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ABSTRACT

This student text deals with the human respiratory system and its relation to the environment. Topics include the process of respiration, the relationship of air to diseases of the respiratory system, the chemical and physical properties of gases, the impact on air quality of human activities and the effect of this air pollution on health. Superimposed on the lessons in scientific principles throughout the text is a continuing case study of a man's life span using respiratory health as the concept under analysis in this context. (RE)

BIOMEDICAL SCIENCE

UNIT I

RESPIRATION IN HEALTH AND MEDICINE

RESPIRATORY ANATOMY, PHYSIOLOGY AND PATHOLOGY; THE BEHAVIOR OF GASES; INTRODUCTORY CHEMISTRY; AND AIR POLLUTION

STUDENT TEXT

REVISED VERSION, 1975

THE BIOMEDICAL INTERDISCIPLINARY CURRICULUM PROJECT

SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION

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SECTION 1:

Welcome. We wish we writers could be in a big meeting room together with all of you who are about to begin the Biomedical Interdisciplinary Curriculum. You could tell us about your interests and aspirations. In turn, we could introduce ourselves, explain our views on the curriculum and tell you how the curriculum will respond to your goals. You would probably be surprised at the number of us in the meeting room. Perhaps fifty or more individuals have made a significant contribution to the product--teachers, scientists, medical professionals, social scientists, mathematicians and others. The assortment of "creators" includes many different backgrounds and viewpoints. Each of us might not explain the curriculum in the same terms, yet each would agree on at least two points. First, there is a pressing need for a curriculum specifically designed for young people interested in careers in medicine and health. Secondly, this biomedical curriculum should be "interdisciplinary." That is, it should discuss the important medical problems in relation to whatever concepts are needed to solve them--whether these principles come from physiology, mathematics, chemistry, social sciences or wherever.

1-1 Why a "Biomedical" Curriculum?

Perhaps you may wonder why we feel that there is such a need for a medically-oriented curriculum. After all, we live in the United States, a country with a high standard of living and with some of the world's finest medical institutions. We have certainly benefited from the great international developments in medical technology made during the last fifty years or so. These developments have dramatically changed the relation between man and disease.

Defective hearts may be repaired through cardiovascular surgery. Perhaps most spectacular has been the replacement of defective organs through transplantation. Insulin is now used to control diabetes. Vaccines have been developed to prevent polio and many other diseases. Malaria and typhoid fever are far less common than they were formerly, and tuberculosis has been almost completely eliminated in the United States.

But despite the remarkable advances in technology, the American people are not enjoying the best health possible. Listed below are a few facts that indicate the nature of some of our health problems.

1. Over one million Americans die each year from heart disease. Medical specialists estimate that the death rate from heart disease could be cut in half if what is known by medical specialists was known and heeded by the entire population.

2. The average American Indian dies when he is 20 years younger than the average non-Indian.

3. Death from pregnancy and childbirth is almost four times as frequent among non-whites as among the white population.

4. It is estimated that over 400 million days of work are lost each year because of problems related to health.

5. There is no sharp line separating health and disease, for there are many degrees of health and diseases. Probably all of us could be healthier than we are--more alive, more productive.

The reasons for America's health problems are many and complex. Some problems are related to technology itself. Technology has added pollutants to the air we breathe and the water we drink. Technology has eliminated for many the physical exercise once required to perform life's daily tasks. And technology has added ingredients to our food whose role in the body is not always well understood.

Ignorance is a major problem confronting health. The human body is very complicated, and the processes going on within it are not entirely understood. There is also ignorance by many people of some very basic and readily available information on the human body and its health. Ignorance of what is known about health is one problem which it is hoped this curriculum will reduce.

Other problems involve the health care professions themselves. The shortage of many types of trained personnel and the high cost of medical care are but two examples.

How can the health of our population be improved? We can suggest a few general possibilities.

More people are needed to enter careers in health professions. Also, more attention must be given to the underprivileged parts of our own population and the populations of less affluent countries.

Technology and social values are changing so rapidly in our society that an individual must take greater responsibility for his own health. You must obtain information on matters of health and make many decisions that concern your own health. The most important part of health education should be not on cures but on prevention. You can better enjoy health by avoiding disease than by knowing its treatment when you are ill.

And perhaps medical care should be directed more toward the patient as a person. The whole person should be considered, not merely the parts of his body. We should focus our concentration not on his diseases but the health of his entire body.

It is hoped that the Biomedical Curriculum will prepare you to help in these needed changes. It will provide you with the background to understand the current state of medical science and the needs of medical science.

Though some of the health professions are overstaffed, most others are in need of qualified workers. There are now over 200 different health careers and it is almost certain that there will be many more in the future. In the curriculum you will learn not only about health and disease, but about some of the profesional roles you may someday play in health-related fields. Our idea will be to provide you with a glimpse of many possible medical careers so that you can judge which one(s) is best suited to your interests and talents.

1-2 Why an "Interdisciplinary" Curriculum?

Having established the need for a "biomedical" curriculum it becomes easier to explain the need for courses that are also "interdisciplinary." Workers in the health fields must often consider the total person or the parts of that person (biology). Sometimes, the crucial consideration may involve one or more of the thousands of different substances housed in our body or the reactions of these substances (chemistry and biochemistry). At other times, the human being must be viewed as a complex machine that transforms energy from one form to another, moves at some speed and does work (physics). However, more often than not, the solution of a health problem requires input from all of the sciences--in other words, an interdisciplinary approach.

Nor is this interdisciplinary approach to health problems limited to science alone. Almost every scientific concept has a mathematical basis. The computer, for example, is based on mathematical principles that you will be learning in the curriculum. This device is changing virtually every aspect of medicine from library research to the diagnosis of disease. It is no wonder that most health professionals are expected to have some foundation in mathematics.

Finally, we should note that health problems cannot be solved by even the most brilliant scientists and mathematicians alone. These problems are human problems profoundly affected by society, human values, culture, money, government, politics, law--in short, social sciences. So the complete biomedical interdisciplinary package contains many areas of social science related to health and medicine.

1-3 The Biomedical Science Curriculum--A Bird's Eye View

From here on, we will be concerned mainly with the science part of the package. To understand disease and health, we must first comprehend the human body and how it should function ideally. After all, it is significant deviations from normal or ideal functioning that we recognize as disease. But to understand the nature of our incredibly complex body is a real challenge.

Because of this complexity, we will proceed to study man one part at a time. The most meaningful way to do this is to consider parts that function together in what biologists call systems or organ systems. For example, the mouth, the lungs and the other parts of the body involved in breathing compose one of these systems--the respiratory system. There are only a limited number of systems in the body and each of these will be considered in some depth. When you have a good understanding of these systems, you will know a lot about the human organism. If you add to this knowledge, a comprehension of the social sciences, you will know a lot about how humans function in society.

A preview of coming attractions is in order. The biomedical science curriculum begins with the respiratory system which we have already mentioned. The early lessons develop basic concepts and techniques that will be used in the laboratory throughout the curriculum. The unit on the respiratory system will proceed to consider the air we breath in and out and what happens to this air within the body. These subjects are medically relevant because many important diseases ranging from the common cold to lung cancer involve the respiratory system and these diseases will be considered when appropriate. To understand these diseases and the respiratory system, we will probe into the chemical nature of gases and some basic chemistry. Finally, we will consider some effects of technology on the respiratory system--in particular, health problems stemming from air pollution.

Later units will include nutrition and the digestive system, the circulatory system (blood vessels and the heart), the brain and the nervous system, the muscular system, the skeletal system (bones) and the reproductive system and genetics. Throughout, the major emphasis will be on disease, health and health careers. A second major emphasis will be on laboratory activities. You will have the opportunity to experience what is involved in the different kinds of health careers through the laboratory. In the final unit, health problems may be selected for more intensive study and projects may be done involving these health problems.

SECTION 2:

2-1 Biomedicine and the Balance

How is the balance used in biomedicine?

How much of substance X do I have? From earlier science courses, you probably remember that one answer to this question can be found by weighing substance X. You are probably also aware that chemists spend quite a lot of their time weighing out quantities of substances. One of their most important tools is the laboratory balance.

What you may not have known before is that the laboratory balance plays just as important a role in biomedicine. In a typical case, the identification of a patient's disease is based, at least in part, on the results of laboratory tests made on samples taken from the patient. These may be blood samples, urine samples or other kinds of samples. The physician sends the samples off to the lab for particular tests. After a time the lab report comes back, and the physician uses the results of the lab tests in deciding the best treatment for the patient.

What the patient never sees is what happens in the laboratory. There he would find a laboratory technician whose business it is to perform the required tests. It is the technician who uses the balance time and time again to weigh out chemicals that are used in the tests.

As you proceed through this course, you will have an opportunity to perform many of the tests that are used in medical laboratories. In the process, the balance will become like an old and trusted friend (or perhaps a hated enemy, if it doesn't work properly). If you learn to use it carefully and properly from the beginning, you will find that the results of the tests that you make will be much more accurate.

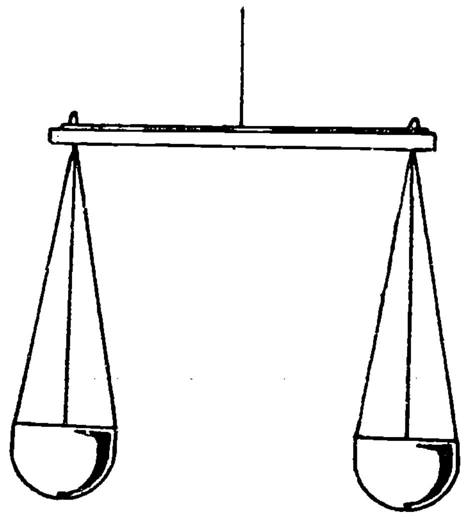
It is important to realize that the making of measurements in biomedicine is a very serious business. If a physician bases his judgments on faulty lab reports, he may prescribe drugs or other treatments that not only do not help the patient but actually harm him.

Speaking of drugs, they constitute a second major area in which the balance is used in biomedicine. Pharmacists frequently use the balance in making up prescriptions. Again, it is easy to imagine what might happen if a pharmacist became careless about the amount of a potent drug in a patient's medicine.

2-2 King Toot and his Glurk of Silver

The invention of the balance preceded the beginnings of recorded history. And apparently it was invented more than once in different parts of the world. This is not surprising since it satisfied an economic need.

In its simplest form the balance is nothing more than a horizontal beam hung from its center by a piece of string or cord. At each end of the beam a container is attached. If the balance is made properly, the beam remains horizontal when the two containers are empty. In other words, the containers are "in balance."



You can probably think of many uses for such a device even in a prehistoric society. For example, two families cooperate in raising a crop of grain, agreeing to share the grain equally after the harvest. It is easy to see how they can use the balance to make a fair division of the crop.

Let's take a somewhat more complicated example that involves a medium of exchange. King Toot's people have quite a lot of silver, and silver is their medium of exchange. A typical transaction might go as follows.

Buyer: "I'll give you this lump of silver for that cow over there."

Seller: "No deal! I sold a cow yesterday for these two lumps of silver."

Buyer: "But those two lumps put together would be smaller than my lump of silver."

Seller: "Who are you trying to kid? My two lumps would make one and a half of yours."

Perhaps eventually a deal is made, but the problem is clear. No one has a way to tell how much silver he has.

King Toot has been concerned about this problem for some time, mainly because his people spend more time arguing than they do working. One day he hits upon a solution. He decrees that the value of all types of goods will be related to the weight of a sacred silver nugget which he keeps at the Royal Treasury. He calls the weight of this nugget a "glurk." From now on, the unit of exchange will be the glurk of silver, which is a weight of silver equal to the weight of his sacred nugget.

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Let's listen in on a later transaction which follows the King's decree.

Buyer: "I'll give you three glurks for your broken-down nag."

Seller: "That's a fair price. Let's go down to the treasury to weigh out your silver."

Buyer: "I'm sure getting tired of going down there every time I want to buy or sell something."

The next step, of course, is the minting of coins, all of which contain a specific weight of silver. In order to get them the right weight, once again the King's nugget and the balance are used.

What has all this to do with science? You might think not very much, but there is one important connection. King Toot's people needed a way to determine the quantities of substances that was reproducible. This is what the balance did for them; it provided a measurement that could be reproduced at will. A glurk of silver was the same amount on Thursday as it had been on Tuesday.

Underlying all scientific research is the need for reproducible measurements. Without reproducibility, the reporting of scientific findings would become a meaningless hodgepodge of claims and counterclaims. This is so because no one could report precisely what he did or precisely what the results were.

2-3 What Does a Laboratory Balance Measure?

We have discussed the use of the balance in weighing various objects and substances. But what is weight?

The weight of an object is the force with which gravity acts on an object, and consequently, the force the object exerts on what is underneath it. Since the force of gravity changes from place to place, weight is dependent upon location.

Consider an ordinary bathroom scale. A large man steps onto the platform. The platform presses down on springs that are inside the scales. The compression of the springs gives a dial reading of 200 lb. If the scales are accurate, this is the force that the man exerts on the platform.

Now let's transport the man and the scales to the surface of the moon. There we find a dial reading of less than 40 lb, because the force of gravity is only one-sixth as much on the moon as on the earth.

Perhaps more surprising is the fact that a man who weighs 200 lb at the equator would weigh over 202 lb at the North Pole. In other words, gravity and weight vary even on the surface of the earth.

Although the concept of weight is an important one and has many uses, scientists tend more often to deal with a property called mass.

Mass may be said to be the quantity of matter in an object. It is a property that does not change as the object moves from one place to another. In other words, mass is independent of the force of gravity.

Recall that the balance may be used to compare the quantity of a substance in relation to some standard. In King Toot's realm that standard was the king's glurk of silver. If a quantity of gold or grain balanced the glurk of silver in Tootland, the two sides would remain in balance at the North Pole or on the moon. What the balance measures is mass; and it measures mass in relation to some standard mass.

The standard mass used by scientists throughout the world is the kilogram. At Sevres, near Paris, there is a block of platinum-iridium alloy known as the "international prototype kilogram" The mass of this particular block of metal is defined as one kilogram.

The prefix "kilo-" comes from the Greek word for "thousand" and, as you might expect, there is a second mass unit--the gram--which is defined as one-thousandth of a kilogram. As you will see in Laboratory Activity 2, laboratory balances are designed to measure mass in relation to the gram.

Although it is important that you know the difference between mass and weight, you will find that scientists are not always consistent in their use of the words. Even our language gets in the way of keeping these two ideas separate. For example, the word "weigh" might mean to find the weight or to find the mass of an object. The problem is that we have no single word in English that can be substituted for "find the mass."

When you step on a bathroom scale, the dial gives your weight in pounds. But when you are weighed in a doctor's office, a balance is used. Since a balance measures mass, this instrument gives your mass in pounds. When people of most other countries step on a bathroom scale the resulting weight is given in kilograms. In other words, there are kilograms of mass and kilograms of weight, as well as pounds of weight and pounds of mass.

The important thing to remember out of all this is that whether you are dealing with a weight or a mass depends upon the kind of instrument used to make the measurement. Moreover, weight changes with location, while mass does not.

The following table gives the abbreviations for grams and kilograms plus some equivalences to give you an idea of how these units compare with the units you are more familiar with. The symbol "≈" stands for "approximately equal to."

UNIT	ABBREVIATION	EQUIVALENCES
gram	g	
kilogram	kg	1 kg = 1000 g
		1 kg ≃ 2.2 lb
		1 lb ≃ 453.6 g

Why is it important that you learn to use the laboratory balance carefully and properly?

How does a balance differ from a bathroom scale?

What is the difference between mass and weight?

What is the meaning of the prefix "kilo-"?

What are the units in which mass is measured by scientists? What are the abbreviations for these units?

Vocabulary:

gram--a unit of mass equal to one-thousandth of a kilogram. Also commonly used as a unit of weight.

kilogram--a unit of mass based on the mass of a special block of metal located near Paris. Also commonly used as a unit of weight.

mass--a measure of the quantity of matter in an object.

weight--a measure of the force with which gravity acts on an object.

SECTION 3:

3-1 The Limitations of Measurement

Can errors be avoided in our measurements?

Every measurement that has ever been made is in error! We can safely make this statement because the process of measurement is by its very nature an inexact process. Every object has an exact mass, for example, but there is no way to determine that mass exactly, whether the object be an atom, a pebble or your body. Nor can anyone ever state, exactly, your height, your weight or any other characteristic you might have that can be described in terms of numbers and units. In fact, the only exact numerical statements that can ever be made have to do with the counting of objects. We can correctly state, for example, that you have exactly ten fingers (unless you have some other number of fingers).

Science and mathematics textbooks typically give problems that have exact answers. For instance, if a bus travels 25 miles in 30 minutes, what was its average speed during the trip? The speed for this bus is exactly 50 miles per hour. Such problems are very useful in helping students to understand new ideas, but the problems are drawn from an ideal world, not the real world in which we live. In the real world, we cannot determine exactly either the distance traveled or the time it took. If we made very, very careful measurements of such a trip, we might find that a bus traveled 24.97431 miles in 31 minutes and 11.65 seconds. Notice that such a "real" problem usually involves much more complicated arithmetic. (The average speed, thanks to our trusty calculator, turns out to be approximately 48.04 miles per hour.) More importantly, the two measurements just described are not, and cannot be, exact. Therefore, the answer cannot be exact either.

People who deal with measurements in the real world, whether they are doctors, scientists or carpenters, learn to live with error in almost everything they do. But don't give up hope; there are usually ways to keep measurement errors within reasonable limits.

As a student, you are probably used to thinking of error as a bad thing--the kind of thing that gets you low grades on tests. But error is something that is taken for granted in measurement. Although every measurement has its error, the decisions we make that are based on measurements may well be correct ones.

3-2 Accuracy and Precision

How can a measurement be highly precise and yet very inaccurate?

In everyday language, accuracy and precision mean pretty much the same thing. In the language of scientists, however, these two words have quite different meanings.

When a scientist questions the <u>accuracy</u> of a mass measurement, for example, he is asking how close the measured mass is to the actual mass of the object that was weighed. This is a difficult question that can never be answered completely, since we can never know the exact mass of any object.

The precision of a measurement, on the other hand, has to do with its reproducibility. In Laboratory Activity 2, you were asked to repeat the same mass measurement several times. Let's say that the following results were obtained.

28.97 g	28.97 g	28.96 g
28.98 g	28.96 g	28.97 g
28.97 g	28.97 g	28.97 g

As you can see, all nine of the results lie between 28.96 g and 28.98 g. In this case, one might conclude that the best statement of the result would be 28.97 g and that this result might be off as much as .01 g in either direction. The second half of this statement is a description of the precision of the measurement, or actually how imprecise it might be.

The precision of a measurement is normally a built-in feature of the instrument used to make the measurement. We say "normally" because the precision may be reduced if the instrument is damaged or not functioning properly and also if the measurer used faulty or sloppy measurement technique.

What about the accuracy of a measurement? If the measurement device is in good working condition and the measurement is made with proper skill and care, then we can be reasonably confident that the measurement is as accurate as we can make it. Beyond this, we cannot go.

But it is important to realize that a measurement can be highly precise and yet quite inaccurate under certain circumstances. For example, consider the possibility of a hospital pharmacist who is asked to prepare an extremely potent drug for a critically ill patient. The prescription indicates that the drug should contain 0.5 gram of the active ingredient; the rest is a harmless liquid in which the drug is dissolved.

The pharmacist carefully weighs out 0.50 gram of the drug, thinking to himself that the quantity of the drug must certainly lie between 0.49 and 0.51 gram, which is well within safe limits. He dissolves the drug in the liquid and sends the prescription upstairs to the patient.

Thirty minutes later the patient is dead. A subsequent autopsy shows that the patient had received a lethal dose of the drug--approximately one gram, instead of half that amount. The measurement made by the pharmacist was quite precise, but its accuracy was off by a factor of two to one. How could this happen?

Perhaps you have already guessed the answer. The pharmacist forgot to adjust the balance to zero with the pan empty before he weighed out the drug. In actual practice, an error of this kind is very unlikely, but our example underscores the need to be concerned about accuracy as well as precision.

We have discussed the adjustment of the balance as one procedure for increasing accuracy. There are other methods that can be used to provide an idea of the accuracy of measurements. In general, they involve comparing one measuring instrument against another or against a known standard. If, for example, two different balances give a measurably different mass for the same object, one of them is more inaccurate than the other. Unfortunately, there is no way to tell which balance is the more inaccurate, if the object's mass is unknown to start with.

Comparison with a known standard is much more profitable, if one is available. For checking the accuracy of balances, sets of weights are manufactured to highly accurate specifications. If one has a weight that is known to have a mass somewhere between 0.999 gram and 1.001 grams, the accuracy of a balance designed to measure mass to the nearest .01 gram can easily be checked.

3-3 The Measurement of Space

What units are used in science to measure a quantity of space?

In Section 2, we discussed one fundamental property of matter--mass. A second basic property of matter is that it occupies space. In fact, a common dictionary definition of matter is, "that which has mass and occupies space."

The word volume is commonly used to describe the size of a quantity of space, whether it be empty space or the space taken up by some quantity of matter. Thus we may speak of a volume of space, the volume of a solid object or the volume of a quantity of liquid or gas. In each case, the word refers to an amount of space, whether it is empty or occupied by matter.

As is the case with mass, scientists the world around use units of volume that differ from those in everyday use in the U.S. Actually there are two different sets of volume units in scientific use. We will introduce one set of units here and postpone discussion of the others until Section 5.

One important unit of volume is the liter. As you will see later, the liter is not considered to be a fundamental unit of measurement because it is based on other units. Nevertheless, it is commonly used in biomedicine to express the volumes of liquids and gases and less frequently to express the volumes of solids.

The volume unit you will be using most consistently in this course is the milliliter. The prefix "milli-" comes from Latin and means "one-thousandth." Thus a milliliter is a volume that is one-thousandth of a liter.

The following table gives the abbreviations for these units and some comparisons to some of the volume units still being used in the U.S.

UNIT	ABBREVIATION	EQUIVALENCES
liter	l	
milliliter	ml	1000 ml = 1 liter 1 liter ≈ 1.06 liquid quarts 29.6 ml ≈ 1 fluid ounce 3.7 ml ≈ 1 teaspoonful

The comparisons to U.S. units are provided primarily to give you a "feel" for the size of a liter and a milliliter. It is not intended that you memorize these numbers, although it is useful to remember that a liter is slightly larger than a quart.

Also note that the printed abbreviation for the liter is easily confused with the numeral "one." For this reason, the liter will not be abbreviated in any of the material to follow. It is prefectly acceptable, however, to use a lower-case handwritten "ell" (ℓ) in your own work.

Why isn't it possible to make exact measurements?

How do the accuracy of a measurement and the precision of that measurement differ from one another?

How can the accuracy of a balance be tested?

How can the precision of a balance be tested?

What circumstances can increase the imprecision of a measurement?

What is the relationship between a liter and a milliliter?

What is meant when we talk about the volume of an object?

Vocabulary:

accuracy--the extent to which a measurement agrees with the true value of the property being measured.

liter--a unit of volume slightly larger than a liquid quart.

milliliter--a unit of volume equal to one-thousandth of a liter.

precision--the extent to which a series of measurements of the same property agree with one another.

volume--the size of a quantity of space, or the space occupied by a quantity of matter.

SECTION 4:

4-1 Density

What do we mean when we say that lead is heavier than feathers?

In the preceding two sections, we discussed two fundamental properties of matter. Matter possesses mass and it occupies a volume of space. Mass and volume are two different measures of the quantity of matter being described. For the same kind of matter, twice as much mass will occupy twice the volume of space and ten times the mass will occupy ten times the original volume. If 60 g of Uncle Zeke's molasses fills a 50-ml beaker, then 120 g will fill a 100-ml beaker. In other words, mass and volume are proportional for any particular kind of matter.

On the other hand, it is obvious even to small children that the relation between mass (or weight) and volume (or size) is different for different kinds of matter. In everyday language we talk about iron being "heavier" than aluminum. What we really mean is that a given volume of iron is heavier than the same volume of aluminum. Or, to put it another way, the ratio of mass (or weight) to volume is greater for iron than it is for aluminum.

This property of a substance is called its density. Density is the ratio of mass to volume. (It is also possible to define a weight density as the ratio of weight to volume, but in this case it should be kept in mind that the ratio will vary with location.)

As an example of how density is handled, let's say that we make these measurements on a certain chunk of iron. We find that the mass is 291 grams and the volume is 37 milliliters. We may state that the density of the sample of iron is the ratio of 291 g to 37 ml, or 291 g per 37 ml. Recall that a ratio may also be expressed as a fraction. Thus, we may write,

$$\text{density} = \frac{291\ \text{g}}{37\ \text{ml}}$$

Since a fraction implies division, we may divide 37 into 291 to obtain,

$$\text{density} \approx 7.86\ \frac{\text{g}}{\text{ml}}$$

(Note the use of the symbol "≈" to mean "approximately equal to." It is used here because we have rounded the quotient to the nearest hundredth.) Instead of leaving the units with g in the numerator and ml in the denominator, the result of this division would normally be shown in one of the following two forms.

density ≈ 7.86 g per ml   density ≈ 7.86 g/ml

In the second case, the slash is used to stand for "per."

The meaning of this result is that one milliliter of our sample of iron has a mass of approximately 7.86 grams. In other words, the density is approximately 7.86 grams per one milliliter. Density is most commonly expressed in terms of mass per unit volume, which means mass per one unit of volume. This makes it easy to compare the densities of different materials such as water and lead.

The division we performed in order to obtain the mass per unit volume was based on an important assumption. It was that our sample of iron was the same throughout. This is a very reasonable assumption for a chunk of iron, but let's consider a second example.

A small portable radio has a mass of 312 grams and a volume of 195 milliliters. What is its density?

$$\text{density} = \frac{312\ \text{g}}{195\ \text{ml}} = 1.6\ \text{g per ml}$$

This result suggests that each milliliter of radio has a mass of 1.6 grams. But the radio consists of a plastic case, inside of which are various pieces of metal and plastic and a considerable amount of air. Clearly the density of the radio must vary from one portion of it to another. What we have just calculated is the average density of the radio, which may have little relation to the density of any particular part of it.

All densities expressed in terms of mass per unit volume are average densities. Only when the object being measured has the same composition throughout can we expect each part of the object to have the same density as the average density.

Density is an important concept in biomedicine because the diagnosis of a variety of diseases is based, in part, upon the density of body fluids. For example, an abnormally high density of urine may be an indication of diabetes.

If you have ever donated blood, you may remember that first you answered a lot of questions about your health history and that some simple tests were made on you. Your temperature and pulse were measured. A drop of blood was taken from your ear lobe and dropped into a blue liquid. This was done to check your blood density. If the drop of blood did not settle quickly, the nurse would have assumed you could be anemic and your blood would not have been taken.

4-2 Averaging Measurements

Is an average more accurate than the measurements it was obtained from?

In many situations, repeating the same measurement can lead to a series of results that are quite noticeably different. For example, one test of the health of a person's lungs involves measuring the volume of air that can be exhaled in one breath. The patient is asked to fill his lungs as fully as possible and then to blow as much air as he can into a tube. The tube is connected to a machine that measures the volume of air in liters.

