brightly marked kingfisher, parrot, and woodpecker build nests which conceal the sitting bird.

Man has made many adaptations, or adjustments, to his environment. He has learned to control some of the things in his environment, for his own benefit. He wears clothing to keep warm or to keep cool. He builds a shelter to protect himself from other creatures and from the weather. He builds fires to keep himself warm and to cook his food. He grows the plants he needs for food, and keeps some domestic animals, such as cows, sheep, goats, chickens, and pigs, for the same purpose. He uses tools to help his hands. He also uses some of the animals to help him to do his work. He travels through the air and over the water and the land, and can live almost anywhere on the earth's surface. All this and more he does, not by any changes in himself, but through his control of earth and air, fire and water, plants and animals, and many other factors in his environment. It is through the study of science that man has learned most of what he knows about how to control the factors of his environment and to use them for his own advantage.

Thus we see that living things are all about us, millions of them, living, moving, and growing. Scientists tell us there are about four million different kinds of plants and animals, so many that no one has ever named them all. Each is a distinct organism, each has its own way of living, but each, as we can see from those in our own back yards, depends for its life on other living things around it.

We are interested in these familiar plants and animals of our dooryard, and in others in more distant places. All of them, like us, must have food and air to carry on their process of living — from the tiny little specks of animals in the pool of water to the giant trees of California; from the century-old turtle to the day-old tadpole; from the animals of the northern snows to the plants of the tropical jungle; and from the gay-colored birds of the tree tops to the little gray ground moles with extremely tiny eyes. No matter where we go or where we look, — on the ground, in the water, in the tree tops, — we are almost sure to find living things of some sort, and each living thing is probably best fitted to live in the environment in which we find it.

The earth is the home of many living things. All life depends upon certain factors in the environment. Among these factors are water, heat, light, soil, and air. In their efforts to exist, living things make many different adjustments to the environment.

Can You Answer these Questions?

1. There is an interdependence between plants and animals. What does this mean?

2. What five factors are necessary in the environment of every living thing? Can you give any evidence to support your answer?

3. Why is it that many forms of life can exist in the polar sea, even in the coldest weather, when most forms of life on land are inactive?

Questions for Discussion

1. The animals in the Arctic are generally fur-bearing. Can you give any other examples of special adaptations that make living possible in various regions?

2. The food of the polar bear comes from plants. Explain. Does all your food come from plants? Explain.

3. Can you name one plant or animal that lives by itself and does not depend upon any other plant or animal? Have you any evidence to support your answer?

4. What living thing is found in nearly all parts of the world and depends less upon a special kind of environment than any other creature? How would you defend your answer?

5. Name three or four forms of living things that are especially adapted to live in (1) the Arctic; (2) the tropical jungle; (3) the desert; and (4) the temperate zone. Can you explain the ways in which each of the organisms you have named is peculiarly adapted to the environment in which it lives?

6. Can you say that any one factor of the environment is more necessary to life than any other? Be prepared to defend your statement.

Here are Some Things You May Want to Do

1. Write a good word picture on one of the following topics, showing the interdependence between the environment and living things. You may want to read some other books before you write your story. You may want to read your story in class.

a. Christmas Day in the Congo.
b. The Cold, Dark Depths of the Arctic Sea.
c. With Camel Train in the Sahara.
d. Ranch Life on the Prairies.
e. Life on the Farm.
f. Winter in the Arctic.

2. Measure off one square yard of ground in your garden or in a field or park. Count all the things you can find that live within that area.

3. Make a list of plants and animals which live most comfortably in cold regions, hot regions, or temperate regions. See if you can give any reasons why each plant and animal you place on your list lives most comfortably in the region where it is usually found.

4. Make a list of the advantages and disadvantages which would come to you from living in cold, temperate, and hot regions. Consider such topics as food, warmth, scenery, or any others you may want to add. Finish your list by telling where you would really like to live and why.

5. In any museum you will find "habitat groups," that is, exhibits of things that live together in one particular region. If you have collected any specimens or if you are good at making models, you may want to make a habitat group for your classroom or school museum.

6. Read one of the stories in Kipling's *Jungle Book*; for example, "Riki-Tiki-Tavi." As you read it, keep in mind how one living thing depends upon the other living things around it. Tell the story in class and explain why you think it is a good story to illustrate this particular chapter.

7. A bibliography is a list of books or other references on a particular subject. You might build a list of books dealing with the environment. One group in your bibliography might be "True Stories" (including travel books), such as Stefansson's *Friendly Arctic* or Byrd's *Little America,* Du Chaillu's *Lost in the Jungle* or Martin Johnson's *Safari.* Another group might be "Fiction." It is always a good thing to add a line under each book, telling what there is about the book that you like.

8. A similar list of references might be made of sources of pictures dealing with life in these various regions. You may

want to make a scrapbook. If so, be sure that good magazines or books are not ruined by the cutting out of pictures.

9. Make a drawing of a scene as you would imagine it in the depths of the ocean, in the tropics, or in the heart of the jungle. Make it show the abundance of living things.

10. Read one of Beebe's books, such as *Jungle Days* or *Jungle Peace*. Someone has said that the jungle has a very definite personality, and at times seems almost like a green, superhuman monster. See if you have this feeling after you have read some of the things that Beebe has written.

11. Perhaps you have had the opportunity recently to see some motion picture showing such features as life in the jungle or life in the depths of the sea. There have been several, filmed by famous scientists and explorers, which would be well worth your while to see. You might write a short story with the title "Life in the African Grasslands," "Life on the Sahara," "A Thrilling Deep-Sea Adventure," or "With the Dwellers of the Tree Tops." Base your story upon the picture of the particular environment which was presented.

Perhaps you could even arrange to have some good picture of this type shown in your school auditorium. Consult your teacher about this.

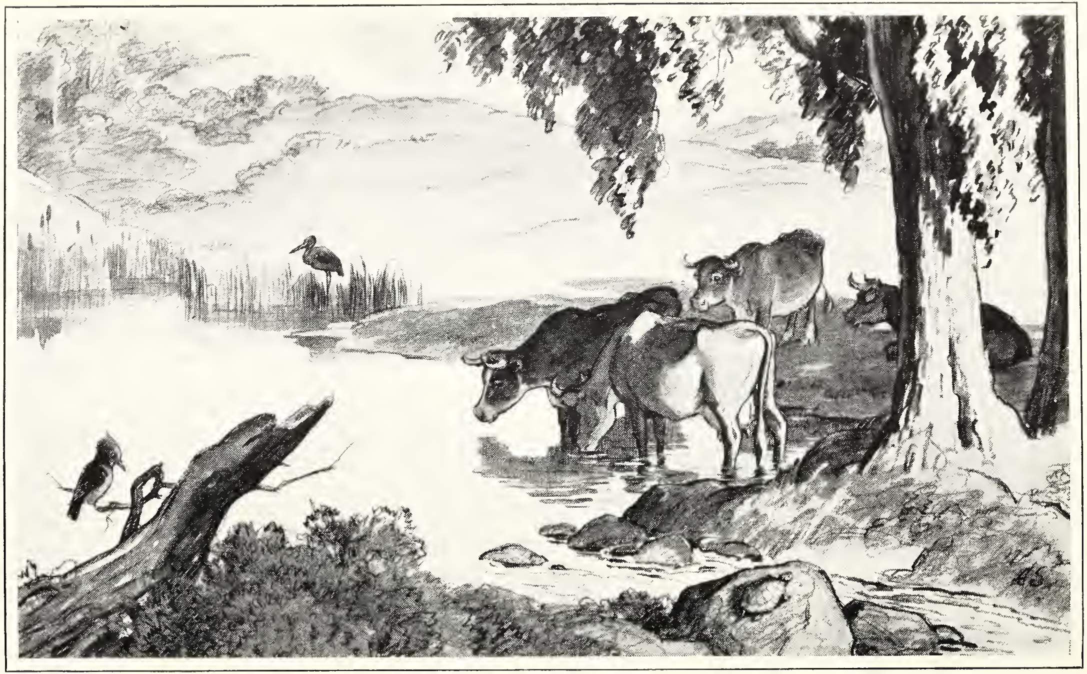
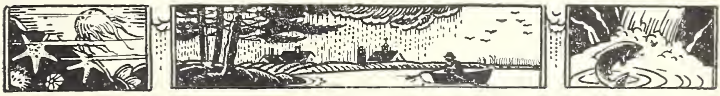


FIG. 21. Water is a Necessary Factor in the Environment

UNIT III

Why is Water a Necessary Factor in the Environment of All Living Things?



Chapter III · What is the Relationship of Water to Life?

Chapter IV · What is the Water Cycle?

Chapter V · Why do Some Things Float while Others Sink?

Chapter VI · What is Water?

Chapter VII · What are the Essentials of a Satisfactory Water Supply?

IF YOU have ever gone camping during the summer months, you know that there are several things you look for in picking a good camp site.

You want a place with shade trees, so that you will have a cool and comfortable place to rest. Surely you want a dry location; a tent at the bottom of a hill is not very cozy in rainy weather. You probably never pick low, marshy ground for your site. Again, you probably see to it that there is a good supply of firewood handy.

If you go with a group, you may disagree on some things. Some of the party may want to camp within easy distance of some town; others may want to get far away from all signs of civilization. Some of the party may prefer the mountains; others the seashore.

Regardless of how much you may disagree about some things, there is one thing on which you all agree: you never think of selecting a camp site or a place for a vacation except where there is a plentiful supply of pure drinking water.

Why do we all consider water so important? What does it mean to us?

Chapter III · What is the Relationship of Water to Life?

A. Is Water a Part of All Living Things?

Let us imagine ourselves on an oasis near the northern edge of the great Sahara Desert. The temperature in the shade has reached one hundred and ten degrees, and we are resting in the shelter of a tent.

We visit an oasis in the Sahara Desert

Looking toward the south, past the small grove of palm trees that grow so tall and straight in the oasis, we see a caravan of Arab traders moving slowly toward us. Hundreds of camels and as many men follow in a long train behind the leader. The camels, swaying under their loads, walk with difficulty through the dry and barren sand. We note the costumes of the men, as the party draws nearer, and think how different they are from our own. Our guide explains that their peculiar head coverings and white flowing robes are a most effective protection against the blinding overhead sun and the hot air filled with sand. Their sandals furnish a layer of leather that protects their feet from the burning sands. The guide tells us these men have brought their burden of dates and other products across the sands and wind-swept rocky wastes all the way from Timbuktu, nearly fifteen hundred miles distant to the south. They are now nearing the end of their journey to the city of Tunis on the shore of the Mediterranean Sea. Many weeks have been required for the journey. Their trip has taken them from one oasis to the next, and sometimes they have traveled as many as three or four days without seeing a single green thing. The camels go without water from oasis to oasis, but water must be carried for the men, for the horses and donkeys, and for the other ani-

There are no green things in the open desert. There is no water

Fig. 22. The Caravan approaches an Oasis after Traveling for Days without Water

mals taken along to be killed for food. The caravan travels along at the slow rate of two or three miles an hour during the early morning and late afternoon. During the intense heat of midday it is compelled to rest. The men tell us that the temperature may go down even below the freezing point during a night in the winter season, and we realize that there may be nearly as much difference in temperature between day and night in the desert as there is between summer and winter at home in the United States.

We are excited by their story of adventure, which to them is all in the day's work. We marvel at the endurance of the men and their beasts. It is likely that we, unaccustomed to the desert with its dry and barren sands, could not live through such dangerous experiences. But now there is rest for the weary travelers. Here in the oasis there are wells and springs. Groves of date palms having clusters of ripe fruit spread their branches overhead. Fresh foods are at hand for all.

There are food and water in the oasis

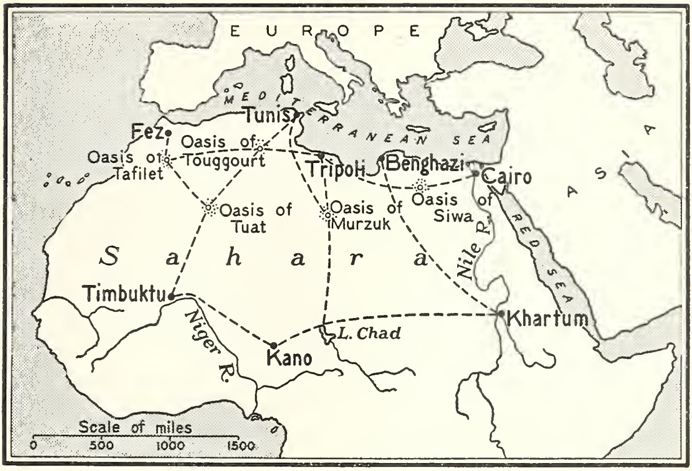


FIG. 23. The Sahara Desert is a Barren Waste, except for Occasional Oases

Oranges, grapes, and fresh vegetables are abundant. Many other forms of vegetation grow luxuriantly. There are also many different kinds of wild animals found here.

What makes the difference, we ask, between this area of green plants, with its relative comfort, and the waste desert lands which lie all about us? We can answer our own question in one word — water. Here is water, and here is life. Out in the sandy wastes of the desert there is little water, and so there is little life.

Such desert wastes are found in many of the continents. In Africa is the Sahara Desert, which we have just described. In Asia we find The Gobi, and in Australia the Great Victoria Desert. Even our own Western states have areas of desert land. In all these places there are regions where neither plants nor animals can live and grow, for there is not enough water. In the desert the struggle for life is a struggle for water.

We have noticed that life is most abundant where water is plentiful. We have found that there are few if any living

Fig. 24. Water is continually being expelled from the Body

When do you think your body loses more water, in summer or in winter?

things where water is scarce. One of the most distressing feelings anyone can experience is that of intense thirst. This discomfort is a call of the body for water. Why is water so necessary to life? Let us see what water does in our own bodies.

Thirst is the call of the body for water

Water is the carrier in which food is conveyed to the cells and in which wastes are removed from them. Water not only bathes every living cell of our bodies, but it also makes up a large part of the cell itself. The body of a normal-sized man contains about twelve to thirteen gallons of water. Our foods must be dissolved in water before they can pass into the blood vessels in the walls of the intestines and in this way into the blood stream. The blood, which is mostly water, carries this dissolved, or digested, food in solution to all the body cells. Waste products, also in solution, are carried away from the cells by the blood. Some of these wastes, still dissolved in water, are taken from the blood by organs called the kidneys and are eliminated from the body. Per-

Our food is dissolved in water

spiration, or sweating, is another way in which water leaves the body. This process goes on, as you have doubtless observed, more rapidly in hot weather than in cold; but it goes on, to some extent, all the time. Some water, too, is lost from the body with every breath. The air you breathe out is more moist than the air you breathe in. When you "see your breath" in cold weather, you really see the moisture in it. Fig. 24 illustrates two familiar forms in which water is lost from the body. You have noticed, too, that drops of water form when you breathe on a cold windowpane.

The water which the body loses must be replaced

Thus the human body is continually losing water through the action of the kidneys, the skin, and the lungs. This water must be replaced if life and health are to be maintained. At some times more water is lost than at others, and thus we are thirstier at some times than we are at others. We find ourselves drinking more water on a hot day than on a cold day. This is also true after vigorous bodily action, such as work or exercise. Under such conditions the body loses more water through perspiration than it does under normal conditions.

All foods contain water

Some of this water which is lost is replaced by the liquid content in the foods we eat. Vegetables and fruit are from 60 to 90 per cent water. Milk is 85 per cent water, and meat from 40 to 75 per cent. You could find this out for yourself rather easily as follows: secure a green vegetable, such as spinach, cabbage, or lettuce. Weigh out a pound of it and place it in a covered cooking pot. After it is cooked, take out what is left of the vegetable, squeeze it as dry as you can through a strainer, and weigh it. You would get results not unlike those given above.

Your grandmothers dried apples in the sun. You might try this, too, by cutting several apples into small pieces, weighing them, and spreading the pieces on a piece of paper in the sun. After they are dry, weigh them. You may want to try the same thing with oranges, cucumbers, peaches, carrots, or potatoes.

We need to drink plenty of water

Since we need more water than we get through our food, we are advised to drink plenty of water every day. While no definite standards can be set, it has been found that the normal grown person needs from six to eight glasses of water a day. Not all of this should be taken at mealtimes. Neither should it be ice cold, for the shock of an ice-cold liquid may be harmful to the warm and delicate membranes of the stomach.

Other animals, as well as plants, use water also. In these organisms too water conveys food to the cells and removes waste from them.

It is easy to find out for yourself the part water plays in the life of plants. Suppose you secure two plants of the same kind and size. Select plants with tender leaves, such as primroses, begonias, or coleuses, rather than cactus or ivy. The plants should be growing in pots of like size which contain the same amount and kind of soil. One of your plants should be used as a "control." This plant will be watered regularly and cared for as usual. The other plant should be used for experimental purposes. Do not water it for several days. During the interval compare the control plant with the experimental plant every day and note results. After one week set it in a pan of water and observe the results. After three or four more days you will be able to answer these questions: (1) What has happened to the experimental plant (the one which is not watered) at the end of the first day? (2) at the end of the third day? (3) at the end of the sixth day? (4) What happens after it is watered? (5) Why did we need a control plant in this experiment? (6) What conclusions can we draw from this experiment?

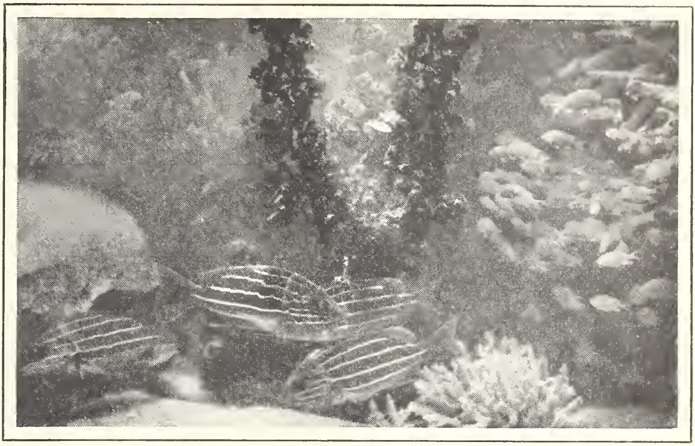


FIG. 25. The Ocean has as Dense a Population as a Modern City

Photograph by Captain F. Hurley. Courtesy of the Australian Museum

B. Are Living Things as Abundant in Water as on Land?

Think of the largest crowd of people you have ever seen. Perhaps it was at a football game. Perhaps it was at a political meeting you attended with your father. Or perhaps you would think of your own Main Street on a Saturday afternoon with people hurrying about concerned with their week-end shopping. Oceans, lakes, ponds, rivers, and brooks — even springs and wells — may have as large a population of living things as any city street on Saturday afternoon. Indeed, if the number of inhabitants were considered, the census figures of New York or Chicago would be small as compared with those of an ordinary pond or a small plot of land along the shore of the ocean.

In our last chapter, you will remember, we imagined ourselves as members of a group of people who decided they would find out for themselves about the many different kinds of living things. Some of our committees did their work in localities where water was abundant. From the reports they made we found that many kinds of plants and animals live in the water. In ponds and brooks they found fishes, turtles, frogs, snakes, bloodsuckers, newts, water bugs, countless insect larvæ, and a multitude of other creatures. They discovered that some of these always live under water and breathe the air that is dissolved in water. Others, such as frogs and turtles, must come to the surface for air. If your home is near the seashore, one of the groups may have decided to combine pleasure and work and go swimming at a neighboring ocean beach. If they did, they probably found in the salt water starfish, clams, oysters, crabs, mussels, and sea urchins. Some of them might report having seen the delicate floating jellyfish borne here and there by the waves and carried in currents set up by the rising and falling tides.

Many kinds of living things are found in water

Some of these larger water creatures are already familiar to you. They are not the only inhabitants of water, however. There are countless others, but they are not so easy to find. You will need some very special help if you wish to locate them.

Some are large, but many can be seen only with a microscope

One of the greatest helps in the study of very small things is a microscope, similar to the type usually found in science laboratories. Let us use one of these for our further study of life in the water. Let us imagine that we have ready for examination a drop of water from a roadside mud puddle. The water seems perfectly clear; but when you look at it through the microscope, you find that there are many kinds of little animals darting about in every direction. These little fellows are of different shapes. Some are slender and slipper-shaped; some are nearly round. Others may appear somewhat flattened and shapeless. Some seem to be in a great hurry; others move more slowly. All of them take tiny bits of food from the water. They may be eating other living things smaller than themselves.

Fig. 26. Leeuwenhoek, *the Janitor who made a Hundred Microscopes (1632–1723)*

Anton van Leeuwenhoek was fortunate to obtain a job as janitor in the city hall at Delft, his native city. The work was not heavy, and he had time for a hobby · He made hundreds of lenses which would make little things look big, and many of them he put together to make compound microscopes better than anyone else had ever dreamed of making · With the aid of his microscopes and his own boundless patience, he discovered countless small animals which no one had seen before. In a drop of water which looked perfectly clear to the naked eye, he found tiny one-celled creatures · He studied the blood as it coursed through the capillaries in a tadpole's tail. He saw the tiny red corpuscles, and the white ones, which looked like some of the one-celled animals · After more grinding and polishing to make even better lenses, he discovered still smaller one-celled plants, which he called bacteria. No one had ever seen bacteria before. No one even knew that they existed · At first Leeuwenhoek was not looking for anything in particular, but after a while his work came to the attention of a group of scientists in England. James Watt was one of them, and Robert Boyle and Erasmus Darwin and Robert Hooke. These men appreciated the value of the work the patient little Dutch janitor was doing, and they made him a member of their society. They helped him, but he helped them, too. He worked patiently with his microscope day in and day out. He had discovered the world of the one-celled, and the discovery had given him a place in the history of scientific progress.

Many of the tiny living things you see through your microscopes are animals consisting of but one cell. There seem to be a great many of these tiny creatures moving in every direction. These cannot be seen with the naked eye and so were not known until the microscope was perfected. Now they have been studied by many scientists. In Fig. 27 you see the picture of a drop of water under a microscope. Notice the things that are revealed.

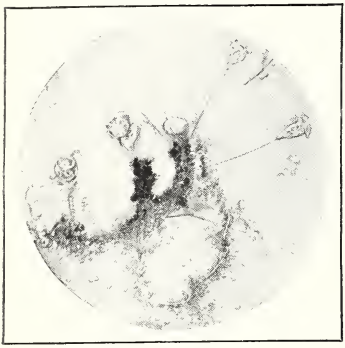


Fig. 27. Many Living Things are revealed in a Drop of Water under a Microscope

Some animals live part of the time on land and part of the time in water (Fig. 28). Such animals are called amphibians. Frogs, toads, and salamanders are amphibians. The young of these animals live entirely in the water, but the adults live on the land. The polliwog that lives in water becomes a toad that lives on land.

Some animals are amphibians

Many insects spend the early part of their lives in water. The young are hatched there and live in the water until they change to the adult stage. Mosquito larvæ, or wrigglers, are well-known residents of ponds. Dragon-fly larvæ, with their savage faces, eat mosquito larvæ and other small insects. Young caddis flies live in mud-and-stick "houses" on the bottoms of ponds.

Water animals secure their food and air from the water

Some of the little one-celled animals we see through the microscope take in both food and air directly through the walls of their bodies, but the bigger animals eat and digest their food in much the same way as we do. The one-celled animals are eaten by small many-celled animals. These small many-celled animals are eaten by larger ones, and

FIG. 28. Some Animals live Part of the Time on Land and Part of the Time in Water

these larger ones by still larger ones. The polar bear catches fish from the arctic sea. These fish had eaten smaller animals that live in the sea, and these smaller animals had eaten still smaller ones.

Animals that live in the water all the time, such as fish, lobsters, jellyfish, and sponges, soon die if they are kept out of water. All of these must get their food in the water, and they use the air that is dissolved in the water.

If a glass of cold water is left standing in a warm room, bubbles may soon be seen clinging to the inside of the glass. Those bubbles consist of air which came out of the water as it was warmed. Water that has been boiled and quickly cooled does not contain enough air to keep fish alive. A fish will die from suffocation if it is placed in water that has been boiled and cooled in such a way that it has but little air dissolved in it. Merely by shaking the water, however, the amount of air dissolved in it is increased so that fish can again breathe and live in it. The shaking mixes air with the water. Wherever the two meet, some

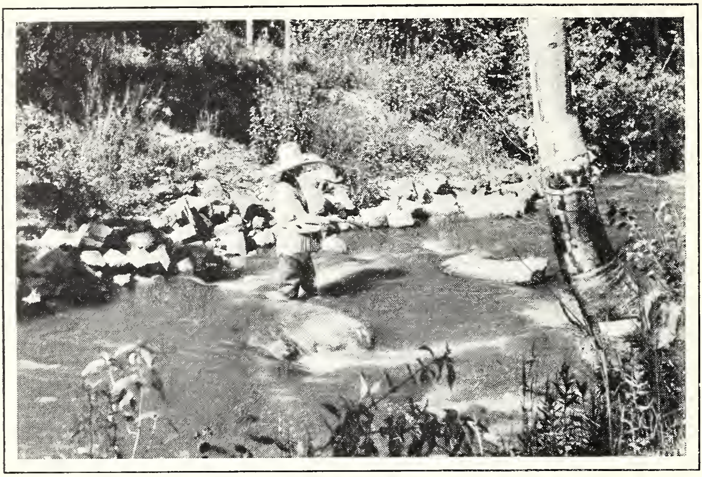


Fig. 29. Sportsmen go to Rapid Streams to find Active Fish

of the air dissolves. After going over falls or rapids the water in a stream has more air dissolved in it than it had before. As the water splashes against the rocks, it is mixed with air. Fish that are very active are the ones that need most air. Brook trout are active fish, and so the fisherman goes to the rapids of mountain streams to find them.

Active fish need much air

Whether they live on land or in the water, animals must have air. A fish, like every other animal, must secure oxygen from the air and get rid of carbon dioxide if it is to live. We know from experience that no matter how much air there is dissolved in water, we and other land animals cannot breathe it. Our lungs are not fitted to receive a stream of water. How then does a fish or lobster breathe? These, like some other animals that live in the water all the time, have gills. Fig. 30 shows a fish with the gills exposed. These special organs serve the same purpose for them as lungs

Gills and lungs serve similar purposes

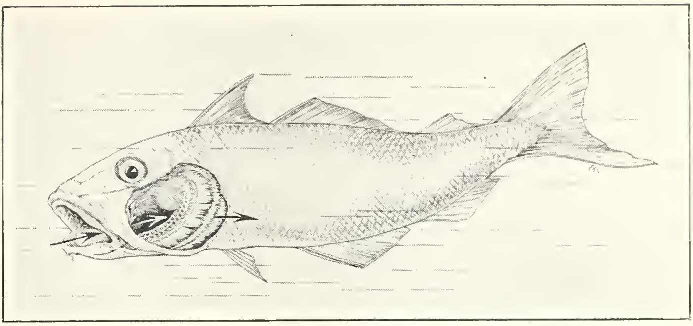


Fig. 30. As Water flows over the Gills in the Direction of the Arrows, Oxygen is absorbed into the Blood Stream

do for land animals. The fish constantly takes in water through its mouth and forces it out over its gills in the direction shown in the picture. As the water, with oxygen dissolved in it, passes through the gills, some of the oxygen leaves the water and enters the tiny blood vessels in the gills. From there it enters the fish's blood stream. At the same time carbon dioxide, which is a waste product, passes from the blood in the gills to the water around them and is carried away.

Some animals begin life in the water but later in their lives change into a form which lives on land. Tadpoles have gills; but when they grow into frogs or toads or salamanders and come out of the water, they lose their gills and develop lungs.

Plant life is abundant in water

Thus far we have discussed animal life in the water. There is also much plant life in the water. You know from observation that there are many large water plants, such as seaweed, water lilies, pickerel weed, grasses, and sedges. Your microscope will reveal a great abundance of one-celled water plants, just as it did one-celled water animals. Figs. 31 and 32 illustrate some forms of small plant and animal water life.

These plants, whatever their size, need light and air and water, just as land plants do. Some may fasten themselves to rocks or other objects and do not need soil to support them as garden plants do, but they get mineral salts from the water. Like the land plants they use air for respiration and for food-making. The air they use is the air that is dissolved in the water.

Fig. 31. This Museum Group is a Much Enlarged Picture of a Section from the Bottom of the Sea

The group includes animals as well as plants. Can you tell whether this is a section from the deep ocean or shallow water? (Courtesy of the American Museum of Natural History)

Water plants serve as food for water animals, just as land plants do for land animals. In fact, life in the water is not so different from life on land. There are the same needs, and there is the same struggle for food. Air, water, and food are necessary for life anywhere, and the same general processes go on in living things, no matter where they live.

In some ways, life in the water seems easier than life on land. For one thing, there is never any lack of water, as there often is on land. A fish in water never suffers from thirst! Again, water creatures do not have to stand any great extremes of heat or cold, and changes in the water temperatures are always slow. It is never as hot in the ocean as it is on land on the hottest day under the tropical sun, nor as cold in the Arctic Ocean as it is on land on the coldest day in that region. Sea water is but little warmer at noon than at night, nor is there a great deal of

The sea is warmer than land in winter and cooler than land in summer

FIG. 32. This Drawing illustrates the Life in a Rocky Pool such as you find along a Shore where the Tide moves In and Out

From Linville, Kelly, and Van Cleave, *A Textbook in General Zoology* difference in the sea between summer and winter. Even the water in a pond or small lake grows warmer more slowly than the land around it. On the hottest days of summer the pond is still cool enough to be a place of escape from the heat. In winter the temperature on land may be many degrees below the freezing point of water. Ice may form on the surface of lakes or rivers, but beneath the ice there is water which is not cold enough to freeze. Many forms of plants and animals live through the winter in the water beneath the ice.

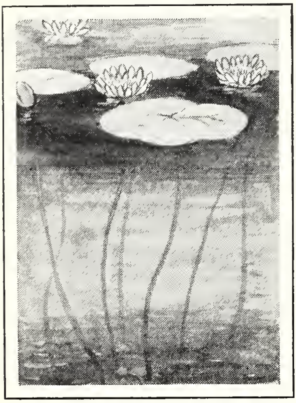


Fig. 33. The Water supports the Weight of the Broad Leaves and Huge Blossoms of the Water Lily

Did you ever try to arrange water lilies in a vase?

Another advantage of life in the water is the support that water gives to the bodies of the animals and plants that live in it. We have all noticed how much lighter a stone seems to be when we lift it under water. This is because the water buoys it up.

Plants and animals are buoyed up in water

In the same way plants and animals in water seem lighter in weight and need less support. While trees must have strong trunks to uphold their leaves and branches, plants that live in the water may have much more slender stems, for the water supports their weight. Water lilies develop very large leaves and flowers, as shown in Fig. 33. The stems of these plants would be quite insufficient to support in air the weight of either leaves or flowers, but the water buoys them up and keeps them exposed to the sun.

The weight of tiny microscopic animals and of fish and of whales is supported by the water that surrounds them. It is obvious, of course, that these animals are well adapted for life in the water but not at all adapted for life on land.

These are some of the reasons why life is easier in water than it is on land. It is no wonder, then, that living things are so abundant in the sea, in streams, in lakes, and even in roadside pools.

Life is most abundant where water is plentiful. Water carries dissolved food into the blood stream and is a part of every living thing.

Can You Answer these Questions?

1. What evidence can you give to show that there is less air in water after it has been boiled than before?
2. Why is water so essential to the life of the cells in the body?
3. How do fish get air? How do frogs get air?
4. When water lilies are placed in a vase with the stems partly exposed, their stems will not support them. Why?

Question for Discussion

Many common words impart a much more complete meaning to the person who knows science than they do to those not so trained. For example, the word *thirsty* means much more to the scientist than it does to other people. After reading this chapter, what does this word mean to you?

Here are Some Things You May Want to Do

1. Start an aquarium for your classroom. Buy a glass jar, tank, or globe, or use a large pastry or cooky jar. Stock it with water plants and later with animals. Before you begin, read some references telling you how to prepare your aquarium and how to stock it. *Do not overstock it!*

2. Get a fish's head from a fish that you have caught or, if you live in the city, from a fish market. Cut it open carefully so that you can see the gills. Notice how they are adapted for taking air from the water.

3. Keep a record of the amount of water you drink each day for a week. This, of course, will not include the water in the foods you eat, such as fruit, vegetables, and milk. You might estimate the amount of water in your food and add to the record.

4. Read Beebe's *Beneath Tropic Seas* or *Nonsuch: Land of Water*. The pictures of ocean life in either book are excellent.

5. Have you ever wondered how it would feel to live in the water? Kingsley's *Water Babies* is the make-believe story of children who became water fairies. You may want to read this.

6. If you have the opportunity to study the life near a fresh-water pond or stream, you might keep lists of the following:

a. Some animals which live on the land, but are usually found near the water.

b. Some animals living part of their life in the water and part of their life on land.

c. Some animals which spend all their life in the water.

d. Some plants which live in the water.

e. Some plants which, though living on the land, are usually found near water.

7. See if you can find any evidence to answer the question, "Where do you think you will find a greater number of living things — on the land or in the water?"

Chapter IV · What is the Water Cycle?

A. How does Water get into the Air?

> The fog comes
> on little cat feet.
>
> It sits looking
> over harbor and city
> on silent haunches
> and then moves on.
>
> CARL SANDBURG[1]

There is water in the air

No doubt you have, at one time or another, been drenched by a rainstorm. Perhaps you started on a hike, on a morning when the sun was bright and the sky cloudless. After you had walked for an hour or so and were far away from shelter, you noticed that clouds were forming. In a little while the sky was overcast; clouds were everywhere. Soon a few drops fell, as if in warning, and then the rain came down in torrents. Your clothing was soaked in a moment. Little brooks began to flow in ditches that had been dry only a short time before. The long grass by the roadside was flattened by the force of the falling water. The raindrops cascaded in a stream through the leafy branches of the trees.

Such experiences furnish convincing evidence that there is water in the air. The rain came out of the air. It must have been in the air before the storm, even though you could not see it. How did it get there? In order to answer this question, let us recall some everyday observations.

Water evaporates from wet surfaces

Water remaining on the pavement after a rain soon disappears when the sun comes out. The mud puddle by the roadside dries up in a few hours. Water left in a pan disappears in a short time. Wet clothes hung on the line dry quickly in the sun.

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[1] "Fog," from *Chicago Poems*, by Carl Sandburg, reprinted by permission of Henry Holt and Company.

Fig. 34. Have you ever had this Experience?

Where has all this water gone? The answer to this question is the answer to our first question. The water on the pavement, in the mud puddle, in the pan, and in the wet clothes has escaped into the atmosphere. That is, it has evaporated. Evaporation is a process that goes on wherever there is water. It goes on faster on hot sunny days than it does at night or in winter, although it goes on to some extent at all times. It is this evaporated water that falls back to earth again in the form of rain.

Evaporation is a slow process, but it is going on all the time

But, you may object, the time required for a little water to evaporate from a pan shows evaporation to be a very slow process. How can enough water evaporate from wet pavements and wet clothes to make heavy rains? Well, it is true that evaporation is a slow process. But when we look at such a scene as that pictured in Fig. 35 and are reminded that this process of evaporation is going on all the time over all the oceans, over all the lakes and rivers, from moist soil wherever it is exposed, and from the leaves of plants, we begin to understand the

FIG. 35. The Process of Evaporation is going on All the Time

source of the great quantities of water that fall during heavy rainstorms and run off in raging streams.

Suppose you try to secure more direct evidence on this problem of evaporation by a simple experiment. Choose three vessels. One is flat and shallow like a cereal dish; another is tall and thin like an olive bottle; and the third is neither very tall nor very thin. For the latter use a drinking glass. Put a teacupful of water into each of the three vessels and stand them on the window sill. Observe them each day for a few days. What happened? Did the water evaporate from all of them? Which dish was dry first? Which next? Which last? Perhaps you have tried this and know.

So far you have learned several things about evaporation. Can you find out anything else which will help us to understand this process more fully? Suppose you try several other experiments.

For the first one take two similar dishes of equal size and put the same amount of water into each one. Place one dish on a warm radiator and the other in a cool, dark corner of the room. Observe them for several days. Again you will find that the water evaporated. But again one dish was dry before the other. Which one? What conclusions can you draw from this result?

For another experiment take three small flat dishes. In the first one place a few drops of water; in the second, a few drops of alcohol; and in the third, a few drops of ether. (Keep alcohol and ether away from any flame.) Then place the three dishes side by side on the window sill and observe them. You will find that the ether evaporates fastest and that the water evaporates slowest. Again you can draw some conclusions about evaporation. What are they?

B. How does Evaporation Take Place?

Another question suggests itself promptly. How does the process of evaporation take place? You have probably found it reasonable enough that water should fall from the clouds and that it should flow downhill into ponds and rivers, because everyone has seen it do so. But how does it get from the surface of a pond up into the air? In order to answer this question you will have to use your imagination. That is what a trained scientist does. When he faces a puzzling question, he first makes careful note of all the facts he can observe in connection with it. Then he draws upon his imagination to help him to make the best possible explanation of what he has observed. He calls this explanation a *theory*, or a hypothesis. He then tests his theory by finding out if it satisfactorily explains all new cases. The best answer as to how water gets into the air is a theory. This theory has been tested in many different ways, and it is now generally accepted as true.

We use our imagination and form a theory

Let us examine some water in a pan or a dish. The water seems to have, as usual, a smooth unbroken surface. But, according to the theory, the water is not so smooth and unbroken as it seems. The theory assumes that the water is composed of many, many small particles. They are moving very rapidly. The surface of the water seems to be a mass of them, bounding in every direction. Some break away from the others and pass into the air. As the moments pass, more and more of the little particles of which the water is composed bound clear of the dish. The water is evaporating.

Particles of water bound into the air

Now we turn our attention to the air into which these tiny water particles are passing. In our imagination we see that it too is composed of tiny particles. There are several different kinds of air particles; yet all of them look considerably alike and considerably like the water particles that are escaping from the surface of the water in the pan. Water particles and air particles mingle and float away together.

Now let us change the scene a little. Suppose we place a flame under the water in the pan. As the temperature of the water increases, the tiny particles move even faster than before. By the time the water reaches the boiling point, the water particles are flying away in such quantities that they have crowded away almost all the air particles near the surface of the water. In a short time all the water particles are gone, and nothing but the dry surface of the pan remains. Evaporation has taken place very rapidly. Boiling is rapid evaporation.

Boiling is rapid evaporation

In our imagination we have seen water particles escaping from the surface of cool water. We have seen them mixed with air particles and carried away. We have seen that as water is heated the water particles escape more rapidly, and that after water boils it is only a short time until all the water particles have left the pan.

Now let us get back to what we can really see. We know that water does evaporate, and we know that it evaporates more rapidly when heated. We know that there is water in the air and that it is usually distributed in the air in such a way that we cannot see it. What is the explanation of all this? This scene we have developed in our imagination furnishes the best explanation of evaporation that has been suggested. As we progress in our study of science, we shall see that there are many reasons for believing it true. It is therefore an accepted theory that water and air are really made up of extremely tiny particles and that these particles are always in motion, that heat makes them move more rapidly, and that cold, or absence of heat, causes them to move more slowly.

In a gas, particles move freely

It is supposed that these particles move aimlessly and the collisions between particles occur frequently; that in a liquid the particles are close together, but in a gas, like air, the particles are relatively far apart and moving freely. This theory is called the molecular theory, for the particles are known as molecules. There is no direct way to prove the theory, for we cannot, of course, really see the particles. But it is a very serviceable and satisfactory explanation.

Molecules are extremely tiny. We can never hope to see them

You must be sure to understand that these particles of water and air are extremely tiny. Molecules are very, very much smaller than the tiny little one-celled animals you saw in a drop of water. They are so small that we can never hope to see them, even with the most powerful microscope. Scientists do, however, have several methods for observing the behavior of molecules.

A pan of boiling water is such a common sight that you have probably never paid much attention to it. But with your knowledge of the molecular theory it should be full of interest. Let us consider it once more. Fill a glass beaker about half full of water. A glass beaker, unlike an ordinary drinking glass, is not likely to break when you heat it. Set the beaker on a support and heat it over a flame. You will recall, according to the theory, that heating makes the molecules move faster. Very soon after the flame touches the glass something will begin to happen. The molecules closest to the flame will be the hottest and will consequently move the fastest. This rapid motion causes them to collide with one another more often than do the molecules of the cooler water, and the more frequent and more violent collisions cause them to bump one another farther and farther apart. When the molecules are far apart, the same volume of liquid is lighter than it is when the molecules are close together, because there is more space between them. In other words, heat causes the molecules of a liquid to spread farther apart. This makes a given volume of the warm liquid lighter than an equal volume of the cool liquid. When equal volumes weigh different amounts, we say that one volume is denser than the other. Cold water is denser than warm water because a pint (or any other volume) of cold water weighs more than an equal volume of warm water. The less dense liquid rises because the denser, cool liquid sinks and pushes it up. If you look, you can see the currents produced as the cooler liquid sinks and pushes the warmer liquid upward.

In boiling, the molecules move very rapidly

Suppose you continue to heat the water. As its molecules move faster and faster and push one another farther and farther apart, the liquid begins to change to a gas. Water changes to the gas we call steam, or water vapor. In a little while bubbles nearly as large as the tip of your finger will be seen forming one at a time just over the flame. These are bubbles of vapor, or steam. These rise toward the surface, but the first ones you see probably do not reach the surface. They get smaller as they rise and disappear in the liquid. The hot steam is cooled as the bubbles rise away from the flame and pass through the cooler liquid above. As the steam is cooled, its molecules move more slowly, bump one another less

In boiling, the molecules take up more space, and the water turns to steam

often, and consequently come closer together. In other words, the steam is condensed to a liquid again before it has time to escape.

But the heating still continues. Soon the water near the surface is as hot as the water directly over the flame. The bubbles grow larger and larger, and soon some of them escape from the surface. Now you can see little white clouds rising from the water. These are droplets formed from water vapor condensing in the colder air. If you hold a cold piece of glass or of metal over the beaker, you will see drops of water form on it. At last the water is boiling, and your beaker looks like the one in Fig. 36. The molecules are now pushing one another so far apart that the change from liquid to gas is very rapid. But if you turn out the flame or remove the beaker, the boiling stops almost at once, and the water slowly cools until its molecules are no farther apart and are moving no faster than they were when you started the experiment.

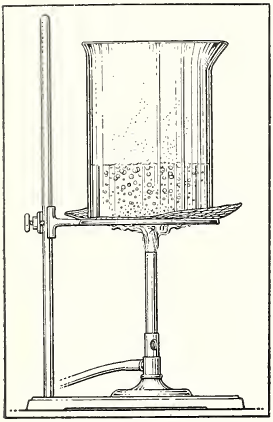

Fig. 36. When Water boils, Bubbles of Steam rise and burst at the Surface

Can you explain the process of boiling in terms of the molecular theory?

C. Does Water boil at a Constant Temperature?

Now that we are on the subject of boiling water, suppose you find out how hot boiling water really is. Does it continue to get hotter the longer you boil it? You will need a good thermometer now like the one used by the boys and girls in the chemistry and physics classes.

Start as before with a beaker of cold water. Put the thermometer in the water. After about half a minute,

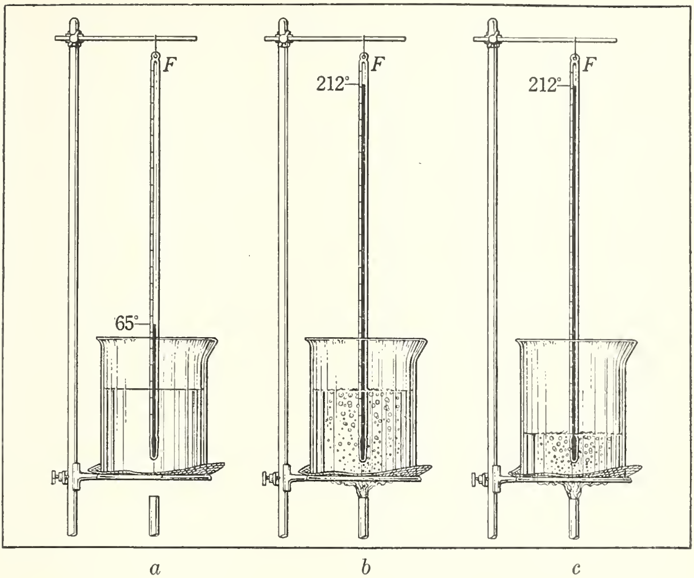

FIG. 37. After Water begins to boil, the Temperature does not Change

read it. This reading tells the present temperature of the water. In one experiment this was as indicated in Fig. 37, *a*. Now without removing the thermometer place the beaker over the gas burner and watch the little thread of mercury in the thermometer. In a very short time you see that it is beginning to rise slowly. Now you must pay close attention to the thermometer. Do you want to know why the thread of mercury rises? You have learned that when water is heated, the molecules move faster and push one another farther apart. When the molecules are farther apart, the water occupies more space, or, as we say, it expands. Mercury acts in the same way. As it gets warmer, its molecules move faster and push one another farther apart. In other words, the mercury expands as it is warmed. Now you can see why it rises in the tube. When the water cools, the thread of mercury goes down again. Why?

The little thread rises higher and higher as the water grows warmer and warmer. How high will it go? Will it reach the top of the stem? The best way to find the answers to our questions is to experiment. In a short time the water is boiling vigorously, and large bubbles of steam are escaping from the surface. Without taking the thermometer from the boiling water, read carefully the position of the mercury. It reads about 212° F. or 100° C., depending upon the kind of thermometer you use. Notice Fig. 37, *b*. Allow the boiling to go on for a time and watch continually the level of the mercury. You may be surprised to learn that after water in an open vessel starts to boil, its temperature does not change. No amount of increase in the heat will make it any hotter. In Fig. 37, *c*, you will notice that half of the water has boiled away, but that the temperature is just the same. Greater heat will hasten evaporation, but it will not affect the temperature of the water that is boiling in an open dish.

After the water starts to boil, its temperature does not change

Other liquids evaporate just as water does, but at different rates. You know that gasoline evaporates more rapidly than water. If the man at the service station spills some on the ground as he is filling a car, it disappears very quickly. Gasoline also boils at a lower temperature than water. Alcohol, like gasoline, evaporates more rapidly than water and boils at a lower temperature than water. The temperature at which mercury boils is very much higher than the temperature at which water boils. In general, you may expect that liquids which evaporate more rapidly than water also boil at lower temperatures.

What happens to all these evaporated liquids? If you could see the molecules of which air is made up, you would see floating among them molecules of a great variety of substances that have entered the air by evaporation. Since water is the most abundant liquid on earth and since it evaporates from all exposed surfaces, you would expect to see many water molecules. In the immediate neighborhood of the gasoline station there might be many molecules of gasoline in the air. The odor in the pitcher is caused by molecules of food substances that have entered the air by evaporation. Odors are caused by molecules of various substances which have bounded off into the air and have been distributed through it. Some molecules have no odor. Others, molecules of ammonia and gasoline, for example, do have. A few minutes after a bottle of ammonia is opened in a room, one can smell ammonia in all parts of the room, even though there is no wind or draft. The fact that we can do this in the case of such a liquid as ammonia is one of the reasons for believing in the molecular theory.

Some molecules cause odors

D. Does Any Water enter the Air from the Leaves of Plants?

You have already learned that there must be a continuous flow of water into and out of all active living cells. In the stems of plants — corn, wheat, or trees, for example — there is an arrangement of cells through which water can pass from the roots to the leaves. Water enters the roots from the soil. In a healthy plant these cells for conducting water are continuously wet throughout the length of the stem. Some evaporation is going on continuously from the undersurfaces of the leaves. This evaporation of water from the leaves of plants is a process called transpiration.

Evaporation goes on from the leaves of plants

The usefulness of this stream of water to the plant is a little like the usefulness of the stream of blood to animals. Materials necessary for the living cells are carried to the cells in this water, and the waste products of the living cells are carried away by it. By a simple observation you may prove that a large amount of water enters the air from plants. If you place a large jar over a healthy potted plant, some of the water that escapes from the plant will condense on the walls of the jar. After a time, say about an hour, the inside of the jar will appear wet (Fig. 38).

You may be surprised to learn how much water passes from the soil through stems of plants into the air during a growing season. Careful observation has shown that one acre of meadow grass takes up through its stems and gives off to the air by transpiration more than five hundred tons of water between the time it first starts to grow and the time when the seed is ripe. This is as much water as there is in a swimming pool 80 feet long and 30 feet wide when the water is about 6½ feet deep. Consider the many thousands of square miles of the earth's surface covered with vegetation similar to that shown in Fig. 39, and you will realize that a great deal of moisture reaches the air from plant life. A large tree gives off several tons of water by transpiration during a single summer.

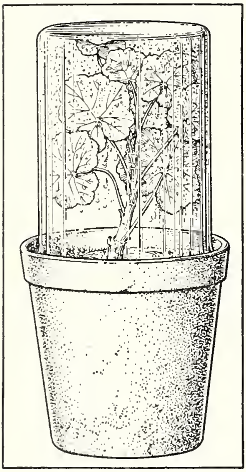

Fig. 38. Water escapes from the Leaves of Plants

Since you have become more familiar with the process of evaporation and know something of the extent to which it takes place, you are probably no longer amazed that enough water can collect in the air to cause rain.

E. What happens to Water in the Air when the Air is Cooled?

Are you curious to know some of the processes by which water comes out of the air? One way is the formation of clouds, where the tiny invisible dust particles in the air play an important part. You have learned that water changes from liquid to gas more rapidly as it is heated.

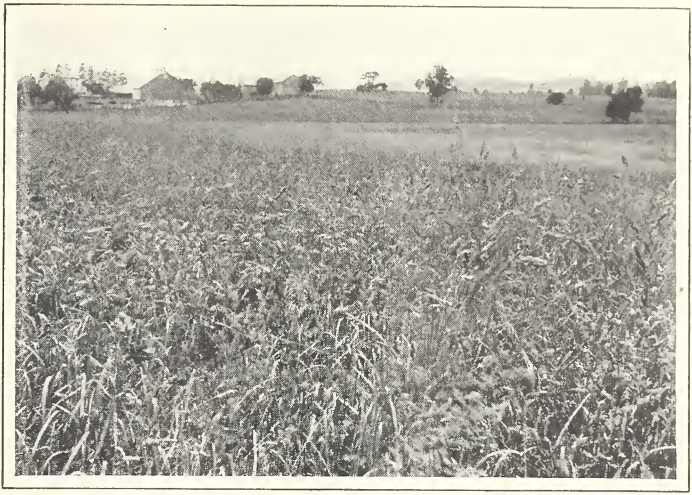

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FIG. 39. Many Hundred Tons of Water per Season are evaporated from Fields of Grass Such as this One

Clouds are tiny droplets of condensed vapor

You might expect, then, that water vapor, or water in the form of gas, would change back to liquid if it were cooled. And this is exactly what does happen. When water vapor is cooled, the molecules move less rapidly. Soon they condense in the form of tiny droplets on the little particles of dust that are always present in the air. These tiny droplets floating in the air are clouds. A dense cloud is simply a great number of water droplets floating in the air. As condensation continues, these droplets grow larger and larger until they are finally large enough to fall as rain. If the temperature is down to freezing when condensation takes place, the droplets fall as snow. We usually say that rain or snow falls from the clouds. We should be more accurate if we said that when it rains or snows, the clouds fall.

Dew is another form in which water comes out of the air. It is quite different from rain, for it does not form except when the skies are clear. Where does dew come from? To

Fig. 40. The Beads of Water, formed upon the Cobweb, came out of the Air during the Night

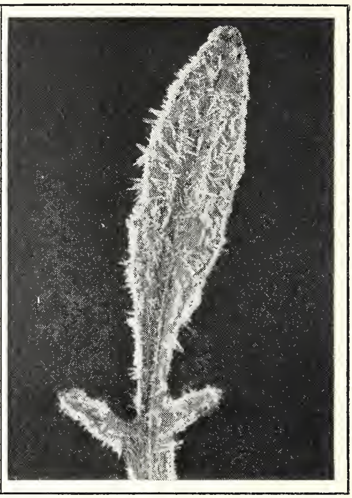


Fig. 41. When the Temperature is below Freezing, Moisture condenses in the Form of Frost

Photographs by Cornelia Clarke

Dew forms on clear nights

answer this you recall that when air is cooled, some of its water vapor condenses. The air gets cooler after the sun goes down. Things on the surface of the earth — grass, boards, and steel rails, for example — cool faster than air, with the result that water condenses on them. Sometimes this dew forms on a spider web, making beautiful lacy patterns similar to the one shown in Fig. 40. Dew, then, comes out of the air. It doesn't fall in the ordinary sense of the word, nor does it rise. If the temperature is below freezing, the moisture will condense in the form of frost. Is Fig. 41 familiar?

Moisture forms on an ice-water pitcher

A familiar sight that you may have been unable to explain is the moisture on the outside of a pitcher of ice water on a warm day. The same thing takes place in this case as in the case of dew. The cold pitcher cools the air about it. This cooling causes the water in the air to condense on the cold surface of the pitcher. Water enters the air by evaporation and leaves it by condensation.

The temperature at which water vapor condenses is called the *dew point*. When it is rainy or foggy out of doors, the dew point is the same as the temperature of the air. When it is clear, the dew point is lower than the temperature of the air. You may determine the dew point by means of an experiment. For this experiment you will need some cracked ice, a bright tin cup, and a thermometer. Put some water in the cup and cool the water by adding the cracked ice. Place the thermometer in the cup. Watch the outer surface of the cup carefully, and as soon as little drops of water begin to form on the cup, read the thermometer. The temperature at which the drops of water first appear is the dew point.

This experiment was done by one class on a warm day in autumn when the temperature of the air was 70° F. Cracked ice was added to water in the cup, and drops of water formed on the outside of the cup when the temperature of the water was 58° F. The dew point at that time was 58° F., as shown in Fig. 42.

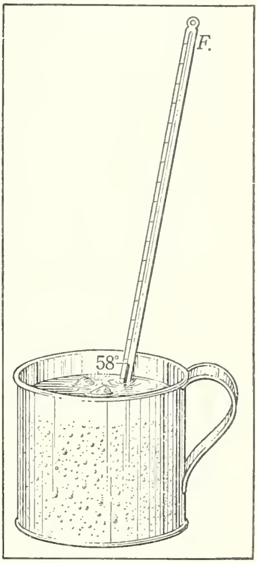


Fig. 42. The Temperature at which Drops of Water begin to appear on the Cup is the Dew Point

F. Are Water Molecules always in Motion?

Let us use our imaginations and see if we can follow a water molecule through some of its experiences. Following the experiences of a water molecule will take us for an interesting and possibly a very long journey. We may choose for our companion a molecule that we find in the ocean. It makes no difference which one we choose; for although the ocean extends for thousands of miles, all the molecules of water are alike. We pay attention now to the molecule of our choice, and we see that it is continuously moving, continuously bumping its neighbors and bounding away from one collision only to bump another neighbor and rebound in another direction. Each of these countless molecules is behaving much like the molecule we are following.

We follow a water molecule on an imaginary journey

On frequent occasions we meet another kind of molecule, quite unlike the molecules of water. These are molecules of the salt that is dissolved in the ocean, and they too are bumping others and bounding about.

After a time the molecule we are following reaches the surface of the water, and we see its bounding movement carry it free from the liquid and into the air. But it has not really escaped, for a collision with a molecule of one of the gases in the air causes it to rebound and again become a part of the liquid. But it is still moving with just as much speed as when we started with it. Possibly it is now moving a little faster; for at the surface of the water it is exposed more directly to the warm rays of the sun, and heat causes it to move with even greater speed. In a little while it bounds free from the liquid and this time floats away into the air. It still has numerous collisions with other water molecules; but since water molecules are much farther apart in the air than they are in liquid, it cannot have so many as before. Nor are the molecules of the gases in the air, with which it also collides, so close together as water molecules in liquid. Now our molecule is caught by the wind and carried off on a long journey over the land. We shall have to have a good imagination now to follow it. But we'll try. We see it moving first in one direction and then in another. At one

FIG. 43. Here are Some Stages of the Water Cycle

How many can you find?

time it is close to the ground, and at other times it is high in the air. Whatever its position, it is mingling with the *molecules of the gases that make up the air* and at the same time with countless molecules of water just like itself. Now and again we see dust particles also. Although these are very numerous, they are not nearly as numerous as the molecules.

Now conditions are changing. It is getting colder, and the molecules begin to move less rapidly. Soon we see the water vapor condensing on the dust particles as tiny little drops of water. The molecule we have been following is caught in one of these. It is now part of a rapidly gathering cloud. After a time, when the droplets have grown so large that they can no longer float in the air, they fall as rain.

Soon we find our molecule on the ground. It has become part of a little stream running down the hillside. Together with its companions it is tearing away some of the earth as it travels. When the little stream joins a larger stream, our molecule goes along, too, and so continues on its long journey back to the ocean. If we should continue to follow it, we should find that in the course of time it would start its journey all over again. We have tried to illustrate some steps in this cycle in Fig. 43. How many stages can you find there?

Now we may inquire where this molecule came from in the first place and how long it has been making these trips from the ocean to air to land and back to the ocean. These questions are hard ones. We believe that molecules do not wear out, and that they are only rarely destroyed. So far as we can tell, this cycle has gone on forever and will continue forever. But forever is a very long time. The question we have raised is a hard one, and we must leave it unanswered.

On other journeys a water molecule may have many other experiences besides those we have described. After falling to the ground it may ooze into the spaces between particles of soil. It may find its way to the roots of a tree and together with others of its kind pass up through the trunk of the tree, carrying in solution to the leaves the materials that are necessary for life and growth. Or it may fall for a time into a filthy, stagnant mud puddle and associate with deadly germs of disease; but when it is again condensed and collected after evaporation, it is pure water, regardless of the source from which it evaporated.

A large amount of water seeps downward through the soil. Some of it goes to great depths. We know that there is an abundance of water beneath the surface of the ground, for if we dig deep enough we can always find it. In dry regions we may have to dig to great depths to find water, but in damper climates we may find it at or near the surface. The level at which water stands in wells is known as the water table. This is illustrated in Figure 44. In swamps the water table is at or above the sur-

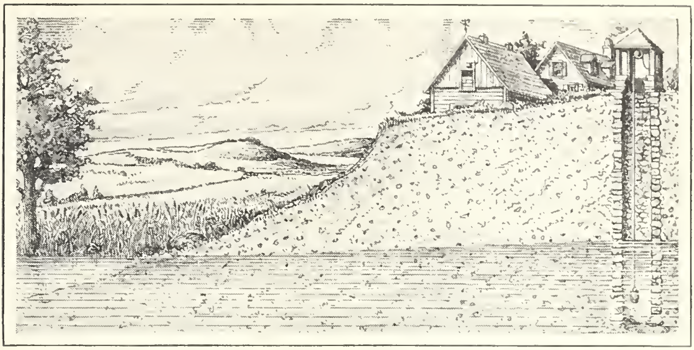


FIG. 44. The Level at which Water stands in Wells is known as the Water Table

face of the ground. The water table in any region is nearer the surface during wet weather than during dry weather.

Nor do these further examples exhaust the experiences of a water molecule. We might find it locked up in a huge iceberg. We might find it slowly working its way through the earth deep under the surface, and, as you will learn later, it may be caught and become part of the chemical composition of certain rocks. In such an event this ordinarily actively moving molecule is held fast, perhaps for countless ages. Other molecules may be caught in such a way as to form part of the chemical composition of common substances like sugar and starch. These molecules are not likely to be held for a long time. As the sugar and starch are used for food, the water molecules that were a part of their composition are released to continue their journeys.

Molecules do not remain at any one place for long

This is the story of the water cycle. Wherever you see water, you may think of it as at some stage of one of its many journeys, for it is not likely that molecules of water will remain long at any one place. When water is in the form of gas, the molecules move with a great deal of freedom. In the form of liquid they move with less freedom, and in the form of ice their movement is even more limited. Heat makes them move faster, and cold makes them move more slowly. Water molecules are constantly changing their position. When they get into the air, they may have many different adventures. But time seems endless, and the molecules that leave the ocean may return to it again and again.

Water enters the air by evaporation, and leaves the air by condensation. This continuous process, which is explained by the molecular theory, is called the water cycle.

Can You Answer these Questions?

1. What is the water cycle?

2. Three new words used in this chapter are condensation, evaporation, and transpiration. Can you explain what they mean?

3. What is meant by dew point?

4. Does frost form on the inside or on the outside of a window? Why is this so?

5. We often say that a puddle, a brook, or even a river has dried up. Does this mean that the water has been destroyed? What does it really mean?

6. Can you explain the boiling of water in terms of the molecular theory?

7. Can you explain in simple terms what a cloud really is? rain? snow? dew? frost?

8. The soil often becomes very dry after a week or more of fair weather. Why is this?

Questions for Discussion

1. Why is it that liquids which evaporate more rapidly than water will boil at a lower temperature than water?

2. Can we make use of the molecular theory only in our study of water? Can you give examples of any other familiar occur-

rences which may be explained by using this theory? Be sure you can explain your own selections.

3. Can you explain why it is that once water in an open pan has reached the boiling point it will not get any hotter?

Here are Some Things You May Want to Do

1. Make an experiment to get evidence as to whether a pint of water evaporates at the same rate from a shallow dish as from a deep one, and from a dish standing in the sun as from a dish standing in a dark place. You might want to see whether the same amount of water (in a dish of the same kind in each case) would evaporate more quickly in a warm room than in a cool room. Keep a record of the results and draw any conclusions that are supported by your observations.

2. Determine the temperature of boiling water as suggested on pages 82 and 83. Make a strong salt solution and determine carefully the boiling point of the solution. Try some other liquids.

3. See if you can get two flowerpots. One should contain a healthy growing plant in soil. The other should contain soil but no plant. Place a battery jar upside down over each pot and observe results after an hour or so. What conclusions are supported by your observations?

4. Set up a demonstration to show that moisture may form as air cools.

5. Write a story with the title "The Further Adventures of a Water Molecule." What may happen to a molecule that sinks deep into the ground? to one that happens to rise twenty miles above the surface of the earth? You may think of other things that might happen to a water molecule.

6. Set up a demonstration to show that cold water is denser than hot water.

Chapter V · Why do Some Things Float while Others Sink?

A. Of What Use is a Knowledge of the Laws governing Floating Bodies?

Have you ever visited a shipyard and seen a large steamship in the process of construction? Perhaps you have been fortunate enough to be permitted to go through a new boat before it was launched. If so, you too, perhaps, have wondered about this tremendously heavy iron or steel shell, towering high above a foundation of strong timbers, surrounded by a forest of derricks and covered with hundreds of men who are busily engaged in a score of different tasks. Perhaps you have seen some of the enormous machinery which will some day furnish the power for this new giant of the seas. You may have clambered up and down the many ladders leading to many steel decks. You may have seen the rough divisions like cells in a honeycomb which will some day be a succession of luxuriously furnished staterooms.

If you have had this experience, you, like others, have thought and wondered about the tremendous weight of this new ship. Engines and steel hull, decks and steel furnishings — all one sees is weight and more weight. Perhaps a doubt has entered your mind as to whether this tremendous mass of metal will really float. But if you returned on the day of the launching, you saw the new vessel slip gracefully into the water amid flying flags, a cheering crowd, and shrieking whistles, to come to an even rest upon its surface.

How is this possible? A piece of iron or steel thrown into the water sinks, doesn't it? Then why doesn't this huge ship sink? Can man calculate just how much a ship and its cargo can weigh and still float? Or does he guess at it and trust to luck? Are there any laws which control such things? If so, what are they? Let us see how some boys of our acquaintance discovered some of these laws.

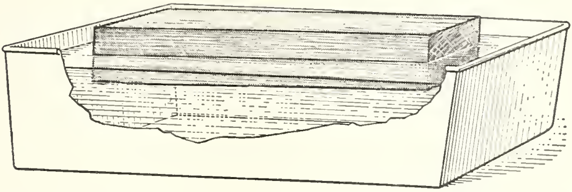


Fig. 45. A Block of Wood displaces its Own Weight in Water

Most wood floats with about half of its volume above the surface of the water

After spending the greater part of the early summer in collecting suitable materials and experimenting with them the boys built an evenly balanced raft. They soon learned how to manage it. As a result of their work they learned many interesting and important things about floating bodies.

Wood floats because it is lighter than an equal volume of water

They told us that wood floats because it is lighter than water. We questioned them as to just what they meant by this statement. "Lighter than *how much* water?" we asked, and continued, "We can get a tank of water which will weigh just as much as your raft." "Oh, yes," argued one of the boys, "but it wouldn't be as big as the raft. If you brought just as much water as we have raft, the water would be heavier than the raft. A block of wood is lighter than a block of water of the same size." "You mean, then," we said, "the same *volume* of water, or the same amount of water as far as size is concerned, would certainly weigh more than the wood. Can we say, then, that the wood floats because it is lighter than the same volume of water?"

"Yes," they agreed. "Anyone can prove that by weighing a block of wood and then weighing the same volume of water." "All right," we said, "suppose you prepare to prove it in our next science period."

Two days later the boys arrived with a dish pan, a scale, and a block of wood. "Go ahead," we told them, "the floor is yours." George filled the pan with water and began: "This is a block of wood one foot long cut from the end of a 'two by four.' Let me put it in the water, and we'll see what happens." He did so and asked, "Now what do you notice?" Jean told him that it was floating on the water. "All of it?" he asked. "Well, no," she replied; "part of it is beneath the surface." "Ah!" said George, looking very wise, "that's just the point. How much of it is under water?" "About half of it," Jean replied. "All right," said George. "Now let's see how much the block weighs." He put it on the scale, and we saw the hand stop just under $1\frac{3}{4}$ pounds. "Now, what's the volume of it?" he continued. We figured it out loud, "$2 \times 4 \times 12$ inches $= 96$ cubic inches." "That's right," said George, and continued: "Here is a block of wood weighing about $1\frac{3}{4}$ pounds with a volume of 96 cubic inches. When we put it in the water, we found that about half of the block floats above the surface of the water. Now if our original statement is correct, this block of wood should weigh about half that of an equal volume of water. We have looked up our figures and found that 96 cubic inches of water weighs about $3\frac{1}{2}$ pounds. Does that prove our statement?" George turned to us for an answer.

A pine block displaces about half its volume

We thanked the boys for their demonstration but were still curious. "How," we asked, "did you come to discover all this?" "Well," said Joe, "we learned it through experience. We built one raft and launched it. When we tried to climb aboard, we found it would not carry us. Right then and there we decided to be scientific about the thing. We hunted up all the information we could and finally thought we had hit upon the answer." "What was it?" we asked. "Well, just what George demonstrated to you," said Joe. We pressed them for more information. "How did that help you?" we asked. "We did a lot of figuring," said George. "We found that the best raft we could build from our materials was one 8 feet wide, 9 feet long, and a third of a foot thick. The volume of this raft would be 24 cubic feet. Since it was made of the same kind of wood we used in our demonstration, half of it should float above the surface and half of it should be beneath the surface. Instead, then, of carrying a load equal to the weight of 24 cubic feet of water, our raft would carry a load equal to the weight of 12 cubic feet of water. Our textbook told us that 1 cubic foot of water weighs about 60 pounds. Our raft, then, should hold about twelve times 60, or about 720 pounds. The three of us weigh about 300 pounds. If our figures are correct, the raft should support us easily."

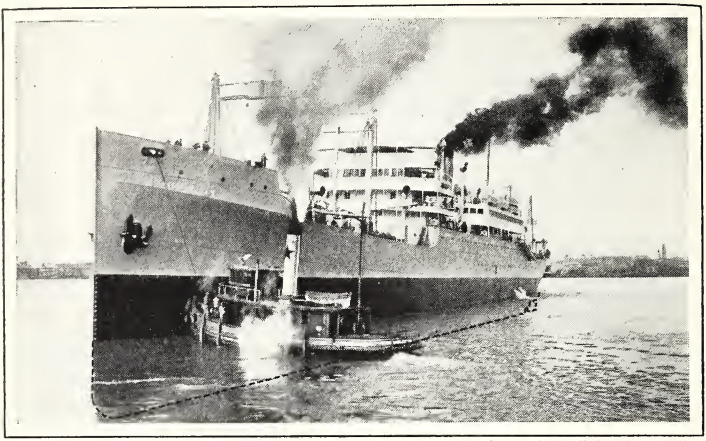
A cubic foot of water weighs a little over 60 pounds

"How about it?" we asked. "Were they? And did it?" "Well," responded George, "we built it anyway and launched it. There it was. Would it hold us? We hopped on, and what do you think? Not a single drop of water came over the top except at the edges when we climbed on or when all of us moved over to one side."

B. Why does a Boat Float?

At this point Grace asked a question: "An iron boat does not sink, even though iron is heavier than water. Why couldn't you make an iron or steel raft? It would be stronger." This was another problem, wasn't it? This is the way we answered Grace.

First of all, we tried an experiment. We took a tin can and filled it to the very top with water. Then we set it in a large pan. Next we floated a small dish or toy boat on top of the water in the tin can. As the small dish or toy boat settled, some of the water in the can flowed over the top into the larger pan. We weighed the water which



© New York Shipbuilding Corporation

Fig. 46. Even an Ocean Liner will float only when it is Lighter than an Equal Volume of Water

The dotted lines in the picture show the part of the boat under water

overflowed. What do you think we found? We did the job as carefully as we could and found that the overflowing water weighed almost exactly the same as the small dish or toy boat.

There is a great difference, of course, between the toy boat in the tin can and a great ocean liner. You may think therefore that this problem too is different and that the mighty ocean liner must surely be heavier than the water it displaces. If you have ever visited a large ship, you know that it is not a solid mass of iron or steel. As you go down and down into the depths of the liner, you find there is much open space between decks. This space is filled with air, which is much lighter than the same volume of water, and so the boat floats. (When you see a boat in the water, you should realize that there is a large part of it below the water line. Notice in Fig. 46 how much of the ship is beneath the surface of the water.) If we replace the air with cargo or if water gets in over the edge or through a hole, the total weight of the ship will be increased. If by any chance too much water gets in or too much cargo is taken on, so that the whole ship weighs as much or more than an equal volume of water, then down goes the ship. When filled with water or a heavy cargo, the iron ship will sink just like any other heavy metal. The same principle holds true for both the toy boat in our tin can and the mighty ocean liner. The total weight of each is just equal to the weight of the water it displaces.

A boat displaces its own weight of water

Over two thousand years ago a Greek scientist named Archimedes studied floating bodies and stated his conclusions somewhat as follows: "Any body placed in a liquid is buoyed up by a force equal to the weight of the liquid it displaces." If a body weighs less than the same volume of a liquid, the buoyant force of the liquid not only will keep it from sinking but will keep it floating partly out of the liquid. In this case it displaces *less* than its own *volume* of liquid. It displaces exactly its own *weight* of the liquid. Thus, as Archimedes knew, and as you learned in your experiment with the toy boat, the weight of a floating body is exactly equal to the weight of the liquid it displaces. If the body weighs more than the same volume of a liquid, then the buoyant force of the liquid will not be enough to hold it up, and it will sink. Thus the buoyant force of water may not be strong enough to support heavy bodies. But it operates just the same. Perhaps you have lifted a heavy stone from the bottom of a stream and pushed it up toward the bank. When you got it to the top of the water and tried to move it farther, however, you discovered that you could no longer lift it. The reason for this is that the buoyancy of the water helped to support the stone while it was in the water. You may prove this by an experiment. Tie a piece of string around a stone and attach the other end of the string to a spring scale. Record the weight of the stone. Now lower the stone, still

FIG. 47. ARCHIMEDES, *killed by a Roman Soldier while drawing in the Sand (287?–212 B.C.)*

SOME two thousand years ago Hiero, king of Sicily, thought he had been cheated. His crown, supposed to be solid gold, seemed too light. He suspected his jeweler of adding silver, but he did not know how to prove it. So he appealed to Archimedes, inventor and mathematician, to play detective. Archimedes too was puzzled, until one day as he jumped into the bath tub he noticed that the water rose higher. He jumped out and ran to the King, shouting "Eureka! Eureka!" which is Greek for "I've found it!" · When his excitement had subsided, he explained as follows: "My observation in the bath shows that an irregular-shaped body submerged in water will displace just as much water as its own volume. We'll drop the crown in a pan of water and measure the water that spills over. Then we'll put pure gold weighing just as much as the crown into water and measure the water it displaces. Gold is denser than silver, so we can tell if the crown is not pure gold; for it will displace too much water. Eureka!" Archimedes tried his plan and found the jeweler was dishonest. He discovered also that a body which floats in water displaces just as much water as its own weight, and a body which sinks is buoyed up by a force equal to the weight of the liquid it displaces. This discovery is known as Archimedes' law · Archimedes wanted to be remembered as a mathematician, and many of his writings on geometry and mechanics are still in existence. We think of him, however, as an inventor of practical appliances, an ancient Edison whose personality shines out of the history of two thousand years ago.

attached to the scale, into a pan of water. Does the scale register the same weight as it did before? Study Fig. 48, which illustrates one such experiment. You will notice that the stone used here weighed exactly 10 pounds when it was hanging in the air, but that the pointer of the scale dropped back to 6 pounds when the stone was let down into the pan of water. The difference may be explained by saying that the stone is buoyed by a force equal to the weight of the water it displaces. In the experiment illustrated, this was equal to 4 pounds. The force that is required to raise a stone weighing 50 pounds from the dry ground would be enough to lift a stone weighing more than 80 pounds if the stone were under water. This is the scientific explanation of why water plants do not need strong stems to hold them up. It is the real explanation, too, of why fish can float or keep up with little effort and why the whale can grow to a size not approached by any land animal. The buoyant force of the water helps to support the weight of any object that is in it.

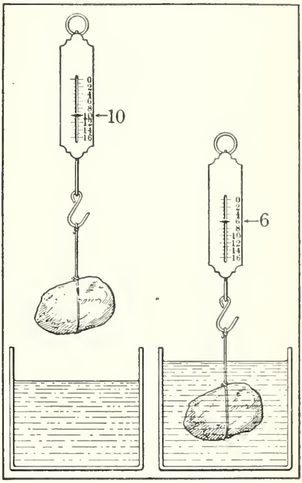


Fig. 48. Does this Picture explain why it is Easy to lift Stones under Water?