A set of four such measurements might give readings of 5.37, 5.56, 5.19 and 5.62 liters. How can we best express the result of these measurements?

One procedure that naturally comes to mind is to take the average or mean of the four results. As you probably recall, the mean is obtained by finding the sum of the values and dividing by the number of values. In this case,

$$\frac{5.37 + 5.56 + 5.19 + 5.62}{4} = \frac{21.74}{4} \simeq 5.44 \text{ liters}$$

So we can say that the mean of the four tests was 5.44 liters.

Is the mean a more accurate value than any of the four readings it was calculated from? Unfortunately, we have no way of knowing the answer to this question. The use of the mean is based on the assumption that about half of the measurements are higher than the true value, while the other half are lower. Often this may be the case, but we cannot know it to be the case.

Nevertheless, the mean of a set of values can be very useful for some purposes. For example, we may need to use a measurement to make a number of very lengthy calculations. In this case, it is very handy to be able to use what we hope to be the best single statement of our results, rather than repeating the calculations for each separate measurement.

Another point to remember about a mean is that when stated by itself, it provides no information on the precision of the original measurements. In our preceding example, a mean of 5.44 liters was obtained from a set of values that ranged from 5.19 to 5.62 liters. But note that readings of 1.06, 3.33, 7.54 and 9.18 liters would give us the very same mean of 5.44 liters. In the first case the range of readings is less than 0.5 liter, while in the second case the range is more than 8 liters.

What two fundamental properties of matter are used to calculate density? Which is divided into the other?

In what units may a density be expressed?

Why is density important in biomedicine?

How is a mean calculated?

What information does a mean give about the precision of a set of measurements?

Vocabulary:

density--the ratio of the mass of a quantity of matter to the volume it occupies. Density is usually expressed in terms of mass per unit volume--for example, g per ml.

mean--the sum of a set of values divided by the number of values. Also called an average.

SECTION 5:

5-1 Length

What units of length are used in science?

At first thought, one might think that measurements of length would have little importance in biomedicine. Except for the measurement of body height, you might find it difficult to think of a way in which length or distance could enter into the work of health professionals. Yet length units crop up time and time again in almost every area of biomedicine. We will have more to say about this later in this section, but first it is necessary to discuss length in some detail.

In 1799, a system of measurement, called the metric system, was adopted in France. This system was based on a unit of length called the meter, which was defined as one-ten-millionth of the distance from the equator of the earth to either of the earth's poles.

The difficulty in obtaining a precise measurement of the distance from equator to pole led later to a new definition of the meter as the distance between two lines marked on a metal bar kept near Paris. Today, even this definition has been replaced by one that is even more precise. The current definition of the meter is beyond the limits of this course. (It has to do with a certain kind of radiation given off by atoms of krypton.)

In the U.S. we have a variety of length units to express lengths of different sizes, for example, inches, yards and miles. The same is true of the length units used by scientists. But their system is much simpler than ours, because each kind of unit is a decimal multiple of the other units in the system. This makes it very easy to convert from one kind of unit to another, since all one has to do is move the decimal point.

Table 1 on the following page shows the complete range of length units used by scientists everywhere.

There are two important things to notice about this collection of length units. First, all of the units except the meter consist of a prefix followed by the word "meter." Second, each prefix has its own abbreviation, which is attached to the abbreviation for "meter" to form the complete abbreviation of the unit. For example, in the abbreviation "km," the "k" stands for "kilo-" and the "m" stands for "meter."

If we look at the righthand column of Table 2, we see that the prefix "kilo-" stands for "1,000." You may recall that 1 kilogram = 1,000 grams, and that the abbreviation for kilogram is "kg." The fact is that the prefixes shown in the table are used with grams and liters and seconds in exactly the same way. We could replace "meter" with "gram" throughout the table, and "m" with "g" in the column of abbreviations and have a list of mass units.

TABLE 1: LENGTH UNITS BASED ON THE METER

UNIT	ABBREVIATION	SAME LENGTH IN METERS
terameter	Tm	1,000,000,000,000 meters
gigameter	Gm	1,000,000,000 meters
megameter	Mm	1,000,000 meters
kilometer	km	1,000 meters
hectometer	hm	100 meters
dekameter	dam	10 meters
meter	m	1 meter
decimeter	dm	.1 meter
centimeter	cm	.01 meter
millimeter	mm	.001 meter
micrometer	μm	.000 001 meter
nanometer	nm	.000 000 001 meter
picometer	pm	.000 000 000 001 meter
femtometer	fm	.000 000 000 000 001 meter
attometer	am	.000 000 000 000 000 001 meter

If we know the meanings of the prefixes, we can understand at a glance the meaning of any unit within the system. For example, a milliliter (ml) is a thousandth of a liter, a centigram (cg) is a hundredth of a gram and a microsecond (μs) is a millionth of a second.

Of all of the prefixes shown in Table 1, only a few are important to remember for this course. These are shown in Table 2 on the next page. The abbreviation for "micro-" is the Greek letter "mu," and is pronounced "mew."

You may wonder why prefixes as large as "tera-" and as small as "atto-" are included in the system at all. We will show just two examples of their use here. The distance to the nearest star is about 40,000 terameters (Tm). On the other hand, some of the events studied in nuclear physics take place in as short a time as a thousandth of an attosecond(as).

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TABLE 2: PREFIXES WORTH REMEMBERING

PREFIX	ABBREVIATION	MEANING
kilo-	k	1,000
centi-	c	.01 or one-hundredth
milli-	m	.001 or one-thousandth
micro-	μ	.000 001 or one-millionth

To return to the more prosaic world, a few comparisons to U.S. units may help to give you an idea of the size of some of the more common metric units of length (see Table 3).

TABLE 3:

A COMPARISON OF U.S. AND METRIC UNITS OF LENGTH

1 meter ≈ 39.37 inches
2.54 centimeters = 1 inch
1 millimeter ≈ .04 inch
1 kilometer ≈ .62 mile

Note that 1 inch is defined as exactly 2.54 centimeters.

In the laboratory, the precision of a length measurement is fairly straightforward. It has to do with how well you can estimate distances in between the division marks on a ruler. There are two things to watch out for, though. One is the position of your eye. The best technique is to close one eye and line up the other eye with the point on the ruler where the reading is to be made. Getting the eye off to one side can seriously affect precision and accuracy.

The other thing to watch out for is the condition at the end of the ruler. If the zero mark is located some distance from the end of the ruler, there is no problem. Otherwise, the best technique is to measure from some other mark, such as the "one" mark. In this case, of course, one must be subtracted from the reading obtained--something that is quite easy to forget.

5-2 Area

What has area to do with biomedicine?

As you no doubt know, area is a description of the extent of a surface. Area cannot be measured directly, but it can be calculated from two or more length measurements. For example, the area of a rectangle is the product of its length and its width. A rectangular field with a length of 40 feet and a width of 20 feet has an area of 800 square feet. The most important thing to remember about area is that its units are square units.

When we convert from one kind of square unit to another, a slight problem arises. Take, for example, a square having a side with a length of 1 foot. The area of the square is 1 square foot. But we may also express the length of a side as 12 inches. In this case, we can obtain the area in square inches. The area is 12 inches x 12 inches = 144 square inches. So,

1 foot = 12 inches

but, 1 square foot = 12 x 12 = 144 square inches

A similar situation exists for all square units. (We will use "sq" as an abbreviation for "square" in all square units.)

1 yd = 3 ft
1 sq yd = 3 x 3 = 9 sq ft

1 m = 100 cm
1 sq m = 100 x 100 = 10,000 sq cm

1 cm = 10 mm
1 sq cm = 10 x 10 = 100 sq mm

1 km = 1,000 m
1 sq km = 1,000,000 sq m

The concept of area is of great importance in health and medicine. Many examples could be given. The area inside our lungs partially determines how much oxygen we obtain as we breathe. The surface area of our bodies is a factor in the rate at which we lose heat to the environment. The cross-sectional area of our blood vessels is a factor in the rate at which blood flows through them. Area is an important factor in determining our blood pressure.

We could go on and on, but we hope we have already convinced you that for much of what is to come in this course, it is essential that you understand what area is, how it differs from length and volume and the nature of the units in which it is expressed.

5-3 Volume

How are liters related to length?

We have already discussed volume in Section 3. There we introduced the liter and mentioned that it is based on other units. The "other units" are cubic length units.

We can make three measurements of a rectangular solid--length, width and height--and determine its volume by finding the product of the three lengths. In this case, the volume is expressed in cubic length units. For example, a rectangular solid with a length of 4 ft, a width of 2 ft and a height of 3 ft has a volume of 4 x 2 x 3 = 24 cu ft. (We will use "cu" to stand for "cubic.")

For a cube with a side of 1 yd, the volume is 1 x 1 x 1 = 1 cu yd. But if we express the length of the cube's side as 3 ft, we get a volume of 3 x 3 x 3 = 27 cu ft. Thus 1 yd = 3 ft, but 1 cu yd = 3 x 3 x 3 = 27 cu ft. The same situation exists for all cubic units. To find the relation between two kinds of cubic units, we must multiply the number in the length equivalence by itself three times.

1 cm = 10 mm
1 sq cm = 10 x 10 = 100 sq mm
1 cu cm = 10 x 10 x 10 = 1,000 cu mm

1 m = 100 cm
1 sq m = 10,000 sq cm
1 cu m = 1,000,000 cu cm

Now we can finally tell you about the liter. The liter is defined as 1,000 cu cm. Since there are 1,000 ml in a liter, this definition makes the milliliter exactly equal to the cubic centimeter. 1 ml = 1 cu cm.

5-4 Specific Gravity

How can the density of an object change?

In Section 4, we discussed density as a measure of the ratio of mass to volume. For a specific quantity of matter mass is a permanent, unchangeable property. But volume is not. For example, we can squeeze a marshmallow and change its volume. A squeezed marshmallow has less volume and a greater density than an unsqueezed one.

Another condition that affects volume is temperature. If this were not true, thermometers wouldn't work, as we shall see in Section 6. All substances change their volume to one extent or another as temperature changes. Water is rather unusual in this respect. As we cool water down, its volume decreases until we reach a temperature of about 39 °F (Farenheit). If we continue to cool it, its volume begins to increase until it freezes at 32 °F.

So at about 39 °F, water occupies a minimum volume. This is the temperature at which its density is a maximum. The maximum density of water is approximately 0.999973 g/cu cm (or g/ml). This value is so close to 1 that, except for the most precise kinds of measurements, we can assume the maximum density of water to be 1.

The closeness of the density of water to 1 has led scientists to define a second measure that is very similar to density. It is called specific gravity and is merely the ratio of the density of a substance to the maximum density of water. For example, if the density of gold is 19.3 g/cu cm, the specific gravity of gold is the ratio of 19.3 g/cu cm to 1 g/cu cm, which is 19.3. In other words, the specific gravity of gold is numerically the same as the density of gold expressed in g/cu cm. The only difference is that specific gravity has no units.

In biomedicine, specific gravity is often used instead of density, because instruments are available which measure specific gravity directly. The specific gravity of body fluids such as blood and urine is important in identifying a number of diseases.

Why are length units important in biomedicine?

Which is longer, a meter stick or a yardstick? How much longer?

Which metric prefixes are important to remember? What does each of them mean?

What factors can affect precision and accuracy in the measurement of length?

What is the difference between area and length? How does volume differ from either of them?

What is the difference between specific gravity and density?

Vocabulary:

area--a measure of the extent of a surface.

meter--the fundamental unit of length used by all scientists.

specific gravity--the ratio of the density of a substance to the maximum density of water.

SECTION 6:

6-1 Temperature Scales

How does one convert Fahrenheit t -perature to Celsius temperature?

In the last several sections we have discussed several properties of objects or quantities of matter. Among them were length, surface area, volume, mass and density or specific gravity. Yet another property of matter is its temperature.

You are no doubt familiar with the Fahrenheit temperature scale. On this scale water freezes at 32 °F (degrees Fahrenheit) and water boils at 212 °F. But have you ever wondered why water freezes at 32 °F instead of some other number? Or why water boils at 212 °F?

The Fahrenheit temperature scale was invented in 1714 by the German physicist Gabriel Fahrenheit. History gives us conflicting stories on just how he arrived at the scale which was named after him. One story says that he set the zero (0 °F) on his scale at the lowest temperature he could obtain by mixing salt and ice together in much the same way that "home-made" ice cream is made.

Then Fahrenheit decided to create a temperature scale that had exactly 180 divisions between the freezing point and the boiling point of water. (Some scholars have speculated that he chose the number 180 because this is the number of degrees in a semicircle.)

This is the explanation of 32° and 212°. Fahrenheit made a thermometer containing the liquid mercury. He marked the zero-point at the lowest temperature he could obtain. Then he marked a second point for the mercury level in a mixture of water and ice. And he marked a third point for the mercury level when his thermometer was placed in boiling water. Once he had decided that there would be 180 degrees between the freezing and boiling points of water, the rest was just arithmetic. He could mark his thermometer on down to zero with degrees of the same size. Then, by counting back up the scale, he found that the freezing point of water was 32° and the boiling point was 212°.

In 1742 a different temperature scale was invented by the Swedish astronomer Anders Celsius. He chose the freezing point of water as 0° and the boiling point of water as 100°. It is this temperature scale, now known as the Celsius scale, which is used by scientists everywhere.

Since we live in one of the very few countries still using the Fahrenheit scale for everyday purposes, it is important to be able to convert temperatures from degrees Fahrenheit (°F) to degrees Celsius (°C) and vice versa. The equation for this purpose is

$$°F - 32 = °C \times 1.8$$

We can divide both sides of this equation by 1.8 to give us an equation for converting from °F to °C.

$$\frac{°F - 32}{1.8} = \frac{°C \times \cancel{1.8}}{\cancel{1.8}}$$

$$\frac{°F - 32}{1.8} = °C$$

To convert from °C to °F, we can add 32 to both sides of the original equation.

$$°F - 32 + 32 = (°C \times 1.8) + 32$$

$$°F = (°C \times 1.8) + 32$$

The 1.8 in these equations comes from the fact that there are 180 °F between the freezing and boiling points of water and 100 °C between the same two points. The ratio of 180 to 100 is 1.8. The 32 in the equations comes from the fact that the Fahrenheit temperature is 32° when the Celsius temperature is 0°.

We will give two examples to show how these equations work.

EXAMPLE:

Convert 20 °C to degrees Fahrenheit.

SOLUTION:

$$°F = (°C \times 1.8) + 32$$

$$°F = (20 \times 1.8) + 32$$

$$= 36 + 32$$

$$= 68\ °F$$

EXAMPLE:

Convert 100 °F to degrees Celsius.

SOLUTION:

$$°C = \frac{°F - 32}{1.8}$$

$$°C = \frac{100 - 32}{1.8}$$

$$= \frac{68}{1.8}$$

$$\simeq 37.8\ °C$$

6-2 How Does a Thermometer Work?

Why do you have to shake down a fever thermometer?

The typical laboratory thermometer consists of a small quantity of mercury enclosed in a glass tube. Most of the mercury is in a bulb at the bottom of the thermometer. As the temperature rises or falls, the mercury expands or contracts, changing its level inside

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the stem of the thermometer. By having a very narrow bore in the stem, the movement of the level of the mercury in the stem is made quite large, even though the total change in the volume of the mercury is small.

In most thermometers the mercury level rises and falls in response to changes in temperature. But the fever thermometer is different. When a fever thermometer is removed from a patient's mouth, the temperature of the thermometer goes down. But the mercury level stays where it was. This is a useful property because it means that a doctor or nurse can put a thermometer aside, if need be, and read it later. It will still give the highest temperature it reached inside the patient's mouth.

The reason for this rather strange behavior is a very narrow constriction in the tube through which the mercury moves, located just above the bulb of the thermometer. When the mercury cools and contracts, the thin thread of mercury separates at this narrow point, leaving the mercury in the tube isolated from the bulb. Before the thermometer can be used again, the mercury must be shaken back down into the bulb.

What is the freezing point of water in the Celsius temperature scale? What is the boiling point of water in °C?

What is -40 °F in degrees Celsius?

How does one convert Celsius temperatures to Fahrenheit temperatures?

How is a fever thermometer different from other types of thermometers?

PROBLEM SET 6:

1. Convert 30 °C to degrees Fahrenheit.

2. Convert 67 °C to degrees Fahrenheit.

3. Convert 30 °F to degrees Celsius.

4. Convert 67 °F to degrees Celsius.

5. Average body temperature is 98.6 °F. What is average body temperature in degrees Celsius?

6. Room temperature is about 23 °C. How many degrees Fahrenheit is this?

7. What was the temperature in degrees Celsius of the ice and salt mixture that Fahrenheit used to design his temperature scale?

REVIEW SET 7:

1. Why do you think there is a need for a biomedical curriculum?

2. What is the difference between the mass of an object and the weight of an object?

3. In the making of measurements, what is the difference between accuracy and precision?

4. Give the basic units used by scientists for each of the following properties.

   a. mass

   b. length

   c. area

   d. volume

   e. temperature

5. What two measurements can be used to find the density of an object?

6. Which of the following prefixes would make the unit larger? Which would make the unit smaller?

   a. centi-

   b. kilo-

   c. micro-

   d. milli-

7. What is the meaning of each of the prefixes in Question 6?

8. Define specific gravity. What are the units for specific gravity?

9. All units of measurement are "arbitrary." What does this mean? (Hint: look up "arbitrary" in the dictionary.)

SECTION 8:

8-1 Tommy's Case Record--Age 0

John Young sat on a lumpy chair with a cup of cold coffee in one hand and an unlighted cigarette in the other, watching the sunrise through a little square window. His eyes burned and his scalp itched. His clothes were beginning to stick to him, and every time he moved, he started shaking. He wasn't cold. Just bone tired. And scared.

He knew this corridor, by now, like the back of his hand. He knew where the bathroom was, and the drinking fountain, and the snack bar. He'd tried every chair. He knew when the nurses changed shifts, and how many there were, and which ones did what, and who was in charge. He knew that the little old man who washed the floors had a slight limp, whistled silently between his teeth and gave great attention to the cleaning of doorknobs. He knew everything there was to know about the north wing of City Hospital, except for one little thing. He didn't know what was happening to his wife.

His elbow slipped off the arm of the chair and the coffee sloshed all over his hand and dripped on the carpet. Oh, well, he didn't need any more coffee anyway. He poured the rest of it into the base of the potted plant next to his chair and stood up. Time to walk up and down the hall again. His knees were stiff and he was light-headed. Things were beginning to tingle. He walked close to the wall, just in case. It had been a while since he'd stayed up all night.

It had even started out scary. The night before--it seemed like a week ago, now--he'd been fixing supper for Evette and himself when she made a funny little noise. He went in to see what was wrong. She was very pale.

"Just a little cramp," she said.

"It's not--you're not--I mean, are they--"

"No," she said, "I don't think so. I think labor pains are worse than that. Anyway, I'm not due for six weeks." She sat very still, with her hands resting on top of the great bulge the baby was making.

"Shall I call the doctor?" said John.

Evette shook her head "no." She sat still a moment longer, then got up and went into the bathroom. John stood there a moment, staring at the chair, before he smelled something burning. He hurried into the kitchen and turned off all the fires, then looked into each pot to see what was burning. Everything was burning. He was a hopeless cook.

He went back into the living room, and Evette was back in the chair. She looked scared.

"Everything all right?" he said.

Evette didn't answer for a moment, then she shook her head "no."

"There's a little blood," she said. "I don't know what it means, but I don't think there's supposed to be any--any blood. Maybe you'd better call the doctor."

So John had called the doctor, and the doctor had said they should meet him at the hospital right away.

At the hospital, the doctor had examined Evette and then said it looked like premature separation of the placenta. John had no idea what that meant, but the doctor explained it very clearly: the baby's pipeline was coming loose, and they would have to get him out of there. They would have to induce labor; the baby would be six weeks early.

That was hours ago. John supposed they had to work her over for a while and get everything ready before they induced labor, and then he supposed it would be a while before the baby was born. But it seemed to be taking an awfully long time. He walked up and down the corridor. When he came to one of the little square windows he would stop and look out at the lightening sky. Just as the sun peeped up over the horizon there had been a great burst of bird singing from somewhere. The traffic noise was beginning to pick up as the commuters started pouring into the city. Everything seemed to be going along normally, just as if nothing had happened.

"Mr. Young?"

It was a nurse. He turned around and looked for her. Couldn't see her. Maybe he was hearing things. No, there she was, sticking her head out a half-opened door.

"Would you like to see your son?"

A son! Thank heavens. He hated pink.

The nurse showed him into a little room with bright fluorescent lights on the ceiling and a row of fish tanks along one wall. The nurse led him over to one of the fish tanks and pointed at it. He was about to ask if this was her idea of a joke--he was in no mood to admire tropical fish--when he realized that what was in there wasn't a fish at all.

It looked horrible. Tiny and scrawny, with a head that looked too large. It was hardly anything but a skeleton. And it was blue. He stared at it for a moment. It must be alive, or they wouldn't have showed it to him. But it didn't seem to be moving. Then he looked a little closer and saw that it was breathing--not breathing very well, but breathing. And then all at once it gave a little kick and made an awful face. John Young stood up straight and smiled. Alive and kicking. He had a son.

"How's Evette?"

"She's fine," said the nurse. We've given her a sedative, she'll be asleep in a few minutes. Would you like to see her?"

"Of course I would," said John. What kind of a question was that, anyway?

The nurse showed him into another room with a lot of beds in it. One of them had a curtain around it, and inside was Evette. She didn't look a lot stronger than the baby just then, but he was awfully glad to see her. He took her hand and squeezed it, and she opened her eyes and smiled. They looked at each other for a moment, having a very long conversation without any words. Then she spoke.

"Did you see him?"

John tried to say "yes," but his voice didn't seem to be working. He nodded.

"Isn't he beautiful?" she said.

"Y--Yes," said John. Actually he was ugly, but of course he was beautiful too. "But why is he in that tank? Is he going to be all right?"

Evette nodded. Her eyes were closing. She patted his hand very gently.

"Don't worry," she said. "He's just a little early. He'll be all right."

"Do you still want to name him after your father?"

She nodded. Her eyes were closed.

"Okay, Thomas Arwen it is. Thomas Arwen Young. My son, Thomas Arwen Young."

Evette mumbled something John didn't quite catch. He bent down over her and said "Hm?"

"Our son," she said. "Our son, Thomas Arwen Young."

John straightened up and looked at his wife. She was asleep. He put her hand down, very gently, and stepped outside the curtain. The doctor was standing there at the foot of the bed, waiting for him.

"Why is he in that tank?" said John.

The doctor motioned him toward the door and back out into the waiting area in the corridor. They sat down.

"That little tank is an incubator," said the doctor. "We have to keep him in there for a few days because he wasn't ready to come out. There's really nothing to worry about. For a six-weeks premature baby, he's perfectly normal."

"What does it do? The tank. I mean the incubator."

"Well, the main thing it does is help him breathe. At his "age" --seven and a half months, I mean--his respiratory system isn't fully developed. His breathing equipment doesn't work too well. So we give him an atmosphere that's about 50 per cent oxygen, instead of 20 per cent, like the air. And we keep the humidity up so the mucus in his lungs won't get sticky and clog up the air passages."

"So it's to help him breathe."

"Yes. And to keep his temperature stable. That's another problem at his age--his regulation system isn't very good. If we kept the air at room temperature, his body temperature would go down. So we keep the air warm."

"How about food? Can he eat?"

"Probably not. That's another problem. His digestive system isn't ready to digest yet. And besides that he probably isn't strong enough to get anything out of a nipple. So for the first three or four days we'll feed him by injecting fluids right under the skin on his back. That will keep him going until he's strong enough to suck on a nipple, and then we'll put him on a formula."

"Well, I guess that just about covers it. One more thing, though--can I see him again?"

"Sure," said the doctor. He led John back into the room with the tanks--incubators--and John Young looked at Thomas Arwen Young. He was still blue, but more purplish now.

"Why is he that funny color?" said John.

"Lack of oxygen," said the doctor. "It affects the color of his blood. Like I said, he's having trouble breathing, and that's why he's in the incubator."

"How long will he have to stay in there?"

"Oh, not too long. We'll take him out to feed him and change him, of course, and in a few days we'll start to wean him from the incubator--cut down the oxygen percentage until it's the same as the percentage in the outside air. Usually doesn't take more than ten days. He'll be home in ten days to two weeks."

John took one more close look. Thomas Arwen Young was mighty small, not to mention purple, but the doctor didn't sound too worried. It looked like Tom would make it. No wait a minute. You can't call a baby Tom. Tommy would make it. That was better. Tommy Young. Not bad at all. Tommy Young, shortstop. Tom Young, manager. Thomas Young, Ph.D. Thomas Arwen Young, President of the United States!

"Well, doctor, take good care of the future president and his mother. I'm going home to get some sleep."

8-2 The Nature of Respiration

What is respiration?

Respiration is a process that is fundamental to life. On one level it is the process of getting gaseous substances into and out of the body. In a broader sense, the word is also used to refer to the chemical changes within our bodies that supply us with life-giving energy.

For human beings, respiration begins with drawing air into the lungs and ends with expelling a somewhat changed--and "polluted"--air out of the lungs.

The air in the lungs is a swarm of gas particles or molecules of several kinds. Some of these molecules dissolve in the body fluids that coat the lining of the lungs and pass through the lining into the blood stream.

The molecules that get into the blood are transported to the rest of the body, where they combine with other substances to give needed energy. Then some of the products of this process are transported by the blood back to the lungs, where they are expelled from the body in the breath.

This unit on respiration will be mostly concerned with how gases get from the atmosphere to your blood stream and back out again. Just how the body uses the gases it takes in and generates the gases it gives off are questions left for later units to answer.

The process of getting the right amounts of the right gases into and out of your blood is hardly a simple one. And it is a process that can easily go wrong at various points along the way.

8-3 The Air You Breathe In

How much oxygen does air provide?

The sea of gas that you live and breathe in is made up of a number of different gases. But around 98 per cent of it is just two gases--nitrogen and oxygen. And of these two only oxygen is essential to the body.

Oxygen is essential to almost all animal life. Many animals get it as you do, directly from the air. But many others, such as fish, get it from taking in water that contains dissolved oxygen.

The following table shows the composition of a sample of clean, unpolluted air on an ordinary sort of day. Values are for a temperature of 20 °C and a humidity of 50 per cent--that is, for air containing half as much water vapor as possible at that temperature.

THE COMPOSITION OF CLEAN AIR
(TEMPERATURE 20 °C, HUMIDITY 50%)

GAS	PERCENTAGE (of molecules)
nitrogen	77.2
oxygen	20.7
water vapor	1.2
carbon dioxide	0.03
other gases	0.9

Besides nitrogen, oxygen and water vapor, air contains a small but important amount of carbon dioxide, which is vital to plant life, plus a variety of other gases of no biological importance. Almost all of that component is argon gas.

The composition shown is in terms of the molecules (gas particles) in a sample of air. For example, in a sample of air containing 10,000 molecules you would expect about 7720 of them to be nitrogen, 2070 of them to be oxygen, 120 of them to be water vapor, a mere 3 to be carbon dioxide and 90 to be argon or any of several other gases normally found in air.

How are the two definitions of respiration related to one another?

Why is respiration essential to life?

What are four of the different gases that make up our air? Which two of them constitute about 98 per cent of our air? Which one is vital to almost all animal life?

What fraction of the air is oxygen?

Vocabulary:

respiration--1. The process of breathing. 2. The chemical changes within us that supply us with energy.

SECTION 9:

9-1 How Our Lungs Get Air

What makes air go in and out of our lungs?

Models are useful because they help us visualize an object and understand how it works. Space engineers build models of rockets to test in wind funnels and other devices. Although a model rocket could not get to the moon, the information gained from the tests may be used to get a real rocket to the moon.

A bell jar with a flexible diaphragm attached to the bottom, such as shown in Figure 1, is often used as a model to demonstrate how the lungs work. If you pull down on the rubber diaphragm at the bottom, the two balloons expand and air flows into them through the tube at the top. If you relax your hold on the diaphragm, it returns to its original position, the balloons collapse, and air flows out through the tube.

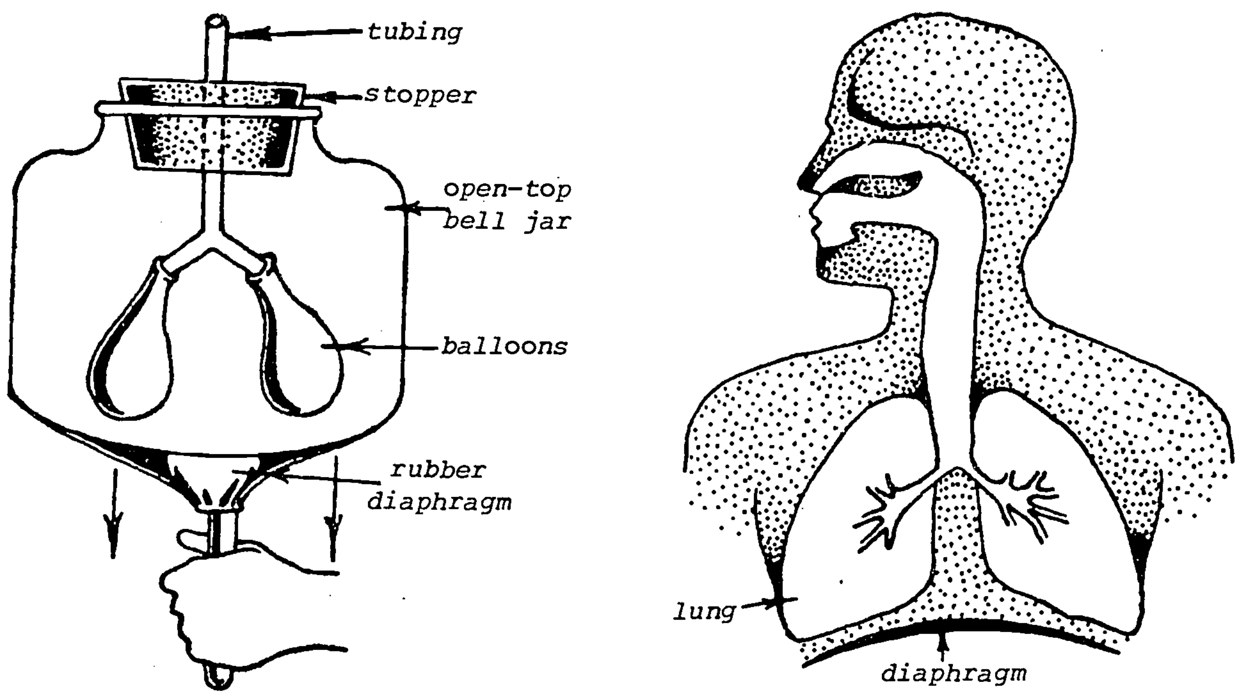


FIGURE 1: *A simple model of breathing action.*

The actual lungs are somewhat more complicated than the model, but their behavior is similar. Figure 2, on the following page, shows the main parts of the body involved in breathing. The lungs, like the balloons, are elastic and need to be made to expand. They are surrounded by a fluid (in the pleural spaces), just as in the model, though the fluid is a liquid rather than a gas, and there is a much, much smaller volume of it.

The lungs may be expanded by pulling down the diaphragm, which is a wall or partition between the chest cavity and the abdominal cavity. Contraction of some of the muscles attached to the diaphragm make it move downward. The lungs then expand to fill the larger volume made available.

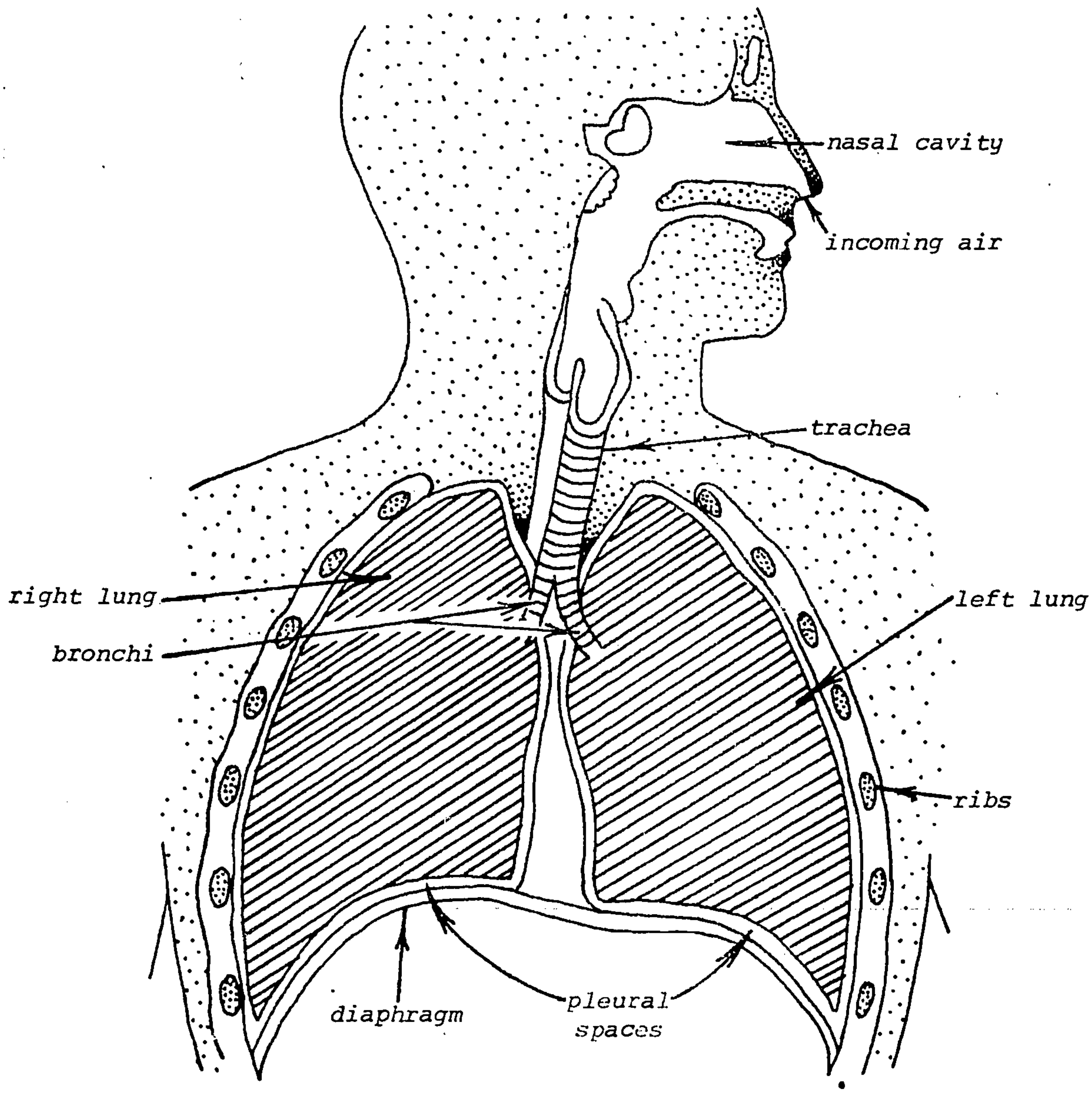


FIGURE 2: *Anatomy of the respiratory system.*

The lungs may also be expanded by enlarging the rib cage. Contracting some of the muscles connected to the ribs pulls them up and out, making a larger chest cavity into which the lungs will also expand. Unfortunately, the bell-jar model can't be used to demonstrate that action.

In normal relaxed breathing, both the diaphragm and the ribs participate. During each inspiration (the usual medical term for the inflow of air to the lungs), the muscles of the diaphragm and ribs contract. During each expiration, the muscles relax and the normal elasticity of the lungs causes them to deflate.

As in the bell-jar model, air enters and leaves the two lungs through separate passages. These are the bronchi (singular: bronchus). The bronchi join to form a common "windpipe" called the trachea.

The air passage between the trachea and the atmosphere also serves other functions: eating and drinking, talking and singing, smelling and tasting.

9-2 The Air You Breathe Out

How does your body change the air you breathe?

Several significant things happen to the air that you draw into your lungs. For one thing, it warms up to body temperature (normally 37 °C). Or if it's a very hot day, it cools down to body temperature. For another, the air becomes humidified. The surfaces of the lungs are moist, and the air drawn into them reaches approximately 100 per cent humidity (all it can hold). And naturally the air also loses some of its oxygen.

The lungs are usually thought of as the place where the body picks up oxygen. But they are just as much the place where the body gets rid of carbon dioxide. The human body cannot survive without the constant addition of oxygen to the bloodstream. But it also cannot survive without a constant removal of carbon dioxide from the bloodstream. The lungs are essential for both processes.

The table below shows how air changes in the lungs. The changes that occur depend partly on how long the air lingers in the lungs.

A COMPARISON OF INSPIRED AND EXPIRED AIR
(BASED ON CLEAN AIR AT 20 °C AND 50% HUMIDITY)

GAS	TYPICAL PERCENTAGES	
	Inspired	Expired
nitrogen	77.2	74.5
oxygen	20.7	13.1
water vapor	1.2	6.2
carbon dioxide	0.03	5.3
other gases	0.9	0.9

Because of the water vapor entering the air while it's in the body, more molecules are breathed out than are breathed in. This is the reason the nitrogen percentage is less in expired air--because it is a percentage of a larger total.

Part of the air you breathe never gets to your lungs. Some air gets no farther than the nasal cavity, mouth, throat, trachea, or bronchi, and so loses no oxygen and gains no carbon dioxide. What is shown in the table is the composition of expired air that has actually been in the lungs.

What are the two ways in which we can expand our lungs?

How does the diaphragm function?

What is a bronchus? The trachea?

Describe three ways in which expired air differs from inspired air.

Why do we breathe out more air than we breathe in?

Vocabulary:

bronchi (BRONK-ee)--the two tubes by which the lungs are connected to the trachea. (Singular: bronchus.)

diaphragm (DY-uh-fram)--the muscular wall separating the chest cavity and the abdominal cavity.

expiration (EK-spur-A-shun)--the process of breathing out or exhaling.

inspiration (IN-spur-A-shun)--the process of breathing in or inhaling.

trachea (TRAY-kee-uh)--the "windpipe," which divides at its lower end into the bronchi.

SECTION 10:

10-1 Tommy's Case Record--Age 3

John Young was driving home from work. He wasn't paying much attention to his driving. He didn't have to. He'd come this way too many times before. He could drive the whole distance clear across town, without noticing a thing. It was automatic.

That came in handy when he had a lot on his mind. And tonight he had a lot on his mind.

He was up for a raise, and he needed it. He had a wife and a son to support, and nothing was getting cheaper. He had a mortgage to pay off, payments to make, bills piling up. No question about it, he needed a raise. The question was whether he would get it.

But that wasn't the most important thing on his mind. The most important thing was Tommy, his son; Tommy was sick. It's frightening when a three-year-old child is sick, because he can't tell you what's wrong. He just suffers; it's up to you to figure out why.

He hadn't been sick that morning. He'd been fine. But earlier in the afternoon John had had a phone call from his wife, Evette, and she'd sounded worried. She must have been really worried. She never called him at work. She didn't want to get in the way.

The conversation had been running through John's mind ever since the phone call. He didn't expect to get any more out of it, but right now there was nothing else he could do but run through it again.

"Tommy's got a fever," she'd said. "A little over a hundred and four."

"When did it start?"

"Well, I don't know. Around noon he started getting fussy and acting like he didn't feel good. He was all hot and sweaty. You know, his neck was wet. So I took his temperature and it was a hundred and four. A little bit over."

"Well," said John, "if you think it's bad, maybe you'd better call the doctor."

Evette didn't say anything right away. When she did speak her voice sounded smaller.

We're four months overdue on the last bill," she said.

"Hmm," said John. Bills.

"Hmm," said John. Bills.

"Anyway," said Evette, "he'd just tell me to give him two baby aspirin and call back later if he didn't get better."

"Yeah, I guess he would," said John. It was an easy out. He was just as embarrassed about the bill as she was about mentioning it. Well, why don't you just give him two baby aspirin and see what happens?"

"Okay," said Evette.

"And call me back later if he doesn't get better."

"Okay. You ought to be a doctor." She sounded a little more cheerful. "Good-bye."

"Bye."

John found himself sitting in his car, parked in his own driveway, staring at the keys dangling from the ignition. When he got into the house, Evette gave him a kiss and a hug, and a smile.

"How is he?"

"Not bad," she said. "He's been coughing a little, but he seems a lot better." She hugged him again. "I guess I'm just a worrywart."

John went in and had a look for himself. Evette had given Tommy some soup and put him to bed early. He certainly didn't look healthy, but then he didn't look awfully sick either. He had a cough, but it wasn't bad. Maybe it was just a cold.

John and Evette had dinner. John talked about his day at the office and Evette talked about the neighbors. Nobody mentioned the raise, or the bills. Every once in a while Tommy would cough, and they would stop for a moment and listen. The cough seemed to be getting worse.

They watched a comedy show. It wasn't funny. When it was over they turned off the television and sat, listening.

Tommy was tossing around and coughing quite a bit now. John said he sounded like a hoarse beagle, but that wasn't funny either. They listened.

"I've never heard a cough like that," said Evette. She looked worried. She went in to check on Tommy. "He's hot," she said. "I think I'd better take his temperature again."

She went to get the thermometer. John heard the medicine chest open and close. Then he heard his wife say "Oops!"

"Oh, Honey," she said. "I broke it."

"Did you cut yourself?"

"No."

"Well, don't get mercury on you. It's poison."

They cleaned up the remains of the thermometer. Tommy kept coughing.

They gave him a couple more aspirin and sat down to wait for it to take effect. This time it didn't seem to work.

Tommy was sweating a lot now. The strange, barking cough was getting louder, and he was breathing fast. Evette was beginning to pace. John was getting worried, too. He looked at his watch. Ten o'clock. It was getting late, and whatever Tommy had, it wasn't a cold.

"I'm going to call the doctor," he said. "You go sit with Tommy. Maybe if you turn him on his stomach it will help." He dialed the number. "Dr. Jones' office." It was the answering service. "Doctor is not on call this evening. I'll have him call you as soon as possible." John hung up. He sat down to wait.

He was jolted out of the chair by a scream from the bedroom.

"John! He can hardly breathe! He's turning blue!"

John rushed into the bedroom. They bundled him up in a blanket, ran out to the car and jumped in. They didn't talk. They didn't have to. John drove with one hand on the horn.

At 10:30 he carried his nearly unconscious son into the emergency room of the hospital and laid him on the examination table. Evette ran around in circles, telling people that her son was dying.

A nurse came from somewhere. She looked like she knew what she was doing. She put a suction tube in Tommy's mouth and drew out some stringy-looking stuff. Then she put a mask over his face that filled with some kind of fog. Several times she put another mask over his mouth that forced air into him.

John saw all the machinery, but he wasn't watching it. He was watching his son's face.

After a few minutes, the face moved. The mouth opened and out came one of those hoarse-beagle barks. Tommy was breathing easy again. And so was his father.

10-2 Tommy's Trouble

What was the matter with Tommy?

Tommy, as you may have guessed from your own childhood experiences, had croup. The name "croup" comes from the sound made by the victim when he coughs.

Tommy's croupy cough gives a clue to the location of his problem. A closer look at the upper part of the respiratory system will reveal just where his trouble lay.

Figure 1 on the following page shows how air passes from the atmosphere to the trachea. It enters through the nose or the mouth and travels to the pharynx, a region at the back of the mouth that serves to carry food and drink as well as air. From there it passes into the larynx, an extension of the trachea, where our voice sounds are produced. The larger larynx in the deeper-voiced male has earned it the familiar name of Adam's apple.

The pharynx is connected to the larynx by a narrow opening called the glottis, which is rimmed by the vocal cords. Above the glottis is the epiglottis, a flap that may pull down to close the glottis. It normally closes during swallowing, keeping food or drink from going down "the wrong way" into the lungs. But occasionally something goes wrong. No doubt you've had the unpleasant experience of food entering the larynx. The natural response is to cough, which helps to clear the passage and let air through.

The clue to Tommy's distress lies in the fact that voice sounds are produced in the region that includes the glottis, the vocal cords and the larynx.

Croup is a condition that may have a number of different causes. Whatever the cause, croup involves inflammation and swelling in the larynx and epiglottis. In Tommy's case, the cause is infection by a bacterium called *Hemophilus influenzae*.

Tommy's body responded to the infection in four different ways.

1. The inflammation and swelling are a result of the defense procedures undertaken by the body to fight off infection.

2. The walls of the air passage are normally covered with mucus. During infection, the production of mucus is increased. The mucus serves to protect and lubricate the inflamed tissues and to carry off infected material.

3. Coughing serves to clear the air passage of the excess mucus and infected material.

4. Fever is a response to the infection that is thought to help kill bacteria, which are very sensitive to changes in temperature.

As you can see, all of the responses are involved in fighting off the infection. In Tommy's case, however, their combined effects led to a serious problem. The swelling and the excess mucus partially blocked the air passage. The fever increased his body's need for oxygen. Together, these factors caused Tommy's breathing rate to increase in order to get enough oxygen.

The increased air flow dried out the mucus until it became thick and stringy. It became harder and harder for Tommy to clear the thick mucus out of his throat by coughing. Eventually the flow of air was almost completely blocked, and Tommy began to turn blue from lack of oxygen.

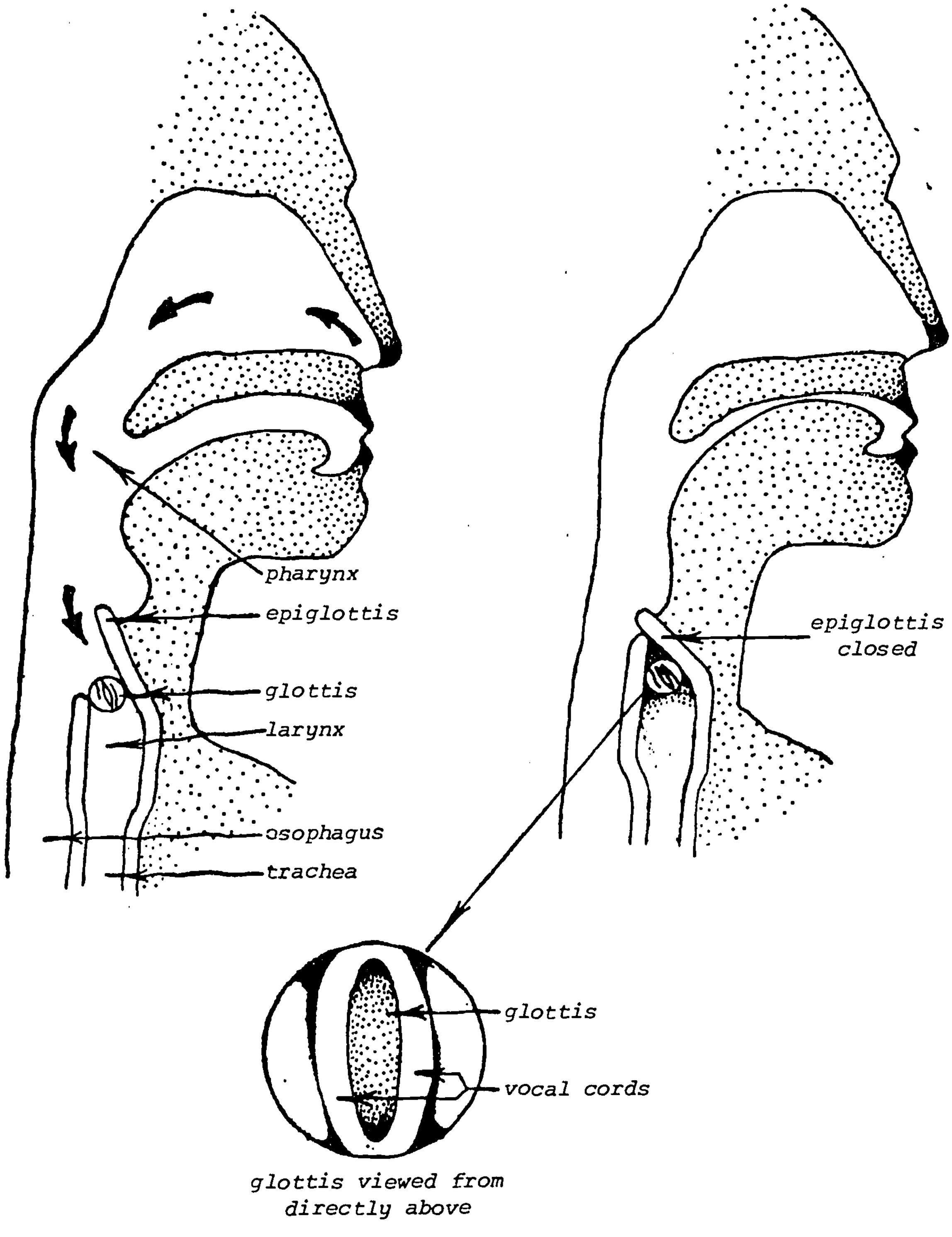


FIGURE 1: *Anatomy of the upper respiratory system.*

What would you do if your younger brother or sister, or a child you were taking care of, became sick with croup? Your first thought should be to prevent the mucus from drying out. A child with a croup cough should have a vaporizer working in his room. A hot shower is another good source of vapor. If the child is having difficulty breathing, immediate medical attention is necessary.

Aspirin is effective in reducing fever. However, aspirin, as well as other medications, should be given only on the advice of a qualified medical person.

At the hospital, three emergency procedures were used to relieve Tommy's distress. A suction tube was used to remove mucus. One mask provided air filled with water vapor to re-moisten Tommy's throat and prevent further drying of mucus. The second mask provided air at a somewhat higher pressure than normal to assist Tommy in his breathing.

If these procedures had not worked quickly, it would have become necessary to perform a tracheostomy. This consists of making a hole in the wall of the trachea below the larynx and inserting a breathing tube into the hole. By this means, the blocked region is bypassed. Breathing can be carried on quite satisfactorily through the tube. This procedure is often used when an object gets stuck in the throat.

Following whatever emergency procedures are necessary, bacterial croup is treated with antibiotics, which usually clear up the condition in a few days.

Tommy's croup was caused by bacteria, but croup may also be caused by <u>viruses</u>. Viral croup comes on more slowly and is not accompanied by a high fever. It is usually less severe than bacterial croup, but it may last for days because there is no specific treatment for it.

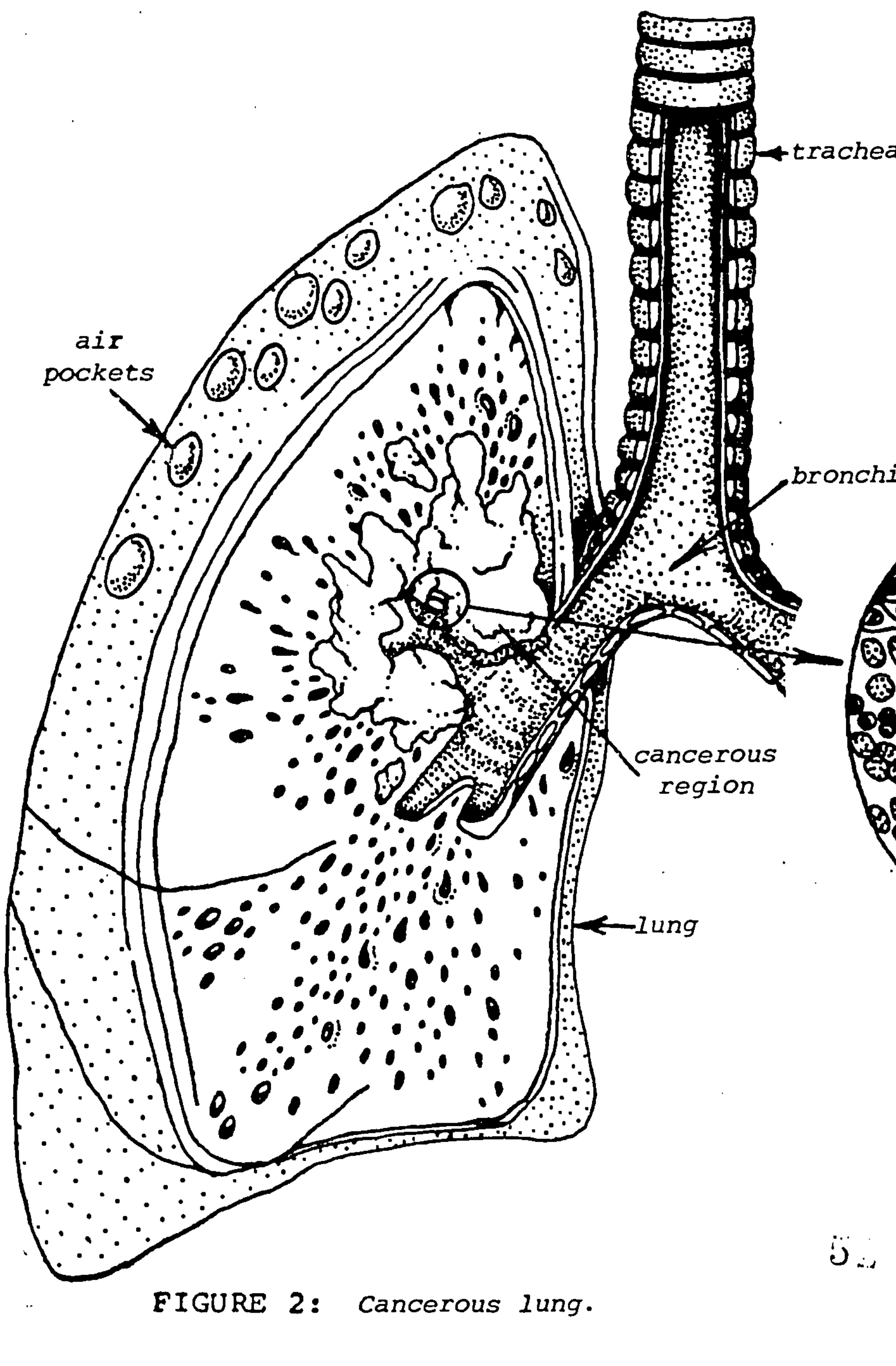
There is a special reason not to give aspirin for croup, except on a physician's advice. Giving a child aspirin may mask one of the symptoms (fever) the physician uses to distinguish between bacterial and viral croup.