It is easy to lift stones under water

C. What has the Principle of Buoyancy to do with Swimming, Floating, and Diving?

Have you ever stood on the beach and watched someone swimming far out near the life lines? If you have, perhaps you too have commented, "That man swims like a fish." Or perhaps you have seen someone splashing

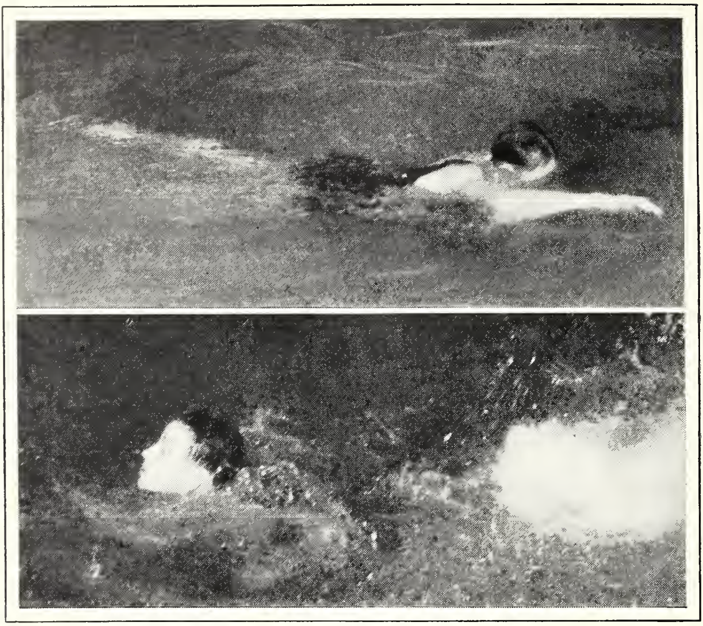


Fig. 49. A Good Swimmer takes Advantage of the Buoyancy of the Water, but the Poor Swimmer does Not

around wildly in the shallow water as he pushed himself along with one foot on the bottom half the time. The first person was a good swimmer; the second, a very poor swimmer.

It is easy for a person to float

Boys and girls who are used to the water soon learn that they can float. They learn, too, that when one floats he must keep his lungs well filled with air and must keep as much of his body under water as possible. The weight of the human body is nearly the same as the weight of an equal volume of water. Floating, then, is not difficult if you will first learn two things. You must learn to lie on your back in the water with only your nose above the surface. You must learn to breathe while exhaling but little air from the lungs. You will float if your lungs are kept filled with air and if practically all of your body is kept quietly under water.

A good swimmer takes advantage of the buoyant force of the water

Now how about swimming? Watch a good swimmer. He moves with his body and head almost entirely under the water. He has learned to make the water carry the weight of his body. At regular intervals he raises his face above the surface for a deep breath of air. Notice a poor swimmer. He holds his head far above the water and struggles laboriously to keep it there. He has not learned to take full advantage of the buoyant force of the water. The good swimmer lets the water support his head and is able to use the strength of his muscles to push himself through the water. The poor swimmer uses a great deal of strength in his effort to keep his head out of water. Contrast the two swimmers in Fig. 49. Did you ever notice a dog as he swims? Most of the dog's body is under water. Only his nose is above the surface. We have already observed that an elephant is a good swimmer. He swims with the tip of his trunk showing above the surface. Most animals swim in about this same way.

A bird floats like a boat

Birds, however, are unlike other animals, for when they swim a large part of their bodies is above water. If you will look at Fig. 50, you will see that a swan or a duck seems almost to sit on top of the water; but it doesn't. Like everything else that floats, its body displaces a weight of water that is just equal to its own weight. The bird's feathers themselves are very light, and the spaces between them are filled with air. Its bones are hollow. The feathers and air spaces are very much lighter than an equal volume of water. Now you see why a small part of the volume of the swan will displace a weight of water equal to the bird's whole weight. It can swim easily with its head high above the water. We cannot. The average density of our bodies is greater than the average density of the body of a bird.

Fig. 50. A Bird's Feathers help it to Float

It appears to sit on top of the water. Like other floating bodies, however, it displaces its own weight in water. (Photograph by Cornelia Clarke)

The principle of buoyancy explains why it is possible for larger animals to live in water than on land. The largest form of animal life in the world is the whale. Some whales weigh more than one hundred tons. An animal as large as this could not live on land, for the leg bones required to support such a weight would be so large that the muscular system could not move them. Bones are the heaviest part of an animal's body; as an animal gets larger, more and more of the weight is bone. The elephant is the largest land animal of today. There was a time in the history of the world when animals as heavy as forty tons lived on the land, and this is probably the upper limit in size for land animals. The whale, although fifteen times as large as the largest elephant and possibly two and a half times as large as the largest land animal that ever lived, moves easily and rapidly through the water. As he swims he is supported, or buoyed up, by it.

Fish seem to swim with very little effort. As you see them in an aquarium or in their native surroundings, you

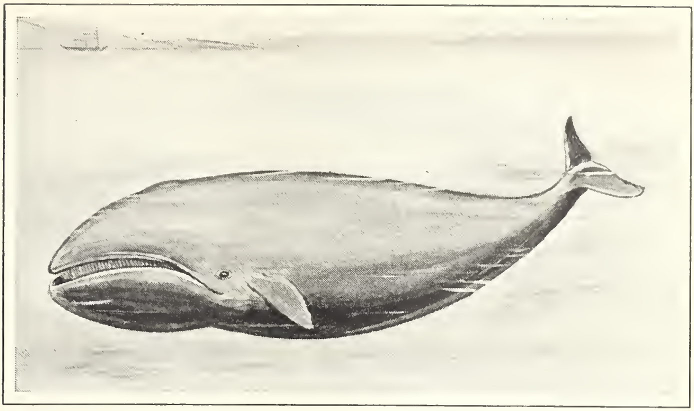


FIG. 51. The Huge Whale is buoyed up by the Water in which it Lives

Many fish have an air bladder

marvel at their grace. Some fish have an air bladder inside the body that looks somewhat like a toy balloon. By means of this bladder they keep a fine adjustment between the weight of their bodies and the weight of the water displaced. A slight enlargement of the air bladder causes these fish to rise, and a slight compression permits them to swim to a lower depth.

A submarine works on a similar principle. It is equipped with large ballast tanks which sometimes run the whole length of the boat. When the submarine is on the surface, these ballast tanks are filled with air. When the submarine is ready to submerge, water is let into the tanks. The weight of the water increases the weight of the submarine, and it sinks. By increasing or decreasing the amount of water in the ballast tanks one can make the submarine go deeper or come to the surface.

How deep may a submarine dive? The present record is nearly 400 feet. "Why can't it go deeper?" you may ask. The answer may be found in the tremendous pressure of the water at great depths. You have already learned that the weight of a cubic foot of water is about 60 pounds.

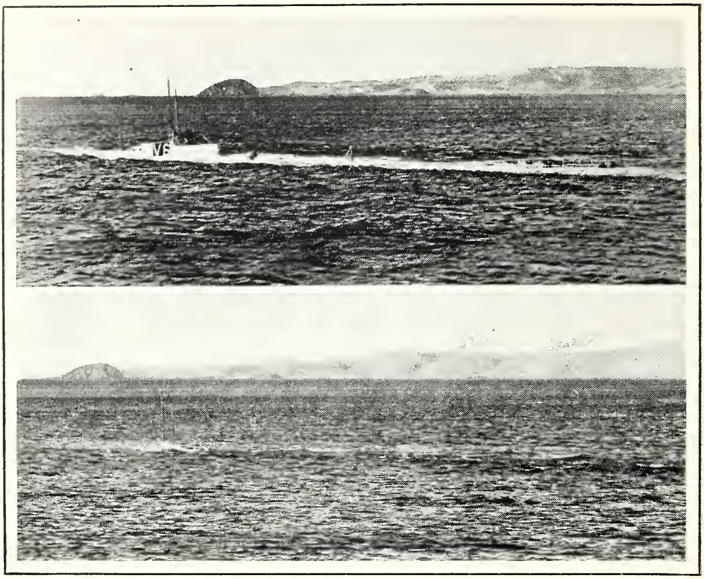


FIG. 52. How did this Submarine shift its Position from that in the Upper Picture to that in the Lower Picture?

Courtesy of the United States Navy

More accurately the weight is 62.4 pounds. At a depth of 400 feet the pressure on each square foot of the submarine is nearly 25,000 pounds. This is more than 170 pounds on each square inch. Remember that, in order to submerge, the ballast tanks of the submarine are filled with water. In order to rise again this water must be forced out of the tanks. This is done by means of pumps. These pumps must be powerful enough to force out the water against the pressure outside the submarine. The best pumps now in use are not strong enough to overcome a pressure of much more than 170 pounds per square inch. You must understand that the pressure at any depth is equal in all directions, so that, so far as pressure alone

The power of the pumps limits the depth to which a submarine can go

is concerned, a submarine could be made to go deeper. The reason the captain doesn't dare send it deeper is that he knows the limit of pressure that his pumps will stand. He knows he can go deeper; *but* he could not get to the surface again, for his pumps would not operate against the tremendous outside pressure.

Deep-sea fish are adapted to life under great pressure

There are deep-sea fish that live at greater depths than the submarine can go. Animals have been hauled up in dredge nets from depths of more than 20,000 feet. Some creatures probably live at even greater depths. These living things are adapted to life under heavy pressure. At 20,000 feet the water pressure is nearly 9000 pounds on each square inch. But a fish adapted to life at this pressure is crushed no more by it than we are by the pressure of the air on the outside of our bodies. The fact is that in either case the pressure inside the body is equal to the pressure outside the body; and so long as the pressure does not change too much or too rapidly, neither we nor the deep-sea fish are injured by it.

Pressure should be changed gradually

It is when the pressure changes that living things may be injured. Some deep-sea fish are killed by the expansion of the air in their air bladders when they are brought to the surface by force. You may understand this better by considering the work of the diver. Men have gone down in diving suits as deep as 300 feet. The suits for such work must be specially made, and when the diver is ready to descend (Fig. 53), he looks like a monster in a fairy tale. At a depth of 300 feet the water pressure on the body is about 130 pounds per square inch. When a diver descends to this depth in a collapsible diving suit, sufficient air must be pumped into the suit to withstand this pressure. Thus at a depth of 300 feet the diver is working in an air pressure of about 150 pounds per square inch, while at the surface this pressure is only about 15 pounds per square inch. This difference in pressure must be adjusted gradually. Therefore the diver is not dropped rapidly to the ocean floor, as one might suppose, but is let down a short distance at a time. As he goes deeper and deeper, his body adjusts itself to the increasing pressure. At whatever depth he may be working, the pressure inside the cells of the diver's body must be a little but not too much greater than the pressure outside his body. The change in pressure must also be adjusted when the diver is ready to come to the surface. Now he is pulled up only a short distance at a time. At each stage he rests until the adjustment is made. When working at great depths the diver often spends more time in going down and coming up than he spends at the bottom.

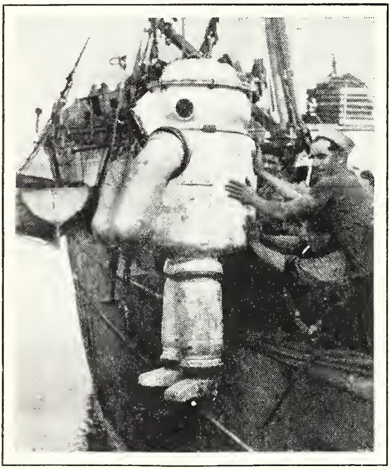


FIG. 53. Deep-sea Divers need Special Suits constructed to resist Tremendous Pressure

These changes in pressure do not seem to affect some forms of life as much as they do man.

The whale is one of the greatest divers

The whale is one of the most famous of deep-sea divers. In case of danger he may plunge as rapidly as he can dive to a depth of nearly half a mile. The pressure on his body changes during this dive from that of air pressure, which is 15 pounds per square inch, to a pressure of more than 1000 pounds per square inch. And he may return to the surface from this great depth in a comparatively short time. Yet he is not injured by this tremendous change in pressure, which would kill other animals. Once more we see that animals are adapted to the life they live.

The fact that some bodies float and others sink when they are placed in the water may be explained by the principle of buoyancy. According to this law, a body in water is buoyed up by a force equal to the weight of the water it displaces

Can You Answer these Questions?

1. Some deep-sea fishes live at a depth of three miles. How is it that fish can live at such a depth while a man cannot, even if he is protected by a heavy steel diving suit?

2. Explain why an iron boat will float.

3. Can you give a good explanation for the term *buoyancy*? Give your definition as a scientific law if you can.

4. What is a most important difference between the swimming of a good swimmer and that of a poor swimmer?

5. Suppose a body displaces less than its own weight of water. Will it sink or float? Can you tell why?

6. Can a body be made to displace more water than its own volume? Can it be made to displace more water than its own weight? Give examples to support your answers.

7. An elephant swims with the tip of his trunk above water, and nearly all of his body under water, but a swan swims with most of its body above water. Why this difference?

8. How does a submarine submerge and come to the surface again? Explain the various steps in the process, and give your reasons why these steps result as you say they do.

9. Why must a deep-sea diver come up slowly?

Question for Discussion

Three boys planned a raft very carefully according to the figures given in this chapter. One of them found some old oak boards in his cellar, and they built the raft. When they launched it, however, much to their surprise it would not support their weight. They checked over their figures carefully and could find no mistakes. Why do you think the raft was not a success?

Here are Some Things You May Want to Do

1. Read Commander Ellsberg's *On the Bottom.* This is a really exciting story about the work of the deep-sea diver and the dangers of life in a submarine.

2. Make a collection of pictures and stories about good and poor swimmers. Perhaps someone in your school might be glad to talk to your class about swimming and diving.

3. For many years people have argued whether a ship that sinks in deep water goes all the way to the bottom of the ocean or whether the pressure of the water will support it at a certain level above the bottom. What do you think? See if you can find the answer.

4. Read the story of Archimedes in Plutarch's *Lives.* It is told under the life of Lucullus, the Roman general.

5. Draw up plans for a raft or small boat to be used by you and several of your friends. To help yourself in checking up on your work you might talk over each step of it with the class. You might try to build the raft or boat from your plans.

6. We have said that no land animal ever weighed as much as the whale. You might wish to see whether this is so by reading about some of the dinosaurs, which lived millions of years ago. Some of these animals were over eighty feet long; some of them had two thousand teeth in their mouth, and some had tails over twenty feet long. Doesn't it seem reasonable that an animal as large as this must have weighed more than a whale?

7. Read Melville's *Moby Dick,* a story of a white whale.

8. A fresh egg will sink in pure water. When salt is added to the water, the egg rises to the surface. Try it and explain your observations.

Chapter VI · What is Water?

Fig. 54. Water is found in Many Forms

In each of the sketches above you will find water in some form. But perhaps you will say: "There are ice and frost and snow and several other things illustrated. Are all these water? If so, what is water?" Several questions must be considered in order to answer this single apparently simple one. How many forms of water are there? What is it made of? How does water differ from other liquids? In what ways is it unlike the alcohol you put in the radiator of your car as winter approaches? In other words, what are some of the properties, or particular qualities, of water that make it water instead of some other substance?

Let us see what we can find out about it.

A. What are the Boiling and Freezing Points of Water?

You have already learned that water boils at a certain temperature and that while it is boiling its temperature does not change. You have used a thermometer, and you know that it is an instrument for measuring temperature. What else do you know about it? If you look at it carefully, you will see that it is marked with figures which run from low to high. In reading your thermometer you read the figure that tells the position of the top of the thread of mercury. But how are these figures determined when the thermometer is made? Perhaps you can find out by using a thermometer and taking some observations.

Suppose you take a laboratory thermometer. Place a beaker of water over a burner and suspend the thermometer so that the bulb is immersed. The thermometer might break if you allowed it to rest against the bottom of the beaker. Light the burner. If you watch the thread of mercury carefully, you see it rise in the tube as the water gets warmer. It continues to rise slowly in the stem until the water boils. Now it remains constant. In other words, the temperature has reached the point at which water boils. To make certain that you will get the same result you may wish to repeat the observations using another thermometer. You have now determined that the boiling point of water is a definite temperature.

Now suppose you try an experiment in which you reverse the process you have just followed. This experiment is interesting but difficult to do. Place your thermometer in a slender test tube. Pour water into the test tube until it is about half full. Then set the test tube in a cup of ice water. The thread of the mercury begins to fall. Next pack some cracked ice fairly firmly around the test tube in the cup and sprinkle about two tablespoonfuls of salt on the ice. Then await results, watching the mercury in the thermometer and also the water in the test tube. The mercury keeps falling. Keep adding ice and salt and after a while notice that ice begins to form in the test tube. When this happens, you will notice that the mercury has stopped falling and remains stationary. Again read the thermometer. This time you have found the freezing point.

You could bring the mercury even lower by continuing to add ice and salt until all the water in the test tube changed to ice. After all the water is frozen, the temperature will go lower; but as long as ice is forming, the temperature remains the same.

The distance between the two readings you have made on the thermometer is the distance through which the tip of the thread of mercury moves as pure water is warmed from the freezing point to the boiling point. The process that you have followed is just the same as the one that is followed in making a thermometer, except that the freezing point and the boiling point are marked much more carefully than you are able to do it.

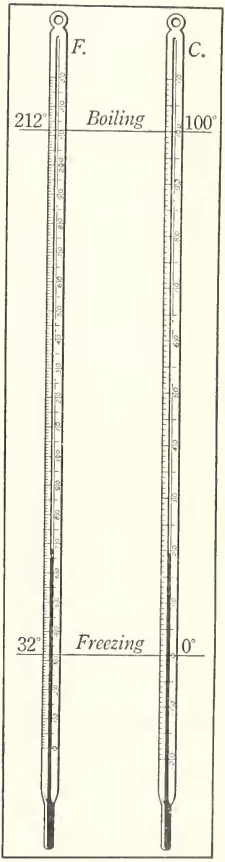


Fig. 55. Two Scales for Thermometers are in Common Use, Fahrenheit (F.) and Centigrade (C.)

The other day we saw a statement which said, "The temperature of the liquid was 158° F., or 70° C." (Read thus, "a hundred and fifty-eight degrees Fahrenheit, or seventy degrees centigrade.") What did this mean? Can the same substance be of two temperatures at the same time? Of course not. There are two thermometer scales. The one ordinarily used in the science laboratory is called a centigrade scale, and the one most often found in homes is called a Fahrenheit scale. On the stem of the thermometer with the centigrade scale the freezing point of water is marked 0. The boiling point of water is marked 100. On the stem of the thermometer with the Fahrenheit scale the freezing point of water is marked 32, and the boiling point is marked 212. It seems unfortunate that there are these two kinds of scales; for when you say the temperature is so many degrees, you have to say whether you mean degrees centigrade or degrees Fahrenheit. On a centigrade scale lines are drawn to mark each of the 100 degrees between the freezing point (0°) and the boiling point (100°). On a Fahrenheit scale lines are drawn to mark each of the 180 degrees between the freezing point (32°) and the boiling point (212°). The temperature of 0° C. and 32° F. is the same, and the temperature of 100° C. and 212° F. is the same. Notice Fig. 55. The mercury is at the same point in the stems of both thermometers, but the markings are different.

There are two kinds of thermometer scales

When you study physics in high school, you may learn about other liquids that freeze. These liquids freeze in the sense that they turn to a solid, just as water does, when they are sufficiently cooled. Other liquids boil just as water does. Boiling is a process of changing rapidly from liquid to gas at some temperature that does not change while the gas is forming. Freezing is a process of changing from liquid to solid at some temperature that does not change while the solid is forming.

B. What Happens to Water when it Freezes?

Water has one peculiar quality; it expands as it freezes. Most substances contract as they change from a liquid to a solid. Water contracts until it is nearly cold enough to freeze, and then it expands. A volume of freezing water is less dense than the cold water about it. For this reason

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FIG. 56. **Frozen Water makes Travel Difficult**

ice forms on the surface of bodies of water. In some parts of the world enormous masses of ice form, over which it is almost impossible to pass. Imagine traveling over icy wastes similar to those illustrated in Fig. 56. Ice is in one sense like a raft; it floats. If ice were not less dense than water, a tank or a lake of water would, when it freezes, freeze solid. It is fortunate for the plants and animals that live in water that water has this peculiar property.

Freezing water causes damage through expansion

You, like the man in Fig. 57, may have had first-hand experiences in cold weather that illustrate this expanding of water as it freezes. If you have, you may have wished that water did not have this property. If water freezes in pipes, the expansion of the water as it changes to ice may burst the pipes. If water freezes in the radiator of an automobile, it damages the radiator. You may have seen many other demonstrations of this force of freezing water. But you soon learn to take proper precautions against the possibility

FIG. 57. Cold Weather often means Trouble

What evidences can you find of the force of freezing water?

of such damage. The force exerted by expanding water is really very great. Not only is it enough to break water pipes; it will also break rocks. One of the most powerful natural forces for breaking rocks is the force of expanding water as it freezes in rock crevices.

C. What is the Difference between the Freezing Points of Water Solutions and the Freezing Point of Pure Water?

In your experiment with the thermometer you observed that the temperature of a mixture of salt and ice is lower than the freezing temperature of pure water. Water with salt dissolved in it freezes at a lower temperature than that at which pure water freezes. If you have been to the ocean in fall or winter, you may have observed that this is so; for ocean water, even when trapped in small inlets, does not freeze as readily as fresh water. Ocean water has salt dissolved in it. If we

The ocean does not freeze easily

were to set our thermometer in a tube of ocean water and pack ice and salt about the tube, we should find that it does not freeze at 0° C. It does freeze at about 2.5° C. below zero. Temperatures below zero are written with a minus sign. Thus the temperature at which ocean water freezes is written $-2.5°$ C.

As winter approaches, the garage man may remind your father to put some "anti-freeze" liquid in the radiator of the automobile. Alcohol is a common "anti-freeze" liquid. You let some water run out of the radiator, put in two or three quarts of alcohol, and finish filling the radiator with water. Now you are "prepared for winter." This solution of alcohol in water acts like the solution of salt in water in that the solution does not freeze as readily as pure water. For cold-weather driving you could use a solution of salt in the radiator if it were not for the injurious effect of the salt on the pipes of the cooling system. From these illustrations it is obvious that the freezing point of a water solution is lower than the freezing point of pure water.

D. Is Water a Simple Substance?

Some time ago you learned that water is not a continuous liquid, but a mass of molecules. If we are to understand what water really is, we must pay further attention to these molecules. What are they? What are they composed of? One way of finding out more about water would be to take it apart, or, to use another term, to decompose it.

Fig. 58 illustrates the apparatus used. This is commonly called an electrolysis apparatus. If you pour water into the middle tube, it flows into the other two, so that there is water in all three tubes. A few drops of acid should be added to the water that is used for electrolysis. Now attach a battery of two dry cells to the posts of the apparatus and turn on the current by closing the switch.

After a short time you will notice bubbles rising in the two smaller tubes. What is really happening? The electric current is decomposing molecules of water. By this process gases are formed. These gases rise to the top of the tubes and may be drawn off in test tubes. Suppose you collect the gas from the side where there is less in one test tube and from the side where there is more gas in another test tube. Can you find out what these gases are?

Water is decomposed by an electric current

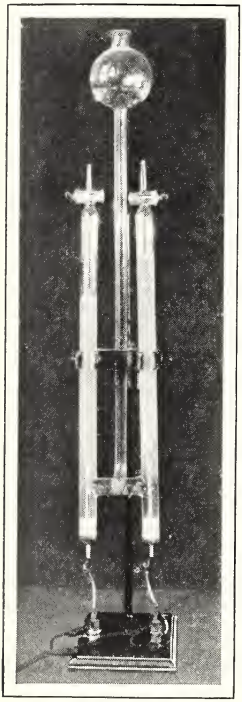

Fig. 58. The Picture shows the Apparatus for Decomposing Water into Hydrogen and Oxygen

One thing to do in studying a gas is to find out if it will burn. Another is to discover whether or not a burning stick will continue to burn in it. Light a splinter and push the burning splinter into the gas collected from the side where there was less gas. You will be surprised at what happens. The splinter continues to burn when pushed into the tube, and it burns with greater brightness in the tube than it does in the air. A chemist would tell you that this gas is oxygen. Now bring a burning splinter up to the mouth of the other tube. This time you are equally surprised and even startled a bit, for you will find that the gas in this test tube explodes. The noise of the explosion may cause you to jerk the burning splinter away from the tube. A chemist will tell you that this gas is hydrogen. In this experiment the electric current has decomposed water molecules and released the hydrogen and oxygen of which they are composed. The oxygen has collected in one tube and the hydrogen in the other.

A water molecule is composed of three atoms

But that is not all the story. If you could examine one of the molecules of water, which up to this time you may have thought was a simple particle, you would find that really it is not so simple. You would see that each molecule of water is composed of three smaller particles. The particles of which molecules are composed are called atoms. If you could examine each molecule closely, you would see that all the water molecules are exactly alike. Each one is composed of two atoms of hydrogen and one atom of oxygen. Probably you have heard that water is H_2O. This is called the formula for water. A formula is an expression which tells the composition of a substance. This one tells you the composition of the water molecule. You will learn more about the chemistry of water at a later time.

Water may be a solid, a liquid, or a gas. In each of these three states it has certain peculiar properties. Water is made up of molecules, and these are composed of atoms of hydrogen and oxygen.

Can You Answer these Questions?

1. What is the difference between the centigrade temperature scale and the Fahrenheit temperature scale?

2. In making ice cream why is it necessary to pack the container in a mixture of ice and salt? Should you get the same results in making ice cream if you used plain ice without salt? Can you explain why this is?

3. Can you name the three forms in which water is found and give an example of each?

4. Why do we place alcohol in the radiators of automobiles to prevent freezing as cold weather approaches?

5. How could you tell apart the two gases oxygen and hydrogen?

6. How can you show that water expands as it freezes?

7. Can you describe at least one method by which water may be decomposed?

8. What does the formula H_2O mean to you?

Questions for Discussion

1. Would you expect the temperature of steam as it escapes from the surface of the water to be higher or lower than the temperature of the boiling liquid? Why?

2. Do you know of any substances that freeze at a lower temperature than the temperature at which water freezes? that boil at a higher temperature than the temperature at which water boils? Can you see any use that might be made of such substances?

Here are Some Things You May Want to Do

1. Try to make a thermometer, following the suggestions on pages 114 and 116.

2. Try to decompose water by electricity as suggested on page 119. You will find more detailed directions in a book on chemistry, or your science teacher will be glad to help you.

3. Look up the words *Fahrenheit* and *centigrade* in an encyclopedia. See if you can find the meaning of these two words, and why we use two scales for thermometers.

4. The United States government has a coast-guard patrol which cruises the northern steamship lanes on the lookout for icebergs. See if you can find some books telling about their work, and how the icebergs are destroyed when they are found. This might make a good report for class.

5. See if you can find a list of substances which freeze at a lower temperature than pure water. What is the lowest temperature you can find as a freezing point? At what temperature does liquid air freeze?

6. Look up the meaning of the word *thermometer*. What is the derivation of the word?

7. One of the worst accidents in the history of ocean travel was the one which happened to the steamship *Titanic*. See if you can find this story, and also find what has been done to prevent similar disasters.

Chapter VII · What are the Essentials of a Satisfactory Water Supply?

A. How does your Community secure its Water Supply?

"Did you see the headlines in this morning's paper?" John asked one morning as he came into the science room. "No. What do they say?" asked several of the boys. John began to read:

> CITY FACES WATER FAMINE
>
> Citizens Warned to Guard Supply;
> New Orders Prohibit Waste

Other boys stopped talking and turned to John. "Say, that may be serious," said one of them. "Read the whole article, will you?" John continued his reading:

> The City Council last night warned the people of this city of a threatened water famine. The water in the Clear Spring Reservoir yesterday morning was the lowest it has been for fifteen years. "Unless precautions are taken immediately," said Councilman Murray, "the city faces a very serious situation. The reservoir now contains just enough water for a normal three weeks' supply. We must take immediate steps to guard this. Even with the strictest care, however, heavy rainfalls must arrive soon to prevent a water famine."
>
> At the Council Meeting held later in the evening the Board passed new rules and regulations to govern the use of water in the city. Beginning today no one may use water for gardens or lawns. Sidewalks may not be sprinkled, and all street-washing has been stopped until further orders. Householders are instructed to examine all plumbing fixtures and repair immediately any which leak. An immediate study is being started of the commercial users of water in the city, and it is possible that regulations will be set up to control the use of all water not absolutely necessary.

The boys looked at one another. "That shows how much I know about my own city," said George. "I've never even thought about our water supply. To be perfectly honest, I don't even know where the reservoir is, except that you go out along Clear Spring Road somewhere. All I've ever known about our water is that you turn a faucet and the water is there. The idea never occurred to me that there might not be enough. But," he added, "I'm going to find out about it now."

Fortunately for Smithtown, heavy rains arrived the next week, and the danger of a water famine was avoided for the time being. But the boys had become interested in their problem of water supply. They spent considerable time making trips and writing letters. They reported on where their local water came from, how it was safeguarded, and how it came to the city. They drew pictures and diagrams explaining sources and means of purifying the water. Before they finished, they had a complete story of their own local water supply. They gathered all this together in the form of a class booklet called "Facts about Smithtown's Water Supply." This booklet contained so much and such interesting information that it was put on display at the Chamber of Commerce for three weeks and was finally placed in the school library for the use of future classes.

What do you know about your own water supply? Where does it come from? How does it reach you? Who is in charge of it? Is there ever any danger of a water shortage in your community? See if you can find the answers to these questions. This chapter has been written to explain some things which may not be clear to you even after you find out what you can about your local water supply.

B. How do Soil Particles get into the Water?

The water you use for drinking, for bathing, for the laundry, and for other purposes has fallen as rain or snow many times before it comes to you.

Water from the clouds is pure

Water as it comes from the clouds is a clear transparent liquid and very nearly pure. Suppose you use your imagination in considering very carefully some water caught in a clean drinking glass during a summer shower. You would find there but few molecules except those of water. Since air dissolves in water, you would expect to find some molecules of the gases that make up the air. There are always some dust particles in the air; so there might be an occasional one of these. Occasionally you might find some other molecules than those of water and of the gases of the air, but of these others there would be very few indeed. Rain contains so few molecules of anything else than water that we commonly say rain water is pure. You may drink it without any fear that it is injurious.

Rain water soon gets muddy

Now let us consider the water that falls to the ground during a heavy shower. The rain fills the little ditches and runs down into little valleys. Let us dip a glass of water from one of the ditches and examine it. In appearance it is quite unlike the water that came from the clouds. You do not need to use your imagination to see that it is muddy. The things that make it so are particles of soil small enough to be carried along by the little streams. If you place the cup of muddy water on the table and observe it for a few minutes, you will see that some of the soil particles are settling to the bottom of the cup. Although the larger particles soon settle, some of the smaller ones do not settle even after several hours. The water remains muddy in appearance.

Another observation will show you how tiny these particles of soil are, and how difficult it is to separate them from the water. You probably have a glass funnel and some filter paper in your science workroom. You do not need to examine the filter paper very carefully to learn that you cannot see through it. Fold a piece of the paper and fit it snugly into the mouth of a funnel, as shown in Fig. 59. Pour some of the muddy water into the funnel, and you will see it trickle slowly through the filter paper. You may catch some of it in a clean glass. Examine the filter paper after all the water has trickled through, and you will see mud on the paper. Not all the mud has been removed, however, for the water in the glass is not as clear as pure rain water or drinking water. Some of the particles carried in water are so extremely tiny that they pass through the filter.

Some particles pass through a filter

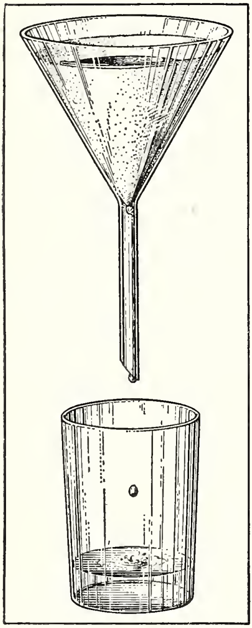

Fig. 59. Solid Substances may be removed from Water by Filtering

You have examined a glass of water from a little ditch, and you have seen some of the things in the water. There are particles of mud that quickly settle out, and there are particles that do not settle out even after a long time. On every hillside there are many little ditches. In each of them many gallons or possibly many barrels of water flow away after a rain. There are little particles of soil in all this water, just as there were in the glass of water you examined. You come to the conclusion that running water picks up particles of soil and carries them along as it flows from high to low places. The water you drink once flowed on the surface as muddy water. One step in the purification of water is to remove the mud.

C. Are there Any Substances dissolved in Water?

In addition to the tiny particles of soil that make it muddy, water carries along other things as it flows over the surface of the earth and seeps into the ground. You know that salt and sugar will dissolve in water. When you stir a spoonful of sugar in a glass of lemonade, the sugar disappears. It dissolves in the water. As you drink the lemonade, the last drop tastes just as sweet as the first one if the sugar has completely dissolved. This means that one drop of the solution has just as many molecules of sugar in it as any other drop. You could watch a lump of sugar as it disappears in a glass of clear water. As it dissolves, the sugar molecules are thickest near the lump. But since the molecules are moving, they quickly get farther apart. After a time they will have spread uniformly through the glass of water. Then every part of the liquid contains an equal number of the molecules of the dissolved substance. You can learn by experimenting that a large portion of salt will dissolve in a glass of water. If you continue to add salt, however, there will come a time when even though you stir thoroughly, you can dissolve no more salt. Additional quantities will simply settle to the bottom of the glass.

Dissolved substances are distributed uniformly through liquids

There are substances in the soil that are like salt and sugar in that they will dissolve in water. Indeed, a little of almost anything, even of the hardest rock, will dissolve in water.

Substances dissolved in water are quite invisible. A solution of sugar or of salt is just as clear as pure water. A colored substance dissolved in water makes a colored solution, but you can still see through the liquid. It is not cloudy like the muddy water that flowed in the ditch. If you could examine the molecules of a dissolved substance such as sugar, you would see them moving about among the molecules of water and colliding with them. But you cannot see the molecules and so cannot tell by looking whether water is pure or whether it has some colorless substances dissolved in it. You might tell by tasting it, but some things that dissolve do not have much taste. Besides, it is not safe to taste things unless you know what they are.

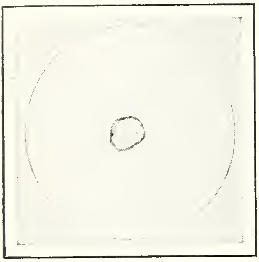

Fig. 60. Water contains Solids in Solution

Are there substances dissolved in the water we drink? Let us find out by experiment. Place a drop of drinking water on a piece of clean glass, and put the glass where the water will evaporate. The water molecules will escape into the air, but the molecules of the solids that were dissolved in the water will be left on the glass. You may be surprised to see what is left. Fig. 60 shows such a deposit. This solid material is called mineral matter. Even though there is a great deal of mineral matter in most drinking water, the water from the faucet is just as good for drinking purposes as rain water. In fact, we like it better, for the dissolved minerals give it taste. Rain water has no mineral matter in it.

Dissolved solids are left when water evaporates

Sometimes in using water we are reminded unpleasantly of its mineral content. Mineral matter interferes with the action of soap. Combined they form a flaky substance that floats on the surface of the water. You can easily see what mineral matter does to soap by trying to make suds, first in water that contains mineral matter and then in rain water, which has no mineral matter in it. For laundry purposes mineral matter in water is very objectionable. Not only is more soap required, but the flaky substance referred to sticks to the clothing and soils it. The laundryman adds washing soda to water from the faucet to remove part of the

Hard water is bad for laundry work

objectionable mineral matter. Water that has such mineral matter dissolved in it is called hard water. The minerals that make water hard are dissolved from the soil as the water flows along over or seeps through it.

D. May Water contain Any Living Things that cause Disease?

There are living things in water

Soil particles and mineral matter are not the only things that are picked up by running water. You have already observed many kinds of living things in water. A drop of water from a roadside pool has many tiny living things in it. Some of these you can see only with a powerful microscope. Since these tiny organisms live in water, you may expect water which has flowed over the ground to contain some of them. You know that all the water you drink has flowed over the surface of the ground before it comes to you. Therefore you may expect your drinking water to contain many living organisms like the ones you saw under the microscope.

Some of these are harmful

Most of these microscopic creatures will do no harm even if you do "eat them alive." But there are some that might do great harm if you took them into your bodies. Some of the organisms that cause disease are carried in water. Among these are the ones that cause typhoid fever and dysentery. Not all water that contains living organisms contains these dangerous bacteria, however. They enter the water through sewage which carries excretions from the body of some human being infected with the disease. Unless the water supply has been polluted by such excretions, these harmful organisms will not be found. It is difficult to tell without testing, however, whether or not unknown water is polluted. For this reason you should not drink water from untested streams. Thus the danger is always present that some of the living things in such water may make

Fig. 61. It pays to believe in Signs

you ill. Health officials are continually on the lookout for harmful bacteria in the water supply. If you have ever hiked along unknown country roads, you may have found signs posted over seemingly good drinking water, just as the boys in Fig. 61 have. On such occasions it pays to believe in signs.

E. How do Cities provide Enough Safe Water?

A city uses much water

A very great deal of pure water is necessary for life in a city. A most obvious use of water is for drinking. A much larger quantity is needed to keep the city clean, while in manufacturing cities still larger amounts are used for industrial purposes. The city of New York uses more than one billion gallons of water each day. It is hard to imagine how much water this is. If you are good at arithmetic, perhaps you can prove that this is about as much water as flows by a given point in 24 hours in a stream that is 25 feet wide and

10 feet deep and in which the water is flowing at the rate of 5 miles an hour. If the water that flows through the pipes were turned into a single stream, it would make a river large enough to carry boats of considerable size. This water does not flow through the city as a single stream, but is distributed through thousands of pipes that carry the water into the buildings.

The water that flows in the city pipes must be pure in the sense that it must be fit for drinking. There must be no harmful bacteria in the water, and it must be clear. It is desirable to remove the minerals that make water hard, as well as those substances that have odor or taste. No one wants to drink water that is muddy or water that has an unpleasant odor or taste, although it is not ordinarily injurious to health unless bacteria that cause disease are also present.

The process of purifying water is one of removing from the water the things that make it objectionable for drinking and for bathing and laundry purposes. In some regions the work of supplying pure water for large cities is much easier than in others. The difference is due to the kind of soil over and through which the water flows before it reaches the city reservoir. If the water for a city is collected from a mountainous region of rock formations, the work of purifying it is quite unlike that which is necessary to purify water from a flat region covered with clay soil. In order that you may know more about the methods used to make water safe and wholesome for drinking, let us examine the processes used in some of our American cities.

A large amount of the water supply of New York City comes from the Catskill Mountains more than a hundred miles north of the city. Study the map in Fig. 63 and see the large area, or *watershed,* from which this water comes. In these mountains have been built two large reservoirs in which water collects from the streams that flow into them. The water from the Catskill Mountains is usually very clear, but after heavy rains it may be muddy. Although most of the particles of mud settle in the reservoirs, the water is so muddy occasionally that it must be specially treated. A reservoir called a settling basin is used for this. Aluminum sulfate, a substance much like ordinary alum, is added to the water as it flows through this basin. As a result a chemical change takes place, and a white substance is formed which has the appearance of snowflakes. This flaky substance is heavy enough to settle in the water and carry the particles of mud with it.

Mud must be removed from the water supply

The next step in purifying water is to kill or remove dangerous bacteria. This is the most important step, for a failure here would result in sickness and death among those who live in the city and drink the water. So important is this work that men who have made a special study of bacteria, known as bacteriologists, are continually at work testing the water to see that it is safe. In order to kill any bacteria that may be present a small amount of a poisonous substance called chlorine is added to the water. Such a small portion of chlorine is necessary that it is entirely harmless to those who drink the water. This step in the process of purification is done so well in all American cities that almost no cases of illness develop which can be traced to the water supply.

Bacteria are killed

A third step in the purification of water is one of removing mineral matter. This is a chemical process. A "softening agent" is added to the water. This substance acts with the soluble minerals and forms a substance which is not soluble. In the laundry objectionable minerals are removed from the water by adding washing soda. Fortunately for New York the water from the mountain streams has such a small amount of minerals in it that no attention is given to the removal of them.

Mineral matter may be removed

© Hamilton Maxwell, New York

FIG. 62. Large Reservoirs such as this are needed to supply Great Cities with Enough Water

Odors are destroyed

The fourth step in water purification is that of removing from the water the substances that give to it the odor of decaying leaves and grass. This odor is not injurious to health, but it is objectionable. In this process the water is sprayed into the air at what is called the aëration plant. In aëration (mixing with air) oxygen from the air is dissolved in the water, and the sunlight falls upon it. These two agencies destroy the substances that produce the odor.

The work of building reservoirs in the mountains similar to the one shown in Fig. 62, of constructing aqueducts to carry the water from the reservoirs, and of laying pipes to distribute it to the houses, office buildings, and factories of New York City is a great feat. It is a task which is never finished, for new sources of water must be found and additional pipes constantly laid to take care of increasing demands for pure water.

The main aqueduct through which the water now flows

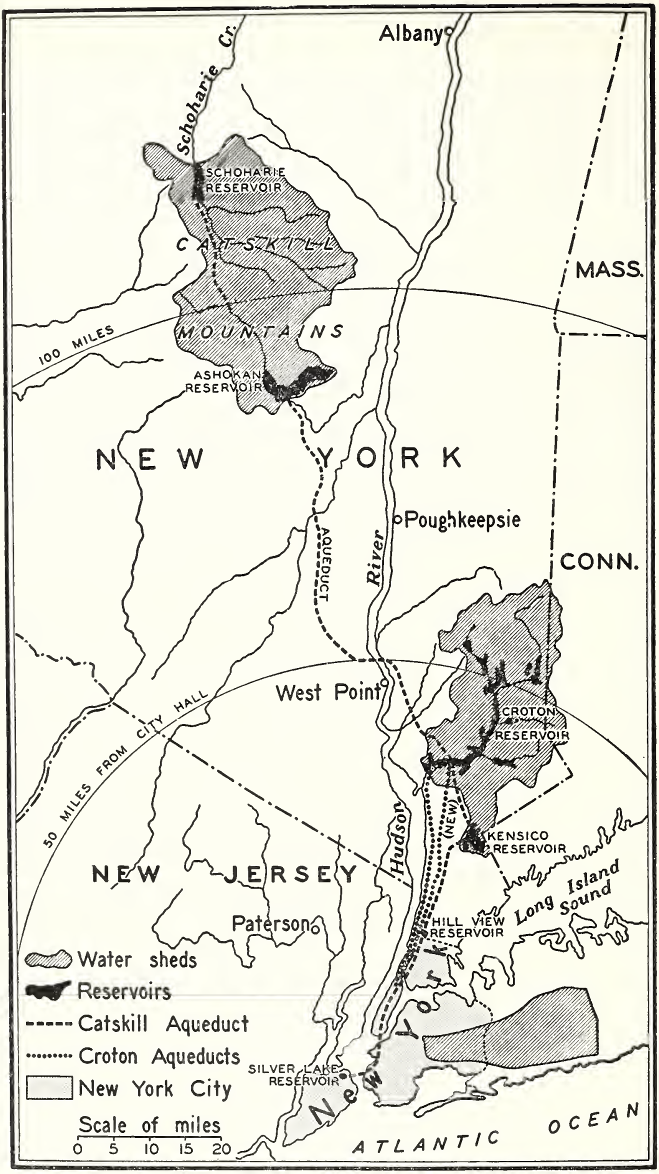

FIG. 63. Water for New York City comes from Points Many Miles Away

into the city is a tunnel more than large enough for the passage of a freight train. It passes through mountains and under rivers, starting in the Catskill Mountains at an elevation of more than 1000 feet above sea level. About fifty miles above New York City the tunnel passes under the Hudson River. Here the engineers had to cut through solid rock far beneath the river bed. At its greatest depth the aqueduct is more than 1100 feet below sea level and more than 1500 feet below the ground level on each side of the river. It is hard to believe that a tunnel big enough for a freight train to pass through could be built through solid rock as deep as 1100 feet below sea level. But New York City had to have water, and it seemed that the easiest way to get it was to build this tunnel. Under New York City the tunnel is cut through solid rock about 300 feet beneath street level. As it continues southward to Brooklyn, the aqueduct runs under the East River, some 600 feet below the level of the sea. Another aqueduct (shown in the map) almost as large as the Catskill aqueduct carries water from the Croton Reservoir to the city. Since a sup-

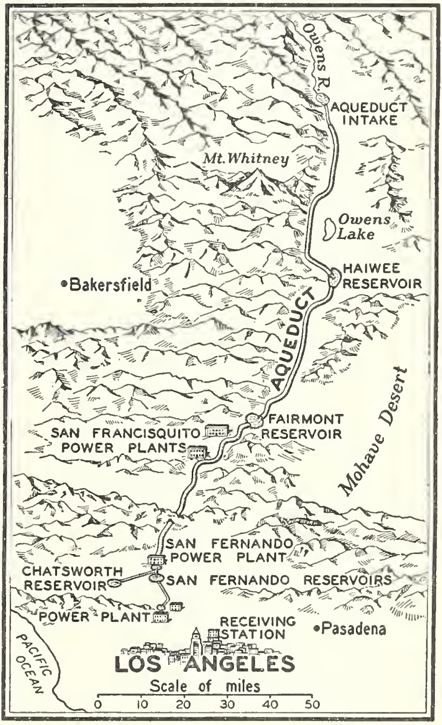

Fig. 64. Water for Los Angeles is obtained from Mountain Reservoirs Many Miles Away

ply of pure water is necessary for the life of its citizens, New York City like other large cities has spared no expense to secure a sufficient amount.

Minneapolis is one of several cities which take their water supply from a river. This city is on the Mississippi River and takes its supply from the river above the city. This water is muddy and it may contain bacteria that cause disease. It is pumped from the river into a reservoir, where it is treated to remove some of the mud particles. In order to remove the tiniest particles of mud and some of the bacteria, the water is treated with aluminum sulfate and filtered through a layer of sand. From the filtering basin it is pumped into another reservoir, where it is treated with chlorine to kill any dangerous bacteria that remain. It is then safe and wholesome for drinking purposes. From the purification plant it flows through pipes into the city to supply homes, office buildings, and factories.

Chicago takes its supply of water from far out in Lake Michigan. St. Louis gets water from the Missouri River. Los Angeles is supplied from mountain lakes far away from the city. The treatment necessary to make the water safe for drinking depends upon the conditions at the source. Since the water supply of all large cities is carefully guarded, one need have little fear about drinking from a city water supply.

The water supply of cities is often taken from lakes and rivers

F. How are Country Residents assured of Enough Safe Water?

In most cities one can have excellent water at all times by the mere turn of a faucet. In the country, however, this problem is not so simple. A suitable supply must be located, it must be constantly protected against pollution, and it must be made easily obtainable by the life that needs it, animal and plant alike.

FIG. 65. What do you think the Chances are of Securing a Pure Water Supply under these Conditions?

In the country the water supply is usually taken from wells. Sometimes people depend upon springs and cisterns. Occasionally water is secured from neighboring streams or ponds. The latter sources are always dangerous, for the possibilities of pollution are great. Rubbish and other undesirable matter may be thrown into the stream or pond. Rain water, as it flows over the ground, may wash such material into the source of the water supply.

Water must be protected against pollution

Whatever the source of the supply, however, certain care needs to be taken. One simple precaution is to make it impossible for running surface water to get into the source of the water supply. This may be done by making sure that a tight, well-fitting cover is provided for the well or spring. A ditch may be dug around the well to carry off any surface water which may flow toward it. The well or spring may be fenced in to keep out cattle, poultry, or other forms of life that might pollute the source of the water. Study Fig. 65 and see if you can find any evidence that precautions have been taken to make sure that the water supply will be pure.

The water in a well or from a spring has seeped or flowed through the ground. If there are sources of pollution close by, such as a cesspool, it is quite possible that bacteria from this may seep through the ground into the water supply. Therefore the location of the water supply must be carefully studied to see that there are no sources of pollution in the neighborhood. It is always wise to locate a well on the highest ground possible. This in itself, however, is not sufficient protection, since the level of water in the well may be below that of a neighboring cesspool or other source of pollution.

In general, water from shallow wells should always be looked upon with distrust. One should always consider that water from a spring or stream is bad unless it has been tested and found pure. Any water used for drinking should be tested at regular intervals.

This testing should be done in a scientific manner. We sometimes say that water which looks and smells clean *is* clean. It *may* not be. On the other hand, water which does not look and smell clean *may* be safe.

Unless you are quite sure that water from a well or spring does not contain dangerous bacteria, do not drink the water until after it has been boiled. It should be heated until large bubbles break in the center of the mass of water. It is much safer to boil the water too long a period of time than not long enough.

Distilled water is pure, but expensive

There are several other methods used to provide pure water. Water used in storage batteries is purified by the process of distillation. In this process the water is boiled until it evaporates as steam. This steam is then condensed to form pure water. While this process makes the water safe, it is slow and expensive. Water that has been boiled is just as safe for drinking purposes, so far as bacteria are concerned, as water that has been distilled. Sea water may be made fit for drinking by distillation, for this process separates the water from the salt that is dissolved in it.

Filtered water is not always safe

Another common method for the purification of water is filtering. This process is frequently used in country homes in which the supply comes from a cistern. A charcoal filter is commonly used, and rain water from the roof passes through the filter as it enters the cistern. This process is not altogether satisfactory, chiefly because these filters require more careful attention than they usually receive. A charcoal filter may give to its owner a feeling of security that he should not have.

A pure and ample water supply is essential to healthful living. Such a supply contains no harmful bacteria and no undesirable materials dissolved in it. Most cities have secured a pure water supply through careful planning.

Can You Answer these Questions?

1. In describing pure water someone has said that "pure water is tasteless, colorless, and odorless." Would you consider any water pure and safe for drinking that met these three tests? Defend your answer.

2. Describe the steps some of our cities have taken to protect their water supply from the following:
   a. Mud due to heavy rains.
   b. Bacteria.
   c. Odors due to decaying leaves and grass.

3. Rain water is pure and safe for drinking and may safely be used in storage batteries. Water from wells, however, may not be safe for either of these uses. What makes the difference?

4. What are the differences between hard water and soft water? Which is to be preferred for washing purposes? Why?

5. What are some of the precautions to be taken to make sure of pure water in wells and cisterns?

6. Can you explain why it is that the taste of salt or sugar spreads through an entire glass of water?

7. How does drinking water sometimes cause disease?

8. Is hard water good to drink?

9. Where does your community get its water? What processes are used to purify it?

Questions for Discussion

1. Would you carry water with you when you went on a picnic, even though you knew that there were a spring and a brook near your picnic site? Defend your answer.

2. Suppose you were given a liquid which you suspected contained a colorless substance, such as salt or sugar, dissolved in it. How could you tell without tasting it whether or not a substance was dissolved in the water?

Here are Some Things You May Want to Do

1. Mix some mud, molasses, ammonia, and bits of wood in a glass of water. Divide the mixture into two glasses, and

a. Distill the mixture from one glass.
b. Filter the mixture from the other glass.

2. Set up an experiment to find out which of these two processes has given the purer water. See if you can explain the results of your experiment.

3. Take a dish of salt water, a dish of limewater, and a dish of rain water. Test them with soap to see which are hard.

4. You might like to read the chapter in De Kruif's *Microbe Hunters* which tells of the search for the typhoid-fever bacterium. This is an excellent description of the work of the scientists who have helped us to live healthier lives.

5. Under a microscope find some living things in a drop of stagnant pool water. Describe the things you find.

6. Find out about the source of the water you drink. Make a diagram or map showing how it comes to you. If you live in the country find out how deep your well is. Are all the wells in your community about the same depth?

7. Dissolve various substances in water and, following the suggestion on page 128, study the deposit left on the glass after evaporation. Keep a record of anything which seems unusual to you.

8. Look up references on pure water supply and see how many different ways you can find in which communities secure an ample water supply.

9. Write a set of "Don't's" which you think might be used in connection with the selection of a pure water supply. You might do this for a country district or as helps for a camping party.

10. You may demonstrate the manner in which aluminum sulfate is used to remove sediment from water as follows: Mix a little black mud with water in a test tube and add to it a few drops of ammonia or of limewater. Shake the mixture thoroughly. Now add a small bit of aluminum sulfate or alum and shake it again. You will be surprised to see how quickly the mud settles out after you stop shaking it.

Fig. 66. Otto von Guericke's Water Barometer was not a very Convenient One

UNIT IV

Why Is Air a Necessary Factor in the Environment of Living Things?

Chapter VIII · What is the "Ocean of Air"?

Chapter IX · How may the Action of Air be Explained?

Chapter X · What has Man learned by Exploring the Upper Regions of the Air?

Chapter XI · Of What Gases is Air Composed? Of What Importance to us are the Different Gases?

Chapter XII · How does Air sustain Life?

Chapter XIII · What happens to the Carbon Dioxide which is released into the Air?

Chapter XIV · What Differences are there between Pure and Impure Air?

THE air, another important factor in the environment of living things, has been studied for thousands of years. The ancient Greeks had gained some understanding of it. Aristotle himself suggested the theory that clouds and rain resulted from the condensation of vapor which had risen from the earth. Rain fell out of the air, he argued; therefore the air was partly water vapor. Beyond this, however, even Aristotle knew very little about the air.

Today we know that water vapor is but a very small part of the entire mass of air which surrounds us. Experiments and discoveries have shown that air is made up of many things. Scientists have determined many of the laws which govern the behavior of air, and a knowledge of these laws is being used in everyday life.

If these laws are understood, they will help to explain many things which are quite common and yet appear to be unrelated. The flight of dirigibles and airplanes, the force of the wind, the effect of air pressure upon work and life, all these things depend upon the air.

In this unit an attempt is made to show why this is so.

Chapter VIII · What is the "Ocean of Air"?

Who has seen the wind?
  Neither you nor I:
But when the trees bow down their heads
  The wind is passing by.

C. G. Rossetti

Tornado Kills 22
1000 Homeless

HALF TOWN RAZED

Twister injures 124—Buries victims in ruins of buildings—School children among dead—Blinding downpour of rain follows wind and floods town

Fig. 67. Have you ever found Clippings and Pictures Similar to These?

Does a study of the clipping and picture above raise some questions in your mind? For example: What is air? How do we know that there is such a thing as air? Can we see it? Can we feel it? Do we ever see it at work? Is air everywhere? Is air a real substance in the same sense that water and iron are real substances?

Perhaps instead of raising such questions your study would supply answers to them. Can you give complete answers to them? Are you sure your answers are right? How do you know they are? Perhaps you may feel that you need some more information before you try to answer the questions. If you do, you may find the information in this chapter.

A. Is Air a Necessary Factor of the Environment?

Suppose someone should ask you to name two or three things most necessary to a living plant or animal. You would probably say "water" for one of them. Then you might say, "Food too is necessary." Someone among you might think of sunshine. Perhaps a rather considerable number of you would not think of *air* at all, for we commonly overlook things that are always at hand. And yet, about sixteen times every minute, we breathe a fresh supply of air into our lungs, use a part of it, and expel the rest. You know that if you put an animal in a tight box, it will die because it cannot get the air it needs. You will learn later that green plants also need air. If they cannot secure it, they too will die. You can probably give even more vivid proof of the importance of air to life. You may have read of mine disasters where men have died of suffocation. Occasionally one hears of children killed when the sides of a cave they are digging fall in and smother them. From these and other examples it is obvious that air is essential to life.

Air is necessary for life

B. Is Air Everywhere?

Is there any nook or corner in the world where there is no air? In order to find an answer to this question you must, as always, use your science tools — observation and experimentation.

Let us first recall some of the things you already know about air.

You know that you breathe air and that you cannot live without it. You know that you can feel it brushing your cheeks gently or rumpling your hair or pushing against a door you are trying to open. Sometimes it blows your hat off; sometimes it knocks you down. Sometimes it blows cars off the road or

Air is a familiar substance

Fig. 68. Air in Motion can be Felt

carries whole houses away, and it has been known to blow heavy steel railroad trains off the track. You know that besides these varying degrees of strength, it has certain other properties: sometimes it feels cool, sometimes it feels hot, sometimes it feels damp. You know too that air in motion can be heard: you recognize the sound of air as it comes out of a tire or as it comes out of the pipes of a pipe organ or as it blows through the trees in the forest. You have seen the effects of air, too. The waters of a lake are rippled by soft breezes; a river is sometimes a tumbled mass of foamy waves whipped into form by the driving wind. All these are everyday experiences. You have simply to record your observations of them.

Does this little store of knowledge secured by observation explain all the things you want to know about air? Are there any questions about air that cannot be answered by what you already know? Let us see. You might want to know, for example, how high up in the sky there is air.

Fairchild Aërial Surveys, Inc.

Fig. 69. **We live at the Bottom of this Ocean of Air**

Aviators have explored as high as eight miles above us

Can you answer this? Not without additional information. You cannot get this through experiments in the classroom, but there are other ways.

Aviators have flown as high as eight miles above the surface of the earth. Box kites with recording thermometers have been sent up by the Weather Bureau to even greater heights. These kites are so constructed that they close up when they reach a certain height and bring to earth samples of the air from that height. These samples prove not only that air is much thinner and colder at considerable heights than it is near the earth, but that there is some air more than twenty miles above the surface of the earth. Meteors, or shooting stars, testify to the presence of air at an even greater altitude than do the box kites.

Meteors have been seen to glow at a height calculated to be a hundred and fifty miles above the earth. Passing

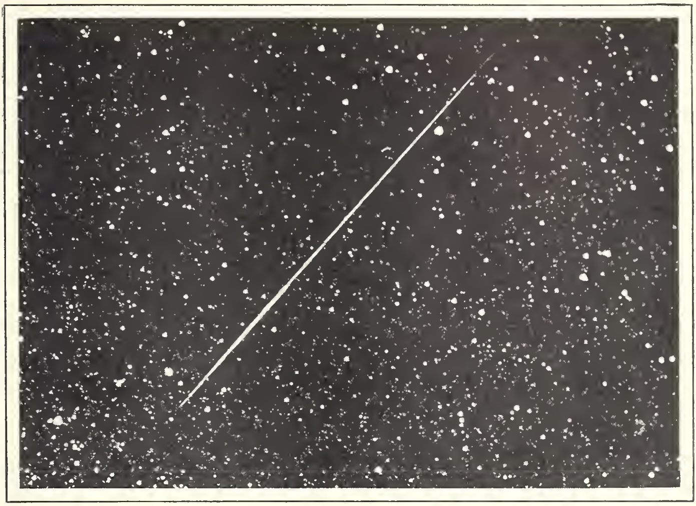

FIG. 70. Air Friction makes Meteors glow High in the Sky

This proves that the ocean of air extends for many miles beyond the surface of the earth. (Courtesy of the American Museum of Natural History)

Friction with air makes meteors hot enough to glow

through air at a terrific speed is what produces sufficient friction to make meteors hot enough to glow. The white streak you see in Fig. 70 is the trail of a burning meteor rushing through the upper atmosphere. This observation, then, shows that there is enough air beyond one hundred and fifty miles above the surface of the earth to make a meteor red-hot.

There is air in soil

Now let us get down to more familiar ground. What about the presence of air nearer the surface of the earth? Is there air in empty boxes, in the trunk of a tree, in an electric-light bulb, in the soil itself? When we say that a box is empty, we mean that it contains nothing but air. You can easily prove that there is air in soil. Fill a water glass half full of soil taken from the lot across the street or the flower bed outside the school. Pour water on top of the soil until the glass is almost full. What evidence do you have that there is air in soil? (See Fig. 71.)

No one has made a perfect vacuum

If the air could be removed from such a space as the inside of a bottle so that nothing at all was left there, the space would be called a perfect vacuum; but no one has ever yet made a perfect vacuum. A partial vacuum is the best man can produce. We can pump nearly all the air from a container, but the container still holds a great many molecules of gases. In radio receiving sets we use what we call vacuum tubes, but even the best of them contain some air. Some electric-light bulbs are called vacuum bulbs, but we can say only that *most* of the air has been removed from them. Why should we want to take as much air as we can out of electric-light bulbs? Because if we did not, the filament would burn up quickly, and that would make the bulb useless. Some bulbs, instead of being emptied of air, are filled with a gas called nitrogen; for not only will the filament not burn out quickly in nitrogen, but the nitrogen causes the bulb to give a better light. A gas called argon is sometimes used in place of nitrogen in light bulbs.

If you should make the statement "Air is everywhere in the world," it would not be far from correct.

C. Is Air a Real Substance?

We live and move about, then, at the bottom of an ocean of air. We do not always realize that this air is around us, but from time to time we are reminded that it is a very real substance. Like all other substances it occupies space, it has weight, and it exerts pressure. Can this be proved?

In washing dishes have you ever pushed a milk bottle or ginger-ale bottle down quickly into the water and noticed bubbles escaping from it? Have you ever tried to fill a narrow-necked bottle from the faucet? The water splatters, and the bottle fills slowly. If you know that air

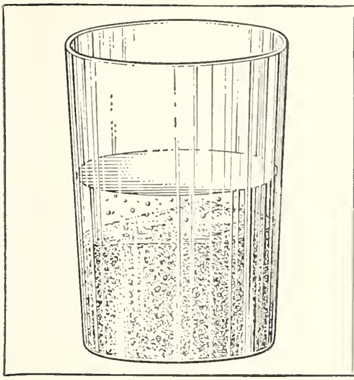

FIG. 71. There is Air in Soil

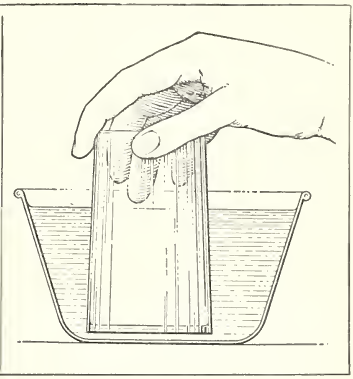

FIG. 72. Air occupies Space

occupies space, however, the explanations are simple. The empty milk bottle is full of air. Water is denser than air. When you put the bottle into the pan of water, the air is forced out by the weight of the water. The bubbles you see are bubbles of air. In the case of the narrow-necked bottle the exchange takes place slowly. The air cannot escape rapidly. Similarly, you may show that water will not flow from a bottle unless air can get in. Why?

Try the following experiment on yourself: Try to breathe in without moving your chest. Can you do it? Then take a good deep breath and fill your lungs full. Now try to breathe out without letting your chest go down. Can you do that? Why is it impossible to breathe without moving your chest?

A simple experiment furnishes convincing proof that air occupies space. Take a glass tumbler, turn it upside down, and push it downward into a basin of water, as shown in Fig. 72. Very little water will enter the tumbler. The space in the tumbler is already filled with air, and no two substances can occupy the same space at the same time.

What other illustrations can you find to prove that air is a real substance?

Did you ever blow a paper bag full of air as the boy in Fig. 73 has done, hold the end tight, and hit the bag hard with your hand? The bag felt as if it were filled with something. That substance was air. The pop you heard was caused by the quick rushing of air from one place to another.

We have already mentioned the wind, which is nothing but moving air. You have seen how it destroys houses and breaks limbs from trees. You know, too, that it drives sailboats and turns windmills. Later on you will see that air supports the weight of a balloon in much the same way as water supports the weight of a ship. You will learn that air, like water, is buoyant.

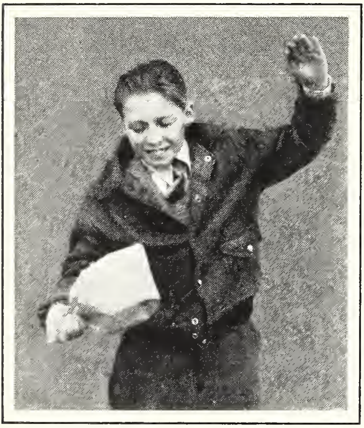
Fig. 73. Air is a Real Substance

We have said that air is a real substance and that a substance has weight. Can we prove that air has weight? We use the expressions *as thin as air* and *light and airy* to describe something that is very light. When a space contains only air, we usually say it is "empty," though, as you have learned, this is not true. It is evident, then, that ordinarily you don't think of air as something that has weight. And, to be sure, if you compare the weight of air with the weight of water or with the weight of stone, air does not seem to weigh very much. But air does weigh something, and you can find out how much.

Air has weight

All the necessary apparatus for such an experiment is shown in the picture (Fig. 74). It consists of a balance and some weights for the accurate weighing of very light objects. The weights commonly used in the science workroom are gram and tenth-gram or hundredth-gram weights instead of pound and ounce weights. Besides the balance and the weights there are a clean dry flask and an air pump. The flask is fitted with a rubber stopper having a small hole through the center. A glass tube in which there is a valve has been thrust through this hole. This valve may be opened or closed. The valve is opened to pump the air out of the flask and then closed to keep the air from entering it again.

Now you are ready to follow through the experiment of weighing air as it is done in science laboratories. The flask, fitted with the rubber stopper and the glass tube, is placed on the left-hand pan of the balance, and the larger weights are put on the right-hand pan. The valve in the glass tube is left open. The larger weights are added first instead of the smaller ones. When the weight of the flask, on the left-hand side, is nearly equal to that of the weights, on the right, the little "rider" on the beam of the balance is pushed from the left toward the right side of the scale until the two pans are balanced. Now the weight of the flask full of air is equal to the sum of the weights on the pan plus the weight indicated by the number on the beam of the balance nearest the rider. This step is shown in Fig. 74, *a*. This completes the first step in the experiment. The flask full of air has been weighed in much the same way as a basket full of potatoes is weighed. The chief difference between the processes is that we have used finer weights than would have been used in weighing potatoes and have done the work with greater care.

The next step is to pump the air from the flask and weigh the flask again. But first the flask is removed from the pan of the balance.

The glass tube in the stopper of the flask is now connected with the air pump. The valve in the tube is open, as we have said, and the connection between the tube and

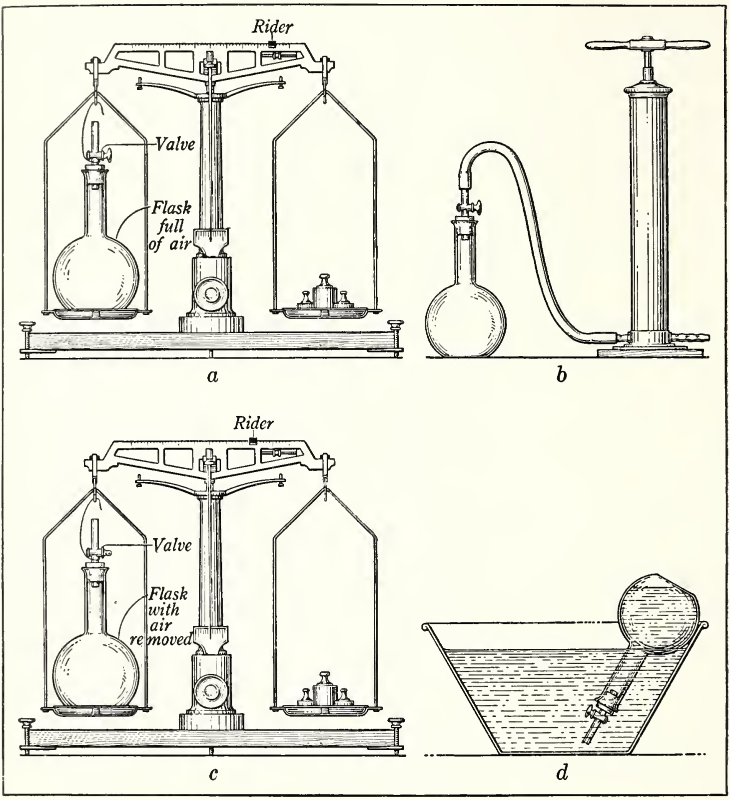

Fig. 74. Air has Weight

a, flask is weighed with air in it; *b*, air is pumped out; *c*, flask is weighed after air is pumped out; *d*, water replaces air

the pump is air-tight (Fig. 74, *b*). The pump is operated for four or five minutes in order to remove most of the air. Just before the pumping is stopped, the valve in the glass tube is closed so that air cannot reënter the flask. The tube is now disconnected from the pump, and the flask, with attachments, is again placed on the pan of the balance. The rider on the beam is moved back toward the left; that is, weight is taken from the right side until the loads on each side of the balance seem to be equal again. The sum of the weights on the right-hand side plus the number on the beam nearest the rider is the weight of the flask with some of the air removed. Fig. 74, *c*, indicates the result. The flask now weighs less than when it was filled with air. Air really weighs something! The weight removed from the pan is, of course, the weight of the air which has been pumped out of the flask.

Once when this experiment was performed, a liter flask was used. (A liter is about one quart.) These results were obtained:

Weight of flask full of air (together with attachments) = 148.7 grams.
Weight of flask with some air removed (together with attachments) = 147.5 grams.
Weight of air removed (figure obtained by subtraction) = 1.2 grams.

As a further step in the experiment, we may determine with reasonable accuracy the proportion of the air that was removed from the flask. We now remove the flask from the balance and place the free end of the tube under water as shown in Fig. 74, *d*. While the flask is in this position, we open the valve in the tube. Air pressure forces water in to take the place of the air that has been pumped out, until the same volume of water has entered as there was air removed.

When the experiment described in the preceding paragraph was carried to this point, it showed that nearly one liter of water entered the flask; that is, the flask nearly filled. That means, therefore, that nearly one liter of air had been pumped out. Putting this with the figures obtained in the preceding paragraph, we see that, roughly speaking, one liter (or one quart) of air weighs about 1.2 grams. A liter of water weighs 1000 grams. Water is therefore about 800 times heavier than an equal volume of air (1000 divided by 1.2 equals $833\frac{1}{3}$).

A liter of air weighs about 1.2 grams

In comparing the weights of different substances we find it convenient to use the term *density.* The density of a substance, you may remember, is the weight of any definite volume of it. The density of water is about 1000 grams per liter, and the density of air is about 1.2 grams per liter.

You have already learned that 1 cubic foot of water weighs a little more than 60 pounds. Since a cubic foot of water weighs about 800 times as much as the same volume of air, 800 cubic feet of air weigh about 60 pounds. This means, of course, that 1 cubic foot of air weighs about $\frac{60}{800}$, or $\frac{3}{40}$, of a pound, or a little over an ounce. It is clear, then, that even though air seems light, the total weight of the air about us is very great. The air in a room 40 feet long, 20 feet wide, and 10 feet high weighs about 600 pounds.

All the air together weighs billions of tons

At sea level the weight of the air above each square inch of the earth's surface is about 15 pounds. Air pressure is 15 pounds per square inch. Notice that this weight is given at sea level. This is important, for a cubic foot of air does not always weigh the same amount. As you will learn later, air at high altitudes is less dense than air at sea level. The density also changes as air is heated or compressed. For the purposes of our figuring here, however, we shall consider the normal pressure of air at sea level, which is about 15 pounds per square inch. You could find out how much all the air in the world weighs if you would determine the area of the earth in inches and multiply the area by 15. The product is such a large number that you might not be able to read it. Let us make the problem a little simpler. The weight of the air over one single square foot (144 square inches) of the earth at sea level is 144 times 15 pounds, or 2160 pounds. This is more than the weight of a small automobile. You can imagine from this that the total weight of the air about the earth must run into billions of tons.

D. Is Warm Air less Dense than Cold Air?

Warm air is less dense than cold air

You have been told that warm air weighs less than an equal volume of cold air. You don't have to accept that statement on faith. You can prove it, just as you were able to prove that air weighs something. The experiment is very simple. Use a clean, dry flask like the one used for the last experiment. Set the open flask, with no attachments, on one pan of the balance and weigh it. Remove the flask and heat it over a low gas flame. When it is thoroughly warmed, place it again on the balance. Now it weighs less. This is visible proof that a flask full of heated air is not so heavy as the same flask full of cold air. What makes the difference? What happens to air when it is heated? The answer is simple. It expands. The explanation of expansion may be made in terms of the molecular theory. A more complete discussion of this will be given shortly. For the present it is sufficient to remember that we found in our study of water that a volume of heated water weighed less than an equal volume of cold water. The same is true of air; a volume of heated air weighs less than an equal volume of cold air. Our experiment has given proof of this. In other words, then, the heat has caused the air in the flask to expand; and in the process of expanding, some of the air has been forced out of the flask.

The reverse of this process is also true, as you will see if you leave a warmed flask and the weights on the pans until the flask loses its heat. The pan with the weights will slowly rise to the level of the pan with the flask. As air is heated its density gets less; as it is cooled its density gets greater.

When you realize that warm air is less dense than cold air, you can explain certain common experiences that you may not have understood before. You can explain the phenomenon of wind, for example. Every one of you has probably at some time or other wondered what causes the wind. You know, of course, that wind is only air in motion; but what makes the air rush along at such speed and what gives it so much force? What makes the strong draft you feel across your own schoolroom when someone opens a window? Is the draft stronger in cold or in warm weather?

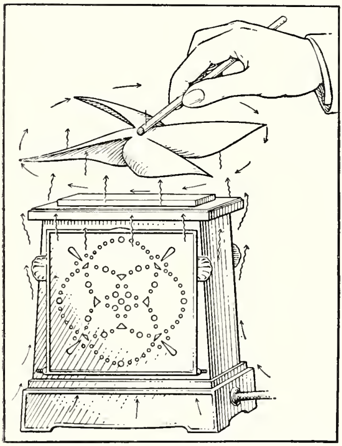

Fig. 75. Air Currents cause the Pinwheel to Revolve

Before you try to answer these questions, see how much help you can get just from looking about you. If you hold your hand several inches above a hot radiator, and then the same distance in front of it, you will find not only that the air above the radiator is warmer than the air in front of it, but that it seems to exert a little pressure against your hand. While riding in an airplane you may frequently feel the effects of unequal heating of the air. Sometimes the air is very "bumpy." The "bumps" which are experienced while riding in a plane and which sometimes cause air sickness are due to the passage of the plane from regions of warmer and less dense air to regions of cooler and more dense air.

The warmer the air the less dense it is, and the more quickly the cold air rushes in to take its place. You may see a very simple demonstration of this process if you hold a pin wheel over an electric toaster, as shown in Fig. 75.

Now we are ready to study the winds again. As the air surrounding the earth passes over certain parts of the earth's surface, it is heated and expands. It becomes less dense and is forced upward by the colder and therefore denser air from surrounding regions. The colder air moves in to take the place of the less dense air. These movements of air are the winds.

In general, the hottest part of the earth is in the region of the equator, and the coldest parts of the earth are in the regions of the north and south poles. If heat causes air to expand and cold causes it to contract, the air near the equator should be much hotter and therefore much less dense than the air near the poles. This is in fact true. At the equator the less dense air is forced up just as the air over a hot radiator is forced up. As it rises, its place is taken by the colder and denser air flowing in toward the equator from the north and south polar regions. But the expanding air at the equator is not pushed up indefinitely. As it moves upward it loses some of its heat. As it cools it flows away from the equator toward the north and south polar regions again. In other words, there is a continuous air movement as the cold air flowing down from the poles is heated at the equator, is forced upward, and flows back again toward the poles.

Winds are moving currents of air

In this simple explanation is found the answer to the cause of winds. It does not, however, explain east winds, west winds, and winds which seem to blow from all directions. In order to understand these, it must be remembered that the earth is not a smooth round ball, standing perfectly still while the currents of air flow gently back and forth. Mountains, oceans, deserts, lakes, rivers, and other natural features cover the surface of the earth. Then, too, the earth rotates on an axis. As currents of air flow back and forth, they are affected by the motion of the earth and come in contact with the irregularities of the earth's surface. Thus the winds are turned from their straight north and south direction. There are many things that influence the direction of the wind. In the United States the general direction of the wind is from west to east; but, as you know, it may blow from any direction.