10-3 From Organs to Cells

What are some of the different levels at which the human body is studied?

In any study of the human body and its diseases, one frequently runs into three important terms--organs, tissues, cells. Tommy's croup caused a swelling and inflammation in the larynx, an organ (see Figure 1). An organ is a part of the body that performs a specific function. You are already familiar with many organs such as the brain, the lungs and skin.

Organs may be studied at many different levels. In medicine it is often illuminating to peer at a sample of a diseased organ through a microscope to diagnose the disease. As an example, consider a cancerous lung (see Figure 2). To the naked eye, the lung might appear darker than a normal lung, the outer surface of the lung might show pockets of air and the bronchus might be partially or almost entirely blocked (Figure 2). Little more could be said about this lung unless a small piece is removed and studied with a microscope. In Figure 3, the region circled in Figure 2 has been enlarged approximately fifty-fold by microscopy. The experienced laboratory technician would recognize that this picture represents a very severe or late stage of cancer. The sample is almost filled with cancerous cells. In this particular case, the verdict would be a gloomy one--it would be too late for surgery.



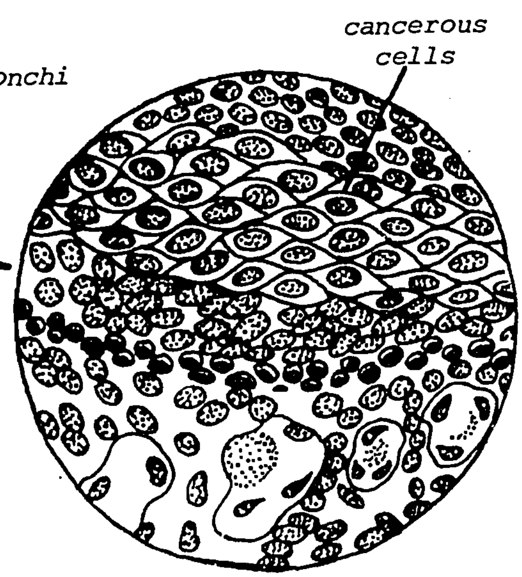


FIGURE 3: *Cancer cells.*

FIGURE 2: *Cancerous lung.*

The microscope has become a major tool in clinical medicine and much of microscopy is centered on observations of cells. Cells are the fundamental unit of life. They are the building block of every part of the body. We will study many kinds of cells in this course.

Between the cellular level and the organ level of study, there is another one, the tissue level. Cells very rarely exist as individuals in our bodies. They are generally found attached to similar cells. These groupings are called tissues and the cells in a tissue cooperate in performing a function. How then does a tissue differ from an organ? The answer is that tissues, like cells, are not loners in the body--different kinds of tissues are grouped together to form organs. The mixture of tissues in an organ allows the organ to perform more complex tasks than the separate parts.

We'll have much more to say about organs, tissues and cells in the Biomedical Science course. Perhaps the essential point to remember is that the medical scientist who investigates diseases is like a detective. The clues to the cause of a disease may be found at the organ or tissue or cell level or even at levels smaller than the cell. Another point to keep in mind is the relation of the organ or tissue to the individual. Organs are grouped together into organ systems. For example, the larynx and the lungs are part of the respiratory system. The brain and the nerves are part of the central nervous system. In the Biomedical Science course, we will typically study a new organ system in each unit. When we finish the study of all of these systems, we should have a good idea of the way a human organism works.

Can you place the following in correct order in terms of the flow of air from the outside in the direction of the lungs? Larynx, pharynx, bronchus, glottis, trachea, epiglottis.

What is the function of the epiglottis? The larynx?

Why does the sound of the cough in croup help to identify the site of the trouble?

Can you describe the events which can lead to breathing difficulty in a case of croup?

How can aspirin make it difficult to identify the cause of a case of croup?

Vocabulary:

croup (KROOP)--a condition characterized by a hoarse, barking cough, inflammation and swelling in the region of the larynx and epiglottis and increased production of mucus.

epiglottis (EP-uh-GLAH-tiss)--a flap that closes the glottis during swallowing.

glottis (GLAH-tiss)--a narrow opening near the top of the larynx.

larynx (LAIR-inks)--the portion of the air passage between the pharynx and the trachea, where voice sounds originate.

mucus (MEW-kus)--a slimy substance that serves to protect and lubricate the air passages and many other parts of the body.

pharynx (FAIR-inks)--the region at the back of the mouth, which carries food and drink as well as air.

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SECTION 11:

11-1 Bacterial Respiratory Diseases

What respiratory problems are caused by bacteria?

Tommy's croup was cuased by bacteria that have the scientific name of Hemophilus influenzae. Had he been invaded by bacteria called Hemophilus pertussis instead, he would also have suffered from a cough. But it would have been a "whooping" cough rather than a "croupy" cough. Whooping cough or pertussis is now seldom seen because of the common childhood DPT shots (combination shots for diptheria, pertussis, and tetanus).

These two Hemophilus bacteria are a good example of how scientists name organisms. The first part of the names (Hemophilus) indicates that both organisms belong to the same genus. That means they have quite a lot in common. Horses, asses, and zebras, for example, belong to one genus. So do lions, tigers, and leopards.

The second part of the scientific name of these two bacteria shows that despite their similarity, they are really different species. Like the lion and the leopard, or the zebra and the ass, they have definable differences.

The second part of the name of the croup bacterium illustrates an interesting feature of scientific names. Scientific names are rarely changed simply because they're inappropriate. The scientist who discovered and named that bacterium thought it was the cause of influenza. It isn't, but the name survives.

Several other bacteria may affect the upper respiratory system. Corynebacterium diphtheriae causes diphtheria, a disease in which an obstructing membrane is formed on the tonsils. The DPT shots already mentioned have largely eliminated it from common experience.

Also affecting the upper respiratory tract are various bacteria of the genus Streptococcus. These cause the painful "strep throat" that you may have experienced.

The lungs themselves may be affected by bacteria that go by the names of Diplococcus pneumoniae and Mycobacterium tuberculosis. As the scientific names suggest, the first of these causes pneumonia, the second TB.

Such bacterial infections, though still the cause of discomfort and occasionally death, are not the problem in this country they once were. Antibiotics such as penicillin cure most of them. And many can be avoided by getting the appropriate shots.

11-2 Viral Respiratory Diseases

What respiratory problems are caused by viruses?

Croup can be caused by a virus as well as by a bacterium. But though the cough sounds much the same, the disease is significantly different. Viral croup comes on more slowly, is less severe, causes little fever. Also, it can't be treated with antibiotics. Despite the common coughing symptom, it is obviously a different disease.

Actually, the difference between a bacterium and a virus is more striking than the difference in the diseases they may cause. Bacteria are one-cell organisms with a typical size of about 0.001 mm While a bacterium is microscopic, a virus is submicroscopic. This means that viruses are invisible in even high-power light microscopes Viruses require electron microscopes for viewing.

A more dramatic difference is their way of life. While some bacteria rely on a host for food to support life, a virus relies on its host for life itself. Until a virus enters a living cell, it is a quite lifeless assemblage of substances. But once inside a cell it may, in effect, come to life. The virus puts the cell's resources to work helping it to function, including reproducing more virus particles just like it.

We will return to bacteria and viruses later in the course, where they will be discussed in much more detail. But our main interest here is in the respiratory diseases they cause.

Just as viruses may cause a mild form of croup, they may cause a mild form of pneumonia as well. They may also cause respiratory diseases that have no bacterial counterparts: notably, the common cold and influenza.

Between them, viral respiratory diseases account for 60 to 80 per cent of school absences, as well as 30 to 50 per cent of work absences.

Probably the most serious viral respiratory disease, since it often reaches <u>epidemic</u> proportions with resulting deaths, is <u>influenza</u>. Often called "grippe" in other countries and "flu" in this one, it has been responsible for many worldwide epidemics--pandemics, as they are called.

11-3 <u>Influenza</u>

How do pandemics come about?

Influenza is primarily an infection of the respiratory system in the region of the trachea and bronchi. However, because of the weakening of the body's defenses, the primary infection may be followed by bacterial infection of the sinuses, ears, bronchi and lungs.

The most frequent initial symptoms are headache and muscular aches. The abrupt onset of fever and chills usually follows. Vomiting and diarrhea are rare, and there is no evidence that influenza viruses infect the digestive system. Influenza patients almost always have a cough and often a sore throat. Complete recovery takes from ten to fourteen days if no complications occur.

Antibiotics or other drugs have not been successful in treating influenza. Any chemical that inhibits the growth of the virus is also likely to damage the body's cells. The best treatment is taking aspirin for the pain and fever, drinking plenty of liquids and resting.

Influenza viruses pass directly from the respiratory system of one person to the respiratory system of another. It has been found that the crowding of people together is a major factor in flu epidemics.

Before 1889 influenza was uncommon in Europe, but in that year the first worldwide epidemic occurred. Since then such pandemics have become frequent. The pandemic of 1918 caused an estimated 20 to 40 million deaths, mostly from pneumonia that accompanied the influenza. Since then epidemics of influenza have been thoroughly studied.

You may have observed that every few years the country is threateded with a new kind of influenza. Asian flu, Hong Kong flu and London flu are recent examples. The specific name given to the influenza changes because the virus causing the disease changes with time.

A "disease of change" presents special problems to public health personnel. They must identify the new virus, determine when and where it occurs, how it is spread and who is susceptible. They must determine what vaccines must be developed and what other measures must be taken to prevent or limit epidemics.

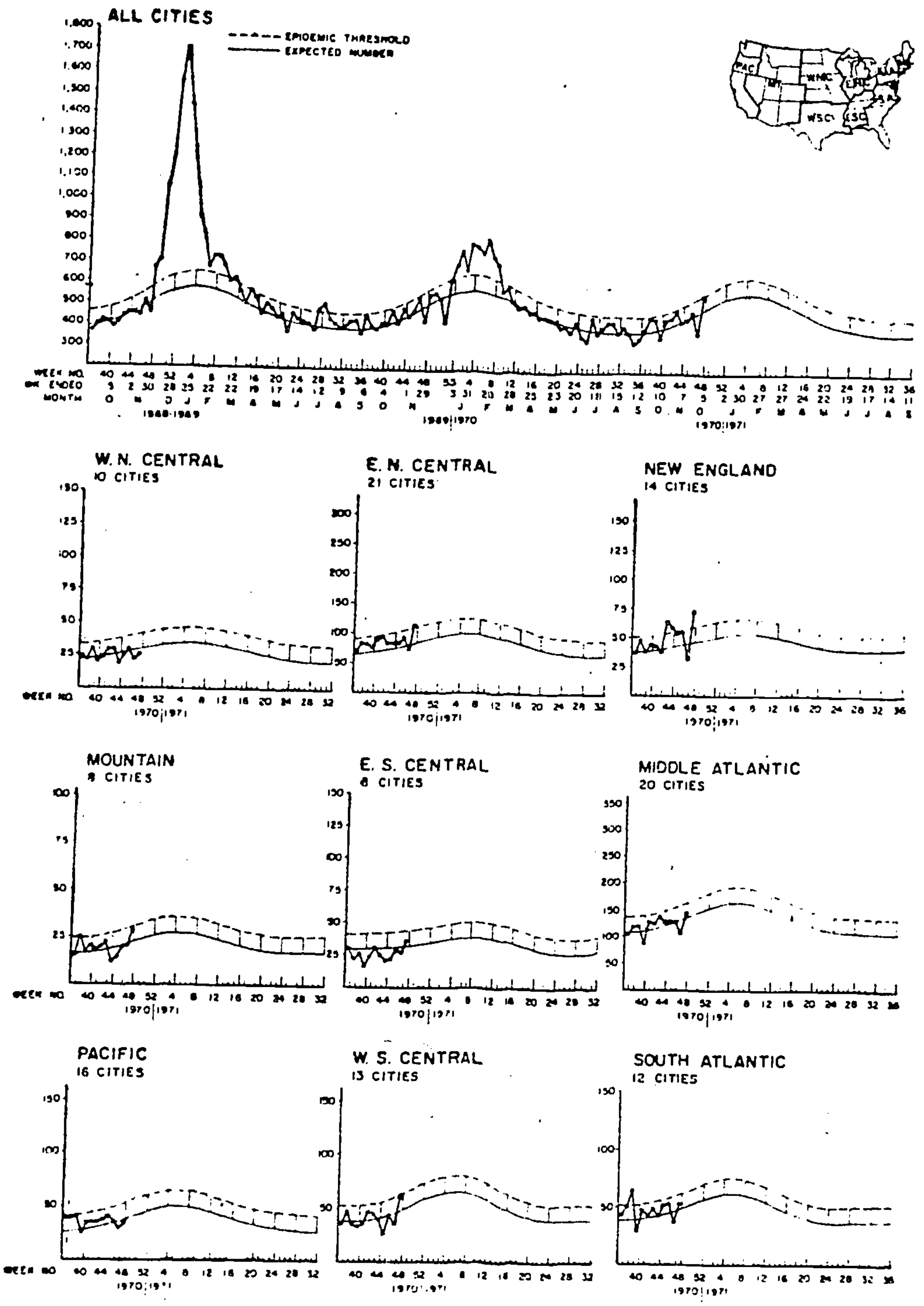
Public health workers are constantly surveying the occurrence and spread of influenza not only in the United States but throughout the world. From the data, predictions are made concerning the type of influenza and the number of people that will be affected. Typical data are shown in the graphs on the next page, which were compiled in December 1970.

The graphs are labeled pneumonia-influenza deaths, since the deaths were a result of pneumonia that developed in the lungs of influenza sufferers. Presumably the secondary infection would not have occurred or would not have had such consequences without the primary influenza infection.

Notice the two wavy lines on each graph. The lower solid line gives the expected number of deaths for each week during the year if no epidemic occurs. The upper, dashed line is called the epidemic threshold, because if the number of deaths rises above this line it is likely to mean the start of an epidemic. The two wavy lines represent predictions based on information collected in previous years.

The jagged line on each graph shows the actual number of deaths reported each week. The first graph shows the number of deaths reported from September of 1968 through November of 1970. Note that the epidemic threshold was first exceeded in December of 1968. In the following weeks a major epidemic occurred. This was the first

PNEUMONIA-INFLUENZA DEATHS IN 122 UNITED STATES CITIES



From Influenza-Respiratory Disease Surveillance, Report No. 86, U.S. Dept. of Health, Education and Welfare, 1970.

outbreak of Hong Kong flu in this country. In July of 1969 the dashed line was again exceeded. This time, however, no epidemic followed. A second, less severe epidemic occurred between January and March of 1970. Look at the end of the jagged line at the end of November 1970. Is a new epidemic about to begin? Reports for the next week or two should give the answer.

We can take a closer look at the situation by examining the graphs for different sections of the country. The graph for New England, in particular, looks suspicious. Has a new influenza virus entered the country at some New England port or airfield? Again, only data for the next week or two will tell. If such is the case, we might expect the number of deaths to rise rapidly--first in New England and within a few weeks in other areas as the disease spreads across the country.

What good are all these statistics? How do they help prevent the spread of influenza? Public health surveys are necessary to determine what specific kind of virus is likely to be spreading and where. If a new type of virus is suspected, immediate steps must be taken to isolate the virus and to prepare a vaccine to combat it.

A "flu shot" is an inoculation with a vaccine containing influenza viruses. The vaccine has been produced in a chick embryo and made inactive either by chemicals or ultraviolet radiation. Because a "shot" protects a person for only about one year, protection of all the population is not feasible. However, the vaccine is specifically recommended for three groups: people whose services are essential to the community, such as physicians and nurses; people whose health is such that a battle with influenza could be fatal; and groups of people who live in close contact and are particularly susceptible to epidemics. Examples of the latter are those living in boarding schools and other institutions, and military camps.

Name four respiratory diseases caused by bacteria. Name four that are cause by viruses.

Give two differences between bacteria and viruses.

How is influenza transmitted? Why is it called a "disease of change?"

What are the symptoms of influenza?

How is influenza related to pneumonia deaths?

Vocabulary:

epidemic--a widespread outbreak of a disease in a community or larger area.

influenza--a viral respiratory disease characterized by headache and muscular aches, coughing and fever.

REVIEW SET 12:

1. What kinds of problems does a premature infant have in his fight for survival? How are these problems treated?

2. What are the differences between viral and bacterial croup in cause, symptoms and treatment?

3. Trace a breath of air as it is inspired. Name all the structures in proper sequence that it will pass after entering the nose.

4. Compare and contrast inspiration and expiration. Include changes in the volume of the chest cavity and lungs, changes in muscle movement and changes in the air being breathed in or out.

5. We can study the functional parts of our bodies on at least three different levels. Name the different levels and tell how each is related to the others.

6. What is air?

7. Describe the job of public health workers in watching the occurrence and spread of a contagious disease. In what ways is the job they perform important to you and your family and friends?

SECTION 13:

13-1 Tommy's Case Record--Age 14

"Runners take your mark!" commanded the starter.

Tommy's heart pounded with excitement as he waited for the gun that would start the race. The quarter-mile sprinters from Kennedy Junior High were the best in the league. It was not going to be easy to finish in the first three. Tommy pressed his toe a little harder against the starting block. A fast start could make the difference.

"Runners get set!"

It was the next to the last meet of the season, and Tommy needed three more points to earn his first varsity letter. A second-place finish would do it; but in this race, even finishing third would take his best effort of the season. He promised himself that no matter what happened, he would push himself as hard as he could.

The starting gun cracked.

Before Tommy realized the gun had sounded he was ten yards down the track. He had his good start.

The sprinters moved swiftly around the first turn in the oval track. Tommy tried to pace himself, but the two lead runners from Kennedy were setting a very fast pace. He couldn't afford to let up and lose ground.

Around the back stretch Tommy still remained three strides behind the two lead runners. They weren't letting up either.

By the time they reached the last turn Tommy had closed the gap to one stride. A strong dash at the finish might do it. His heart was pounding, and his breath was coming short and fast.

They flew around the last turn and into the stretch for the tape. Now it was all or nothing. Tommy broke his pace and started his dash to overtake the leaders. His heart beat violently, and every time he took a breath it felt as if his chest would explode.

He was now in second place, but there were still twenty yards to the finish line. Every time he gasped for breath the pain in his chest was more intense. Ten more yards to go. He couldn't quit now.

Tommy reached the finish line a stride ahead of the next runner, but two strides behind the winner. He was disappointed, but mostly he was worried about the tightness in his chest and the way he was gasping for breath. He had never had these problems before--but then he had pushed himself harder today than he'd ever done before.

Several moments went by before he realized his teammates were slapping him on the back and congratulating him for his second-place finish.

13-2 Pressure

What is the difference between force and pressure?

Tommy's problem, simply stated, was pressure. It began with the "pressure" of the race. But the real problem was a pressure that developed inside his body and gave him the intense chest pains.

To understand Tommy's problem, you need to understand just what pressure is and does. You probably know something about pressure already. It's what you measure when you inflate the tires on a car or bicycle. Knowing just that is actually quite useful to an understanding of pressure.

When air molecules strike the inside of a tire, they exert force on the tire. They also exert pressure on the tire. Water exerts force on a diver. It also exerts pressure on the diver.

Force and pressure are related concepts, but they are not the same thing. Pressure is defined as the ratio of the force exerted to the area over which the force is distributed. In mathematical language,

$$P = \frac{F}{A}$$

An example will illustrate the difference between force and pressure. Support a heavy book on your fingertips. The force exerted by the book on your fingertips is equal to its weight. The pressure is this force divided by the area of your fingertips. Now hold the book on the palm of your hand. The force exerted by the book on your hand is equal to the weight of the book. The area over which the force is distributed is the area of your palm. The pressure exerted by the book is therefore its weight divided by the area of your palm.

In the one case:

$$\text{pressure on fingertips} = \frac{\text{weight of book}}{\text{area of fingertips}}$$

In the other case:

$$\text{pressure on palm} = \frac{\text{weight of book}}{\text{area of palm}}$$

The weight of the book is of course the same in each case. However, the pressure on your fingertips is greater than the pressure on your palm, because the area of your fingertips is less than the area of your palm. Can you feel the difference?

Consider now a situation in which the area remains constant but the force changes. Support one book on your fingertips; then support two books on your fingertips. The pressure on your fingertips is greater when supporting two books.

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When supporting one book:

$$\text{pressure} = \frac{\text{weight of one book}}{\text{area of fingertips}}$$

When supporting two books:

$$\text{pressure} = \frac{\text{weight of two books}}{\text{area of fingertips}}$$

Just as a length or an area or a volume must be expressed in some units, pressure also must be expressed in units. The units of pressure come from the equation

$$p = \frac{F}{A}$$

Although the kilogram is properly a unit of mass, it is often used informally as a unit of weight or force. Area is given in units such as square centimeters. Force divided by area is therefore in the units kilograms per square centimeter. Since the units on the right side of an equation must agree with the units on the left side, one set of units in which pressure can be expressed is kg/sq cm.

EXAMPLE:

A 2-kg block of ice is supported by a pedestal with a cross-sectional area of 8 sq cm. What is the pressure on the pedestal?

SOLUTION:

$$P = \frac{F}{A}$$

$$P = \frac{2 \text{ kg}}{8 \text{ sq cm}}$$

$$P = \frac{1}{4} \frac{\text{kg}}{\text{sq cm}} \text{ or } .25 \text{ kg/sq cm}$$

A unit of pressure with which you may be more familiar is the British unit of pounds per square inch, or lb/sq in. Another example will illustrate the use of this unit.

EXAMPLE:

An individual weighs 200 lb. The combined area of the palms of both his hands is 25 sq in. What is the pressure that his hands exert on the floor when he is doing a handstand?

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SOLUTION:

$$P = \frac{F}{A}$$

$$P = \frac{200\ \text{lb}}{25\ \text{sq in}}$$

$$P = 8\ \text{lb/sq in}$$

EXAMPLE:

200 lb is approximately 91 kg, and 25 sq in is about 161 sq cm. Repeat the preceding example, expressing the pressure in units of kg/sq cm.

SOLUTION:

$$P = \frac{F}{A}$$

$$P \simeq \frac{91\ \text{kg}}{161\ \text{sq cm}}$$

$$P \simeq .565\ \text{kg/sq cm}$$

These last two examples show the importance of including units in the answer. An answer of "8" or ".565" would be meaningless.

Figure 2 shows two cylinders of the same material sitting on a flat surface. One is twice as heavy as the other. It exerts twice as much force on the surface. But the pressure it exerts is the same. The force is twice as much, but so is the area. Therefore, the force per unit area--that is, the force divided by the area--is unchanged.

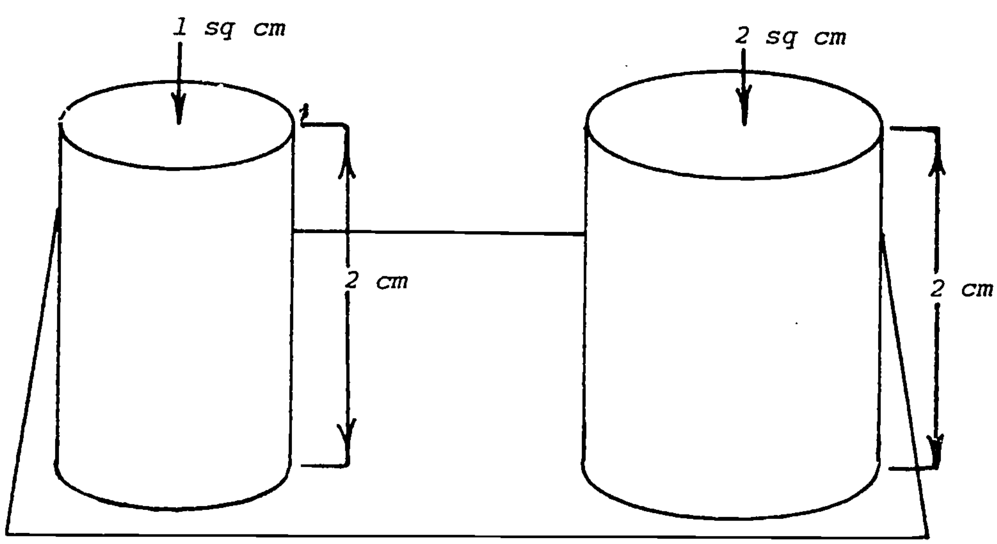

FIGURE 2: *Objects that give the same pressure.*

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The cylinder on the left exerts a pressure of $\frac{100\ g}{1\ sq\ cm}$ = 100 g/sq cm, and the pressure on the right is $\frac{200\ g}{2\ sq\ cm}$ = 100 g/sq cm.

All of our examples have ignored the fact that the air around us already has a pressure. For the moment, that fact may safely be ignored. Atmospheric air can be thought to have a pressure of zero. Or to put it another way, all pressures discussed here are measured relative to the atmospheric pressure. Just as the mean elevation of the sea is often taken as zero in measuring elevations, so the pressure of the atmosphere is often taken as zero in measuring pressures.

13-3 Pressure in a Fluid

How is the pressure determined at the bottom of a fluid?

Before we return to Tommy's problem during his race, it is necessary to discuss the pressure of fluids and also how pressure is measured.

Pressure exists inside a substance as well as on its surface. A square centimeter inside an object may push on an adjacent square centimeter of the same object, just as a square centimeter on the surface may push on some other object.

The internal pressure may be determined as in the following example. Figure 3 shows the vertical forces acting on a cylinder of a substance. The substance might be solid, liquid, or gas. The object rests upon something that provides an upward supporting force F. If it is a liquid or a gas, it also must be supported on the sides by a container or by more of the substance so it doesn't flow sideways. If a gas, it also needs to be confined at the top so it won't flow upward. In this example, the pressure on the top of the cylinder is taken to be zero.

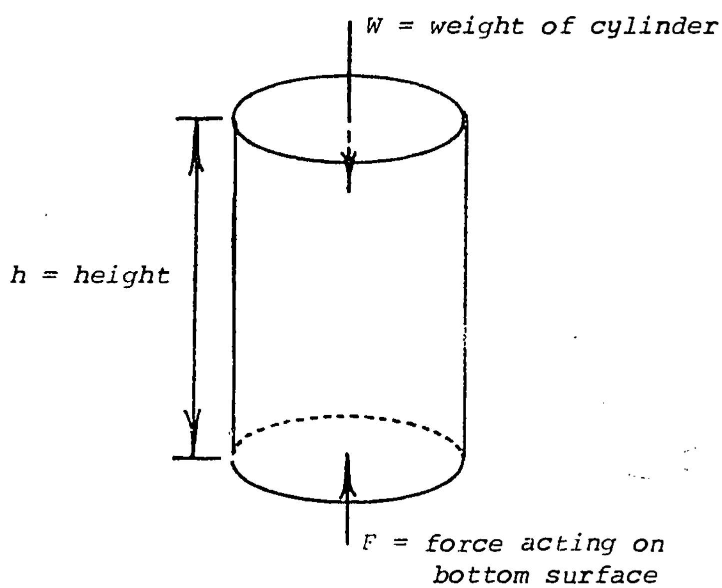

FIGURE 3: *The vertical forces on a cylinder.*

We can find the volume of the cylinder by multiplying its height, h, by the area of its base, A.

$$V = Ah$$

The density, D, of the cylinder can be expressed as its weight, W, divided by its volume, V. (Notice that this is a weight density, instead of a mass density.)

$$D = \frac{W}{V}$$

Multiplying both sides by V, we have

$$VD = \frac{\cancel{V}W}{\cancel{V}} \quad \text{or} \quad VD = W$$

Since V = Ah, we can substitute Ah for V.

$$AhD = W$$

The pressure, p, at the bottom of the cylinder is

$$p = \frac{F}{A}$$

The force, F, must just balance the weight, W. Therefore F = W and

$$p = \frac{W}{A}$$

But we found earlier that

$$W = AhD$$

Making one last substitution,

$$p = \frac{AhD}{A}$$

$$p = hD$$

So the pressure may be found merely by multiplying the height by the density. The pressure doesn't depend on the area, A, of the cylinder.

If the substance is a fluid--either liquid or gas--the same pressure acts in any direction. The horizontal pressure at the bottom of the cylinder, for example, is also hD.

An example will show how these ideas can be used. In Figure 4, on the next page, a flask of water is connected to a tube containing mercury. What depth of mercury is needed to keep the water from flowing out of the flask and into the tube?

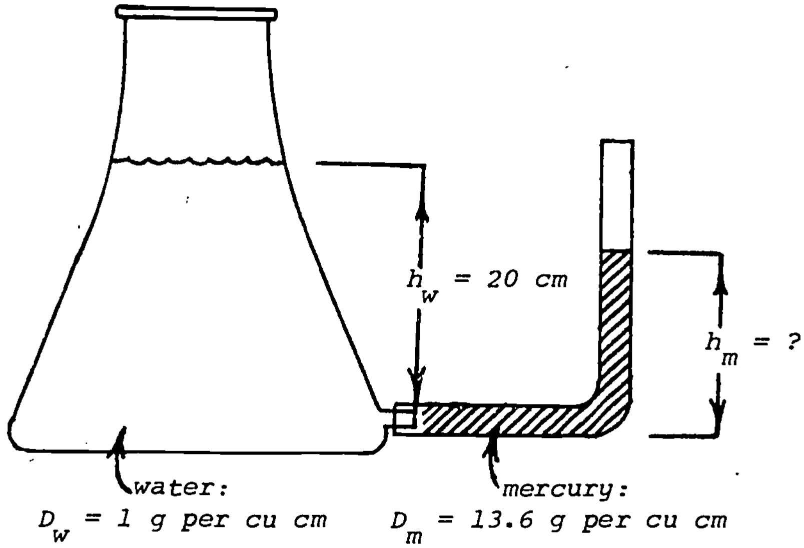

FIGURE 4: *A balance of pressures.*

The pressure at a depth of h_w in the water is $p = h_w D_w = 20 \times 1 =$ 20 g per sq cm.

The pressure at a depth of h_m in the mercury is $p = h_m D_m = h_m \times 13.6$. These two pressures must be the same or liquid will flow one way or the other:

$$h_m \times 13.6 = 20$$

or

$$h_m = \frac{20}{13.6} \simeq 1.47 \text{ cm}$$

It is important to notice that the shape and size of the containers for both the water and the mercury don't matter. In a stationary liquid, the only thing that affects pressure is the density and the depth--plus the pressure at the surface.

13-4 Measuring Pressure

How are pressures measured in biomedicine?

The relation of pressure to height in a liquid makes it easy to develop a pressure-measuring device. A U-tube partly filled with a liquid of known density is all that is needed. The height difference, h, in the U-tube of Figure 5 on the next page tells what the pressure, p, is provided that the density, D, of the fluid is known.

If the pressure at level A in the right leg of the U-tube of Figure 5 is taken as zero, the pressure at level B is

$$p = hD$$

But that same pressure exists at level B in the left leg of the U-tube. And the pressure there is the gas pressure that is being measured. Therefore, that simple relationship gives the gas pressure.

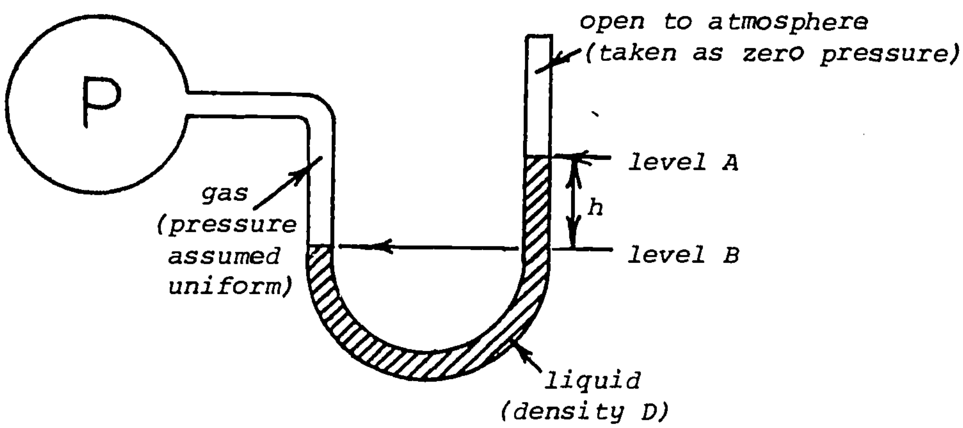

FIGURE 5: *Measuring pressure with a U-tube.*

As an example, if the height difference is 5 cm and the liquid in the U-tube is mercury with a density of 13.6 g per cu cm, the gas pressure is

$$p = 5 \times 13.6 = 68.0 \text{ g per sq cm}$$

Although pressure may be expressed in this way as grams of force per square centimeter of area, it is more common in medical practice to express it directly in terms of the height difference of mercury in a U-tube. The pressure in the example might be expressed as "5 cm of Hg," (Hg being the chemical symbol for mercury).

More commonly, though, the pressure in the example would be expressed in millimeter units as "50 mm of Hg." This pressure unit, a millimeter of mercury, is so commonly used that it has been given a name: the torr (after a man named Torricelli). It is the unit in which blood pressure, along with many other pressures, is expressed.

The general term for a pressure-measuring instrument is manometer. If used to measure blood pressure, such a device is called a sphygmomanometer.

Explain the difference between force and pressure.

How is the pressure affected by an increase in the force contributing to it?

How is the pressure affected by an increase in the area over which it is distributed?

How is the pressure found at the bottom of a liquid of known density?

How is a U-tube manometer used to measure pressure?

Explain the meaning of a pressure of 100 torrs.

Vocabulary:

manometer (muh-NAHM-uh-ter)--a device used to measure pressure.

pressure--the ratio of the force exerted to the area over which it is distributed.

sphygmomanometer (SFIG-mo-muh-NAHM-uh-ter)--a device used to measure blood pressure.

torr (TORE)--a pressure unit equivalent to the pressure exerted by a column of mercury one millimeter in height.

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SECTION 14:

14-1 Where Air and Blood Meet

What caused Tommy's chest pain?

The pain that Tommy felt during the race came from a pressure inside his chest. But it wasn't, as one might guess, the pressure of the air being moved so forcefully in and out of his lungs. To discover just what it was requires a closer look at what goes on in that part of the body.

As you may recall, air enters each lung through a tube called a bronchus. But that's only the start. Each bronchus divides into many small tubes called bronchioles. The many branches of the bronchioles finally end in clusters of air sacs (see Figure 1 on the next page).

The air sacs are not really the end, though. From the walls of the air sacs protrude tiny chambers called alveoli (singular: alveolus). It is through the alveoli that oxygen leaves the lungs and carbon dioxide enters. A pair of human lungs contains on the order of 300 million alveoli.

But there's more subdividing going on inside the chest than in the air passages. A similar amount of subdividing occurs in passages carrying blood to the lungs.

The blood system of the lungs is called the pulmonary circulation. As much as one-fourth of the blood supply of the body may be found in pulmonary vessels.

Blood is supplied to the lungs through the pulmonary artery. The lower right side of the heart, which is called the right ventricle, pumps blood into the pulmonary artery. The pulmonary artery divides into two branches, one of which goes to each lung. These arteries in turn branch into smaller arteries, which lead to nets of small capillaries which surround each alveolus. It is here that oxygen enters the bloodstream and carbon dioxide leaves it. The pulmonary capillaries are so numerous that the combined length of those in one human body is hundreds of kilometers.

The blood which has received oxygen returns to the heart by passing from the capillaries to small veins. The small veins converge to larger veins, which eventually join to form the pulmonary vein. The pulmonary vein returns the oxygenated blood to the heart.

The pulmonary vessels are easily stretched, up to a certain point. The average adult heart pumps about four to five liters of blood per minute. If the heart output increases, the pressure in the pulmonary blood vessels rises. But the vessels then stretch, providing a larger flow passage. Because the vessels stretch easily, arterial pressure increases only slightly.

When something is stretched, we say that it is distended. When the heart output is about 16 liters per minute, or four times normal,

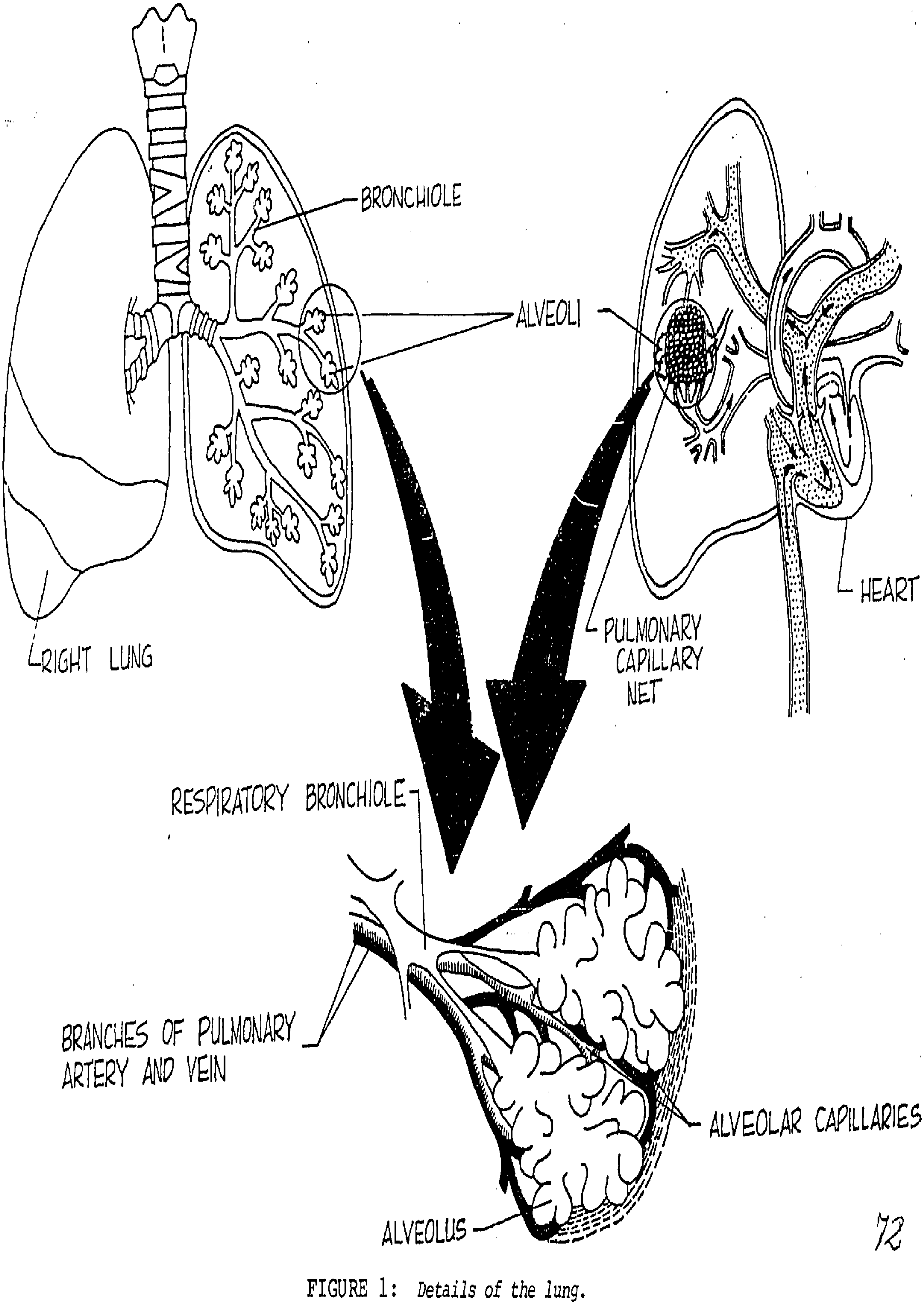


FIGURE 1: *Details of the lung.*

the pulmonary vessels are fully distended. Since they cannot stretch further, if the heart output increases much beyond that, arterial pressure increases greatly.

The increase in pressure is shown in Figure 2. The graph gives pulmonary arterial pressure as a function of the volume of blood put out by the heart.

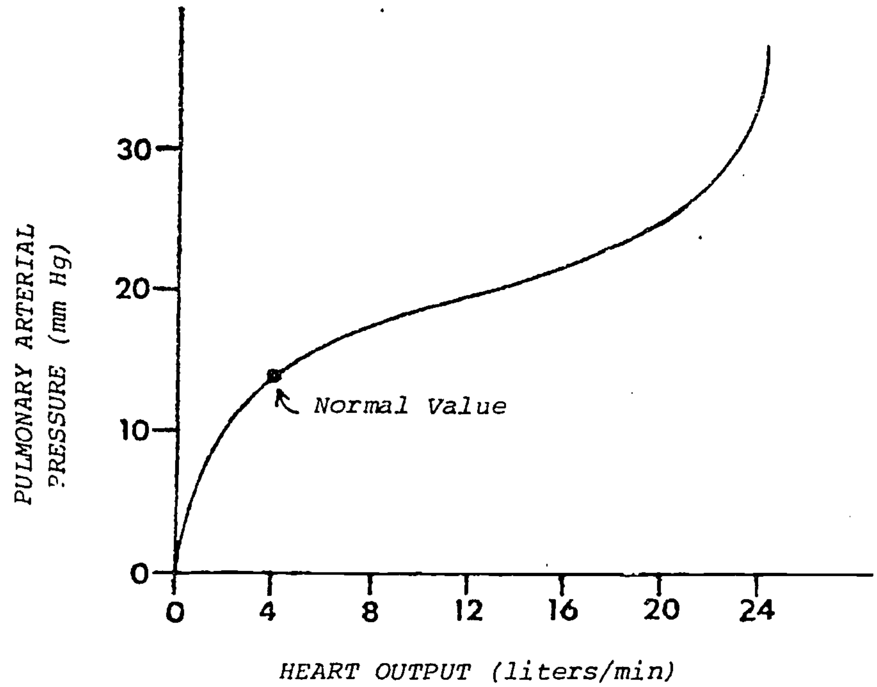


FIGURE 2: *Pulmonary blood pressure.*

The scale used for pressure on the graph represents millimeters of mercury above atmospheric pressure. The graph is relatively flat in the domain between 4 and 16 liters of blood per minute. In the domain beyond 20 liters per minute, pressure increases rapidly as heart output increases. This is reflected in the slope of the graph, which becomes increasingly great.

Like the pulmonary vessels, your skin stretches easily up to a certain point. Beyond that point the skin offers greater resistance, and further stretching is painful. When the pulmonary arteries are fully distended, increased blood flow causes increased pressure and pain for the same reason.

This explains the pain felt by Tommy in his chest. Tommy's heart was beating rapidly during the race. As he approached the finish line and needed an extra effort to win, his heart output exceeded the amount his pulmonary vessels could comfortably accommodate. The pain was caused by the increasing pressure within these vessels.

If Tommy had ignored the pain and pushed himself even further he would have been in danger of suffering a very serious distress called pulmonary edema. Pulmonary edema occurs when the blood pressure is so high that the fluid portion of the blood begins to be forced out of the capillaries and into the alveoli. Fluid accumulating in the air sacs of the lungs cuts down the surface area through which oxygen or carbon dioxide can pass and has serious consequences if widespread.

14-2 Aerobic Capacity

How is our use of oxygen related to physical fitness?

How vigorously your heart must pump when you do a particular job is generally considered an indication of your physical fitness. The fact that Tommy's heart had to work very hard, giving excessive pulmonary pressure, suggests that he may not have been in the best of shape.

Medical scientists have generally agreed that a good measure of physical fitness is the maximum rate at which a subject can use oxygen. If the subject engages in as strenuous an activity as he is capable of, the amount of oxygen taken in through his lungs and utilized in supporting his muscular exertions shows how well his body has been tuned to such a task. The body of a well-conditioned athlete is capable of using oxygen much more rapidly than the body of an ordinary person.

The maximum rate at which a person can use oxygen is called his aerobic capacity. It is usually measured in liters per minute and may vary from less than two to over six.

In comparing individuals, the best guide to fitness is the aerobic capacity per unit of body weight. A person weighing fifty kilograms will have an aerobic capacity half that of an equally fit person weighing one hundred kilograms.

Medical scientists have discovered that a good measure of aerobic capacity can be obtained without demanding an all-out effort from the subject. The pulse rate attained during less than maximal exertion is rather closely related to aerobic capacity. For example, an athlete with a large aerobic capacity can jog along with a slow-beating heart supplying plenty of oxygen to his muscles, while the heart of his untrained friend jogging beside him pounds hart in its effort to keep the oxygen coming.

Several tests have been developed that use treadmills or bicycles or other exercisers to provide a standard amount of exertion. The general idea is to exercise the subject at a particular "work rate" and discover what happens to his pulse.

One version makes use of a "step test." The subject steps up onto a stool and then back down to the floor at a specified rate. After a specified time--about five minutes--the subject's pulse rate is measured. From the work rate and the pulse rate, the subject's aerobic capacity can be estimated rather accurately.

The work rate in a step test depends on several factors. First it depends on how heavy you are. It is twice as much work for a 100-kg person to raise his weight to the elevation of the step as for a 50-kg person. Then it depends on how high the step is. It's twice as much work to step up a height of 40 cm as to step up 20 cm. Finally it depends on how often you repeat the process. It is twice as hard to step up 20 times a minute as 10 times a minute.

From this it would appear that the product of the subject's weight, the step height, and the steps per unit time would give a measure of the work rate of the subject. In fact, that product would give exactly the work rate (or power) involved in raising the subject's weight that high that often.

The relationship between work rate and pulse rate depends somewhat on sex. An adult male and an adult female with the same fitness (the same aerobic capacity per kilogram) doing the same amount of work in the same time will usually not exhibit the same pulse rate. In comparable situations, the pulse rate of the female is greater.

How do the bronchi, bronchioles and alveoli differ from one another?

What two anatomical structures are involved in the transfer of gases between the lungs and the bloodstream?

Explain the reason for Tommy's distress at the end of his race.

What might have happened to Tommy if he had pushed himself even harder? Why?

Why must body weight be taken into consideration when a person's physical fitness is determined from a step test?

Vocabulary:

aerobic capacity (air-OBE-ik)--the maximum rate at which a person can use oxygen.

alveoli (al-VE-uh-ly)--the smallest chambers of the lung, through which gases enter and leave the bloodstream. Singular: alveolus (al-VE-uh-lus).

bronchiole (BRONG-key-ole)--one of the small tubes into which the bronchi divide.

capillary (KAP-ih-LAIR-e)--the smallest of the blood vessels. In the lungs, the site at which gases are exchanged between the bloodstream and the lungs.

pulmonary (PULL-muh-NAIR-e)--pertaining to the lungs.

pulmonary circulation--the blood system of the lungs.

pulmonary edema (uh-DEE-muh)--a condition in which fluids from the blood are forced out of the capillaries and into the alveoli as a result of excessive blood pressure.

SECTION 15:

15-1 Tom's Case Record--Age 16

Tom stretched out his legs on the back seat and stared out the rear window at the receding scenery. The road wasn't getting any steeper, but the car seemed to be slowing down.

"Step on it," he said. "I don't want to sleep in this heap tonight."

"Don't distract the driver," said John from the front seat. "If he piles it into a tree we'll all have to sleep on the pavement."

"Okay, okay," said Tom. He didn't want to think about piling it into a tree.

"Got to take it slow," said Tim, the driver. "You saw the Lincoln we just passed with the hood up, didn't you? That guy standing there scratching his head? That's known as vapor lock. Happens when you overheat the engine at high altitudes."

"Give us a lecture about it," said Tom. John laughed, and Tim shut up about vapor lock. Tom leaned back again to watch the scenery.

The three of them were on their way to climb a mountain. Mt. Whitney. The top of it is higher than anything else in the U.S. outside of Alaska. From what Tom had heard the trail was rocky but not difficult, and the view from the top was worth everything you had to go through to get to it.

None of the three had spent much time on high mountains, but they all liked the outdoors. Tim had just finished his junior year of high school, and he'd said all he really wanted to do was get as far away from the place as he possibly could. The top of a mountain seemed like a good place to go. John, the oldest of the three, had just graduated. He was an athlete. A real one. He'd received a football scholarship to the University. He wanted to keep in shape.

Tom still had two years of high school to go. He was taking two weeks off and then planned to look for a summer job. The first three days of it were gone--counting the weekend--and he was anxious to get out of the car and hit the trail. But Tim's car wasn't at all in a hurry. These last two miles of the road were over a mile and a half high, and the old beast was really getting sluggish.

Finally they made it to road's end at Whitney Portal, over 8,000 feet above sea level. They piled out of the car and unloaded their packs and locked it up. The high, clear air was exhilarating, and it had been a long ride. In a few minutes they had shouldered their packs and were on their way up the first steep stretch of the trail. Just before they got out of sight of the car, Tim stopped and looked back at it.

"Don't tell me," said Tom. "You forgot your girlfriend's picture."

"Nah. I was just thinking. I wish somebody would steal the old wreck so I could collect on it. I should have left it unlocked."

The first overnight camping spot was about four miles--and four hours--from the trailhead, but nobody was bothered. The trail was no sweat. There were a lot of people on the trail. After that first steep half-mile their route joined the stock trail, and soon they passed two large groups, each with several burros. When they were out of earshot of the second group Tom looked back over his shoulder at the pack train and laughed.

"What have they got in there?" he said. "Lawn furniture?"

"Booze," said Tim. "They're climbing the mountain to get high."

"They're just American tourists," said John. "They think they're getting away from it all, but they ain't. They're taking it with them."

The three turned back up the trail and started off again. It seemed to Tom that they weren't moving quite as fast. As they ground out the miles they had to slow down even more. There were some steep places in the trail, and their packs weren't getting any lighter. By the time they came in sight of Mirror Lake, where they were going to spend the night, those tourists with the burros didn't seem funny at all.

"Somebody [illegible]d rent burros *here*," said Tim. "They'd make a killing."

When it was almost dark they found a campsite that was far enough off the main trail so they wouldn't get stepped on if they slept past dawn. They spent an hour or so setting up camp and then sat down to eat, but when it came to actually getting the food down they all discovered that they weren't hungry. Tom ate a few crackers and some cheese, but it made him feel a little nauseated. By this time it was almost ten o'clock, and he was glad to crawl into his bag and stretch out.

But he couldn't go to sleep. He'd been up since dawn, and he ached in places where he didn't even know he had muscles, but after an hour he was still wide awake. The ground under his bag must have been the hardest substance known to man, and also the bumpiest. The stars were bright. His nose was cold. He saw a shooting star.

"There goes another one," said John in the dark. "That's three."

"Four," said Tim. "There was one way down over there by that tree."

Nobody else was sleeping either.

They lay there watching the stars in silence. Once in a while somebody would roll over and grope around under his bag and then throw the offending rock into the bushes. Finally, about two o'clock, Tom fell into a fitful sleep.

When he woke up he could tell by the sun that the morning was half gone. He could hear people out on the trail, early risers already on their way. He propped himself up on his elbows to look at his fellow outdoorsmen. Tim heard him moving around and opened one eye, then closed it again. John rolled over and sat up, still in his bag.

"Can either of you guys cook?" he said.

"I made toast once," said Tim without opening his eyes.

"You're hired. Get up and make breakfast."

"Ain't got a toaster."

"Well, improvise. I'm starving."

Tom got out of his bag and into his clothes as fast as he could. He went over to the water bucket to wash his face and discovered that the water was covered by a thin sheet of ice. He broke through it and got ready to splash some of the freezing water on his face. It took him a couple of minutes to get ready. When he finally felt up to washing with the stuff it took his breath away, but when he was finished there was no doubt that he was awake.

The three of them ate a big breakfast and then sat down to study the map and plan their hike for the day. They had come four miles--and climbed over 2000 feet--on their first day. The next camping spot was only two miles away, but it was another 1500 feet up. Considering how tired they'd been at the end of the first day, they decided that was enough for the second. That would leave the third day for a climb of four miles and almost 2500 feet to the top of California. They broke camp, made up their packs and hit the trail.

Before long Tom was definitely short of breath. The going was a lot harder up here than it had been down at the trailhead, 2,000 feet lower. They had climbed above the timberline now, so there wasn't even any shade. Several times Tom had to stop and rest. After a few minutes he would get his breath back and they would continue on up the trail.

By the time they reached their base camp, 12,000 feet up, Tom was walking very slowly to keep from breathing too hard and to keep his heart from pounding. He had never been so glad to see a flat place on the ground that was six feet long and three feet wide.

They quickly made camp and got supper out of the way. It wasn't very late, but they were exhausted, and they turned in immediately. This time Tom thought he would drop right off for sure, but he didn't, and neither did the others. It was last night all over again, only this time with a little wind to make it colder.

The second morning on the trail was colder than the first, but the sun warmed the thin, clear air quickly. Tom was first out of the sack, and he felt great. He cooked breakfast in silent protest against Tim's performance at the skillet the previous morning, and within an hour after they got up they were on the summit trail.

At first they made good time--they'd left their packs at the base camp and just brought food for lunch--but as they went on the trail got steeper, and there was still no shade anywhere. Everybody slowed down, but Tom was the slowest of all. They had to stop and let him catch his breath every ten minutes or so.

"Wouldn't happen if you'd cut out the coffin nails," said John.

"I only smoke about ten a day," said Tom.

"Yeah, right down to the filter. I guess ten a day is all it takes."

After lunch the three were sitting around, digesting, and two men--both with hair graying at the temples--came swiftly up the trail.

"How is it at the top?" one of them asked Tim.

"Don't know. We're still on our way up."

"We want to be sure we don't miss anything along the way," said John, with a pointed look at Tom.

"Well. Maybe we'll see you up there." The two men went on up the trail at the same fast pace and were soon out of sight.

"How do you like that?" said Tim. "Those guys are at least twice our age. Let's catch 'em."

"Sure," said Tom. "You first."

They hit the trail again, but Tom was clearly holding them back. He had to stop and rest too often. After two miles of steady climbing they came to a half-mile of downhill trail. At the bottom of that was the junction with the John Muir Trail, and from there it was two miles--and almost 1000 feet--to the summit.

Tom sat down at the side of the trail. He coughed a little. He'd been coughing at the last few rest stops. John looked at him.

"You don't look too good, my boy. Getting a bit pale."

"Don't feel too good, either," said Tom. He did feel a little sick.