E. May Air be Compressed?

There are many familiar observations which indicate that air may be compressed. Ask some of the older people at home if they remember the earlier days of the automobile. They will probably laugh as they tell you how the family would start out on a warm summer day for a ride in the country. They will recall the puncture that occurred. After a long and tiresome repair job, out would come the hand pump, and under the pitying stares of more fortunate motorists the men in the party would take turns in pumping up the tire again. The first strokes were easy; but as the tire became harder, it was more and more difficult to force air into it. In other words, the air in the tire was being compressed and was resisting the introduction of more air from the outside. The longer the pumping continued, the more difficult it was to force more air into the tire. If you have had experience in pumping air into a basket ball or football, you know you must continue pumping long after the ball seems full of air.

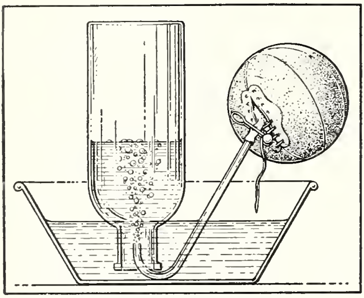

Fig. 76. More than Seven Quarts of Air were taken out of this Basket Ball, and still it seemed to be Full

As an experiment, open a basket ball which is in about the right condition for play and measure the volume of air that comes out of it. First of all, fill a quart jar or flask full of water. Then turn it upside down in a pan of water. Now unlace the basket ball. Insert a piece of glass tubing in the rubber valve, or "neck," which is attached to the basket-ball bladder. Slip a piece of rubber tubing over the other end of the glass tube. Do not allow any air to escape from the ball while these preparations are being made.

Lower the free end of the rubber tube into the pan of water and put it under the mouth of the flask or jar. Now the air may be allowed to escape from the basket ball. It flows up through the water in the flask in the form of bubbles and collects at the top of the flask, as shown in Fig. 76. Gradually the water in the flask is forced out by the air. When all the water has been forced out of the flask, one quart of air has been collected. Stop the flow of air from the basket ball and remove the flask. Fill it up with water again and repeat the process. Continue this until there is no more air in the basket ball. You will know when this point is reached, for there will be no more air to force water out of the flask. In one experiment the basket ball still seemed to be full after seven quarts of air had been collected. The air in a basket ball is compressed air. One liter of air under pressure in a basket ball as it is used in play weighs about twice as much as a liter of air under ordinary pressure. When the pressure is released, the air escapes as it expands to its normal density.

Air is a necessary factor of the environment. It surrounds the earth, but decreases in density as altitude increases. It is a real substance, occupies space, has weight, and exerts force. When compressed it may be made to do work.

Can You Answer these Questions?

1. Here are some statements about air:
a. Air is everywhere.
b. Air is a real substance.
c. Air occupies space.
d. Air has weight.
e. Warm air is less dense than cold air.
f. Air may be compressed.
g. Air exerts force.

Suppose someone said "I don't believe it" to these statements. How would you try to prove each of them?

2. Can you give a simple explanation of what causes wind?

3. Why is nitrogen used in electric-light bulbs? Why is air not used?

4. If, owing to friction, meteors glow as they pass through the air, why is it that they often seem to go out as they near the earth, where the air is heavier and friction is greater?

5. What is the scientific definition of density?

6. Why is the term *vacuum bulb* not entirely correct?

Questions for Discussion

1. Have you ever heard aviators speak of "air pockets"? What is the real explanation of these?

2. Aviators will tell you that the air is much more "bumpy" following a sudden change in temperature. Can you explain why this is?

Here are Some Things You May Want to Do

1. Make a drawing of the apparatus you have used to show that air has weight. Show the different steps in the experiment. If the flask used is of a different size from that used in the experiment described in this chapter, what results will differ from those given? What results will be the same?

2. Look up some of the weather charts issued by the United States Weather Bureau and note the differences recorded in barometric pressures in different parts of the United States. Try to find some reasons for these differences.

3. Some simple experiments on various properties of air are suggested on pages 151, 152, and 160 of your text. Try these experiments and make a record of them in your notebook.

4. Try the experiment with warm air as given on page 157. Keep a record of your results. What conclusions can you draw?

5. See if you can find any good descriptions or pictures which will show the force of the wind.

Chapter IX · How may the Action of Air be Explained?

You have now seen how air acts under different conditions, and have found out some things about it. You know, for example, that air exerts pressure, that warm air is less dense than cold air, that air has weight, and that it is a real substance. Suppose someone asked you to tell him *why* these things are so. Could you do it? Do you know the reasons why air acts as it does under certain conditions? Let us see if we can help you to answer such a question if it were asked you.

A. Does the Molecular Theory help to explain the Action of Air?

A few pages back, in explaining expansion and contraction, we referred briefly to the molecular theory. Let us find out now a little more fully what part molecules play in the changes that we know take place in air.

Air is composed of molecules of gases

In your study of evaporation you found it reasonable to believe that water and the gases of the air are made up of molecules; that molecules are continuously in motion, that when they are heated they move faster, and that when they are cooled they move more slowly; that water in evaporating passes into the air, the molecules of water mingling with the molecules of the gases of the air.

Let us turn our attention to the air in the clean flask you used when you compared the density of warm air with the density of cold air. If you could see the molecules in it, you would find them to be tiny particles moving with great speed in every direction. Although there is a great deal of space between the molecules, there are many collisions, both with one another and with the walls of the flask.

When air is heated, the molecules are set in rapid motion and the spaces between them become greater

Molecules from the outside are continuously entering the flask through the open neck, while an equal number are leaving. Now suppose you heat the flask. Heat, as you know, causes molecules to move faster. If they move faster, they collide oftener and more violently and push one another farther and farther apart. The open neck of the flask offers them a lane of escape. Now they are pouring out of the bottle in such a rush that few molecules outside the flask can push their way through them to the inside. Many more molecules are leaving the flask than are entering it. The air is expanding. Since there are now fewer molecules in the flask, of course the spaces are greater between those left. Now perhaps you can understand more clearly how air expands and why the density of hot air is less than the density of cold air.

Let us take an everyday example of the powerful pressure of heated air. You may have noticed that the tires of an automobile get warm during a long drive, especially on hot cement pavements. After a fast drive they may be so hot that you cannot comfortably place your hand against them. What makes a tire grow so warm? A tire is heated by the hot pavement and by friction as it runs over the road. This heat causes the molecules within the tire to move faster, and, since they cannot escape, they exert a great deal more pressure inside the hot tire than they did in the cold. If the pressure in your tires when the car stands in the garage is 35 pounds per square inch (the common pressure for ordinary cars), it is greater than 35 pounds after a long, fast drive. If the tire is worn, it may not be strong enough to hold the increased pressure. As a result the tire blows out.

The molecular theory accounts not only for expansion but for compression too. You don't have to look far for a simple illustration. When you pump up a bicycle tire, you force air in through the valve in the tire by pushing the pump handle down. Each time you push the handle down, you pack one pumpful more of air into the tire, pressing the molecules within the tire closer and closer together. Each time you start to raise the handle of the pump, the valve closes mechanically, and the air that you have just forced in cannot escape. You continue the process of pushing the pump handle down and lifting it up until the pressure of the molecules inside the tire is sufficient to support your weight as you ride on the bicycle.

When air is compressed, the molecules are nearer together

You have learned from the experiment with the basket ball that the density of a volume of compressed air is greater than the density of the same volume of ordinary air. Now you can see that it is the crowding, tightly packed molecules of the compressed air that make the greater density. Perhaps this statement will mean more to you if you translate it into specific examples. When the tire gauge at the garage shows a pressure of 35 pounds per square inch, that means that the pressure within the tire is really 35 pounds more than the pressure outside. Since the pressure outside (ordinary air pressure) is about 15 pounds per square inch, the total pressure within the tire is about 50 pounds per square inch ($35 + 15 = 50$). A tire that shows a pressure of 35 pounds per square inch contains more than three times ($35 + 15$ is more than 3×15) as many molecules of air as a tire of the same size that seems full but that shows no pressure when it is tested by a gauge. A tire that tests 35 pounds contains twice as many molecules as a tire that tests 10 pounds ($35 + 15 = 2(10 + 15)$). In other words, the density of the air in the tire that tests 35 pounds is twice as great as the density of the air in the tire that tests 10 pounds.

We ride on cushions of air

B. Does Air exert Pressure which may be Measured?

From your experiments you have learned that air, like water, weighs something. You know from observation that anything which has weight can exert pressure upon objects under it. Air, then, having weight, must exert pressure on the earth under it. The density of air is so little when compared with liquids and solids that it does not in small quantities exert much pressure, but there is so much of it altogether that the total pressure of the air on the surface of the earth is enormous. We have already determined the total weight of air on one square foot of the surface of the earth. Because we have always lived under this air pressure, we are not ordinarily conscious of it.

Ordinarily we are not conscious of air pressure

Air at any point — on a mountain top, on the seashore, in the valley — exerts an equal pressure on all sides of our bodies. It surrounds us and exerts pressure upon us just as water surrounds a fish and exerts pressure on it. The water pressure on a fish 400 feet beneath the surface is about 170 pounds per square inch; but the fish is not crushed by it, for water pressure is equal in every direction outside the fish's body and is equally distributed throughout the cells within the fish's body. The area of a human body of average size is about 2000 square inches. Since the air pressure is normally about 15 pounds per square inch, the total air pressure on the body of a man of average size is about 30,000 pounds. This pressure does not crush him any more than water pressure crushes a fish. Air enters the body through the lungs and is distributed by means of the blood to every cell of the body. The pressure inside the cells is equal to the pressure outside. Unless this exact balance between the inside pressure and the outside pressure is disturbed we are hardly conscious of air pressure at all. This balance is disturbed when the pressure outside is increased, as in deep-sea diving, or when it is lessened, as in mountain-climbing or in high-altitude flights in airplanes or balloons. In experiences like these we immediately become conscious of the fact that there is such a thing as air pressure. Very sudden changes in air pressure are dangerous. You have seen the effects of increased air pressure on the heated automobile tire. In this case the pressure may be great enough to cause a blowout. We are conscious of air pressure if the pressure on the outside of the body is suddenly decreased while the pressure on the inside remains the same. People who climb high mountains often suffer from nosebleed when they reach altitudes where air pressure is considerably lower. Airplane pilots too tell of severe nosebleeds at higher altitudes. At higher altitudes the pressure outside the body is much less than at lower altitudes and the small blood vessels in the nose often break.

Sudden changes in air pressure are dangerous to living things

Another danger is present if the pressure on the outside of the body is suddenly increased over that on the inside of the body. Such a change in pressure might compress the tiny blood vessels to the point where the blood could not flow through them. In our discussion of water, you will remember, we described how slowly and carefully divers must descend and rise. We came to the conclusion that sudden changes in water pressure are dangerous and must be avoided. The pressure of the air on the diver's body is the same as the pressure of the water outside his diving suit. Compressed air at high pressure is often used to prevent water, quicksand, and earth from entering the open end of a tunnel being dug under a river. The men who work under such conditions must be protected against sudden changes in air pressure. They do not go suddenly from the ordinary air pressure at the surface to the higher pressure at the bottom but, like the diver, travel by easy stages. The diver is lowered a few feet at a time and, when he is ready to come up, is raised in the same

People who work under high air pressure must be protected against sudden changes

way. The men who work in the tunnel are put through a number of air chambers. These chambers are so arranged that the air pressure in each succeeding one is a little higher than that in the one before. On their way down the pressure gradually increases; on their way out the pressure gradually decreases. The workmen rest in each chamber until they become adjusted to the change. Like the diver, they may spend more time in going to and from the place in which they work than they do in the actual work itself.

We are adapted to live under a pressure of 15 pounds per square inch. We should be uncomfortable under a pressure of 10 pounds per square inch and quite unable to do vigorous work, for at 10 pounds' pressure oxygen cannot be taken into the lungs fast enough to support vigorous activity.

You observed in your experiment with the basket ball that if you fill a vessel with water and turn it upside down quickly in a basin of water, the water does not flow out of your vessel. Something is holding the water back. That something, quite evidently, is air pressure. The downward pressure of the air on the surface of the water in the basin is greater than the downward pressure of the water in the vessel. A column of water is being held up, or balanced, by a column of air. How high a column of water can the column of air support?

A water barometer is possible but not practical

Many years ago, when scientists first became interested in the problems of air pressure, a German scientist, Otto von Guericke, mayor of the city of Magdeburg, made an attempt to find out how tall a column of water could be held up by the air. He was already familiar with the facts which you have just learned. After many experiments he built a tube, or column, 36 feet long, which, except for an upper end made of glass, was constructed of brass pipe. The lower end was open, and the upper end of glass was closed. The tube was filled with water and turned upside down in a tub of water outside the house. It reached from cellar to

Fig. 77. Torricelli, *Famous Pupil of Famous Teacher* (*1608-1647*)

When Evangelista Torricelli was a boy at school, he was better at mathematics than anyone else in his class. He liked geometry and showed great ability in working problems · Now there was an old man down in Florence, Italy, an experimenter, who had had many problems to solve. The old man was blind and could not work on his experiments as he had previously. He had the problems, but he no longer had the eyes with which to observe the results of his experiments. This old man, as you may have guessed, was Galileo; and young Torricelli was just the man to help him · Together Galileo and Torricelli tried to measure air pressure. Philosophers had said that "nature abhors a vacuum"; but Galileo had discovered that nature apparently objected only up to a certain point, namely, the height of thirty-four feet or less! He had observed that a suction pump would lift water only that high, and so he set Torricelli to study the problem · Torricelli reasoned somewhat as follows: "It is not the vacuum that is responsible, for the vacuum is empty. It is the weight of the air outside, and the air will balance a column of water equal to its own weight. It cannot balance any more · I cannot experiment conveniently," he said, "with a tube of water thirty-four feet (408 inches) high. I will try mercury. Since in equal volumes this weighs 13.6 times as much as water, I shall need a tube only a little more than thirty inches high ($408 \div 13.6 = 30$). This I can make, and with it I can really study air pressure." · Thus Torricelli did his famous experiment. He used a glass tube about thirty inches long closed at one end and filled with mercury. He turned the open end upside down in a dish of mercury and found that air will support a column of mercury just about thirty inches high. For the first time air pressure had been measured.

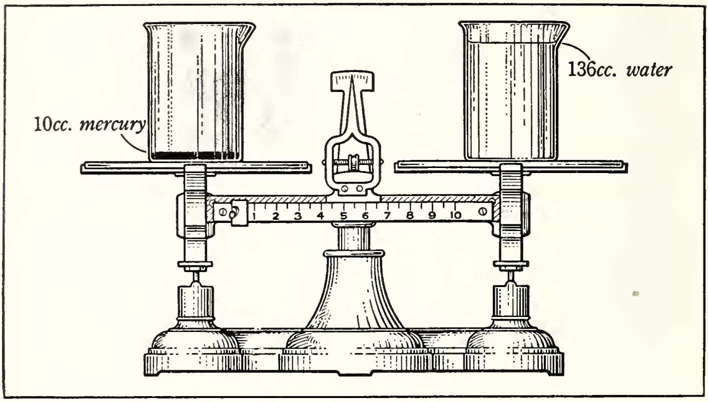

Fig. 78. The Weight of a Small Volume of Mercury balances that of a Large Volume of Water

attic. The height of the water in the Mayor's tube remained between 30 and 34 feet, differing a little from one day to another, but never rising to the top of the tube and never falling lower than about 30 feet. On the surface of the water within the tube, which was just about on a level with an upstairs window, floated an image of a man, made of cork. It could, of course, be seen through the glass. On account of the changes in the pressure of the atmosphere from day to day, the little cork man moved up and down. On pleasant days he bobbed up at the window, but on rainy days he disappeared from sight. No wonder ignorant people were inclined to believe in magic! (See Fig. 66.)

Instruments similar to Von Guericke's constructed for the purpose of measuring the force of air pressure are called barometers. The word *barometer* comes from two Greek words meaning "weight" and "a measure" or "a rule." A mercury barometer is a clever yet simple instrument for this purpose. Mercury is a very heavy liquid. It is 13.6 times as heavy as water. It is, then, much more convenient than water for the making of barometers. We can substitute for a column of water 408 inches, or 34 feet, high a column of mercury $\frac{1}{13.6} \times 408$ inches, or 30 inches high. Notice the small amount of mercury which is needed to balance the water in Fig. 78.

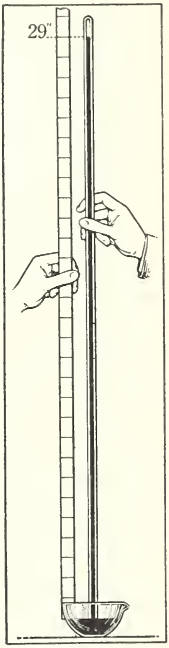

FIG. 79. Air Pressure supports the Column of Mercury in a Barometer

Suppose you now try an experiment in which you will use mercury instead of water. Find in the science workroom a glass tube, about 30 inches long, open at one end and sealed at the other. Find also a jar of mercury, a small glass or porcelain dish, and a yardstick. All these materials are shown in the picture. To make a mercury barometer, first pour mercury into the dish. Then fill the long tube with mercury. Now place a finger firmly over the open end of the tube and turn it upside down over the mercury in the dish exactly as you did the bottle of water over the pan of water. Fig. 79 shows the apparatus after it has been set up. Does the mercury flow out of the tube? You will find that some of it does, for an empty space appears in the top of the glass tube. But only a little of the mercury flows out. If you set the measuring stick alongside the mercury, you may find the height of the column of mercury remaining in the tube. You may find in this one experiment that the height of the column of mercury is about 29 inches. You will understand from this that air pressure can support a column of mercury. But it can support a column of mercury not more than about 30 inches high. However long a tube you use for your experiment, you will find that when you turn the tube upside down, the mercury runs out at the opening until the column is at just that height which

A mercury barometer is simple to make

will balance the pressure of the atmosphere in your laboratory on that day. The space it leaves at the closed end of the tube is a vacuum. A barometer does not measure air pressure in pounds. It simply shows the height of the vertical column of mercury that air pressure will support. Is air pressure always the same? How could you find out?

Compare the mercury barometer you have made with the ones used in laboratories for accurate work. The only differences between them are the greater care and skill that were used in the construction of the manufactured instrument and the greater convenience of its mounting.

The process of breathing depends upon air pressure

Your attention has already been called to the part air pressure plays in some of the things you do — in your motor trips, for instance, and in your basket-ball games. Now think for a moment about breathing. Breathing also depends upon air pressure. It is a sort of pumping process. You alternately increase the size of the chest cavity and decrease it. Study Fig. 80. When the muscles of the chest and of the diaphragm act to increase the size of the lung cavity, the air pressure within the cavity becomes less than the air pressure outside the body. This unequal pressure forces air into the lungs until the pressure in the lungs is the same as the pressure outside. The process of breathing out is just the reverse of this. The muscles of the chest and the diaphragm act to reduce the capacity of the lung cavity, thus increasing the pressure of the air in the lungs and forcing some of the air out of them. When we exercise vigorously we need more air, and so the breathing process occurs more rapidly. If we are sitting quietly, the process goes on more slowly. A person in good health breathes about fourteen or fifteen times per minute while he is asleep. The process of breathing is a very good illustration of the way man and other living things depend on the physical forces of their environment.

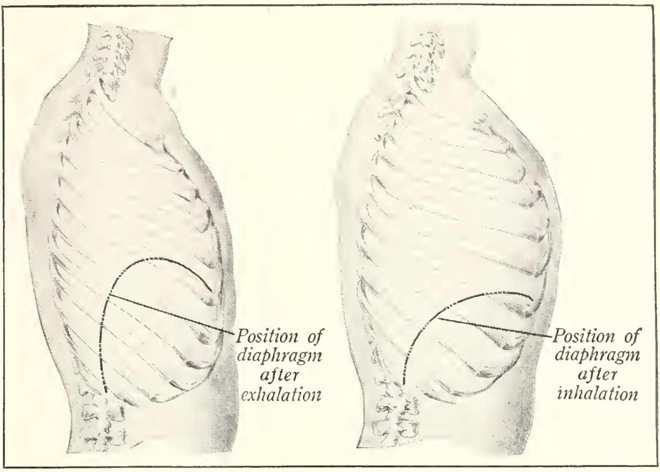

Fig. 80. Air Pressure forces Air out of the Lungs when a Person Exhales and into the Lungs when he Inhales

Air pressure may be used to do work

Besides the illustrations already given in this chapter, there are many other examples of air pressure that has been put to some practical use. There is the familiar medicine-dropper for instance. A medicine-dropper is a glass tube with a rubber bulb attached to one end. As you compress the bulb, the air in it is driven out; and as you release the bulb, air rushes into it again. Air pressure forces it in. If you release the bulb while the end of the tube is under water, air pressure on the surface of the water will force water into the tube. The filler in a fountain pen works exactly like a medicine-dropper. When you raise the lever on the side of the pen, you compress a rubber bulb inside the pen. This compression forces air out of the bulb. As you lower the lever you release the bulb, and the air pressure on the surface of the ink forces ink into the bulb. When you drink "soda" through a straw, it is air pressure that forces the liquid upward through the straw and into your mouth.

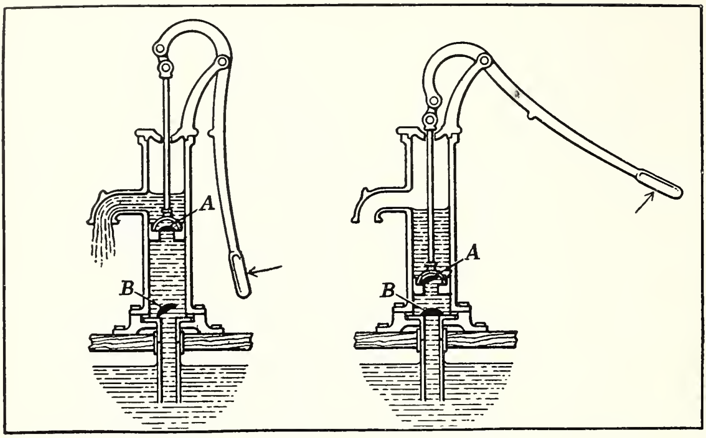

Fig. 81. The Operation of this Simple Pump depends upon Air Pressure

A pump operates because of air pressure

The pumping of water from a well is based upon this same principle of air pressure. Fig. 81 illustrates the mechanism of a simple pump. The essential parts of such a pump are a cylinder and a movable piston; the piston fits within the cylinder. A pipe usually runs from the bottom of the cylinder to the water in the well. A handle is attached to the piston for the purpose of raising and lowering it. The illustration also shows two valves, one in the piston itself (*A*), and the other at the bottom of the cylinder (*B*). When the operation of the pump is begun, the piston may be at the top of the cylinder near the outlet pipe. This means that the handle will be down. The first stroke of the pump is made by lifting the handle. This pushes the piston down to the bottom of the cylinder. As the piston moves down through the air, the small, hinged piston valve is pushed up by the increase of pressure beneath the piston. The second stroke is made by lowering the handle, which raises the piston. The small valve in the piston is closed by its own weight at the end of the downward stroke. A partial vacuum is created beneath the piston, into which the water from the well is forced by the pressure of the atmosphere on the surface of the water down in the well itself. As the piston rises, the water follows it because of this pressure, coming up through the cylinder valve, which opens. The third stroke again lowers the piston. The weight of the water in the cylinder exerts a downward pressure, and this closes the valve in the bottom of the cylinder. As the piston is lowered, water in the cylinder passes through the piston valve into the upper part of the cylinder. On the next stroke of the pump the piston again comes up. The pressure of the water above the piston closes the piston valve. The water cannot flow back through the piston and is carried to the top of the cylinder, where it escapes through the outlet pipe. As the pumping process continues, water is continually forced into the cylinder by air pressure. It is carried up and escapes through the outlet pipe.

This type of pump is very simple, but it has one serious defect: its use is limited. This can best be illustrated by a story. Some years ago some men dug a deep well, and in it was set a pump of this kind. When they began to pump, however, no water came to the surface. After a long period of hard pumping the men still had no water. The pump was carefully examined, but nothing wrong could be found. The men tried again, but still secured no results. Finally, as a last resort, they packed the pump into a wagon and took it into town, where the man who ran the general store knew a little about everything. When he heard their story, he asked them one question, "How deep is your well?" When they told him "Fifty feet," he laughed and said, "Neither this pump nor any other of that type will ever work in your well." "Why?" they asked him. His explanation was essentially what you already know from this chapter. Air pressure will support a column of water about 34 feet high. Since this type of pump depends upon air pressure for its operation, it very plainly will not work in any deep well. Another type of pump must be used here.

The behavior of air, like the behavior of water, may be explained in terms of the molecular theory. Air pressure plays an important part in life, and sudden changes in this pressure, unless precautions are taken, may have serious consequences.

Can You Answer these Questions?

1. How would you defend these statements?
a. Air exerts pressure.
b. The air is thinner at higher altitudes than it is near the earth.

2. What is the cause of air pressure?

3. Can you explain in terms of the molecular theory why warm air is less dense than cold air?

4. What is the normal air pressure per square inch on the surface of your body? Why do you feel uncomfortable if this air pressure on your body is rapidly reduced? if it is rapidly increased?

5. Explain the principle of a water barometer; of a mercury barometer. What are the chief differences?

6. Can you describe the process of breathing?

7. How many pounds of pressure will your tire gauge show when the total pressure in the tire is three times as great as when the tire gauge shows 10 pounds?

8. Why is it that an ordinary lift pump will not work in a well when the valve of the pump is as much as 35 feet above the level of the water?

Question for Discussion

When workmen enter a compressed-air chamber, they suffer some discomfort because of change in air pressure. Can you explain how the body adjusts itself to this change?

Here are Some Things You May Want to Do

1. Measure the air pressure of the tires on the family automobile before and after a long drive.

2. Find out what Torricelli did in connection with the invention of the barometer. Write a paragraph about him in your notebook.

3. Find some stories of mountain-climbers and list the difficulties they met which you think were due to differences in air pressure. Some of the most thrilling stories of this kind tell of the attempts which have been made to climb Mt. Everest, the world's highest mountain.

4. Construct a barometer as suggested on page 170. See if you can mark a scale on this barometer so that you may keep a record of changes from day to day. At the same time keep a record of weather conditions. See if you can draw any conclusions by comparing these two records. Continue your observations for a period of two or three weeks.

Chapter X · What has Man learned by Exploring the Upper Regions of the Air?

For I dipt into the future, far as human eye can see,
Saw the Vision of the world, and all the wonder that would be;

Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales;

Heard the heavens fill with shouting, and there rain'd a ghastly dew
From the nations' airy navies grappling in the central blue.

Tennyson

Man has always looked forward to the time when he could fly

For thousands of years man looked with envy at the birds as they soared easily and gracefully through the air, and dreamed of the day when he too would be able to fly through the limitless space of the sky. This desire was expressed in poetry and prophecy throughout the ages. We read of Pegasus, the winged horse, and Icarus, the boy who flew too near the sun. We find legends of the flying carpet and the flying trunk. Even Sindbad, that mighty traveler, depended upon the wings of the eagle to carry his treasures from the Valley of Diamonds.

During all these years prophecies and predictions were made. Some of them seem foolish now:

> There are four ways in which man might fly: (1) by spirits or angels; (2) by the help of fowls; (3) by wings fastened immediately to the body; (4) by a flying chariot.

Some of them sound as though they were written only yesterday. This one was written over seven hundred years ago:

> There may be some flying instrument, so that a man sitting in the middle of the instrument, and turning some mechanism, may put in motion some artificial wings which may beat the air like a bird flying.

Today man no longer dreams of flying. Huge planes roar over mountains and valleys, over towns and countryside and land and sea. The arrival and departure of commercial airplanes are scheduled as carefully as are the fastest trains. Most of the comforts of other forms of travel are provided for those who wish to use this new form of transportation.

Many of you know something about the different kinds of machines used in this conquest of the air. You have seen balloons and dirigibles, biplanes, monoplanes, and autogyros. But what do you know about these air-borne machines? How is it possible for such a heavy mass of machinery as the modern airplane to take off and glide smoothly through the air? Why doesn't it fall? Does the propeller of an airplane pull it through the air as the propeller of a ship pushes it through the water? Is there any real difference except in shape and appearance between a dirigible and an airplane? Have the experiences man has gained in flying taught him anything new about the unfamiliar ocean of air?

Can you use any of the things you have already learned about air and air pressure in finding answers to these questions? You may already know the answers to some of them but probably will admit that you know very little about others. If you will make use of the knowledge you have already gained, you will be much better able to answer them.

A. How does a Balloon float in the Air?

Have you ever heard of a fire balloon? This term is a strange one today, but once upon a time such balloons were common. Balloons of today are filled with a gas which is less dense than air, but such gases were little used in 1783, when the first flight in a balloon was made. At that time the balloon was built with a metal pan hung by chains under the opening in the bag. A straw fire was kept burning in this pan, and the warm air rising from the fire collected in the bag. Since warm air is less dense than an equal volume of cold air, the balloon in due time rose from the ground. You can imagine what a busy time the early balloonists had. Their fire had to be fed continually so that there would always be enough warm air in the bag. But what was equally important, their fire had to be watched very carefully or their balloon would be destroyed in a mass of flames.

Balloons will rise when filled with heated air

What caused these balloons to rise? The same principle that explains the flight of the modern balloon may be used to answer this question. In your study of water you learned that a boat is buoyed up in the water by a force equal to the weight of the water it displaces. You found that a submarine comes to the surface when its total weight becomes less, and sinks when its total weight becomes more than the weight of the water it displaces. This same principle of buoyancy applies to air. A balloon is pushed up by air pressure and rises if its weight is less than the weight of the air it displaces. This same balloon will descend if its weight is greater than the weight of the air it displaces.

The principle of buoyancy applies to air as well as to water

But what, you may ask, has all this to do with the hot air that filled the balloons of an earlier day? If you remember what you learned about the properties of heated air, the answer to this question will not be difficult. As air is heated, the molecules of the gases of which it is composed are pushed farther and farther apart. The air expands, and as it expands it becomes less dense. Suppose you use this knowledge in solving your problem. The heated air which filled the bag of the fire balloon was less dense than the air outside the bag. After a time the balloon was lifted off the ground by the pressure of the denser air outside. As long as heated air was supplied, this difference in density was maintained between the air on the inside and that on the outside of the bag, and the balloon continued to float. If the inside air was permitted to cool, however, it contracted and became more dense. When contraction reached the point where the weight of the balloon and the load carried in it was greater than the weight of the air it displaced, the balloon settled to earth.

Some gases are less dense than air

A balloon rises when it is lighter than the air it displaces

How about our modern balloon? This is usually a large, rubber-lined bag filled with some gas lighter than air. There are several common gases that have this property. Hydrogen, for example, is only $\frac{1}{14}$ and helium only $\frac{1}{7}$ as dense as air. The gas commonly used for fuel in gas stoves is about half as dense as air. Our modern balloons, then, may be filled with different gases: fuel gas, helium, a mixture of fuel gas and hydrogen, or with pure hydrogen. Each has its advantages and disadvantages. Hydrogen is the least dense and will therefore support the greatest load. Another advantage is that it is comparatively cheap. It is highly explosive, however. Helium is not explosive, but is more dense than hydrogen. Therefore it will not support as heavy a load as hydrogen will support. It is also more expensive. The main point to remember is not the kind of gas used; it is that the weight of the gas plus the materials of which the balloon is made plus its cargo must be lighter than the weight of the air it displaces if the balloon is to rise.

Let us illustrate this by a balloon which won an important race a few years ago. The bag when filled was more than 50 feet in diameter. It had a capacity of about 80,000 cubic feet. This amount of air would weigh about 6000 pounds, but the balloon was filled with a mixture of fuel gas and hydrogen, having a density about $\frac{1}{4}$ that of air. Fifteen hundred pounds of gas, then, displaced 6000 pounds of air, a difference of 4500 pounds. In other words, the gas in this balloon would support a weight of 4500 pounds, or, to put it in another way, the lifting force was 4500 pounds.

Balloons have been used to study the upper air

Much of man's knowledge of the upper atmosphere has come through the use of balloons. Scientists have gone up in them to high altitudes to study and observe conditions there. Other balloons without any pilots have gone to even greater heights, carrying self-recording instruments for further observations of the air. These studies and observations have given fairly accurate knowledge of what the air above the surface of the earth is like. Let us summarize some of these findings, for they will play an important part in the rest of our story.

You have learned that the ocean of air spreads over the rough surface of the earth in much the same way as the ocean of water spreads over the uneven surface at the bottom of the ocean. Just as there is more water over the deepest places in the ocean, so there is more air over the lowest places on the surface of the earth. Water pressure is greater in deep water than it is in shallow water, for there is more water to exert pressure above the deep places. Similarly the air pressure is greater in low places than it is in high places.

Air pressure decreases at higher altitudes

In the last chapter you found that air pressure at sea level supports a column of mercury about 30 inches high. As the altitude increases, there is less air to exert pressure, and so pressure decreases. At sea level it is a little less than 15 pounds per square inch; at 500 feet, it is approximately 14 pounds; and at 12,000 feet, only about 10 pounds. As this pressure decreases, the length of the column of mercury it will support becomes less. At 500 feet it is about 29 inches; at 12,000 feet, about 19 inches. At an altitude of 15 miles air pressure will support but one inch of mercury. The higher the altitude, then, the shorter the column of mercury which is supported.

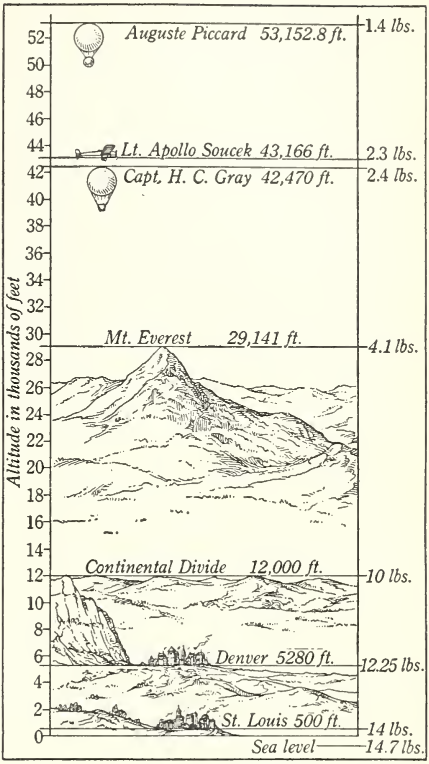

Fig. 82. Air Pressure decreases as Altitude increases. Have the Aviation Records shown been broken Recently?

In one respect the ocean of air is quite unlike the ocean of water. If you could examine the molecules of water in the depths of the ocean and the molecules of water at the surface, you would find that in both cases the molecules are about the same distance apart. The pressure at the depths is very much greater than at the surface, but this makes very little difference in the space between the molecules of liquids. This is not true of air, however, for gases may be compressed much more readily than water, and when a gas is compressed, the molecules are forced closer together. Similarly air expands to a greater extent than water, and by expansion the molecules spread farther apart. Other liquids behave in this respect like water, while gases behave like air. If you could examine the molecules of air at an altitude of 500 feet and again at 12,000 feet, you would find that a body of air large enough to contain 140 molecules at the lower altitude would contain only 100 molecules at 12,000 feet.

Molecules of a liquid are closer together than molecules of a gas

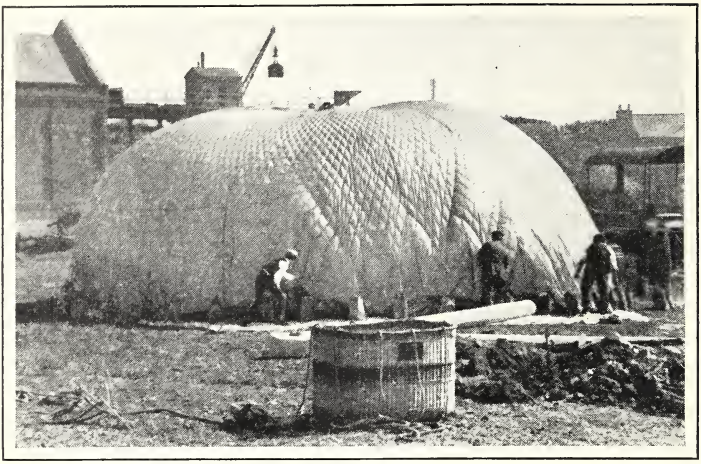

Fig. 83. The Pilot begins early in the Morning to fill his Balloon for the Coming Race

Now suppose you see if you can make use of any of these facts in your study of the modern balloon. Every year balloon races are held in the United States. These races are unlike those held in other branches of aviation, for the winner is not the person who flies from New York to San Francisco, for example, in the shortest time, but is the one who covers the greatest distance, or, as is often the case, the one who manages to stay in the air for the longest period of time. Two important accomplishments often determine the winning of such a race. In the first place, the balloon must be kept in the air. Since this depends upon gas, it is plain that gas must be saved as much as possible. In the second place, a balloon used in balloon races has no driving or steering mechanism. It simply goes up into the air and is carried along by the wind. It is necessary, therefore, for the pilot to take advantage of every wind current. He knows that these currents move at different speeds and in different directions at different altitudes. His job is to use the information he has.

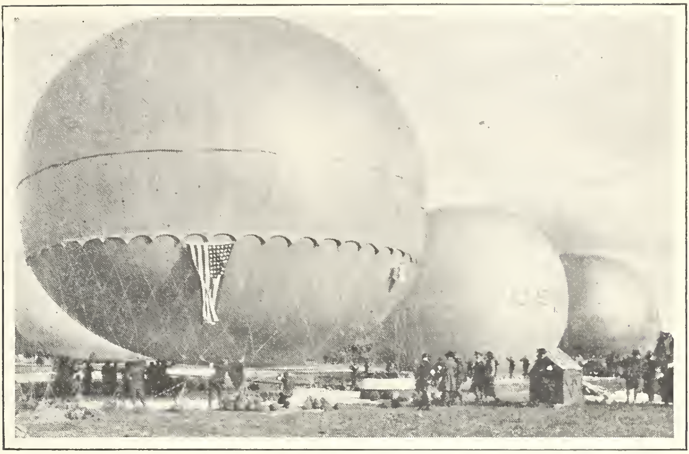

FIG. 84. Toward Evening the Bags are nearly filled with Gas

How should you like to be one of the passengers in a racing balloon? Let us see if we can picture your experiences for you.

You arrive at the starting point the night before the race. The next morning you awake before sunrise and go out to the field. In spite of the hour, work has already begun, for the pilots start early in the morning to fill their enormous gas bags. This is a slow and often a dangerous task, for the gases commonly used are highly explosive. During these early morning hours the balloon has not yet taken the form it will finally take but looks like the bag in Fig. 83. The work of filling the bags and putting on a proper load of ballast takes up most of the first day. (A pilot carries with him sand bags, or ballast, as the load is called, which he can throw out from time to time to make the balloon lighter so that it will rise to a higher altitude.) This slowness does not worry the pilot, however, who tells you that he prefers to start in the evening. He explains that the bags hold more of the precious gas in the cool of the evening than they do when the hot sun of midday shines upon them. This is all he tells you, but from your knowledge of air pressure and of warm and cool gases you see why it is so. Toward evening the bags are nearly filled with gas and begin to take on the balloon shape illustrated in Fig. 84.

At last everything is ready. You climb into the basket and look around you. The big bags are beautiful in the twilight as they stand out against the sky. One by one they are released, and you watch them rise slowly from the ground. Your own pilot now climbs into the basket with you. Last-minute instructions are given, and the men on the ground begin to release the ropes. Suddenly the ground seems to drop away from you. The balloon is in the air. It rises gradually, buoyed up by the weight of the air it displaces. As it rises, it moves into air that is less and less dense. When an altitude is reached at which the weight of the air displaced by the balloon is just equal to the weight of the balloon with its load, the balloon rises no higher. Having reached this position, possibly at an elevation of about 2000 feet, the balloon floats along, carried by the wind.

Gas is released to make a balloon come down

During the first night there is little to do except to float through the air. The hours are uneventful even to the extent of becoming monotonous. But as the sun rises things begin to happen. The warm rays of the sun on the balloon cause the gases in it to expand. As it expands, the bag of the balloon is enlarged, so that it displaces more air. Therefore the balloon rises to still higher altitudes. In a short time it may rise to 10,000 or 12,000 feet. You begin here to appreciate the heavy clothing you wore for protection against the cold. Now your pilot has to make an important decision. He doesn't want to go very much higher, but can stop climbing only by releasing some of the gas from the balloon. The longer he can avoid such a waste of gas, the longer he can stay up in the air, and the better are his chances of winning the race. "What shall I do?"

he asks. Finally he decides to let some of his gas go, which he does by opening a valve in the bag. As a result the balloon is brought again into a condition in which it goes neither higher nor lower but simply floats along with the wind.

Now you have a new experience. A cloud passes between the balloon and the sun and shuts off some of the heat from the sun. As the air cools, the gas in the bag cools rapidly and contracts. The bag grows smaller. Since the balloon now displaces less air, it starts downward with a rush. The cloud is a large one, and it is necessary to lighten the balloon in order to stop the rapid downward fall. Some of the sand ballast is thrown out.

After the cloud passes, the rays of the sun cause the gas in the balloon to expand again, and now it starts upward with as much speed as a few minutes before it started downward. Now the pilot needs to release gas again in order to stop climbing! As the evening comes, the cooler air once more affects the balloon; and again you are reminded of the importance of a good supply of sand, for the gases cool and contract, and the balloon starts once more to descend. The experiences of the day have cost a good deal of gas, and as darkness approaches it is necessary to throw still more sand overboard in order to keep the balloon in the air. After sufficient sand has been dumped, a condition of equilibrium is again established; in other words, you go neither higher nor lower, but once again float along on a favorable air current.

The race is over soon after the ballast is gone

The experiences of the second day are like those of the first. Gas is released whenever you wish to lower the balloon, and sand is thrown overboard to cause it to rise. But near the close of the second day the sand is nearly gone; and when the balloon starts to descend this time, there is no way to check it. You watch the ground come up to meet you.

The basket finally touches the earth. You and the pilot hop out and watch the large bag settle slowly as the gas escapes. After seeing that everything is fastened down you select some of the more valuable instruments. With these under your arms you start a hike across country to find some house from which to telephone your safe landing. A few days later you find that the winner of the race traveled over 1000 miles. This is not a record, for distances as great as nearly 1500 miles have been covered in previous races.

B. What has Man experienced in Attempting to reach Higher Altitudes?

In your imaginary trip as a passenger in a racing balloon, the greatest height you reached was about 12,000 feet, which is not exceptional for balloons. Yet, as you know, many dangerous adventures were met in reaching it. Suppose that instead of rising to 12,000 feet you had soared far up into the air in an attempt to set a new altitude record. Would your experiences be different at heights of from 40,000 to 50,000 feet? Very few men have reached these altitudes. From their own descriptions of their experiences we get a picture of real danger and adventure.

Captain Gray has sailed at an altitude of eight miles

For several years members of the United States Army Air Corps sought new balloon altitude records. One of their leaders in these attempts was Captain H. C. Gray. His own story of a flight to a new record of 42,470 feet illustrates again many of the facts you have learned about air and air pressure. Preparations for the flight were carefully made. From the knowledge gained in previous explorations Captain Gray knew that at the height he was attempting to reach he would find extremely cold weather. Since he was riding in an open basket, he was bundled up in furs and leather clothing. These were not very comfortable in the warm weather on the ground, but he knew he would need them later. He also knew that the air at high altitudes is extremely thin. He knew that this thin air was not sufficient for breathing, and so he was provided with tanks of oxygen and a mask through which he might breathe from this extra supply. He had all kinds of instruments for measurements and observations. The outside of the basket was hung with a heavy load of sand, carried in bags with special attachments which permitted the sand to run out slowly.

As soon as the balloon left the ground, Captain Gray began to release this sand. The balloon continued its steady rise into the lighter air. At about 12,000 feet he began to use his oxygen. At this height the air was noticeably less dense. At 18,500 feet the oxygen mask was put in place, and from that point oxygen was used continuously until the highest altitude was reached.

At 25,000 feet Captain Gray found much lower temperatures. He now put on warm gloves and bundled up even more tightly in his heavy clothing. At this height, too, the condensed moisture from his breathing began to freeze on his goggles, and he found difficulty in seeing anything. Still the balloon continued to rise. At 40,000 feet it stopped climbing. The bag had reached a point of equilibrium. The sand bags were empty and it was plain to Captain Gray that in order to break a previous altitude record of about 41,000 feet something else would have to be thrown overboard. The only way to raise the balloon still higher was to lighten its weight. A parachute was attached to an oxygen tank. The tank was lifted over the side of the basket and floated downward. The balloon again began to climb. Finally, at what Captain Gray thought was a record height, he decided to come down. By now the balloon had expanded enormously, for the pressure of the gas within it pushed out the covering of the envelope against the light air pressure outside. The gas valve in the bag was opened, and the balloon began to descend. As it fell, the pressure of the denser air in the lower altitudes compressed the gas. This compression reduced the size of the bag, and it displaced less air. Its lifting power was reduced and the balloon fell faster and faster. The balloon had climbed at a rate of from 500 to 800 feet a minute, but it was now falling at the rate of from 1400 to 1900 feet a minute. Plainly something would have to be done to slacken this rate at which it was coming down, for if the balloon hit the earth at that speed it would be hopelessly smashed. Captain Gray threw overboard all his remaining equipment, including empty sand bags, oxygen tanks, and radio batteries, but still the rapid fall continued. Finally, at a height of 8000 feet, he regretfully climbed to the rim of the basket and stepped off into space. His parachute opened, and he floated safely to earth, landing in a swamp over a hundred miles from his starting point. The flight had taken about an hour and a half.

These and other explorations increased rather than satisfied man's curiosity about the upper regions of the air. It was obvious that conditions in the extreme upper regions of the air were quite different from those nearer the surface of the earth. Enough had been learned to indicate that there were no storms at these higher altitudes, and that rain, snow, and clouds were not to be found there. As a result of these findings, it was believed that in these upper regions man would find a calm zone suited to high-speed air travel. It was believed, too, that many other questions of interest to science could be solved, if more could be learned about this region of air. It was plain, however, that new methods of exploration would have to be found, for the dangers of the ordinary balloon were too great at higher altitudes.

Air conditions in the extreme upper regions of the air are different from those near the surface of the earth

Finally a European scientist named Auguste Piccard became interested in the task. The practical problems of such a flight as Piccard planned were tremendous. Although air pressure at sea level supports a column of mer-

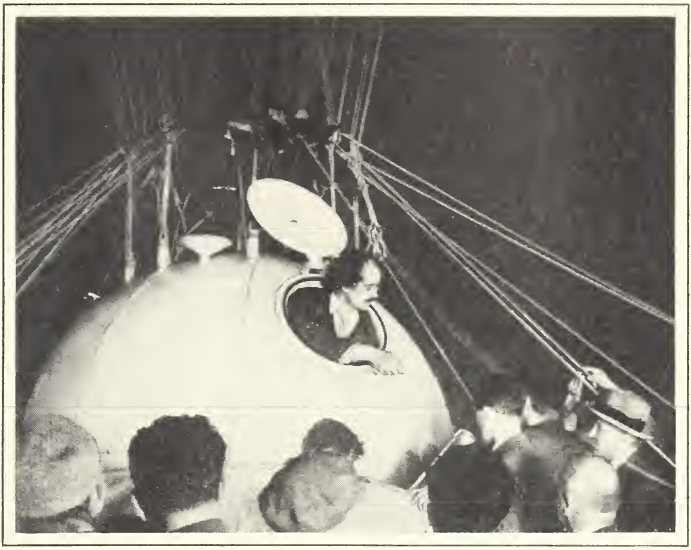

FIG. 85. Here is Professor Piccard just before he started on his Trip to the Stratosphere

cury 30 inches high, at 40,000 feet the column is only about five inches high. Since Piccard planned to go higher than Captain Gray had gone, it was plain that the lifting power of a balloon which would support any weight in such a rare atmosphere would have to be very great. But if a balloon large enough to meet these needs were completely filled with gas before it left the ground, it would expand to such an extent that the bag would probably burst in the rarer atmosphere at the height desired. At such a height, too, the cold would be unbearable, varying from 58° F. to 76° F. below zero. Anyone attempting this trip in an open basket would never live to tell of his experiences. Professor Piccard designed a balloon with an inclosed cabin, as illustrated in Fig. 85. This cabin was in the form of an air-tight aluminum ball about seven feet in

Piccard reached an altitude of ten miles in an inclosed metal sphere diameter, fitted with a window and equipped with oxygen apparatus. Finally a bag with a diameter, when filled, of about a hundred feet was designed to lift the cabin. This balloon was filled with hydrogen to about a fifth of its total capacity. Professor Piccard estimated that in the pressure he would find at 50,000 feet the gas would expand enough to inflate the balloon completely. In his first attempt he and a companion reached a height of 52,000 feet. In his second attempt he climbed to over 53,000 feet. Two Russian scientists, in a balloon similar to that of Professor Piccard, have reached an altitude of almost twelve miles, and two Americans, Lieutenant Commander T. G. W. Settle and Major Chester L. Fordney, have reached a height of 61,327 feet.

The balloon offers real difficulties as a means of regular transportation. It is at the mercy of the winds and the storms, and cannot be directed or propelled, that is, driven forward under power. These difficulties were recognized many years ago by the pioneers in aviation, and they soon began to look for a solution to the problem. How could a balloon be designed, they asked, so as to make use of the lifting power of gas and yet be controlled and directed? The answer was found in the "rigid" type of balloon. The type of balloon used by Captain Gray has no framework. It is merely a large nonrigid bag filled with gas. Balloons used for passengers are built on a frame; accordingly they are called rigid. The framework is made of aluminum or aluminum alloy and is covered with special cloth. Inside the frame are located tanks or bags filled with gas. Engines and steering apparatus are attached, and the result is a balloon which may be driven by power and steered to its destination. Much of the first successful work with this kind of airship was done by Count Zeppelin, a German, and his name is still attached to this type of ship today. Another name for it is "dirigible." A dirigible is a cigar-shaped rigid balloon that may be propelled and steered.

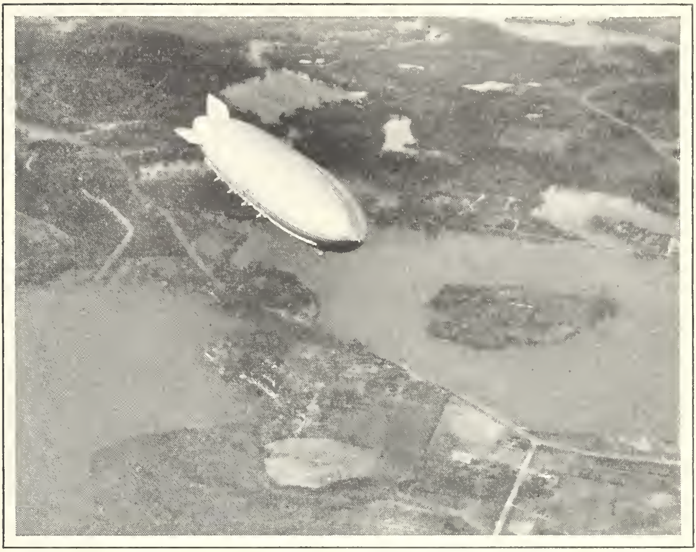

Fig. 86. More than Two Hundred Tons of Steel and Fabric ride upon the Air

Some idea of how this type of airship has developed may be gained by comparing one of the early Zeppelins built about twenty-five years ago with a modern dirigible (Fig. 86). This Zeppelin was about 420 feet long, with a diameter of 38 feet and a capacity of 400,000 cubic feet of gas. One of the large dirigibles built recently in the United States is 785 feet long, with a diameter of 133 feet and a capacity of 6,500,000 cubic feet of gas. As this monster floats in the air, it displaces 6,500,000 cubic feet of air. This volume of air at the temperature of freezing water weighs almost 500,000 pounds. The dirigible is filled with helium, which has a density only about a seventh as great as the density of air. The weight of helium required to fill it is, therefore, a little more than 70,000 pounds. The lifting force is equal to the difference between the weight of the air and the weight of the helium, or somewhat more than 400,000 pounds. Tests showed the lifting power to be 403,000 pounds. The material of which the ship is made, together with the necessary equipment, including the engines, weighs about 221,000 pounds. The "useful load" this dirigible may carry is 183,000 pounds, or more than 90 tons.

C. May the Flight of Airplanes be explained by the Same Principles of Buoyancy that explain the Balloon?

In spite of the progress made by these lighter-than-air machines, man was far from satisfied. He wanted a flying machine as reliable as a railroad train or a ship, and not one which was at the mercy of the wind. The ideal machine was one which would take him wherever he wanted to go, and when he wanted to go. In the modern airplane this dream is almost realized. The story of this development is too long to be told here, but many books have been written about it, some of which you may have read.

Our interest now is in explaining if we can how this large mass of metal, far heavier than air, may be made to leave the ground and roar along at speeds of over 100 miles per hour.

In order to explain how a knowledge of the principles of air pressure made the airplane possible, we need to consider the purposes served by two essential parts of the airplane, — the propeller and the wings.

Suppose the propeller of an airplane is 8 feet long and that its average width is 6 inches. The area of one side of this propeller is 576 ($96 \times 6 = 576$) square inches. Since air pressure at sea level is about 15 pounds per square inch, the pressure on the front surface of the propeller is more than 8000 pounds ($15 \times 576 = 8540$). The area of the rear surface is, of course, just the same as the area of the front surface; therefore the pressure is the same. While the propeller is stationary, as in Fig. 87, air pressure is equally

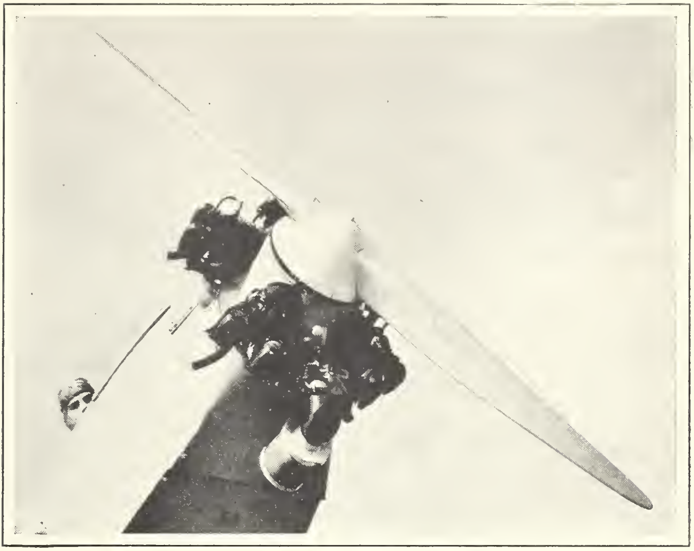

Fig. 87. Notice the Shape of this Propeller

As the propeller turns in the air, air pressure pushes the plane forward

distributed over all its parts. It is so constructed, however, that, as it turns, the air pressure on the rear surface increases while air pressure on the front surface decreases. The pressure on the rear surface of this rotating propeller is more than 8000 pounds, but the pressure on the front surface is less than 8000 pounds. The faster the propeller turns, the greater the pressure becomes on the rear surface and the less it becomes on the front surface. If you will recall what you have learned about air pressure, it is easy to see that this difference in pressure between the rear and the front surfaces of the propeller acts as a force which moves the airplane forward along the ground.

The propeller moves the airplane forward, but there is nothing about the propeller to make the plane leave the ground. You must look closely at the wings in order to understand how air pressure raises the plane. The picture

(Fig. 88) shows how a wing is constructed. You will notice that it slopes slightly to the rear. The effect of this slope is to force air away from the top surface of the wing as the wing moves forward. At the same time the pressure increases against the lower surface of the wing. As the speed increases, the pressure on the top surface of the wing continues to decrease, and the pressure on the undersurface continues to increase. In other words, the pressure on the top surface becomes increasingly less than 15 pounds per square inch, while the pressure on the undersurface becomes increasingly more than 15 pounds per square inch. At a speed of some 40 to 60 miles per hour the upward force of air pressure under the wings is great enough to lift the plane from the ground. The airplane gains speed very rapidly after its wheels leave the ground. You see, then, that air pressure on the rear surface of the propeller pushes the airplane forward, and air pressure on the undersurface of the wings pushes it off the ground.

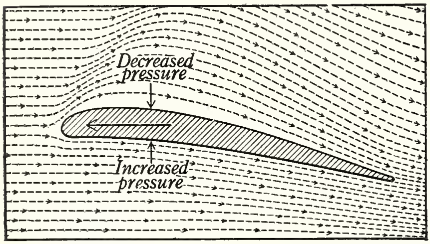

Fig. 88. Notice the Shape of this Airplane Wing

As the pressure is decreased above, the pressure from below forces the plane upward

An airplane is held up by air pressure

Again we appreciate how man is able to control his environment by a knowledge of natural laws. But even here it is a limited control. Like the balloon, the airplane is practical only within certain limits. It too, for example, is unable to fly above certain heights. The reasons for this may be understood if we follow an airplane pilot in his attempts to reach a new altitude record.

The aviator is dressed in warm clothing and like Captain Gray carries a tank of oxygen. Fig. 89 pictures an aviator

Fig. 89. A High-Altitude Flier needs Heavy Clothing and a Supply of Oxygen

ready for an altitude flight. Notice the heavy clothing and the oxygen tube. As the pilot drives his plane upward, he rides in comfort to an altitude of about 15,000 feet, where he begins to feel sleepiness coming over him. The experienced aviator recognizes this feeling as a warning that the air about him does not contain enough oxygen for his needs. He takes the tube attached to his oxygen tank and draws into his lungs a few breaths of pure oxygen. He watches the altitude indicator and sees that he is climbing rapidly. He soon reaches 30,000 feet. He continues to climb and finally reaches 40,000 feet. At this altitude the density of the air is only about three pounds per square inch — less than one fourth the pressure at sea level. In this thin air the plane climbs slowly. The aviator travels in wide circles with the nose of the plane turned upward, so that each trip around the circle carries him a little higher.

Air pressure supports the plane, but as the pilot drives higher and higher this pressure on the plane becomes less and less. The plane cannot continue to climb indefinitely, for finally it will reach an altitude at which the air pressure is so low that it cannot carry the plane any higher. In order to keep the engine running in this thin air it is necessary to equip it with a device, known as a supercharger, which compresses the air before it enters the carburetor.

Planes of the type now used cannot go higher than about eight miles

Finally the aviator reaches an altitude beyond which he cannot go. As he descends he continues to fly in wide circles, coming down to earth gradually. Because the air pressure on his body must change, while he comes down, from about 4.5 pounds per square inch to about 15 pounds per square inch, it is dangerous to make this change too rapidly. In less than an hour, however, the plane may again touch the ground.

D. Do the Experiences in Mountain-Climbing tell us Anything about Air Pressure?

Comparatively few people have gone to high altitudes in balloons or airplanes. But this does not mean that many people have not experienced for themselves some of the difficulties which accompany changes in air pressure caused by altitude. In the mountains of the western United States there are many peaks 14,000 feet high and numerous plateau regions 10,000 feet high. Railroads cross these mountain ranges at altitudes of nearly 10,000 feet, and automobile roads are built as high as 12,000 feet.

A trip through these mountains will illustrate rather vividly some of the things you have now learned. Let us suppose we are starting from St. Louis and driving westward to the mountains, through Denver. At St. Louis the altitude is about 500 feet. At Denver it is 5000 feet. The

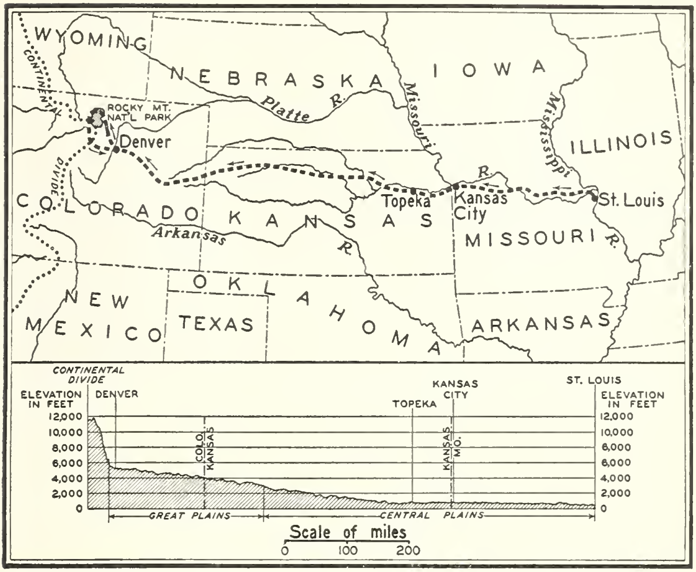

Fig. 90. It is Uphill All the Way from St. Louis to the Continental Divide

long journey over what appears to be level plains is a gradual climb of 4500 feet. A reference to Fig. 90 will confirm this. From Denver the high peaks may be seen just ahead, in such a view as that illustrated in Fig. 91, and we begin to look forward eagerly to the experiences of mountain driving and mountain-climbing. Soon we pass through a gorge, on a narrow road built alongside a swiftly flowing mountain stream. The rate of flow in the stream shows that the water is running down a steep incline, and waterfalls are numerous. As we drive onward, the slope becomes even steeper. Our car, which usually climbs hills "in high," is now pulling hard, and we shift into second gear. We approach the first of a series of "hairpin" curves, by means of which the road winds up the side of the mountain range.

After some time we reach a stretch of apparently level

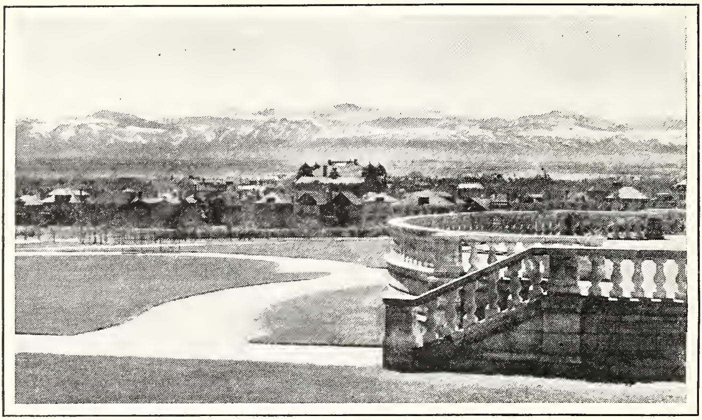

Fig. 91. Looking westward from Denver, we see the High Mountains just Ahead

Courtesy of the Denver Tourist Bureau

road. We stop at a shelter cabin by the side of the road to look about us. The mountain peaks are still far above. During all the trip up the mountain we have been perfectly comfortable. The sky is clear, and in the bright sunshine the cold air seems to make us feel unusually energetic. We are moved by the splendor of the mountain scenery. We discover from records in the cabin that we are now on the Continental Divide, at an elevation of nearly 12,000 feet above sea level. We are more than two miles higher than we were when we left St. Louis.

Walking at high altitudes is difficult

This is our first experience in mountain-climbing, and like most tourists we have traveled upward by automobile. Now if we care to go higher we must go on foot. We start off at a rapid pace, but our ambition soon dies, for in a very short time we are out of breath and panting furiously. We must stop to "get our wind." Although we breathe deeply and draw as much air as possible into our lungs, we seem not to be able to get enough. We have heard before that air is "thin" on mountain tops. Now we know what thin air really is. It is thin in the sense that we must take a large quantity of it into our lungs in order to get enough oxygen to meet the needs of our body cells. We do not need so much oxygen as long as we are quiet, but the exercise of climbing calls for more oxygen than our lungs are able to supply.

After a few minutes of rest and deep breathing we feel comfortable and start climbing again. This time we go more slowly and without much discomfort. But it is easier to ride in this thin air than it is to walk, and after a short time we return to the car and continue our journey.

You have already learned that a volume of air large enough to contain 140 molecules at an altitude of 500 feet would contain only 100 molecules at an altitude of 12,000 feet. Now you can understand why it is so "hard to get your breath" on a high mountain. If we are breathing as deeply as we can, it is necessary to breathe 14 times at the elevation of the Divide in order to get the same amount of oxygen as may be taken in by breathing 10 times at the elevation of St. Louis. At an elevation of 16,000 feet the pressure is only about half as great as at St. Louis. A volume of air large enough to inclose 140 molecules at St. Louis would inclose only 70 molecules at an elevation of 16,000 feet. At 40,000 feet a volume of air large enough to hold, at sea level, 140 molecules would hold only about 20 molecules. In this thin air the human body is entirely unable to get enough oxygen to support life.

Thin air contains fewer molecules

The law of buoyancy applies to air as well as to water. The operation of this law explains why balloons and dirigibles float in the air. Through exploration of the air by the use of balloons and airplanes, man has found that air at higher elevations is different in many respects from air at the surface of the earth.

Can You Answer these Questions?

1. What do we really mean when we say that the air at high altitudes is "thin"? Why is it difficult to "get your breath" on a high mountain?

2. What principle, or law, used to explain why a boat floats is also used to explain why a balloon rises?

3. Can you explain how an airplane is lifted off the ground and kept in the air?

4. Can you explain the part played by the propeller of an airplane in driving the machine forward?

5. What is meant by the lifting force of a balloon or a dirigible?

6. Why does not a balloon keep going up and up indefinitely?

7. Why does an aviator have to take a supply of oxygen with him when he is attempting flights at high altitudes?

Questions for Discussion

1. In some of the bulletins issued by our National Park Service, people who plan to drive over the Continental Divide are warned that they need to have their carburetors adjusted to the high altitudes. Why is any adjustment necessary? In general, what would this adjustment have to be?

2. The first successful attempts of man to fly were made in balloons and not in airplanes. Can you think of any reasons why this should have been so?

3. Which would you say is the more important factor in reaching higher altitudes in an airplane, the type of engine used or the design of the wings? Defend your answer.

Here are Some Things You May Want to Do

1. Make a collection of pictures or write a description (perhaps you might want to do both) of the scenes along some journey you have taken similar to the one described at the end of this chapter. If you have not taken such a trip, perhaps you may like to illustrate the one given in this chapter by collecting suitable pictures.

2. Describe an experience of your own in mountain-climbing.

3. Make a diagram showing the air pressure at sea level, at an altitude of two miles, and at an altitude of eight miles.

4. There are many good books on aviation, such as Maitland's *Knights of the Air*, Fraser's *Heroes of the Air*, Humphreys and Hosey's *Romance of the Airman*, or Hodgins and Magoun's *Sky High*. You may want to read some of these and tell your class about them.

5. Make a collection of stories about flying and call it "Record Flights" or "Famous Flights." Collect pictures and clippings to put in it. See the Scientific American Annualog.

6. Make a study of our most recent dirigible and report on it to the class.

7. Have you a good imagination? Write an exciting story of a balloon race. A good title for your story might be "Bumping your Head on the Clouds." You might write in the margin of your story the reasons for some of the experiences you have.

8. In the May, 1931, number of the *National Geographic Magazine* you will find a good description of the dangers of flying at high altitudes. Some very fine mountain pictures taken from high altitudes are also given. Read this story and report on it in class.

Chapter XI · Of What Gases is Air Composed? Of What Importance to us are the Different Gases?

What is air made up of?

Suppose you were asked the apparently simple question "What is air?" Could you answer it? From what you have already learned about air, you could probably give some answers to the question. You might say that it is a real substance, that it occupies space, and that it can be weighed. You might add that air is a buoyant substance, and explain how this property of buoyancy accounts for the flight of balloons and dirigibles. All these, however, would be only a part of the whole answer. Suppose that the person who asked you the question said: "Yes, I know all these things about air. What I want to know is what is air made up of and why do we need it?"

Do you know what air is composed of? The dictionary tells you that air is the atmosphere, or the mixture of gases, which surrounds the earth, and which we breathe. Does that help any in answering the question? As you think more about it, perhaps you will feel that you need more information about air than you now have.

A. What is Air?

In previous chapters we have found it helpful to explain many of the properties and actions of air in terms of the molecular theory. Differences in density, for example, may be explained rather clearly by assuming that in dense air the molecules are closer together than in less dense air.

Again we are going to ask you to use your imagination. Suppose this time that you have a volume of dry air just large enough to contain 10,000 molecules and that you can see these molecules clearly enough to distinguish them one from the other. Of course you know that you cannot do this, for molecules, as you have now learned, are extremely tiny things. The cavity which usually holds an eraser at the end of an ordinary lead pencil is about $\frac{1}{8}$ of a cubic centimeter, and yet this small space would hold about three thousand billion molecules of a gas. A volume which would hold only 10,000 of them would be so small that it simply could not be seen, even with the most powerful microscope. But imagine that you can actually see what is going on among those 10,000 molecules.

Molecules are extremely tiny particles

Now observe them. They are moving rapidly in every direction, continuously colliding with one another and bumping the sides of the vessel which incloses them. The vessel does not seem very crowded, however, for the space between each molecule and its nearest neighbor averages more than ten times the diameter of a single molecule.

At first the molecules all appear alike. You examine your sample of air more carefully, however, and decide that there are at least two kinds, for they can be clearly distinguished. You are not sure that there are not some other kinds too, for some of the molecules look unlike either of those you have identified. Now imagine that you can count them. You do, and find that you seem to have about 7800 molecules of one kind and about 2100 of a second kind. You look more closely and find about 93 of a third type, and about 4 of still another type. There are now only 3 molecules left in your vessel, and each of these three is different from the others.

There are several kinds of molecules in air

Now what have you found out about the molecules of air? At least you know that there are several different kinds of molecules in the air. But what are they? If you took your count to a scientist, he would tell you that you had a fairly representative sample of dry air, for your figures agree rather closely with those of other studies made of such air. He would tell you that the 7800 molecules were molecules of nitrogen, that the 2100 were molecules of oxygen, that the 93 were molecules of argon, and that the 4 were molecules of carbon dioxide, but that he would have to "see" the remaining 3 molecules to determine whether they were helium, neon, or some other rare gas. These last, he would tell you, are extremely rare gases and present in such small quantities that he would hardly expect you to find even a single molecule of any of them among a volume of air containing 10,000 molecules. To summarize, he would say that

Air contains oxygen, nitrogen, carbon dioxide, argon, and several other gases

Of 10,000 molecules of dry air there are about

7800 molecules of nitrogen.
2100 molecules of oxygen.
93 molecules of argon.
4 molecules of carbon dioxide.
3 molecules of other gases.

These numbers are commonly stated as percentages, as follows:

78 per cent of the air is nitrogen.
21 per cent of the air is oxygen.
0.93 per cent of the air is argon.
0.04 per cent of the air is carbon dioxide.
0.03 per cent of the air is of other gases.

These percentages might change under different conditions. As you learned in your study of water, there is always some water vapor in the air out of doors. The amount changes of course. In the dry air of the desert there is relatively little water, while in the moist air of a foggy day there is a great deal. But in a sample of dry air, from which the water molecules have been removed, the percentages of the different gases present are always very nearly the same.

The different molecules move with definite speeds

One more observation should be made. Notice the speed with which the various molecules are moving. You see that the nitrogen molecules move slightly faster than the oxygen molecules. Molecules of argon and of carbon dioxide seem to move more slowly than those of either nitrogen or oxygen. Again you speak to the scientist, and he tells you that at the same temperature a molecule of nitrogen will move 8 feet, a molecule of oxygen 7 feet, and a molecule of carbon dioxide about 4 feet during the same interval of time. He adds that if by chance you should catch a glimpse of a helium molecule, you would see that it moves much faster than molecules of nitrogen or oxygen, racing 64 feet while a molecule of oxygen is moving 8 feet. The fastest-moving molecules, he says, are those of hydrogen, which move about twice as fast as molecules of helium. Can you build in imagination a picture of these moving molecules?

At this point you would be quite fair in asking, "How has anyone found this out? All that we have done has been imaginary. Can what we have only imagined be really done?" We cannot answer this question now, except to say that scientists who have studied the subject and have done a great deal of experimenting believe that this is the real story of air. As you go forward in your study of science, you will learn more and more about why they think so. It may be interesting to know that when extremely tiny particles of dust are seen under a microscope, they appear as if they were being knocked about by a bombardment of molecules. Of course these molecules cannot be seen, but the motion of the tiny particles of dust can be seen. By putting together the facts he knows, the scientist builds a theory. Let us suppose then that we have, in imagination, constructed a true picture of the nature of the gases in the air. This picture is not complete in all details, but it will help us to understand many things about air.

B. Of What Use is the Oxygen in the Air?

The ocean of air in which we live is not the simple substance you may have thought it to be, but a rather complex mixture of several different gases which are always present in about the same proportions. Are these of any importance except as a part of the entire mixture? Does oxygen serve any special purpose? Does nitrogen? Does carbon dioxide? Some very common occurrences which seem difficult to understand can be explained if you know the answers to these questions.

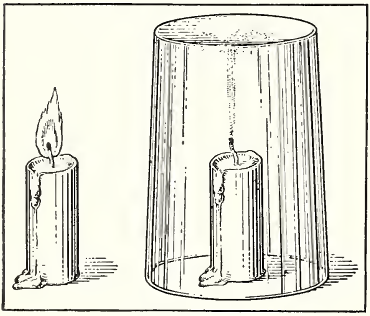

FIG. 92. The Flame goes out when the Candle is Covered

You turn on the gas in the stove for a moment, but do not light it. Very soon you begin to smell the odor of gas. From what you already know about molecules you realize that the molecules of gas are coming out of the gas pipe and mixing with the molecules of the air. These gas molecules cause the odor you notice. But if you light a match and touch it to the burner, a flame appears and heat is given off. What has happened? Perhaps an experiment or two will help you.

Place a candle on the table and hold a burning match to the wick. The wick catches fire and burns. As it burns, the wax in the candle seems to disappear, and the candle itself becomes shorter and shorter. While the candle is burning, set a glass over it. Very shortly the flame becomes less bright, the candle begins to smoke, and soon the flame goes out.

The same results may be observed in another simple experiment. For this experiment several things are needed:

a flat cork, a little of the substance called plaster of Paris, a flat dish filled with water, a tall jar which will fit over the dish, and a small amount of red phosphorus, a chemical element used in the science laboratory. Hollow out the cork and fill it with plaster of Paris. When the plaster is dry, place the phosphorus on it. Now float the cork with the phosphorus on it in the dish. Touch a lighted match to the phosphorus, and it will immediately begin to burn. Now cover the dish and the burning phosphorus by turning the jar upside down over them. Very shortly the phosphorus stops burning, and the flame goes out.

When air is shut out, burning stops

What conclusions can be drawn? The natural one is that air is needed for burning. But remember that we can no longer think of air as a simple substance, for we have learned that it is composed of several different gases. Are all these necessary for burning or do only some of them help in the process? If we say that *air* is necessary for burning, we mean that when the candle or the phosphorus stops burning, all the air in the jar has been used up. If this is so, there should be a vacuum in the jar. But this is not so. If you look again at the jar under which you burned the phosphorus, you will notice that the water has risen in it to a level higher than the level of the water in the dish. The reason for this, of course, is that part of the air in the jar has been used in burning, and the pressure of the air outside the jar has forced water from the shallow dish into the jar to replace the air which has been used in burning. If, however, there were a vacuum in the jar, the water would rise and fill the jar. Since this does not happen, you can be sure that there is still "air" left in the jar even after burning stops. But it is not the same kind of "air" as was there originally. If you could examine this air as you did the sample you used at the beginning of this chapter, you would find one very important difference. You would find that some of the oxygen was used up in the burning process, and that therefore there were fewer molecules of oxygen present in the air which surrounded the burning candle or phosphorus. In other words, some of the molecules of oxygen were used up in the burning process. The correct conclusion from our experiments, therefore, is not that *air* is necessary for burning, but that a certain percentage of *oxygen* is necessary for burning. Nitrogen and the other gases of the air take no part in burning. The molecules of these other gases do pass through the flame, of course, but they are in no way changed by it.

Oxygen is needed for burning

Now let us see if we can explain what really happens in the burning process. A candle is made of paraffin, which melts readily. When the melted paraffin is heated, it changes to gas, just as water changes to gas when it is heated. As you know from experience, when you bring a match to a candlewick, you must hold it there a short time before the candle starts to burn. In this short time the heat from the match changes some of the solid, first to a liquid and then to a gas. It is the gas which burns. As the gas burns, enough heat is given off to change more of the paraffin to liquid, and this in turn is changed to gas. This process continues until the candle is entirely gone.

As the candle burns, chemical changes are taking place, and these changes produce energy in the form of heat and light. These changes are rather simple and can be easily explained. The molecules of paraffin are composed of two chemical elements, carbon and hydrogen. Some of the oxygen in the air combines with the carbon from the candle gas and forms molecules of carbon dioxide. This can be proved by a simple experiment. When carbon dioxide is mixed with a water solution of slaked lime, the solution, or the limewater, as it is called, changes in appearance. In this experiment, then, a bottle of limewater is used and two clean, wide-mouthed bottles. Hold the mouth

In burning, oxygen combines chemically with elements from the fuel

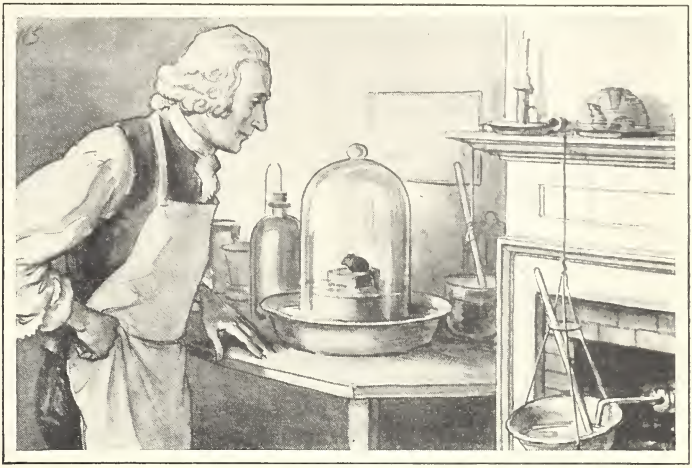

FIG. 93. PRIESTLEY, *the Minister who had a Hobby* (*1733–1804*)

BY VOCATION JOSEPH PRIESTLEY was an English minister. In his spare time he was a scientist, interested in experimenting with chemicals and electricity · As frequently happens with a hobby, Priestley became so interested in his experimenting that he forgot about his preaching. His experiments made him famous. A few months before the signing of the Declaration of Independence in America, he discovered how to make oxygen. He focused a burning-glass on some "red rust of mercury," the heavy orange powder which we call mercuric oxide. From the powder there escaped a colorless gas, which he collected in a bottle. Where the powder had been, there were little drops of mercury. He experimented with mice and found that they could live in the bottle in which he had collected the gas; and he observed that when they were first put into the bottle, they seemed even more active than when kept in air · Priestley was unpopular in England because he held certain unpopular political beliefs. As soon as the war was over, he moved to America. He liked America because new ideas were common and he could think or say what he pleased · Among his friends were Benjamin Franklin, James Watt, and the French scientist Lavoisier, who named Priestley's newly discovered gas oxygen · Joseph Priestley died at his son's home in Northumberland, Pennsylvania, and is buried in that town. He is one of several men who became famous as scientists, though their scientific work was an avocation, not a vocation. His work as a minister would have been forgotten long ago. For the experiments he made in his spare time he is remembered today as a famous pioneer in the study of science.

of one of the bottles directly over the flame of a candle for about half a minute. Then pour about two teaspoonfuls of limewater into each bottle and shake the bottles. The limewater in the bottle that was held over the flame will appear milky. The limewater in the bottle that was not held over the flame will remain clear. Carbon dioxide from the flame caused the change in the appearance of the limewater.

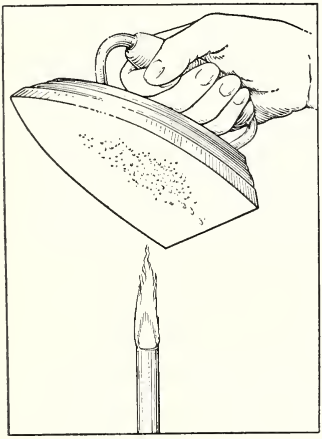

Fig. 94. Oxygen from the Air combines with Hydrogen from the Gas and forms Water Vapor

Oxygen from the air also combines with hydrogen from the candle gas and forms water vapor. Again, this may be proved by a simple experiment. Hold the smooth surface of a cold laundry iron two or three inches above the flame of a candle. Soon moisture forms on the iron. In a similar manner, as is shown in Fig. 94, you may find evidence that water is formed in the flame of a gas burner.

If any of the essentials for burning are removed, the process stops

Thus the oxygen from the air and the carbon and hydrogen from the candle gas all play a part in the burning process. As long as these substances are present in the proper percentages, the burning may continue. Now it should be easy to understand why the candle or phosphorus flame went out when you covered it. You shut off the supply of oxygen molecules from the outside air. When about 5 per cent of the oxygen had been used in the burning process, the chemical change that takes place as a candle burns could not continue, since a proper proportion of one of the necessary parts to the change was missing. The candle goes out when one fourth of the oxygen has been used. The burning of the phosphorus will continue until nearly all the oxygen has been used.

Chemical changes very similar to these take place in all burning, whether it is of wood, coal, or fuel gas from the gas stove. As long as the elements necessary for burning are present, the burning process may continue. When one or more are removed, the process stops. More will be said about these chemical processes in a later chapter.

Conditions on earth would differ if the percentage of oxygen differed

Let us now consider a little further two of the things we have already learned: first, that oxygen is necessary for burning, and second, that the air contains 21 per cent of oxygen and 78 per cent of nitrogen. Suppose there were less oxygen and more nitrogen in the air, or that there were more oxygen and less nitrogen. Under these conditions would the process of burning still be the same? Suppose you repeat the experiment of covering a burning candle with a bottle. If the air left in the bottle after the flame goes out is analyzed, it will be found to contain about 16 per cent of oxygen. If, then, the percentage of oxygen in the air were 16 per cent instead of 21 per cent (a difference of only 5 per cent), candles would never burn. By similar experiments you could show that neither wood nor coal would burn in air containing as little as 16 per cent of oxygen. Indeed, if the percentage of oxygen in the air were even 1 per cent less than it is, things would burn less rapidly than they do now, and the heat given off would be less intense.

If the amount of oxygen in the air were more than 21 per cent, that too would make conditions on earth different from what they are now. Some experiments with pure oxygen will help you to understand this. For these experiments you will need at least three bottles of oxygen and two or three bottles of ordinary air. These bottles should have wide mouths. Half-pint bottles will do. Oxygen may be easily prepared from chemicals.

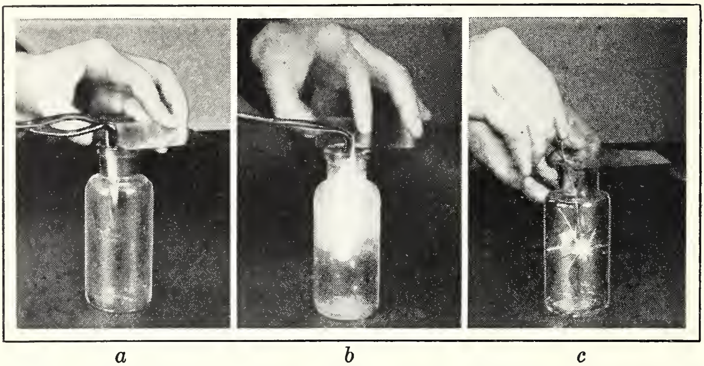

Fig. 95. *a*, in Air the Splinter burns slowly; *b*, in Oxygen, however, the Splinter burns with Great Brightness; *c*, even Iron Wire burns brilliantly in Pure Oxygen

A candle flame burns brilliantly in pure oxygen

In the first experiment use a burning candle. Before lighting it wrap a piece of wire about it in such a way that the candle may be lowered into and removed from a bottle. Light the candle, lower it into a bottle of air, and place a glass cover over the bottle. The candle soon goes out. Do the same thing with a bottle of pure oxygen. The candle now burns very brightly and very rapidly.

For the second experiment light a splinter of wood. Push the burning splinter first into a bottle of air and then into a bottle of oxygen. If there is only a glow on the end of the splinter, the glow will burst into flame when the splinter is pushed into pure oxygen. Thus you find that wood also burns brilliantly and rapidly in pure oxygen. The differences are shown in Fig. 95, *a* and *b*.

For the third experiment use a piece of braided iron wire, such as is commonly used for hanging pictures. Take a piece 8 or 10 inches long. Loosen about half an inch of the braid at one end of the wire and place on this braid a little tuft of cotton. Set fire to the cotton and quickly lower it into a bottle of air. The cotton burns, but nothing happens to the iron. Now place another tuft of cotton on the wire and set fire to it. This time thrust it into the bottle of pure oxygen. In pure oxygen the burning cotton kindles the iron wire. The shower of sparks from the end of the wire (see Fig. 95, *c*) shows that even iron burns brilliantly in a bottle of pure oxygen.

Even iron burns in pure oxygen

It is clear from these tests that fire would be very difficult to control if there were more oxygen in the air. If the percentage of oxygen were to increase by as little as 5 per cent, fire control would be difficult, if not impossible.

C. Of What Importance are the Other Gases in the Air?

You may now feel sure that oxygen plays a very important part in the life of man. But what about the other gases? Are they equally important? All of them cannot be treated here. Carbon dioxide, for example, plays a tremendously important part in our lives, as does nitrogen. Each of these gases will be treated more fully a little later.

Let us look at some of the rarer gases which we know are present in the air. The names of these are argon, neon, krypton, xenon, and helium. Some of these gases are important because of their usefulness in industry. You have already learned that in 10,000 molecules of the gases of the air, there are about 7800 molecules of nitrogen, 2100 molecules of oxygen, 93 molecules of argon, and 4 molecules of carbon dioxide. These four make up 9997 of 10,000 molecules of dry air. It is evident, therefore, that the other four gases — neon, krypton, xenon, and helium — are present in extremely small amounts.

Argon is used in electric-light bulbs. With a small amount of this gas in them, the bulbs give off light that is more nearly like daylight than light from the ordinary vacuum bulb.

Helium was known to be present in the atmosphere around the sun some years before it was discovered on earth. Later it was found in extremely small quantities in the atmosphere of the earth. Still later it was found in the natural gas (fuel gas) that comes from wells in the western part of the United States. Next to hydrogen, helium is the lightest known substance. You have already learned that hydrogen is a dangerously explosive gas but that helium will not explode or burn under any conditions. You have seen that because of these properties it is used in dirigibles. The helium that is used for this purpose is obtained from natural gas.

Fig. 96. Many of the Rare Gases in the Air have Commercial Value

Neon is also an important substance. This is a colorless gas, but when an electric current is passed through a tube containing neon at low pressure the familiar red light is produced. The colored lights used in advertising signs, such as that illustrated in Fig. 96, and in guiding airplanes on their courses are neon lights. These lights are useful at the landing fields and as beacon lights along air routes because the neon light will penetrate through fog to a greater distance than other kinds of light.

Some of the rare gases in the air have commercial value

At present there are no important commercial uses for krypton and xenon, but only a few years ago no commercial uses were known for argon, helium, or neon. The discovery of uses for three of these gases that are present in the atmosphere in such small amounts shows that elements that seem to be of no particular value today may be of great value a few years from now when more is known about them. Among ten million molecules of air gases there are 10 of krypton and 5 of xenon.

There is another thing which is found in the air. If you remember your study of water, you will recall the travels of a water molecule and how it made its way through the air as a part of the water cycle. With this story in mind, then, you will realize that there is also water vapor in the air. While nitrogen, oxygen, argon, carbon dioxide, and the other gases you have been studying are always present in dry air in the same percentages, the percentage of water vapor is continually changing. Water is always evaporating from the surface of oceans, rivers, and lakes, from the soil, and from the leaves of plants. It is also continually leaving the air as rain or snow, and on cool, clear evenings it condenses as dew or frost.

There is also water vapor in air

The amount of water vapor in the air has much to do with our feeling of comfort or discomfort. Water evaporates from any moist surface exposed to the air. The surface of our bodies is always slightly moist with water which comes through the skin from over two million tiny sweat glands. This water is constantly evaporating from our skin. You have noticed, of course, that more water comes out through your sweat glands in hot weather than in cold weather and that you perspire more when you are playing hard than when you are resting quietly. On the average about two quarts of water pass through your sweat glands every day. Usually this water does not gather on the skin. Ordinarily it keeps the skin moist but not wet, for it comes out slowly and evaporates as soon as it reaches the surface. There are some conditions, however, under which water evaporates slowly from the skin and others under which it evaporates rapidly. Under either of these conditions you may be more or less uncomfortable.

When water evaporates from the skin too rapidly or too slowly, you are uncomfortable

The evaporation of moisture from the skin helps to control the temperature of the body. Certain processes carried on in the cells of the body make heat. Since these processes are going on all the time, heat is always being produced. Unless this heat is released, the body will become too hot. In the process of evaporation molecules of water, carrying away heat, pass from the skin into the air. Therefore the evaporation of perspiration cools the body.

Perspiration controls body temperature

A simple experiment will illustrate how the skin is cooled by evaporation. Blow gently against the skin of your hand. Then place a single drop of water on it and blow again. You will notice that blowing on wet skin makes it feel cooler than blowing on dry skin. The blowing causes the water to evaporate faster; that is, it causes the molecules to escape faster and carry away more heat. You may try this in another way if you wish. No apparatus is needed except warm water and your two hands. Wet one hand with warm water, but keep the other one dry. Shake the water off the wet one, but do not wipe it. Now wave *both* hands in the air rapidly. Do they feel alike? Do you believe evaporation has any effect on temperature? Do other liquids have similar effects? Pour some alcohol on the back of your hand and swing it through the air in the same way. In these experiments you have felt that your wet hands were cooler, and have come to the conclusion that this was due to evaporation. You can prove this more certainly if you wish by another simple experiment.

Evaporation is a cooling process

Get a thermometer, a strip of linen cloth, and a dish of water. Read the thermometer and record the temperature. Now cover the bulb of the thermometer by wrapping one end of the piece of linen around it. Be sure that only one thickness of the cloth is used. Let the other end of the linen strip hang in the dish of water. Fig. 97 shows the arrangement. Watch the temperature of the thermometer as the cloth becomes saturated with water. What do you find? If you wish to hasten the process, you may fan the air around the bulb. Can you explain what you see?

You have noticed, no doubt, that there are some conditions under which perspiration seems to evaporate very slowly. You can recall hot, sultry days during which perspiration formed on your skin and collected in large drops. You felt very uncomfortable. You may have heard some people say that this was because "the humidity was high." You may be curious to know what this statement means.

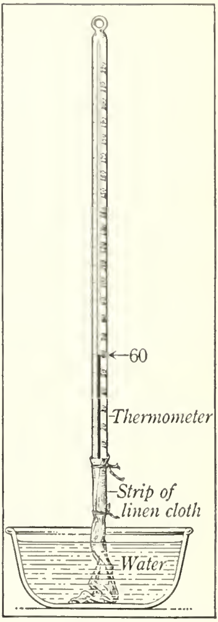

Fig. 97. Evaporation affects Humidity

Humidity refers to the amount of water vapor in the air. When the humidity is high, there is a large amount of water vapor in the air. When the humidity is low, there is less water vapor in the air. If the air is nearly saturated, water will not evaporate from the skin rapidly. You may have experienced two days during which the temperature as shown by the thermometer was the same. Yet you suffered more from the heat on one day than on the other. The reason is that the humidity was higher on one day than it was on the other, and you suffered more from the heat during the day when the humidity was high than when it was low. The high humidity interfered with the process of carrying heat away from the body.

Air is composed of a number of gases, including among others nitrogen, oxygen, argon, and carbon dioxide. The first two combined make up 99 per cent of the atmosphere. Each of these gases plays an important part in life processes. In dry air they are found in a constant proportion.

Can You Answer these Questions?

1. What gases compose the air? What percentage of each of these may be found in a sample of dry air?

2. What part of the air is necessary for burning? What proof can you give?

3. What chemical change takes place as a candle burns?

4. What uses have been made of some of the rarer gases in the air?

5. What is the relative speed of motion of the molecules of oxygen and nitrogen? of hydrogen and helium?

6. What is carbon dioxide?

7. Of what use to man is the nitrogen in the air?

8. Why is the percentage of water vapor in the air continually changing?

9. What is perspiration? How does it help to cool the body?

Questions for Discussion

1. Why is the molecular theory a good one to explain the behavior of air?

2. What are the relative advantages and disadvantages of hydrogen and helium as gases for dirigibles and balloons? Suppose that you wanted to set a new record in ballooning for altitude. Which of these two would you use? Why?

3. What has the percentage of water vapor in the air to do with our feelings of comfort or discomfort?

4. We often say, "It's not the heat; it's the humidity." What do we mean by this?

5. What is the evidence that a difference of 5 per cent more or less in the amount of oxygen in the air would make a great difference in the conditions on earth?

Here are Some Things You May Want to Do

1. What is the experimental evidence to support the following statements?

a. Air is necessary for burning.

b. Water vapor is formed in a flame.

c. Carbon dioxide is formed in a flame.

d. Substances burn more rapidly in pure oxygen than in air.

2. Make a circle graph showing the proportions of the various gases of which the air is composed.

3. Demonstrate to your class a method used for artificial respiration.

4. Read Faraday's *Chemical History of a Candle* and tell your class about it.

5. In your neighborhood you may find many different kinds of colored electric signs. See if you can tell the kind of gas used from the color of the sign. What gas is used the most? Why do you think this is so?

6. The rare gases argon, neon, krypton, and xenon, which we have mentioned as being present in the air, all derive their names from the Greek. Look up their derivation (*derivation* means "where the word came from").

7. You will find that in spite of their seeming differences, all these names have one thing in common. Can you find it?

8. You have already read something about the work of certain scientists. You may want to look up and read about the life and work of some others, such as Ramsay, Lavoisier, Cavendish, or Rutherford. These names are not as familiar to you as some of the others, but these men have all made important contributions to our knowledge of the air. See what you can find out about them and report your findings in class.

Chapter XII · How does Air sustain Life?

"Why, it's as simple as breathing!"

How often have you heard this statement given to explain some apparently easy problem which was difficult for another person? Perhaps you have used it yourself when you could not get your ideas across to the other fellow. But is it a correct comparison? Is the process of breathing really a simple one? Of course we all know that it is an important one. We can go without water and food for some time and still live, but if breathing is stopped for just a few minutes life will stop with it. Yet, in one way, breathing *is* simple. We need to pay little attention to it. Every minute of our lives we inhale and exhale a little more or a little less than sixteen times. If we exercise or run or do hard physical labor, this speed increases; when we rest or sleep, the rate is lower. It is all so easy, isn't it? The air is all around us; we take it into our lungs, we exhale it again; and life goes on.

But let us be scientists now, and therefore curious. Let us ask some questions. What becomes of this air we breathe into our lungs? We have learned that it is composed of different gases. Are all of them important to life? Or is oxygen again the only important part of the air? What is "fresh" air? Is it correct to say that without air we could not live?

We are not the first to ask these questions. They have been asked for thousands of years. The ancients asked them. They answered them, too. Their ideas about the composition of air were entirely different from ours, however, and their explanations of the relationship between air and life were different as well. You will find it interesting to read about these ancient ideas concerning air. This story is told in many books. Our own story will tell about our present knowledge of this relationship.

A. What happens to the Air that you breathe into your Lungs?

The process of breathing is in itself a simple one. As you breathe in, the diaphragm and the muscles attached to the ribs move so as to enlarge the chest cavity, and air pressure forces air into the lungs. As you exhale, your muscles act to make the chest cavity smaller. In this manner some of the air in the lungs is forced out. This has been illustrated in Fig. 80.

Branching tubes reach from nose to lungs

But what happens to the air which reaches the lungs as a result of inhaling? You know that this air is composed of several gases, and these are not separated before they enter the body. They all pass together into the lungs — nitrogen, oxygen, argon, and the others. A tube called the windpipe, with an opening about as large as your little finger, serves as a passage for the air on its way from the nose and the mouth. In the chest this tube branches. One branch passes to each lung. In the lungs the branching continues. If you could see these branches in the lungs you might think they resembled the roots of a plant, for each branch divides into smaller branches, and these in turn divide into still smaller ones. This continues until the tiniest branches end in little air sacs, or pockets, as shown in Figs. 98 and 99. As you breathe, then, air enters the lungs, fills all the little branches of the air passages, and finally reaches the air sacs themselves.

Tiny blood vessels surround the air sacs

Let us now consider another important part of the bodily mechanism. As you of course know, a supply of blood is continuously circulating, or moving around, through the body. The blood passes from the heart through large tubes. One large tube leads directly from the heart to the lungs. Near the lungs it branches just as the large air tube did, so that one branch goes to each lung. In the lungs these tubes

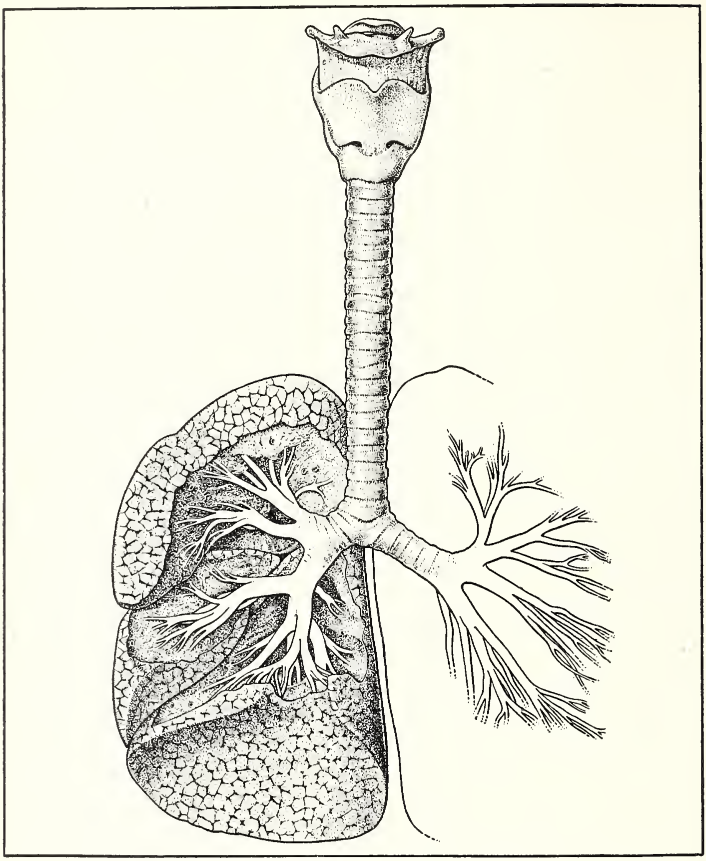

Fig. 98. As you breathe, Air enters the Lungs, fills all the Little Branches of the Air Passages, and finally reaches the Air Sacs Themselves

This illustration shows how these air passages branch out to all parts of the lungs

branch again and again until they have divided into extremely tiny blood tubes, or capillaries, which carry the blood to and around the tiny air sacs. These capillaries are so small that they cannot be seen without a microscope. Their walls are very thin. Here then we have air being

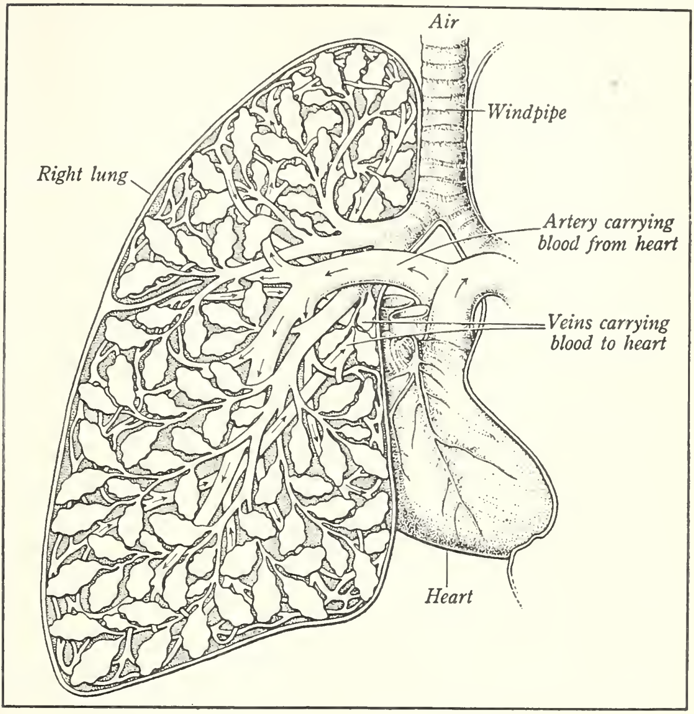

Fig. 99. This Picture shows how Air and Blood reach the Lung

When the air enters the lungs, it contains a normal proportion of oxygen. When it leaves the lungs, it contains less oxygen

taken into the lungs and held in little air sacs which are surrounded by blood circulated through countless little blood tubes called capillaries. Thin walls are always between the air and the blood.

The air, as you know, is forced in and out of these sacs by breathing. The blood in the capillaries does not remain there indefinitely. Since it circulates, it must keep moving. If you followed the branching blood tubes away from the air sacs, you would find the tiniest ones joining with other tiny ones to form larger tubes, called veins, and these in

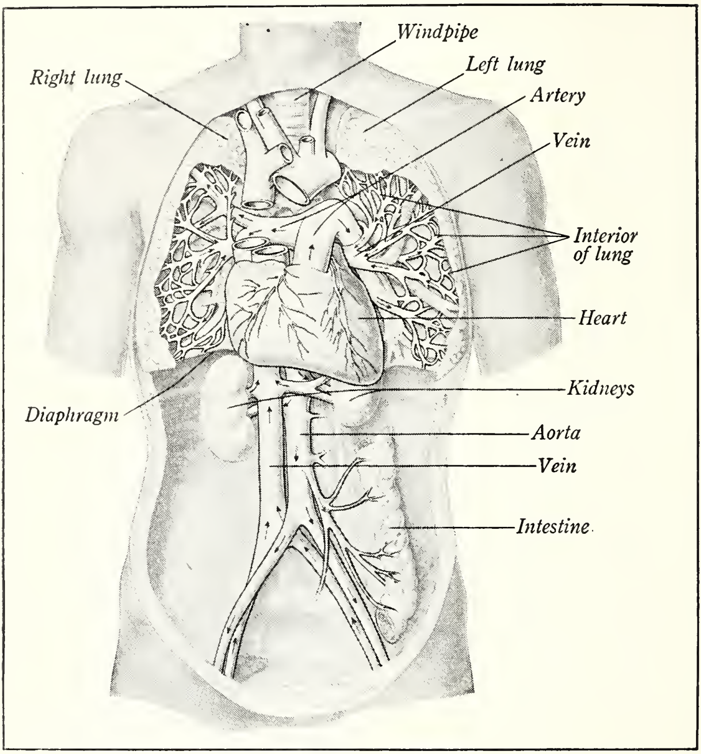

Fig. 100. Air is carried in the Blood to All Parts of the Body

turn join to form still larger ones. Finally two large branches are formed, one from each lung, which unite in one great vein leading back to the heart. The blood flows into this vein in very much the same way that countless little streams of water unite to form a river. Thus you have a steady circulation of blood to and from the heart, and a constant supply of air coming to the lungs during the breathing process. Figs. 100 and 101 illustrate this system.

Let us go back now to the air in the air sacs and see what happens to it. Remember that it is separated from the blood in the capillaries by very thin walls. What hap-

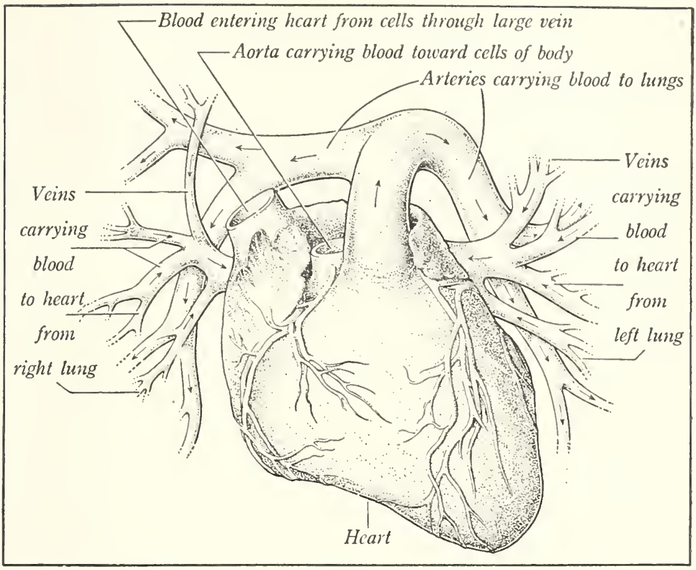

FIG. 101. There is a Steady Circulation of Blood to and from the Heart

Air passes in and out of the blood stream

pens? The gases which make up the air pass through the thin walls into the blood, and the gases dissolved in the blood pass from the blood into the air sacs. Thus the blood leaving the lungs carries a supply of oxygen with it. As you follow the blood, you see it carried back to the heart, and you see the heart immediately pumping it out again to all parts of the body.

In your imagination you may follow this blood as it leaves the heart by a large blood tube to supply the cells of the body. The tubes which carry blood away from the heart are called arteries. This large blood tube (the largest artery) is called the aorta. Smaller arteries branch from it and carry the blood to the cells in all parts of the body. Most of the arteries are well protected and are located deep down under the muscles. If they were near the skin,

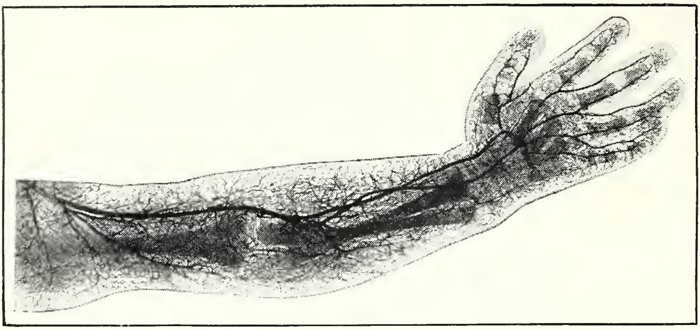

Fig. 102. This X-Ray Picture shows how the Arteries divide until there are Enough Tiny Tubes to supply Blood to Every Part of the Arm

From Gruenberg's *Biology and Human Life*

you could see them full of blood, and throbbing as each beat of the heart sent along additional quantities of blood. There are a few places on the body, the wrist, for example, where an artery comes so close to the skin that we may feel it throbbing. When this is possible, we say that we can feel the pulse.

Suppose we follow the tube that carries blood to the arm. At the shoulder it is about as large as a lead pencil. In the arm, this artery divides again and again, until there are enough tiny tubes to supply blood to every part of the arm. This system of tubes is illustrated in Fig. 102. Just as in the lungs, these tiny blood tubes in the arm have thin delicate walls, and some of the liquid part of the blood with oxygen dissolved in it seeps through these walls into the spaces about the cells in the arm and bathes these cells. Every living cell of the body is bathed continuously in this liquid that seeps through the tiny tubes. This liquid in the blood keeps the cells alive. Hence it keeps the body alive. If you could examine this liquid which bathes the cells you would find that it is clear like water. But blood, you say, is red. You know that it is, for you have sometimes cut into one of the small blood tubes and have seen the red blood flow out of it. What, then, is this clear, watery liquid? It is really a part of the blood. The red blood corpuscles, which are tiny bodies that float in the blood and give to the blood its color, do not pass through the walls of the blood tubes. Therefore the liquid, called lymph, in which the cells are bathed is not red. No doubt you have had water blisters on your hands or heels. The "water" in these blisters is lymph.

The liquid which bathes the cells is called lymph

At this point let us raise the same question that we considered in the last chapter. Are all the gases in the air used in this process? Again the answer is the same. Only the oxygen takes part in the changes that go on. Our lungs are adapted to breathe a mixture of nitrogen and oxygen, it is true. In this mixture there are about four times as many molecules of nitrogen as of oxygen. But the part played by the nitrogen is that of diluting the oxygen. If we were to breathe pure oxygen continuously, so much would enter the lungs and the blood that it would be injurious. Oxygen is needed, but ordinarily not more than can be taken from the mixture of nitrogen and oxygen that makes up the normal air. In the case of burning, you remember, nitrogen passes into and out of the flame but takes no part in the process of burning. The same is true of the changes which take place in the cells of the body. Most of the changes are due to the oxygen which enters the blood from the air sacs.

All air gases enter the lungs, but only oxygen takes part in the changes that go on

B. How does this Air help to carry on Life Processes?

You have now traced the course by which oxygen gets to the cells of the body. Air pressure drives air, of which oxygen is a part, into the air sacs. Some oxygen passes through the walls of the air sacs and through the walls of the tiny blood tubes into the blood. Carried by the blood

Fig. 103. Harvey, *the King's Doctor who proved that the Blood is used Over and Over* (*1578–1657*)

"The breath of life" is an expression as old, probably, as the oldest written language, and yet it is only within recent times that we have known why breath and life are so closely related. We now know that the air we breathe becomes a part of the blood stream, and thus is an essential part of the living organism • A great deal of what we know we owe to William Harvey, who made some remarkable discoveries about the workings of the human body. He had given these facts to his students at the hospital, but he had given them in Latin, as was the custom in those days, and it took some time for the new ideas to make an impression • Just about the time the Pilgrims landed on Plymouth Rock the students in Dr. Harvey's classes in England were learning that the blood flows continuously around and around, absorbing food and oxygen and losing waste products in its course. Dr. Harvey had discovered that the blood flows from the left side of the heart, through the blood tubes, and back to the right side. He had traced its course from the right side of the heart to the lungs and back again to the left side. He corrected the notion that blood seeped through the walls of the heart from the right side to the left, proving that there was no connection except through the lungs. He also proved that the arteries carried blood and not air, as had been thought before • There was one thing he could not prove because he could not see it, and it remained for Leeuwenhoek, with his microscopes, to see the blood as it works its way through the capillaries. Harvey found that blood flows in both the arteries and the veins, and Leeuwenhoek proved that the capillaries join the arteries and the veins.

from the lungs to the heart and from the heart through arteries the oxygen, dissolved in lymph, finally reaches the tiniest tubes, or capillaries, around the body cells. But for what purpose? Before you can answer this you must learn something more about the blood.

The human body, like the bodies of all other animals, is an extremely complex organism. You have seen that there is a fine arrangement which allows oxygen to pass into the blood. There is another fine arrangement that allows food to pass into the blood. Food passes directly from the mouth into the stomach and from the stomach into the small intestine. It is changed by digestion in the stomach and intestine into liquid form. On the inner walls of the small intestine are many little slender projections. These forms, called villi, are continually bathed by the digested food and are so constructed that digested food may pass through their walls and into the tiny blood tubes that pass through them. Fig. 104 is an enlarged drawing of the inner wall of the small intestine, showing these villi. The inner surface is much greater on account of the villi than it would be if the surface were smooth. This is a fine adaptation for absorbing food, for the greater surface makes it possible for more food to pass through in a given interval of time.

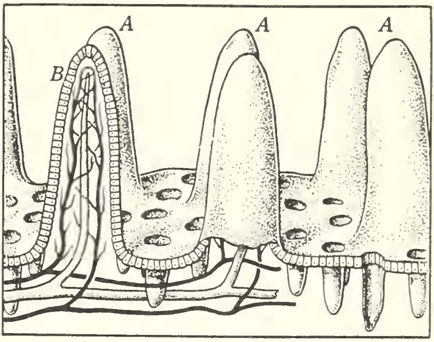

FIG. 104. Countless Villi, Similar to those illustrated by *A*, project from the Inner Walls of the Small Intestine

This drawing shows these highly magnified. The cross section *B* shows the tiny blood tubes which carry the digested foods to the body cells

Food is also carried to the body cells

Thus you find that the lymph that passes through the walls of the tiny blood tubes to bathe the body cells has both food and oxygen dissolved in it. The food is composed of carbon, hydrogen, oxygen, and several other chemical elements. Here, then, is a familiar mixture made up of oxygen molecules from the air and molecules containing carbon, hydrogen, and oxygen from the food. What chemical change may take place when these come together?

Oxygen molecules are present with hydrogen and carbon

Recall the experiment with the candle. The flame of this candle, you will remember, was produced by a chemical change in which oxygen from the air combined with carbon and hydrogen in the paraffin. The burning made light and heat. In the cells of the body a similar chemical change takes place. As the oxygen in the blood combines with the carbon and hydrogen in the digested food, heat is produced. This chemical change differs from that which takes place in the candle in that the change goes on more slowly. This heat is not produced so rapidly. Nevertheless heat from this chemical change keeps our bodies warm. You use the energy from this chemical change when you move your muscles.

Oxygen combines with food in a chemical change, producing heat and muscular energy

Now you see why oxygen and food are necessary for life. Oxygen is essential in the body in the same way that it is essential in a flame. A chemical action between the molecules of substances in the food and the molecules of oxygen found in the liquid which constantly bathes the body cells produces the heat and other forms of energy that are essential for life.

The process of taking air into the cells, using it in the production of energy, and expelling the waste products is called respiration. The process of breathing is one of taking air into the lungs and forcing it out. All living cells must carry on respiration, but only animals with lungs (or gills) carry on breathing.

C. What happens to the Waste Products?

What else was found in the experiment with the candle? You learned that the products from a burning candle are carbon dioxide and water. These same products (and some others) are formed by the chemical change which takes place in the cells of the body. The carbon dioxide and water thus formed in the body are waste products and must be removed from the cells. They are carried away from the cells by two different routes, but by either route they move from the cells toward the heart. The capillaries that carry oxygen and food to the cells act as connections between the arteries and the veins and serve to carry away some of the waste products. The blood flowing back to the heart through the veins carries waste products in it.

There is another set of tubes, called lymph tubes, which start at the cells. These carry lymph, with some waste products dissolved in it, away from the cells. As in the case of the veins and arteries, the tiniest lymph tubes join and form larger ones. Finally the largest lymph tube joins a vein (Fig. 105), and the lymph enters the blood just before the blood reaches the heart. From the heart the blood passes to the lungs and to the tiny blood tubes surrounding the air sacs. Carbon dioxide and water pass through the walls of the blood tubes into the air sacs, and from them out of the lungs. Molecules of carbon dioxide and of water are carried out into the air by exhaling. This may easily be proved. You may see evidence that water vapor reaches the air from the lungs by breathing on a windowpane. The moisture shows on the glass. You may see that carbon dioxide reaches the air from the lungs by breathing through a glass tube into some limewater held in a bottle. The limewater takes on the same milky appearance as you blow into it that it did in your experiment with the candle. This is proof that carbon dioxide is exhaled in the breath.

Carbon dioxide and water are exhaled

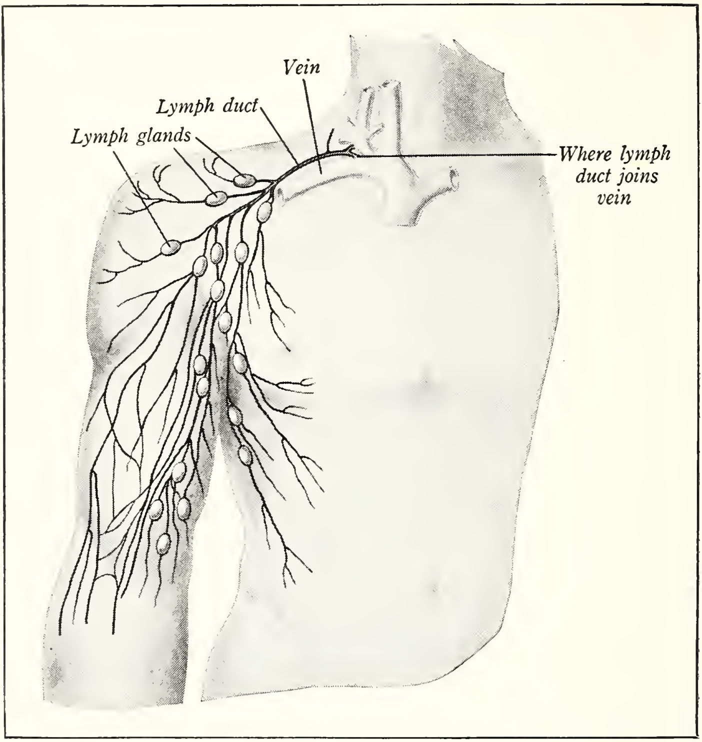

Fig. 105. Lymph is carried to the Blood Stream

The oxygen that enters the blood through the lungs is returned to the lungs combined with the hydrogen in the form of water molecules or with carbon as molecules of carbon dioxide. The carbon and hydrogen with which the oxygen combines entered the body through the stomach and intestines as part of molecules of food. Most of the carbon dioxide and a great deal of the water leave the body by way of the lungs.

There are other waste products from the cells besides carbon dioxide and water. Let us consider some of them and how they are eliminated, or removed.

As can be seen from the explanation just given, food is absorbed into the blood stream, and oxidized in the cells by the action of the oxygen which is breathed in with the air. The food has been prepared to be thus absorbed, in other words for absorption, by the process of digestion. More will be said later about the process of digestion; for the present you should remember that while it may seem very simple it is really very complex, beginning when food is first taken into the mouth and continuing in the stomach and intestines. If you could follow this food as it passes along and is digested, you would see many changes taking place. As it is chewed, saliva is released, and the process of breaking up the food is begun. Later on, the stomach releases other secretions, and finally the intestines play their part in this mixing process. The food is prepared for absorption by the blood stream and finally reaches the cells themselves.

Not all the material which we eat is digested. Some of it is indigestible and remains in the intestines to be eliminated by them.

There are certain waste products which are found in the cells, from the food and oxygen. This waste matter does not remain in the cells but is passed back into the blood stream and circulates through the system just as did the food and oxygen which was absorbed. Two of these waste products have already been recognized. These are carbon dioxide and water, and, as you already know, they are removed from the blood stream in the lungs and carried with the breath into the air. The other waste products formed in the cells are carried in the blood stream to the kidneys, and here they are removed from the blood and later eliminated from the body in the urine. From this it will be seen that the wastes removed through the action of the kidneys and those removed through the action of the intestines are different. The latter are largely indigestible matter which is the remains of materials taken as food, and from which all digestible matter has been absorbed into the blood stream. The waste products removed by the kidneys, however, are those which have resulted directly from chemical changes in the body cells.

The failure of the human organism to get rid of these waste products properly may be the cause of much discomfort and serious illness. Thoughtless people overload their systems with rich foods, hard to digest, and give little attention to the proper elimination of waste. As a result, their systems become clogged with waste products. The indigestible matter in the intestines is decomposed by bacteria, and harmful products are formed. As the process of absorption goes on, products from the decomposition of these wastes pass into the blood with disagreeable effects upon the body. Under such conditions the bodily system registers a complaint. In minor cases this complaint may take the form of a headache; but if the neglect continues, the symptoms show in much more serious ways.

The proper elimination of waste products from the system is extremely important. The removal of both liquid and solid waste material should be made habitual and should be practiced at regular times each day. The use of laxatives should be avoided except in emergencies, since their continual use only serves to make the condition which they are intended to remedy worse. The best remedy is found in a proper diet, which includes plenty of water and fruit, together with proper quantities of green vegetables.

D. What would happen to Life if the Percentage of Oxygen in the Air was Changed?

In your experiment with the candle you will remember that instead of the 21 per cent of oxygen usually present in the air you found only 16 per cent in the air left in the jar after the candle had stopped burning. What should you expect to find in the air which is exhaled from the lungs? Experiments have been carried out to determine this, and it has been found that this air contains only a little more than 16 per cent of oxygen. In other words, only a little more than one fifth of the oxygen that enters the lungs takes part in the changes that go on in the cells. If the percentage of oxygen in "pure" air were as low as 17 per cent, the animals that live on the earth today, including man, would not be able to take from the air enough oxygen for vigorous activity. There is, of course, no certainty that there would be any living things on the earth if the percentage of oxygen in the air were very much less than it is now. It is certain that if the air contained very much less oxygen than this, living things would necessarily be quite different from those on the earth today. Living things on this earth are adapted to live in air containing 21 per cent of oxygen. If the air contained more oxygen than this, that too would make a difference. Probably no one would be conscious of any effect on his body from a very slight increase in the percentage of oxygen in the air. But our bodies would probably wear out faster than they do now if we lived continuously in an atmosphere of pure oxygen.

21 per cent of oxygen is "just right"

Oxygen, then, is the active element in the air. Nitrogen is inactive. Oxygen mixed with nitrogen is less active than pure oxygen. A mixture of oxygen and nitrogen which seems to be proper to serve the needs of living bodies on earth is one in which there is 21 per cent of oxygen and 78 per cent of nitrogen. The reason this proportion of oxygen seems right is that life has been adapted to it.

Oxygen enters the lungs and passes into the blood stream and to the living cells, where it combines with certain food elements to furnish energy for the human machine.

Can You Answer these Questions?

1. The statement is made that energy is sometimes released in a chemical change. Can you show that any chemical changes take place in the body?

2. What is the difference between blood and lymph? What part does lymph play in the life of the body?

3. Suppose you have just eaten your lunch. Can you tell how this food supply is changed into bodily energy?

4. What part does nitrogen play in breathing?

5. Can you define these words: capillaries, veins, arteries, oxidation, absorption, pulse, inhale, exhale?

6. What are some of the waste products of the bodily processes? How are they removed from the body?

Questions for Discussion

1. The body is often referred to as a human machine. Do you think this is a good statement? Why?

2. Have you ever heard someone say, "I'm just burning up?" What do you think causes this feeling?

3. Do you still think that breathing is a simple process? Why?

4. When people are ill the pulse rate sometimes increases very rapidly and the bodily temperature rises. What causes this?

Here are Some Things You May Want to Do

1. Write a story of what you think would happen on the earth if 30 per cent of the air were oxygen.

2. Write a story of what you think would happen on the earth if 15 per cent of the air were oxygen.

3. Harvey was one of the really famous men in the history of the science of the human body. He demonstrated the circulation of the blood. There were many others whose work has contributed toward the knowledge we now have of the action of the body. See if you can find out about any of these men.

4. See what you can find out about old beliefs regarding the composition of air and how it was used in breathing. Report your findings to the class.

Chapter XIII · What happens to the Carbon Dioxide which is released into the Air?

A. How Much Carbon Dioxide is released into the Air?

Carbon dioxide is constantly released into the air

You will remember in your experiments with burning that carbon dioxide was formed during the process and became part of the air. In your study of the air and its relationship to breathing you again found that carbon dioxide was formed in the process of respiration and passed into the air from the lungs. But, you will recall, too, the composition of air shows that carbon dioxide makes up but a very small percentage of the total air. Do you see anything strange here?

Burning and breathing! Two very common processes. Through them more and more carbon dioxide is released into the air. Let us see if we can find out how much.

One man alone releases about 16 cubic feet of carbon dioxide into the air in 24 hours. Consider the amount of carbon dioxide breathed into the air by all the people and all the animals in the world. Then consider these facts. About 40,000 cubic feet of carbon dioxide are formed from burning 1 ton of coal. More than one million tons of coal are burned in the United States every day. Burning 1 gallon of gasoline makes about 150 cubic feet of carbon dioxide. More than four million gallons of gasoline are burned in automobiles in the United States every day. Many other fuels, such as gas, wood, and coke, are burned in great quantities. Multiply the scene in Fig. 106 by all the thousands of factories in this country, and you will have an idea of the vast amounts of carbon dioxide released every day. In addition to these the process of decay in leaves, grass, and other forms of vegetation also results in the formation of carbon dioxide. This too is added to the quantities released from other sources.

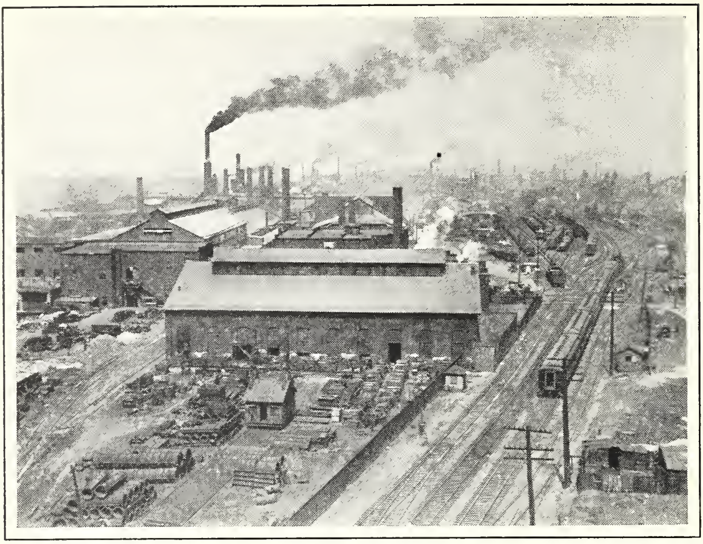

Fig. 106. This is Only One of Many Factory Sites where Carbon Dioxide is released into the Air in Huge Quantities

But the percentage of carbon dioxide in the air remains the same

Is it not strange, in view of all this, that the percentage of carbon dioxide in the air should remain as low as 0.04 per cent? Might not one naturally suppose that the percentage would be increasing? If a chemist were to analyze a sample of air taken from near a large factory or from a crowded room, he might find a greater percentage. Yet if he analyzes a sample from a place out in the open, away from factories, the percentage is always the same. In other words, the percentage is not increasing. There may have been a time in the history of the world when the percentage of carbon dioxide in the air was greater than it is today, but there is good reason to believe that the percentage has remained for many thousands of years very nearly the same as it is now. What, then, happens to the carbon dioxide? For an answer to this question you must turn to a study of plants.

B. How does a Plant use Carbon Dioxide?

Consider a typical plant. You are familiar through pictures if not through experience with the great fields of corn which cover many thousands of acres in the United States. As you look at a stalk of corn, you see it with its roots extending downward into the soil. You see its stalk extending upward into the air. Its broad green leaves reach out from the stalk and spread to the bright sunshine. If you could in some way look into this corn plant as it stands in the sunlight, you would see evidence that the plant is very much alive. You would see water entering the roots and passing upward through tiny fibers inside the stalk. You could follow the passage of water all the way up into the leaves. In the leaves these little fibers are called veins. As you followed the water along through these veins, you would find it passing to all the cells in the leaves. Thus you would find that the water in the leaf cells has come up from the soil. This is true not only of the corn plant, but also of blades of grass, of tall trees, and of all other green plants that grow from the soil.

Water in the leaf has come up from the soil

Now suppose you examine one of the cells in the green leaf. Under the microscope you can see that the cell is filled with water. You also notice that a thin wall incloses it. You look again and see that there are many tiny green particles floating about in the liquid inside the cell. The cell is surely alive, for these little green particles are continuously in motion. Upon further study you see that the cells are so arranged that there is considerable open space between them. There are openings from these spaces to the air outside through the undersurface of the leaf. These little openings are called stomata. An examination of the lower surface of a corn leaf under a microscope, as in Fig. 107, would reveal many thousands of these stomata in a square

Openings between the cells in a leaf are called stomata

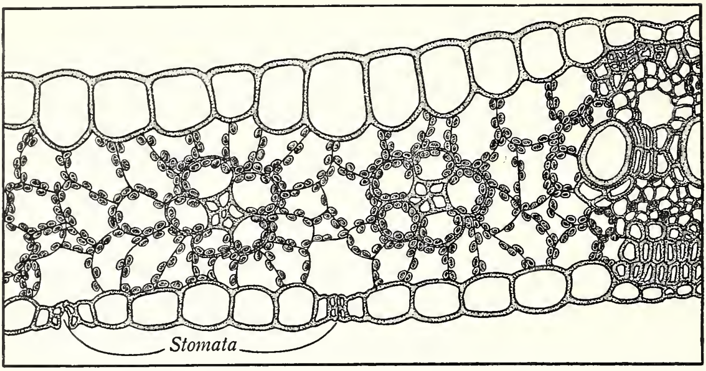

Fig. 107. If you should cut a Leaf in Two and look at the Edge under a Microscope, you would see the Cells as shown Here

Notice the stomata, which allow air to enter the inside of the leaf

inch. Some of the water passes through the cell walls into the spaces between the cells and from these spaces through the stomata into the air. You have already seen evidences of this evaporation in Fig. 38. Most of the water that enters the plant through the roots leaves through the stomata. Not all of it leaves the plant, however. What happens to it? you may ask.

To get an answer you must go back to a consideration of the carbon dioxide which you know is in the air. The plant leaf is a food factory which uses water and certain other substances from the soil and carbon dioxide from the air. This carbon dioxide is essential to the life of green plants. Remember that the percentage of this gas in the air is very small, and that among some ten thousand molecules, probably not more than three or four are molecules of carbon dioxide. Imagine the molecules of the gases of the air continuously in motion, passing in and out of the open spaces in the leaves through the stomata. As these molecules circulate, some of them come in contact with the thin walls of the cells containing the little green particles. What is more important, however, is that some of them pass through these thin walls into the cells themselves. Now what happens? In these green cells a very important chemical change takes place. No one knows in detail how this chemical change occurs; but it is known that molecules of carbon dioxide, which are composed of carbon and oxygen, act chemically with molecules of water, which are composed of hydrogen and oxygen. From this chemical action molecules of sugar and molecules of oxygen are formed. Thus the green leaf is a food factory in which sugar and oxygen are made from carbon dioxide and water.

The green leaf is a food factory

But let us see now what part the sunshine plays in all this. We have called the green leaf a food factory. As you know, a factory is a place in which energy from engines is used to run machinery and make new products. But what about our green leaf? Is energy used in this factory? Yes, it is, and it is supplied to the leaf by sunshine. This process of food-making cannot go on at night, for the leaf does not get the necessary energy when the sun is not shining. You have noticed of course that most plants do not grow well in shade and that they die in a dark room. The reason is that green plants must have sunshine in order to make food. You can observe the effect of sunlight on the growth of green plants for yourself. Place a geranium or other greenhouse plant in a sunny window for a few days. Observe the leaves and stems of the plant. They seem to turn toward the sun. Now turn the plant around and leave it for several more days. What do you find now? What conclusions can you draw? Have you ever watched a sunflower follow the sun around? Do you know of any flowers that close up at night and open again in the rays of the sun?

The needed energy for the food-making process comes from the sun

If you have a true picture of the food-making process, you will imagine molecules of oxygen, carbon dioxide, nitrogen, and the other gases in the air circulating in the spaces between the cells, in the cells themselves, and in the air outside the leaf. These molecules will be moving in every direction and passing continuously in and out through the stomata. But more molecules of carbon dioxide pass inward than outward, for many are caught and used by the cells in food-making. As a result of this process, the leaf manufactures sugar and oxygen. Some other things are made in these plant cells, too, but we need not consider them now, since we are concerned only with the direct results of the gases in the air. Now let us ask, What happens to this oxygen and sugar?

In food-making carbon dioxide is used and oxygen released

The oxygen formed in the process of food-making may pass through the walls of the cells into the open spaces of the leaves, out through the stomata, and into the air. What becomes of the sugar? If you have eaten sweet corn, you may guess that some of the sugar made in the leaves is stored in the grains of corn. As the corn ripens, some of the sugar changes to starch and forms hard kernels. Other changes occur, in which material that was once sugar becomes roots, stems, and leaves. In other words nearly the whole plant is made of material formed from carbon dioxide and water, although small amounts of soluble minerals enter the plant through the roots.

A plant is made largely from air and water

In this study of plants, then, you have observed the process of food-making. Remember that this process goes on only in the green cells and that some of the food made by these cells is used by other living cells of the same plant.

The oxygen produced as a part of the food-making process in the green cells may not leave the plant, but may remain there and combine with food in the plant cells. When this happens, carbon dioxide and water are formed as the result of oxidation, just as in the cells of animals. Energy is then released. Thus the plant is both a food-maker and a food-user.

Can the food-using process go on during the hours of darkness? You will find an answer to this question if you will remember that oxygen is a part of the air itself, and that it circulates freely at all times through the stomata in the leaves. In this way oxygen, already a part of the outside air, reaches the plant cells. There are also openings in the stem and roots of the plant through which oxygen may reach the living cells. As a matter of fact the cells in the roots must have a continuous supply of oxygen. If they are covered with water, the plant soon dies; for the water shuts off the supply of oxygen. You can water a plant too much.

C. What is the Carbon Cycle?

Carbon from air forms the largest part of a living plant

As we travel through the country, we see grass, flowers and weeds, forests, and fields of grain. The material of which all these plants is composed is mostly carbon that came from the air in the form of carbon dioxide, and hydrogen and oxygen that came from the soil through the roots. The carbon from the carbon dioxide of the air is combined with hydrogen and oxygen, which entered the plant as water. Thousands of pounds of carbon dioxide are taken from the air to make a field of corn, and thousands of pounds are required to form a tree. But it does not remain long in this form. In the course of a comparatively short time the ears of corn will have been used for food, and the roots and stems will have decayed. The tree may be cut and burned for fuel. Now what happens to the carbon? It is again released into the air as carbon dioxide. These changes in carbon make up what is called *the carbon cycle*. See if you can trace this cycle in Fig. 108.

Now you understand how some of the carbon dioxide that is released into the air from the lungs of animals, from

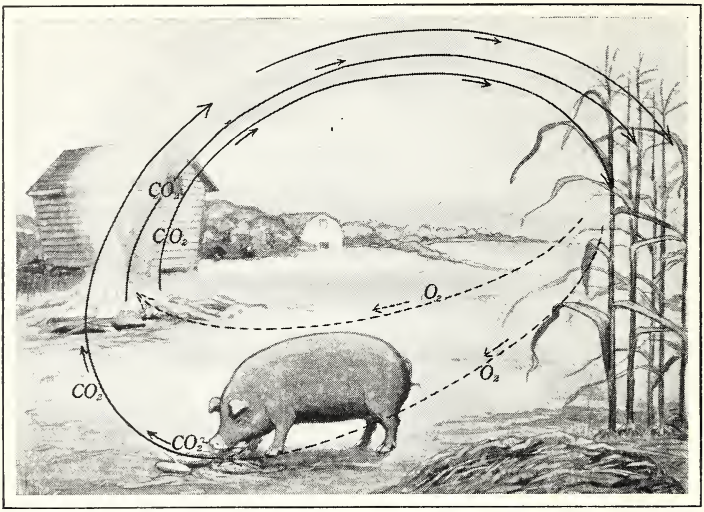

Fig. 108. Carbon Dioxide is released into the Air when Plants are Burned or Eaten or when they Decay

Can you trace the carbon cycle here?

the fuel burned in the furnaces throughout the country, and from the processes of decay is used by the green plant cells in the process of food-making. This process of food-*making* that goes on only in the green cells of plants may be seen as the reverse of the process of food-*using* that goes on in the cells of your body and in all the living cells of plants and animals. Let us summarize these processes:

It is released when plants are burned or eaten or when they decay

Using food, a process that goes on in all living cells.

> Molecules of oxygen act with food and produce molecules of carbon dioxide and of water and release energy.

Making food, a process that goes on in the green cells of plants.

> Molecules of carbon dioxide and of water, with the help of energy from sunshine, produce food and molecules of oxygen.

FIG. 109. This is an Artist's Idea of the Vegetation that grew in the Dense Forests of Long Ago

Energy is *required* in food-making; this energy comes from the sun. Energy is *released* in food-using; this energy supplies the needs of living cells. The amount of energy that is released in food-using is equal to the amount that is used in food-making. The energy that you get from your foods keeps you warm and enables you to work and play.

If you wanted to remember just one statement concerning energy, it would be this: Energy comes from the sun. Would you accept this statement? Perhaps some of you would. Others of you, however, might say, "But doesn't energy come from coal, and wood, and running water?" Of course it does. But where does it have its origin? How about water power? Do you remember the story of the water cycle? What part did the sun play in this? How about wood? What has the carbon cycle to do with this source of energy? Does the sun play any part in this? And, finally, how about coal? Does the sun have any part in this form of energy? Let us see. Coal beds were formed from the remains of dense forests that once grew on the earth, as pictured by an artist in Fig. 109. The energy from the sunshine acting in the leaves of these plants changed carbon dioxide from the air and water from the soil into sugar. The sugar was changed to roots, stems, and leaves, and a forest arose. As a result of changes on the surface of the earth this dense forest was covered over, and in the course of a very long time it was changed to coal. Today we burn this coal and use its energy. Where did this energy come from?

The energy of fuels comes from the sun

In a cycle of changes carbon from molecules of carbon dioxide in the air becomes a part of living things and in the course of time becomes again a part of the molecules of carbon dioxide in the air. This cycle is called the carbon cycle.

Can You Answer these Questions?

1. Can you show that energy is associated with the chemical changes that take place in food-making and food-using?

2. Coal has been called "buried sunshine." What does this expression mean?

3. Why does the amount of carbon dioxide in the air remain the same in spite of burning and breathing?

4. The green leaf is called a food factory. Can you explain why?

5. It has been said that all energy comes from the sun. Does this chapter give you any evidence that this is true?

6. Why do you think that in general plants grow better in the sunshine than they do in the shade?

7. Why is it that trees will die when their roots are covered with water?

8. What are the differences between the food-making process and the food-using process?

9. Why would there possibly be more carbon dioxide in the air near a large city than in the country?

10. Can you see any likenesses between the food-using process in plants and the same process in man?

Questions for Discussion

1. Can you think of any form of energy which does not come from the sun?

2. Would an increase in the percentage of oxygen in the air make any change in the rate at which plants grow? Would a lessening make any change? Defend your answer.

3. Can one properly refer to a growing tree as a factory? Why do you think so?

Here are Some Things You May Want to Do

1. Investigate the formation of coal and report your findings to the class.

2. See if you can find out about any plants which do not get their food in the manner described in this chapter.

3. The age of luxurious vegetation thousands and thousands of years ago is now sometimes called the Coal Age. The scientific name for this period is the Carboniferous period. See what you can find out about life during this time and describe it to your class. Remember what you have already learned about the relationship of luxuriant plant growth and animal life.

Chapter XIV · What Differences are there between Pure and Impure Air?

A. Is there Dust in the Air?

Have you ever heard anyone say, "No matter how often this house is cleaned, it is always dusty again the next minute"? Have you ever emptied the bag of the vacuum cleaner? Sometime when rays of sunlight are streaming in through the windows, take a broom and sweep across the floor or the rug for a minute or two. Do you see anything in the rays of the light? Do you think there is any dust floating in the air? If you are not yet sure of your answer, you can find out for yourself in another way.

Get two or three small pieces of glass. Clean them thoroughly and put each in a different place. One might be put outside the window of your classroom; one in your cellar at home; and another one in a room at home. After two or three days examine them carefully. What do you find? What conclusion do you draw?

There is dust in the air

There are many other common experiences which support this same conclusion. You have observed dust on furniture, on an automobile, and on clothing. You have found it when you washed your face after an automobile or train trip. Your eyes, nose, and mouth may have been filled with dirt as the result of walking in a strong wind.

All these experiences furnish evidence that the air contains many fine particles of dust. What is this dust which seems to settle on everything? Are there any places where you may be reasonably sure that there is little dust? How can you control it? Where does it come from?

The last question is far easier to answer than any of the others. If you will take a piece of blotting paper, rub it in your fingers until it falls to pieces, and then rub the

FIG. 110. How should you like to be in the Second Car?
Courtesy of the United States Bureau of Public Roads

smaller pieces until they are as fine as you can make them, you will see something that is dust. Imagine this sort of thing on a much larger scale. The wheels of automobiles and wagons crush stones and rubbish on the streets; the wind picks up the small crushed particles and carries them through the air. Rocks fall as a foundation is dug, and clouds of dust rise into the air. Again the wind picks up this solid material and carries it along as dust. Ash barrels are emptied on a windy day; loads of dirt are dumped into an empty lot; a field is plowed; a barefooted youngster trudges along a hot, dusty country road. A volcano blows off its head, and ashes thrown into the air may be carried to all parts of the world. Meteors are burned and change to dust as they enter the atmosphere. All these are sources of dust. The larger particles settle when the air is still, but may be taken up again when there is a slight breeze. The finer particles may float in the air for days or even months.

Dust is formed in many ways

In cities where soft coal is burned, enormous quantities of soot escape from the chimneys and are scattered about the city as dust. Look again at Fig. 106. A report from one of the large industrial cities in the United States shows that 1031 tons of soot fall on each square mile of that city in twelve months. In this soot there are 10 tons of coal tar, 317 tons of carbon, and 704 tons of fine cinders. It is easy to understand why such a rain of soot quickly soils clothing and collects as black dirt on the skin and in the air passages of the nose.

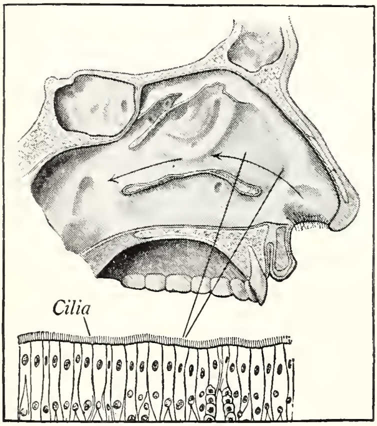

Fig. 111. These Cilia catch the Dust before it gets to the Lungs

Is this dust-filled air injurious? To some extent it is. You can easily imagine what dust may do to the delicate air sacs of the lungs. Fortunately, however, the passages leading through the nose to the lungs are so constructed that most of the dust is removed before the air reaches the air sacs. Some of the dust settles on the moist surface of the air passages and is removed when you blow your nose. Some is caught by the hairs and smaller hairlike structures called cilia which line the nose. These are shown in Fig. 111. Since you have this protection, you may breathe dusty air, at least for a time, without any great harm.

Dust-filled air is injurious

There are, however, certain occupations, like those of stonecutter, cement worker, and tool-grinder, in which the workers are really injured by the dust in the air they breathe. Stonecutters and tool-grinders are very likely to have lung trouble, caused apparently by inhaling dust. People living in the smoky air of industrial cities may also be injured if they breathe for a long period the tiny black particles of carbon that come out of the chimneys.

Everywhere there is dust in the air. At one time an examination of the air outside the fifty-eighth floor of a city office building showed thirteen particles of dust per cubic inch of air. At the street level the air carried sixty-eight dust particles per cubic inch.

Fig. 112. Pollen from Ragweed is thought to be Responsible for Hay Fever in Many Cases

This weed should be destroyed. (Courtesy of the United States Public Health Service)

The dust we have described is called nonliving dust, since it is composed of little particles of soil, cinders, smoke, and some other lifeless substances. It is unpleasant, dirty, and it may be injurious. There is another kind of dust, however, called "living dust." This form of dust consists mostly of very small plants. Some kinds are harmless, some are very useful, and some are dangerous. One type of living dust in the air is the pollen which comes from flowers. You have seen this yellow or brown powder as it falls from flowers in full bloom. Pollen must be blown by the wind or carried by insects from one flower to another if the seeds of most flowers are to form. Many communities destroy various types of pollen-bearing flowers or weeds because the pollen from some of them causes some people to have hay fever. A common weed responsible for this is ragweed, shown in Fig. 112. Its pollen is carried by the wind.

Some dust is nonliving, but some is "living dust"

Another kind of living dust comes from tiny plants known as molds. These molds produce tiny particles called spores, and these spores float in the air. When these fall on "fertile ground," like bread, moist leather, or damp cloth, they grow and produce more mold. You can find this out for yourself. Place some pieces of different kinds of food on a plate, and put them in a warm place which is also dark and damp. You might try a piece of bread, a piece of apple, a strawberry, a small spoonful of jelly, a prune, a piece of cheese, or other kinds of food you have handy. Moisten the food with water and keep it in a covered dish, so water will not escape by evaporation. Place the dish in a warm dark place. Examine the foods after one day, after three days, and after a week. Can you describe what you see? If you used a strawberry, does it look like Fig. 113? The growth that has developed on the pieces of food is called mold, and you say that your samples are moldy or mildewed. Some molds spoil quantities of food; other kinds cause diseases among the larger plants, like trees and grain; and still others are responsible for certain diseases in man, including ringworm, one form of which is commonly known as athlete's foot.

Spores of mold are living dust

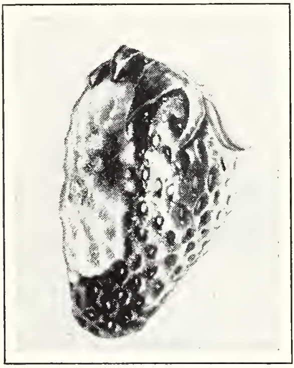

Fig. 113. Food for the Mold is furnished by the Berry

Yeast is a third kind of living dust. You buy yeast in the grocery store in small cakes. These cakes contain millions of tiny yeast plants inclosed in a medium in which they are kept alive. Some kinds of yeast plants float in the air. If one of them happens to fall into something sweet, like fruit juice, it will grow and form new yeast plants very rapidly, until

Living dust may spoil food

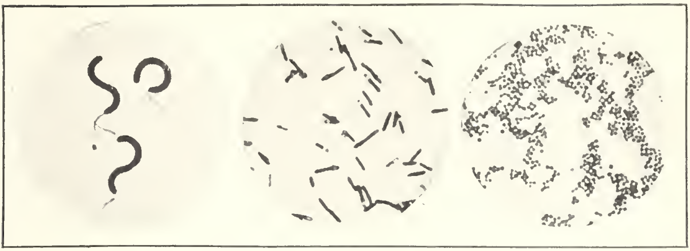

Fig. 114. The Microscope shows that Bacteria which cause Disease are of Many Different Kinds

Some of these may float in air as living dust. (Photographs by E. Zettnow)

soon there are a great many where a few hours before there was one. The growth of these little plants spoils our canned fruits and fruit juices. When fruits or vegetables are preserved at home today, you are very careful to seal the jars tightly so that no air can get into them. Cans for fruits, vegetables, and juices of all kinds are air-tight. Do you see why this is necessary?

Bacteria are a form of living dust

A fourth kind of living dust is the bacteria. You cannot see these tiny organisms without a very good microscope. Although some of these cause endless trouble, there are others without which we could not live. There are some that add nitrogen to the soil; others convert sewage to liquid form; and there are still others that give flavor to cheese. Decay of dead plants and animals is caused largely by bacteria. But some kinds are very dangerous, for they may cause disease. A single diphtheria bacterium breathed into your throat may cause diphtheria. Tuberculosis, tetanus, typhoid, dysentery, spinal meningitis, scarlet fever, and other diseases are caused by bacteria, each kind different from the others. Fig. 114 shows different types of bacteria as they appear under a microscope. Do you see any differences in the several kinds?

There are large numbers of bacteria in the air. An examination of air at the street level of one large city showed that there were 1330 bacteria in each cubic foot of air. At the level of the tenth story of a building there were 330 in a cubic foot. In a cubic foot of "pure" country air there have been found as many as 50 bacteria. In crowded shops the number may be as large as 1000.

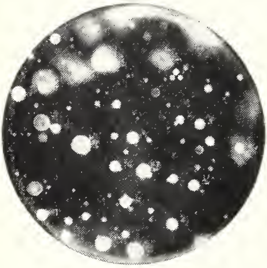

Fig. 115. Under Favorable Conditions Bacteria increase Rapidly

The bacteria from which these colonies grew came from the air

Scientists can show by a simple experiment that bacteria are always present in the air. You can try this experiment yourself if you care to, and have the necessary materials. A food substance such as beef broth is prepared and heated until all bacteria in it are killed. This food substance is then mixed with gelatin, so that when it cools it forms a jellylike mass. The mixture is poured into a flat dish, covered, and allowed to cool. After it is cool, it is uncovered for a short time and exposed to the air. The dish is then covered again and placed in a warm place for a day or two. An examination of the mixture after this period shows that little spots have formed on the surface. The picture in Fig. 115 illustrates a plate exposed in this manner. As time passes, these spots grow larger and larger. Each spot is composed of many thousands of bacteria.

Under favorable conditions bacteria increase rapidly

Where did these come from? What has happened to the dish of lifeless jelly? When the food was uncovered, a few bacteria from the air settled on it. Single bacteria, of course, are so tiny that you cannot see them except with a very good microscope. But with plenty of food and a warm temperature they increase very rapidly. In a few hours a single bacterium increases to hundreds of bacteria and in a few days to thousands or millions. These feed upon the food in the dish, and in the process of growth form the spot on the food which is large enough to be seen without a microscope. Each of the spots probably began as a single bacterium. The number of bacteria that settled on the food substance while the cover was off the dish can be determined by counting the number of spots.

Fortunately most of the bacteria in the air are harmless; but dangerous bacteria, which cause diseases, may enter the air from persons who are suffering from disease. During normal, quiet breathing practically no bacteria get into the air from the lungs, even from those people who have a disease. But in coughing, sneezing, or even in talking, people throw off into the air tiny droplets of saliva. The saliva is very likely to carry bacteria, and if it comes from a person suffering with a cold, diphtheria, or tuberculosis, it is dangerous. The droplets float in the air and may be taken into the body with the air in breathing. Most people cover their noses and mouths when they sneeze, but there are still some who do not. One should stay away from the careless and thoughtless person who does not cover his mouth and nose with his handkerchief when he sneezes.

Bacteria may be spread by coughing or sneezing

From this discussion of bacteria you may see the necessity of observing careful habits of cleanliness. None of you would think of using a handkerchief already used by another person. You realize the dangers of infection, especially if that person is suffering from some illness. Similarly none of you would think of using a toothbrush belonging to someone else. Yet there are some people who use the towels, wash cloths, combs, hairbrushes, and other toilet articles belonging to other members of the family or even to strangers. These are unsanitary practices and may result in illness. Many common ailments, such as skin and scalp infections, are spread in this way. Not so many years ago common roller towels were provided in wash rooms, to be used by everyone. Drinking water

Habits of cleanliness are important in preventing the spread of bacterial disease

was secured by the use of a common drinking cup or glass, also used by everyone. Today most of our states and cities have laws against the use of such articles, and we have paper towels and sanitary bubbling drinking fountains. As a result of man's increased knowledge of the dangerous possibilities of bacteria, greater precautions are being taken and all of us are living healthier lives.

Personal cleanliness today is a matter of good taste and good manners. It is also an important factor in good health, for an increasing number of people have an appreciation of the possible dangers which may result from the carelessness that overlooks sources of bacterial infection. Some boys and girls look at their hands before eating and decide they are clean enough without washing. Yet they would not consider a doctor very careful who did not wash his hands before an operation. Each of us handles many objects which may be covered with bacteria, some dangerous and others harmless; we shake hands with other people, we may hang on to a strap in a crowded train or trolley car, and probably do all kinds of other things which expose us to the dangers of bacterial uncleanliness. The hands, then, should be thoroughly cleaned with soap and warm water before every meal. Finger nails should be kept as clean as possible, for much dirt is picked up under them and remains there until removed.