"Hey!" said Tim. "Look at his lips!"

"Turning blue," said John.

Tom thought about getting up and continuing on the trail. He decided against it.

"Listen," he said, "you guys go on without me. I'll stay here and wait for the bus."

"That ain't funny," said John. "You gonna be all right?"

"Just as long as I don't have to climb that mountain," said Tom, "I'll be fine. Go on. I got water and the leftovers from lunch. After I rest here a little bit I'll just go back down to the base camp. Go on."

"Well, okay," said Tim. "Don't run off now, you hear? I got the map."

"Keep it. I'm not going anywhere except back down that trail, and when I see my own sweet bag I solemnly promise to collapse on it."

"All right. See you."

Tim and John went on up the trail. Tom rested a while longer and then got up and started back toward the base camp. Going downhill wasn't much easier than going up. He still had to stop and catch his breath every few minutes.

Finally he made it back to camp. He unrolled his bag and lay down on it for a while, then propped himself up against his pack and sat there, staring up the trail, waiting for the others to come back.

After a few minutes he felt pretty good, and it seemed silly that he had been afraid to try for the top of the mountain. But then he remembered the way he'd felt up there, coughing and wheezing on that mountainside, and he decided that he hadn't really been afraid. He just hadn't been able to go any farther.

15-2 Hypoxia

Tom's problem, as you may have guessed, was that his body wasn't getting enough oxygen. The process of moving the oxygen molecules from the atmosphere about him to the cells within his body where they were needed wasn't working well enough.

The condition of oxygen deficiency is given the name hypoxia. (The prefix "hypo-" means less than normal or too little; "-ox-" is short for oxygen; the suffix "-ia" means condition.)

The effects of hypoxia are many. Hypoxia causes mental and bodily fatigue, loss of appetite and drowsiness. It may cause headaches and nausea, and occasionally a feeling of euphoria. Other important effects are a partial loss of memory and a decreased ability to perform tasks requiring motor coordination.

Hypoxia may come about in several ways. It may be caused by the increased use of oxygen by the cells. This occurs, for example, during vigorous exercise. Or hypoxia may occur because the respiratory and circulatory systems are unable to supply the normal amount of oxygen. This may be caused by a variety of conditions, some of which you have studied. Hypoxia may also be caused by insufficient oxygen in the air.

15-3 The Air at High Altitudes

How is the air different at high altitudes?

The start of Tom's problem was in the air he breathed. It was a different gas from what he was used to breathing at low elevations. But how was it different, and how did its difference affect Tom's respiration?

One way it wasn't different was in composition--unless, perhaps, it was less polluted. Of the two principal components of air, the oxygen molecules are about 14 per cent heavier than the nitrogen molecules. So you might expect to find a smaller percentage of the heavier oxygen molecules at higher elevations. And you do, if you go high enough--a matter of dozens of miles above the earth's surface. But at the elevation of Mt. Whitney--or even Mt. Everest--the difference wouldn't be detected.

One feature of the air that was somewhat different was its temperature. That was surely lower than the temperature at low elevation. But temperatures such as Tom and his friends experienced on Whitney are not uncommon at low elevations. The difference in temperature, if it mattered at all, was hardly significant.

But another difference in the air--its pressure--was significant. We live in a sea of air. If we're at the bottom of the sea, the pressure is higher than if we're at "shallower" locations. At the top of Mt. Whitney the pressure is about three-fifths as much as at sea level. That decrease in pressure was the important difference as far as Tom was concerned.

15-4 Differences in Substances

How are solids, liquids and gases different in their properties?

If you dive to a lower elevation in a swimming pool, the pressure goes up, just as when you go to a lower elevation in the atmosphere. In fact, diving seven feet under the surface is like coming down from an elevation of over six thousand feet, as far as pressure change is concerned. But if the water is well mixed, the temperature is not noticeably warmer at the lower elevation, as it is at lower elevations in a well-mixed atmosphere. And the number of molecules of water in a unit volume is only the smallest bit greater, as compared to the atmosphere, where the number increases substantially as you go to lower elevations.

Clearly a liquid such as water and a gas such as air behave quite differently in some ways. In a liquid the molecules are crowded together. They might be likened to a cluster of sticky marbles. They can move over and around each other--in other words, they can flow. But if you try to push them closer together, they resist. By raising or lowering the pressure, you may change the volume a liquid occupies a little. Unless the liquid changes into a gas, you can't change the volume much.

Changing the temperature of a liquid also has a relatively small effect on its volume. If the liquid is cooled, the molecules usually crowd closer together, though occasionally they may spread out. In any event, the change isn't usually dramatic.

With enough cooling, a dramatic change does occur, though not in volume. The liquid changes to a solid. Typically the molecules line up in regular patterns called crystals and no longer are able to flow. Ice is a solid that forms from a liquid as crystals. The temperature at which it forms is the freezing point.

Some liquids never crystallize in this way. Instead, as the liquid is cooled the molecules become less and less able to flow and eventually just stop without forming any regular arrangement. Solids of that sort are often called "glasses." As you might guess, ordinary window glass is such a solid. You can't really talk about the freezing point of a glass. The point at which it stops being a liquid and starts being a solid is hard to decide.

When liquids are heated instead of cooled, the molecules usually spread out a little and become more fluid. But again, the changes aren't dramatic--until the boiling point is reached. Then the liquid changes into a gas.

The most noticeable difference between a liquid and a gas is in the distance between the molecules. In the usual liquid the molecules are clustered together. In the usual gas they are far apart. For this reason, the same number of molecules of a substance usually need a volume hundreds of times as large when they form a gas as when they form a liquid. A gram of liquid water at the boiling point has a volume of about one cubic centimeter. As steam, it occupies a volume of about one and two-thirds liters--some 1,600 times as much. This means that the molecules in the gas are nearly 12 times as far apart as in the liquid.

Besides having a much larger volume because of the much larger distance between molecules, gases also have a much more variable volume. In a liquid, where molecules are elbow to elbow, it's hard to push them closer. In a gas with lots of free space between molecules, it's much easier.

15-5 Pressure in a Gas

What causes a gas to exert a pressure?

The reason that the molecules of a gas stay apart is that they keep bouncing off each other. Gases can be treated as if they were swarms of marbles charging this way and that, continually striking one another and rebounding with a new direction and a new speed. If not held together by a container, such a collection of rebounding "marbles" would spread out indefinitely. The "stickiness" observed in a liquid is overpowered by the liveliness of the molecular motion.

The molecules of a gas move fast and collide often. In ordinary air, the typical molecule travels about half a kilometer per second but collides with another molecule (or the container wall) after traveling a few millionths of a centimeter.

The collisions with the continer wall explain the pressure a gas exerts. Each molecule that bounces off a wall exerts a little force of its own. The little forces of the many molecules that continually bombard any wall add up to the total force that acts on the wall. Figure 1 shows a highly magnified picture of what goes on at a wall.

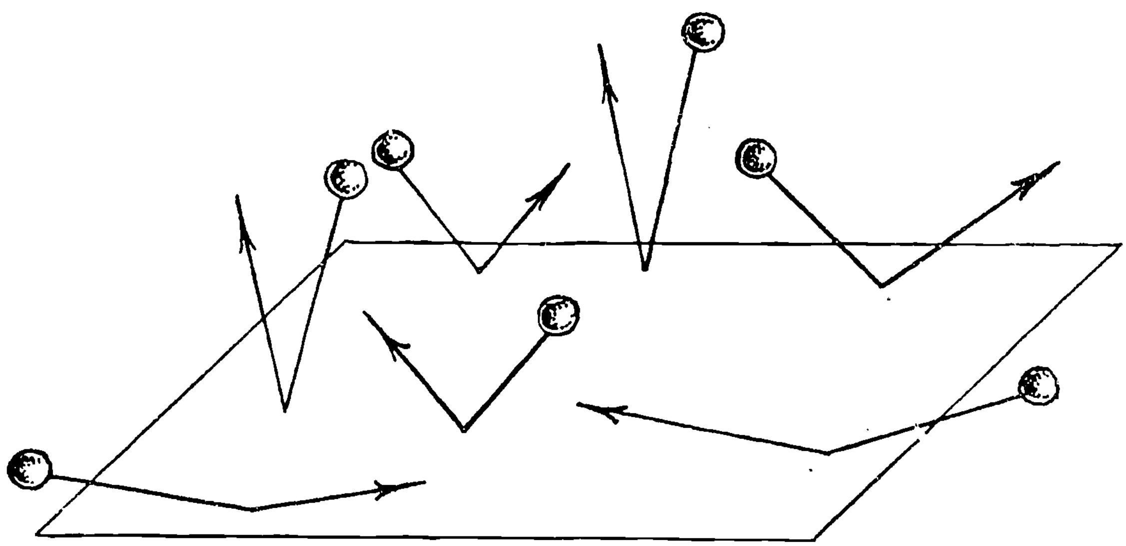
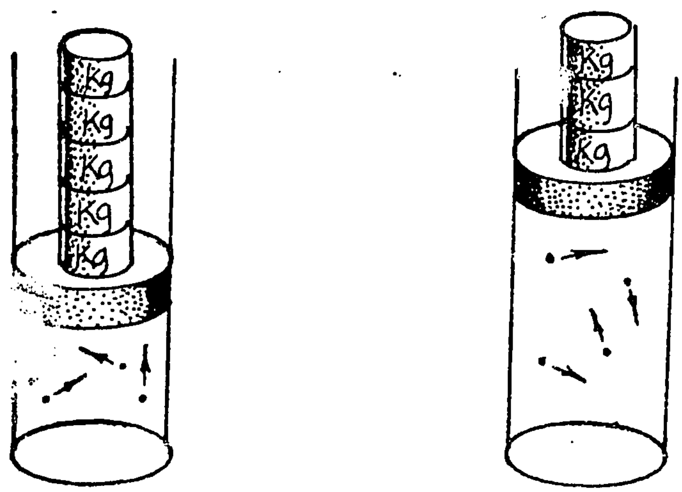


FIGURE 1: *Bouncing molecules give pressure.*

From this picture of a gas, it becomes evident what must happen when its pressure is lowered, as on the top of Mt. Whitney. The left side of Figure 2 on the next page shows a volume of gas at the pressure it might have at sea level. (A few sample molecules are shown, appearing much larger and moving much farther than they really do.) The atmosphere above the gas bears down with a force represented by the kilogram weights.

The right side of Figure 2 shows the same sample of gas at the elevation of Mt. Whitney. Less atmosphere now lies above it, and the force it must bear is less.



pressure at sea level

pressure on Mt. Whitney

FIGURE 2: *The effect of pressure.*

As indicated, what happens is that the plunger moves upward until the pressure in the sample drops to the value needed to support the lighter load. With more room for the gas, the molecules are farther apart and strike the plunger less often. The pressure on the plunger is therefore lower.

So the effect of the reduced pressure on the top of Mt. Whitney is to spread the molecules of air out--to make the air thinner. But there's more than a change of pressure to consider.

15-6 Temperature in a Gas

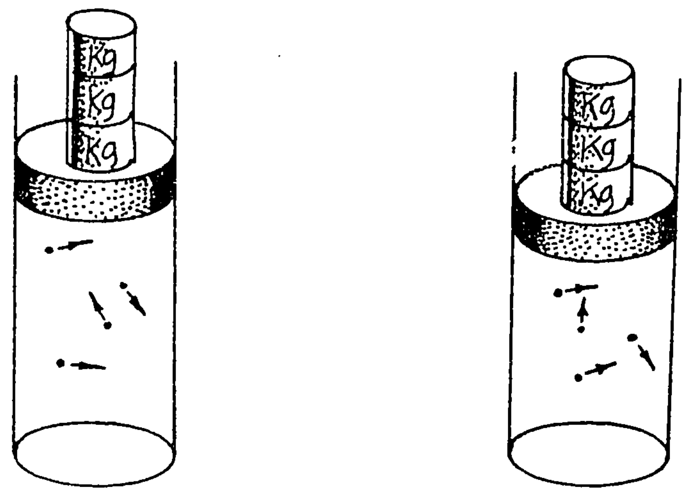
How does temperature affect the volume of a gas?

When the temperature of a substance is raised--whether solid, liquid, or gas--the activity of the molecules ordinarily increases. In fact, temperature is nothing more than a measure of molecular activity. In a solid, the molecules or other particles that make it up are bound together so that they can't move far (unless they leave the solid entirely). But they can quiver or vibrate more energetically as the temperature is raised. In a liquid, the molecules can move about, and do so more quickly as the temperature goes up.

In a gas the molecules are even freer to move, and their movement is more responsive to temperature. Every rise in temperature makes their movement more rapid.

Because it so strongly affects the motion of the molecules, the temperature can have a strong influence on the pressure or the volume of a gas. If a particular volume of gas is heated, the molecules in it speed up and therefore strike the walls of the container harder. If the volume doesn't change, the pressure will go up. To keep the pressure from rising, the volume of the gas would have to be increased.

These ideas can be applied to the air on Mt. Whitney, where the temperature is lower than at sea level. In figuring the change in volume of the sample in Figure 2, it was assumed that the temperature didn't change. But now suppose the sample having the pressure on Mt. Whitney is cooled to the temperature on Mt. Whitney. Figure 3 shows the change.



temperature at sea level　　*temperature on Whitney*

FIGURE 3: *The effect of temperature.*

Lowering the temperature lowers the average speed of the molecules. They strike the plunger less vigorously. The plunger therefore drops until the molecules strike it more often, again providing the necessary pressure.

So the effect of the lower temperature on the top of Mt. Whitney is the opposite of the lower pressure. It tends to increase the air density--to make the molecules closer together.

Was this a help to poor Tom? Actually not. As air is drawn into the body, it very rapidly warms to body temperature. The amount of air Tom could draw into his lungs per breath depended on the pressure of the atmosphere around him, but on his <u>own</u> temperature.

These relationships can be investigated in the laboratory. From the data produced, a mathematical expression can be developed that relates all three properties of a gas--temperature, pressure and volume.

What is the general term used to describe a condition of insufficient oxygen?

How many different possible reasons for hypoxia can you list?

What are some of the effects of hypoxia?

Describe three differences in the air at sea level and the air on top of Mt. Whitney.

Compare a solid, a liquid and a gas in terms of molecular motion and the distance between molecules.

What is temperature a measure of?

Vocabulary:

hypoxia (hy-POK-see-uh)--the condition of oxygen deficiency.

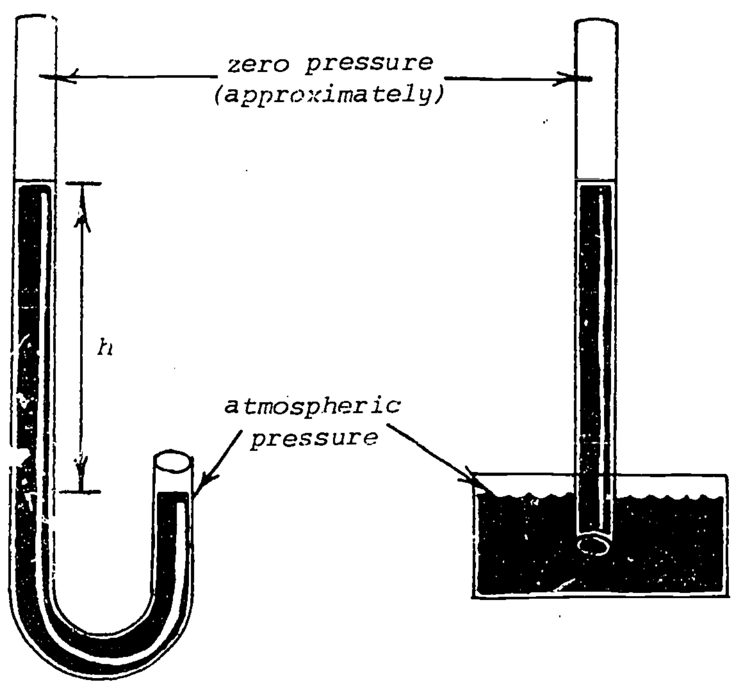
SECTION 16:

16-1 The Pressure of the Atmosphere

How is atmospheric pressure measured?

The pressure of the atmosphere can be measured in much the same way as any other pressure. All that's needed is a manometer in which one leg is subjected to a zero pressure--that is, a perfect vacuum. The figure below shows two such manometers. The lefthand one looks more like the usual liquid-in-glass manometer but is not the sort commonly used. In the righthand one, the atmospheric leg of the manometer is given a large surface area so that its level won't change much as the liquid moves up and down in the tube. The manometer difference, h, can then be determined from the position of the liquid surface in the tube. The tube may be marked with divisions so that the pressure can be read directly from it.

The liquid can't run out of the tube because of the vacuum above it. A liquid stays in a pipet when you close the top with your finger for much the same reason.



Manometers that measure atmospheric pressure.

Manometers that measure the pressure of the atmosphere are called barometers. The liquid used in them is invariably mercury, which has the advantage of high density and therefore requires a shorter tube than less dense liquids. At sea level the manometer difference, h, in a mercury barometer is about 760 mm.

The pressure on the evacuated side of a mercury barometer is not exactly zero. The mercury vaporizes slightly, and the moving molecules of the mercury vapor give a slight pressure on the upper leg of the barometer. But at 20 °C the pressure from this vapor is only about a thousandth of a millimeter of mercury and can usually be ignored. Knowledge of atmospheric pressure (also called barometric pressure) is useful for predicting winds and weather and for judging elevations. It is also often needed for finding absolute pressure.

As was discussed in Section 13, a U-tube manometer that has one leg open to the atmosphere measures pressure relative to atmospheric pressure. In other words, the pressure of the atmosphere on the open leg is taken as zero. The same is true of pressure gages that are used to measure the pressure of tires. Such manometers and gages give the pressure difference above or below atmospheric. The measured pressure is often called gage pressure, since it's the pressure given by the usual gage.

But sometimes you need to know the total pressure exerted by a gas or liquid. To get it you simply add the atmospheric pressure to the gage pressure. The result is called the absolute pressure.

As an example, if the barometric pressure was 760 mm Hg and you measured a blood pressure of 120 mm Hg, the absolute pressure in the bloodstream would be

$$120 + 760 = 880 \text{ mm Hg}$$

On the other hand, if the barometric pressure was 456 mm Hg, the absolute pressure in the blood would be about two-thirds as much.

$$120 + 456 = 576 \text{ mm Hg}$$

The two barometric pressures selected in the example are part of a so-called "standard atmosphere." The atmospheric pressure at any particular elevation varies because of climate. But scientists have agreed on certain average values that can be used when a standard is needed. The standard sea level atmospheric pressure is taken as 760 mm Hg. The standard atmospheric pressure at 13,500 feet (the highest elevation Tom reached) is 456 mm Hg. The two absolute pressures that were calculated, therefore, might describe the total pressure of Tom's blood at sea level and on the slopes of Mt. Whitney.

This change in Tom's absolute blood pressure, however, and should not be considered in any way responsible for his difficulties. To the solid and liquid parts of the body--as long as they stay that way--the absolute pressure doesn't matter much. The behavior of blood and tissue depends primarily on the pressure differences they are subjected to. Only where gases or vapors are involved does the absolute pressure become of interest. For Tom, an absolute pressure was of interest; but it was the absolute pressure in his lungs, not in his bloodstream.

The barometric pressure of the standard sea level atmosphere, 760 mm Hg, is sometimes used as a pressure unit called the atmosphere

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(abbreviated atm). With this unit, standard atmospheric pressure at sea level is 1 atm; at 13,500 feet, it is 0.6 atm (456 divided by 760). Although it is usable for any pressure, the use of this unit is usually restricted to absolute pressure. The pressure in a tire would probably not be described as two atmospheres, gage pressure, but rather as three atmospheres, absolute pressure.

16-2 Respiration at High Altitude

Why was Tom the only one who couldn't reach the summit?

The problem Tom had with getting enough oxygen came from the low absolute pressure in his lungs. Each time he filled his lungs with the low-pressure air, he drew in fewer molecules of oxygen than at sea level. As a result, fewer molecules of oxygen passed from his lungs into his bloodstream.

Breathing more rapidly improved the situation slightly, but only slightly. No matter how rapidly he breathed, he could only have so many molecules of oxygen in his lungs at any one time. And that number was always low because of the low pressure.

Breathing more deeply helps more than breathing more rapidly, for it inflates all of the lungs' alveoli and provides a larger area for oxygen transfer to the blood.

Unfortunately, though, the lung actions that promote the pickup of oxygen by the blood also increase the removal of carbon dioxide from the blood. And the result is an upsetting of the blood chemistry (in ways that will be studied later in the unit).

All of these problems were shared by Tom's companions and everyone else on the mountain. Why, then, were his friends able to continue, while Tom was not?

The biggest help for coping with the low pressure of high altitude--as Tom painfully discovered--is having red blood cells that are in good shape. How rapidly oxygen will pass from the lungs into the bloodstream depends in part on how rapidly it is picked up by the red blood cells and carried away to the body cells that need oxygen.

Because of his smoking, Tom's red cells were seriously hampered. Some of the carbon monoxide that Tom drew into his lungs with each puff on a cigarette also passes into the blood and is picked up by red blood cells. In fact, it is picked up about 200 times as readily as oxygen. And once a red cell is loaded with carbon monoxide, it can't pick up oxygen. In Tom's red blood cells, many sites that should have been carrying oxygen were carrying carbon monoxide.

16-3 Adaptation to Altitude

How do people adjust to high altitude?

If Tom had set up residence on the slopes of Mt. Whitney, he might eventually have reached the point where he could cope with the reduced pressure. The body's adaptations to the low pressure at high altitude don't happen all at once. The only immediate responses are in the depth and rapidity of breathing.

This immediate adaptation is a mixed blessing because of its side-effects. But for individuals who continue to live at high altitude, a change occurs in the functioning of the kidneys that tends to correct the blood chemistry so that the body will tolerate the greater loss of carbon dioxide from the lungs caused by rapid or deep breathing.

Continuing to live at high altitude also causes another change in the blood. A fully adapted person may have 40 to 70 per cent more red blood cells. That adaptation may take several years to develop fully, but significant changes occur in as quickly as a month's time.

Several other differences are also noted in people who live at high altitude. Whether these are differences that develop during years of living at those altitudes, or are simply characteristics of the sort of people who can survive such a life, isn't fully known.

High-altitude dwellers generally have a greater profusion of capillary blood vessels in their pulmonary circulation, which provides more effective transfer of oxygen between lungs and bloodstre... They also apparently have more lung surface area.

The capillaries appear to be more profuse in other parts of the body as well, which may facilitate the use of oxygen by the cells.

Why is mercury used in barometers?

How are gage pressure, absolute pressure and atmospheric pressure related?

What is the relation between 1 atm and 1 mm Hg?

Why does atmospheric pressure affect the rate at which oxygen enters the bloodstream?

Why are smokers especially vulnerable to the effects of high altitude?

What is the only immediate res... to high altitude?

How do people adapt to high altitude after staying there for a period of time?

Vocabulary:

absolute pressure--the total pressure exerted; the sum of gage pressure and atmospheric pressure.

atmosphere--a unit of pressure equal to 760 mm Hg (abbreviated atm).

barometer--a device used to measure atmospheric pressure.

gage pressure--the pressure relative to atmospheric pressure.

SECTION 17:

17-1 Tom's Case Record--Age 17

Tom stopped at a level place in the trail and shifted his back pack. His shoulders felt like they were about to fall off. All three of them, he and Dad and Uncle Jim, were supposed to be carrying the same weight packs. Tom had a feeling there had been a mixup somewhere.

They'd already hiked two miles uphill and one mile down, and Uncle Jim kept saying they were almost there, but Tom couldn't see the lake. Just trees, and now and then a glimpse of the ridge on the other side of the valley in the morning sun.

He set his pack and started off down the trail again. Dad and Uncle Jim were out of sight, but Tom had lost interest in keeping up. He took his time and thought about the fish in that lake. Brown trout, they were. Big ones. Last time he'd caught one fourteen inches long and put everybody to shame. He couldn't wait to do that again.

"Come on, Tommy. Those fish won't wait all day." The voice was Uncle Jim's, from somewhere down the trail. Tom hooded his thumbs in the shoulder straps and pushed himself a little harder.

He came around a bend in the trail and saw a boulder as big as a house, with the trail winding around behind it. Suddenly he felt a lot better. Just on the other side of that boulder was the clearing where they would camp, ard beyond that there was nothing but water. Clear, cold water and great big fish.

Uncle Jim already had his pack off when Tom rounded the boulder. When he saw Tom coming, he flashed his big old country grin and slapped his belly.

"Trout for breakfast," he said.

Tom dropped his pack and got out his fishing gear. In no time at all he had his rod together and a fly on the leader. He wasn't tired any more. He couldn't even remember being tired. He jumped up and started toward the water.

"I got the log," he said.

"Don't shout," said Uncle Jim. "Trout don't dine with noisy neighbors."

The log was a huge fallen tree that lay across the little stream flowing into the lake. At the other end of it there was a shady bank and that was the best fishing spot on the lake. Uncle Jim said the browns assembled there for prayers every morning, and he'd spent the last twenty years trying to hook the preacher.

Tom one-handed his way up over the roots of the fallen tree, holding his rod high with the other hand so as not to get it tangled up. When he reached the top he turned to see if the other two were watching. They were. He waved and started across the log.

About halfway across that log, the going got tricky. The log got narrower, there were snags to dodge, and on top of that the rotten bark was slippery. Tom's theory about logs like that was that you have to keep going or you'll never get to the other end. He'd seen people get more and more cautious in tight places like that until pretty soon they weren't moving at all. That was not for him. He kept moving.

"Tommy, be careful." That was his dad. "That water is cold."

"You ain't no trout," said Uncle Jim.

<u>Now</u> who was shouting?

Tom stopped astraddle a snag where the footing felt pretty solid, and turned to wave to show them he was all right. As he turned he felt his foot slip, and when he looked down he saw that the chunk of bark he'd been counting on had come loose, and he was standing on thin air.

It wasn't deep, but it was cold. He found the bottom and stood up. The water was up to his chest. He couldn't catch his breath. He couldn't see anybody. It seemed like hours before he could get enough breath to yell, though it was really only seconds.

"Help!" It sounded like somebody else. He tried to get enough air to yell again. He was still gasping.

"You all right?" said Uncle Jim.

Tom was shivering so hard he couldn't talk. He was soaked, but he didn't feel like he'd broken anything, so he nodded "yes."

"Well, wade on out of there," said Uncle Jim, "I sure wouldn't want to have to come in after you."

By the time Tom had made it to the shore, his dad was standing beside Uncle Jim. The two of them reached down and hoisted Tom out onto the bank.

"Go on over there in the sun and sit down," said Uncle Jim. "And stop shaking before your teeth come loose."

Tom sat down in the sun. He tried to stop shaking, but he couldn't. Uncle Jim brought a blanket and wrapped it around him and told him to stay put. Tom wasn't about to go anywhere. He was breathing fast.

Slowly the sun warmed him up. After several minutes he could feel the heat through the blanket, and then his breathing slowed down.

Uncle Jim sat on a rock nearby, looking over his fishing gear.

"I can just hear him," he said. "That old preacher trout."

He crouched and looked up, bugeyed, like a trout on the bottom of a lake. "Man, oh man," he said. "That's the biggest danged fly I ever seen."