The general care of the skin requires equal attention. Cold water will not properly remove the dirt which collects in the pores of the skin as a result of elimination from the skin glands and as a result of the dust and dirt that come from contact with the air. Warm baths, therefore, should be taken frequently if possible. Soap should be used freely at bath time as a help in removing these impurities. The use of cheap and dangerous cosmetics should be avoided, for many of them are poisonous and will result in ugly skin eruptions and, in some cases, permanent injuries to the skin.

Special attention should be given to the cleanliness of the nose, throat, and teeth. The nose and throat are particularly susceptible to bacterial infection. By careful attention to the cleanliness of these two organs much may be done to prevent one of the most common causes of illness, a cold.

There may be some people who carry this idea of cleanliness to an extreme. There are those who wash their hands after they shake hands with another person, and who surround themselves with disinfectants of all kinds. Such extreme precautions are not necessary, but you should remember that reasonable habits of cleanliness will go far in preventing the spread of bacterial infection. The person who said that cleanliness is next to godliness may not have had all our present-day knowledge of health, but he without doubt realized its tremendous importance in happy living. When a person is in good health his body is usually able to resist the attacks of disease germs,—but not always. It is a good idea always to be careful.

B. Do Burning Fuels give off Any Dangerous Gases to the Air?

Carbon monoxide is a dangerous gas

How would you answer this question from the knowledge you already have of the common gases in the air? Is carbon dioxide dangerous? water vapor? oxygen or nitrogen? No, none of these, but there is another gas called carbon monoxide, and this is extremely dangerous. Do not confuse carbon *mon*oxide with carbon *di*oxide, however. They are very different.

Where does carbon monoxide come from? You have already learned that carbon dioxide is one of the products of burning. This is also true of carbon monoxide. When carbon burns in air or oxygen, the carbon combines with oxygen. If there is sufficient oxygen for the burning process, carbon dioxide is produced; but if there is not enough oxygen, then carbon monoxide results. This dangerous gas, then, is the result of incomplete combustion, or burning. Under normal conditions both carbon dioxide and carbon monoxide are formed when gasoline is burned in the cylinders of an automobile. If the carburetor is properly adjusted, a minimum amount of carbon monoxide is formed. In the open air the carbon monoxide mixes with the air, and the proportion present is so small that it produces no noticeably harmful effects. In a closed garage the gas may collect in such large proportions that it is extremely dangerous. Every once in a while you may read in a newspaper of someone who has been killed by carbon monoxide while working in a closed garage on an automobile with its engine running. Immediately after an automobile has been run into a garage, the engine should be turned off.

Carbon monoxide is the result of incomplete combustion

Carbon monoxide may be given off by coal burning in a stove or furnace. Some of this poisonous gas may enter the room if the drafts of a stove or furnace are not properly adjusted or if a chimney or flue leaks.

C. What Sort of Air is Best for Good Health?

You have already learned that neither plants nor animals can live without oxygen. While human organisms can adapt themselves to varying conditions, they seem to be most energetic, most comfortable, and most healthy in an atmosphere which may be described as follows:

1. The air pressure is about fifteen pounds per square inch.
2. The air contains about 21 per cent of oxygen and a small amount of carbon dioxide mixed with nitrogen and other gases.
3. The air temperature changes considerably during each day and from day to day, but is most agreeable between 50° F. and 70° F.
4. The air is between 40 and 70 per cent saturated with moisture.
5. The air is in motion; that is, there is a slight breeze.

In the above standards are important factors which need to be considered in deciding whether any particular air condition is satisfactory or not. These are air pressure, oxygen content, carbon dioxide content, temperature, temperature change, humidity, and air movement. When man is outdoors, there is little he can do about these. They are part of his environment. But man spends far more time indoors than he does outdoors. His problem, then, is to meet the necessary standards of good air as nearly as possible when he is indoors. This he attempts to do through proper ventilation. What is proper ventilation? How may it be achieved? Let us consider it in relation to each of these factors, bearing in mind that the human organism like other organisms has remarkable powers of adjustment.

What air conditions are most satisfactory to health?

Ideally the best ventilation will duplicate the air conditions described above, which are most favorable for health and comfort. Yet any one of the factors may vary considerably from the standard without noticeably harmful effects, especially if the unusual condition does not continue for too long a time.

Under ordinary conditions no attention needs to be given to the factor of air pressure in ventilating a room. When special problems arise in relation to furnishing a sufficient supply of air, as in the case of deep-sea diving or flying to high altitudes, this factor is of course important. Though our standards call for air containing 21 per cent of oxygen and but a trace (4 parts in 10,000) of carbon dioxide, it has been demonstrated experimentally that people may live in relative comfort in air containing less oxygen and more carbon dioxide than outdoor air. In these experiments people have been kept in tightly closed rooms, breathing air specially prepared so as to contain as little as 18 per cent of oxygen and as high as

Air pressure is not important in ventilation in ordinary circumstances

The oxygen and carbon dioxide content of the air may vary without causing discomfort

2 per cent of carbon dioxide. These people were quite comfortable and in fact were unaware that the air they were breathing was in any way different from the air out of doors. Such extreme changes in oxygen and carbon dioxide content could come only as the result of experimental conditions and could not be due to breathing. The capacity of the lungs is so small compared with the capacity of an ordinary room that the proportions of the gases in the room are changed but little by breathing. Under the usual conditions of life there is almost no chance that the percentage of oxygen in the air of a room will be reduced by as much as 1 per cent by breathing, and almost no chance that the percentage of carbon dioxide will be increased by as much as one half of 1 per cent. Besides, even in what may seem to be a tightly closed room, air from inside is constantly passing out and air from outside is constantly coming in through cracks about doors and windows and through the walls. When the air outdoors is at 0° F. and the air indoors at 70° F. there is nearly a complete change of air in one hour in a tightly closed house. Of course the conclusion to be drawn from all this is that we need not worry about ventilation so far as oxygen or carbon dioxide is concerned.

Temperature should be carefully controlled

From the point of view of health, comfort, and energy the factor of temperature is one of the most important in determining satisfactory air conditions. For health and comfort the temperature of the air in a room in which people are sitting may vary from about 64° F. to about 70° F. Notice how the thermometer in Fig. 116 is marked to indicate these limits. In factories where men are working at physical labor the temperature should be considerably lower than in a room in which people are seated. The temperature in the living-room or in the schoolroom should change slightly from time to time but should not go higher than 70° F. or lower than 68° F.

We are adapted to live in air that has some water vapor in it; it is not healthful for us to live for long periods of time in air that is too dry. If it were possible to get perfectly dry air, the humidity would be referred to as zero. In air completely saturated the humidity would be 100. There is no fixed percentage of water vapor necessary for health and comfort. People may be quite comfortable within rather wide limits. In regions of favorable climate the humidity of outdoor air varies from 40 per cent on hot dry days to 100 per cent during rain. Humidity varies generally from 40 to 70 per cent during clear weather. Air with this percentage of water vapor seems most satisfactory for health and work.

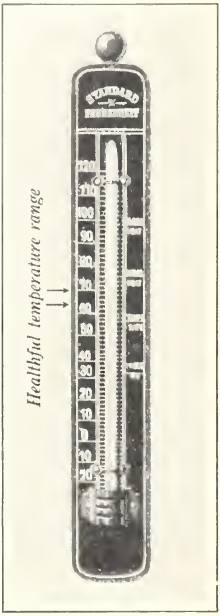

FIG. 116. The Best Temperature for the Air in a Room is between 64° F. and 70° F.

These two factors, temperature and humidity, are closely related, as you learned sometime ago in your study of evaporation. The amount of water which can exist as water vapor in any space increases rapidly with an increase in temperature. When water no longer disappears by evaporation into a space, we say that the space is saturated. It follows that unless water is added, an increase in temperature makes the space less nearly saturated. It is this fact that makes the problem of maintaining a proper standard of humidity in heated rooms a rather difficult one, especially when it is extremely cold out of doors. It is not uncommon during winter in some localities to find the temperature outdoors at 0° F. and that indoors at 70° F. At 0° F. air is saturated with water vapor when it contains about 0.5 grain of water in one cubic foot

Humidity and temperature are closely related

Fig. 117. Crowded Rooms may be Very Humid

High humidity is very uncomfortable

(7000 grains make one pound). At a temperature of 70° F. it is not saturated until it holds as much as eight grains of water per cubic foot. In other words, a room at 70° F. may hold sixteen times as much water vapor as at 0° F. ($0.5 \times 16 = 8.0$). But if air is taken from outdoors at a temperature of 0° F. and heated to 70° F. the air is only about $6\frac{1}{4}$ per cent saturated, unless more water is added during the process of heating ($0.5 \div 8.0 = \frac{1}{16}$, or $6\frac{1}{4}\%$). A humidity of $6\frac{1}{4}$ per cent is as dry as desert air. Certainly we should not want to live in such air all the time. While there is no convincing evidence that it is harmful to live in dry air for short intervals, it is likely that continuous exposure to air with a humidity of from 6 to 20 per cent is in a measure injurious. Of course you must remember that there are not many places in the United States where a temperature of 0° F. prevails for many days at a time. Therefore, unless living-rooms are overheated, the humidity is not likely to get low enough to affect people harmfully.

High humidity is uncomfortable

Conditions may develop in which the humidity in a room becomes very high. This condition causes greater discomfort than low humidity. Hot days in summer attended by high humidity are extremely uncomfortable. A condition like that on an uncomfortably hot summer day may develop in a crowded room. In normal conditions of health perspiration forms continuously on the surface of the body. The body perspires more freely in a warm room than in a cool room. Since heat is required for evaporation, the evaporation of perspiration removes heat and tends to reduce the temperature of the body. When there is a crowd of people in a room, their bodies give off a considerable amount of water vapor by evaporation. This causes an increase in the humidity of the air in the room. At the same time heat given off from the bodies of the people causes the temperature to be higher. This in turn causes perspiration to form faster. As a result of the increase in humidity and increase in temperature the room becomes hot and "stuffy." The air may become more uncomfortable than on a hot, sultry day in summer. Have you ever been in a poorly ventilated room similar to the one in Fig. 117? This condition may be remedied by allowing a draft of fresh air to enter and replace the hot humid air. Unpleasant humidity develops only in overcrowded rooms, not in ordinary living-rooms. So far as health is

Fig. 118. Window Ventilation is Usually Sufficient for Satisfactory Air Conditions in the Home

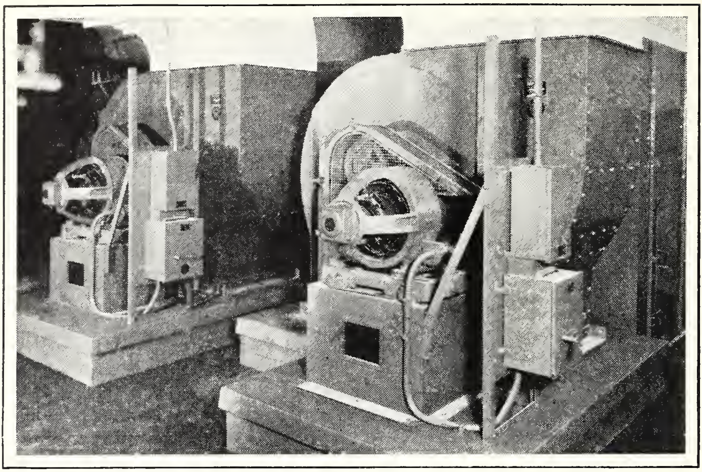

Fig. 119. Large Rooms, such as Theater Auditoriums and Lecture Halls, need Special Machinery for Forced Ventilation

concerned, therefore, little or no attention need be given to the control of humidity in homes.

The last factor of satisfactory air conditions is air movement. The motion should be barely noticeable. A window which is slightly opened is sufficient under ordinary circumstances. Sometimes an electric fan may be used to keep the air in motion.

Window ventilation is usually sufficient for satisfactory air conditions

All these factors may be satisfactorily controlled in the home by window ventilation. Fig. 118 illustrates how currents of air pass in and out of open windows. Large rooms, such as theater auditoriums or lecture halls, need special machinery for ventilation. Part of such a ventilating system is pictured in Fig. 119. You have learned that poisonous gases may be in the air. A well-ventilated room is of course free from these.

From what you have now learned you can conclude that the air which is most healthful and most invigorating is that which approximates conditions out of doors on days which we call pleasant. We are likely to call air fresh when it is pleasant and stimulating; that is, when there is moderate temperature, moderate humidity, and a slight breeze. These are the conditions to which the human organism has become adapted.

Living and nonliving dust, as well as some gases that are injurious to breathing or that are unpleasant, may be present in air as impurities. Very definite standards for healthful air conditions are now available. These standards are fairly easy to maintain.

Can You Answer these Questions?

1. What is the difference between carbon dioxide and carbon monoxide gas? What are some of the sources of each?

2. How is the human organism protected against the dust in the air?

3. What is the difference between living and nonliving dust? Can you name a few examples of each?

4. What is really happening when the dough for bread is rising?

5. A very frequently repeated health rule is "Cover your mouth and nose when you sneeze." Why is this important?

6. What is a relationship between temperature and humidity?

7. Why do we often feel uncomfortable in a crowded room?

8. Many heating plants today are equipped with instruments called thermostats to control temperature. At what temperature do you think these thermostats should be set to secure the best health temperature for the home?

9. Can you name seven factors which play a part in ventilation? Why is each one of these important? Are any of these more important than others?

Questions for Discussion

1. Today we find advertisements of office buildings and of trains that are "air-conditioned." What do you think this means? What factors do you think need to be taken care of before such advertisements are truthful?

2. The climate of the temperate zone, including most of the United States, has been called an "energetic climate." Do you think this is so? Do you know some differences between the climate of the United States and those of other regions, such as the Congo or the Arctic? Why might not these other regions also be said to have an energetic climate?

3. Consider what has been said about the dangers of bacterial infection, cleanliness, and satisfactory air conditions. What do you think twelve rules might be for a "Health Creed"?

Here are Some Things You May Want to Do

1. Write to some company that sells ventilating systems or artificial cooling systems and get information as to how they work. You will find addresses in the advertisements of nearly any popular magazine.

2. Keep a daily record of the temperature in your classroom or in your home and see whether it meets the standards set up in this chapter.

3. Write to some insurance company for information on what such companies call "hazardous occupations." How many of these are called hazardous, or dangerous, because of dangerous air conditions? What occupations are they and what air conditions make them dangerous? You might want to report your findings to the class.

4. Study some molds or yeast under a microscope and keep a record of your findings. You may grow molds on a piece of bread or cheese. To experiment with the action of yeast, break a very small piece of yeast into a spoonful of water. Observe results over a period of several days.

5. Read over again some of the earlier chapters of this book and begin to prepare a list of health and safety rules for your class. You may want to add to this list as you read further.

6. Make a chart of air conditions most satisfactory for health and work. Select a list of countries or regions in the world and contrast these for each of the items on your chart. Do you find any great differences? Draw your conclusions and present them for class discussion.

7. Make a list of the factors having to do with the determination of satisfactory air conditions and contrast the standard for each with the corresponding condition you might find in your schoolroom, in an Eskimo igloo, in a pygmy's hut in Africa, in a theater, and in as many other places as you may want to add.

8. Have you ever heard of the Black Hole of Calcutta? Look it up and see what relation it has to this chapter. What air conditions caused it to be called the Black Hole?

9. If you have a board of health or a health department in your community, investigate and report on any laws it may have drawn up to prevent the spread of infection by bacteria.

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Fig. 120. Even Lofty Peaks such as this One slowly but surely are worn Away

UNIT V

In What Respects is Soil an Important Factor of the Environment?

Chapter XV · What is Soil and How is it Formed?

Chapter XVI · What Part have Natural Forces played in Preparing Soil Suitable for the Growth of Plants?

FOR SEVERAL THOUSANDS OF YEARS agriculture has been one of the most important of man's industries. In our present civilization, as well as in those long past, man has depended upon agriculture not only as the means of making a living, but as the means of maintaining life itself. Imagine conditions in the world today if there were no farming industry, no cattle-raising industry, no dairying industry, no fruit industry, no lumbering industry — if there were none of the industries that furnish the raw materials for food and manufacturing.

All these industries are dependent upon living things, both plants and animals. These in turn, as you have learned, depend upon certain factors in the environment — air, water, soil, and sunshine. You have already studied two of these factors, air and water. In this unit you will learn something about soil.

To many people, especially those who have always lived in the cities, agriculture may seem a rather simple thing. The ground is prepared and some seed is planted. The rain waters it, the sun shines on it, and in due time the crop is harvested and sold. If you live in the country, however, you know that it just isn't as easy as this. Not only do different conditions exist with respect to air, water, and sunshine, but the soil itself differs in many ways, sometimes even on the same farm. Every farmer knows that there are many kinds of soil, each different from the other and each suitable for different kinds of living things.

What makes these differences? What is soil? Where does it come from? How does it help to support life?

Chapter XV · What is Soil and How is it Formed?

A. What is Soil Composed Of?

Is all soil alike? Only a moment's thought will give you the answer to this question. If you live in the country you have seen a freshly plowed field as it lay black and rich, ready for planting; you may have seen another field bleached by rain and wind until it was light brown or almost gray in color. If you live in the city you may have seen a steam shovel biting its way into a hillside or digging itself into the ground as it prepared the foundation for what later became a new fifty-story skyscraper. If you watched the work for several days, you may have seen the layers of different-colored earth in the sides of the deep pit. Perhaps even in the city you have spaded a garden and turned over soil of different colors and textures. From these observations and others you come to the conclusion that there is more than one kind of soil.

Let us ask another question. How does one kind of soil differ from another? To answer this requires a little more knowledge. You may have noticed differences, but perhaps cannot tell what the differences are. Some first-hand observation and experiments may help you.

First suppose you secure several samples of soil. Go into the garden, the school yard, the fields, and other places. Collect samples of the soil you find there. Put these samples in different envelopes. Label the envelopes to indicate where you found the soil. After you have collected your samples, you are ready to begin your investigation. Suppose you start by examining each of them under a good hand lens, a reading glass, or a microscope. What should you look for? Let us suggest some questions which you might try to answer as the result of your work.

Are some soil particles coarser than others? Do they differ in color? What do these particles seem to be made of? Are they all of the same size? Are they all of the same shape? What else do you notice that is interesting? Keep a record of what you find out about each of your samples.

What other tests can be made?

Place a teaspoonful of black soil on an iron plate and heat it for several minutes with the flame from a gas burner. Observe that the black soil soon changes appearance. Why? The original dark color is due to carbon left from the partial decay of plants. When the soil is heated with a hot flame, the carbon burns and the black color changes. Try the same experiment with some of your other samples. Do you get the same results? Can you draw any conclusions?

Soil is a mixture of particles varying in size and kind

Now mix thoroughly a small portion of soil and water in a test tube. Allow the mixture to stand for a short time, and you will see the soil particles begin to settle. Examine the test tube after most of the soil has settled, and you will see that the largest particles have settled to the bottom of the tube, while the smallest ones are on top. Does your sample look like that in Fig. 121, *a*? Possibly there may be some carbon particles. These will rise and float on the surface of the water. Soil, you decide, is clearly a mixture of particles, varying upward in size from extremely tiny dust particles.

The water covering the soil in the tube will appear muddy even after it has stood for some time, for there are some very tiny particles of soil left in it. These settle very slowly. After you think the process of settling is complete, pour the water which is above the soil through a piece of filter paper that has been carefully fitted into a funnel, as shown in Fig. 121, *b*. The water comes through nearly clear and appears to be very much like the water from the faucet. Catch on a clean glass plate a few drops of the

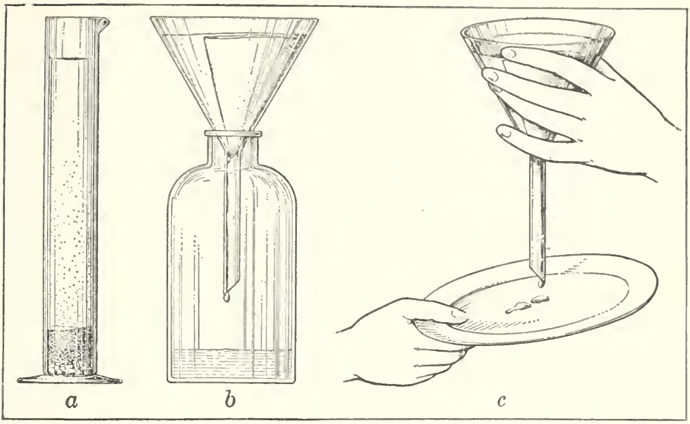


FIG. 121. *a*, Soil is a Mixture of Particles varying in Size and Kind; *b*, Substances in Solution pass through Filter Paper; *c*, Substances in Solution remain as Solids after Water has Evaporated

Some material in the soil is soluble

water as it flows from the funnel, as in Fig. 121, *c*. Expose this plate in a warm place for a short time. You will see that the water evaporates and a white sediment is left on the glass. Evidently some of the material composing soil is soluble in water and cannot be seen until the water evaporates. Now evaporate a few drops of distilled water in the same way. You find there is little or no sediment left; for, as you have learned, distilled water is nearly pure water. Try the same experiment with water from the faucet. Do you find any material dissolved in it? If possible, try the same thing with some water from a lake or river. Try it, if possible, with some water from the ocean. Which of these samples do you find leaves the largest deposit? Usually it is the water from the ocean, for there is more material dissolved in salt water than in fresh water. Was this true in respect to the samples with which you worked?

How did this soluble matter get into all the water you sampled? From your study of the water cycle you will remember that all the water on the surface of the earth has at some time flowed over the soil after it has fallen as rain or snow. All material dissolved in water, then, was at some time a part of the soil.

There are living things in the soil

What else can be learned about the soil? Get several flowerpots. Fill them with fresh surface soil from various places. Water these pots carefully from day to day. You may be surprised to find that after a time plant life will begin to sprout in the apparently dead dirt. Seeds are distributed everywhere, and a sample of soil taken from almost anywhere out of doors is likely to contain seeds of some kind.

Are there any other kinds of things in the soil? How about animal life? Have you ever dug worms for a fishing trip? If you have, you know that many kinds of animal life, such as worms and beetles, live in the soil. A sample of soil taken from out of doors is likely to contain some of these forms of animal life, as well as seeds.

The bacteria in soil are very important

The soil contains also enormous numbers of bacteria. These are so small that they cannot be seen, but there are several means by which their presence in the soil may be shown. The scientist would again prepare a food solution (see page 256), similar to that with which he showed that there are bacteria in the air. In this case, however, he might use on the jelly a drop of water filtered from soil. He would again cover the dishes carefully, and put them away in a warm place. If you tried this experiment with air, you might wish to repeat it with soil. Your results will show beyond all doubt that there are bacteria in soil. Some of these bacteria play an important part in keeping the soil in proper condition for the growth of plants.

Soil contains many other substances. There are particles of broken rock of various sizes, as well as particles of clay and sand. Water does not dissolve these to any extent. Mixed with the insoluble particles there is a small amount of some soluble substances. There are also, as has been said, some carbon particles left by the partial decay of plants. As you have seen, the soil contains many bacteria, seeds of plants, and small animal forms like worms, ants, and beetles. Natural forces bring the particles in the mixture together from many sources. Samples of soil from different regions of course show differences in composition.

B. What is the Origin of Soil?

We are now ready to raise another question. Where did all this soil come from? In order to arrive at an answer to this question let us recall our imaginary trip to the Rocky Mountains.

A few weeks ago in our study of air we talked about some of the results of changing air pressure which were observable as we traveled to the top of the high mountains beyond Denver. Of course the effect on our breathing was not the only memory we had of this trip. We recall vividly the natural beauty of the region, with its towering Rocky Mountain cliffs. We remember the narrow roadway built alongside rapidly flowing streams. Occasionally this road cut through solid rock. On one side was a steep wall of rock; on the other a gorge through which a creek roared as it dashed over the bowlders lodged in its bed. At frequent intervals the stream was interrupted by a waterfall. Here the water plunged from a high cliff in a silver stream, to strike with great force on the rocks below. Showers of spray rose in the air, and in the sunlight this vapor glistened with rainbow colors. We remember particularly a narrow gorge walled on both sides by steep mountains. There were few trees or bushes, and but little grass was found on its sides. The mountains here were masses of solid rock. There was little soil to support vegetation.

The mountains are masses of solid rock

Then we came to a valley far up in the mountains. How different the scenery was! The roadway was nearly level. The stream flowed more slowly. There were trees and underbrush, grasses and bright-colored flowers. Soil had collected in the valley. There was plenty of rain and sunshine and an abundance of vegetation. But towering above the rich green valley rose the rocky mountains, solemn, dignified, and splendid.

The soil accumulates in the valley

If you have ever visited this part of the United States or have taken trips similar to this one in other sections of the country, you can perhaps appreciate our feelings as we gazed with reverence at this magnificent environment. We could sympathize with the many people who, seeing these same things, had spoken of "the everlasting hills." And as we thought of the protection these and similar mountains have given to many valleys for year after year,— for thousands and millions of years,— we too could see why people use the words "as eternal as the hills" when they wish to call a thing permanent.

"As eternal as the hills!" This does seem secure, doesn't it? But if one is interested and begins to investigate just how eternal the hills are, one soon finds that the phrase is used by the poet rather than by the scientist. The former looks upon the immediate environment, sees its beauties, and writes about the eternal hills. The scientist sees the same environment, asks himself, "How long have these mountains been here?" begins to investigate, and finds that they have been there only a small fraction of the entire age of the earth. And so the scientist will tell you that the rocks of these mountain cliffs are really not eternal.

"The eternal hills" is a poetic phrase and not a scientific one

The part of science which deals with the story of the rocks is called geology, and an expert scientist in this field is called a geologist. If you were to ask a geologist about the beautiful mountains you have seen, he would tell you that natural forces are continuously at work wearing them down. He would ask you what you knew about the mountains in the eastern part of the United States. If you said that you were more interested in the Western mountains because they were much higher, he would tell you that the Eastern peaks are much older than those in the West, and were at one time just as high as the Rockies. The mountains in the East are older, and the natural forces that wear down rock have been at work on them for a longer time, with the result that these mountains are worn away.

Mountains wear away

It is difficult to picture these masses of stone being broken down by natural forces, isn't it? How is it done? What happens to them after they are broken up? The answers to these questions will help greatly in understanding the story of soil, where it comes from, and how it is formed. Let us see what other information the geologist can give us which will help in understanding this story.

In the first place, he says, you must realize that not all rock is the same. If you will examine different rock formations as you travel around the country, you will find that they differ. Some seem very hard; some crumble in your hand; some are rough; some are smooth. The layers of some rocks seem even; others are wavy and look as though they were folded together. You can find evidence of this in your own neighborhood. Make a collection of rocks. If you study them, you will see that there are, it is plain, different kinds of rock. Let the geologist go on with his story.

All rock is not the same

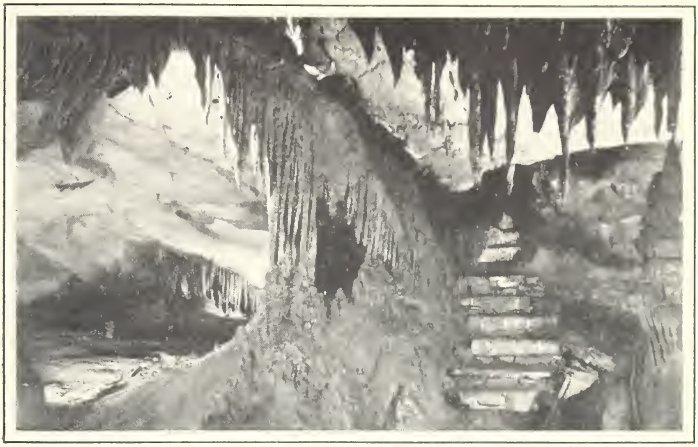
The rock that is most plentiful in the mountains is granite. The surface of this rock is rough, for it is made of small crystals. By close examination you may see that it is composed of at least three different kinds of crystals firmly cemented together. There are crystals of quartz that shine like grains of sand. There are crystals of feldspar, small bits of mica, and still other minerals. There was a time when this rock was a molten mass. In succeeding years it slowly cooled and solidified under the surface of the earth. The earth that covered it has been worn away, and now we see it as part of a high mountain.

Another form of rock that is very common through the mountains everywhere is called basalt. Unlike granite it has at one time poured out on the surface of the earth or come up through cracks and has cooled rapidly. There are many regions in the mountains that seem to be composed entirely of basalt. In appearance it differs from granite in that it does not seem to be granular. The different substances of which it is composed are in the form of smaller crystals that are not easily visible to the unaided eye. Under a microscope, however, the crystals may be seen clearly. When basalt is broken, the pieces have sharp edges. Basalt and granite do not look alike, but they are similar in chemical composition, except that there is no quartz in basalt.

Another common form of rock is limestone. In its purest form limestone is known as marble. Other forms of rock include sandstone, in which little grains of sand are more or less firmly held together. Some sandstone may be easily broken up into the grains of sand of which it is composed. Quartzite is sandstone in which the grains of sand are so firmly cemented together that they cannot be separated. The rock may be crushed, of course; but when this happens, it breaks through the grains of sand as readily as it breaks around them.

Caves are formed in limestone

Now, says the geologist, let us see what we know about the forces that destroy these rocks. Limestone wears away very rapidly. It dissolves slowly in running water that has carbon dioxide dissolved in it. There are some sections in the United States in which there are great areas of underground caves that have formed as limestone deposits beneath the surface have been dissolved in running water. You may know about



© Ewing Galloway

FIG. 122. Caves are formed in Limestone

some of these famous limestone caves in New Mexico, Colorado, Arkansas, Kentucky, Virginia, and in other states. Fig. 122 shows the interior of one famous cave of this type.

If you will examine a mass of granite, you will find that it too is being worn down. You may find regions in which the granite is covered with tiny growing plants called lichens. These plants slowly break down the rock as they take from it the products that are necessary for growth. Rain water with oxygen and carbon dioxide from the air in it will slowly decompose granite and other rocks that are similar in composition. A small part of the substances composing the rock dissolve in water, just as salt does. When dissolved, these substances are carried away toward the ocean by the streams and rivers. It is this dissolved matter that helps to make the ocean salty. Sand and clay are also formed from granite, and these make up part of the soil.

The granite rocks are slowly decomposed

Rocks may be broken by changes in temperature. Great surfaces of the rock on the sides of mountains may be ex-

Fig. 123. Water Freezing in Crevices breaks Rocks

Courtesy of the United States Geological Survey

posed to the hot rays of the sun during the day and to extreme cold at night. Rock, like iron, glass, and other substances, expands when heated and contracts when cooled. As heat and cold alternate with day and night, these rock surfaces are heated and cooled. The accompanying expansion and contraction break off tiny pieces of rock from the exposed surfaces. Rain carries these pieces of rock down the mountain.

Alternate heating and cooling break rocks

Probably a more powerful force than any of those just named is the force of freezing water. During a rainfall water collects in the tiny crevices. If it freezes in the crevices, it exerts pressure against the rock, just as it exerts pressure when it freezes in the radiator of an automobile. This pressure breaks the rocks, and little pieces are chipped off. If the crevices are deep, large bowlders may be broken loose, as illustrated in Fig. 123.

Water freezing in crevices breaks rocks

If you examine the surface of a rocky cliff, you will see that it appears rough. It shows the effects of the dissolving action of lichens and other tiny plants that grow on its surface (Fig. 124). It shows the effects of the dissolving action of rain water. The results of heating and cooling may be seen in the crevices, some tiny and some large, that run through its surface. Large gashes may appear where the force of freezing water has broken away large pieces of the mountain side.

Fig. 124. Lichens growing upon Rocks form Acids which gradually decompose the Rocks

Courtesy of the American Museum of Natural History

Often sufficient soil will be formed by the action of these forces to provide small soil deposits in some of the uneven places on the mountain side. A seed carried on the wind may fall on this soil. It takes root, sprouts, and within a few years a tree is growing. As this tree becomes larger and larger, its roots go deeper and deeper into the soil. Soon they enter some of the small cracks in the rocks underneath the layer of earth. The roots of this growing plant exert tremendous pressure, and gradually they even push the layers of the rock apart (Fig. 125). This action of the roots of growing trees, then, is another force which works to tear down the mountains and change them to soil.

The growing roots of trees break up rock

Finally, says the geologist, there is another tremendous force at work destroying rocks. If, he says, you had continued your automobile tour from the Continental Divide through the mountains and into Mt. Rainier National Park, in the state of Washington, you would have seen this force at work.

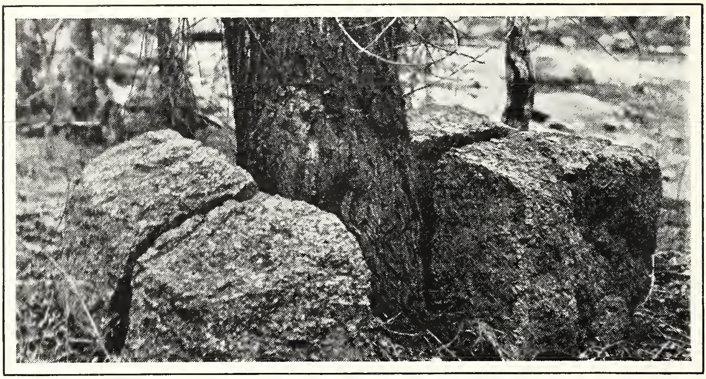


Fig. 125. The Growing Roots of Trees exert Sufficient Force to split Huge Bowlders

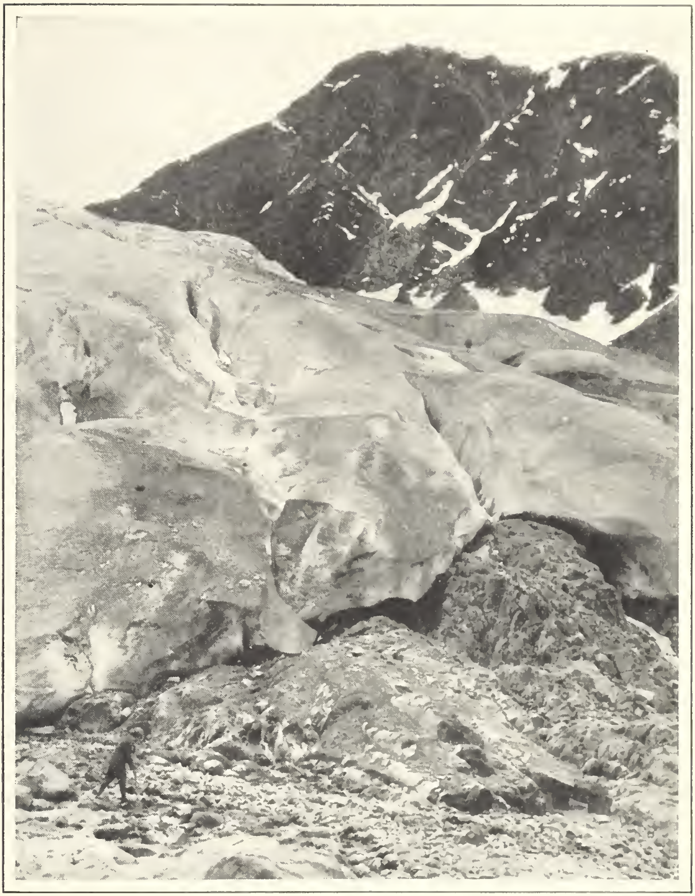
Courtesy of the American Museum of Natural History

As you approached central Washington you would have seen miles away, as in Fig. 120, the snow-capped summit of Mt. Rainier rising more than fourteen thousand feet above the level of the sea. The region surrounding this beautiful peak is famous for its huge glaciers.

These are formed in places where more snow falls in winter than melts in summer. Accordingly the snow piles up to great depths. The weight of the upper mass presses that below with such force that the snow is changed to ice. There are places in the park where the crust of snow and ice is as much as a thousand feet thick. The great pressure of the snow and ice on the upper slopes forces the glacier to flow down the mountain. The ice flows, but it moves very slowly indeed — often only a few feet in a year.

Glaciers wear away mountains

In spite of its slow motion the glacier is one of the most powerful of the natural forces working to wear away mountains. As it moves, rocks and bowlders are caught in the ice. These bowlders scrape against the rock surface over which they are moved. A mass of ice a thousand feet thick exerts a pressure of



© Ewing Galloway

FIG. 126. Deposits of Rock are left by a Glacier as it Melts

about four hundred and thirty pounds on each square inch on the surface over which it moves. The grinding action of the rocks that are held firmly in the ice, on the surface over which the glacier travels, is therefore enormous. Quantities of rock are ground into bits and carried along until the ice melts. Large bowlders are left at the edge of the diminishing glacier. Fig. 126 shows such deposits at the edge of the melting glacier. Smaller rocks are carried down the mountain by the rushing water which is formed as the glacier melts far down the mountain. When the water reaches the foot of the mountain, it moves more slowly. The smaller particles of broken and decomposed rock settle out and help to form the soil of the valley.

There was a time when all the northern section of the United States was covered by a great glacier. This region was, of course, much colder then than now. As you travel through it, you see many bowlders that were carried by the glacier and left when the ice melted. Many of them show scratches on their surfaces, as illustrated in Fig. 127. These scratches were formed ages ago when the bowlders, held fast in the moving ice, were pushed along over the rock surface beneath.

Soil is formed from broken and decomposed rock

From what you have been told by the geologist, you may rightly decide that there are two kinds of forces acting to tear down the solid rock of the mountains, those that dissolve rock and those that break rock. These forces act very slowly, but their action has been continuous throughout the millions of years that make up the age of the earth. Great quantities of rock have been worn away. Even mountain peaks have crumbled as year after year these same forces have exerted their constant power. Now you can understand why we said that the hills are not eternal, that they do wear down and finally disappear.

C. Is Soil moved from Place to Place?

You have evidence now that stones are constantly breaking loose from the sides of the mountains where rock is exposed. Although the process is not easily seen, it is known that these pieces of rock are continuously being decomposed into clay and sand. The tiny particles of

Fig. 127. Many Bowlders show Scratches formed by the Glaciers Ages Ago

Courtesy of the American Museum of Natural History

Fig. 128. The Sharp Edges are worn off as the Stone is moved along by Water

This stone was found on an ocean beach

clay and sand and the pieces of broken rock are washed down the mountain side by rain and flow into the neighboring streams. In hilly or mountainous country the streams flow swiftly, bearing sand or clay with them. In time of flood pebbles and even large bowlders may be moved downstream by the force of the rapidly flowing water. Notice how the stone in Fig. 128 has been rounded by the force of the water. When the water reaches a level valley, it flows more slowly, and the particles "settle out" and form soil along the banks of the stream. Thus the rock of the high mountain is changed slowly into soil and transported to the valleys. Thus it is, too, that cliffs usually are solid rock and the valleys are covered with a layer of soil. Running water is not the only means by which soil is transported, for bits of rock may be moved from place to place by wind as well. Water is, however, the larger factor in this country.

Soil is deposited by a slowly moving stream

The streams that flow from the mountains of the eastern part of the United States and those that flow from the Western mountains to join the Mississippi River all carry

Fig. 129. During a Flood a River carries a Great Deal of Soil

along particles of soil. The largest quantities are carried during floods. If you have ever seen a river in flood (Fig. 129), you know that at such times the familiar river changes its appearance entirely. Gone is the calm peaceful-flowing stream. The angry waters climb high up on the river banks as they toss and whirl in their attempts to reach the sea. Trees and wreckage of all kinds roll and spin as the force of the swollen river carries them on. Most noticeable, perhaps, is the changed appearance of the water. Once clear as crystal, it is now yellow, brown, or black. Instead of its usual light rippling flow the river now takes on a sullen tone as it drives steadily onward. As you may easily guess, this changed appearance in the color of the water is due largely to the vast quantities of soil which it carries. As it continues on its way, muddy with soil, it overflows its banks. Some of the soil particles settle out; and as the water recedes, a deposit of soil is left over the flooded areas,

A river in flood carries a great deal of soil

Fig. 130. New Deposits of Soil are left on Land which has been Flooded

as shown in Fig. 130. Further floods may change these streams again to raging torrents that will pick up the particles deposited as a former flood receded, and carry them onward to lower levels. Soil from the Rocky Mountains, soil from the Appalachian Mountains, and soil from the plains of the north-central states, which were once covered by glaciers, are all mixed in the waters of the Mississippi and carried toward the Gulf of Mexico. The amount of soil carried to the Gulf by this vast stream in one year would make a deposit one foot thick over an area of two hundred and seventy square miles. In a period of a little over eleven hundred years this mighty river would carry enough soil to make a deposit one foot thick over the whole of the United States. These deposits of soil form the delta of the river. As time goes on, the delta grows and extends itself farther and farther out into the Gulf. The Mississippi River today is slowly filling the

Land may be formed in new places, as in the case of deltas

Gulf of Mexico with soil particles gathered by the river and its tributaries from the mountains and plains through which they flow.

To appreciate more fully what this transportation of soil means, it is necessary to see a more complete picture of some region which has been built up in this way. Such a view may be obtained by taking an airplane flight from Columbus, Ohio, to Denver, Colorado. Let us in imagination take this trip across the plains of the Mississippi Valley. If we leave Columbus in the morning, the distance of about twelve hundred miles may be completed during the daylight hours of one day. What will such a trip show us? There are no mountain cliffs and no huge forests. The country is nearly all flat or gently rolling, and much of it is under cultivation. The traveler sees below him fields of corn, oats, and wheat. There are dairy farms with grassland for pasture. There are sheep farms, and feed yards for fattening hogs and cattle. While flying at an elevation of a few thousand feet, we see thousands of square miles of farm land similar to that in Fig. 131. A clump of trees indicates the position of a farmhouse. A smoky region seen in the distance marks the location of a city. The white lines over the ground are the cement roads. Narrow winding streams of water are always in view. The whole country is cut by ditches, creeks, and rivers. Now and again there may be opportunity to follow the course of one of these streams. First it appears as a small creek. Presently other small creeks feed into it, and it becomes larger. Soon the larger creek feeds its supply of water into a river, and the river flows on, finally joining the Mississippi. On and on we go, and ever under us is this comparatively level, cultivated landscape. By the end of the day we are convinced that the Mississippi Valley is indeed one of the richest agricultural regions in the world.

The river valley contains rich soil

© Chicago Aerial Survey Company

FIG. 131. Acres of Farms may be seen from the Plane

As we think over what we have seen, we realize that most of the wealth that has built the fine highways, the railroads, and the great cities in this vast fertile valley has come from the soil. The money which the farmer receives comes to him from the sale of grain, or from the sale of live stock that he has fattened by feeding with grain.

Why is this particular region so rich in agricultural possibilities? The story which answers this question proves how important the effect of natural forces is upon man and his ways of living.

Here was once a sea

There have been times, millions of years ago, when, if it had been possible to fly from what is now Ohio to what is now Colorado, the airplane would have been over water much of the way. The sea once covered what is now the central part of North America, extending all the way from the Gulf of Mexico to the Arctic Ocean.

Since those ancient times there has been a constant cycle of comparatively hot days and cool nights as the sun rose and set. There have been slowly moving glaciers. There has also been the dissolving action of water and carbon dioxide. All these have acted as forces to break up and decompose rock. The water in the swiftly flowing streams of the mountains gathered then, as it does today, the particles of broken rock, clay, and sand and carried them to the sea. The sediment settled to the bottom of that great sea exactly as the particles now carried by the Mississippi River to the Gulf of Mexico settle and form the delta. Slowly these bits of soil carried by the rivers from the mountains filled in the sea.

Other mighty forces acting from the interior of the earth have slowly played their part in raising the surface of this region. The surface that was beneath the sea, covered by the sediment carried in by the rivers, was elevated until it was higher than sea level. As time went on, the land continued to rise, and the shore line of the ocean moved slowly toward the south.

Later, glaciers spread over the region

In another period, after the shore line of the sea had moved toward the south, great glaciers came from the north and spread over the land, extending as far south as the region that is now southern Illinois. These carried more sediment and left it on the surface of the land after the ice melted. The ground bits of rock, together with the large bowlders, make the region that was once covered with ice very different in appearance and in fertility from the sections that the ice did not cover. It is easy to see where glaciers have passed.

In this explanation of how soil is formed we have not attempted to tell the whole story of the changes in the Mississippi Valley. There is evidence that this region has been under water and then elevated many times. In one of the earlier periods when the surface was above the sea, it was covered by a very dense growth of vegetation. The remains of this vegetation later sank beneath the sea, were covered with sediment, and were finally changed into coal. Part of this story you know. You will learn other parts of it in your future science work. For the time being, remember that the surface of the earth is continuously changing. The forces that cause these changes are the forces that break up rock and carry it from high to low places, that lower the land area so that it is covered by the sea, and that raise regions from beneath the sea. Regions above the sea are always exposed to forces that tend to tear them down. The operation of all these forces through many millions of years has produced and distributed over the Mississippi Valley a layer of broken and decayed rock many feet in thickness. This layer of rock particles, mixed with some materials that dissolve in water and with the remains of partially decayed plants, makes the soil. This soil is part of the natural environment in which the people of the Mississippi Valley live.

Land regions are continuously exposed to forces that tend to tear them down

D. Are Deposits of Fertile Soil destroyed by Any of the Forces in Nature?

Our imaginary airplane trip over the Mississippi Valley was a trip over thousands of acres of fertile farm land. As we see this region again in our imagination and think a little more about the natural changes which produced it, we know that the forces that built it are at work changing it. In almost all fertile regions hundreds of small brooks flow through the country. After a heavy rain these brooks are swift and muddy. As a stream rushes along it carries away the soil lining its banks, and the stream bed is cut deeper and wider. Rain pours down the hillsides and flows into the brooks. On the way it picks up particles of soil. The tiny streams on the hillsides make little ditches.

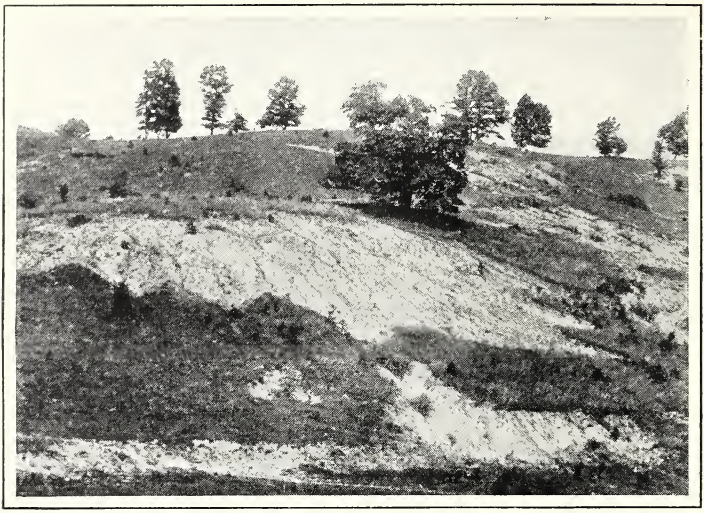


Fig. 132. Running Water carries away the Soil

Courtesy of the United States Forest Service

As more rain falls, these channels are cut deeper and deeper. More and more of the surface soil is carried away by running water. Notice the effect running water has had upon the earth in Fig. 132. Some of the soil is deposited at lower levels to be picked up and carried farther by the water from the next heavy rain. In time this soil may become part of the many substances that are carried by the Mississippi River into the Gulf of Mexico.

Running water carries away deposits of soil

Geologists tell us that the surface of the North American continent is being worn down at the rate of about one foot in nine thousand years. Millions of years were required to form this soil, another interval of some millions of years may see the location of the deposit completely changed. But during the interval of this change other soil deposits will be forming elsewhere. Thus you see that no

Forces are always at work changing the surface of the earth

soil deposit is permanent. The surface of the earth is always changing.

You can find for yourself, if you wish, examples of the forces discussed in this chapter. A field trip into almost any part of the country will reveal many evidences of the way in which natural forces are at work changing the surface of the earth. You should look for brooks and rivers carrying deposits of soil taken from their banks. See if you can find any evidences of rock broken by expansion and contraction due to heat and cold. Perhaps you may find evidences of the action of glaciers revealed in the rocks. You will probably find crumbling rocks. A trip organized for the purpose of observing these natural forces for yourself may give you a great many worth-while experiences to talk over in class.

Soil is formed through the action of natural forces upon matter. Some deposits of soil have taken many thousands of years to form. Soil may be destroyed, as well as formed, by similar natural forces.

Can You Answer these Questions?

1. Here are some statements that scientists have made:

a. The earth is very old.

b. The surface of the earth is continuously changing.

c. The history of the earth may be read in the rocks and soil.

What evidence is there in this chapter that these statements are true?

2. Why are river valleys regions of agricultural industry?

3. We often say that something is "as eternal as the hills." Are the hills eternal?

4. The history of the Mississippi Valley is a history of the work of natural forces in the process of soil-making. Can you trace the history of this region to prove or disprove this statement?

5. The Mississippi River is called a muddy stream. What makes it muddy?

6. Water is called both a soil-maker and a soil-destroyer. How is it possible for it to be both?

7. Can you name half a dozen ways in which rocks are broken up and finally made into soil? Is there evidence of any of these in your own community?

8. What makes the ocean salty?

9. When and where are glaciers formed?

10. What is sediment?

11. What substance, besides rock particles, is present in all good soil?

Questions for Discussion

1. Were there ever any glaciers in your own community? What evidence is there of the truth of your answer to this question?

2. In various parts of New England you often find giant bowlders of granite on the tops of great hills. How do you think they got there?

3. What sort of soil should you expect to find in the Mississippi River delta?

4. How does a pebble differ in shape from a bit of stone recently chipped from a rock? What causes this?

5. Why are better crops usually raised in valleys than on mountain sides?

Here are Some Things You May Want to Do

1. Make a collection of pictures that show weathering of rocks. The so-called faces in stone are the result of such weathering.

2. Read Hawthorne's "Great Stone Face." See if you can find any other stories which tell of similar natural features.

3. Test marble chips with acid and see what effect it has on them. Vinegar or lemon juice will do for acid, but hydrochloric acid will show more results. Can you tell the difference between limestone and other stones by testing them with acid?

4. Make a collection of rocks for a class or school museum. Test and label them to show which are hard and which are soft. If you find any that have been smoothed by water or that show the results of the action of glaciers, label them accordingly. A book for the study of minerals and rocks will help you to identify some of them.

5. Prepare a map of North America, showing where glaciers are found today. You may also wish to indicate where glaciers once were, which have since disappeared.

6. Explore your community and see if you can find evidences of soil-making and soil distruction. You might indicate on a map of your community where these various factors may be seen at work. This map might be used by other classes in your school.

7. One period in the earth's history was known as the Great Ice Age. See if you can find anything that tells you about this; and after you have done your reading, write a vivid picture of conditions as they were at that time.

8. Examine a sample of soil under a microscope and make a list of the things you see. You may wish to make a drawing of what you find there.

9. Show by an experiment that there is carbon in the soil. Is there carbon in all soil? Try samples from various places in your vicinity.

10. Try some of the experiments listed on pages 273 to 276 and keep a record of your findings. See if you can set up experiments that show you some interesting things about soil.

Chapter XVI · What Part have Natural Forces played in Preparing Soil Suitable for the Growth of Plants?

Throughout the earlier chapters of this book you have followed a story which shows the relationship between living things and the natural environment, and which tells how this environment seems to be suited for the conditions of life as you know them. You have seen the various factors necessary for life — air, water, sunshine, warmth, and soil — as they operate, and how these factors seem to depend one upon the other. Abundant life, you have learned, usually accompanies an abundant supply of the necessities of life as supplied by these factors. Similarly sparse life or even absence of life accompanies the absence of these factors. You have learned through observation and experiment how the elements necessary for life are taken from air, water, and soil, and how under the rays of the sun these elements become a part of living things.

In imagination you have observed life in various parts of the world and under varying conditions. You have traveled to the Arctic, to the Congo, to the Sahara Desert, and to the western sections of your own country. You have even flown across the regions of the great Mississippi Valley. In all these visits you have seen plants and animals growing and living in a natural environment.

Fertile soil is necessary for plant growth

In this, the last chapter on soil, we should like to bring together some of the things you have already learned about the factors of the environment, and show you how these provide in soil a suitable medium for the life of plants. As you know, plants take from the soil some of the things that are necessary for growth. In order that these may be obtained, the soil must be fertile, it must contain water, mineral substances, air, partially decayed vegetable matter, and living organisms, especially bacteria. How do these things get into the soil? How do we know they are there? And finally how do plants use them in growing? These are some of the questions we shall want to consider.

There is water in the soil

It is easy, of course, to see how water gets into the soil. Rain, snow, and other forms of condensation fall upon the earth; the water seeps into the soil, and much of it remains there in spite of evaporation. You have been told that all soil contains water. Perhaps you would like to test this statement again. Place about two teaspoonfuls of dry soil in a test tube and shake it down in the tube carefully so that the glass above the soil is clean. Heat the soil in a gas flame, holding the test tube so that the top of it is not heated. Soon you will see moisture collecting on the inside of the tube, as indicated in Fig. 133. You find that a considerable amount of water sticks to the surfaces of the little rock particles. Get some dry dust from a roadway or from a footpath and repeat the experiment, using about two teaspoonfuls of dust. Even though the soil is "as dry as dust," there is still some water in it. Water on the tiny particles of soil is a necessary feature in making the soil fertile.

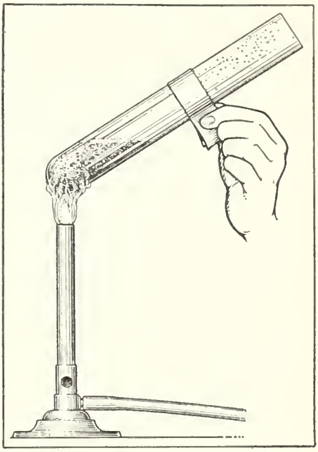


Fig. 133. There is Water in Soil

How much water is there in the soil? This of course is a difficult thing to measure. Estimates, however, have been made. In one cubic foot of good soil there are millions of tiny particles of earth. The area of the surface of each particle is small, but the total area of the millions of particles makes a total surface of about 50,000 square feet. If this soil holds the proper amount of water for plant growth, each of the particles of which it is composed will be covered with a film of water about five hundred thousandths (0.00005) of an inch thick. If the water on the particles of this cubic foot of soil could be spread out as a flat surface, there would be a layer of water about as thick as a thin soap bubble, covering an area of more than an acre (one acre is 43,560 square feet). The total volume of water held by one cubic foot of this soil amounts to about three hundred and sixty cubic inches, or nearly one fifth of a cubic foot. Dry earth, then, is not as dry as you may think.

There is air in soil

How about air? In your study of the food process in plants you learned that soil to be fertile must contain air. It is required by the living cells in the roots of plants, as well as by the bacteria and other living organisms of the soil. You found out, too, that if the roots of a growing plant are flooded with water, the plant will die for lack of air. The presence of air in the soil has been determined already. You put some soil in a glass tumbler and covered the soil with water. Soon you saw bubbles form in the liquid. The air that came to the surface as bubbles came from the spaces between the particles of soil. In good soil these spaces take up nearly as much room as the particles themselves. As water seeps into these spaces, it forces the air out. Another common experience will help to show this. If you have ever walked through the country after a heavy rain, you may have noticed many earthworms on the surface of the ground. Why are they there? Do worms need air to live? Of course they do. Organisms living in the soil get plenty of air except after a heavy rain. When the heavy rains fall, however, much of the air in the soil is forced out by water. The worms, then, came up to the surface of the ground for air.

Worms, beetles, and other forms of animal life are usually thought of either as good bait for fishing or as good food for chickens and other forms of bird life. In addition to this, however, they play an important part in soil preparation. If you wish to see this for yourself, place several worms in the bottom of a glass jar. Add three or four inches of loose black earth. Over this add about the same amount of white sand or sawdust. Moisten the mixture by adding about a quarter of a cup of water. Set the jar in a paper bag and put it away. (The bag around the jar keeps it dark, so that the worms will work near the glass.) Keep its contents moist but not wet. Before many days you will observe results in the white sand which will illustrate the work of such organisms in soil.

There are bacteria in soil

You have already learned that there are bacteria in the soil; you may have found this out for yourself by experimenting. One ounce of fertile soil from a garden may contain billions of these tiny living organisms. These bacteria take their food from decaying plants in the soil and some of them play a very important part in making soil suitable for plant growth.

Ashes left after burning consist of mineral substances, which were once part of the soil

Mineral substances in the soil are formed, as you have learned, from the chemical decomposition of minerals and rocks. These substances in small amounts are essential to the growth of plants. The ash which is left when wood or plant products of any kind are burned is mineral matter from the soil. If you were to burn a bushel of wheat until nothing but the white ash remained, you could show that one bushel of wheat weighing 60 pounds would leave about 6 pounds of ash. Why only 6 pounds? Most of the remainder of the bushel of wheat is composed of starch. As the starch burns, it is changed to carbon dioxide and water and these pass into the air as gases.

One bushel of corn (56 pounds) leaves about 4 pounds of ash. A ton of hay (2000 pounds) leaves about 140 pounds of ash, while a ton of potatoes leaves only about 21 pounds. The mineral matter entered the plant through its roots while the plant was alive and growing in the soil. Burning these plant products, then, decomposes them. The same thing may be accomplished by leaving the plant products on the ground and permitting them to decay. In this case the soluble minerals pass back into the soil when the plant product is decomposed. These materials must be returned to the soil if it is to remain fertile.

Here, then, you have ground which is ready for growing plants. The many little soil particles are mixed with the remains of partially decayed plants. Minerals like those left as ash when plant products are burned are dissolved in the water which surrounds the soil particles. The soil is packed loosely, and there is air in the spaces between the particles. Angleworms, ants, and other animals live in the soil and have burrowed holes through it in search of food. Bacteria are present in great numbers. Some are feeding upon the remains of dead plants and causing these plant remains to decay still more.

Roots penetrate the soil

Let us now consider a plant as it grows in this soil. The growing roots extend downward, deep into the soil, and are held firmly in place by the tiny pebbles, grains of sand, and particles of clay of which the soil is composed. If you should try to pull a corn plant from the ground after it is, say, forty days old, you might find that you were unable to pull it loose. A very careful examination will show you how the plant holds so fast to the soil. The root system of a corn plant is composed of many long slender fibers. In the process of growth these have pushed their way through the soil, some extending outward just under the surface of the soil for as much as two feet and others extending downward as deep as three feet and some as much as five feet. Such a root system is illustrated in Fig. 134. If you could carefully remove all the roots of a healthy corn plant from the

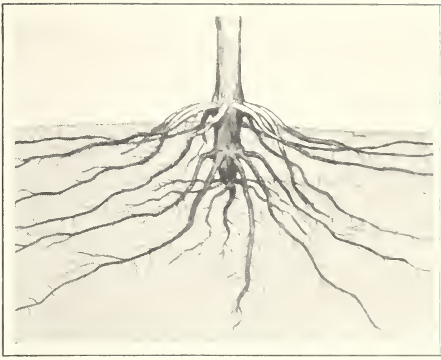


Fig. 134. Roots that penetrate the Soil and take in Water and Dissolved Minerals make it Difficult to pull up a Corn Plant

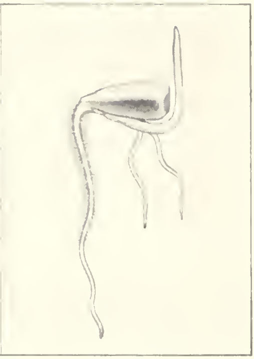


Fig. 135. The Picture shows the Rootcap and Root Hairs of a Young Corn Plant

ground, clip them from the plant, and lay the pieces end to end, you would find the total length probably to be in the neighborhood of five hundred feet.

Now examine one of the roots with care. You see at once that it is not straight. As it pushed its way through the soil, the delicate tip of the root time and again met small pebbles or hard earth. These caused the root to turn in its course. You see also numerous rootlets branching from the root.

An examination under a microscope of the tip of one of the thousands of delicate little rootlets would show you that it is covered with a little pointed cap. This cap serves the very useful purpose of aiding the rootlets to push in between the particles of soil. Just behind the cap on the root tip is a region covered with little hairlike growths called root hairs. These tiny root hairs come directly into contact with the thin films of water that surround the particles of rock in the soil. In fact they are bathed in it. Fig. 135 illustrates the rootcap and root hairs of a young

Each rootlet ends in a rootcap. Tiny root hairs grow near the ends corn plant. The root hair is part of a living cell. Through its walls water and the minerals and air that are dissolved in water enter the plant from the soil. The water, with the minerals dissolved in it, passes into the root and into the plant tissues. It passes upward through the root and stem to the leaves. You can observe this process if you will put a carrot, leaves and all (or a parsnip if you can get one), into a container about the size of a quart milk bottle filled with water that has been colored with red ink. Leave it over night. Next day cut across the root and look for red spots or red rings. Hold the leaves to a strong light and look for red lines. What do you find?

Water and dissolved minerals enter the plant through root hairs

You now have a picture of plant life in relation to the factors of its environment. You have seen how the plant makes use of each of these factors because it is adapted for meeting the conditions of the environment. You have learned that water and mineral matter, together with carbon dioxide from the air, are the products from which plant foods are made. You have seen how these foods may be changed into the tissues of roots, stems, and leaves, or how they may be stored, as in the case of the corn plant, where a great deal of the manufactured food is stored as kernels of corn.

You should now understand that part of the material of which the food of plants and animals is composed was at one time part of the soil, and how it naturally follows that our own bodies are composed in part of mineral matter that was once part of the rock of mountains.

Water, air, bacteria, and mineral elements are present in all good soil. Plants secure from the soil the water and the minerals necessary for growth.

Can You Answer these Questions?

1. What part is played by the roots and the leaves of a plant in the food-making process?

2. What part do the root hairs play in helping a plant to grow?

3. Why is it a good plan to keep dead leaves in a pile in your garden for use in mixing soil for potted plants?

4. How do bacteria help to make soil fertile?

Questions for Discussion

1. Many colleges and the United States Department of Agriculture through its various bureaus make tests of soils in different regions for fertility. What do you think has to be proved before a soil is classified as fertile or not fertile?

2. It is sometimes said that animals are "but one step removed from the soil." This expression refers to the method in which they get their food. What does it mean?

Here are Some Things You May Want to Do

1. Secure samples of soil from various parts of your community. Test these as best you can for soil fertility. This might be a class activity with different members of the class using different methods of testing. Combine your reports into a class paper.

2. Show by an experiment that soil contains air.

3. Place several beans, peas, or kernels of corn on a moist sponge. Keep the sponge moist, so that the seeds will sprout and grow. Observe the way in which their roots penetrate the sponge and how they stick tight to it.

4. Collect about a peck of dry leaves. Put them in a pan. Place the pan where nothing near it will catch fire, and burn the leaves. Save the ashes in a glass tumbler. Add water to them and see if they dissolve. Would these ashes help to make soil fertile?

5. Observe a carrot or, if you cannot get one, remember as well as you can the appearance of a carrot. The yellow part which we eat is a root. How does its length and size compare with the stems and leaves above ground?

FIG. 136. Truths discovered by the Chemist have influenced Ways of Living and Thinking

Courtesy of the Massachusetts Institute of Technology

UNIT VI

What does Energy have to do with Changes in the Composition of Things?

Chapter XVII · What are Chemical Changes?

Chapter XVIII · What are Things Composed Of?

FOR CENTURIES man thought of gold as something to be made from other metals. He was able to refine lead, and thought that if he could only carry this process far enough he would have gold. To him gold was the basis of all substances — the king of metals. For hundreds of years there were men, called alchemists, who devoted all their energies without success to the task of changing baser metals into gold. Some claimed they had found the answer, and the kings and rulers of the day paid unbelievable sums for the supposed secret. But no one ever really succeeded in making gold from cheaper metals.

Even today man is probably no closer to making this old dream of the alchemists come true than he was centuries ago. He has succeeded in changing many substances into new and wonderful materials. Steel is made from iron; explosives and perfumes are both made from coal tar; paper and cloth are made from trees. Man has even succeeded in making small diamonds. But gold and other precious metals are still to be secured only through the primitive method of digging them out of the ground.

The modern scientist has made one tremendous advance beyond the scientist of the old order. Through a better knowledge and understanding of the factors of his environment he knows why the old alchemists were never successful. What is more, he knows why man today, even with his far more delicate machinery and better ways of working, has made little progress along the road to sudden wealth through discovery of the processes which will change baser metals into gold and silver.

Do you know why?

Chapter XVII · What are Chemical Changes?

A. May Chemical Changes be Explained?

Chemical changes are a part of our everyday life

The idea of chemical changes should not be entirely new to you by now. You have seen evidences of these changes in many of the life processes which you have studied. You learned in connection with air that the various gases composing the atmosphere are taken into the lungs during breathing and that oxygen is combined with certain elements in food which reach the body cells after digestion. You have seen how this process, which is one of chemical change, results in heat and energy for the body. You have also studied the food-making and food-using processes in plants and have seen there again how familiar substances are changed into the materials necessary for growth and energy. This is also a chemical change.

Many other chemical changes are familiar. You take a match from a box and scratch it on the cover. It lights and burns. You apply the light to an open gas jet, and a flame results. These are chemical changes.

Some changes may seem a little more mysterious. Fill a water glass with ordinary limewater. It is clear and looks just like the water from the faucet. Blow into the liquid through a straw. The limewater changes to a milklike appearance. What has happened? A certain substance in the limewater has combined with the carbon dioxide in your breath. This has resulted in a chemical change which is revealed in the changed appearance of the liquid.

You might wish to try another experiment. Get a small quantity of powdered quicklime, or calcium oxide. Put two tablespoonfuls of this in a glass. Now slowly pour cold water into the glass. The mixture gets hot, doesn't it? Where does the heat come from? The water was not hot, nor was the powder. The answer here is the same. A chemical change has taken place, and heat has been produced during the process.

Thus you see that chemical changes take many different forms. Can you find out anything more about these changes? Can you see them? Can you really understand them? And what is more important, can you find additional evidence to show the effect of these changes in your daily lives? Let us see.

You will remember that in your study of water you found out several things by the use of an electrolysis apparatus. Among other things you were able to decompose, or break up, water into two elements, hydrogen and oxygen. A further study of electrolysis will help to explain chemical changes in general. It would be well to set up the apparatus again, so that the process may be followed carefully.

Let us suppose that the apparatus is ready. The tubes are filled with a mixture of water to which a few drops of sulfuric acid have been added. The wires leading from the electric cells to the binding posts of the apparatus are attached, and the electric current is flowing. Bubbles are rising, and the level of the water is forced downward as the gases collect. After the process has continued for ten or fifteen minutes, you are ready for further observations. Fig. 137 illustrates the apparatus at about this point. Notice first that the level of the water in one tube is now lower than it is in the other tube. Does this indicate anything? If you measure the amount of gas in each tube, you find that there is twice as much in one as in the other. You already know that the water is being changed into gases. One of these gases is hydrogen, and the other oxygen. If you tested your gases again, you would find that in the decomposition of water twice as much hydrogen is formed as oxygen. Do you remember the test for hydrogen? the test for oxygen?

Twice as much hydrogen as oxygen is released in the electrolysis of water

Let us see what other observations can be made. You know that a dry cell has two binding posts, one in the center and the other on the outer edge. If you check your experiment, you will find that hydrogen is being formed in the tube joined to the wire leading from the binding post on the outer edge of the cell. This post is the negative post and is indicated in the picture by a minus sign (—). Oxygen is formed in the tube which is connected with the wire leading from the binding post in the center of the cell. This post is the positive one and is marked with a plus sign (+). If you were to repeat the experiment many times, this result would always be the same.

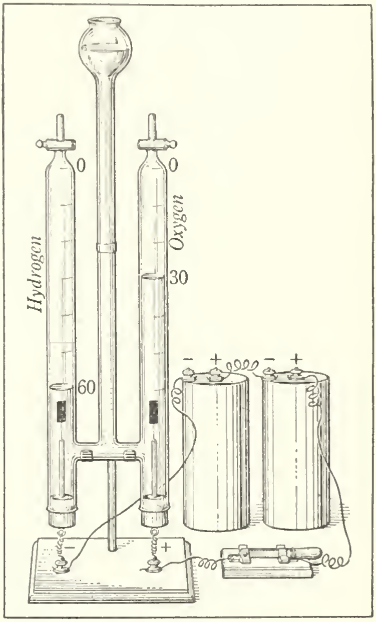


Fig. 137. Twice as Much Hydrogen as Oxygen is released in the Electrolysis of Water

There is no way to tell by direct observation what happens in this chemical change. You cannot see the change. You can only guess at its real nature. If you could do sufficiently careful work, you might learn from direct observations that the weight of the water before it is decomposed is the same as the combined weights of the hydrogen and oxygen formed. After it is decomposed, you would find that there is just as much sulfuric acid after the chemical change as there was before. All the hydrogen and oxygen, then, must be formed by the decomposition of the water.

Recall now, if you will, what you have learned about the molecular theory. Scientists have taken it for granted, you will remember, that water is composed of molecules and that all water molecules are alike. According to this theory, then, a cup of water is simply a large number of these molecules. It follows that the water in the tubes of the electrolysis apparatus was likewise composed of a great number of water molecules.

Molecules of water consist of atoms of oxygen and atoms of hydrogen held together by an electrical force

In order to explain the chemical change it is necessary to consider that molecules are made of still smaller particles. These smaller particles are called atoms, and an electrical force holds the atoms together. Imagine a cup of water as being composed of molecules, and each of these molecules as being made up of atoms. If you could really see the molecules, you would find that each molecule is composed of two atoms of hydrogen and one atom of oxygen. All the atoms of hydrogen in the molecules look alike. Each atom of hydrogen weighs just as much as every other atom of hydrogen. Similarly all the atoms of oxygen are just alike, and one atom of oxygen weighs just as much as every other atom of oxygen.

But atoms of oxygen are quite unlike atoms of hydrogen. One of the important differences is in weight. An atom of oxygen weighs almost sixteen times as much as an atom of hydrogen.

Each molecule of water contains two atoms of hydrogen and one of oxygen

With this picture in mind you can understand why the chemical formula, or expression, for water is H_2O. H is the chemical sign for hydrogen, and O for oxygen. The formula as written means that there are two atoms of hydrogen and one atom of oxygen in one molecule of water. Is this true? See what happens when water is decomposed. The hydrogen collects in one tube, and the oxygen in another. You have already observed that after water is decomposed, there is twice as much hydrogen as there is oxygen. There are twice as many molecules of hydrogen as of oxygen. The formula H_2O, then, seems to be correct, doesn't it?

Let us look at the hydrogen and oxygen more closely. If you could really see these gases in the tubes after electrolysis, you would observe that the atoms do not remain by themselves for any length of time, but combine with one another, forming molecules. You would see molecules of hydrogen, each composed of two atoms of hydrogen. Both atoms of hydrogen are exactly alike. Similarly you would see molecules of oxygen, each composed of two atoms of oxygen, both of which are alike. These atoms combine in pairs and form molecules as fast as the atoms of hydrogen and atoms of oxygen in the water molecule are released from one another. The formula of hydrogen is written H_2. This shows that there are two atoms in each hydrogen molecule. Similarly the formula of oxygen is written O_2.

What are chemical equations? The chemist uses equations a great deal in describing chemical changes. Some of the equations look rather difficult, don't they? Why do we use them? Chemical formulas are used to tell just what certain compounds are composed of and what changes take place in certain processes. When you see the simple formula H_2O, you know that water is composed of two atoms of hydrogen and one atom of oxygen. A formula, then, is a short way of telling just what elements go into the composition of a certain thing.

A chemical formula tells the composition of a compound

The chemical equation for the decomposition of water is

$$2\,H_2O \longrightarrow 2\,H_2 + O_2$$

This equation tells you many things. It tells you that two molecules of water are decomposed, and two molecules of hydrogen and one molecule of oxygen are formed. It tells you that one molecule of water is made up of two atoms of hydrogen and one atom of oxygen. It indicates that one molecule of hydrogen is composed of two atoms of hydrogen and that one molecule of oxygen is composed of two atoms of oxygen. If you will add the figures, you will find that the number of atoms of hydrogen in the two molecules of hydrogen plus the number of atoms of oxygen in the one molecule of oxygen (six atoms) is just the same as the number of atoms of hydrogen plus the number of atoms of oxygen in two molecules of water. The atoms do not change in weight during the chemical change. It follows, therefore, that the weight of the hydrogen and oxygen that is formed is just the same as the weight of the water that is decomposed. If one gram of water is decomposed, the combined weight of the hydrogen and oxygen that is formed is just one gram. From all this you may come to the conclusion that matter is neither created nor destroyed in a chemical change.

The chemist writes equations to express chemical changes

Matter cannot be created or destroyed

In this study of water you have observed three substances: water, hydrogen, and oxygen. In your study of air you learned several things about oxygen, one of the most important of which was that oxygen makes things burn. You may wish to repeat some of the experiments with oxygen referred to on page 214 so that you may have its properties fresh in mind. Is hydrogen different from oxygen? Let us examine some and see what we may learn about it. Since hydrogen collects very slowly in the electrolysis of water, you may need to get some from another source. Your teacher may prepare some for you or show you how to prepare it for yourself. Be careful if you do prepare it, for a mixture of hydrogen and air is explosive. Flames must be kept away from the apparatus in which it is made. You will notice that bottles in which hydrogen is kept are turned mouth down. Hydrogen is much lighter than air. It escapes from the bottle less rapidly if the mouth of the bottle is turned downward. Can you explain why this is so?

FIG. 138. LAVOISIER, *who was born a Nobleman and died because of It* (*1743-1794*)

ANTOINE LAURENT LAVOISIER was born and brought up in France during the troublesome times just preceding the French Revolution · He was interested in the work of two pioneer English experimenters, Priestley and Cavendish. Priestley had discovered a gas which could be made from the red rust of mercury. He found that he could keep mice alive in it and that a candle would burn brightly in it. Cavendish had discovered still another gas, and this would burn in air · When it burned, water was produced. Lavoisier experimented with the same gases. He named the one discovered by Priestley *oxygen*, and Cavendish's gas *hydrogen*. He discovered that the red rust of mercury weighs more than mercury. He found that when he burned tin, the ashes weighed more than the tin. Can you explain why? · Lavoisier was a friend of Benjamin Franklin, and like Franklin he was interested in many things. He was probably a greater scientist than either Priestley or Cavendish, not because he experimented more, but because he was more able in interpreting his results · Although Lavoisier had always befriended the poor, he had held government offices, and the mob asked for his life. The guillotine, a huge machine containing a sharp blade, was used to sever the heads of hundreds of noblemen, as well as the heads of the King and Queen. Lavoisier's turn came on May 8, 1794. He was in the midst of some chemical experiments. But the mob did not care. It said, "The republic has no need of wise men." · Lavoisier submitted to the will of the mob. His friend Lagrange, the mathematician, said after it was over, "It took only a moment to cut off that head, and a hundred years perhaps will not be sufficient to produce another like it."