17-2 The Neural Control of Breathing

Why did Tom's experience affect his breathing?

When Tom plunged into the frigid water, his respiratory system responded in two quite different ways. First, the painful shock of the cold water seemed almost to paralyze the muscles of his chest and diaphragm. He had to fight to breathe. But then his breathing became rapid. Both reactions were automatic responses of a part of his brain to the messages it was getting.

Our breathing is controlled by the respiratory center, which is located in the brain. The respiratory center is composed of cells called neurons, which are the basic units of the nervous system. Some neurons control inspiration, while others control expiration. The respiratory center both receives and sends information along nerve pathways that are themselves composed of neurons.

One of these pathways carries information from the respiratory center to the diaphragm and the chest muscles and information from those regions back to the respiratory center. It is this nerve pathway that carries the signals that determine how often we inhale and exhale and how deeply.

But the respiratory center receives information from many other parts of the body as well. For example, if we consciously decide to hold our breath, a message goes from a higher portion of the brain to the respiratory center. From there appropriate information is sent to the diaphragm and chest to stop breathing. This message gets "overruled" before long.

Many different kinds of stimulation will cause the respiratory center to change our breathing. The prick of a pin or a sudden drenching with cold water will make us gasp for breath. Many emotional states, thoughts, sights or sounds may change our breathing rate. In each case, the stimulation is transmitted to the respiratory center, which responds by changing its signals to the diaphragm and chest muscles.

Any condition that interferes with the normal function of the respiratory center can depress or even stop respiration. Brain swelling resulting from brain concussion is one such condition. Another is overdosage of anesthetics or narcotics.

17-3 Respiratory Response to Cold

Why did Tom breathe rapidly after he left the water?

After Tom left the water, his breathing was rapid for several minutes. In order to understand the reason for this, we must first recognize that Tom's body lost a great deal of heat while he was in the water. His body responded by temporarily speeding up the chemical processes in his cells that produce heat. Most of these processes require oxygen, and the temporary speed-up requires more oxygen than usual. This is why Tom was breathing rapidly. It is an automatic response that supplies the additional oxygen necessary to generate more heat.

In mice and men and other mammals, as well as birds, the body uses many mechanisms to maintain its temperature near some particular value. Animals that maintain constant body temperature are said to be "warm-blooded" or <u>homeothermic</u>. Some mammals, however, have a special reaction to extreme cold. Their breathing rate becomes very slow, as low as one breath every five minutes. The other bodily functions become correspondingly slow, and the body temperature drops. This state is called hibernation.

Other animals, such as reptiles and fish, have uncontrolled body temperature, and their temperature varies greatly. Animals that do not maintain constant body temperature are called <u>poikilothermic</u>.

Why did the sudden shock of the cold water make Tom gasp for breath?

What is the function of the respiratory center? Where is it located?

What is the respiratory response to the loss of body heat? Why is this response necessary?

Is man homeothermic or poikilothermic?

<u>Vocabulary</u>:

<u>homeothermic</u> (HO-me-o-THUR-mik)--able to maintain a constant body temperature.

<u>neuron</u> (NEW-ron)--a cell of the nervous system.

<u>poikilothermic</u> (POY-key-lo-THUR-mik)--having a body temperature that changes with the temperature of the environment.

<u>respiratory center</u>--a region of the brain that controls the rate and depth of breathing.

SECTION 18:

18-1 Lung Volumes and Capacities

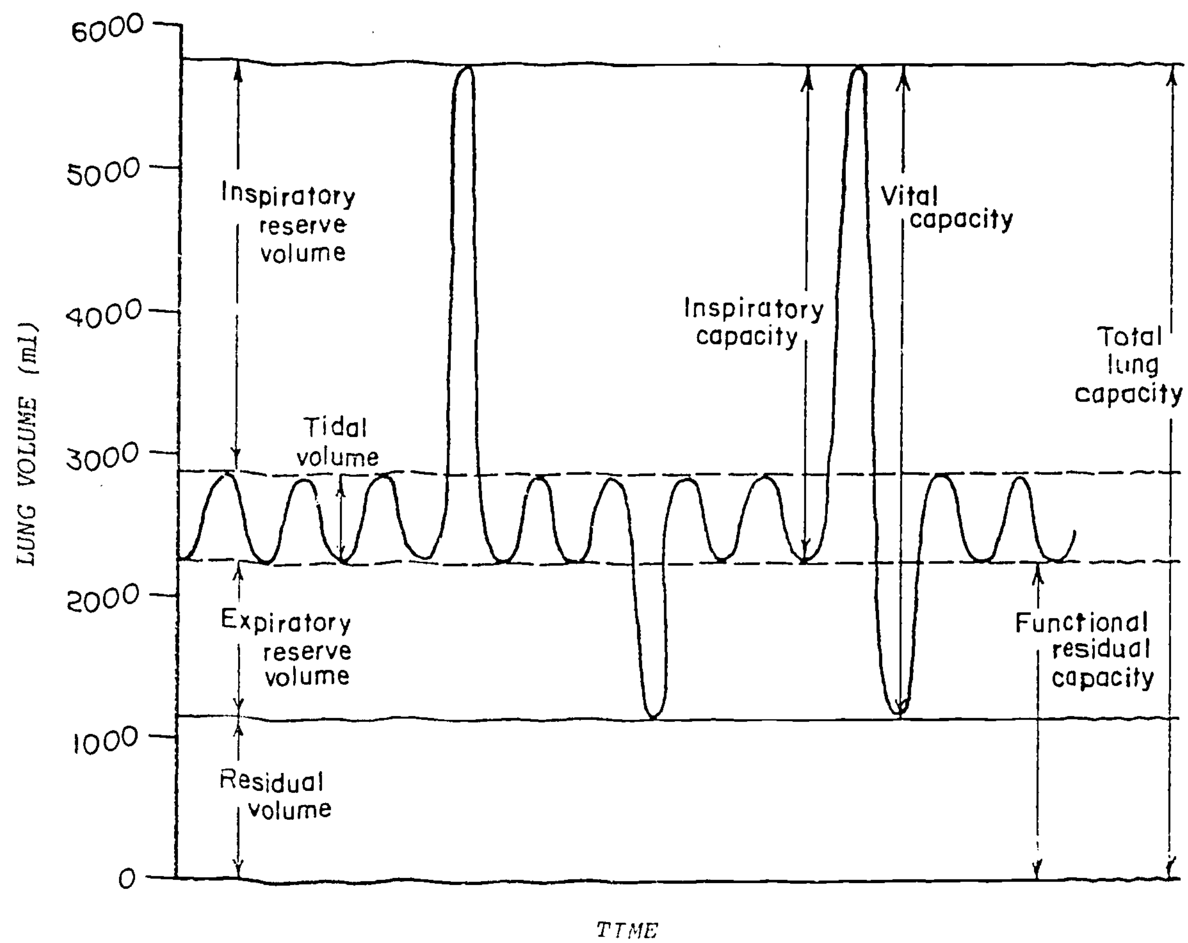
What are some of the measurements made on the lungs?

The demands that the respiratory center may make on the lungs are limited. The chest and diaphragm muscles can be moved only so fast. And they can enlarge and shrink the chest cavity only so far.

An adult at rest inspires about half a liter of air with each breath, but is able to inspire many times that amount when it is necessary. That is one reason why the lungs of an individual, such as a smoker, may deteriorate significantly without his realizing it.

Measurements of volumes of air involved in a person's breathing and the capacity of a person's lungs are an important part of diagnosing malfunctions of the lungs. For that reason, it is important to understand the definitions of the various volumes and capacities connected with breathing.

These quantities can be best defined by referring to the figure below in which the volume of air in the lungs is shown as a function of time.



Lung Volumes and Capacities

The amount of air inhaled and exhaled during a normal breath is called the tidal volume. The first three cycles on the graph represent normal breaths.

Once a person has taken a normal breath and inspired a normal amount of air, he is able to inspire additional air until his lungs are fully inflated. The amount of additional air a person may inspire is called the inspiratory reserve volume. In the fourth breath on the graph the lungs are fully inflated.

It is al o possible to expire additional air after normal expiration. Th mount of additional air that may be expired is given the name ex y reserve volume. It is shown on the graph after the sixth b . Observe that even after a person expires as much as he can, a tain amount of air remains in his lungs. It is impossible to expire all of the air in your lungs. The amount remaining after you have exhaled as completely as possible is called the residual volume.

The amount of air remaining the lungs after normal expiration is given the name functional residual capacity. It is the sum of the expiratory reserve volume and the residual volume.

The tidal volume plus the inspiratory reserve volume is called the inspiratory capacity. This is the amount of air a person can inhale after normal expiration.

The vital capacity is the maximum amount of air a person can exhale after inhaling a maximum amount. Also called the forced expiratory volume, or FEV, it is the greatest amount of air that can be exchanged in one breath. Of all of these volumes and capacities, FEV is the most important measure of the condition of a person's lungs.

The total lung capacity is the sum of vital capacity (or FEV) and residual volume or, as may be seen from the graph, the total of all four of the lung volumes shown. Residual volume, and therefore total lung capacity, cannot be measured directly; but they can be estimated from other data.

18-2 The Breaking-Point Reflex

Why can't we hold our breath indefinitely?

If you stop breathing, the respiratory center will eventually force you to start again--unless it has been incapacitated or damaged for some reason. The action of the respiratory center that forces you to take a new breath is sometimes called the breaking-point reflex.

How quickly the breaking-point reflex takes over depends on how fully the lungs are inflated. If you inflate your lungs to the total lung capacity, you can hold your breath much longer than if you shrink them to their residual volume.

The time before the breaking-point reflex acts also depends on the amount of carbon dioxide in the lung air at the time you start holding your breath. If you first hyperventilate (breathe more rapidly than necessary) to reduce the carbon dioxide in the lungs, the breath-holding time will increase.

The origin of the breaking-point reflex lies in the chemistry of the blood and will be discussed after you have learned the basic chemical facts that are needed to explain it.

Why are measurements of lung volumes and capacities important in biomedicine?

Why is FEV, or vital capacity, of special importance?

Why can't the residual volume be measured directly?

What are two factors that affect how long we can hold our breath?

Vocabulary:

breaking-point reflex--the action of the respiratory center that forces one to resume breathing after holding one's breath.

forced expiratory volume--the maximum volume of air that can be expired in a single breath. Abbreviated FEV.

residual volume (reh-ZID-u-ul)--the volume of air remaining in the lungs following maximum expiration.

tidal volume--the volume of air inhaled or exhaled during normal breathing at rest.

total lung capacity--the maximum volume of air that the lungs can hold.

vital capacity--same as forced expiratory volume.

SECTION 19:

19-1 Tom's Case Record--Age 18

Tom put the key in the ignition and turned it. The starter ground a few times and then the engine started with a bang. In the 6 A.M. silence it sounded like some kind of a bomb going off. He backed out into the deserted street and headed for work.

He didn't like the idea of working the rest of his life, but he was out of school now. The summers seemed to be getting shorter as he got older, and now it was getting hard to tell them from the winters. They were warmer, but they weren't much more fun. He hadn't seen a baseball in over a month. Couldn't remember when he'd last gone fishing.

Working did have its good points. There was money in it, and even if money couldn't buy happiness, it seemed to buy a certain degree of independence. That he liked.

But it took time. It seemed that he spent so much time earning his money that he didn't have any time left to enjoy it. He'd mentioned that to his father recently. His father had just nodded and said, "Welcome to the real world."

Driving to work this time of the morning was probably the hardest part of his job, and he didn't even get paid for it. Most mornings he would be halfway there before he woke up. The empty highway didn't help any. The white lines flying by in the half-light were hypnotic.

This morning was a little different, because this morning he felt like he hadn't even been asleep. He'd been out late the night before with Kathy, and between the time he got home and the time the alarm went off he had just been able to catch a little catnap. Now, roaring down the empty highway, he felt like this morning was just an extension of the night before. He was having his first forty-eight-hour day.

He looked at his watch. Quarter after six. He was ahead of schedule, moving faster than usual because he wasn't groggy--just sort of hazy in the brain. At this rate he would have an extra ten minutes. Just time for some coffee and doughnuts. That would set him straight.

He reached for his cigarettes on the dashboard. They weren't there. He took his eyes off the road to look for them. There they were clear over on the other end of the seat. He unbuckled his seat belt, leaned over and grabbed the pack, and sat up again.

When he got his eyes back on the road he saw the curve coming, much too fast. He jammed on the brakes and gripped the wheel, waiting for the back tires to break loose so he could skid into the curve and then power out of it. That was how race drivers did it.

It didn't work. There wasn't any road, and then there was a tree, and he was heading straight for it.

* * *

Leroy Pickett saw the car sitting at a crazy angle in the ditch at the side of the road, and he thought somebody had probably run out of gas and pushed it off there to get it out of the way. But then he saw that the front end of it was mashed in, and he began to slow down. Finally he saw the young man sitting on the shoulder, looking at the pavement between his feet.

His wife saw him at the same time.

"Somebody's hurt," she said.

"Yep."

Leroy pulled off the road and jumped out of the car. He jumped down into the ditch to see if there was anybody in the car. Nobody. He looked around quickly to see if anybody else had been thrown clear of the wreck. Didn't see anybody.

"Go get help!" he yelled at his wife, and waved off down the road. She slid over behind the wheel and roared off. Leroy scrambled up the bank and ran over to the young man who was still sitting there, dazed, looking at the ground. He looked the young man over for major bleeding. There were a few deep cuts on his face and in his chest, but it didn't look like any major blood vessels had been cut. But there was a strange noise--a soft sucking sound coming from a wound in the young man's chest, just below and in front of his armpit.

Leroy asked the young man how he felt, but all he could get out of him was an uncomprehending stare.

"You'll be all right," he said. "The ambulance is coming." The young man didn't seem to care.

Leroy noticed that his breathing was becoming shallow. It was getting faster, too. And his lips were turning bluish-gray. The sucking sound continued.

He was beginning to worry about that sucking noise. He bent down and listened. The wound seemed to be sucking air in, but not blowing it out. He tore the young man's shirt away from the wound and watched as he breathed. When he breathed in, air was sucked in through the wound; but when he breathed out, only a little of the air came back out. His breathing was getting faster and faster.

Leroy scratched his chin and tried to think. He knew something about chest wounds that sucked like that, but he couldn't remember what it was. Sucking wounds, they were called.

Then he had it. He'd sat through a whole lecture on sucking wounds in paramed training before he went to Vietnam. They can kill you in about ten minutes.

Quickly he bent down and clamped the wound shut with his fingers and held it firmly so that it was airtight. The young man was gasping for breath. Leroy had been just in time.

When the ambulance got there, an attendant immediately covered the wound with a piece of wide surgical tape. Then they picked the young man up and laid him on the stretcher. As soon as they got him into the ambulance they put an oxygen mask over his face.

Leroy's wife drove up just as the ambulance was pulling away. She turned around and pulled up beside him on the shoulder of the road. Leroy's knees were starting to feel funny, like he had just run a long way. He opened the door and plopped into the seat. For a minute he just sat there with the door open and one foot still out on the ground, staring after the flashing red lights.

He took a long, slow, deep breath of air.

"Wow," he said. "That was a close one."

19-2 The Mechanics of Breathing

What keeps our lungs from collapsing?

To appreciate the nature of Tom's chest injury, a more complete understanding of the mechanics of breathing is necessary.

As mentioned earlier, the lungs are a vast collection of air sacs bulging with alveoli. The air sacs are balloon-like structures that will collapse unless the pressure inside is enough to keep them inflated.

To inflate a balloon, you have to force more air molecules inside to make the pressure on the inside greater than the atmospheric pressure on the outside. The pressure difference overcomes the elasticity of the rubber and keeps the balloon inflated.

The same sort of action is needed to inflate the air sacs of the lungs. But in the lungs it isn't accomplished by raising the pressure inside. Instead, it is accomplished by lowering the pressure outside the sacs.

The fluid in the pleural spaces maintains a pressure below atmospheric. In this way a pressure difference always acts on the air sacs, keeping the sacs inflated to fill the chest cavity.

The pressure in the pleural spaces changes somewhat depending on how much the lungs are inflated. As with a balloon, full inflation requires a greater pressure difference, therefore a lower pleural pressure.

The pressure in the pleural spaces is also affected by the pressure in the lungs. As you inspire, the volume of your lungs increases. Until enough air can flow into them, the lung pressure drops below atmospheric. As you expire, the volume of the lungs decreases and the lung pressure rises above atmospheric. As a result, a lower pleural pressure is needed to keep the lungs inflated during inspiration than during expiration.

A graph of typical pressure variation in the lungs and the pleural spaces is shown in Figure 1 on the following page.

19-3 Collapse of the Lung

What happens when air enters the pleural space?

These facts about the operation of the lungs explain why Tom was in dire straits. If the pressures both inside and outside a lung become equal, the lung will collapse because of its elasticity. This is what occurs when a wound in the chest wall exposes a pleural space to the air outside.

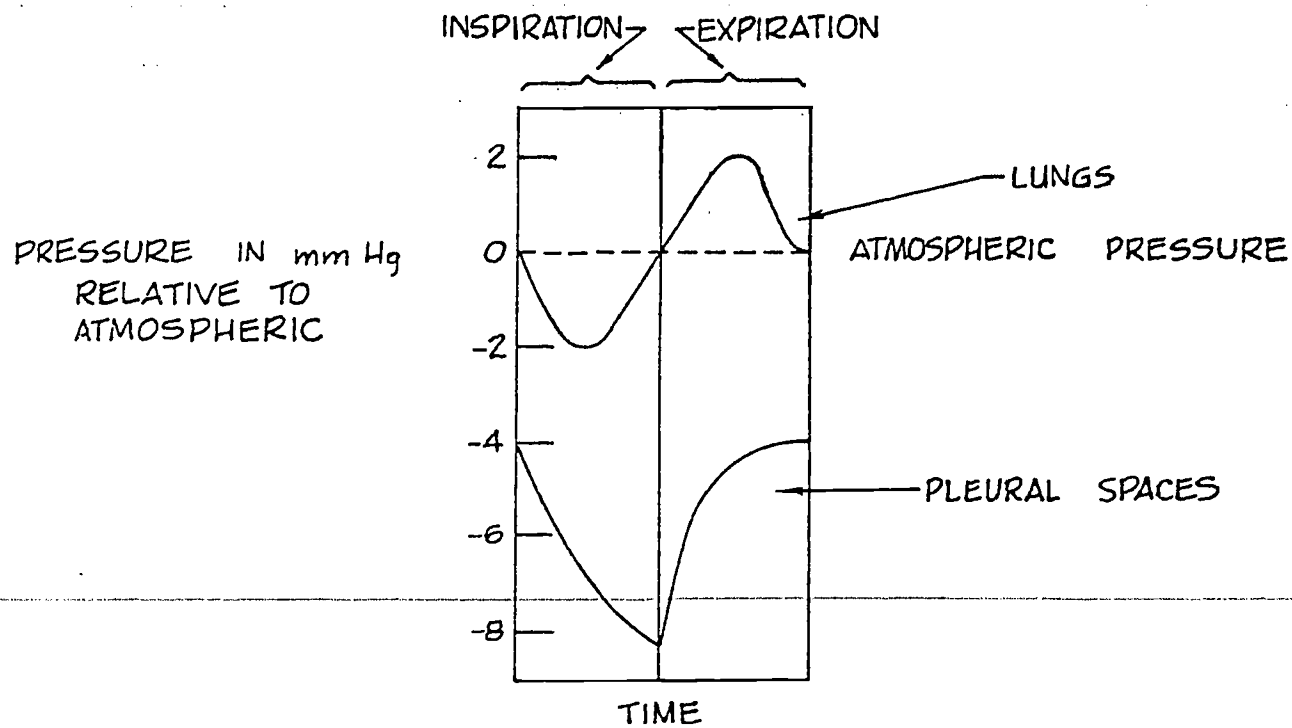


FIGURE 1: *Pressures during respiration.*

A situation in which air enters a pleural space is called a pneumothorax. ("Pneumo-" is from the Greek word for air, while "thorax" means chest.) A pneumothorax may occur not only by air entering a pleural space from outside, but also by a rupture of a lung allowing it to enter from within.

Fortunately each lung has its own separate pleural space, and if one lung suffers a pneumothorax, the other suffers only indirectly. How the other lung is affected depends on the type of pneumothorax, of which there are three.

Before describing the three types of pneumothorax we must mention a part of the anatomy we have not yet encountered. It is called the mediastinum, and it is a wall of tissue which separates the right lung and pleural space from the left lung and pleural space.

We will first describe a closed pneumothorax. A closed pneumothorax is one in which a hole is opened but quickly closes. The pressure in the pleural space rises to atmospheric, and the lung on that side collapses. Since the pressure in the pleural space on the wounded side is greater than that on the normal side, the mediastinum moves a little toward the normal side.

Although the functioning of the intact lung is impaired, several compensations occur. First, the trapped air in the injured pleural space changes in pressure in a way that gives some assistance to the intact lung. During inspiration the volume occupied by the trapped air increases and so its pressure is reduced. This tends to move the mediastinum toward the injured side, permitting more air to enter the intact lung. During expiration the volume of the trapped air is decreased and its pressure therefore goes up. That moves the mediastinum toward the uninjured side, helping to expel air from the intact lung.

Another compensating feature is that the collapsed lung offers greater resistance to the flow of blood. As a result, the flow of blood to the unaffected lung increases, and the amount of oxygen passing into the blood may not be seriously diminished. A closed pneumothorax tends to correct itself. Within a few weeks the air in the pleural space is absorbed into the body and the collapsed lung becomes inflated again.

If the patient is suffering severe discomfort, he may be treated at a hospital by having a rubber tube inserted through the chest wall. The tube is connected to a pressure regulator which reduces the pressure in the pleural space to less than atmospheric. This procedure is called decompression.

At one time it was common practice to treat tuberculosis by injecting air into the pleural space to collapse a lung. The purpose was to give the lung a rest. This technique was found to be of little or no value, however, and is no longer practiced.

A more serious condition is an open pneumothorax, in which the wound remains open. (See Figure 2.) With such a wound, the air within the injured pleural space stays at nearly atmospheric pressure. During inspiration its pressure can't drop nearly as much as with a closed pneumothorax, since air is drawn in through the wound. During expiration, the pressure can't rise significantly. Therefore the mediastinum tends to remain fully deflected, seriously impairing the capacity of the intact lung. An open pneumothorax is fatal if the wound is not closed.

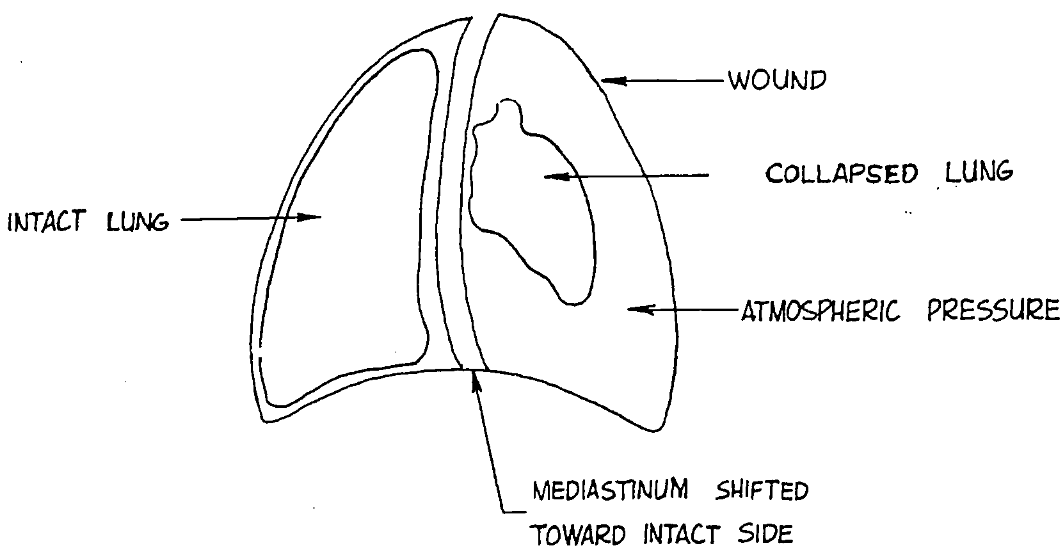


FIGURE 2: *An open pneumothorax.*

An even more serious type of pneumothorax is a tension pneumothorax (see Figure 3). This is the type suffered by Tom when he had his automobile accident. A tension pneumothorax involves a flap of skin over the wound which opens during inspiration and allows air to enter, but closes during expiration and allows little or no air to leave.

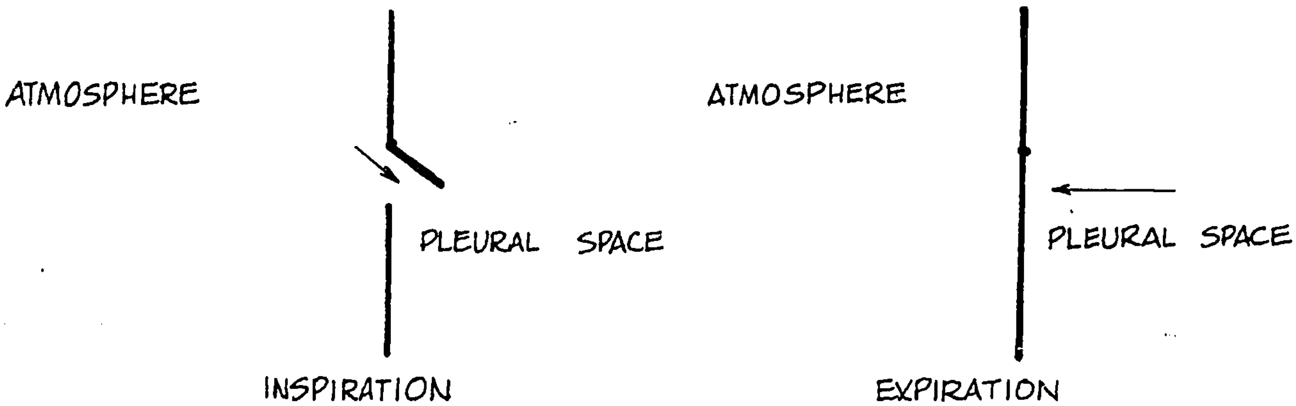


FIGURE 3: *The mechanics of a tension pneumothorax.*

More air enters the pleural space than leaves, and the pressure in the pleural space becomes further above atmospheric with each breath. The effects are the same as in the case of an open pneumothorax, except that the pressure difference between the two pleural spaces is greater. The shift of the mediastinum is consequently greater. Death in this case can occur in as little as ten minutes.

First aid for a tension pneumothorax, as for an open pneumothorax, involves forming an airtight seal over the wound. Surgical tape two inches wide is ideal. If no tape is available, the person giving first aid should clamp and hold the wound closed with his fingers until help arrives. Gauze and cloth pads do not keep air out and should not be used.

In the case of tension pneumothorax, closing the wound is not sufficient to keep the victim from suffering. It is essential that a doctor insert a rubber tube to decompress the pleural space. The patient will also be given oxygen at a pressure above atmospheric to aid his breathing.