Hydrogen burns as it combines with oxygen, forming water

For one of your experiments lift a bottle of hydrogen from the table. Hold the mouth of it downward and bring a lighted match to the mouth of the bottle. The hydrogen will take fire, and, if it is pure (not mixed with air), it will burn quietly for a short time in the bottle. It explodes only when it is mixed with air. When hydrogen burns, a chemical change takes place. In a very definite sense it is just the opposite of the change that takes place when water is decomposed. In the process of decomposition, molecules of water are broken up into hydrogen and oxygen. In the process of burning, atoms of hydrogen and oxygen combine and form molecules of water. This may be shown in the equation the chemist uses to record the burning of hydrogen:

$$2\ H_2 + O_2 \longrightarrow 2\ H_2O$$

This equation tells that the atoms of hydrogen in two molecules of hydrogen combine with the atoms of oxygen in one molecule of oxygen and form two molecules of water.

For your second test secure a wood splinter about six inches long. Set fire to the end of the splinter and, holding a bottle of hydrogen, mouth downward, thrust the burning splinter well into the bottle. Your observation will show something very different from what you saw when you thrust a burning splinter into a bottle of oxygen. In hydrogen the splinter does not burn at all. In oxygen the splinter burned furiously. You decide that hydrogen will burn, but a splinter will not burn in it.

B. What Chemical Changes take Place in Burning? How may these be Controlled?

Some time ago, you will remember, you experimented with the process of burning. Carbon, you will recall, combines with oxygen from the air. Heat and light result.

This may be illustrated more clearly. Coal, our most common fuel, is composed of carbon and compounds of carbon. As the coal burns, atoms of carbon combine with atoms of oxygen and form molecules of carbon dioxide. The equation for the change is

$$C + O_2 \longrightarrow CO_2$$

In this change one atom of carbon combines with two atoms of oxygen and forms one molecule of carbon dioxide.

Let us study this process of burning. Whether you wish to burn coal or wood, or light a candle or a gas stove, you know that one thing has to be done. The fuel has to be heated to the point where it will burn. This point at which fuel begins to burn is called the kindling temperature. Different fuels have different kindling temperatures. You know that it is difficult to start a fire of hard coal, but that splinters of pine wood may be lighted very easily. Before matches were invented, our great-grandparents used tinder in starting fires. Tinder is made by heating linen cloth in a closed box. It is partially decomposed by heating; but since oxygen cannot get to it, the cloth does not burn. Try to make some. The kindling temperature of tinder is so low that it may be lighted with a spark from a piece of steel struck with flint. If you wish to discover differences in kindling temperatures for yourself, take any six substances, such as chalk, a bit of wood, hard coal, soft coal, the head of a match, and some cotton. Place them on an iron plate over a fire. Watch for results. List your substances in the order in which they catch fire. Which seems to have the highest kindling temperature? Which seems to have the lowest? Which will not burn?

Different substances have different kindling temperatures

Once a fuel begins to burn, the heat from the chemical change is sufficient to keep it burning. The problem then is one of control. A fire in a furnace is kept under control by using a draft. In order to hasten the fire the draft is

Fig. 139. Fire is Due to the Combination of Oxygen with Fuels

Sometimes this chemical change gets beyond human control

opened. More oxygen is admitted, and the combination of atoms of carbon and atoms of oxygen takes place faster. Since carbon is burned to produce heat, it is plain that the faster it burns, the greater will be the heat produced.

Difficulty arises when this combination of oxygen and carbon cannot be controlled. Typical examples may be found in a forest fire or in a burning building. In these cases there are no controlling drafts, and the oxygen and carbon combine freely. If a wind is blowing, as in Fig. 139, the carbon dioxide formed in the flames is carried away rapidly, and a continuous supply of oxygen is furnished. The result is a fire that is difficult to control.

How may fires be controlled and checked? Your understanding of the process of burning should give you a clue to the answer. Since fire is associated with the combustion of a fuel and oxygen, burning obviously cannot continue if oxygen is by some means cut off from the fuel, if the fuel

FIG. 140. A Fire may be extinguished by Smothering, Reducing the Kindling Temperature, or Removing the Fuel

is removed from the fire, or if the fuel is cooled below its kindling temperature. How may these things be done?

A common method of putting out a fire is to throw water on it. The water serves two purposes. It may cool the burning substance below its kindling point. This will, of course, put the fire out. It may also produce steam about the fire, which will dilute the oxygen, so that the fire cannot burn so rapidly. A simple method of putting out a grass fire is to throw dirt on the burning grass. The dirt shuts off the supply of oxygen. This stops the chemical change, and the fire goes out. In Fig. 140 you will find illustrations of several methods for putting out a fire.

Burning stops when the fuel is cooled below its kindling temperature

There are still other ways. In nearly every school, public building, store, and factory you see fire-extinguishers on the walls. These are effective only for small fires. There are two kinds of these in common use. Both of them work in much the same way. One furnishes a mixture of water and of carbon dioxide. Carbon dioxide is more useful than steam in diluting the oxygen about a fire. It is a heavy gas and thus makes an excellent fire-extinguisher. You can easily test its qualities for this purpose. Collect some carbon dioxide by placing a piece of "dry ice" in a bottle and leaving it until the ice evaporates. Hold the bottle upside down two or three inches above a burning candle. The candle is put out immediately. Why? The carbon dioxide gas, being heavier than oxygen, surrounds the fire and reduces the supply of oxygen. Without this oxygen the chemical change which takes place in burning cannot go on. The fire, then, goes out.

Burning stops when oxygen supply is removed

The second type of fire-extinguisher works in much the same way, but a different substance, known as carbon tetrachloride, is used. This substance is ordinarily a liquid, but, when sprayed on a fire, it is changed to a heavy gas which very effectively shuts off the supply of oxygen from the flame.

Man has used much of his increased knowledge of the chemical changes taking place in burning to perfect inventions for the control of fire. He is, however, still a long way from completely controlling it. Every year hundreds of millions of dollars' worth of property is lost by fire in the United States. Homes, schools, churches, factories, and public buildings are burned to the ground. Large areas in city and country alike are swept by fire and ruined. Nor is the property loss all, for hundreds of lives are lost in these fires every year.

Some of these losses are beyond man's control. Lightning may strike in a forest and set fire to the dry leaves or dead trees. It has been estimated, however, that over 75 per cent of American fires can be prevented and are due to only one thing — carelessness. Of this fault many citizens are guilty. Hot ashes are dumped into wooden barrels; lighted

Many destructive fires are due to carelessness

matches and cigarettes are thrown carelessly into a wastepaper basket, on a wooden floor, into a mass of dry leaves, or into the underbrush along a mountain path. Chimneys are allowed to fill up with soot. Open fires are built in back yards on windy days. Stove and furnace pipes are placed next to wooden beams; oil stoves are carelessly filled or allowed to become dirty. Open fireplaces are left to burn all night without even a protecting screen in front of them. The amateur electrician wires bridge or table lamps but forgets to insulate his connections properly. A citizen, patriotic in other ways, celebrates the Fourth of July by setting off skyrockets or Roman candles which unfortunately throw sparks on the roof of his own or his neighbor's house. Even in this day and age people still attempt to pour kerosene on a slow fire. Others do their own dry cleaning with gasoline in a room where there is an open flame. All these practices may lead to dangerous fires, with loss of life and property. All of them are careless practices and can be avoided.

In spite of all precautions you sometimes meet an emergency caused by fire. At such times each one of you should know what to do. You should know how to turn in a fire alarm, and, if you live in a city, you should know where the nearest fire-alarm box is located. You should know that, though water is effective in putting out some fires, it should not be used in fighting oil or gasoline flames. Water is denser than gasoline; so the gasoline floats on the surface of the water and continues to burn. In such cases sand or soil should be used. You should realize that some kinds of clothing take fire easily and should be especially careful. In case a person's clothing does catch fire, you should know that one of the best means of putting out the fire is to wrap a rug, an overcoat, or any other kind of woolen cloth around the person, and then roll him on the ground or floor. Wool burns very slowly, and it serves to shut off the oxygen supply from the burning clothing. Pure silk burns slowly, but cotton, linen, and artificial silk burn very rapidly. You should be thoroughly familiar with the fire exits in your school or in any other building where you spend much time. You should know what to do in your own home in case of fire. But most of all you should realize the necessity of constant care in handling materials that are likely to burn.

We have now discussed several familiar types of chemical change. There are many others which may not be so familiar, but which are just as definitely chemical changes as those we have mentioned. When iron, which is an element, is exposed to air, it rusts. Iron rust is formed by the combination of atoms of iron with atoms of oxygen. Iron rust is a form of iron oxide. When iron is used in construction work, such as fences or bridges, it is covered with a coat of paint to keep it from rusting. Paint keeps oxygen away from the iron.

Rusting of metals is chemical change

Some metals combine with oxygen less rapidly than iron combines with oxygen. Some combine much more rapidly. Copper combines slowly with oxygen. When you polish copper, you rub off the dark-colored copper oxide that has formed on the surface. Sodium is a metal that combines very rapidly with oxygen — in fact, so rapidly that it must be kept away from the air. In the chemistry laboratory sodium is kept under kerosene.

Iron combines with sulfur

Iron combines with sulfur under conditions somewhat similar to those under which carbon combines with oxygen. You may mix powdered iron and sulfur together, and nothing will happen until the mixture is heated to the kindling temperature. Then the chemical change goes on vigorously, and a great deal of heat is produced. A mixture of powdered iron and sulfur may be heated on an asbestos pad. When the mixture is heated sufficiently, chemical action begins. In this example of the burning process atoms of iron combine with atoms of sulfur and form molecules of iron sulfide. The chemical sign for iron is Fe, and for sulfur S. The equation for this chemical change is

$$\mathrm{Fe} + \mathrm{S} \longrightarrow \mathrm{FeS}$$

In other words, one atom of iron combines with one atom of sulfur and forms one molecule of iron sulfide.

C. Is Energy always associated with Chemical Change?

Let us see now what conclusions we can reach from what we have learned about the processes of chemical change. Is energy associated with all these processes? Was energy used in the decomposition of water? Yes, a great deal of it in the form of electricity. How about the process of burning, whether of an element such as hydrogen, or of fuels such as wood or coal? Is energy in evidence there? The answer is obvious, isn't it? Energy is released in the form of heat. And so it goes. Fuels are burned in a furnace and in a steam engine in order to get, from the chemical change, the heat that is used to warm a house or to run an engine. We eat foods in order to get energy from the chemical change that takes place as oxygen combines with the food. Energy from sunlight is required for the chemical changes that go on in green plants during the process of food-making. The chemical changes in food-making and food-using change energy from sunlight to the energy that is used in the cells of all plants and animals.

We eat foods in order to get the energy secured from the sun in food-making

In all these processes one very interesting thing may be noted. Chemists have found from careful measurements that the amount of energy required to decompose one gram of water is just equal to the amount of energy released when one gram of water is formed by burning hydrogen. Again chemists tell us that the amount of energy required in making one gram of food is just equal to the

Energy used up in the electrolysis of water is released in burning hydrogen

amount of energy released when oxygen combines with one gram of food in the cells of the body. In other words, there seems to be a balance in these energy changes. You will learn more about this as you continue with your science work.

In chemical changes molecules of compounds may be decomposed into elements, and molecules of compounds may be formed from chemical elements.

All chemical changes either release energy or store energy.

Can You Answer these Questions?

1. Suppose you were trying to light a fire and could not succeed. What would you investigate?

2. Why do we say, "Never run if your clothing catches fire"? What should you do?

3. The statement is made that oxygen weighs almost sixteen times as much as an equal volume of hydrogen. What evidence have you already had that there is a difference in the weight of these two elements?

4. The statement is made in this chapter that "matter is neither created nor destroyed in a chemical change." Can you give any evidence that this statement is true?

5. In what ways do each of the following things act in extinguishing fires?

   a. Water.
   b. Sand.
   c. Carbon dioxide.
   d. Carbon tetrachloride.
   e. A wool blanket.

6. Should you expect water to form when hydrogen is burned? Why?

7. Whenever you see the iron framework for a building or even iron fence posts as they come from the mill, you find the iron covered with a coat of paint. If you ask about it, you are

told that the paint is there to prevent rusting. How can a coat of paint prevent rusting? What is rust?

8. Can you give some examples of how energy is released through chemical changes?

9. What is the difference between an atom and a molecule?

Questions for Discussion

1. How can you explain the fact that hydrogen itself will burn, and yet a splinter of wood held in pure hydrogen will not burn?

2. A science teacher, in talking about energy, used the phrase *chemical change* very frequently. Finally one of her pupils said, "What do you mean by chemical change?" Could you have answered this question?

3. Can you give ten or twelve good rules for fire prevention? Defend your list.

4. It is quite possible for rubbish to catch fire, even though no open flame is brought to it. This is called spontaneous combustion? What do you know about this? Do you think chemical changes have anything to do with it?

Here are Some Things You May Want to Do

1. You might write to a number of companies who make fire-extinguishers and ask them for literature on their products. See if you can find out from this literature the factors which they have considered in making their fire-extinguishers.

2. Make a study of fire losses in your community; in the United States; in some foreign countries. Report your results to the class.

3. If you have a fire department in your community, invite a representative of it to come to school and talk on fire prevention.

4. If you have a chemical fire-extinguisher in your school, bring it to the classroom and examine its parts. Ask the janitor to show you how it works.

Chapter XVIII · What are Things Composed Of?

A. What are Some of the Differences between Elements and Compounds?

Many years ago, before man knew as much about his environment as he knows today, he believed the earth consisted of but four things — earth, air, fire, and water. All things were supposed to be a combination of these four "elements." It was believed that different substances were different because they contained these "elements" in different proportions. As time went on, new things were added to the list. As the knowledge of chemistry developed, it became obvious that this notion held by the ancients was entirely wrong, for the things which they had named as elements are not elements at all.

The word *element* is not new to you now. You have seen and heard oxygen and hydrogen referred to as elements. The meaning of the word may not be entirely clear to you, however. What is an element? Is gold an element? salt? water? air? copper? sugar? These are all common things, but are they elements? Perhaps some of the work you did in your last chapter may help you. You learned that molecules of water are composed of the atoms of two substances, hydrogen and oxygen. You learned further that a molecule of hydrogen is itself composed of two atoms, both of which are just alike. Similarly a molecule of oxygen is itself composed of two atoms. Both of these, too, are just alike.

Here, then, are two different types of substances. Molecules of water are a combination of atoms of hydrogen and oxygen. Water is called a compound. Oxygen and hydrogen are called elements. From what you now know, you can define these terms. If the molecules of a substance are composed of more than one kind of atom, the substance is called a *compound*. If the molecules of a substance are composed of atoms that are just alike, the substance is called an *element*. You already know that molecules of water can be decomposed into elements. Knowing that water is a compound, you decide that compounds can be decomposed into the elements of which they are made up. In a chemical change, however, elements cannot be decomposed at all. Since hydrogen and oxygen are elements, neither of them can be decomposed by chemical processes. An element is in a sense a simplest form of matter.

A substance whose molecules consist of more than one kind of atom is a *compound*. A substance whose molecules consist of but one kind of atom is an *element*

Elements make up the parts of every compound. Water is a compound of two elements; but air, as you have learned, is a mixture of elements and compounds. Air is not a compound, for the elements are not combined.

What, then, is the difference between a compound and a mixture? You have learned in your study of water that when water is decomposed twice as much hydrogen as oxygen is formed. This illustrates a definite property of a compound. Elements are always present in exactly the same proportions in any sample of a compound. In the case of a mixture this may not be true, for substances may be mixed in any proportion. Air is a mixture, and the amount of nitrogen, oxygen, and other substances in the air is nearly the same under ordinary conditions. However, it is not always the same. There may be more or less than 21 per cent of oxygen, and there may be more or less than three or four hundredths of 1 per cent of carbon dioxide. The sample is still air. Air dissolved in water contains nearly 35 per cent of oxygen. Close to a large furnace the percentage of carbon dioxide may be as much as five hundredths of 1 per cent. Since air is a mixture, it is still air under all these conditions. Water is a chemical compound, however, and the percentage of hydrogen and oxygen in water is always the same.

If you were to make a guess, you might say that elements are the substances from which all things are made. Would your guess be a good one? Consider some of the things this may mean. As you look around, you see trees and all kinds of living things. You see rocks, soils, and clouds. There are rivers, houses, factories, and cities; airplanes, railroad trains, and airships. Is the material in all these things made up of elements? Is it possible that all these and many more things you are familiar with are made up of combinations of only ninety-two different substances? This may not seem reasonable. And yet it is so!

All the things on earth are made up of ninety-two elements

Chemists have analyzed most of the common substances that compose the surface of the earth. From these analyses, or studies, you may learn the names of the elements of which familiar things are composed. Sand is one of the most common substances in the soil. Analysis shows that it is composed of two elements, oxygen and silicon. Clay is another familiar substance. It is a compound of oxygen, hydrogen, silicon, and aluminum. Granite is a mixture of the minerals known as quartz, mica, feldspar, and some other materials. The minerals themselves are compounds and are composed of atoms of oxygen, silicon, aluminum, potassium, and some other elements. Limestone is the same in composition as marble. Its molecules are composed of atoms of calcium, carbon, and oxygen.

Consider our foods. Sugar is a compound, the molecules of which are composed of atoms of carbon, hydrogen, and oxygen. Molecules of starch contain the same elements as molecules of sugar. Molecules of butter and of all other kinds of fats and vegetable oils used for food are also composed of atoms of carbon, hydrogen, and oxygen.

Notice that some of these foods are made up of the same elements and yet have different properties. This frequently happens. There are cases in which compounds are com-

Fig. 141. Madame Curie, *who discovered Radium*

Little Marie Sklodowska was the daughter of a scientist in Warsaw, Poland · She too wanted to be a scientist. She went to the University of Paris. After a time she got a job as caretaker in one of the laboratories. Soon she married a young assistant in the same laboratory, Pierre Curie · A few years before, Becquerel had discovered that uranium gives off light in the dark. Pitchblende, an ore taken from mines in Austria, also gave off curious and powerful rays. Did it contain uranium? Madame Curie obtained some pitchblende and set to work to see if she could extract uranium · She did; but imagine her surprise to observe that the pitchblende from which the uranium had been taken gave off about as many of the strange rays as it had before! · Was there a still more powerful element in the ore? Now her husband helped her. Getting a ton of pitchblende, they used every means known to chemists to extract the substance responsible for the curious rays. When they had finished they had a small amount of grayish powder — less than a cupful. Rays were given off from it that would pass through wood and sheets of metal, and its power did not seem to diminish even after use. The powder was a chemical compound, containing atoms of chlorine and atoms of the new unnamed element. The Curies called it radium · For their discovery Pierre and Marie Curie were given the Nobel prize in physics. Thirty years ago Pierre Curie was killed in an automobile accident. Since then Madame Curie has gone on alone. She separated the element radium from its compounds. She has received the Nobel prize a second time for her work in chemistry. In this picture she is shown with her daughter, who is also a scientist.

posed of the same elements but are quite different in properties. How is this possible? Gasoline and lubricating oil are composed of the same elements, hydrogen and carbon, yet are different substances. The substances are different because the number of atoms of the different elements in the molecules are not the same in different substances. The difference between sugar and fat is explained in the same manner.

Substances may be different, though the elements in them are the same

Let us examine a few more common things. The protein in meats is composed of carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, and small amounts of some other elements. Table salt is a very simple compound. Its molecules consist of atoms of sodium and chlorine. Ordinary soap is a compound of sodium, carbon, hydrogen, and oxygen. Fuels are composed of carbon or of compounds of carbon. Coal is, for the most part, a mixture of carbon and of compounds of carbon and hydrogen. It also contains compounds of nitrogen, of sulfur, and the compounds which form the mineral matter that is left as ash when the coal is burned. The gas that is used for fuel is a mixture containing hydrogen, compounds of carbon and hydrogen, and a compound of carbon and oxygen.

All these substances are compounds or mixtures of compounds and elements. The molecules of the compounds are composed of more than one kind of atom. Are all the common things around us compounds? No, there are many familiar substances that are not compounds. The metals are elements. Iron is perhaps used for more different purposes than any other element. Other familiar metals are aluminum, copper, zinc, lead, tin, magnesium, nickel, gold, and silver. Oxygen, nitrogen, and argon are also elements.

Metals are elements

We have named many different kinds of substances in the preceding paragraphs; but if you will check through them, you will find the names of the same elements time and time again. From the results of this analysis you may be inclined to agree that perhaps ninety-two elements are all that are necessary. Let us see if we can give you some additional evidence. The following table indicates the percentage, by weight, of the various elements in the earth's crust. The abbreviation which the chemist uses to write the name of the element is in parentheses. The crust of the earth includes rocks, minerals, soil, water, air, and all living things. No one knows for certain what is beneath the crust of the earth, say, ten or twelve miles down, but there are some good reasons to believe that a large part of the interior of the earth is iron.

COMPOSITION OF THE EARTH'S CRUST (BY WEIGHT)

Oxygen (O)	49.2	99.1 per cent	Sulfur (S)	Less than 1.0 per cent
Silicon (Si)	25.7		Nitrogen (N)	
Aluminum (Al)	7.4		Carbon (C)	
Iron (Fe)	4.7		Copper (Cu)	
Calcium (Ca)	3.4		Zinc (Zn)	
Sodium (Na)	2.6		Lead (Pb)	
Potassium (K)	2.4		Tin (Sn)	
Magnesium (Mg)	1.9		Nickel (Ni)	
Hydrogen (H)	0.9		Silver (Ag)	
Titanium (Ti)	0.6		Gold (Au)	
Chlorine (Cl)	0.2		All other elements	
Phosphorus (P)	0.1			

What does this table tell you? From the figures given you can see that 49.2 per cent of the entire weight of the earth's crust is oxygen. In other words, if you were to add together the weight of all the rocks, minerals, soil, water, air, and all living things that make up the surface of the earth, 49.2 per cent of this total weight would be due to oxygen. If you add together the percentage of oxygen and the percentage of silicon, you see that very nearly 75 per cent, or three fourths of everything in the crust of the

Three fourths of the earth's crust is composed of oxygen and silicon earth, is composed of these two chemical elements. Notice, too, that the left-hand column lists twelve elements, and that if you add up the percentages in this list, you get 99.1 per cent. In other words, twelve elements make up over 99 per cent of the total weight of the earth's crust. The remaining eighty elements make up less than 1 per cent. Some of these are extremely rare, for example, radium. If all the radium from all the laboratories in the world were brought together, there would be less than half a pound of it. Several other elements are even less abundant than radium.

A further study of the table will show you some interesting things. You may be surprised to learn that there is more aluminum than iron in the crust of the earth. Aluminum is contained in clay and in many rocks and minerals. It is more expensive than iron because it can be separated from its compounds only by a very difficult and therefore an expensive process.

Some of the elements with which you are most familiar make up but a very small percentage of the total weight of the earth's crust. Nitrogen makes up nearly four fifths of the atmosphere, but it forms much less than 1 per cent of the total weight of the earth's crust. Some of the fairly familiar metals, like lead, tin, copper, silver, and gold, are present on the earth in relatively very small quantities. Carbon is a very familiar element to you, for you know it is contained in coal and in other fuels and is a part of the composition of all foods. Nevertheless carbon makes up only a very small percentage of the total weight of the crust of the earth. It is considerably less than one tenth of 1 per cent of the total.

Elements are the building blocks of the universe

All the ninety-two elements known to the chemist are distinctly different one from another. The elements are the "building blocks" out of which a practically unlimited number of compounds are made. Some elements form a part of a great many compounds. There are tens of thousands of compounds containing carbon and probably an equally large number containing oxygen and hydrogen. There are thousands of compounds containing sulfur. Some of the elements — gold is an example — are found in only a few compounds. There are some few elements, such as argon and helium, that form no compounds at all.

We know more about some of these elements than we do about others. Each of them has its own peculiar properties and acts in its own individual way when it comes in contact with other elements.

Oxygen is one of the most active of all the elements, for it combines readily with a large number of other elements. It combines with hydrogen and forms hydrogen oxide (H_2O), or, as it is commonly called, water. It combines with silicon and forms silicon dioxide (SiO_2). This you know as sand or as quartz. In combination with iron, oxygen forms iron oxide (Fe_2O_3), which is a form of iron rust. It combines with calcium and forms calcium oxide (CaO), or quicklime. When the flash-light powder used in photography explodes, magnesium combines with oxygen to form magnesium oxide (MgO). Oxygen, then, combines readily with many of the metals.

Chlorine is another very active element, and, like oxygen, it combines readily with many metals. A compound of chlorine with a metal is called a chloride. Sodium chloride is the chemical name for common table salt. But here is something that may seem strange: Chlorine has been used as a poisonous gas in warfare. Perhaps you have a piece of sodium in your science workroom. If so, you may learn from observation how furiously it acts when even a very small piece of it is placed on water. If chlorine or sodium were taken separately into the body in any considerable amount, either would cause death. Yet when they combine, we have that harmless and very important factor in our daily diet — ordinary table salt. Fig. 142 shows the interior of a salt mine. This is simply a large deposit of sodium chloride ($NaCl$).

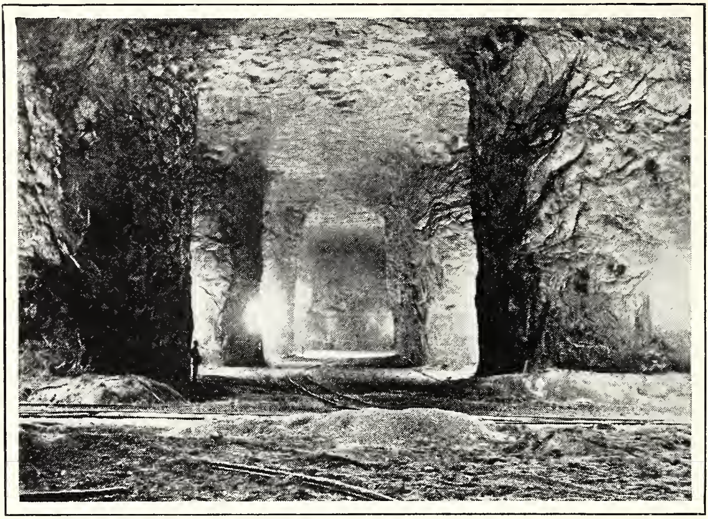


Fig. 142. This Salt Mine is the Result of the Combination of Sodium and Chlorine on a Large Scale

Let us consider one or two other elements. Nitrogen is in some ways a peculiar element. It does not combine readily with other elements, but with some difficulty a considerable number of nitrogen compounds may be made. Ammonia (NH_3) is one of the most familiar of these. When coal is heated strongly in a test tube, ammonia is released from the coal. Gas that is burned in gas stoves is made by heating coal. Ammonia is one of the products of the gas industry. Much of the ammonia that is used in industry has been made from coal. Coal is made from the remains of living things. It must, therefore, contain nitrogen compounds, since nitrogen is contained in all living matter. Ammonia may also be manufactured by causing nitrogen and hydrogen to combine. A large amount of energy is required in the process. Part of the energy from the great power plants at Niagara Falls and at Muscle Shoals is used to make ammonia.

Nitrogen compounds often decompose readily. They make good explosives

Some nitrogen compounds are used to a great extent as explosives. Dynamite and gunpowder are made from nitrogen compounds. They make useful explosives because they decompose so readily. A sudden jar will make the compound of nitrogen known as nitroglycerin decompose instantly. Dynamite is made from nitroglycerin. By the explosion a large volume of gas is suddenly released. It is this sudden release of a large amount of gas that makes an explosion of dynamite so terribly destructive. The force of this may be seen in Fig. 143. You may have seen similar explosions.

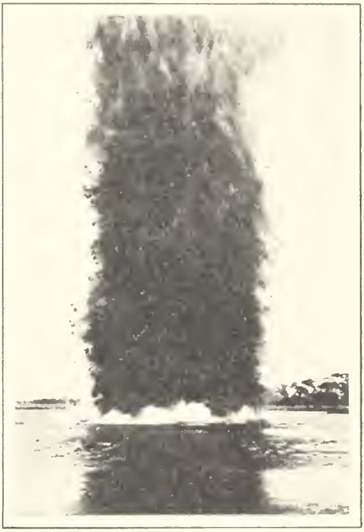


FIG. 143. Some Nitrogen Compounds make Useful Explosives because they decompose Readily

Phosphorus is another peculiar element. It is contained in foods and is a part of the composition of bones, teeth, and nerve tissue. Phosphorus, as an element, combines very rapidly with oxygen and in the process gives off a great deal of heat. Phosphorus is used in the manufacture of matches. One form combines so readily with oxygen that it must be kept under water all the time in order to prevent it from taking fire and burning up. The warmth of your fingers is enough to set it on fire. For this reason one never handles that form of phosphorus except with a pair of pincers. Pure phosphorus is a deadly poison. It is used in rat poison. Yet some phosphorus compounds are absolutely essential in your food.

B. What is a Pure Substance and What is a Mixture?

From what you have now learned, you can understand why the chemist sees everything about him as a compound or a mixture of compounds, an element or a mixture of elements, or a mixture of compounds and elements. Often when you see these substances you ask, "Is this pure?" This is especially true of foods, water, medicines, or rare metals. You use the terms *pure milk, pure air, pure water, pure food, pure gold,* and the like. What is meant by these? Is anything really pure in the sense that it is free from any foreign substances? You speak of pure water; but you learned that if you were to make a list of the number of different kinds of molecules in a sample of very carefully purified water, that list would be rather long. There would be found molecules of oxygen, nitrogen, carbon dioxide, ammonia, and some others. A sample of water from a spring would contain molecules of the gases of the air and of mineral substances dissolved from the soil through which the water has flowed. Ordinarily when you say water is pure, you mean simply that it has no impurities in it that make it dangerous to drink.

It is difficult to get an absolutely pure substance

Soil too is far from a pure compound, for it is composed of little pieces of broken rock, of products that are formed from the decomposition of rock, and of products left from the partial decay of plants and animals. Water and air are also in the soil. The soil is a sort of "catchall" for many things. If you could name all the different kinds of molecules that there are in the soil, you would have a very long list.

Soil is a mixture

Almost every substance is to some extent impure, for it is very difficult to prepare any compound with such care that no molecules of other substances are mixed with it. Even in the case of chemicals prepared under very careful conditions, it is nearly impossible to secure absolute purity. If you buy even the best chemicals, you will find that the manufacturer does not say the chemicals are pure. You usually find on the label the results of a chemical analysis, or examination, that show the amount of impurities present. These will be small, but there will always be some. The following tables give an analysis of two carefully prepared samples of chemicals. These have been taken from the labels of two bottles containing these substances.

SODIUM CHLORIDE (COMMON TABLE SALT)

	Per Cent
Bromide	0.014
Iodide	0.012
Nitrogen compounds	0.001
Phosphate	0.000
Sulfate	0.001
Barium	0.001
Calcium and magnesium	0.005
Iron	0.0005
Other heavy metals	0.000
Potassium	0.180

SODIUM BICARBONATE (ORDINARY BAKING SODA)

	Per Cent
Sodium carbonate	Trace
Chloride	0.003
Phosphate	0.001
Silicate	0.000
Sulfocyanate	0.020
Sulfur compounds	0.003
Thiosulfate	0.006
Ammonium compounds	0.000
Calcium and magnesium	0.010
Iron	0.001
Other heavy metals	0.000
Potassium	Trace

Sodium chloride, as you know, is common table salt. Sodium bicarbonate is baking soda. The substances analyzed have been purified by the most highly refined processes; yet both these substances contain traces of many things.

What is real purity, then? A sample of an element or of a compound is really pure only if there are no molecules of other elements or compounds mixed with it. It is very difficult, if not impossible, to prepare such a sample.

C. What Changes are found in the Carbon Cycle?

All growing things contain compounds of carbon

You are already familiar with carbon as an element and know that it is a very common one. Petroleum is a mixture of hundreds of different carbon compounds. Some of these compounds are used as gasoline, some as kerosene, some as lubricating oil, and some for other purposes. You have learned that many different carbon compounds are used as fuels, and a great many others are used as foods.

If you will in your imagination follow an atom of carbon through some of the changes through which it passes, you will understand that this element becomes a part of many different substances.

We follow a carbon atom through a number of chemical changes

Suppose you start with the carbon atom in a molecule of one of the compounds in gasoline. As the gasoline is burned in the cylinders of an automobile, this carbon atom combines with two atoms of oxygen. A molecule of carbon dioxide (CO_2) is formed. In this chemical change energy in the form of heat is released. This energy helps to furnish the power which runs the automobile. The molecule of carbon dioxide, containing a carbon atom, escapes through the exhaust into the air. The molecule is continuously moving, and with the aid of the wind it may travel for a great distance. At length it comes over a field of wheat. Presently it passes through one of the stomata on the underside of a leaf into one of the cells where the food-making process is going on. Here a chemical change takes place in which the two atoms of oxygen are separated from the atom of carbon. Energy is required to separate these atoms. In this case the necessary energy comes from the sun. In the leaf the carbon atom you are following combines with atoms of hydrogen and oxygen from water molecules that have come up from the soil. Other carbon atoms join the compound, and the three kinds of atoms unite to form a molecule of sugar. The formula for this molecule of sugar is $C_6H_{12}O_6$. You will notice there is a total of twenty-four atoms in this molecule. The sugar passes along with the "sap" in the plant to the head, where grains of wheat are forming. In the wheat grain the sugar changes to starch. Now the carbon atom that only a little while before was part of a molecule in gasoline is part of a molecule of starch in a grain of wheat. After a time the wheat is cut, the grain is ground into flour, and bread is made. The bread is eaten by a man and digested, after which the carbon atom passes into the man's blood. The molecule containing the carbon atom that you are following may be carried by the blood to a muscle cell in the arm. Oxygen is also carried by the blood to this muscle cell. There the carbon atom combines with two atoms of oxygen and becomes again a part of a molecule of carbon dioxide. Once more energy is released. If you could measure this energy, you would find that the amount is just equal to that supplied by the sun and used to separate the two atoms of oxygen from the atom of carbon in the wheat leaf. The molecule of carbon dioxide now passes into the blood from the muscle cell of the body and is carried to the lungs. From there it passes again into the air. In your imagination you might follow this carbon atom further and find that at a later time it became part of a molecule in the trunk of a tree or possibly in a blade of grass. If it were in a blade of grass, the blade might be eaten by a cow, and the carbon atom might finally be sold as part of a molecule contained either in milk or in butter or in beefsteak. In any case, it might return to the body of a human being. Through all these changes the carbon atom remains the same, but the compounds of which it is a part at one time or another are very different. The carbon cycle, then, is a succession of chemical changes. In these changes many chemical compounds have been formed and destroyed, but the carbon atom seems to be everlasting.

D. Are All Things in a Continuous Process of Change?

Changes are effected by rearrangements of atoms

This imaginary journey of a carbon atom reveals only one example of continuous chemical change. All sorts of such changes are going on in the world about us. All of them are simply rearrangements of the atoms of the chemical elements. Atoms in molecules of lifeless things become by chemical changes atoms in molecules of living things. These living things die and decay. This latter process is another illustration of chemical change. Rocks are formed as a result of chemical changes and are decomposed by other chemical changes. Minerals are chemical compounds, and rocks are mixtures of chemical compounds. The molecules of the compounds of which rocks and minerals are composed may be destroyed. But to destroy a molecule is merely to separate or to rearrange the atoms of which it is composed. A new molecule is formed when atoms combine. In all these changes the atoms of the elements remain the same. They are the building blocks of which chemical compounds are formed.

E. Are Atoms the Simplest Form of Matter?

When you first began your study of water, you saw a panful of that substance as merely a mass of liquid. Later you learned about the molecular theory, which pictures water as a mass of particles, or molecules. Still later you found that these molecules may be decomposed into atoms. The theory of atoms, like the theory of molecules, was suggested in an effort to explain observations of the properties

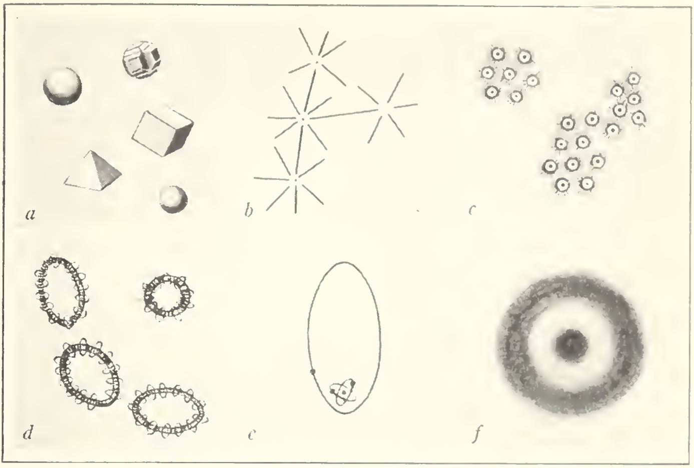


FIG. 144. Man's Idea of the Nature of the Atom has changed as his Knowledge of Matter and Energy has Increased

a, Newton's solid, geometrically shaped particles (1704); *b*, Boscovitch's centers of force (1758); *c*, Dalton's scheme (1810); *d*, Kelvin's vortex atom (1850); *e*, Bohr's solar-system type (1923); *f*, Schradenger's fields of intensity (1925)

of matter. Chemical changes are common observations. Elements do combine to form compounds, and compounds, in turn, may be separated into elements. Careful study of such observations led naturally to the question of how these changes take place.

The ancient Greeks considered that matter is made up of tiny, indivisible particles, that is, particles which cannot be divided into smaller units. The word *atom* is derived from a Greek word meaning "indivisible." The Greeks thought that the atom was so small that it could not be any smaller. Sir Isaac Newton described atoms as "solid, massy, hard, impenetrable, movable particles." His notion of the character of atoms is shown in Fig. 144, *a*. This simple atom, as described by Newton, seemed sufficient to explain all that was known at that time about chemical and physical changes.

As more was learned about the nature of things, it became obvious that Newton's ideas about the nature of the atom were not sufficient. There seemed to be forces within the atoms, for some chemical changes took place with great violence. Diagrams of atoms made in 1758 were efforts to represent them as centers of force (Fig. 144, *b*).

Man's idea of the nature of the atom has changed

After the early part of the nineteenth century the science of chemistry developed rapidly. A notion of the atom as drawn about 1810 is shown in Fig. 144, *c*. Lord Kelvin, late in the nineteenth century, recognized that the atom was more complex. His idea of the atom is shown in Fig. 144, *d*.

After the discovery of the properties of radioactive elements and of X rays it seemed clear that atoms must be in some ways electrical. Diagrams of recent ideas of the nature of the atom are given in Figs. 144, *e*, and 144, *f*.

As man has increased his knowledge of the nature of matter, it has become necessary to make more and more complex theories concerning the nature of atoms, of which it is supposed matter is composed. It seems certain that the atom is not the simplest form of matter. Observations have led scientists to believe that atoms themselves are composed of smaller particles and that these are "particles" of electricity. They believe that these smaller particles are of two kinds. One is a form of positive electricity, and the other is a form of negative electricity. The negative particles of electricity are called electrons, and the positive particles are called protons. According to this theory, termed the electron theory, all electrons are alike, and all protons are alike. Each atom of an element is a group of one or more electrons with an equal number of protons. Let us in our imagination look at an atom of hydrogen, the lightest and simplest of all the atoms. It consists of one electron and one proton. These hold to-

According to the electron theory atoms are composed of electrons and protons

gether and form an atom. How are they held together? you may ask. It is believed that the force is an electrical one. In order to see how this is possible you must understand a law of electricity which states that positive electricity will not attract positive electricity but will repel it. Similarly negative electricity will repel negative electricity. Only opposite charges attract. Thus positive electricity will attract negative electricity. The opposite is also true. Now go back to the hydrogen atom. We have said that the proton is positive electricity and the electron is negative electricity. If our law of electricity is true, these should attract each other. According to the electron theory they do; an atom is composed of an equal number of electrons and protons held together by their attraction for each other.

The proton is very much heavier than the electron, but its positive electrical charge is exactly equal to the negative electrical charge of the electron. The theory supposes that the electrons move very rapidly. In the case of the hydrogen atom the one electron moves about the one proton in an orbit in somewhat the same way that the earth moves about the sun.

Another simple atom is that of helium. It is composed of four electrons and four protons. Here again the positive electricity balances the negative electricity, and so the atom is held together. According to the electron theory each of the ninety-two elements differs from the others only in the number and arrangement of the electrons and protons of which it is composed.

The elements differ from one another in the number and arrangements of electrons and protons

If this is a true picture of atoms, it would seem as if we should be able to destroy them by forcing the protons and electrons apart and, further, that we should be able to form atoms by bringing them together again. Some scientists think that at some time they may perhaps be able to do this. The energy thus released may, they believe, be used for some practical purpose. Atoms of radium and of some other elements break up of their own accord; but no way is known at present to stop them from breaking up, and no way is known to make them break up faster. These problems still remain to be solved. If you wonder why scientists are interested in this problem, consider the energy that would be ready for our use if the countless millions of atoms making up the elements around us could be broken up into electrons and protons.

Is all the matter of the universe composed of the same elements as those on earth?

Have you ever stood out in the open on a cold winter's night and marveled at the canopy of stars which seems to reach from one horizon to the other? Perhaps you have seen a glorious full moon bathe a familiar landscape in the beauty of reflected light. Have you ever wondered as you saw these things just what these distant neighbors were? Are they like the earth? Are they like the sun? Is there life upon them? Not all these questions can be answered, for much still remains to be learned about the stars and other heavenly bodies. We do know, however, that their composition is similar to that of the earth.

How has man learned this? you may ask. He has learned it from his study of the light from the sun. You probably know that the colors of the spectrum, from red on one side to violet on the other, are secured by allowing light from the sun to pass through a glass prism. Every element that is present in the atmosphere of the sun produces an effect on the solar spectrum that may be discovered with the aid of an instrument known as the spectroscope. Since the sun is so extremely hot, many of the elements which we know as solids on the earth are present as gases in its atmosphere. There is very convincing evidence that the chemical elements of which the sun is composed are the same as the chemical elements of which the earth is composed. Not all the ninety-two elements known on the earth have been found in the sun, but many of them have. No elements have been found in the sun that are not known to exist on earth. The same thing is true of the stars. The elements which have been found in the stars are the same as the elements on earth. These elements may be present in different combinations in the sun and the stars, but no new elements have been found.

The stars are composed of the same elements as the earth

We have even more direct evidence. Every once in a while an object comes to the earth from the sky. These objects are called meteorites. You can see collections of them in a museum. Chemical analysis of these strange visitors has shown that there are no chemical elements in them other than elements already known on the earth. For the most part they are composed of the elements that are most abundant on earth. Many of these meteorites are mixtures of compounds of aluminum, iron, silicon, and oxygen. These are the four elements most abundant on earth. Some of the meteorites are composed of metal. An analysis of the metal shows that it is a mixture mostly of iron and nickel. Perhaps you wonder where these strange objects come from. The fact that they are composed of the elements most abundant on earth seems to suggest that they may be bits of some body like the earth or the moon which has been broken to pieces by some kind of accident far out in space. It is possible that these objects may have traveled through space for millions of years and for thousands of millions of miles before coming close enough to the earth to be attracted to its surface by the pull of gravity. Whatever their source, it is interesting to find that they are composed of chemical elements with which we are very familiar. The atoms of the elements in the meteorites and the atoms of the elements in the sun, in the stars, and in the planets are the same. They are composed of electrons and protons, just

Meteorites contain no new elements

like those that make up the atoms of the elements on earth. Therefore we come to the conclusion that the same ninety-two elements that are the building blocks of the matter of the earth are also the building blocks of all matter in the universe.

If the molecules of a substance are composed of atoms that are just alike, the substance is called an element. There are ninety-two elements known to the scientist, and these compose the matter of the universe. The effect of these elements on one another may be explained by the molecular, atomic, and electron theories.

Can You Answer these Questions?

1. How is it that there can be so many compounds when there are so few elements?

2. What additional evidence does this chapter give you of the truth of the scientists' statement that "matter can be neither created nor destroyed"?

3. What evidence is there that the earth and the entire universe are composed of the same chemical elements?

4. What is your understanding of what the scientists call the atomic theory? Give this in your own words, as best you can.

5. Oxygen is called a very active element. Do you know why?

6. Can you name any ten elements and tell a substance in which each may be found?

7. Molecules of starch, sugar, fat, alcohol, and cotton fiber all contain atoms of the same three elements (oxygen, hydrogen, and carbon). Why are these substances not all alike?

8. Are all metals elements? What evidence have you in support of your statement?

9. Are all minerals compounds? What evidence have you?

10. Can you decompose elements as well as compounds? Defend your answer.

11. What is the difference between an element and a compound? Make your answer in terms of the molecules of which each is composed.

12. What is the difference between a mixture and a compound?

Questions for Discussion

1. Can you tell why the ancient alchemist failed in his efforts to change lead into gold?

2. Many times we see on packages labels which read "Absolutely Pure." What does this mean? Are such labels truthful?

3. Which do you think is more likely to be pure, an element or a compound? Why do you think so?

4. Can you see any reasons why the electron theory is important?

Here are Some Things You May Want to Do

1. Make a circle graph for a wall chart and divide it into five parts to show the percentages of (1) oxygen, (2) silicon, (3) aluminum, (4) iron, and (5) all other elements in the earth's crust.

2. Find and write up the story of the discovery of some one element. The story of helium or radium or one of the most recently discovered elements would be interesting.

3. Make a study of explosives used in building and mining operations. See if you can find anything which will tell you the difference between gunpowder, dynamite, and T.N.T. Use any sources you can find and make a report to the class.

4. Make a chart to show a complete cycle of a carbon atom.

5. Make a list of common foods and household necessities. Indicate whether you think they are elements or compounds, and of what elements they are composed.

6. Write a story called "The Further Travels of a Carbon Atom."

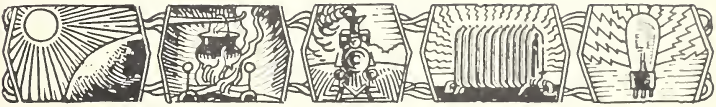
7. Make a diagram of a sample of soil you have examined to show why soil is a mixture and not a compound.

Fig. 145. The Small Engine was built in 1830 and won a Prize of Five Thousand Dollars as the First Practical Locomotive

Contrast it with the modern locomotive shown faintly in the picture. The tremendous change is due to man's increased ability to control energy resources. (From a painting by Herbert D. Stitt. Courtesy of the Baltimore and Ohio Railroad Company)

UNIT VII

What is Heat and How is it Used?



Chapter XIX · What is the Relationship between Heat and Other Forms of Energy?

Chapter XX · How is Heat transferred from Place to Place?

HAVE YOU ever heard the saying "Fire—man's friend and enemy"? What do you think is meant by this?

Do you realize how useful fire really is? Consider life without fire. Our food would be eaten raw; we should try to keep warm by wrapping ourselves in more and more clothing; we should find our way at night, if we dared go out at all, by stumbling through the dark.

Have you ever seen the destructive effects of fire? Perhaps you have been awakened late at night by the shriek of a fire engine as it tore its way through deserted city streets. Or perhaps, looking out of your window in the country, you have seen far away on the horizon the glow of angry flames as they attacked a neighbor's barn or house. Yes, fire can be destructive as well as extremely useful.

But what is fire? May it be explained in a scientific way? How would you explain fire and what it is?

You have learned that fire and heat are results of chemical changes and you have learned that energy is associated with chemical changes. Energy is a source of power. It is used in industry, and energy is essential to the vital processes that go on in living things. We may think of energy as coming from many sources, such as coal, steam, falling water, and wind; but really the energy used in industry, as well as the energy for the vital processes, comes directly or indirectly from the same source, and this is the sun.

How does energy from the sun come to us? How does energy from the sun make it possible for us to use our muscles? How does it run an automobile? How does man control energy and use it for so many purposes?

Chapter XIX · What is the Relationship between Heat and Other Forms of Energy?

A. What Effect has the Control of Energy had upon Ways of Working?

What is the most interesting story you have read or heard? Was it a true one? Did it lead you to find many new and interesting things to do? Did it surprise you and make you wonder what was coming next? Did it explain hundreds of things that you had always wondered about? Did it make you want to read on and on? As you think back over all the stories you have read, you can without doubt find one which you think is absolutely the best. Perhaps it was a story of exploration and adventure; perhaps one of early days on the frontier; perhaps one of cowboys, Indians, and wild bucking bronchos.

But let us tell you another story which we think as interesting and amazing as any you have ever heard. This story we shall call "Man's Control over Energy." We could not begin to tell you all of it, for it is as long as the story of man himself. We can tell you a few interesting things about it, however.

Primitive man used muscle energy

The beginnings of this story lie far back in the dim beginnings of the history of man. You already know something about these days. Consider for a moment how primitive man lived and worked. If a heavy load had to be moved, he and some neighbors carried it as best they could. His tools were rude. Perhaps a stone tied to the end of a stick served as hammer and club alike; sharp pieces of stone were used for the smoothing and cutting of materials. The beams of his hut were lifted into place by hand; and for all his work there was but one source of energy, that of the muscles of men and animals.

FIG. 146. Imagine the Tremendous Labor needed to carry the Massive Blocks of Stone in this Pyramid across the Desert Sands and Pile them into Shape

All this was done by the muscle power of men and beasts of burden

Let us come a little closer to our own day. Thousands of years ago when the kings of Egypt built the pyramids, countless numbers of men and animals labored to cut the huge blocks of stone, and to move them across the river Nile and over the land to the edge of the Sahara Desert. As you look at the size of the blocks (see Fig. 146), it is very easy to believe an ancient writer who tells us that a hundred thousand men worked for twenty years to build one of these pyramids. Again the source of energy was that of the muscles of men and animals.

But, you may say, this was a long, long time ago. True, but if we again jump a long stretch of history, we find the same forms of energy used, even in the days of your own great-grandfathers. A trip of one hundred miles then was an event to prepare for. It took several days to make such a journey in a swaying stage which jolted and bounced

Fig. 147. The Construction of this Building took less than a Year

The engineers here took full advantage of what man has learned regarding the control of energy resources over rough and muddy roads. Upsets were frequent; the coach became stuck in the mudholes along the way, and the deep ruts in the roadway caused many broken axles, not to mention bumped heads as the passengers were tossed about inside. No, even your great-grandfathers knew little about energy except that provided by the muscles of men and beasts.

This is a machine age

Consider now the age in which you live. You have often heard it called the Machine Age. Why? Because machinery is used to do a great deal of the work of the world in place of men and beasts of burden. Contrast the building of the pyramids with the building of a modern skyscraper. The Empire State Building in New York City (Fig. 147) is one of the greatest structures of modern times. It rises more than twelve hundred feet (nearly a quarter of a mile!) above the level of the street. There are eighty-six floors of offices. On each of these floors there are hundreds of square feet of office space. Yet only a few hundred men were employed in the construction of the Empire State Building, and the work was completed in less than one year. These men used modern power-driven machinery — motor trucks, steam engines, and powerful derricks.

In the days of the stagecoach very few people ever traveled as far from their homes as the distance between New York City and Philadelphia. Today as many as three trainloads of people leave New York City for Philadelphia every hour between sunrise and sunset. Several more trainloads go during the night. In addition passenger airplanes cover the same distance every hour during daylight, and busses run at frequent intervals. Over the great highways that connect these cities there is an almost continuous line of automobiles that move along at speeds of from thirty to sixty miles an hour.

It is hard for us who live in the midst of this Machine Age to realize that the inventions we profit by are recent.

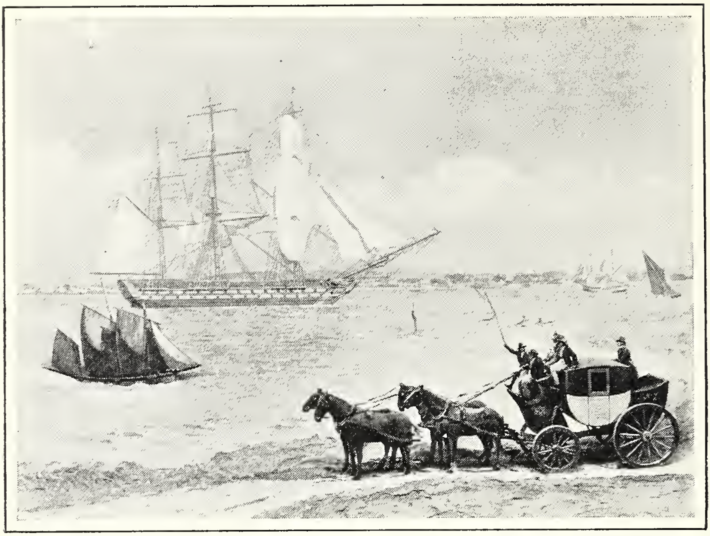
The following prophecy was printed in 1791:

> Soon shall thy arm, unconquer'd steam! afar
> Drag the slow barge, or drive the rapid car;
> Or on wide-waving wings expanded bear
> The flying-chariot through the fields of air.
> — Fair crews triumphant, leaning from above,
> Shall wave their fluttering kerchiefs as they move;
> Or warrior-bands alarm the gaping crowd,
> And armies shrink beneath the shadowy cloud.

Does this seem strange now?

You are probably familiar with the story of the locomotive. How long ago do you think it was invented? In the form we know it today it really is not as old as the Declaration of Independence. Here is an account of a trial trip in 1829 of the famous locomotive the *Rocket*, built in England by George Stephenson.

> On the morning of the 8th October, the "Rocket" was again ready for the contest. The engine was taken to the extremity of the stage, the fire-box was filled with coke, the fire lighted, and the steam raised until it lifted the safety-valve loaded to a pressure of 50 pounds to the square inch. This proceeding occupied fifty-seven minutes. The engine then started on its journey, dragging after it about 13 tons weight in waggons, and made the first ten trips backwards and forwards along the two miles of road, running the thirty-five miles, including stoppages, in an hour and forty-eight minutes. The second ten trips were in like manner performed in two hours and three minutes. The maximum velocity attained during the trial trip was twenty-nine miles an hour, or about three times the speed that one of the judges of the competition had declared to be the limit of possibility. The average speed at which the whole of the journeys were performed was 15 miles an hour, or five miles beyond the rate specified in the conditions published by the Company. The entire performance excited the greatest astonishment amongst the assembled spectators; the directors felt confident that their enterprise was now on the eve of success; and George Stephenson rejoiced to think that in spite of all false prophets and fickle counsellors, his locomotive system was now safe.



© Science Museum, London

Fig. 148. In the Late Eighteenth Century Man's Ways of Travel were Limited

Reproduced by permission of the director

This does not seem very exciting, does it? Yet a person who saw one of the trips of an early train thought differently. Here is what he said:

> It seemed indeed to fly, presenting one of the most sublime spectacles of human ingenuity and human daring the world ever beheld. It actually made one giddy to look at it, and filled thousands with lively fear for the safety of the individuals who were on it, and who seemed not to run along the earth, but to fly, as it were, on the wings of the wind. Within the vehicle, nicely poised on springs, and covered in to exclude the external current of air created by its motion, you might imagine you were in a state of perfect rest, while you are flying along the surface with the speed of a racer. Then the steam horse is not apt, like his brother of flesh and blood, to be frightened from his propriety by sudden fancies which defy the prudence and skill of the driver. Explosion, if it takes place, will not injure the passengers, for they are in a separate vehicle, and the enginemen

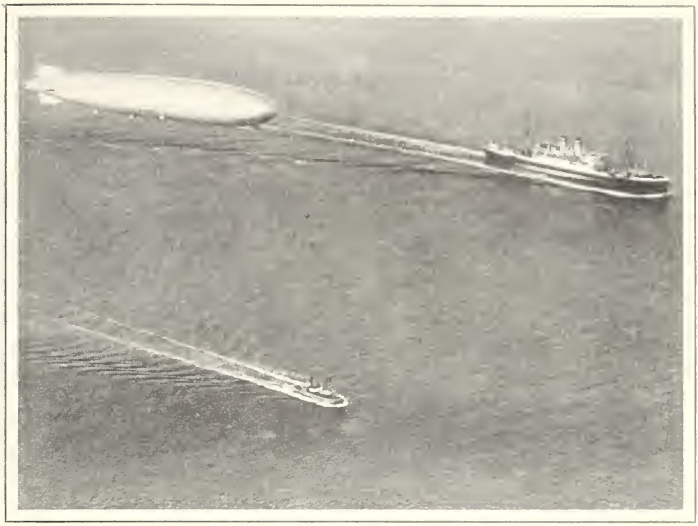


FIG. 149. As the Result of Improved Ways of Travel, Man in the Twentieth Century has First-Hand Knowledge of the Extremes of the Earth

may be trusted with the care of their own lives. In daylight, and with good arrangements, travelling in the steam coach, at twenty miles an hour, may be much more safe, as well as pleasant, than in any ordinary coach at eight or nine.

Man's inventions to control energy are not very old

Even in the United States railroading a hundred years ago was slow and not very practical. In 1831 the directors of the Baltimore and Ohio Railroad offered a prize of five thousand dollars for the best locomotive built in this country. The conditions laid down by the directors of the railroad were that the engine should travel at fifteen miles per hour and pull over a level track a load of fifteen tons. In Fig. 145 an artist has pictured the locomotive which won the prize. In the picture he also has faintly suggested the railroad engine of today, which may weigh as much as four hundred and fifty tons and pull a train weighing more than fifteen thousand tons with a speed of more than sixty miles per hour. How different these engines look!

The same is true of the other devices with which we are familiar. Contrast the means of transportation pictured in Fig. 148 with those in Fig. 149. The development of the steamboat came at about the same time as the development of the locomotive. The first practical steamboat in America was run on the Hudson River in 1807. This boat was small, and it had to labor to average five miles an hour. Today the energy from burning fuels drives giant ocean liners across the Atlantic in a few days, and makes possible swift and reliable transportation on water as well as on land.

This is an age of electricity as well as of steam; yet the electric-light bulb was invented only about fifty years ago. The first electric-light plant was built in 1882. The dynamo was developed at about the same time.

Energy from fuels is replacing energy from muscles of men

Has man made a full use of his control over energy? Certainly not. Every day sees a new use made of this power. You read of factories formerly employing hundreds and thousands of men now producing the same amount of material with just a handful of workers who press buttons and move levers; you joke about mechanical men, the robots, who throw switches, close doors, and do many other things far more capably than real men. You find startling figures which show how rapidly energy from fuels is replacing energy from muscles of men in our age. The power plants in this country, for example, are furnishing fourteen times as much power today as they did seventeen years ago. You read that over a short space of twenty-five years the number of man hours required to produce an automobile has been reduced from 1291 to 92. You hear of machines making 40,000 bricks an hour as against the old rate of 55 an hour.

As one reads, one wonders. It is true that all this has done away with much back-breaking drudgery. Men will not have to spend such long hours at hard labor as they have formerly. Along with this, of course, has arisen the big problem of what shall be done about the large numbers of men and women who will be unemployed because of the use of machines. One thing is certain. If we in America find a sensible solution for this problem, everyone will have more of the comforts of life with less of the harder kind of manual labor. Science has made it possible for us to have better houses and safer and faster airplanes and trains. Some of us may have to learn new occupations, but there will probably be plenty of interesting work and more time for reading, music, sports, and travel than grown-ups now have. Surely one can truthfully say that this is a machine age!

B. Where does this Energy Come From?

Man has learned to control energy

It is easy to decide that the change from an age of hand labor and stagecoach travel to a machine age has come because man has learned to control energy. We say that energy from coal, from gasoline, and from other sources is used to drive machinery, and the machinery is used to do work. Energy from gasoline drives the automobile; energy from coal drives the locomotive. Coal is also used to drive the generators that change energy of fuels into electrical energy, as well as for other purposes.

While most of the energy used to drive machinery comes from coal or from some other fuel, a good deal comes from falling water. Water running over a cliff may be made to strike a water wheel in such a way as to turn the wheel. The water wheel may be used to run a flour mill and grind flour, or it may be used to run a generator which in this case changes energy of falling water into electrical energy.

A smaller amount of energy is obtained from the wind. Windmills may be used to supply energy for pumping

Fig. 150. Wind furnishes Energy for Work and Play

water and for other purposes, and sailboats depend on moving air for their power. The enjoyment of such sport as that pictured in Fig. 150 is possible because of wind power. Finally, the muscles of men and animals are still a source of energy. The energy of muscles comes from the food that is eaten. All living things secure from foods the energy that is necessary for life and for the work they must do. The chief sources of the energy that is used on earth then are (1) coal, gasoline, and other fuels; (2) falling water; (3) wind; (4) foods.

Energy may be secured from many sources

Can we say that these are the real sources of energy? Let us see. In your study of the water cycle you learned that energy from the sun causes water to evaporate, and that if the air carrying water vapor is cooled, the vapor condenses and falls as rain. It is, therefore, the energy from the sun that causes water power. Energy of the wind has its origin in the same source. You have learned that coal beds have been formed from a dense growth of plants that once covered the earth. In your study of food-making you learned that the growing process goes on only in the presence of light. Therefore without sunlight there would be no food-making. Thus you may reach the conclusion that the energy of falling water, the energy of the wind, the energy of food, and the energy of fuels — in fact, nearly all the different kinds of energy that are used on earth for practical purposes — have at some time come to the earth from the sun. One exception to this may be found in the energy of the rising and falling tides. As yet, however, man has not used this energy except on a small scale. There is energy also in an active volcano, and in the hot rock beneath the crust of the earth. There are only a few places in the world in which energy from these sources is used. There are other sources of energy, too. Some energy reaches the earth from the stars, but energy from this source is not used to run machinery.

Energy for man's work has come from the sun

Wind, fuel, and falling water have been in existence throughout the whole period of time that man has been on earth, but only during recent years has man learned to use the energy from these sources to run machinery.

C. Is there Any Relationship between Heat and the Energy of Moving Molecules?

Heat plays an important part in the life of man. Steam engines and gas engines use heat to drive machinery; heat causes winds to blow, and heat keeps the water cycle and the carbon cycle going. All this heat came at one time from the sun. It is our most familiar source of energy. Heat is called a form of energy because it has the capacity to do work. In order to see how this is possible, suppose you recall what you know about the effects of heat.

In the study of water you learned that when water is

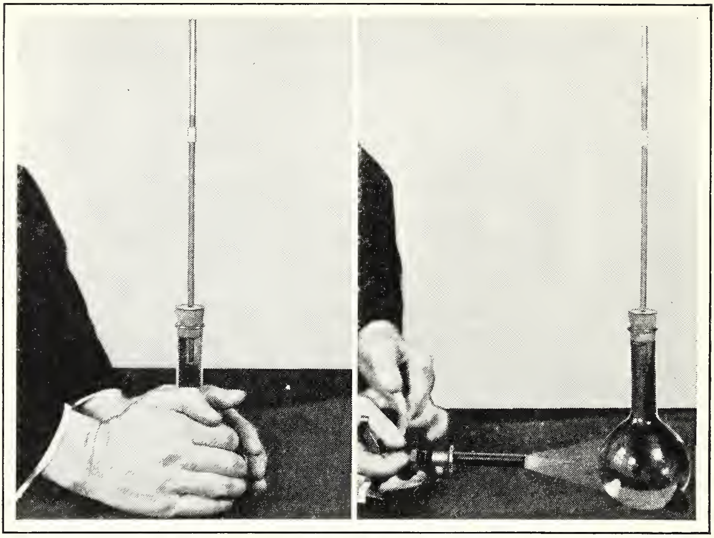


FIG. 151. Water expands when Heated

heated the molecules move faster, and when it is cooled the molecules move more slowly. A simple experiment will show that water molecules move faster when they are heated.

Fill a flask with cold water. Put in a stopper with a hole in it through which there is a glass tube. The apparatus is shown in Fig. 151. Water stands a little way up in the tube. Take hold of the flask as if to squeeze it and hold it in this way for a few minutes. The water rises in the tube. Why? The warmth of your hand is sufficient to cause the molecules to move faster. When they move faster, they collide with the glass and with one another more frequently and more violently. In doing this the molecules are pushed farther and farther apart. Heat, therefore, causes water to expand. Now turn the heat from the gas flame against the flask, and you will see that the water continues to expand. It will probably expand until it flows over the end of the tube. After the flame is

Water expands when heated

taken away, the expansion ceases, and soon the water level in the tube begins to lower. As the water cools, it contracts.

Air expands when heated

You also learned that when air is heated its molecules move faster, and when it is cooled its molecules move more slowly. You have learned in your study of air how the pressure increases inside the tire of an automobile when it is driven over hot pavements. Heat causes gases to expand, and you may explain expansion in both gases and liquids by saying that heat causes the molecules to move faster. The faster motion makes more and harder collisions, and thus the molecules crowd one another farther and farther apart. Molecules that are confined exert a very great pressure when heated. It is the energy in the rapidly moving molecules of steam that drives a locomotive over the rails, and the energy in the swiftly moving molecules of gas that speeds an automobile over the highway.

Solids expand when heated

Metals as well as liquids expand when they are heated. Have you ever tried to unscrew the metal cover of a jar which has become stuck? After much tugging and twisting you finally hold the top of the jar under hot water for a time and find that the cap now turns very easily. Why? The heat of the water has caused the metal cover to expand, so that it does not grip the jar so tightly. This expansion of metals may be illustrated by several common occurrences. Some of the worst railroad wrecks have been caused in summer by "spreading rails." The steel of which the rails are composed expands when heated by the rays of the sun. A steel rail thirty-four feet long will be about a quarter of an inch longer on a hot summer day than on a cold winter day. If not enough space is left between the ends of the rails to allow for expansion, the rails push against each other with such force that they bend, or spread, to one side.

If you wish to see this expansion for yourself, you might try the experiment illustrated in Fig. 152. Get a metal ring and a solid metal ball just large enough to pass through the ring. Now heat the ball and try to pass it through the ring. What happens? Let the ball cool. Now heat the ring and try to pass the ball through. What happens now? Let the ring cool. Heat both the ball and the ring, and again try to pass the ball through. What happens? Can you explain your results?

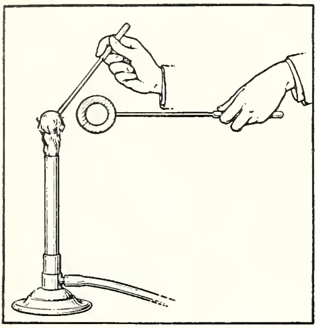


FIG. 152. Metals expand when Heated

You may have seen sidewalks or paved roads that have risen, or buckled, on a hot day as a result of expansion. A typical case is illustrated in Fig. 153. Telephone and telegraph wires sag more in summer than in winter because of expansion. A copper wire a mile long will be as much as four feet longer on a hot day in summer than it is on a cold day in winter. If extra length is not allowed for contraction, the wires will break in winter.

The steel cables (Fig. 154) which support the great George Washington Bridge over the Hudson River are almost a mile long. These cables are nearly four feet longer on a hot summer day than they are on a cold winter day. The lengthening and shortening of the cables makes the level of the bridge about eight feet higher above the river on a cold day in winter than it is on a warm day in summer. In building a bridge space must be allowed for the expansion of the metal of which the bridge is made.

Heat does work by making molecules move faster

In solids, as in liquids and gases, expansion is due to faster motion of molecules, and contraction is due to slower motion of molecules. Heat does work, for as molecules gain more heat they move faster, exert more pressure, and move further apart. A substance expands forcibly as its molecules move faster. This force of expansion may cause a tire to

Fig. 153. Alternate Heating and Cooling of Pavements may cause them to Crack

Courtesy of the United States Bureau of Public Roads

blow out. It may cause rails to spread. But under control this molecular force may be used to pull trains, to push boats through water, and to do many other useful things.

D. How may Heat be Measured?

Measuring the expansion caused by heat is a convenient way to measure the intensity of the heat. The hotter the day, the longer will steel rails become, and the lower will wires and cables sag. It is possible, but not very convenient, to find out the temperature of a summer day by measuring the amount of expansion of a rail or of a telephone wire. It is much easier, however, to use a thermometer, which works on a similar principle. The mercury or alcohol in the stem of a thermometer (see page 115) expands as it is warmed and contracts as it is cooled. Really a thermometer tells how much hotter or how much colder a substance is than melting ice. You have already learned

Fig. 154. Engineers in Building a Bridge must allow for the Expansion and Contraction of Cables Such as These

that the temperature of melting ice on the centigrade-thermometer scale is 0° and that the temperature of melting ice on the Fahrenheit scale is 32°. On a warm day when the temperature of the air is 80° F., it is 48° F. $(80 - 32 = 48)$ warmer than the temperature of melting ice.

The answer to the question of how hot or how cold a substance is, is given in degrees. The heat value of foods and fuels is determined in quantity. Degree of heat and quantity of heat are not the same. Degree of heat is measured in degrees on a thermometer scale. The temperature (in degrees) tells how much hotter or colder a substance is than ice. If it is a small amount of substance, only a little heat is required to change its temperature. If a large amount, more heat is required. The temperature tells nothing about how much heat energy is there. Temperature is not a measure of quantity. Quantity of heat is measured in calories. What is a calorie? Five hundred grams (about one pound) of water in a teakettle over a hot fire soon reaches the boiling point, that is, a temperature of 100° C. One thousand grams (about two pounds) of water in a teakettle over the same hot fire take longer to heat to the boiling point. Twice as much water requires twice as much heat, or twice as many calories. The calorie is a measure of amount of heat energy.

Quantity of heat is measured in calories

One calorie of heat is the amount of heat required to raise the temperature of one gram of water 1° C. Two calories are required to raise the temperature of two grams of water 1° C. To raise the temperature of 500 grams of water 1° C., 500 calories are required. To raise the temperature of one gram of water 10° C., 10 calories are required; and to raise the temperature of 500 grams of water 10° C. requires 5000 calories (500 × 10).

Calorie as just defined is sometimes spoken of as the small calorie or, more exactly, as the gram-calorie. The gram-calorie is a very small amount of heat. For this reason a larger unit called a large calorie or, more exactly, a kilogram-calorie is commonly used to express the heat value of fuels and foods. One kilogram is 1000 grams. The kilogram-calorie is therefore 1000 times the gram-calorie. The kilogram-calorie is the amount of heat required to raise the temperature of one kilogram (1000 grams) of water 1° C. The word *calorie* is frequently used in referring to the energy value of foods and fuels, but in these cases kilogram-calorie is always meant.

The value of fuel is stated in terms of kilogram-calories

One pound of bread will produce about 1200 kilogram-calories. One pound of hard coal releases about 3600 kilogram-calories as it burns. A pound of a sample of soft coal gives off 3500 kilogram-calories. When you buy coal, you are really buying heat energy, and it is important to know how much heat energy you get. Some kinds of coal give off more heat energy than others. In general you will find that the cleanest coal — that is, the coal that burns with the least smoke and leaves least ash — gives off most heat.

The energy of foods is measured in terms of kilogram-calories

The amount of energy that you get from different kinds of foods may likewise be measured in kilogram-calories. Oxygen that has been carried into the cells of the body by the blood combines with food and releases energy. This process goes on slowly. Heat energy is released, and this heat keeps the body warm. This chemical process is similar to the one that goes on when foods are burned outside the body; for example, in a fire. Here too the foods combine with the oxygen from the air and are oxidized. There is this difference, however. When the foods are burned outside the body, all the food that can be burned is oxidized. When the food is oxidized in the body, however, a smaller part of the food is used, for some of it leaves the body without being oxidized. A gram of protein when burned outside the body will furnish, on the average, 5.65 kilogram-calories, but only 4 kilogram-calories are used by the body. Similarly fats liberate 9.45 kilogram-calories per gram, but only 9 kilogram-calories can be made use of by the body. Carbohydrates are nearly completely used by the body, 4.1 kilogram-calories per gram being given off when burned. Of these, 4 kilogram-calories are capable of being used by the body.

Different foods release different amounts of energy

Foods may be burned outside the body, and the amount of heat energy that is released may be measured. One pound of butter will release nearly twice as much heat as a pound of sugar. One pound of dried meat will release just about the same amount of heat as a pound of sugar. Thus we see that a man who is doing hard muscular labor should eat more butter and more fat meat than the man who works in an office. The laboring man needs more energy than the office worker.

The energy in foods is chemical energy. It comes from the sun and is stored in the food by the chemical changes that go on in food-making, and it is released from the food by the chemical changes that go on in food-using.

Man's control of energy has changed entirely his ways of working. Muscular energy has been replaced to a large extent by machinery. Energy for man's work comes from the sun. Heat is a familiar form of energy.

Can You Answer these Questions?

1. Suppose you were putting up a telephone line in a region where there were great extremes of heat and cold. What adjustments would you make if you were doing the work during the winter? during the summer?

2. What is the difference between degree of heat and quantity of heat? Can you give examples which will show this difference?

3. Can you explain why a substance expands when it is hot? Make your explanation in terms of the molecular theory.

4. What do we mean when we say that a lump of sugar contains 100 kilogram-calories?

Questions for Discussion

1. Can you think of any types of energy that do not have their origin in the sun? Describe them.

2. We call this age in which we live the Machine Age. Do you agree that this is a good term? Defend your answer.

Here are Some Things You May Want to Do

1. Read *The Boy's Life of Edison,* by W. H. Meadowcroft. As you read it think how Edison helped in man's efforts to control energy.

2. Look up and report to the class on the values of various foods in terms of kilogram-calories.

3. Write the story of some trip or journey you have taken recently, and, by using your imagination or, better yet, by looking up the facts, describe the same journey a hundred years ago. If you wish to do a really good job, describe the trip as you think it would have been a thousand years ago.

4. Take some familiar types of energy and trace them back to their original source, the sun, showing the changing steps in each energy from the time it left the sun until it became the type of energy you are describing.

5. For many years men have wondered how the great pyramids of Egypt were built. One of them rises to a height of almost five hundred feet and is constructed of huge stones, each weighing more than three tons. You may want to read about the pyramids and see what ideas you have as to how they were built without the aid of any modern machinery.

Chapter XX · How is Heat transferred from Place to Place?

In many of our large cities, buildings are heated and machinery is operated by steam which is produced a considerable distance away. Far below the traffic of the busy city streets are large mains carrying steam to buildings which do not have their own power plants. How different this is from the days when nearly every room had a stove or an open fireplace! Many city people still remember the cold winter nights when they undressed hurriedly and jumped into bed to shiver themselves back into warmth, or the mornings when they awoke to find ice in the water pitcher on the dressing table. The kitchen or parlor stove was the center of family life. In the crossroads store a big round stove shone a welcome to the shopper, whose first thought was to get within comfortable distance of its warm glow.

Some of our comforts today have come as a result of improved heating devices, and these in turn have come from a better knowledge of the principles which underlie heating and of how heat energy is transferred from place to place. Does heat really move? Have you ever started a small bonfire with paper and sticks and watched it grow as you fed it? You may have bent directly over the small flickering flames as you tried to nurse them into life. But what happened as the fire grew larger and larger? Where were you when the fire finally took hold and sent roaring flames high into the air?

Can you learn any of the principles governing the transfer of heat? Consider a few common things. Why do you light a flame under a kettle or a pan rather than over it? Why does a furnace have the fire under the water boiler rather than above it? Why do you wear gloves to keep your hands warm? Why do you put coffee in a thermos bottle?

A consideration of these questions should lead you to the conclusion that heat must behave in a certain definite fashion. What is it? What governs this behavior? Let us see if we can find out.

A. What is Conduction?

Suppose you try some experiments. Get two cooking spoons. One spoon should have a metal handle; the other a wooden handle. Let one member of the class hold the spoon with the metal handle in a pan of boiling water and another hold the spoon with the wooden handle in the same water. Which one has to drop his spoon first? Why do you think this is so? The answer is that metal is a good conductor of heat and wood is a poor conductor. To put it in another way, heat from the boiling water is transferred to the molecules of iron, and then it is transferred by conduction throughout the spoon from one molecule to the next. Now suppose you heat, in the same way, a piece of aluminum or copper or any other metal. Again you find that all of them act in much the same way. You may reach the conclusion that metals are good conductors of heat.

There are good and poor conductors of heat

Many substances, however, are not good conductors of heat. Hold one end of a piece of glass tubing, say, ten or twelve inches long, and place the other end in a gas flame. You find that the end near your fingers does not get hot enough to burn you. You probably know, too, that you can hold a burning match until the flame is very close to your fingers, and yet the wood does not get hot. You may decide from this that glass and wood are poor conductors of heat. Asbestos is a very poor conductor of heat. For this reason it is a very useful substance; for unlike glass it does not break, and unlike wood it does not burn. Metal steam pipes are commonly wrapped in an asbestos covering. The heat of the steam inside the pipe is conducted readily through the metal. If the pipes were not covered, they

FIG. 155. Some Substances are Better Conductors of Heat than Others

would lose much heat in the room through which they pass. An uncovered steam pipe gives off a great deal of heat, while an asbestos-covered pipe gives off very little.

Fur and wool are likewise poor conductors of heat. The fur of animals serves to protect their bodies from loss of heat. The woolen clothing that you wear in winter protects your body in the same way. Cotton cloth is a better conductor of heat than woolen cloth. This is one reason why woolen clothing is comfortable to wear in winter, and cotton clothing comfortable to wear in summer.

You may test your conclusions in another way. Get a small piece of tin or iron and a small piece of asbestos. Light two matches, and after they are burning well, place one on the piece of tin and the other on the piece of asbestos. Which went out first? Do you know why?

B. What is Convection?

Let us try a few more simple experiments. First light a candle and place it on a desk near the window of your classroom. Observe how the flame flickers. Move the candle to a desk near the door and observe it again. Now move it into various corners of the room; place it on the floor at various points and also on different desks located at different points. Do you notice anything different about the flame as the candle is placed in various parts of the room? Can you explain any changes that take place? Use thin strips of tissue paper, each about a foot long. Hold these over a register, a radiator, a ventilator, or in front of an open window. What happens? Do you know why? All your observations may be explained, of course, by saying that currents of air are always moving through the room. But what causes these currents? Where do they come from?

When you stand over the register of a hot-air furnace or hold your hand above a hot steam radiator, you are conscious of air motion and might decide that the air over a very hot object is always in motion. Why is this? The chemical change that takes place during burning heats the furnace. Heat is transferred from the furnace to the molecules of the gases in the air that are continuously bumping against the hot iron of which the furnace or the radiator is composed. The heat makes the molecules of the air move faster and push one another farther and farther apart. As you know, a cubic foot of hot air weighs less — that is, has lower density — than a cubic foot of cold air because there are fewer molecules in one cubic foot of hot air. When warm and cold air come in contact, the cold air, which is denser than warm air, pushes the warm air upward. The upward movement of air that you notice over a hot radiator is due to the fact that the denser cold air forces the less dense warm air upward. This movement of air is called a current of air. When a current of air is set up in this way, it is called a convection current. These currents carry warm air away from a radiator, and at the same time carry cold air to the radiator, where it in turn is warmed. You may come to the conclusion, then, that heat is transferred from a radiator throughout

Air currents around a radiator are caused by convection the room by convection currents. This same type of current may be observed in many other instances.

If you hold your hand before the open draft of a hot furnace, you will notice that a current of cool air is entering through the draft. The hot air inside the furnace is less dense than the fresh air which comes in through the draft, and a convection current is formed. If you open the window of a heated room, convection currents will carry air in and out of the window. If you lower the window from the top and raise it from the bottom, the less dense warm air will pass out above and the dense cold air will come in below. The room is then ventilated by convection currents.

Rooms are ventilated by convection currents

So far we have discussed convection currents in the air. Let us now consider water. An apparatus like the one in Fig. 156, *a*, may be used to show how heat is transferred in water. If the glass tube is heated at the position shown, it will be but a short time until the water in the flask is hot. It is heated by convection. Heat causes the molecules to move faster and push one another farther apart. The molecules of the warm water are farther apart than those of the cold water. The warm water, therefore, is less dense than the cold water. The denser cold water forces the less dense warm water to rise. So long as the tube is heated at the position shown, the convection current causes water to rise and return to the flask through one of the tubes, in this case the one on the left. Water will leave the flask through the other tube. Water circulates through the radiators of a hot-water heating plant in much the same way that it circulates in this apparatus. You may see convection currents more clearly by filling a glass flask about three quarters full of water and adding to it a spoonful of sawdust. Place the flask on a stand over a burner. Observe what happens as the water is heated to the boiling point. Can you account for this?

Heat is transferred through water by convection currents

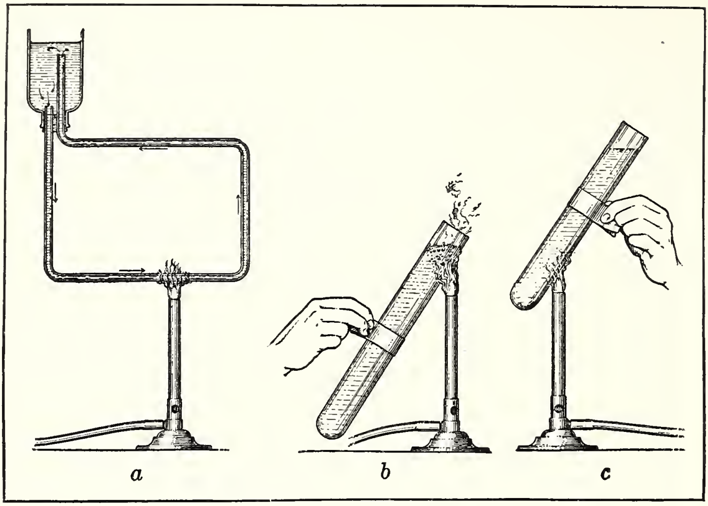


Fig. 156. *a*, Heat is transferred through Water by Convection Currents; *b*, Water is a Poor Conductor of Heat; *c*, Heat is distributed through the Tube by Convection

As you may have found out, water conducts heat very poorly. A simple experiment will show you that this is so. Fill a test tube full of cold water. Hold the top of the tube in a flame, as shown in Fig. 156, *b*. When the water boils at the top the bottom of the tube is still cold. In the same way heat a piece of iron the same length as the test tube. It very quickly gets too hot to hold in your hand. Finally heat the test tube at the bottom, as shown in Fig. 156, *c*. Soon the water throughout the tube will be hot. You may decide that heat is distributed rapidly through water by convection but very slowly by conduction.

C. What is Radiation?

Doubtless you have stood around bonfires at picnics. You have felt the heat in whatever position you stood. You felt it close to the ground. You felt it higher up also.

Even if there was a wind blowing the fire away from you, you still felt the heat against your face. This experience illustrates the third method of heat transference — that of radiation. Heat is a form of energy that is carried by molecules. Radiant energy should not be called heat; for, as you know, radiant energy passes through glass, and molecules cannot pass through glass. Radiant energy may be changed into heat. A hot object radiates energy away from itself in every direction, and this radiant energy is changed into heat when it falls upon molecules.

A hot object radiates heat

Let us see now if we can explain these three types of heat transference more clearly. You have learned that heat is transferred by conduction and by convection. Heat that is transferred in these ways may be conveniently referred to as molecular heat. Heat that is transferred by radiation is sometimes referred to as "radiant heat." Molecules take no part in the transfer of heat by radiation. Radiant heat travels as light does — in waves, through space, through glass, and through transparent substances. It also travels in straight lines, as light does. It is changed to molecular heat when the rays fall upon an object. The sidewalk grows hot in the heat of the midday sun; a pan becomes hot as the gas flame under it sends out radiant energy. In each case radiant energy is changed into molecular heat. Another striking example is seen in Fig. 157. In a strict sense "radiant heat" is not heat at all. It is a form of energy that is readily changed to heat energy.

Radiant heat travels in waves

Again, the radiant energy that may be changed into heat is reflected from a polished metal surface just as light is reflected. The electric heater is built to reflect radiant energy in very much the same way that light is reflected from the headlight of an automobile.

You have seen these different types of heat transference in many different forms. A fireplace has a large chimney,

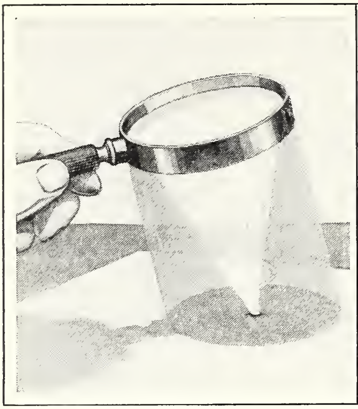


FIG. 157. Radiant Energy from the Sun may be changed into Heat Energy

FIG. 158. The Flame of the Electric Arc is Cold, compared with the Temperature of the Sun

and convection currents set up by the heat from the fire pass up the chimney. Cool air in the room, coming through the walls and through cracks and crevices around doors and windows, forces the hot air about the fire upward. Only a small amount of heat from a fireplace is transferred to the room by convection, most of it coming to you as radiation. Most of the heat produced by convection goes up the chimney. Heat is transferred from a stove both by radiation and by convection. The heat you feel against your face as you stand before a stove is transferred by radiation. Convection currents carry heat into the more distant parts of the room.

D. What is the Original Source of Heat?

A short time ago, you will remember, you learned that most of the energy used on earth comes from the sun. You also learned that heat is a common form of energy. What do you know about the sun as a source of heat? You see it, and you have felt its effects on a hot summer day. But what else do you know about the sun as a source of heat? Let us see.

In the first place the sun is an enormous round body, 1,400,000 times larger than the earth. There are millions of square miles on the surface of the sun, and this surface is much hotter than any temperature ever measured on earth. Two of the hottest things on earth are the oxyacetylene flame, used by welders, and the electric arc. Both have a temperature of about 3500° C. The temperature at the surface of the sun is about 5000° C. Pure iron melts at about 1500° C.; yet the surface of the sun is more than three times as hot. The interior is much hotter. This enormous hot mass of millions and millions of tons of matter radiates energy out into space equally in all directions. The earth is 93,000,000 miles from the sun, and an extremely small fraction of the total amount of energy radiated from the sun reaches the earth; yet all the heat that is of any practical use on the earth has come as radiant energy across this 93,000,000 miles of space. Beyond the earth's atmosphere there is nothing but empty space. Heat, then, cannot come from the sun by conduction, for there is nothing to conduct it. It cannot come by convection, for there is no air (or any other gas) or liquid to form convection currents. How is this energy turned into heat?

Heat comes from the sun by the process of radiation

Radiant energy does not warm the air to any extent, because the air is transparent and most of the radiant energy passes through it. This energy from the sun is changed into molecular heat when the rays fall upon a dark object. The soil is heated by this radiant energy, and heat is transferred by conduction from the soil to the molecules of the gases of the air. By the same process energy warms the surface of the water, and this warms the air.

Radiant energy from the sun passes through space without warming it. There are no molecules in the space beyond the earth's atmosphere, and without molecules there can be no warmth, even though in outer space the radiation from the sun is much more intense than it is on earth. You know this is so from your study of the experiences of aviators in the upper air. They found that the higher they flew, the colder it became. This seems strange, doesn't it? You might think that as you came closer to the sun, you would become warmer. But perhaps you can now understand why this is not so.

In outer space there are practically no molecules of any substance, and in this region the temperature is very nearly the temperature of absolute zero. Absolute zero is the temperature at which molecules cease to move. The temperature of absolute zero is 273 centigrade degrees or 491 Fahrenheit degrees below the freezing point of water.

Radiant energy may be changed into molecular heat

Radiation is not heat at all. It is really a form of energy that is changed into heat when the rays fall upon molecules. There is heat on the sun, for the sun is composed of molecules. The energy of the hot molecules of the sun is changed into radiation, and the rays travel outward through space. When the rays reach the earth, they are changed again into the heat which warms us.

There are many forms of radiant energy in addition to the form that is changed into heat. Light, X rays, radio waves, and cosmic rays are other forms of radiant energy, which you will learn about in your further study of science.

Let us see now what we have learned about the sun and heat, and how it helps us to live. We have found that only a very small fraction of the heat from the sun comes to the earth, although there is an equal amount going out in every direction from the sun. Most of the heat from the sun seems to be lost in empty space. Though we get only a small fraction of the total amount of energy that is radiated away from the sun, what we do get serves all our needs. It is sufficient to cause plants to grow, and to evaporate water, thus keeping up the water cycle. The energy for life comes from the sun through the foods made by plants.

Energy from the sun makes the winds blow. These winds are really great convection currents. All the energy on earth used for any practical purpose has come from the sun. Man has learned to use this energy and to make it do the work required in industrial processes. He has learned how to use energy from the sun to run steam engines, automobiles, and airplanes, and to do a great many other things. Electric power plants change heat energy and the energy of falling water into electricity, which is another form of energy. The electrical energy is sent out over wires, and it is used to light homes and streets, to run machinery, to operate telephones and radios, and for many other purposes. This Machine Age is an age in which the energy from the sun contained in fuel and falling water is used to run machines. Most of the work of the world is done with the help of these machines.

From what you have learned, you see that really most of the work of the world is done with the help of the sun.

Heat may be transferred from place to place by three methods — conduction, convection, and radiation. All heat has its origin in the sun, but is obtainable on earth in different ways.

Can You Answer these Questions?

1. What is the difference between molecular heat and the radiant energy that produces heat?

2. What evidence is there that heat comes from the sun as radiant energy?

3. How is heat transferred from a fireplace to a room?

4. How is heat transferred from a steam radiator to a room?

5. Which of the following are good conductors of heat: steel, glass, asbestos, copper, air, water, soil, wood? Can you defend your answers?

6. The air at the top of a heated room is warmer than it is near the floor. What explanation can you give for this?

7. When the window of a heated room is open at top and bottom, what is the direction of the air currents through each opening?

8. When you wish to cool a room, why is it a good plan to open a window a little at both top and bottom?

Questions for Discussion

1. We say that woolen clothing is a poor conductor of heat, and cotton clothing a good conductor. Why, then, should we not wear woolen clothes in summer when we want to keep out the heat, and cotton clothes in winter, when we want to get all the heat we can?

2. Why is a furnace usually placed in the basement or cellar of a house rather than in the attic?

3. Why is it necessary to have a water tank somewhere on the upper floor of a house heated by a hot-water system?

4. Give three or four examples of each method of heat transference and explain why you list your examples under a particular method.

Here are Some Things You May Want to Do

1. Make a wall chart of a hot-water heating system, showing how it depends upon convection currents.

2. Prove in any way you can that radiant energy travels in straight lines from its source.

3. Set up an experiment to determine the relative value of various substances as conductors of heat. Write up your experiment and report to the class your list of poor conductors and good conductors, with your reasons for placing them as you do.

4. See if you can find out how scientists have determined the temperature of the sun, in spite of the fact that it is some 93,000,000 miles away.

5. Make a chart of the various kinds of heat transference and then list in their proper columns all the various kinds of heat devices you can find.

6. Wind some copper wire about a test tube so as to form a coil. Place some ice in the test tube. Take the coil off the outside of the tube and place it inside on top of the ice. Fill the test tube with water. The coil will keep the ice confined in the bottom of the tube. See if you can boil the water in the top of the tube while the ice remains confined by the coil of wire at the bottom.

7. Make a list of good and poor conductors of heat, and explain why you believe each substance belongs in the list where you have placed it.

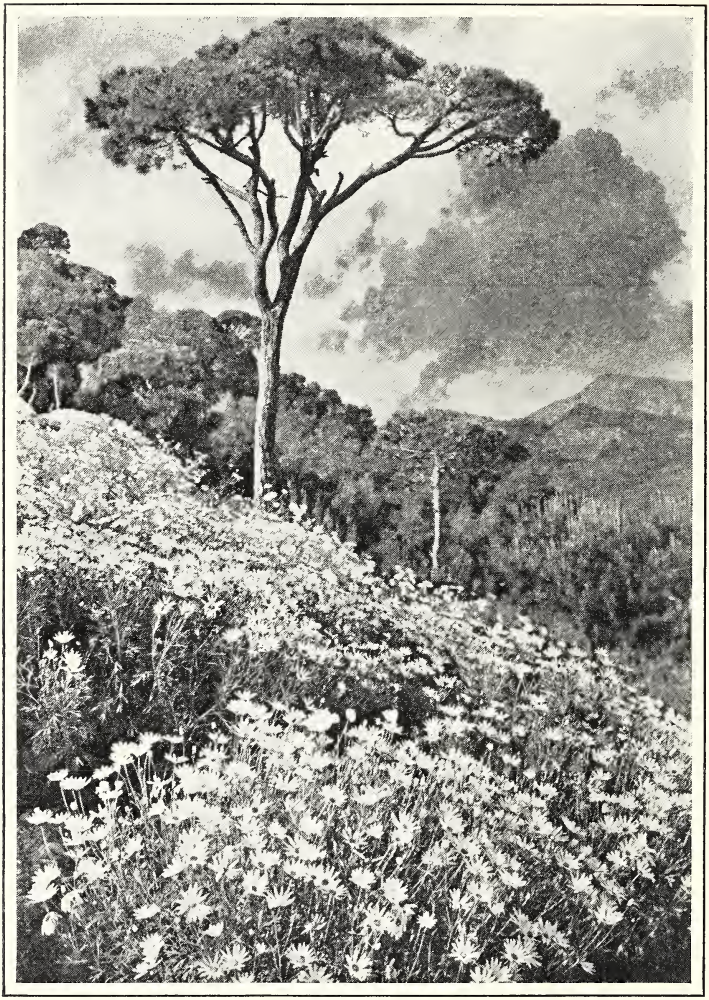


FIG. 159. All the Living Things which make up the Beauty of this Landscape depend for Life upon their Physical Environment

UNIT VIII

What is the Relation of Living Things to their Environment?

Chapter XXI · Are Living Things Interdependent?

Chapter XXII · What Part does Food play in Life?

Chapter XXIII · How do the Physical Factors of the Environment support Life?

YOU ARE NOW READY to begin the final unit of this book. If you will think over your work so far, you will see that you have studied three types of things. The first of these are living things — plants and animals. The second are the nonliving things — the elements, or the building blocks, from which all things are made. The third are the natural forces of the environment. These have their origins in solar radiation.

In this last unit we should like to show the relationship between all these and life. Some of these relationships are probably quite clear to you now. You have seen living things as they depend upon the other two factors of the environment. You have seen these factors as they influence life.

Let us ask some questions. Is the manner in which living things depend upon and make use of these other factors entirely clear to you? Do you understand the origin of living things? You see a tree grow larger and larger. Do you know the origin of the materials that aid in this growth, and how these materials are used in the growing process? How about the common food materials that man depends upon — meat, milk, fruit, vegetables, and the like? Do you know where these come from?

The title of this unit might have been "The Life Cycle." After you have studied the unit, see if you can explain why.

Chapter XXI · Are Living Things Interdependent?

> And what is so rare as a day in June?
>   Then, if ever, come perfect days;
> Then Heaven tries earth if it be in tune,
>   And over it softly her warm ear lays:
> Whether we look, or whether we listen,
> We hear life murmur, or see it glisten.[1]
>
> LOWELL

As one recalls a trip to a forest in late spring, it is easy to feel with the poet the beauty of life as it is revealed in the world about. Let us retrace in imagination our last trip to the woods or, better yet, take another.

Here is the giant oak tree over a hundred feet tall. Its branches extend over an area greater than that covered by a house. Here is the rotting log with its countless forms of life. It is late spring, and a great variety of living things are about us. The trees are covered with such a dense growth of green leaves that they shut out the sun and cast shade over the ground. On some of the trees blossoms still grow, but on most of them the flowers have faded, and nuts or acorns or some other form of seed have started to form.

Under the trees many kinds of animals search for food. After walking a short distance we decide to sit quietly in the shade of a tree and watch the animals around us.

June is a busy month in the forest

There is a suggestion of happiness in the woods as the birds go about in their care-free way. There is the rustle of leaves as a breeze blows through the trees. The air is sweet with fragrance from the flowers. The life activities of the many living things about us give a feeling of joy and restfulness as we sit idly in the shade.

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[1] Used by permission of, and by special arrangement with, Houghton Mifflin Company, the authorized publishers.

With a jerk of its tail a chipmunk scampers about over the dead branches of a fallen tree. He is probably looking for food. A shy mouse appears from a hole under a log. We know that moles carry on their lives in little underground colonies. They seldom appear aboveground; so we probably shall not chance to see one. We do see, however, a fat old toad just in the act of catching and eating a fly. We see, too, a snake, a shiny blue racer as it glides gracefully through the leaves.

There are many kinds of insects, and they are present in great numbers. There are crickets, grasshoppers, and beetles feeding upon the green leaves of growing plants. We recognize the call of a catbird and of a song sparrow. Another bird voice probably belongs to a warbler. Near the path leading to an orchard is an oriole, and there a scarlet tanager flashes by with its bright-red jacket and black wings.

All the birds seem extremely busy. There are nests of hungry little birds in the branches of the trees, and probably in the bushes or upon the ground very close to us. The birds we see are gathering food for their young ones. Enormous numbers of crickets, grasshoppers, caterpillars, beetles, and other forms of insects pass down the hungry young throats.

The work of living is to find food

Squirrels are seen frisking about from one branch to another. One is spread out on a large branch as he takes a sun bath. If we could peek into the hollow trees in the forest, we should find many nests of baby squirrels still too small to get about and search for food for themselves. Their mothers must feed them and find their own food as well. If the mulberries and other fruits are ripe, the squirrels may be seen eating them. We usually think of squirrels as eating nuts; but in early summer there are no nuts, and in this season they feed upon fruits, twigs, birds' eggs, and to a limited extent upon insects. As we sit in the shade of the forest, we see a great variety of animal life all actively at work in search of food and in taking care of the young.

This makes a beautiful picture, doesn't it? It is easy to imagine that all the animals of the forest live together in peace and happiness. Really, however, they do not. At any moment a hawk may swoop down and capture the merry little chipmunk for a meal. A great black snake may glide out and swallow the timid mouse in one mouthful. He may return later and make a meal of the fat toad that was so contentedly enjoying his meal of flies and other small insects. As we think about it, we realize that life in the forest is anything but care-free. It is a constant search for food, in which many animals destroy others smaller than themselves.

Suddenly we realize with a start that sunset has arrived. The shadows are lengthening in the clearing close by. A hush falls upon the busy forest. The sinking of the sun in the west has stilled the call of the birds. Soon it is dusk. We rise from our resting place and start for home.

A. Is Life within the Forest by Day Different from what it is at Night?

If you remained in the forest overnight and in some way could see the activities during the hours of darkness, should you see anything different from what you observed during the day? You know of course that the process of food-making that has gone on throughout the day in green leaves everywhere ceases as darkness approaches. But what about the different forms of animal life? Do they change their habits at night?

You of course know part of the answer. The animals that have gone about their work so busily during daylight settle down for their night's rest. As soon as these animals have gone to rest, others come on the scene. You may be startled by the screech of an owl in the early twilight, but when you collect your thoughts you realize that these birds cannot harm you. Indeed, they are useful to

FIG. 160. The Opossum seeks its Food at Night

Photograph by Cornelia Clarke

man; for they catch and eat mice, rats, gophers, and other pests. A new set of noises begins when darkness arrives. The call of the whippoorwill is a familiar sound on June evenings in some sections of the country. The whippoorwill and the nighthawk feed upon insects, catching them on the wing as they fly about in the early twilight.

If you could see in the darkness, you might glimpse a number of night-prowling animals going about in their search for food. Let us see what we can find out about some of them.

The night prowlers sneak out to find food

The opossum is one of these night workers. Have you ever seen him? Look at Fig. 160. For food he sometimes catches birds as they sleep on their roosts. Nor does he dislike insects. If a chicken yard is near at hand, he may make a call there; for he eats both eggs and young chickens. He is also fond of mulberries, and may visit the same tree by night in

Fig. 161. The Parents of these Little Red Foxes were probably away looking for Food

Courtesy of the National Museum of Canada

which you observed the birds and the squirrels during the day. The possum usually lives in the hollow of an old tree.

The red fox sets out at nightfall, looking for mice, ground squirrels, rabbits, wild birds, and chickens. Foxes dig dens in which they live together in families. The little ones in Fig. 161 are red foxes. These dens are cluttered up with the bones of animals brought in for food.

Down near the brook at night there may be a mink. This slender little animal passes easily into the dens of other animals of whose blood he is particularly fond. He is a vicious little animal, for in these raids he kills and devours the occupants of the dens. He may then claim for his own the home that he has raided. He feeds upon rabbits, muskrats, and birds — not always overlooking the fowls of the barnyard.

Fig. 162. The Skunk sneaks out at Night to pick up Eggs and Insects

Photograph by Cornelia Clarke

Skunks, famous for the odor they give off, sneak out at night to pick up turtles' eggs, snakes' eggs, and insects. They spend their days sleeping in burrows in the ground which they have dug under old stumps or rotting logs. If you do not know what they look like, see Fig. 162.

The beautiful little raccoon, who has spent the day in the safety of a hollow tree, goes down along the brook at night to get himself a supper of fish and mussels. Many of the empty shells on the bank have been cleaned out by him. The white-tailed deer bounds over the stone wall and helps himself to a meal of tender string beans in the farmer's garden.

In the morning there remain only a few tracks, the bones of a barnyard fowl, and a few eggshells to tell the tale of the night before. Before the sun appears most of the night prowlers will have returned to their dens and gone to sleep, and the life processes of daylight hours begin again.

The animals that go out at night in the forest and the animals that go out by day are continually in search of food. Some animals eat only plants, many eat both plants and animals, and some (minks, skunks, and foxes, for example) are very partial to animal food. In the animal world insects are used to a great extent as part of the diet. Insects are very numerous during the warm weather; so animals that feed upon them are never without food during summer. Insects feed upon plants, with very few exceptions.

Insects are a universal diet

Thus the food made in green leaves supplies, directly or indirectly, all the animals of the world, as well as the mushrooms, bacteria, and similar plants.

B. May Similar Life Processes be observed in Other Locations?

Suppose that, instead of a visit to the forest, you visited a pasture or field. Should you expect to find different forms of life there? Should you expect to see the same life processes under way? Suppose in imagination we visit a pasture. Perhaps you have had or may have an opportunity to visit a real one. If so, see whether our description presents a good picture of life there. Perhaps you may see many things that we have missed.

The most striking thing about the pasture is the grass which you see everywhere. The ground is covered with it. In each green blade the process of food-making is going on, just as it was in the green leaves of the forest. Thistles, dandelions, daisies, mustard, burdock, cocklebures, and other weeds are scattered here and there. The farmer would like to destroy them. He has tried again and again to do so, but in spite of him they continue to grow. Stalks of red clover may be seen with their flowers waving above the green grass, and white clover may be growing abundantly.

Grass, weeds, and clover cover the ground of a pasture

The roots of the field plants, like those of the forest, reach into the soil and bring up from it needed water and mineral salts. If you dig into the soil of the pasture, you will find that the top layer is run through with a mass of roots. The roots of the grass holding the sod together are like a tangle of little fibers. Not all the pasture plants have the same kind of roots. Those of the dandelion consist mainly of a large taproot, which extends downward into the soil some four or five inches.

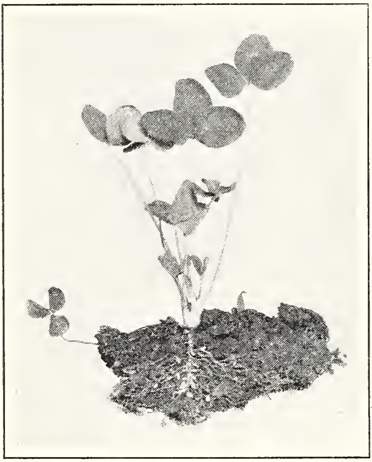

Fig. 163. Nodules of Bacteria grow upon the Roots of Clover

We examine the root of red clover

Now let us take the time to examine a root of red clover very carefully. Study Fig. 163, and you will see that attached in bunches to many of the roots are little nearly round bodies. The farmer calls these nodules, and he knows that if he grows clover having these nodules on its roots he may greatly improve the soil in a field and thus have better crops the next year. He may plant corn or wheat the next year and have a bigger yield because of the clover he has grown the year before. A field such as that illustrated in Fig. 164 is not grown for the sake of beauty alone.

There is life in these little nodules, and it is this life which makes the soil richer. Inside the nodules are millions of a kind of bacteria which have the power to take nitrogen from the air into their cells, combine it with other chemical elements, and make nitrogen compounds. No one knows how this is done. It is known that these nitrogen compounds are necessary for the making of proteins, which, as you

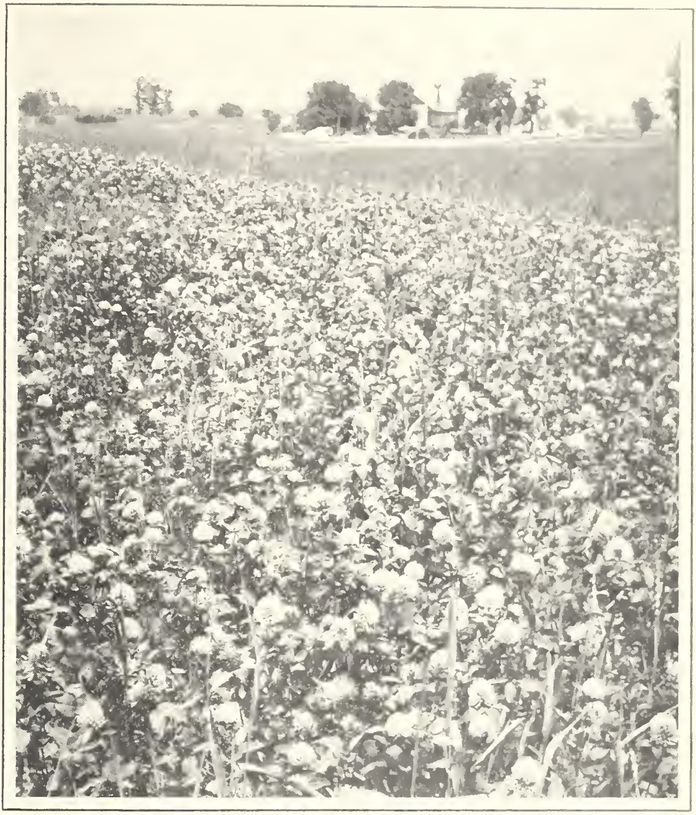

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Fig. 164. Clover is not grown for its Beauty Alone

On the root of red clover are bacteria which can take nitrogen from the air and make nitrogen compounds

learned, are made by green plants. The green plant cannot by itself take nitrogen from the air; it depends upon these tiny bacteria to do it. The nitrogen compounds are used by the clover plant in the process of making proteins, and in this manner the nitrogen compounds are stored in the plant. The farmer may leave this crop of clover in the field and plow it under, in which case the plants decay and the nitrogen compounds are left in the soil. They may be used by the next crop of grain that grows in the field. The nitrogen in the protein molecules in the cells of your own bodies probably came from the air by way of the bacteria growing on the roots of clover plants in some far-off field.

We are dependent on bacteria

Peas, beans, and alfalfa also have these nodules of nitrogen-fixing bacteria upon their roots. The process of making nitrogen compounds from the nitrogen in the air, as it is done by bacteria, goes on rather slowly. It is so slow that hardly enough is formed in this way to supply to the soil the nitrogen that is needed for the growth of plants. During recent years chemists have learned how to make nitrogen compounds from the nitrogen of the air, so that life on earth no longer depends upon the activities of these tiny bacteria.

The nitrogen cycle is completed

In the pasture common white clover may be very abundant. This, as well as the red clover, has nitrogen-fixing bacteria upon its roots. It too is useful in the completion of the nitrogen cycle. Nitrogen passes from the air to the bacteria, to the cells of the clover, to an animal which eats the clover, perhaps to another animal which eats the first, and so on until in the processes of decay or food-using the living cells are finally broken up and the nitrogen is released again. Some of this nitrogen may go directly back into the air; some of it may be changed by other bacteria into simple nitrogen compounds, called nitrates. In the form of nitrates the nitrogen may be absorbed and used again by green plants, to build up protein material in the cells. These plants die and decay or are eaten by animals which in turn die and decay. Thus this set of chemical changes is continuously going on, the nitrogen passing from the air into the composition of living things, and from the living things back into the air. This set of chemical changes is called the nitrogen cycle.

In the pasture, as in the forest, there is much insect life.

Upon a head of white clover is a bee, busily gathering nectar, a sweet liquid in the flower. Upon other clover blossoms are many other bees, all at work getting food. In Fig. 165 the photographer caught one at work. A bee lights on one blossom, stops a minute, and flies to another. It works over the second blossom for a minute and passes on again. The bee is gathering the nectar from which it makes honey. As it flies from blossom to blossom, it pushes a long tube which serves as a mouth down between the parts of the flower and sucks the nectar. After a time it has taken its fill. It then flies away to its hive. Within the body of the bee the nectar is partly digested and changed into honey. The bee deposits the honey in the comb already prepared. This honey serves as a store of food for use by the bee during winter, when there are no flowers.

FIG. 165. As the Bee gathers Nectar for Food, it carries Pollen from Flower to Flower

Photograph by Frank Overton. (Courtesy of the American Museum of Natural History)

The nectar that the bee gathers seems to serve no other essential purpose for the plant than to attract the bees. But if you should examine a bee at work, you would see that besides nectar it is also gathering yellow dust. This dust, which sticks to the fuzzy body of the bee, is pollen. The bees and other insects gather nectar and pollen, not only from clover, but from roses, apple blossoms, peas, beans, and many other flowering plants.

A bee carries pollen from flower to flower

Pollen is essential in the life of the plant. In order that a seed of white clover may form from a flower, it is necessary that a grain of pollen be carried to the flower to fertilize the little egg cell that is deep down in it. Let us study this process a little further.

Pollen is required in seed-making

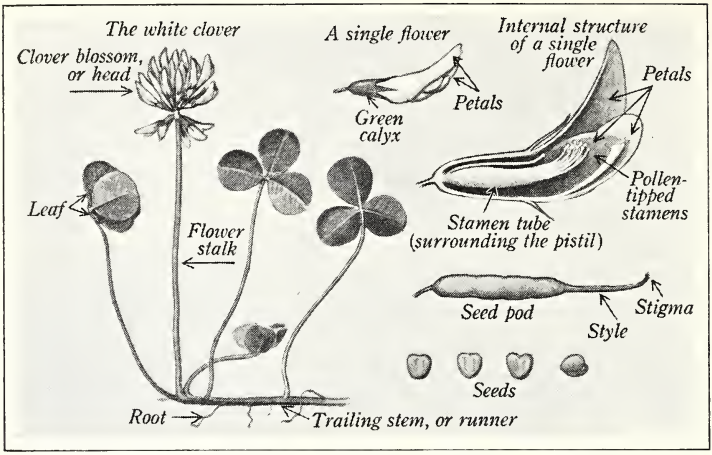

FIG. 166. Seeds are formed in the Clover Head

You have many times seen white clover growing in a lawn. Doubtless you have seen the bees busily at work moving from one head to another. The picture shows a clover head, or "blossom." The head is composed of many small flowers clustered together. You may examine one of these with a magnifying glass. When you pull it loose from the head, you find that it looks like the single flower shown in Fig. 166. You may see the green calyx and the petals. Just inside the petals you may see the stamens. The pollen is formed on the ends of these. Within the group of stamens you may see a single structure somewhat thicker than the others and shaped somewhat like a very tiny pop bottle with a long neck, or style. This thicker structure, not shown in the drawing of the internal structure of the flower, is the pistil. The upper end is sticky. The sticky top is called the stigma. In order that the flower may produce seeds, tiny grains of pollen must be carried from the stamen of one flower to the pistil of another. You may wonder why the pollen must be transferred from one flower to another. In this flower from the clover head, as in many other flowers, the pistil is not fully developed at the time when the pollen is ripe. For this reason the pollen of one flower does not affect the pistil of the same flower. In larger flowers, like the morning glory, these parts may be more easily seen.

With this description in mind, let us see how a seed is formed. A pollen grain that has been carried from the stamen of one flower to the pistil of another sticks fast to the sticky stigma. In a short time the pollen starts to sprout, somewhat as a seed does. It bores its way down into the pistil and into the very center of the flower. Here a part of the pollen grain, which is known by the name *sperm cell,* touches and combines with another tiny cell, known as an *egg cell.* The two cells unite to form one new cell, and a seed develops from this new cell. At the base of each single flower there are as many as three or four egg cells. In order that a seed may be produced from each egg cell, it is necessary that the egg cell shall combine with a sperm cell. The pod in which the seeds are formed is also shown in the picture. In the fully matured flowers (that is, the ones turning brown) you may find the seed pod deep down within. If you find the pod, you will be able to find the three or four seeds like those shown in the picture.

As you look at a sack of clover seed, does it not seem strange and wonderful to think that each seed has been formed by the complex process just described, and that a bee or some other insect has played an essential part in the process?

The pollen from a good many flowers is carried from one flower to another by the wind. Pollen of the many forms of grass is blown by the wind, and there is such an abundance of it in the air that some will reach the pistils of other grass flowers that are round about. The flower of these plants is usually hard to see, so difficult, in fact, that you may think the plant has no flower at all. But the flower is the seed-producing organ of the plant, and all plants that produce seed must first produce a flower, with the exception of such plants as pine, hemlock, spruce, and others, which bear their seeds in cones.

If you were to watch a field of red clover, you would never see any honeybees on the blossoms, for the mouth parts of the honeybee are not long enough to reach the nectar in these flowers. Very likely there will be no insects of any kind except one upon the blossom of the red clover, for the nectar is so deep within the flower that no other insect can reach it.

Where there are no bumblebees, there are no red-clover seeds

The only insect that can carry the pollen of red clover from one blossom to another is the bumblebee, which is much larger than the honeybee. An interesting illustration of how clover depends on bumblebees is given in the experience of introducing clover into Australia. Before white men went to Australia neither red clover nor bumblebees lived there. As the country was settled, the farmers tried to introduce red clover. They planted the seed. The crop grew, and the soil seemed to be most satisfactory, but the crop which grew and blossomed did not produce seed, for there were no bumblebees to carry pollen from one blossom to another. Finally bumblebees were sent to Australia, and red clover has thrived ever since.

Another example of this way in which red clover depends on the bumblebee may be found in the fact that farmers often report that red clover does not produce a plentiful crop of seed during a very wet season. Can you guess why? Let us tell you that the nest of the bumblebee is usually in a hole in the ground. What do you think happens to this nest and the bees in it during a wet season? What effect would this have on the crop of red clover? Can you explain now why a wet season may hurt the clover crop?

Several years ago in England someone said more or less jokingly that the number of cats in England affected the price of beef, and explained the statement in this way.

FIG. 167. FABRE, *who wrote for Boys and Girls* (*1823-1915*)

JEAN HENRI FABRE was born in France a few years after the guillotine had cut short the life of Lavoisier · As a boy at school he was interested in natural history, and for many years was a professor in one of the French colleges. In case you have never heard of natural history, it would be well to explain to you that it was the ancestor of our "general science" of today, for natural history dealt with the science of the environment · Fabre taught his students about the common things which they saw and lived with every day. He told them about the earth, its rocks and mountains and rivers, about the stars and the planets. He experimented with them in the chemistry of soils and foods. But he became most enthusiastic when they studied the living creatures, particularly the insects, which buzzed and bit and burrowed just outside his window, for Fabre was not only a good teacher but a painstaking and thorough scientist in the field of insect life · Throughout his long life he made many observations of the insects around him and wrote careful treatises on wasps and ants and bees. For the boys and girls whom he knew and for the many others who have since grown up in France and England and America, in fact all over the world, he wrote no less than twenty books on various phases of natural history. You will find them interesting reading. The next time you go to the library, you might look for some of them upon the science shelves.

Field mice sometimes destroy the nests of bumblebees and eat the honey. Cats eat field mice; and so, if there were many cats, there would be few mice, but many bumblebees. If there were many bumblebees, there would be much red clover, and so many cattle would thrive upon it. If there were many cattle, there would be much beef, and, according to the law of supply and demand, beef would be cheap. On the other hand, if there were few cats, there would be many mice and few bumblebees. With few bumblebees there would not be enough clover for many cattle, and beef would be expensive. Thus the conclusion was that an abundance of cats brought down the price of beef, and that a scarcity of cats made beef expensive.

To a certain extent at least, this person was wrong, for contrary to common belief cats do not catch a great many mice. Owls and hawks catch many more, and it is quite certain that if there were no owls or hawks there would be more field mice, and it is possible that in this indirect way owls and hawks might have an influence on the price of beef.

Let us see what other forms of animal and insect life we can find in the pasture. A beautiful brown-and-black butterfly hovers over some milkweed blossoms growing in a corner of the field by the fence. Upon a partly eaten leaf is a huge green caterpillar. It is rather an ugly-looking thing, and its appetite is enormous, as is evidenced by the way the leaves about it have been destroyed. Who would think its mother was the beautiful monarch butterfly? In the past ten days it has developed from a tiny egg about the size of a pinhead. During that time it ate almost steadily. Finally its too tight skin split right down its back, as a boy's jacket will when he has outgrown it. But the caterpillar had a new and more elastic skin under the old one. He ate and grew and filled this one. It too was split and was left behind like the first one. This green caterpillar before you is now wearing his fourth coat.

The monarch butterfly is mother to the green caterpillar on the milkweed

FIG. 168. There are Four Stages in the Life of Most Insects

Three stages are illustrated here. (Courtesy of the American Museum of Natural History)

One after another formed as the organism grew. When insects shed their skins or birds their feathers, we say they "molt." After the fourth molting the caterpillar will change to another form, called a pupa. In the pupa stage it will appear to be entirely inactive. It will look very unlike the caterpillar, and not at all like the butterfly it is going to be. The pupa of the monarch butterfly will hang on a fence or hedge and remain quiet for about two weeks. When at last the pupa splits open, the butterfly will appear. There are four stages,

It will change to a pupa

then, in the life history of this butterfly, as there are in the lives of all butterflies and moths and most other insects. These stages are the egg; the caterpillar, or larva; the pupa; the adult. Fig. 168 illustrates three of these. The adult butterfly will lay eggs, and the life cycle will be repeated.

There are four stages in the life history of most insects — egg, larva, pupa, adult

Beetles have the same four stages in their lives. So do bees, ants, flies, and mosquitoes; but grasshoppers, crickets, katydids, walking-sticks, and praying mantes do not. The young hatched from the egg of the grasshopper looks very much like the adult, except that it is smaller and has no wings.

It is during the larval stage that insects are frequently most destructive. It is because they are growing fast that they are so hungry and eat so much. Many caterpillars are very destructive, and man continually makes war upon them. Some beetle grubs, which are the larvæ of beetles, are even worse than the caterpillars. Among these are the grub of the Colorado potato beetle, with which boys and girls who live in the country are all too familiar; the grub of the European corn-borer, a pest in the cornfields of the East; and the grub of the Japanese beetle of New Jersey, New York, and Pennsylvania. Do you recognize the pests in Figs. 169 and 170?

Many birds — bobwhite, meadow lark, kingbird, chickadee, robin, wren, and others — do endless good by keeping the insect life of the field and orchard in check. If you could watch a wren as it gathers food for its young, you would appreciate the value of these little birds. In the course of a day a wren may make perhaps a hundred trips from the nest to the field, bringing back an insect on each trip.

Many birds eat insects

In addition to insects and birds many other small animals live in the pasture. Many field mice inhabit holes which they dig in the ground. During the summer they feed upon blades of grass and upon the stems of other

Fig. 169. The Caterpillar of the Cabbage Butterfly eats Several Times its Weight Each Day

Photograph by Cornelia Clarke

Fig. 170. Farmers make War on the Potato Bug Each Summer

Courtesy of the United States Department of Agriculture

plants. Ground squirrels and gophers and cottontail rabbits also make their homes in fields. Some of these little animals are pests because in meeting their own needs for food they destroy some of the farmer's crop. They eat green things during the summer, and in fall and winter they feed on the seeds of plants. They may destroy considerable quantities of corn in a season.

Snakes are familiar reptiles of the field and pasture. Among the most common are garter snakes, black snakes, blue racers, bull snakes, and king snakes. Most of these are useful to man on account of their food habits. They eat mice, rats, and gophers, and together with owls and hawks help to keep these destructive little animals from becoming too numerous. Some snakes also eat birds, especially young birds. None of these snakes are poisonous. But they will fight back if they are attacked, and their bite, like the bite of a mouse or of a rat, may cause a bad infection. Unless you know how to handle these snakes, you should not touch them. They are harmless if you do not disturb them. There are some sections of the United

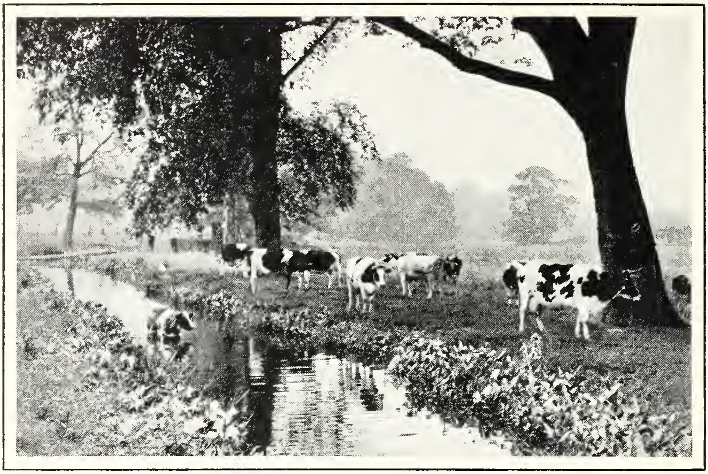

Fig. 171. Man uses Animals that feed upon Plants

Courtesy of the United States Department of Agriculture

States in which rattlesnakes and copperheads may be seen occasionally. These are dangerous. Fortunately they have become very scarce, especially in the more thickly settled sections of the country.

Probably the most familiar animals of the pasture are the herds of cattle and sheep. These eat the grass of the field and change it into milk and into beef and mutton, which become the food of man. Such a scene as that in Fig. 171 is a familiar one to many people. Man is in one respect like the owls and like some snakes. For part of his food he uses animals that feed upon plants. We call an animal a pest if, in its manner of living, it interferes in any way with the efforts of man to secure food for himself. A field mouse is a pest because it takes for food some of the corn that the farmer grows to feed to the cattle that supply him with milk and meat. Animals, such as the snakes, hawks, and owls, that feed upon field mice are helpful to man, for they eat animals that are pests.

FIG. 172. Toads help to keep Insects in Check

Photograph by Cornelia Clarke

In the pasture, field, or forest the different kinds of animals tend to keep one another in check. Where there are many birds, there are fewer insects. Similarly the more owls, hawks, and snakes there are, the fewer mice, ground squirrels, and gophers. Even the toad helps. Look at Fig. 172. All about us are examples of the way in which plants and animals depend upon one another and upon their physical surroundings.

C. What Effect does Seasonal Change have upon Life in the Forest and Pasture?

Forests and pastures change with the seasons. With the coming of fall the forest and pasture take on a different appearance. The leaves (except those of the evergreens) lose their green color, and the grasses and weeds of the pasture turn brown. Seeds of plants are ripe in their pods, wild fruits ripen, and acorns and nuts fall. The animal life changes tremendously. Most of the fully developed insects are killed by cold weather, but they lay eggs before cold weather comes. The eggs of some insects remain on the ground all winter and hatch in the spring. The grasshopper is one of these. The eggs of other insects are laid during the summer and hatch before winter comes. In such cases the insects live through the winter as either larvæ, pupæ, or adults. Many moths and butterflies live through the winter as either larvæ or pupæ. A few insects, including the bumblebee and house fly, live through the winter in the adult stage.

Birds migrate when cold weather approaches

Some birds feed almost entirely on insects, and when winter approaches and insects become scarce, many of these birds migrate to the south. The robin, bobolink, blackbird, thrush, swallow, brown thrasher, wren, and others migrate when winter comes. Some of these birds travel great distances; others make only a short journey. Robins stop in the states along the Gulf of Mexico. The bobolink travels a much greater distance, going as far as the valley of the Paraguay River in South America. The distance between the southern home and the northern home of these birds may be as much as five thousand miles. This round trip of ten thousand miles every year requires a great amount of time spent in travel. One of these birds might start in early September from the wheat fields and pasture lands of Manitoba. It would continue southward over the plains of western United States through Mexico and Panama to Venezuela. It would cross the equator and fly over the dense tropical forests of the valley of the Amazon, over the plains of Brazil, and into a region the climate of which is very much the same in January as the climate of the Mississippi Valley in June. There the bird lives until February and then journeys back to the plains of Canada. The vireo and kingbird winter in Bolivia. When you welcome these birds in the spring, you are greeting travelers from distant lands.

With the approach of winter, field mice and gophers retreat to their dens, where they have laid up a supply of food.

Some animals remain during the winter

Some of the animals remain active and continue their search for food. If there is snow, you may see the tracks of rabbits, squirrels, opossums, raccoons, minks, and foxes. With the approach of winter these animals grow a heavy fur to serve them as a protection against the cold. Life in winter is severe for the animals because food is so scarce. Squirrels, rabbits, foxes, and other animals that stay active through the winter are round and fat in the fall. Before spring comes they are thin and bony. Some of them are unable to endure the hardships of a severe winter. Many freeze to death, and others starve.

And so you see that life does not depend upon nonliving things alone, but upon life itself. The growing plants and the seeds they produce are food for animals, either directly or indirectly. Interesting stages in the life cycles of plants and animals are the work of the bacteria in making nitrogen from the air suitable for plant growth; the part of the bee in seed-making; the changes that go on in the life histories of insects; the migration of birds; and the struggle for food that is continually in evidence among animals. All forms of life adapt themselves to their environment. They live and they die in a continuous cycle. In dying they furnish the materials for other forms of life, and in living they make use of things that have died. Even while they live, they depend upon other forms of life. Life, after all, is a highly interdependent affair.

Living organisms depend upon one another. The processes of life observed in different locations have certain things in common. All of them illustrate how living things adjust themselves to their environment.

Can You Answer these Questions?

1. Many people living in the city would think it wasteful for a farmer to plant a whole field of clover when he could plant so many other food plants and vegetables. What do you think?

2. In previous chapters we have talked about the water cycle and the carbon cycle. Now we add the nitrogen cycle. Is this different from the others? What similarities are there?

3. Make a list of animals that feed mostly at night.

4. The grass on a lawn may be brown and apparently dead during a long hot spell in summer, but the dandelions will remain green. Can you offer a possible explanation of this?

5. How may too much rainfall in early summer hinder the formation of seed in red clover?

6. Can you tell the story of a clover seed?

7. In this chapter we have another example of the life cycle as revealed by the life of a butterfly. Can you trace it?

Questions for Discussion

1. Some forms of insect life produce thousands of their own kind each year. Why is it, then, that we are not overrun by insects?

2. What do we mean when we speak of the interdependence of plants and animals?

Here are Some Things You May Want to Do

1. Make a chain of animals that eat other animals, like this: "Cats eat birds, birds eat insects, insects eat green leaves," or "Cats eat mice, mice eat corn." See how long a chain you can make before you come to the plant that uses only air and soil.

2. Make a diagram to illustrate the meaning of the nitrogen cycle. Consult an encyclopedia and a textbook on biology.

3. There are many fine books written on the life of animals. You might read Ernest Thompson Seton's *Wild Animals I Have Known* or *Lives of the Hunted,* which tell the stories of wild animals in their struggle for life. Another interesting book is F. M. Chapman's *Travels of Birds.*

4. Trace with pictures the life history of a butterfly or a moth.

5. Make a study of bird migration in your own neighborhood. You may wish to have a class book containing the information you have collected.

6. Read Maeterlinck's *Life of the Bee.*

7. You might extend your study of bird migration in your own community to a study of similar migrations in other parts of the United States or of the world. Some of the distances traveled by birds in these migrations will surprise you.

8. One of the most interesting types of animal migration is the one illustrated by the life of the lemming. This animal lives in the Far North. See what you can find out about it and report to the class.

9. Make a diagram of a bee on a flower, showing the parts of the flower and how the bee gathers the pollen.

Chapter XXII · What Part does Food Play in Life?

Have you ever read Irving's "Legend of Sleepy Hollow"? If so, you remember the tall, lean schoolmaster, Ichabod Crane. You remember, too, Ichabod's terrific ride on his old decrepit horse Gunpowder when he tried to escape from the headless horseman who rode at his side. What else do you remember? Do you recall Katrina, the daughter of the prosperous Dutch farmer, and how Ichabod wished he might belong to that family where the harvests were rich and food was plentiful? Food! That word to poor Ichabod had a beautiful sound. Irving describes an afternoon tea at Katrina's house in this way:

> Fain would I pause to dwell upon the world of charms that burst upon the enraptured gaze of my hero as he entered the state parlor of Van Tassel's mansion. Not those of the bevy of buxom lasses, with their luxurious display of red and white; but the ample charms of a genuine Dutch country tea table, in the sumptuous time of autumn. Such heaped-up platters of cakes of various and almost indescribable kinds, known only to experienced Dutch housewives! There was the doughty doughnut, the tenderer oly koek, and the crisp and crumbling cruller; sweet cakes and short cakes, ginger cakes and honey cakes, and the whole family of cakes. And then there were apple pies and peach pies and pumpkin pies; besides slices of ham and smoked beef; and moreover delectable dishes of preserved plums and peaches, and pears, and quinces; not to mention broiled shad and roasted chickens; together with bowls of milk and cream, all mingled higgledy-piggledy, pretty much as I have enumerated them, with the motherly teapot sending up its clouds of vapor from the midst — Heaven bless the mark!

No wonder Ichabod could scarcely wait until it was time to eat.

If you know any elderly people, ask them about a Sunday dinner of years ago. Why do you think our ideas of proper diets have changed? Why do not we have the kinds of dinners that the people had years and years ago?

Different people need different foods

The story of food is an interesting part of the story of the development of the human race. The cave man had his special foods, the Indian his; today the Eskimo has one diet, the dweller in the jungle another. Even you differ from your friends in the kinds of food you like. Perhaps you have heard your mother discuss what she is going to have for dinner when company is coming. She cannot have this dish, for Aunt Elizabeth does not eat it; she must have another kind of dish because it is the favorite of Uncle Bill.

What do you know about the menus of various people? Perhaps you would like to find out something about them. See if you can plan a menu for one of the following occasions. In your planning be sure to consider the people, the climate, the season, and whether or not the things you want to include can be obtained. You should not, for example, suggest pumpkin pie for a dinner in the South Sea Islands.

The Feast of a Roman Emperor
A New England Christmas Dinner One Hundred and Fifty Years Ago
The Dinner of a Cave Man
An Indian Feast
A Sunday Dinner in Modern Italy (or in some other foreign country)
A Banquet in the Middle Ages in Central Europe
A Holiday Feast in the South Sea Islands
A Thanksgiving Dinner in the Congo
A Birthday Party for an Eskimo Boy
The Best Dinner I can Think Of

Perhaps you may like to talk over some of these menus in class.

A. What is a Well-Planned Diet?

Civilized man, in his search for foods, has visited the entire globe. In his travels he has sought a variety of foods, as well as the bare necessities. Hunger has led man to many discoveries and has forced him into war again and again. Columbus discovered America while trying to find a new route to India. The Europeans were interested in India because from that country came, among other things, their spices and other desirable foods. Uncivilized tribes have become shepherds because they wanted to keep sheep and cattle for milk and meat. In some parts of the world shepherds are nomads because they have to keep wandering in search of food for their herds. In these countries a small patch of land will not grow enough to feed the animals.

In our own land we find farms developed where there are rich soil and plenty of rainfall. Thus you see that the food supply determines how people shall live.

This morning, when you sat down at the breakfast table, you probably found grapefruit from Florida, California, or Texas, cereal from the Middle Western plains, milk from a farming district within your own state, sugar from the West Indies, and coffee from Brazil.

Our food comes from many sources

The sources of the food upon the dinner table are even more varied. There may be beef or lamb or pork from the Middle West or perhaps fish from the ocean a thousand miles away. There is salt, probably from the mines in New York, and beside it pepper from somewhere in the tropics. The potatoes may have been grown in Idaho, Long Island, Bermuda, or Maine. The vegetables may have come from the Southern states. Perhaps they were canned last season and are only now being used. There may be olives from Italy. The dessert may have come from any number of different places. Bananas, coconuts, dates, apricots, peaches, rice, tapioca, and raisins indicate only a few of the geographic possibilities.

The scientist has played an important part in making such a varied diet possible. Once the family's food supply depended largely on the products which came from the immediate community. Fresh vegetables were unknown during northern winters. Today fast steamers, express trains, and airplanes rush perishable foods to our large cities and in turn to the smaller communities. Modern methods of refrigeration have made this possible. Iced freight cars carry perishable food products without danger of spoiling. Automatic refrigeration keeps foodstuffs safe for human use for months.

More than this, your food supply is protected through strict inspection by national and city authorities. Severe penalties are handed out to merchants who fail to observe sanitary precautions. Such foods as meats, fruits, and vegetables are as far as possible kept under glass, in huge refrigerators, or at least under netting, away from flies, insects, dirt, dust, and careless handling by customers. The milk you drink must meet certain standards, and the eggs you eat are graded. No longer do you need to fear, as people once did, the dangers of impure food.

Our meals are well balanced

No less interesting than the source of your dinners is the way they are put together and planned so that they contain all the substances you need for growth and energy. As you eat, you may not think of the problems of planning a meal. The cook or housewife attempts to include enough energy foods to meet the needs of the active boys and girls of the family, but not so much that extra starch or sugar will be stored in their bodies in unnecessary layers of fat. She chooses the fresh vegetables (or the canned ones of a reliable brand) which contain a variety of mineral substances and the needed vitamins. She provides lean meat, eggs, or cheese for growth material. She requires that the growing members of the family each drink a glass of milk at each meal, for milk is easily digested and is rich in the necessary

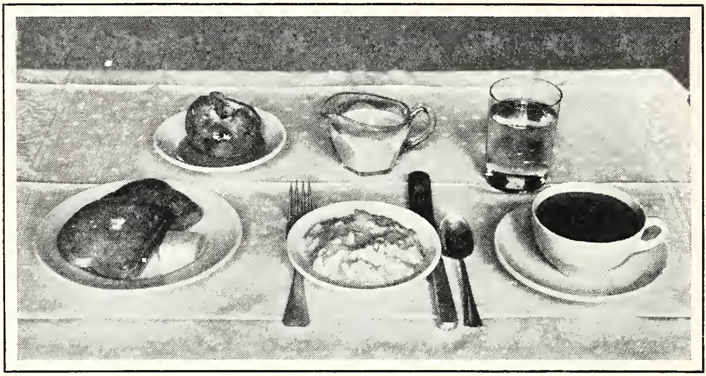

Fig. 173. This Meal, consisting of Oatmeal, Cocoa, Toast and Butter, Milk, and Baked Apple, is an Excellent Breakfast for Anybody

Courtesy of the American Museum of Natural History

food substances. She prepares a simple dessert which probably contains fruit of some kind, possibly of several kinds, for she knows that fruits as well as vegetables contain mineral substances and vitamins in generous amounts.

As a result of this better knowledge of proper diets, great care is taken to make sure that people generally are provided with foods best suited to their needs. Many places, such as hospitals, have experts trained in the study of foods to plan the diets for their patients. School cafeterias too usually have someone in charge who plans menus which contain the proper food values.

Care should be taken in selecting meals

The best work of these experts, however, must be helped along by intelligent food selection on the part of everyone at all times. Consider the problem of choosing a proper meal from a restaurant menu. Many different kinds of dishes are suggested, most of them good, well cooked, and nutritious. How shall a person select from this list? Only a knowledge of proper food combinations can help here. In general one tries to select a varied meal which will produce both energy and growth. Food rich in mineral salts, such as vegetables, will be selected. One of these vegetables will be a leafy one, such as spinach or lettuce. Some liquid food will be chosen also, and this will probably be milk. A dessert will be chosen to satisfy the longing for sweets which so many of us have. Merely to select large quantities of food is not enough. Smaller amounts of varied and wisely selected foods are better for the body, for they are more likely to contain the elements so necessary for proper nourishment. Fig. 173 illustrates a good breakfast for a school child.

B. Why is a Large Variety of Foods Necessary to a Well-Balanced Diet?

In order to find the answer to the question in the heading you must recall some of the things you learned about food.

You have seen that most plants can make food from air, water, and soluble mineral salts. Sugar is made in the leaves of a plant from carbon dioxide and water, and it can be produced only in the green cells. Experiments have shown that food is made only when the sun is shining. The sugar which has been formed in the green cells of the leaf circulates in the sap to the living cells in all parts of the plant.

Sugar is made in green leaves in the presence of sunlight

Sugar may be changed into starch and stored in the leaf, or it may be carried to stem or root and changed into starch there, as in potatoes and other vegetables. Seeds of plants — wheat, oats, corn, and rice — are a main source of foods for men and animals. Seeds are composed chiefly of starch. No other chemical elements are added when starch is formed from sugar. Because these substances are compounds of carbon, oxygen, and hydrogen, and because, as in the case of water, there are usually twice as many atoms of hydrogen in their construction as there are of oxygen, these substances are called carbohydrates (carbo = carbon;

hydrate = water). Fats and oils, which are produced from carbohydrates by a chemical change, are also compounds of carbon, hydrogen, and oxygen, but in different proportions. Sugar and fats are composed of the same elements, but these elements are not present in the same amounts. Fat and sugar do not look alike, and, of course, they do not taste alike.

Foods may be used by the plant which makes them or may be eaten by animals

The carbohydrates and fats (the oil in plants is really fat) may be used by the plants in which they are formed. Proteins, about which we shall say more presently, are also found in green plants. These foods are used in the plant cells for energy and growth. The carbohydrates, fats, and proteins which are made by plants are not all used by the plants themselves. A large part of them is taken by animals of one kind or another for their use. Animals cannot make their own food, and thus depend upon plants.

Starch, sugar, fats, and oils are energy foods

These carbohydrates, fats, and oils are commonly called *energy foods*, or fuel foods. When an animal eats quantities of potatoes, rice, corn, wheat, sweet fruits, or sugar made from beets or cane, he supplies himself with carbohydrates, which will give him energy. A plant stores some of the energy foods that are formed in the process of food-making. An animal eats the foods in which the energy is stored. The complex molecules of sugar, starch, and fat are broken down as they are changed chemically by the oxygen in the animal's body; and heat is produced. This heat keeps the animal warm. The products of food-using are the same as those of burning, namely, carbon dioxide and water. Some of the energy that is released may be used by the animal in running, jumping, or working. A person who exercises a great deal needs more energy-giving food than one who spends most of his time sitting still. A person needs less fuel food in summer than he does in winter. Eskimos need more energy food than the Pygmies, who live at the equator. But Eskimos can get neither starch nor sugar, except in limited quantities. For energy food they have to depend chiefly upon the fat of whales and seals. Properly enough, they burn these same substances to warm their homes and to cook their food.

Many of the best energy, or fuel, foods are indeed used for making fires in other parts of the world besides the Far North. Many farmers burn their cornstalks, either to get rid of them or as fuel. The waste from sugar cane is often used to feed the furnaces in the sugar mills. Although it is usually unnecessary and uneconomical to destroy good food materials to make a fire, it is interesting to know that all these energy, or fuel, foods which are used in our bodies will burn. A similar chemical process is taking place in either case, whether the complex molecules are broken down by burning or by food-using.

Proteins are necessary for all living cells

A second important group of food substances is the proteins. Proteins are essential to all living cells. All forms of protein, both plant and animal, contain nitrogen. Proteins also contain sulfur, phosphorus, and some other elements. The living cell is probably the most complex bit of material with which the chemist has to deal. He cannot duplicate it. He cannot even completely analyze it, but he can tell of what elements it is composed.

Every animal and every plant must have protein foods out of which its own body cells may build new cells. The protein foods are therefore called *growth foods*. Growth goes on most rapidly throughout the periods of childhood and youth, but throughout life new cells are continuously forming.

Every seed contains proteins. Thus beans, corn, peas, wheat, acorns, peanuts, and other seed foods are useful to animals for growth. Protein foods are obtained by carnivorous, or flesh-eating, animals when they eat other

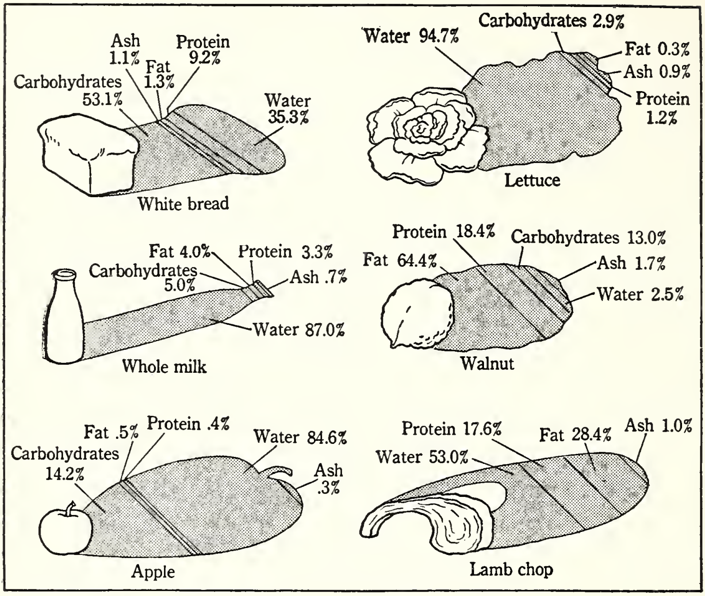

Fig. 174. Our Common Foods are Composed of Different Elements

The proportion of these elements differs in various foods

animals. Eggs, cheese, milk, and lean meat are all rich in proteins. The white of an egg is nearly all protein. It is food used in the growth of the baby chick or baby bird before it is hatched.

Mineral substances, especially salt, are needed by animals

Small quantities of mineral substances are needed by all animals. These substances, with few exceptions, are obtained through eating plant materials. One exception is common salt. Salt is the chemical compound sodium chloride, and it is absolutely essential to all animals. Cows must have a "salt rock," where they may lick salt occasionally. Birds peck at bits of salt as hungrily as at suet in winter. Deer and bears visit regularly the "salt licks" in the forests. African natives in a few places in the central part of the continent are more eager to get salt than sugar. The word *salary* comes from the Latin word *sal*, meaning "salt." In most places salt is abundant, and therefore cheap. It is obtained either by evaporating sea water or from deposits in mines which were formed in past ages when the water of an inland sea dried up.

Salt is a necessary part of the blood of all animals. In many cases when a person has lost much blood from an accident or from an operation part of it may be replaced by introducing a solution of common salt into his veins.

Iodine is also necessary to the human body. A compound of iodine is obtained from sea animals, from giant seaweeds, and from some salt deposits. There is usually a very small amount of an iodine compound dissolved in drinking water. When iodine is lacking in the diet, a disease called goiter may develop. There are certain regions in the United States and in other parts of the world in which there is not enough iodine in the soil to supply the needs of people living there. In some cities this shortage is met by adding an iodine compound to the city drinking water.

Other mineral substances, taken from the soil by growing plants, are compounds of calcium and phosphorus. These are important in the formation of bones and in other chemical processes that go on within the body. Iron is needed for forming red blood corpuscles, and still other elements have other important duties.

Vitamins are necessary to life

It is not sufficient that we plan our meals wholly in terms of carbohydrates, fats, proteins, and the minerals that supply chemical elements necessary for the processes that go on in the body. It has been proved that one may eat a sufficient amount of each of these and still be quite unhealthy because one is improperly nourished. Milk, green vegetables, and fruit juices are essential in the diet because they contain substances known as vitamins. But little is known about the chemical composition of the vitamins; so they are described in terms of their effects on growth. They are known by letters. The effects that result from a lack of the vitamins A, B, C, D, and G are well known, and in order to avoid them foods that contain these vitamins must be eaten. The disordered conditions that result from a deficiency, or lack, of vitamins in the diet are known as *deficiency diseases.*

Lack of Vitamin A reduces ability to resist disease

Vitamin A builds up a person's ability to resist infectious disease. Its absence from the diet causes certain eye disorders to develop. You need not worry much about this, however, for vitamin A is contained in so many foods that the deficiency diseases caused by a lack of it are almost unknown in this country. In experimental work with animals (white rats are commonly used) the effects from a lack of vitamin A may be readily demonstrated. Vitamin A is contained in butter, cod-liver oil, egg yolk, liver, sweetbreads, green vegetables, and tomatoes. Foods that have little or no vitamin A are beans, onions, radishes, lean meat, white bread, corn bread, oatmeal, bacon, and molasses. It would be possible, therefore, for ignorant people to make up a diet that does not contain enough of this important vitamin. Vitamin A is not destroyed by ordinary cooking.

The lack of vitamin B causes beriberi

The absence of vitamin B from the diet causes a nervous disorder known as beriberi. In extreme cases this disease becomes very serious. Vitamin B is abundantly distributed in nature. It is contained in vegetables, fruits, cereals, milk, and meat. It is not present in noticeable amounts in polished rice, white corn meal, white flour, sugar, or fat. In some countries, particularly in China and Japan, polished rice has been used to a great extent as food. In these countries beriberi has been the cause of much suffering and loss of life. In experiments in which animals are fed only on polished rice or on other foods known to be deficient, or lacking, in vitamin B, this disorder soon develops. Vitamin B is not destroyed by cooking.

The deficiency disease that develops from a lack of vitamin C is known as scurvy. It is accompanied by loss of weight, deficiency of red blood corpuscles, shortness of breath, and an unhealthy condition of gums and teeth. Vitamin C is present in fruits and vegetables, and to a considerable extent it is destroyed by cooking. In the days of sailboats sailors were frequently away from land for months at a time. During this time they were, of course, unable to obtain fresh foods, and the suffering from scurvy was often very great. Scurvy is not uncommon among children, but it does not develop if fresh vegetables are included in the diet.

Scurvy is caused by a lack of vitamin C

Deficiency in vitamin D is the cause of rickets, and a large percentage of children suffer more or less from this deficiency disease. In experiments with animals it has been shown that the body of the animal suffering from rickets does not properly make use of the elements calcium and phosphorus and that these elements are essential to the proper development of teeth, bones, and nerve tissue. One of the main symptoms is the effect on the bones. Rickets is cured by the use of foods that contain vitamin D. Strange as it may seem, sunlight has an effect similar to vitamin D in the prevention and cure of rickets. The disease is therefore not likely to develop in children that play out of doors in the sunshine. It is for children in crowded cities that a substitute for sunshine must be provided, and this substitute is vitamin D. Children both in the city and in the country may suffer during winter from deficiency of vitamin D. This vitamin is not present in quantity in many foods, but it is present in cod-liver oil. The best-known substitute for play in the sunshine is, therefore, cod-liver oil.

Vitamin D is the sunshine vitamin

Cod-liver oil is a source of vitamin D

Vitamins A, B, and C are well distributed in foods, and there will be no deficiency of these in a well-balanced diet. The diet should contain plenty of milk and plenty of green

Fig. 175. Liver, Carrots, Butter, and Spinach are Rich in Vitamin A; Peas, Prunes, and Whole-Wheat Bread are Rich in Vitamin B; and Oranges, Grapefruit, and Tomatoes, Cooked or Raw, are Rich in Vitamin C

vegetables. Vitamin D is not abundant in foods, but it is abundant in cod-liver oil. Taking Vitamin D and exposing the body to sunshine have similar effects in preventing and curing rickets.

Pellagra is due to a lack of vitamin G

A deficiency disease known as pellagra is caused by a lack of vitamin G. Pellagra is common among people who have been deprived of fresh meat, milk, eggs, and fresh vegetables. In one section of the country where this disorder was prevalent, it was found that the main articles of food used by the sufferers were refined wheat flour and corn meal, polished rice, fat pork, and molasses. Experimental work has shown that these foods are deficient in vitamin G. The cure for pellagra is fresh meat, milk, eggs, and fresh vegetables. These are the foods that are rich in vitamin G.

The vitamins, except vitamin D, are widely distributed in food. In Fig. 175 are shown some well-known foods, rich in the different vitamins. There are, however, some foods that are rich in some vitamins and deficient in others. Green vegetables have vitamins in greatest variety. Milk and eggs are deficient in vitamin C. Cereals and cereal products and fats are all deficient in vitamin C. These foods are eaten for their protein content, which is important for building new tissue, or for their carbohydrate content, which is important for energy. A well-balanced diet will include fresh vegetables, milk and milk products, meat and meat products, and cereal and cereal products.

Thus you see that food is not the simple substance that many of you may have thought it is, but a combination of many different elements which help to support life in many different ways. Because of this, the combining of these elements into proper and well-balanced diets has a tremendous effect upon life.

Plants and animals need food for fuel and food for growth. Through increased knowledge of food values modern diets are well planned and provide for the food elements which guarantee energy, growth, and vitamin content.

Can You Answer these Questions?

1. In naming the important food elements a student gave carbohydrates, fats, and proteins. What very important group was left out? Why is this group important?

2. A diet selected from beans, white bread, onions, and oatmeal might be not only tiresome, but even insufficient for good health. Why?

3. Polished rice is lacking in one very important food element. What is it?

4. Which vitamin might be called the sunshine vitamin? Have you ever seen this term used? Where?

Questions for Discussion

1. Would it be possible for a person to eat large quantities of food and still starve to death? Defend your answer.

2. What differences would you recommend between the diet of a bricklayer and that of a bank cashier? of an Eskimo and that of a native of the Congo? of an American family in the winter and that of the same family in the summer?

3. There is one common substance required for life which cannot be obtained by eating plant materials. What is it?

Here are Some Things You May Want to Do

1. Read Paul de Kruif's *Hunger Fighters*. This will tell you in a really exciting way about how the vitamins were discovered.

2. Set up an experiment to furnish evidence that starch or sugar is made in green leaves in the presence of sunlight.

3. Find out about and report to your class the ways in which common salt has been secured by people in the past.

4. Plan a well-balanced diet for your family for a week. Ask your mother if she will let you plan at least one meal which you will really eat.

5. If you have a cafeteria in your school, you may want to prepare a list of recommended food combinations to be placed on the walls of the cafeteria. One large school has such a chart labeled "For a well-balanced meal select one dish from each of the following groups." For the benefit of the smaller children the various recommended dishes are also pictured. Find out what your school cafeteria is serving throughout the week and prepare a chart of its dishes. You might all work together on this, with some members of the class preparing the chart, some others printing the chart, and still others painting the pictures.

6. Keep a record of the various meals you eat during a week and list the countries from which the various foods come.

7. Make a list of the different food substances found in milk. Pretend that you work for a large milk company and write a good advertisement for milk or make a good poster.

Chapter XXIII · How do the Physical Factors of the Environment support Life?

A. What Physical Conditions are Necessary for Plants and Animals?

You will remember that in the second chapter of this book you read about the experiences of a group of people who decided to explore their environment for themselves. Perhaps you took a similar trip. In either case you will remember the many kinds of life which were found in different environments, and the many adjustments each form of life made to varying environments.

The relationship between the physical factors of the environment and life itself may not have been very clear to you at that early period in your science work. Since then, however, you have spent considerable time finding out more about your environment. In this chapter will be brought together more closely the story of living things and that of the nonliving materials which surround them. Let us begin by summarizing very briefly some of the things we have talked about in this book.

Air, you learned, is needed and used by all living things. A plant uses carbon dioxide from the air in the process of food-making. Both plants and animals use oxygen from the air in the process of food-using. It is clear from all observations made that conditions on earth would be far different if the air itself were different.

Air is necessary for life

Water too is another substance essential to life. You learned by experiment and observation that there is a continuous cycle of water: from the surface of bodies of water into the air, from the air to the surface of the land, and from the land back to bodies of water. Living cells in plants and animals must be

Cells are bathed in water

bathed continuously in water. Blood, which is mostly water, carries food to the cells of our bodies.

Soil is a third factor of the physical environment necessary for the growth of living things. It acts as a support for plants, holding them upright in the ground. It supplies them with water and with the soluble mineral salts which are necessary parts of all new cells. The roots of plants reach deep into the soil. Mineral substances in the water that is in the soil pass into the roots, up the stems, and into the leaves, where foods are made.

Soil contains mineral salts

In addition to air, water, and soil, energy from the sun is necessary for the chemical changes that go on in green plants during the process of food-making. Plants obtain this energy directly from the sun, while animals derive their energy from the plants they eat or from other animals which in turn eat plants. Energy is thus furnished to the cells as a product from the chemical changes that take place in food-using.

Energy is needed for food-using and food-making

We can say, therefore, that the essential things for life are air, water, soil, and energy. If you analyze the first three, you find that they are composed of elements, compounds, and mixtures of elements and compounds. The same chemical elements make up the cells and bodies of plants and animals. You have learned that there is no life in these substances, but that when a plant or an animal takes them into its body in the processes of living, they become part of a living thing. You have seen many examples of this. Water and carbon dioxide are taken into a plant — water through the roots, carbon dioxide through the leaves. With the aid of the sun's energy these substances form sugar and starch. As the result of further changes they may become fats and proteins. A kind of oil commonly used in making salad dressing is extracted from

Chemical changes take place as food and living cells are made

corn kernels. This oil had its origin in chemical changes that go on in the green cells of a leaf. Animals cannot make food; so all the foods for both plants and animals have their origin in the green cells of plants.

Chemical changes play an important part in living. Products of food-using are being continuously changed by green plants into products of food-making. Products of food-making are being continuously changed in all living cells into products of food-using. In this change the energy that is necessary for the life of the cell is released. All cells use food, but only the green plant cells can make it. The products of food-using and the products of food-making are named below:

The processes of living are chemical processes

Products of the Food-Using Process	Products of the Food-Making Process
Carbon dioxide	Oxygen
Water	Sugar
Compounds of	Starch
Nitrogen	Cellulose (plant fiber)
Phosphorus	Fats and oils
Potassium	Proteins
And some other elements	

The chemical changes in the process of the decay of cells are like the chemical changes in the process of food-using. Dead cells are composed of the products of food-making. In the process of decay these products act with oxygen from the air and are reduced to the more simple products used in food-making. The cells of all plants and animals must have energy to live. This energy is furnished to the cells as a product of the chemical change that takes place in food-using.

Let us see if this relationship between the physical environment and life can be made clearer. An ideal place to observe this relationship is in the forest, for here you may observe many varying features of it.

In some parts of our country a visit to the forest in late fall or during the winter season will reveal a dreary scene.

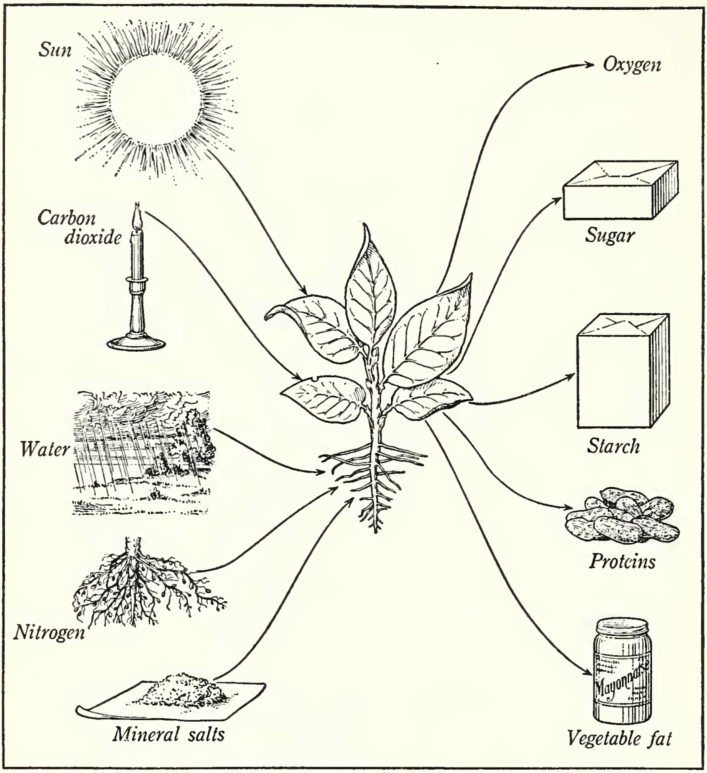

Fig. 176. The Plant manufactures Foods

The trees are bare, for the last leaves have fallen; the ground is covered with a mass of dead vegetation. When you return in the spring or summer, however, the scene is different. The leaves of the trees form a green mass of color hiding the thin far-spread branches. What has happened in the short time of a few months? Is it possible that these trees died in the winter and came to life again in the spring? If they lived during the winter months, where did they get the necessary food? If they could get food, why did the leaves turn brown and fall?

B. How do the Foods produced during One Growing Season help to start Growth during the Next Season?

The changes of the seasons bring many changes in the physical environment. These changes are familiar to all of us. With the coming of warmer temperatures, living things in the field and forest start to grow. The buds on the trees swell and burst, and in a few days the green leaves are spread in the sunshine. Soon blossoms appear among the leaves, and the farmer cultivates the soil and plants grain. As summer advances, the plants grow.

Annual plants grow, produce seed, and die in one season

Many plants produce seeds, and these form and ripen during the spring and summer while conditions for growth are favorable. Some plants, including many common weeds and cultivated plants like corn, oats, and cotton, grow only during one season. These plants are called annuals. The word *annual* means coming once a year. They start from seeds, grow, produce a new crop of seeds, and die as winter approaches. The seeds, composed of carbohydrates, proteins, and fats, produce new plants during the following season.

Biennial plants require two seasons to produce seed

There are many plants that live through one winter and produce seed during the second summer. Such plants are called biennials. The word *biennial* means occurring once in two years. Mullein and burdock are common biennials that grow as weeds. Turnips and beets are cultivated biennials. These plants grow from seeds, and during the first season they make and store food. This food is commonly stored in the roots, although it may be stored in the stems. It is used for growth during the second season. When spring comes, a seed stalk grows, and as the season progresses, flowers and then seeds are produced. After the seeds have ripened, the biennial plant dies, and new plants form during the following season from the seeds.

There are still other plants, called perennials, which include trees and shrubs that live year after year. These also produce seeds. These seeds contain food stored for the growth of new plants. Perennials also store food in their buds, and with the coming of spring this food is rapidly changed into leaves. These foods, stored in seeds and to some extent in buds, are, during winter, a principal source of foods for animals.

Perennial plants may live for many years

All these plants — the annuals, biennials, and perennials — are fitted in different ways to live through the winter. In each case it is the process of making food during the spring and summer that will serve to start new growth during the following spring. The plants make a large quantity of food during the season that is favorable for growth. The great abundance of seeds produced by annual weeds furnish food for birds. Wheat flour is made from the seeds of a cultivated annual. Food that is stored in the roots of turnips, beets, and sweet potatoes, in the stems of white potatoes (the white potato is a stem that grows underground), in the stems and leaves of onions, asparagus, and cabbage, is food for man. Nuts, acorns, apples, cherries, and berries contain the seeds produced by perennials and are used for food by many animals. Animals live on the surplus food that is produced by plants.

Food from plants is used by animals

C. Are All Living Things in the Forest the Result of the Processes of Food-Making and Food-Using?

The processes of food-making and food-using take place on an enormous scale in the forest. Let us see what evidences we can find of this during the spring of the year.

An acorn fell from its parent oak during the previous autumn upon a spot favorable for growth. The rains beat on the soil, and the acorn became partly buried in the ground. Then the tiny plant within the seed began to grow. The plant itself is very tiny and takes up only a small part of the acorn. Most of the acorn is food, which must last until the little tree is able to secure its own food from soil and air. The food of the acorn is composed of starch, fat (or oil), and protein.

An acorn sprouts. The stored food supply of the acorn diminishes

As growth continued, a little root pushed through the covering of the acorn. It grew downward into the soil. Now, with the coming of the warm rains of spring, a small stem pushes upward into the air, and green leaves appear. As the tiny plant grows, it uses the food stored inside the acorn. The two halves disappear as the stored food is changed rapidly into roots and stems and leaves. Before the supply is exhausted, the roots of the infant oak have penetrated the moist soil, and a surface of green leaves has spread in the sunshine. The tiny oak, a short while before locked up within the acorn, is now a growing plant, completely equipped for making its own food. Fig. 177 illustrates the steps in this development.

The small oak is able to secure its own food

Life and death go on

And now the story is repeated. With mineral matter and water from the soil, with carbon dioxide from the air, and with the necessary energy from sunlight to convert these materials into food, the oak grows from year to year until, in fifty years, it becomes a good-sized tree. Nonliving materials — water, carbon dioxide, and minerals — have been transformed into roots, stem, and leaves. This sturdy oak is one of many trees in the forest. Autumns come, and the leaves turn from green to red or brown and fall to the ground. Spring follows winter, and the trees grow new coverings of leaves. These in turn fall to the ground. In the course of years a thick bed of leaves is formed on the ground. The dead leaves decay and, in time, become soil again.

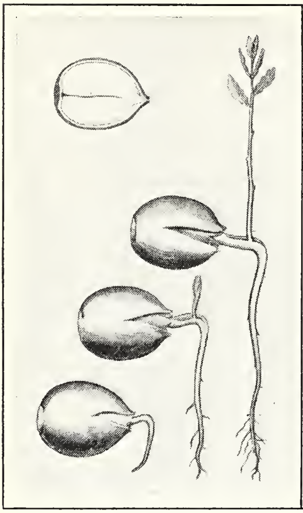

Fig. 177. The Stored Food in a Seed supplies Nourishment

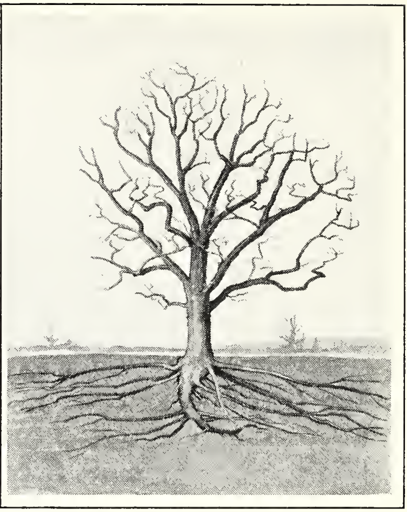

Fig. 178. A Vast Root System is Necessary to support a Tree and Secure Water

The oak has an enormous root system

An examination of the part of an oak tree below the ground would show that the roots have penetrated deeply into the soil. The tree is anchored so firmly that the strongest wind cannot pull it loose. All these strong roots are necessary, for, in addition to serving as an anchor, they, with their many rootlets, enable the tree to draw water and dissolved minerals from a large volume of soil. A large oak tree may use two tons of water (500 gallons) in a single day. A vast root system is necessary in order that this water may be supplied. Notice the root system pictured in Fig. 178.

In a tree there are at least three regions in which growth takes place. One region of growth is in the cells located just inside the bark. Cells are formed on both sides of this region of growth. Those on the outside make new bark.

Fig. 179. The Rings of a Tree indicate its Age

Some time after the cells that make up the bark are formed, they die. The outer covering of a tree, then, is composed of dead cells. The cells on the inside of this region of growth make up the wood of the tree. Soon after they form, they also die. Most of the trunk of a living tree is therefore composed of dead cells. The bark of a tree serves as a protection for the living cells just beneath it. As the tree grows, the pressure from the inside causes the bark to split; and as time passes, the dead cells on the bark scale off slowly. New bark is continuously forming, and the older bark is continuously scaling off. The wood that is formed inside the region of growth endures usually as long as the tree lives, which may be for hundreds or even for thousands of years.

The region of growth may be noted in a tree stump

The trunk, or stem, of a tree may best be studied by examining a stump that has been cut with a saw. Here upon the stump we may see heartwood, sapwood, and bark. Our attention is attracted to the rings, which stand out clearly marked. The rings which we see upon the surface of the stump show how much of the tree grew from year to year, and the age of the tree may be told by counting the rings. If you examine the rings with a magnifying glass, as the children in Fig. 179 are doing, you see layers of small cells and layers of larger cells. During the late fall and winter, after the leaves are dead, the growth of the tree ceases. In the early spring the growth is most rapid, and large cells are formed. Later in the season growth is slow again, and small cells are formed. These intervals of rapid growth, slow growth, and no growth, following one after the other, form the rings. One ring is formed each year. You may have an opportunity to count the rings in a stump that is left from cutting a large tree. If you do, you may be interested to find out how old and how big this tree was when Lincoln was President of the United States. It is likely that Indians even sought shelter from the rain and sun under its branches. Was the tree alive when George Washington was President? If so, how old was it then? You might even be interested in finding out how old the tree was when you were born.

Food circulates through the region of new cells

The region of growth in the tree is located between the bark and the dead heartwood. Through this region the food made in the leaves is distributed to the different parts of the tree. Therefore this layer is called the sapwood. If the region of growth is cut through with an ax or saw, the tree dies. It dies because the passageway through which food is circulated has been cut. This fact is evidence that the tree does not take food from the soil. It takes from the soil materials from which foods are made; but before these minerals can be of any use to the living cells in the roots or anywhere else, they must pass up to the leaves and be made into food. Food passes from the leaves to the cells in the roots and in other parts of the plant.

FIG. 180. A Second Region of Growth is at the Ends of the Twigs

Courtesy of the American Museum of Natural History

A second region of growth is at the ends of the twigs. After the leaves have fallen in the autumn, you can notice that the tip of each little twig is covered by a bud. When the bud opens in the following spring, growth proceeds at a rapid rate. The growth from one year to the next is marked by the lines that may be seen around the outside of the twig. These lines mark the position at which the scales of buds were attached. How many years of growth do you see in Fig. 180?

A second region of growth is at the ends of the twigs

The third region of growth is at the tips of the roots. Here too new cells are formed, and the root extends farther and farther into the soil. The roots serve to anchor the plant; and as the tree grows, more and more roots are required for anchorage. Water must pass from the soil to the leaves; and as the leaf surface increases, more and more root surface is required to supply the necessary amount. Cells in the leaves and stems are necessary for the life of the cells in the roots, and cells in the roots are necessary for life in leaves and stems. All living cells in the plant depend one on the other.

A third region of growth is in the root tips

In the forest, trunks of trees are built up by the processes of growth from carbon dioxide, mineral salts, and water. There are many trees more than a hundred feet high. Some of the big trees of California are more than three hundred feet high and more than thirty feet in diameter. Twenty children with arms outstretched could just reach around them. Many of the big trees are more than two thousand years old, and some are probably as much as four thousand years old. These old trees sprouted from seed at about the time the pyramids in Egypt were under construction. They were large trees a thousand years old when Moses led his people out of Egypt, and some of them were as much as two thousand years old when Christ was born. The period of time since Columbus discovered America is short compared with the age of these trees. And yet these trees were built up from air, water, and mineral salts. Growth in the forest is a long, continuous process.

Growth and decay are long, continuous processes

Further study of the forest shows that the processes of decay, as well as those of growth, are continuously under way. You can see many rotting logs, the remains of trees which have been uprooted by wind or split by lightning, or which lumbermen have left lying on the ground because they found them defective. If you examine a rotting log, you will find mushrooms and other forms of fungi growing on it (Fig. 181). Fungi cannot make food for themselves. They have no green leaves and so depend upon other plants for food. Molds are other forms of fungi that take food from this rotting wood. Bacteria of a great number of varieties also feed upon the log. In fact, it is the action of these fungi (particularly bacteria) and of other forms of organisms that causes the log to decay. As they feed, they destroy the log. Ants and beetles live in it and under it. In the moist earth beneath it are many grubs and worms. They too derive food from it and in so doing help to turn the log into the substances from which it was formed, namely, water, carbon dioxide, and mineral salts.

Life lives on life!

Beneath the layer of leaves that collects in the forest

FIG. 181. Fungi cannot make Food for Themselves. They depend upon Other Plants

Courtesy of the American Nature Association

you see abundant evidence of decay. The moist region under the dry top layer of leaves is a most favorable place for the growth of bacteria and of other plants that derive food from dead matter. The food-using process that goes on in these organisms causes the decay of the dead leaves. The products of this decomposition mix with the soil beneath and make it black. The black appearance is due to carbon which has been released by decay, but which has not been changed into carbon dioxide. It may be spoken of as a product of partial decay.

The products of partial decay furnish food to many forms of life

Some animals, particularly earthworms, use as food the products from the partial decay of leaves and from the decay of other forms of vegetation. The earthworm eats soil, and as the soil passes through the body of the worm, soluble substances are absorbed from the soil into its blood. In the cells of the worm the soluble products combine with oxygen from the air and liberate energy in

Fig. 182. Countless Animals live in the Soil and get their Food from It

just the same way that oxygen from the air combines with soluble foods in the cells of the human body. This process of food-using in the earthworm changes the soluble matter that is taken from the soil to carbon dioxide, water, and minerals. Careful study has shown that in one acre of land as much as eighteen tons of soil may pass through the bodies of earthworms in one year.

There are many other forms of animal life in the soil under the leaves of the forest. Look at Fig. 182. There are grubs, ants, spiders, and centipedes in great varieties. There are lizards, snakes, moles, mice, and chipmunks. The moles eat earthworms and grubs; ants take their food from a variety of sources; spiders, millepedes, and lizards eat insects; snakes eat insects, moles, and mice. It is surprising to learn how many animals make their homes in the soil of the forest and take their food either directly or indirectly from it. Counts have revealed more than two million animals in the surface layer of one acre of soil.

As you think of the forests you know, you will recall the many different kinds of trees and other forms of life. There are the oak, elm, pine, spruce, maple, willow, and many others. There are also many varieties of vines which are covered with berries. There is usually in the forest more or less underbrush in the form of shrubs; and in regions where the sunlight can shine through the leaves, the ground is covered with grass. All these produce the foods necessary for their own growth; they produce seeds from which new plants grow, and they produce the food eaten by the host of animals, large and small, that live in the forest.

In this study of plants and animals you have learned something about how these organisms live. The food of plants and animals has its origin in the chemical elements of the soil and air. The tiny plant in an acorn sets its roots in the soil and spreads leaves to the sunshine and air. It becomes a tree and continues to grow for many years, adding to itself a larger and larger supply of these chemical elements. The tree produces seeds, and from these seeds more trees grow.

From your study of life processes you realize that plants and animals are composed of chemical elements that come out of the physical environment, and you learn that the sun furnishes the energy that is needed to carry on the life processes, particularly food-making. In the processes of food-using and decay the elements which compose living things again become a part of the physical environment.

Among all living things man alone has the power to look into the past, to understand what is going on about him from day to day, and to profit from it as he plans for the future. The more he knows and the better he understands his environment and his relations to it, the better can he take care of himself and those around him. He has a mind which aids him in working for control of the forces about him, to the end that he may have life and have it more abundantly.

Certain physical conditions are necessary for life of any sort. The processes of life are those of food-making and food-using. These processes are continuous in all living things.

Can You Answer these Questions?

1. Is it correct to say that plants get their food from the soil? Can you defend your answer?

2. Can you illustrate the life cycle through the growth of an oak tree?

3. Can you explain the process by which a tree becomes bigger and bigger as it grows?

4. In what respects do mushrooms differ from the green-leaf members of the plant kingdom?

5. What part of the air is used by the plant in food-making, and what part in food-using?

Question for Discussion

Tell which of the following living things are food-makers:

cow
yeast
corn plant
grass
robin
dandelion
clover
bacterium
thistle
mushroom

What general conclusion can you draw from this?

Here are Some Things You May Want to Do

1. If you can find a tree stump that has been cut recently, try to find out how old it is.

2. Try to find an old rotting log and make a list of the plants and animals you find living on it.

3. Find the region of growth within a branch or trunk cut straight through (transverse section) and make a drawing of some of the cells as you see them through a magnifying glass.

4. Find a shrub or tree that has grown rapidly during the spring. Measure the length of the new growth at the ends of the twigs and report your findings to the class. You may find that some plants grow very rapidly and some rather slowly.

5. Plant some beans, peas, or acorns in moist sawdust. Watch them sprout. Make five drawings on various days over a period of two weeks. Enlarge your seed drawings to make a wall chart.

6. Write a story called "The Growth of an Oak Tree."

CONCLUSION

YOU HAVE NOW COMPLETED the first part of your journey in science. We hope that you have liked it, that you have found it interesting, and that you will want to go further with it. We hope, too, that you have learned some new things, and that the world around you means more now because you know more about it than you did when you began.

We are sure that you have many questions you want to ask. One might be "How far have I gone on this journey in science?" Another one might be "How far can I go?"

The answer to the first question is very simple. You have not gone very far. You have, however, gone over a part of the road which is very important. You have read about and have found out for yourself some of the most essential laws which explain things in your environment. Before these are understood, it is difficult to go much further.

The answer to the second question cannot be given except as a guess and a hope. No one knows. It may be that in relation to the generations yet to come you are in the same place as primitive man was in relation to us. Perhaps within your own lifetime you will see many of the ideas in this book change as man gets new knowledge. Perhaps you will help to open up this new knowledge. Who knows?

Readings in Science

AKELEY, CARL E. In Brightest Africa. Garden City Publishing Company, Inc., New York, 1925.

Big-game hunting in Africa is described, and interesting and scientific observations on lions, gorillas, elephants, etc. are given.

BEERY, P. G. Stuff. D. Appleton and Company, New York, 1930.

This book tells in story form the history of how man has converted air, water, and food to his use. The chemistry of these substances is interestingly treated.

BEEBE, WILLIAM. Exploring with Beebe. G. P. Putnam's Sons, New York, 1932.

This gives many splendid accounts of exploring in nature to see and study wild life.

BOY SCOUTS OF AMERICA. Official Handbook for Boys. Boy Scouts of America, New York, 1931. Section on Woodcraft.

This section serves as an excellent guide for identifying trees, birds, and mammals. It also suggests many interesting ways to study them.

BRADLEY, JOHN H., JR. Parade of the Living. Coward-McCann, Inc., New York, 1930.

The author traces vividly the procession of living forms that has occurred on this earth. He takes up the structure of the earth, the earliest forms of life, the rise and fall of various animal kinds, disease, intelligence, etc.

CARR, WILLIAM H. The Stir of Nature. Oxford University Press, New York, 1930.

This book is written about experiences with pets by one who lives with nature and knows it intimately. A valuable nature calendar is included which suggests seasonal studies one can make.

COLLINS, A. F. Experimental Chemistry. D. Appleton and Company, New York, 1930.

Chapters I and XIV are most useful in connection with this book. The first gives several experiments with oxygen and nitrogen, and the fourteenth gives many useful suggestions for rigging up a home laboratory.

COLLINS, A. F. Experimental Science. D. Appleton and Company, New York, 1929.

The entire book is made up of experiments which any junior-high-school science pupil might do. Chapter IV includes many interesting experiments with gases and air; Chapter VI experiments with water; and Chapter XVII experiments with temperature and heat and cold.

COLLINS, A. F. The Boy's Book of Experiments. D. Appleton and Company, New York, 1927.

This, too, contains many interesting experiments. Chapter V has experiments with heat and heat-operated devices. Chapter XVII has experiments with heat, fire, and fuel. Chapter XVIII has experiments with plants and soils.

DAGLISH, ERIC FITCH. How to See Beasts. William Morrow & Company, Inc., New York, 1933.

A splendid guide for a beginner in the study of nature to use, for it calls to his attention many little clues which should result in discoveries and observations. Illustrations of how the author interpreted his experiences should enable the reader to be alert to the animals of his environment.

DAGLISH, ERIC FITCH. How to See Plants. William Morrow & Company, Inc., New York, 1932.

This book serves the same purpose for plants that the one above serves for animals. The many adaptations that plants have made and do make to their environment are indicated by the illustrations given.

DAGLISH, ERIC FITCH. The Life Story of Beasts. William Morrow & Company, Inc., New York, 1931.

This book brings home the true life of animals by many comparisons of the habits of different ones. It is carefully and interestingly done. The illustrations are attractive.

DAGLISH, ERIC FITCH. The Life Story of Birds. William Morrow & Company, Inc., New York, 1930.

This is an unusually good account of birds and the lives they lead, and is of interest to adults as well as to boys and girls. The illustrations are an attractive part of the book.

DE KRUIF, PAUL. Hunger Fighters. Harcourt, Brace and Company, New York, 1928.

An interesting account of the drama connected with the improvement of wheat, corn, and meats, and of the discovery of vitamins.

DE KRUIF, PAUL. Men against Death. Harcourt, Brace and Company, New York, 1932.

This book, like *Microbe Hunters*, consists of biographical sketches telling about recent scientific discoveries that doctors are making in the fight against disease.

DE KRUIF, PAUL. Microbe Hunters. Harcourt, Brace and Company, New York, 1930.

Interesting biographical sketches of such men as Pasteur, Koch, Roux, Bruce, Reed, Ehrlich, etc. give some of the drama of their history-making discoveries and some appreciation of their significance to us.

DITMARS, RAYMOND LEE. Snakes of the World. The Macmillan Company, New York, 1931.

This gives interesting descriptions of snakes and their habits, together with eighty-four remarkable full-page photographs of them.

Ditmars, Raymond Lee. Strange Animals I have Known. Harcourt, Brace and Company, 1931.

This entire book gives exciting experiences that have occurred with the animals at the New York Zoölogical Garden, of which Mr. Ditmars has charge. One would not believe that so many rather unusual and sometimes queer things would happen at a zoo, but, of course, man has his best opportunity to observe animals at close range there.

Ditmars, Raymond Lee. Thrills of a Naturalist's Quest. The Macmillan Company, New York, 1932.

This book, like the one above, gives many descriptions of animals and interesting accounts of incidents that have occurred in their lives and in the lives of those who come in contact with them.

Downing, Elliot R. Our Living World. Longmans, Green & Company, New York, 1924.

This book is a rich source book of biological nature study. It contains a wealth of material on insects, birds, mammals, flowers, trees, etc. from the immediate environment of any pupil. The style is such that one reads the book for pleasure.

Ewers, Hanns Heinz. Wonders of the Ant World (adapted by Alexander Sprunt, Jr.). Dodd, Mead & Company, New York, 1931.

This book tells in an interesting style of the social habits of the various kinds of ants.

Fabre, J. Henri. Insect Adventures. Dodd, Mead & Company, New York, 1917.

This contains life stories of bees, ants, wasps, caterpillars, spiders, and flies, told in the vivid style so usual with Fabre.

Hamilton, Edwin T. Complete Model Aircraft. Harcourt, Brace and Company, New York, 1933.

This is the most up-to-date, complete book of models of all leading aircraft. There are 540 pages in this book, with many pictures and diagrams giving in unmistakable detail the instructions for building models.

Hayes, E. L. What Makes Up the World. Thomas S. Rockwell Co., Chicago, 1930. Chapters I–VIII.

These chapters mentioned give a simple description of soil and its properties, water and its properties, air and its properties, changes that take place in matter, the story of chemistry, and a discussion of fire.

Henshaw, Henry W. Birds of Town and Country. National Geographic Society, Washington, D.C., 1915.

The first part of this book gives colored plates of common birds and descriptions of them. The remainder of the book treats of bird life. The treatment given to the topic of migration is excellent.

Holway, Hope. The Story of Water Supply. Harper & Brothers, New York, 1930.

This gives an elementary, yet interesting, story of the development of various ways of obtaining a water supply.

Kenly, J. C. Green Magic. D. Appleton and Company, New York, 1930.

This tells simply and well the life story of flowering plants.

Lippy, J. D. Chemical Magic. A. L. Burt Company, New York, 1930.

This gives a lot of simple tricks which are performed by chemical means.

McCreery, James Lindsay. Exploring the Earth and Its Life in a Natural History Museum. Frederick A. Stokes Company, New York, 1933.

As the title indicates, this book serves as a guide to the discovery of the big ideas and relationships that may be learned from exhibits in museums. It is splendidly done.

MacDougal, D. T. The Green Leaf. D. Appleton and Company, New York, 1930. Chapters VIII and IX.

These two chapters are entitled "A Visit to the Green Leaf Mills" and "Green Mills and Their Grist." The treatment that they give of the topic "Photosynthesis" is splendid.

McKay, Herbert. Easy Experiments in Elementary Science. Oxford University Press, New York, 1929.

This book contains easy experiments that may be done with simple apparatus that anyone can make. There are many experiments with water, with air, and with heat.

Mann, Paul B., and Hastings, George T. Out of Doors. Henry Holt and Company, 1932.

This is an excellent book on the out of doors. It is splendidly written and well illustrated. The four parts are "Getting Acquainted with Animal Life," "Getting Acquainted with Plant Life," "Getting Acquainted with Earth and Sky," and "Getting Acquainted with Nature in Camp."

Mather, Kirtley F. Sons of the Earth. W. W. Norton & Company, Inc., New York, 1930.

This gives the history of life from the point of view of geology. Perhaps it is a bit difficult for seventh-grade pupils; but some can use it, and for them it will give a related view of all of life.

Mayer, A. G. Seashore Life. New York Zoölogical Society, New York, 1905.

This book gives a wealth of information about seashore life. It will enable seventh-grade pupils to identify and study any kind of life that they may find at the seashore.

Nelson, E. W. Wild Animals of North America (New Edition). National Geographic Society, Washington, D.C., 1930.

This is a book on mammals of North America. The colored illustrations are beautiful and true to nature. The descriptions of the animals and their habits are interesting.

Page, Major Victor W. A B C of Aviation (Elementary Edition). Norman W. Henley Publishing Company. New York, 1928.

This is a splendid and well-illustrated book on aviation, though it is not so up to date as the book *Skycraft.*

Park, William H., and Williams, Anna W. Who's Who among the Microbes. The Century Co., New York, 1929.

The book is a readable volume on microörganisms. Chapters III, VII, and XX are particularly useful in that they treat, in turn, "How Microbes Live and Act," "The Nitrogen-Using Family," and "How Man Makes Use of His Acquaintance with Microbes to Protect Himself from Them."

Post, Augustus. Skycraft. Oxford University Press, New York, 1933.

This is an up-to-the-minute book that gives in interesting fashion information about all kinds of airplanes. The new models are shown in illustrations. Information is given about aviation schools. An excellent source of information on modern aircraft.

Reed, William Maxwell. The Earth for Sam. Harcourt, Brace and Company, New York, 1930. Chapters II, V, and X.

The entire book is interestingly written and is written for pupils of seventh-grade age. The chapters mentioned above, though, are particularly interesting; for they discuss the air we breathe, mountains and rivers, and glaciers.

Rose, Mary Swartz. The Foundations of Nutrition. The Macmillan Company, New York, 1927.

This is a simple exposition of the science of nutrition written by an authority in that field. It should serve as a source book of information about foods. The treatment of vitamins is splendid.

Washburne, Carleton W., and Washburne, H. C. The Story of the Earth and Sky. The Century Co., New York, 1933.

This is a treatment of the earth and the sky in story form. The four big parts into which the book is divided are "The Story of the Earth," "Neighbors in the Sky," "The Stars," and "How We Found Out These Things." It is interestingly written and should be a valuable addition to the library.

Winslow, C. E. A. Fresh Air and Ventilation. E. P. Dutton & Co., New York, 1926.

This is a treatment of the subject by an authority and may be used as a guide for determining what good ventilation is and just how to obtain it in any type of building.

Science Words

KEY TO THE SOUNDS

ă *as in* at
ā *as in* ate
ȧ *as in* ask
ä *as in* arm
a̮ *as in* sofa
ĕ *as in* bet
ē *as in* be
ẽ *as in* her

e̮ *as in* vowel
ĭ *as in* bit
ī *as in* bite
ŏ *as in* got
ō *as in* go
ô *as in* horse
o̮ *as in* connect

oi *as in* oil
o͞o *as in* food
ŭ *as in* us
ū *as in* use
u̮ *as in* circus
t͜ū *as in* nature
ŋ *as in* ink

absolute zero. The lowest possible temperature which can be reached. Such a temperature has not yet been secured. It is 273 centigrade degrees or 491 Fahrenheit degrees below the freezing point of water (p. 380) [1]

acid. A chemical compound which contains hydrogen and which when dissolved in water has a sour taste. Vinegar and lemon juice contain acids (p. 119)

adaptation (ăd ăp tā′shu̮n). Any character which is useful to an organism is an adaptation. Some adaptations are tendrils on climbing plants, wings on birds, and finger nails on man (p. 49)

adjustment. A change which enables an organism to live better in its environment (p. 49)

air bladder, or swim bladder. An organ in a fish's body which may be collapsed or expanded and which makes it possible for a fish to rise or sink in the water at will (p. 107)

air sac. Small baglike parts of the lungs around which blood circulates. Oxygen enters the blood through the walls of the sacs (p. 224)

air-conditioned. A term used to describe a room in which the air is kept at a comfortable temperature and state of humidity (p. 268)

alchemist (ăl′kē mĭst). A student of alchemy, which preceded chemistry in the Middle Ages; especially one who tried to change metals of little value (base metals) into gold (p. 308)

alcohol. A colorless liquid compound of carbon, hydrogen, and oxygen. There are several kinds of alcohol. Ordinary alcohol is commonly called grain alcohol because it is made from the starch in grains (p. 84)

alloy (a̮ loi′). A substance composed of two or more metals (p. 192)

alum (ăl′u̮m). A compound similar to aluminum sulfate (p. 132)

aluminum (a̮ lū′mĭ nu̮m). A light, silver-white element. Aluminum is a metal used in kitchen utensils and in industry where light weight is required (p. 191)

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[1] References are to pages in the text where the words first occurred.

aluminum sulfate (sŭl′fāt). A compound used in purifying water (p. 132)

ammonia. A gas which is a compound of nitrogen and hydrogen. Ordinary ammonia is a solution of this gas in water (p. 85)

amphibian (ăm fĭb′ĭ a̯n). One of a class of animals which usually live first in water as tadpoles, then on land. The amphibia have moist, smooth skins (p. 66)

analysis (a̯ năl′ĭ sĭs). A test to determine the elements or compounds of which a substance is composed (p. 328)

analyze (ăn′a̯ līz). To determine the elements or compounds in a substance (p. 328)

annual. A plant which completes its entire growth in one season and then dies (p. 431)

aorta (ā ôr′ta̯). The large artery or blood tube carrying the blood from the left side of the heart (p. 226)

apparatus (ăp a̯ rā′tu̯s). A collection of tools and equipment for doing certain work (p. 119)

aquarium. A glass jar or tank which is used as a home for fish or other water animals and water plants (p. 32)

aqueduct (ăk′wē dŭkt). Pipes carrying the water supply to a city (p. 133)

argon (är′gŏn). A rare element found in the atmosphere (p. 150)

Aristotle (ăr′ĭs tŏt ′l) (384–322 B.C.). A Greek thinker and student (p. 21)

artery. Blood tube leading away from the heart (p. 225)

asbestos. A mineral containing silicon. It resists burning and is a poor conductor of heat. The strands, or fibers, may be pressed into sheets or woven into cloth (p. 372)

ash. The substance left when plants or animals are burned (p. 301)

astrologer (ăs trŏl′ō jẽr). A person who claims to gain knowledge and power to foretell events from the stars (p. 11)

atmosphere. The gases surrounding the earth or other planets (p. 170)

atom (ăt′u̯m). The smallest part of a chemical element. Atoms combine to form molecules. According to the electron theory atoms are composed of electrons and protons (p. 121)

atomic (a̯ tŏm′ĭk) **theory.** The theory that the simple substances (elements) are made of very small particles, or bits. These small particles are called atoms. Each atom of an element is like other atoms of the same element, but unlike atoms of different elements (p. 346)

autogyro (ô tō jī′rō). An airplane so constructed that it can land almost vertically (p. 179)

bacteriologist (băk tē rĭ ŏl′ō jĭst). A scientist who specializes in the study of bacteria (p. 132)

bacterium (băk tē′rĭ u̯m) (*pl.* **bacteria**). A plant so small that it can be seen only through a microscope. Some bacteria are harmful to man, but many others are not (p. 47)

ballast (băl′ạst). Any material which can be used to steady a floating body. It is used in ships and in balloons (p. 107)

barometer. An instrument used to measure air pressure (p. 170)

barometric (băr ō mĕt′rĭk). Having to do with the barometer (p. 162)

basalt (bạ sôlt′). A dark-colored, fine-grained rock, which has been formed by heat (p. 280)

base metal. A term applied in the Middle Ages to metals of small value compared with gold (p. 308)

battery. A group of electric cells (p. 119)

beaker. A cuplike glass vessel used in chemical laboratories or workrooms (p. 80)

begonia. A flowering plant common in houses in winter (p. 62)

beriberi (bĕr′ĭ bĕr′ĭ). A nervous disease caused by insufficient vitamin B in the diet (p. 422)

biennial. A plant which requires two seasons to complete its growth (p. 431)

binding post. The attachment by which wires are fastened to electric cells (p. 311)

biologist (bī ŏl′ō jĭst). A scientist who specializes in the study of living things (p. 23)

biology (bī ŏl′ō jĭ). The science of living organisms (p. 410)

bloodsucker. A kind of worm which clings to an animal and sucks blood (p. 64)

boiling point. The temperature at which a liquid boils. For water under ordinary pressure this is 212° F. or 100° C. (p. 114)

bowlder (bōl′dẽr). A large rock with rounded edges that stands out prominently from the other rocks around it (p. 284)

buoyancy (boi′ạn sĭ). The loss of weight in water, which is caused by the weight of the water itself (p. 101)

buoyant (boi′ạnt) **force.** The upward force exerted by a liquid or a gas upon a body which is floating in it (p. 101)

bureau. A department, or branch, of the government (p. 305)

cactus (*pl.* **cacti** (kăk′tī)). A plant with fleshy stems and branches, able to live in an extremely dry environment. The leaves are replaced by stems and spines (p. 62)

caddis fly. An insect whose larvæ live in water, in cocoonlike cases covered with small rocks and sticks (p. 66)

calcium (kăl′sĭ ụm). A white metal, an element, whose compounds are common in nature. Among the compounds are chalk, shells, limestone, and marble (p. 328)

calcium oxide (ŏk′sīd). A compound of calcium and oxygen sometimes called quicklime (p. 309)

calorie (kăl′ō rĭ), or gram-calorie. A unit of heat energy; that is, the amount of heat required to raise the temperature of 1 gram of water 1 degree on the centigrade scale. A thousand gram-calories are

1 kilogram-calorie. The energy value of foods is given in kilogram-calories (p. 367)

calyx (kā′lĭks). The outer covering of a flower, usually green (p. 398)

capillary (kăp′ĭ lā rĭ). Tiny blood tubes with thin walls through which food and gases pass to and from the body cells (p. 224)

carbohydrates (kär bō hī′drāts). Foods which are compounds of carbon, oxygen, and hydrogen. Sugars and starches are familiar carbohydrates (p. 368)

carbon. An element which is part of many compounds. Charcoal and coal are impure forms of carbon. All living material contains carbon (p. 210)

carbon cycle (sī′k′l). A complete chain of events, during which carbon of the carbon dioxide in air becomes part of plant or animal bodies and finally returns to the air as carbon dioxide (p. 245)

carbon dioxide. CO_2, one of the gases of the air (0.04 per cent), necessary for plants in food-making and a product of respiration and burning (p. 210)

carbon monoxide (mŏn ŏk′sīd). CO, a poisonous gas which is formed as a product of burning (p. 259)

carbon tetrachloride (tĕt rạ klō′rīd). A liquid compound composed of carbon and chlorine. Used in one form of fire-extinguisher (p. 320)

carboniferous (kär bọn ĭf′ẽr ụs) **period.** One of the early ages of the earth, during which occurred the growth of great amounts of vegetation which later became coal (p. 249)

carburetor (kär′bū rĕt ẽr). A mechanism which in a gas engine mixes air with certain vapors in order to produce a mixture which will explode inside the cylinders (p. 202)

caterpillar. The larva of a butterfly or moth (p. 388)

cell. (1) The smallest complete unit or part of living matter (p. 235). (2) A means by which electricity may be produced by chemical action and made to flow along a wire or other conductor (p. 119)

centigrade (sĕn′tĭ grād). A thermometer scale whose markings are made so that there are 100° between the freezing (0° C.) and boiling (100° C.) points of water (p. 115)

cesspool (sĕs′pōōl). A drain or pit for the collection of sewage (p. 138)

chemical change. A change in the composition of the molecule (p. 210)

chemical energy. Energy having a part in chemical change (p. 369)

chemical equation (ē kwā′shụn). A statement using chemical formulas to show a chemical change (p. 313)

chemical formula (fôr′mū lạ). A sign or group of signs representing the chemical composition of substances (p. 313)

chemistry (kĕm′ĭs trĭ). The branch of science which has to do with the study of chemical change. For instance, the study of water and how it may be changed to the two gases hydrogen and oxygen (p. 82)

chlorine (klō′rĭn). A heavy, olive-green, poisonous gas (p. 333)

cilium (sĭl′ĭ ụm) (*pl.* **cilia**). A small hairlike structure inside the nasal passages which helps to prevent passage of dust into the lungs (p. 252)

cistern. An underground storage space for water (p. 139)

clam. A small water animal with a soft body covered by two somewhat regular shells (p. 64)

coleus (kō'lē u̱s). A flowering plant whose leaves show a great variety of colors (p. 62)

Colorado potato beetle. A small insect that feeds chiefly on the leaves of the potato vine (p. 404)

combustion (ko̱m bu̱s'chu̱n). Burning (p. 260)

composition. The materials of which a substance is made (p. 281)

compound. A substance whose molecules are composed of more than one kind of atoms. Water is a compound, composed of atoms of the elements hydrogen and oxygen (p. 327)

compression. The act of squeezing or pressing together (p. 107)

condensation (kŏn dĕn sā'shu̱n). The process of changing from a gas to a liquid form, as when water vapor or steam is condensed to form water (p. 87)

conduction (ko̱n dŭk'shu̱n). The transfer of heat from one molecule to another (p. 372)

Continental Divide. The line joining the highest points along the mountains from Canada to Mexico. On one side the water flows to the east and into the Gulf of Mexico; on the other side it flows into the Pacific (p. 283)

contract (ko̱n trăkt'). To become smaller (p. 116)

contraction. The process of becoming smaller (p. 282)

convection (ko̱n vĕk'shu̱n). The transfer of heat by the warm upmoving and the cold down-moving molecules (p. 373)

convection currents. Currents in air or water or other substance, caused as warm and less-dense air is forced upward by colder and denser air (p. 374)

corpuscle (kôr'pŭs 'l). A small living cell in the blood. There are two kinds, white and red. The white ones destroy germs, and the red ones carry oxygen (p. 423)

cosmetic (kŏz mĕt'ĭk). Any material which is used on the surface of the human body to improve the complexion, skin, or hair. Rouge is a cosmetic (p. 258)

cosmic (kŏz'mĭk) **rays.** Rays which reach the earth from outer space. The effects of these rays have only recently been studied (p. 380)

crab. A soft-bodied sea animal covered by a hard shell (p. 64)

crystal-gazer (krĭs'ta̱l gāz'ẽr). One who claims to be able to foretell events by gazing into a "crystal." The "crystal" is often a large glass sphere (p. 19)

current. A movement of electricity through wire or other conductor (p. 120)

cycle (sī'k'l). A continuous process which is constantly repeated, as the water cycle on the surface of the earth (p. 75)

cylinder (sĭl'ĭn dẽr). A chamber in an engine in which gas may expand under control; a solid with circular base and top and with straight sides (p. 174)

decay. A process in which complex chemical compounds are broken into simpler ones when oxidation takes place and energy is released. Usually the breaking up of plant or animal substances (p. 255)

decompose (dē ko̮m pōz′). To separate into more simple parts, as compounds may be decomposed into elements (p. 120)

deficiency diseases. Those diseases which occur because of a lack or deficiency of vitamins or other substances in the diet (p. 422)

delta. Soil deposited at the mouth of a river in a shape resembling the Greek letter delta (p. 289)

demonstration (dĕm o̮n strā′shu̮n). Something the teacher or student does to show others what will happen under given circumstances (p. 158)

dense (dĕns). Heavy, thick, or compact (p. 40)

density. The weight of a unit volume (p. 105)

dew. Moisture which condenses from the air when the air is cooled to the dew point (p. 87)

dew point. Temperature at which water condenses from the air (p. 89)

digest. To make soluble so that it may be absorbed and carried to the body cells (p. 231)

dinosaur (dī′nō sôr). A member of a group of extinct reptiles living millions of years ago (p. 112)

diphtheria (dĭf thē′rĭ a̮). A disease of the throat caused by bacteria. The bacteria live in the throat and produce a toxin which is carried in the blood (p. 255)

dirigible (dĭr′ĭ jĭ b′l). A balloon that has a rigid framework and can be steered (p. 179)

disinfectant. A substance used to destroy bacteria or other germs (p. 259)

displace. To put out of place or position (p. 100)

dissolve. To cause the molecules of one substance to mix with the molecules of another substance (p. 231)

distillation (dĭs tĭ lā′shu̮n). The process of changing a liquid to a vapor and then cooling and condensing the vapor back to a liquid (p. 138)

diver. One who dives; for deep diving, a diver is protected from the great pressures by a suit of metal (p. 109)

dry cell. A metal cylinder containing certain chemicals. The action of these chemicals upon each other produces electricity (p. 119)

dynamo (dī′na̮ mō). A machine which changes mechanical energy to electrical energy (p. 358)

dysentery (dĭs′e̮n tĕr ĭ). A disease of the intestines caused by very small organisms (p. 129)

egg cell. A special kind of living cell which can produce a new organism, or living thing (p. 399)

electric arc. A glow of light between two points in an electric circuit. The points are usually made of carbon (p. 378)

electricity. A form of energy (p. 342)

electrolysis (ē lĕk trŏl'ĭ sĭs). The process of breaking up chemical compounds by the use of an electric current. For example, water is separated into the gases hydrogen and oxygen by electrolysis (p. 119)

electron (ē lĕk'trŏn). In the electron theory the electron is considered to be a particle of negative electricity (p. 342)

electron theory. A theory which teaches that electricity is of two kinds. These are called negative particles (electrons) and positive particles (protons). These two kinds of particles taken together compose atoms (p. 342)

element (ĕl'ē me̱nt). A substance composed of atoms all of which are alike. There are 92 known elements (p. 216)

elimination (ē lĭm ĭ nā'shu̱n). The process of getting rid of something (p. 236)

energy (ĕn'ẽr jĭ). Ability to do work. Heat, light, and electricity are forms of energy (p. 350)

environment (ĕn vī'ru̱n me̱nt). The things and forces around us (p. 11)

European corn-borer. An insect, native of Europe, whose larvæ feed on the stalk of the corn plant and kill it (p. 404)

evaporate. To change from a liquid to a gas (p. 75)

excretion (ĕks krē'shu̱n). A waste product thrown off by an organism (p. 129)

expand. To become larger (p. 116)

expansion. The process of becoming larger (p. 282)

expedition (ĕks pē dĭsh'u̱n). A group organized to go somewhere for some particular purpose (p. 25)

experiment. Something we try because we want to know what will happen (p. 22)

experimental method. The method of learning and proving by experimenting. Experiments are used to test ideas to see if they are true (p. 27)

factor. A part; for example, air is a factor of the environment (p. 45)

Fahrenheit (fä're̱n hīt). A thermometer scale whose markings are made so that there are 180 degrees between the freezing and boiling points of water. Water freezes at 32° F. and boils at 212° F. (p. 115)

fakir (fa̱ kēr'). A magician (p. 15)

Faraday (făr'a̱ dā), Michael. An English scientist (1791–1867) (p. 23)

feldspar (fĕld'spär). A common mineral, most abundant of all minerals on the surface of the earth. Decomposed feldspar forms clay (p. 279)

fertilizer. Any substance added to the soil for the purpose of aiding plant growth (p. 44)

fiber. A threadlike part of a plant (p. 241)

filament (fĭl'a̱ me̱nt). A thin thread, usually of metal, as, for instance, the filament in an electric-light bulb (p. 150)

film. Thin layer (p. 300)

flask. A bottle with a small neck, often made of glass (p. 153)

food-making. The process in which plants take molecules of carbon dioxide and molecules of water and make them into molecules of sugar or starch, with the aid of sunshine. This process is also called photosynthesis (p. 243)

food-using. The process in which living things use food and release energy (p. 245)

force. A push or pull (p. 9)

formula (fôr′mū la̤). A combination of signs which tells the element or elements of which a molecule of a substance is made (p. 313)

freezing point. The point at which a liquid changes to a solid. The same as the melting point. In water, 32° F. or 0° C. (p. 115)

frost. The substance formed if moisture condenses when the dew point is below the freezing point of water (p. 88)

fuel. A substance which burns well, releasing heat (p. 216)

fungus (fŭŋ′gu̱s) (*pl.* **fungi** (fŭn′jī)). Plants with no green coloring matter, such as mushrooms. A fungus plant can make no food for itself, but must live upon other living or dead organisms (p. 47)

Galileo (găl ĭ lē′ō). An Italian scientist (1564–1642) (p. 21)

geologist (jē ŏl′ō jĭst). A scientist who specializes in geology (p. 278)

geology. The study of the history and formation of the earth as shown by the rocks (p. 278)

gill (gĭl). The breathing organ of fish and of some other water animals (p. 68)

glacier (glā′shẽr). A mass of slowly moving snow and ice that does not melt even in summer (p. 284)

goiter (goi′tẽr). An enlargement or growth of a gland located in the neck (p. 421)

gopher. A small animal, about the size of a rat, common in the Mid-West. Gophers make long burrows (p. 390)

gram. The weight of 1 cubic centimeter of water at its greatest density. It requires 1000 grams to weigh 2.2 pounds (p. 153)

granite. A coarse rock formed by heat and composed of crystals. Crystals of quartz, feldspar, and mica may be seen in granite (p. 279)

gravity (grăv′ĭ tĭ). The attraction of two bodies for each other due to their mass. There is an attraction between the earth and bodies on or near its surface. There is an attraction between the earth and the sun and between other heavenly bodies (p. 345)

grub. A larva of some insects (p. 404)

habitat (hăb′ĭ tăt). Place where a plant or animal naturally lives (p. 52)

habitat group. A collection of plant and animal life of a region mounted and placed to show its natural environment (p. 52)

hard water. Water containing dissolved mineral substances such that when soap is added no suds are formed (p. 128)

heartwood. The central, hard part of the trunk of a tree (p. 435)
heat. The energy of moving molecules (p. 361)
helium (hē'lĭ u̱m). A light, colorless element in the form of a gas, used in the United States for filling dirigibles (p. 181)
Herschel (hẽr'she̱l). A German-English astronomer (1738–1822) (p. 22)
horoscope (hŏr'ō skōp). A plan of fortune-telling, by which it is claimed that events about a person's life can be foretold by the position of the stars at the time of his birth (p. 15)
humidity (hū mĭd'ĭ tĭ). The amount of water vapor in the air (p. 219)
hydrogen (hī'drō je̱n). A gas; the lightest known element. Hydrogen is colorless, odorless, and when mixed with air is highly explosive. It is used in dirigibles when helium cannot be obtained (p. 120)
hydrophobia (hī drō fō'bĭ a̱). A disease among certain animals, as dogs, which may be given to human beings by the bite of the diseased animal (p. 23)
hypothesis (hī pŏth'ē sĭs). An explanation which has not yet been tested so completely as a theory (p. 78)

infect. To cause to become affected by organisms which cause disease (p. 129)
infection. A disease or a diseased condition communicated by germs (p. 259)
insect. An animal with three separate body parts and six legs (p. 37)
insoluble (ĭn sŏl'ū b'l). Cannot be dissolved, as paint in water (p. 276)
instinct. A desire or urge to do a certain thing in a certain way or at a certain time, as the instinct of some birds to migrate (p. 38)
insulate (ĭn'sū lāt). To protect or separate by a substance which will not permit heat or electricity to pass (p. 321)
interdependence (ĭn tẽr dē pĕn'de̱ns). Need for one another, as bees for flowers and flowers for bees (p. 51)
intestines. Certain organs of digestion in an animal; their work is to prepare food for absorption into the blood stream and to carry the indigestible part of the food out of the body (p. 235)
iodine (ī'ō dĭn). A solid, brownish-black element. Compounds of iodine are used in photography and medicine (p. 421)
iron oxide (ŏk'sīd). A compound of iron and oxygen; rust (p. 333)
ivy. A climbing evergreen vine (p. 62)

Japanese beetle. A small beetle originally introduced by accident from Japan. The adults are destructive, feeding upon many kinds of leaves and fruit. The larvæ feed on grass roots (p. 404)
jellyfish. A boneless sea animal, somewhat the shape of a cup turned upside down, composed almost entirely of water (p. 64)

katydid. A green insect resembling a grasshopper (p. 404)
kidneys (kĭd'nĭz). Organs in the body of an animal; they separate waste products from the blood stream (p. 60)

kilogram (kĭl'ō grăm). 1000 grams; equals 2.2 pounds (p. 367)

kilogram-calorie. The amount of heat needed to raise 1 kilogram of water 1° C. (p. 367)

kindling temperature. The temperature at which a substance will take fire (p. 317)

laboratory (lăb'ō ra̯ tō rĭ). A workroom equipped for studying science by careful tests and experiments (p. 64)

larva (*pl.* **larvæ** (lär'vē)). The second stage in the life of insects. Some larvæ are called caterpillars. During this larval stage the insect eats great amounts of food (p. 33)

laxative (lăk'sa̯ tĭv). A medicine used to help the body to get rid of waste matter (p. 236)

lead. A heavy gray element. A metal used in the manufacture of paints, of glass, and of plates for storage batteries (p. 332)

lemming (lĕm'ĭng). A small burrowing animal (p. 411)

lichen (lī'ke̯n). A plant formation which lives on the surfaces of rocks, trees, etc., consisting of a fungus and a tiny green plant living together and needing each other in order to live (p. 283)

limestone. A sedimentary rock, usually gray or white in color, formed from the remains of shells and the skeletons of sea animals (p. 280)

limewater. Water in which lime has been dissolved (p. 210)

liter (lē'tẽr). A measure of volume in the metric system. A little more than one quart (p. 155)

living dust. Yeast, molds, bacteria, pollen, and spores which float in the air (p. 253)

lizard. A small reptile with a slender scaly body, long tail, and four legs (p. 440)

lobster. A sea animal with a crustlike shell. The soft body is prized for food (p. 67)

lubricating oil. An oil which reduces friction, or aids in the easy movement of one body over another (p. 330)

lymph (lĭmf). A transparent yellowish fluid found between the cells in the body of an animal. The "water" in a blister is lymph (p. 229)

machine age. An age or period of time in which machines are especially important or especially in evidence (p. 359)

magician. One who appears to be able to do simple or remarkable feats in a mysterious and unnatural manner (p. 11)

magnesium (măg nē'zhĭ u̯m). A silver-white element. Magnesium burns rapidly in air, giving a blue-white light. It is often used in flashlight powders (p. 333)

magnesium oxide. A compound of magnesium and oxygen (p. 333)

manure. Animal waste used as fertilizer (p. 44)

mechanism (mĕk'a̯ nĭz'm). A single part or instrument or a number of connected parts which act together for a certain purpose, as in a machine (p. 184)

medicine man. The magician of the Indians and other half-civilized peoples (p. 11)

medium. A substance in which living things may be cultivated and grown. Fruit jelly is a good medium for the growth of molds (p. 254)

membrane. A skinlike covering (p. 62)

mental. Having to do with the mind rather than with the body (p. 27)

mercury. The only metal which is liquid at ordinary temperature; quicksilver (p. 83)

metal. An element, usually hard, dense, shiny, and a good conductor of heat (p. 12)

meteorite (mē'tē o̮r īt). A body, composed of stone or metal, which has fallen to the earth from outer space (p. 345)

mica (mī'ka̮). A flaky mineral which may be separated into thin transparent layers or sheets; isinglass (p. 279)

microscope. An instrument used to make very small objects visible (p. 64)

microscopic (mī krō skŏp'ĭk). So small that it can be seen only with the aid of a microscope (p. 129)

migrate (mī'grāt). To travel regularly from one region to another, usually depending upon the season; some birds are migrating animals (p. 42)

migration (mī grā'shu̮n). The regular journey or movement from one region to another. Many birds and fish migrate annually (p. 411)

mildew. A spotty or white coloration caused by the growth of a fungus plant or mold (p. 254)

millepede (mĭl'lē pēd). An organism with many pairs of legs (p. 440)

mineral. A substance of some definite chemical composition found within the earth. A mineral differs from a rock in that a rock is made up of several different substances (p. 128)

mixture. A substance whose parts are not combined chemically and whose composition may vary. Air and soil are mixtures (p. 208)

mold. A small fungus plant which does not make its own food with the sun's help but lives upon other life or the remains of life (p. 47)

mole. A small animal which lives underground (p. 388)

molecular theory (mō lĕk'ū la̮r thē'ō rĭ). The theory which states that all matter is made of molecules (p. 80)

molecule (mŏl'ē kūl). The smallest quantity of any substance which can exist separately and still keep its composition and properties, or qualities (p. 80)

molt. To shed, or cast off, an outer layer, as a caterpillar molts its skin (p. 403)

moth. An insect closely related to the butterfly. Moths usually fly at night (p. 404)

mulberry. A tree with a berrylike fruit. Japanese silkworms feed upon mulberry leaves (p. 388)

mullein (mŭl'ĭn). A weed with coarse, large leaves (p. 431)

mussel. A water animal with a soft body covered by two shells. Some mussels are used for food (p. 64)

natural gas. A fuel gas obtained from the earth (p. 216)

nectar (nĕk'tạr). A sweet liquid produced by flowers, from which bees make honey (p. 397)

newt (nūt). An amphibian with a tail; one kind of salamander (p. 64)

nickel. A silver-white metallic element. Nickel does not easily rust. Many metal objects are covered with a thin layer of nickel (p. 330)

nitrogen (nī'trō jẹn). An inactive element. The air is about four fifths nitrogen (p. 150)

nitrogen-fixing bacteria. Bacteria found in nodules, or small bodies, on the roots of certain plants such as beans, peas, clover, and alfalfa. They use nitrogen from the air and make nitrogen compounds called nitrates (p. 396)

nitroglycerin (nī trō glĭs'ẽr ĭn). A compound of nitrogen, carbon, hydrogen, and oxygen; it is highly explosive (p. 335)

nodules (nŏd'ūlz). Small bodies attached to the roots of certain plants. The bacteria living in the nodules can take nitrogen from the air and make it into forms suitable for use by plants (p. 394)

oasis (ō ā'sĭs). A spot in the desert where green things grow because there is water (p. 43)

opossum (ō pŏs'ụm). A small animal, native of America, well known for its trick of pretending death when in danger. The young are carried in a pouch by the mother (p. 390)

orbit (ôr'bĭt). The path of a body in revolution about another body, as the orbit of the earth about the sun (p. 343)

organ. A part of a living organism having a particular use, as the heart in animals and the flower in plants (p. 60)

organism (ôr'găn ĭz'm). A living thing (p. 47)

oxidize (ŏk'sĭ dīz). To cause a substance to combine with oxygen (p. 235)

oxyacetylene (ŏk'sĭ ạ sĕt'ĭ lēn) **flame.** A flame produced by mixing acetylene and oxygen at the point of burning (p. 379)

oxygen (ŏk' sĭ jẹn). A gas essential for breathing. An element which combines with hydrogen to form water. Oxygen is colorless, tasteless, and odorless. One fifth of the air is oxygen (p. 120)

oyster. A soft-bodied sea animal covered by two rough shells. The oyster is attached to stones or objects in salt water. Oysters are of value as food (p. 64)

palmist (päm'ĭst). One who claims to be able to tell fortunes and predict events by the examination of the palm of the hand (p. 19)

particle (pär'tĭ k'l). A very small amount of substance (p. 80)

Pasteur (pås tẽr'), **Louis.** A French chemist and biologist (1822–1895) (p. 23)

pelican (pĕl'ĭ kạn). A large fish-eating bird. Below the lower jaw is a pouch, or sack, in which fish are stored for a short time before digestion (p. 32)

pellagra (pĕ lăg'rạ). A disease due to lack of vitamin G (p. 424)

penguin (pĕn′gwĭn). A short-legged water bird found in the Southern Hemisphere. Penguins cannot fly (p. 32)

perennial. A plant which continues its life season after season, sometimes for many years (p. 432)

phenomenon (fē nŏm′ē nŏn) (*pl.* **phenomena** (fē nŏm′ē na̯)). A happening, or event, particularly one which illustrates a scientific law (p. 9)

phosphorus (fŏs′fo̯r u̯s). An element which takes fire at a very low temperature (p. 209)

physics. The branch of science that has to do with changes in forms of matter and energy (p. 82)

Piccard, Auguste (pē kär′ ō go͝ost′). A Belgian scientist of the present day (p. 190)

pickerel (pĭk′ẽr e̯l) **weed.** A kind of plant which grows in shallow, fresh water (p. 69)

pistil (pĭs′tĭl). An organ in the center of a flower; it receives the pollen and later contains the developing seed (p. 398)

piston (pĭs′tu̯n). A sliding piece inside the cylinder of an engine; the gas may expand against it, thus causing it to move (p. 174)

pollen. The fine, yellow, powderlike "dust" produced by flowers. Pollen is necessary in the formation of seeds (p. 253)

pollute (po̯ lūt′). To make impure (p. 129)

pollution (po̯ lū′shu̯n). Making impure (p. 137)

porcupine. A gnawing animal whose furry body is protected by short spines. Porcupines live in woody areas (p. 40)

porpoise (pôr′pu̯s). A sea animal, five to eight feet long, related to the whale (p. 32)

potassium (pō tăs′ĭ u̯m). A soft, white metal; an element whose compounds are of great industrial use (p. 331)

praying mantis. An insect resembling a huge grasshopper; its position while waiting for its prey seems to be that of prayer. It eats other insects which are caught in its powerful forelegs (p. 404)

primitive (prĭm′ĭ tĭv). Relating to the times of long ago (p. 20)

primitive man. Early man; "cave man." Primitive man had few tools and poor shelter (p. 20)

primrose. A flowering perennial plant, common as a house plant (p. 62)

prism (prĭz′m). Glass prisms are used in the study of light; the ends are parallel triangles and the sides are rectangles (p. 344)

property. A quality of an object. For example, sweetness is a property of sugar, wetness is a property of water, and hardness is a property of iron (p. 327)

protein (prō′tē ĭn). A class of food substances. The protein molecule always contains nitrogen (p. 330)

proton (prō′tŏn). According to the electron theory, a positive particle of electricity (p. 342)

pupa (pū′pa̯). Certain insects during their life history pass through four stages. The third, or resting, stage is known as the pupa (p. 403)

purification (pū rĭ fĭ kā′shu̯n). The process of making pure (p. 132)

quartz (kwôrts). A hard, common mineral composed of silicon and oxygen. Quartz may be colorless or colored. Sand is quartz. Pure quartz is transparent (p. 279)

quicklime. Calcium oxide, a compound of calcium and oxygen (p. 309)

radiant (rā′dĭ a̯nt) **energy.** A form of energy which moves in straight lines through empty space (p. 377)

radiant heat. Heat transferred by radiation (p. 377)

radiation (rā dĭ ā′shu̯n). The giving out of rays, such as light, heat, and radio waves (p. 376)

radio waves. A form of radiant energy produced by electricity (p. 380)

radium (rā′dĭ u̯m). A rare silver-white metal; an element. It gives off radiant energy (p. 332)

refine. To separate a substance from the materials in which it is found; to purify (p. 308)

repel (rē pĕl′). To drive or force away (p. 343)

reservoir (rĕz′ẽr vwôr). A storage basin (p. 123)

respiration (rĕs pĭ rā′shu̯n). The process of taking air into the cells, using it in the production of energy, and expelling the waste products (p. 232)

rickets. A disease of teeth and bones; it is due to the lack of vitamin D in the diet (p. 423)

ringworm. An infection caused by a mold which lives on the skin (p. 254)

robot (rō′bŏt). A mechanical instrument controlled by electricity and often built to look somewhat like a man (p. 358)

rock formation. The nature and slope of the various layers of rock in a region (p. 131)

rootcap. The cells at the tip of a root; they are adapted to aid the root in pushing its way into the soil (p. 303)

root hairs. Outgrowths from cells on the newer roots of plants, shaped so as to absorb the largest possible amount of water from the soil (p. 303)

rust. The combination of oxygen with iron (p. 322)

sacred. That which is set apart for religious or holy use (p. 11)

sacrifice. An offering to a god or to someone else, at a loss to oneself (p. 15)

salamander (săl′a̯ măn dẽr). One of the amphibians (p. 66)

sapwood. Living wood between the heartwood and the bark (p. 436)

science. Knowledge gained by careful observation and experimenting (p. 4)

scientific (sī e̯n tĭf′ĭk). Relating to science. Supported by science, as a scientific belief. A superstitious belief is not based upon science (p. 21)

scientist. A person who bases his reasoning on the results of careful observations and experiments (p. 9)

scurvy (skẽr′vĭ). A disease in which the patient may be short of red blood corpuscles and have poor gums and teeth, due to a lack of vitamin C (p. 423)

sea urchin. A sea animal with a shell covered by spines. It may have various shapes (p. 64)

seaweed. A kind of plant growing in the sea, usually along the coast between high and low water (p. 69)

sedges (sĕj'e̮z). Grasslike plants which often grow in bunches in swampy places (p. 69)

sediment. Solid particles, or bits, which have settled out of water (p. 275)

settling basin. A basin where water which contains fine particles, or bits of matter, may remain quiet, so that the particles settle (p. 132)

silicon (sĭl'ĭ kŏn). A brittle black or brown element common in the composition of rocks (p. 333)

silicon dioxide (dī ŏk'sīd). A compound of silicon and oxygen (p. 333)

snow. Precipitation that is formed at a temperature below the freezing point of water (p. 87)

sodium (sō'dĭ u̮m). A silver-white metal. Salt is a compound of sodium and chlorine (p. 322)

sodium bicarbonate (bī kär'bo̮n āt). A compound of sodium, carbon, hydrogen, and oxygen; baking soda (p. 337)

sodium chloride (klō'rīd). A compound of sodium and chlorine; table salt (p. 333)

soil. Bits of crumbled rocks and decayed vegetable or animal materials which together make up the surface of the earth (p. 126)

soil fertility (fẽr tĭl'ĭ tĭ). The property, or quality, of the soil to grow crops (p. 305)

solar spectrum (sō'la̮r spĕk'tru̮m). The band of colors obtained when the sun's light is passed through a prism (p. 344)

soluble (sŏl'ū b'l). Able to dissolve. Salt is soluble in water (p. 132)

solution (sō lū'shu̮n). A mixture of the molecules of one substance with the molecules of another. In a solution of sugar in water the molecules of sugar move between the molecules of water (p. 127)

soothsayer (so͞oth'sā ẽr). One who claims to be able to foretell events (p. 11)

specimen (spĕs'ĭ me̮n). A sample or object intended for show or study as an example of others of the same kind (p. 52)

spectroscope (spĕk'trō skōp). An instrument containing a prism. It is used to determine (1) the elements in heavenly bodies, (2) the chemical composition of substances, and for other purposes (p. 344)

spectrum (spĕk'tru̮m). A band of colored light produced when light is passed through a prism. The colors of the spectrum are red, orange, yellow, green, blue, indigo, and violet. They are often called the "rainbow colors" (p. 344)

sperm cell. A special kind of cell which with an egg cell may produce a new organism, or living thing (p. 399)

spinal meningitis (spī'na̮l mĕn ĭn jī'tĭs). A disease of the brain and spinal cord caused by a microscopic organism (p. 255)

spore. A single cell capable of developing into a new organism, or living thing. A spore is not formed from the union of two cells. Ferns produce spores (p. 254)

spring. A place where the water table lies at the surface of the ground in such a manner that a continual supply of fresh water comes out of the ground (p. 137)

stamens (stā'mĕnz). Organs, in the center of the flower, which produce the pollen (p. 398)

starfish. A small sea animal whose rough body has the shape of a star (p. 64)

stigma. The sticky upper part of the pistil, upon which the pollen is caught (p. 398)

stoma (*pl.* **stomata** (stō'ma̤ ta̤)). A very small opening through the wall or skin of a leaf, by means of which air and other gases may pass in and out of the leaf and around the cells (p. 241)

stratosphere (strā'tō sfẽr). The upper portion of the atmosphere. The temperature changes but little, and no clouds form in the stratosphere (p. 191)

style. Part of a flower which supports the stigma; the stemlike portion of the pistil (p. 398)

submarine. A ship which may stay under water and be raised or lowered at will by means of compressed-air chambers inside it (p. 107)

submerge (su̯b mẽrj'). To lower an object into a liquid until it is completely covered (p. 102)

suffocation. Death caused by lack of air (p. 67)

sulfur (sŭl'fu̯r). A yellow element. Sulfur is used to vulcanize rubber and in the preparation of many chemicals (p. 322)

sulfuric (sŭl fū'rĭk) **acid.** An acid containing sulfur and oxygen (p. 310)

sun. The star nearest the earth. All the planets of the solar system revolve around it (p. 11)

sun spots. Dark spots on the surface of the sun as seen through a telescope. The spots seem to be large areas in which the sun's atmosphere is disturbed (p. 22)

superstition (sū pẽr stĭsh'u̯n). A belief in, or fear of, unknown forces (p. 14)

survive (su̯r vīv'). To continue living (p. 40)

susceptible (su̯ sĕp'tĭ b'l). Capable of being changed or influenced (p. 259)

sweat glands. The very small organs in the skin which discharge perspiration (p. 217)

symptom (sĭmp'tu̯m). A sign or indication. For example, a headache may be a symptom of eye trouble (p. 236)

telescope. An instrument containing mirrors or lenses so constructed that distant objects are made to appear nearer (p. 22)

television (tĕl'ē vĭzh u̯n). The process by which pictures are sent by means of electrical waves and shown again in some distant place (p. 6)

test tube. A thin glass tube closed at one end, used for making simple tests of different substances (p. 114)

tetanus (tĕt'a̯ nŭs). A disease in which the muscles become rigid; lockjaw (p. 255)

theory (thē'ō rĭ). A reasonable explanation of observed phenomena or events (p. 78)

thermometer. An instrument which measures temperature, or degree of heat (p. 82)

thermos (thẽr'mŏs) **bottle.** A container, made of two glass bottles, one inside the other. The space between is a partial vacuum. Heat does not pass readily through the walls of a thermos bottle (p. 371)

tin. A white metal; an element. "Tin" cans are made of iron coated with tin (p. 330)

tinder. A fine, dry substance, like scorched linen, which will catch fire very easily from sparks (p. 317)

tire gauge (gāj). An instrument for measuring the air pressure in a tire. The number indicated on the gauge tells how much greater the pressure within the tire is than the pressure of the atmosphere (p. 165)

T.N.T. Trinitrotoluol (trī nī trō tŏl'ū ōl); a highly explosive compound of nitrogen, hydrogen, and carbon (p. 347)

Torricelli (tŏr rē chĕl'lē), **E.** An Italian scientist (1608–1647) (p. 177)

transpiration (trăn spĭ rā'shu̯n). Evaporation of water from plant leaves (p. 85)

transverse (trăns vẽrs') **section.** An open, or exposed, part made by a cut straight across. For example, you see the transverse section of a tree when you look at the top surface of a stump or the end of a log (p. 442)

tropics. The land lying between the tropic of Cancer (23½ degrees north of the equator) and the tropic of Capricorn (23½ degrees south of the equator) (p. 38)

typhoid (tī'foid) **fever.** A disease caused by a bacterium taken into the body in food or in drinking water (p. 129)

universe (ū'nĭ vẽrs). An enormous system or group of stars. Our sun is a small star in such a group (p. 6)

urine (ū'rĭn). The liquid waste of the body, removed through the kidneys (p. 235)

vacuum (văk'ū u̯m). A space which contains no matter (p. 150)

vacuum tube. A tube, usually of glass, from which most of the air has been taken (p. 150)

valve (vălv). An opening in various parts of a machine, such as a cylinder, to admit or release gases or liquids (p. 153)

vein. Blood tube leading back to the heart (p. 226)

velocity (vē lŏs'ĭ tĭ). Rate of motion (p. 355)

ventilation (vĕn tĭ lā'shu̯n). The process of maintaining air in a condition that is comfortable and healthful (p. 266)

villus (*pl.* **villi** (vĭl′ī)). A hairlike structure, on the inner wall of the small intestine, through which digested food may pass into the blood stream (p. 231)
vireo (vĭr′ē ō). A small gray or olive-colored song bird (p. 408)
vital (vī′tạl). Necessary to life (p. 350)
vitamins (vī′tạ mĭnz). A class of chemical substances found in certain foods, of extreme importance to health (p. 421)
volume. Amount by size (p. 97)

walking-stick. An insect related to the grasshopper and sticklike in appearance (p. 404)
water table. The level at which water stands upon or below the surface of the earth (p. 92)
water witch. A forked stick whose turning while held in the hand is believed by some to indicate the presence of water in the ground below (p. 16)
weather. Conditions of air temperature, pressure, moisture, and motion which together make up the state of the atmosphere from day to day (p. 4)
weight. Amount of pull exerted upon an object by the force of gravity (p. 96)
welder. One who joins together metal pieces which have been softened by heat (p. 379)
witch doctor. A primitive magician (p. 11)

X rays. A form of radiant energy which penetrates certain substances, as wood, paper, cloth, and flesh (p. 342)

yeasts. One-celled plants which turn sugar in solution into alcohol and carbon dioxide (p. 47)

zinc. A grayish metal; an element. Zinc is used to coat iron to prevent rusting. Iron with a thin layer of zinc is called galvanized iron (p. 330)

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