How does the pressure of the pleural spaces serve to keep the lungs inflated?

Why does a lung collapse if the pressures inside and outside become the same?

What role is played by the mediastinum in the three types of pneumothorax?

What compensating factors help to prevent a closed pneumothorax from being lethal?

Why is a tension pneumothorax even more dangerous than an open pneumothorax?

Vocabulary:

mediastinum (ME-de-uh-STY-num)--a wall of tissue that separates the two lungs and their pleural spaces.

pneumothorax (NEW-mo-THOR-aks)--the presence of air in the pleural space.

closed pneumothorax--a pneumothorax in which the wound is sealed off from the atmosphere.

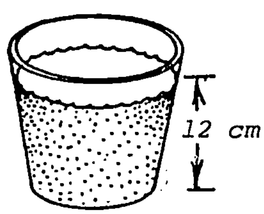
open pneumothorax--a pneumothorax in which the wound is open to the atmosphere.

tension pneumothorax--a pneumothorax in which more air enters the pleural space with each inspiration and little or no air leaves during expiration.

REVIEW SET 19:

1. Imagine that you are exerting pressure on an object. What two changes could you make to increase the amount of pressure on that object? What changes could you make to decrease the amount of pressure?

2. What is the pressure at the bottom of the glass of milk?



Density = 1.03 g/cu cm

3. What is the name of the instrument which is used to take a person's blood pressure? In what units are the readings given?

4. After Tommy ran his race, he experienced severe chest pains. What was the cause of his chest pain and what could have happened if he had run another lap?

5. Trace the path of oxygen from the bronchi to the bloodstream naming all the structures in the order in which they would be passed.

6. What is a person's aerobic capacity? What does it have to do with fitness?

7. Describe the condition called "hypoxia." Give some of its causes and the effects it has on the body.

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8. Contrast the molecular properties of solids, liquids and gases.

9. What effect does an increase in temperature have on the volume of a gas? A decrease in temperature?

10. What is the difference between a manometer and a barometer?

11. Give at least three changes that occur in the bodies of people who live at high altitudes.

12. What changes took place in Tom's body to cause him to breathe rapidly after he left the cold water of the lake?

13. Where is the respiratory center and what is its function?

14. Give the difference between "poikilothermic" and "homeothermic." Name two organisms which are poikilothermic and two which are homeothermic.

15. Define the following: tidal volume, residual volume, vital capacity, forced expiratory volume, total lung capacity.

16. Name two factors which affect how long you can hold your breath.

17. Describe and compare three kinds of pneumothorax. Give the first aid and follow-up treatment for each type of pneumothorax.

SECTION 20:

20-1 Toms's Case Record--Age 21

Tom was going on a picnic, but he was very uneasy. He had meant to ask Kathy something for a long time, several months in fact, but he never seemed to get around to it. Told himself it wasn't the right time, or that he'd forgotten. He'd get home from a date and say to himself, "Gosh, I forgot to ask her again." What he forgot to ask was whether she would marry him.

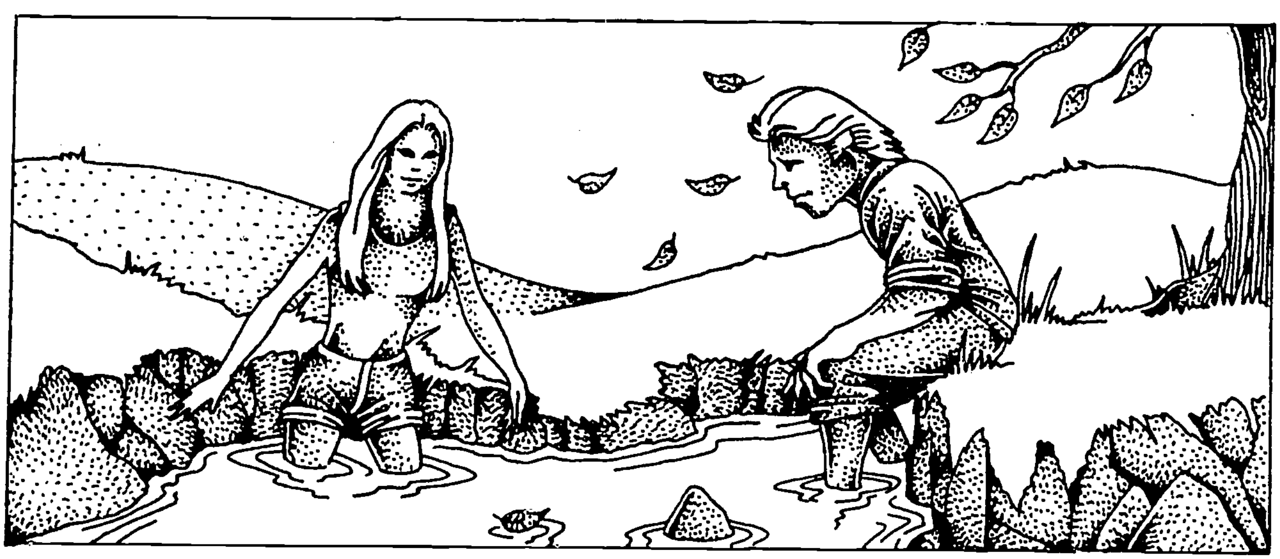
This was why he was uneasy about the picnic. He'd hoped to go to the ball game; there was no way to ask his question in a noisy crowd. But Kathy had gone out of her way to put a nice lunch together, and he saw no way out.

So instead of eating hot dogs at Blue Sox Field, Tom was driving past the shopping mall on the edge of town, on his way toward Roosevelt Park. The car windows were down, and the wind felt good. It had been hot and muggy all week, and the "possibility of afternoon thundershowers" that the weatherman had promised each day had not happened. It was another still, hot day--perfect for watching a ball game.

When they arrived at the park, Tom carried the picnic basket over near one of the large sprawling oaks. Then he and Kathy took their shoes off and walked through the grass down to the stream to cool their feet. Kathy playfully splashed water on Tom, but he was not in the mood to play.

"What's the matter?" Kathy asked.

"Guess I'm just thinking about lunch," Tom replied, not quite truthfully.



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Kathy had prepared ham and cheese sandwiches, hard-boiled eggs and sliced carrots. She had put in two oranges for dessert and chocolate-chip cookies she baked herself. The food reminded Tom of what a good cook Kathy was, so he tried to think of something else. "Wonder how the Blue Sox are doing," he said.

After he had brushed the last ant from the last cookie and eaten the cookie, Tom lay back in the grass, trying to soak up some sun and relax. It was then that he noticed the tall, dark cloud drifting in from the horizon.

As the cloud moved nearer, it became larger and blacker. "Why does it always rain on my picnics?" Kathy wondered as Tom moved their shoes, jackets and the picnic basket under the tree. By now it was too late to run for the car; a lightning flash was followed shortly by the boom of thunder.

Tom and Kathy sat under the tree waiting, but the silence made Tom nervous. So he decided to show off for Kathy by doing a series of somersaults and handstands. This way he could postpone any serious talking.

After a few cartwheels, he swung from the lower branches of the oak. Kathy was apparently not properly impressed, because she gazed off into the distance. So Tom beat his chest and yelled, "Me Tarzan...."

But before he could say, "You Jane," there was a flash of lightning above. Kathy heard almost at the same time a very loud BWAMM, but Tom didn't hear. He landed on his back on the ground.

Kathy screamed, "Are you all right?" She was scared by the loudness of the thunder, Tom's fall and the odor of burnt wood.

Tom didn't answer; he was stretched out on the ground, unconscious. He was sort of rigid, and he was twitching a little. He wasn't breathing.

Two young men with a frisbee, who had been sprinting for their car to beat the rain, heard Kathy scream and came running over.

"Call an ambulance quick!" said the tall one. "He's paralyzed!"

Then, while his friend ran off for help, he went to work on Tom. He stuffed the jackets under his shoulders, tipped his head back and started giving him mouth-to-mouth resuscitation.

After about two minutes he stopped. Tom wasn't stiff any more, but he was still unconscious. He wasn't breathing at all.

After about three more minutes of artificial respiration, Tom began to grunt and struggle a little. A minute later he was breathing on his own, but not very evenly. In a few more minutes he started to regain consciousness. He was very confused.

An ambulance came speeding across the grass, and slammed on its brakes near where Tom lay. "Monday morning someone's not going to like what we did to the grass," an attendant said.

The attendant looked at Tom and then took Kathy aside.

"I think he'll be all right." he said. "But we'll take him to Emergency anyway, just to make sure."

The ride to the hospital seemed long. Kathy was worried about what might have happened to Tom. The attendant said he'd be all right, but how did he know? Kathy knew nothing about lightning, but she knew she was worried.

Later at the hospital they had rushed Tom off somewhere and told Kathy to wait. Finally a doctor came out and sat down beside her.

"Tom is going to be okay," he said, "but I think we'll keep an eye on him until tomorrow just to make sure." Then the doctor explained to Kathy what had happened.

"Lightning tends to follow the path of least resistance between the sky and the ground. Almost all of the electricity must have passed through the trunk, but enough passed through Tom to give him quite a shock."

Kathy knew nothing about electricity and didn't know what resistance meant, but she listened because she wanted to know what had happened to Tom.

"What happens to a person," the doctor continued, "when electricity passes through him depends on the path it takes. It can cause muscles to contract or have spasms, which means that it can cause the heart muscles to stop or lose their natural rhythm. But this isn't what happened to Tom. The electricity passed through the respiratory center, which is located in the brain. If electricity passes through the respiratory center, it interferes with its normal functioning. This can slow down or even stop breathing."

"Can I see him?" Kathy asked.

"Certainly," said the doctor. He led her down the hall and through a door.

There was Tom, lying there propped up in bed. He looked a little the worse for wear, but smiled brightly when he saw Kathy. She rushed over and threw her arms around him.

Tom looked up at her and said, "Will you marry me?"

The doctor chuckled. "Tom may still be a little confused...."

Kathy hugged Tom a little more tightly. "He may be confused, Doctor, but the answer is still yes."

20-2 Attraction and Repulsion

What is the effect of electrical charges on one another?

Man's earliest studies of electricity were observations of the attraction and repulsion between charged objects. As long ago as twenty-five hundred years, a Greek named Thales observed that a piece of amber which had been rubbed would pick up pieces of straw. The word electricity comes from the Greek word for amber, which is "elektron."

The study of the attraction and repulsion between charged objects is called electrostatics, because it is the study of electric charges which are not in motion. A systematic study of electrostatics during the Middle Ages led to a set of observations which we may make for ourselves in the laboratory. Let us list some observations that we may make by performing a series of experiments on a pair of pith balls suspended near one another. (Pith balls are small spheres of a light material.)

1. If we touch a glass rod to each of the pith balls in turn, the balls have no effect on one another.

2. If we rub the glass rod on a piece of silk and then touch each ball in turn, the balls repel one another, as shown in Figure 1.

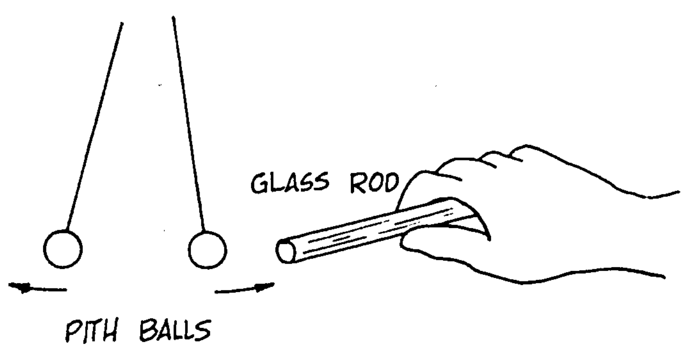


FIGURE 1: *Repulsion of pith balls.*

3. If we touch a rubber rod to both balls, again no effect is observed.

4. If we first rub the rubber rod on a piece of fur before touching the pith balls, the balls repel one another, as they did with the rubbed glass rod. (See Figure 2 on the following page.)

5. The first four experiments suggest that both rods have the same effect on the pith balls. However, if we rub the rubber rod and touch it to one ball and touch the rubbed glass rod to the other ball, we find that the balls attract one another (see Figure 3, on the following page).

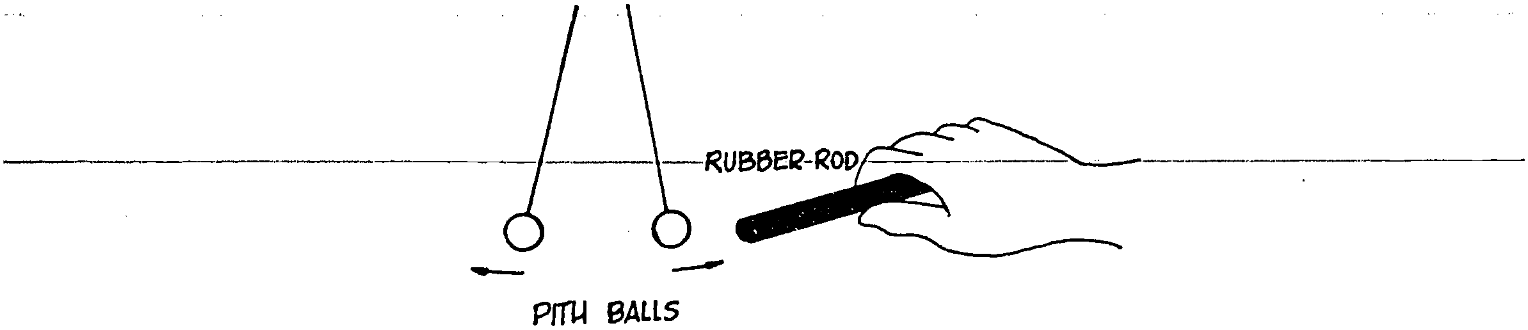


FIGURE 2: *Repulsion of pith balls again.*

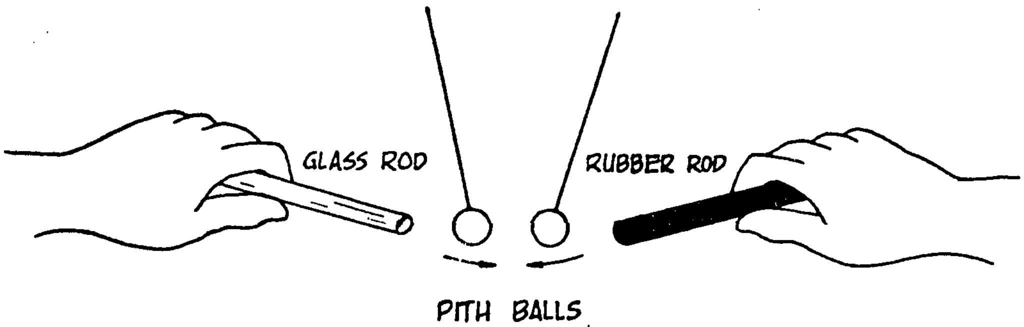


FIGURE 3: *Attraction of pith balls.*

This fifth experiment shows that the effect of the rubber rod is opposite to that of the glass rod.

6. If the rubber rod is rubbed with fur, and the rod is then passed over the fur, the fur is attracted to the rod. Note that the fur is behaving like the pith ball which touched the rubbed glass rod.

7. If the glass rod is rubbed on silk and then passed over the silk, the silk is attracted to the rod. The behavior of the silk is the same as the behavior of a pith ball which has touched a rubbed rubber rod.

The attractions and repulsions observed in the experiments described above are caused by electric forces. An object which can exert an electric force is said to possess <u>electric charge</u>. A rubbed glass rod possesses one type of electric charge, and a rubbed rubber rod possesses a second type of electric charge. Our experiments do not preclude the possibility of a third type of charge. However, an exhaustive examination of other materials would reveal none which possess the properties of a third type of charge, and we may safely state that only two types of electric charge exist.

Scientists of the 18th century hypothesized a model to explain all the electric phenomena that they had observed. According to their model, there are two types of electric charge. Matter in its normal state (the unrubbed glass rod, for example) possesses an equal amount of each charge. When certain materials (such as the glass rod and the silk) are rubbed together, an excess of one type of charge is transferred to one material, and an excess of the second type to the other material. Unlike charges attract and like charges repel.

Benjamin Franklin gave the names positive to the charge on the glass rod and negative to the charge on the rubber rod. The choice of which charge was positive and which was negative was arbitrary, and was intended only to indicate that the effect of one cancels the effect of the other.

We may explain our observations in terms of the 18th-century model. When the glass rod was rubbed with silk, the rod acquired an excess of positive charge and the silk an excess of negative charge. When the pith balls were touched by the glass rod, some of the excess positive charge passed from the rod to the balls. The balls repelled one another because they possessed the same charge.

When the rubber rod was rubbed with fur, the rubber acquired an excess of negative charge and the fur an excess of positive charge. Touching the pith balls with the rubber rod transferred some of the excess negative charge to the pith balls. They repelled one another again because both possessed the same charge.

When one ball was touched with the glass rod and the other with the rubber rod, the first ball acquired a positive charge and the second ball a negative charge. Because the balls had opposite charge, they attracted one another.

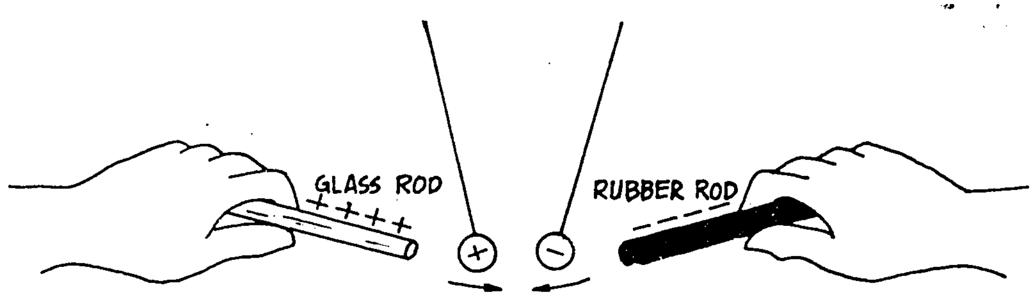


FIGURE 4: *Attraction of unlike charges*

The glass rod attracted the silk because the glass had a positive charge and the silk a negative charge. The rubber rod attracted the fur because the rubber had a negative charge and the fur a positive charge.

Benjamin Franklin's interest in electricity also prompted him to perform an experiment that made him famous. While most of the citizens of Philadelphia went inside to avoid a thunderstorm, Franklin and his son went out to a nearby field with a kite. A pointed wire was attached to the vertical stick of the kite; a silk ribbon was tied to the ground end of the cord and a house key fastened to the silk.

Lightning had always been a mystery, more easily explained as supernatural than as in the realm of science. But Franklin had a notion that lightning was a large-scale version of the spark you get by scuffing your feet on a carpet and touching a door handle, or the sparks that could be obtained from some of the laboratory gadgets being devised in Franklin's time.

The first indication Franklin had that his idea was correct was the loose threads on the cord standing apart, like two charged pith balls. Franklin then touched the key and felt a tingling in his arm: the same tingling he had felt while studying electricity in his laboratory. Modern scientists agree that if lightning had struck the kite, Franklin would probably not have survived to help found the United States. But fortunately, lightning did not hit the kite while he was performing this and other experiments, and he demonstrated that lightning was no more supernatural than the spark from the door knob.

In fact, a spark between a cloud and the ground, or between two clouds, is due to much the same process as the spark between your hand and a door knob. When you scuff your feet, charges are separated, as they are when a rubber rod is rubbed with fur or a glass rod with silk. Positive charge remains on the carpet, while your body picks up an excess of negative charge.

The way in which electrical charge builds up in a thundercloud is less well understood. Apparently the most important fact is the rubbing of air in updrafts against raindrops. Whatever the cause, the result is typically an accumulation of positive charge at the top of the cloud and negative charge at the bottom, as shown in Figure 5.

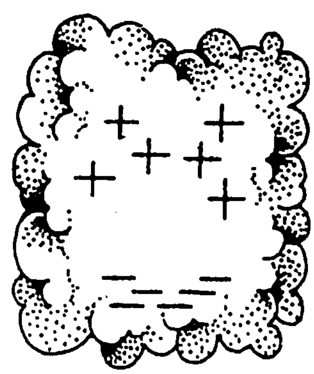


FIGURE 5: *Charges in a cloud.*

Why does this accumulation of charge result in a spark or a lightning bolt? Before we can answer this question we will have to introduce the concepts of electrical current and voltage, and in Section 21 discuss the building blocks of matter.

20-3 Current and Voltage

Why does electricity flow?

We can think of many examples of electricity flowing. It flows from the rubber rod to the pith balls; it flows from the generating station through your toaster; if flows from a car's battery through the spark plugs; and it flowed from the sky through Tom into the ground. We call the flow of electricity in any of these situations electrical current.

Electrical current, the flow of electricity, is the movement of electrical charges and the cause of electrical current is the ~~same as the cause of charged pith balls moving. Like charges repel~~ and unlike charges attract.

As you may know, current requires a path. Electricity does not flow everywhere. It flows through some types of matter more easily than others. For instance, metals are good conductors of electricity, and therefore are used for wires. Air is a poor conductor of electricity, except in special situations, and is thus said to be an insulator.

All that is required to make electricity flow through a wire is an accumulation of positive charge at one end and negative charge at the other end. The negative charges repel one another and are attracted toward the positive charges. Likewise the positive charges repel each other and are attracted to the negative charges.

Based on what was known 100 years ago, charge could flow in either direction. Negative charge could flow toward the positive, or positive charge toward the negative. But experiments performed during the latter half of the 19th century provided evidence that electric charge is usually transported by extremely small, negatively charged particles. These particles were named electrons. Electrons repel one another and are attracted toward positive charges (see Figure 6).

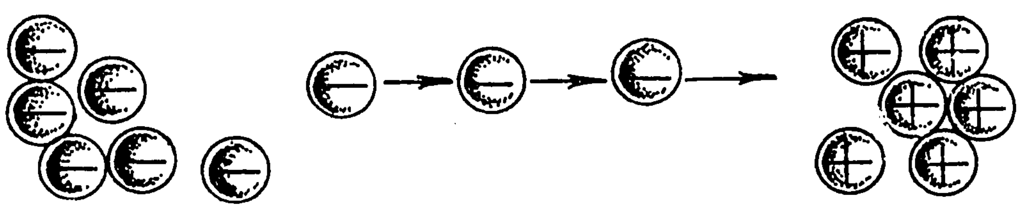


FIGURE 6: *Current--a flow of electrons.*

This flow of electrons is what we call electrical current.

Note the use of the words "flow" and "current," originally used to describe the motion of water. Another word we will introduce, voltage, is not used in connection with water flow, but we will try to make the concept clear by comparing electricity to water.

Voltage is often misunderstood. One problem is that the word is frequently misused. Voltage does not flow through a wire, as is often said. Rather, voltage is the driving force that causes current to flow through a wire.

The role of voltage in causing electricity to flow may be likened to the role of height in causing water to flow. Electricity flows from a point of high voltage to a point of low voltage, just as water flows from a high point to a low point (see Figure 7).

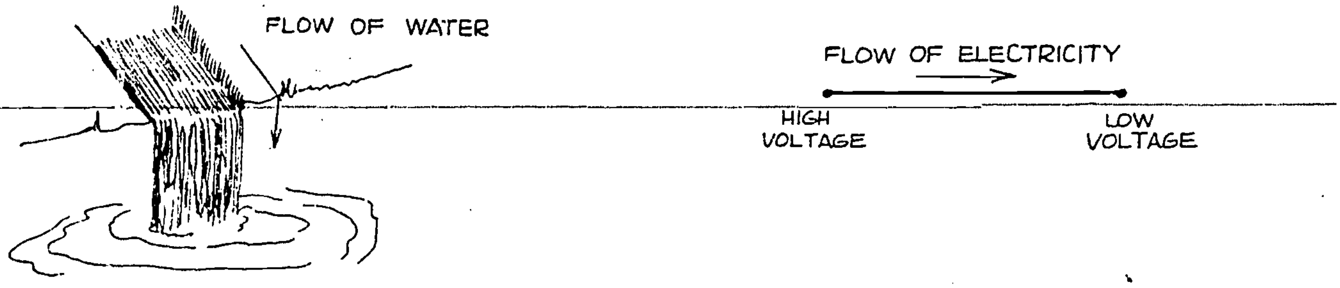


FIGURE 7: *A voltage difference compared with a height difference.*

If two pools of water are at the same height, no water flows between them. And if two points of an electric circuit are at the same voltage, no current flows between them. In terms of individual charges, if two ends of a wire contain the same numbers of positive and negative charges, there is no reason for electrons to flow from one end to the other. The two ends of the wire are at the same voltage (see Figure 8).

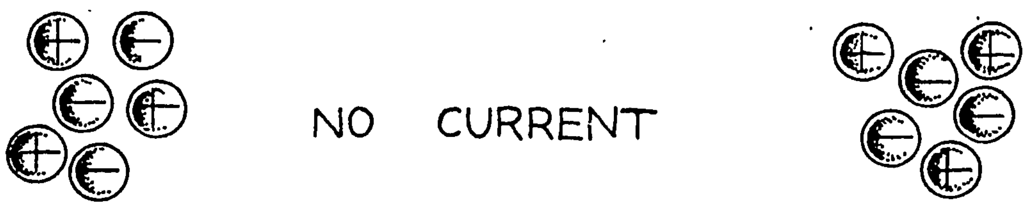


FIGURE 8: *No current flows when equal numbers of positive and negative charges are at each end.*

Effort is required to lift an object against the attraction of gravity. Effort is also required to remove a negative charge from positive charges. The amount of effort is proportional to the size of the charge; twice as much charge requires twice as much effort.

Voltage may be thought of as a measure of the effort required to separate unlike charges. The voltage difference between two points, then, measures this effort. Thus voltage difference is greater when the quantity of charge is greater.

The flow of electricity may be said to be caused by a voltage difference, and the amount of current in the wire is proportional to the voltage difference.

Current is measured in units of amperes, and if the current in a wire is one ampere when the voltage difference is six volts, the current is two amperes when the voltage difference is 12 volts.

Metal wires are good conductors of electricity, so current flows when there is even a small voltage difference between the ends of a wire. But air is a poor conductor unless a large voltage difference exists. Lightning occurs when the voltage difference between a cloud and the ground or between two clouds is so great that atoms in the air are pulled into pieces.

20-4 Artificial Respiration

Why is mouth-to-mouth resuscitation the best form of artificial respiration to apply in emergency situations?

Tom was very lucky, following his bout with the lightning bolt, to have someone close at hand who knew how to perform mouth-to-mouth resuscitation. Otherwise, he might very well have died of hypoxia.

Only a few decades ago, other techniques of artificial respiration were used which were considerably less effective. One of these older techniques involved applying a rhythmic pressure and release to the victim's ribcage, either from the front or the back. Another technique added the step of raising the victim's arms during the "release" part of the cycle.

Mouth-to-mouth resuscitation has several advantages over the other two methods. It is the most effective method for getting air into the victim's lungs, by immediately providing pressure. It is easy to do. The rescuer can sense the victim's response and time his own efforts to the victim's response. If the victim has suffered injury to his body, mouth-to-mouth resuscitation has the advantage of requiring a minimum of movement.

To understand why the mouth-to-mouth method is most effective at getting air into the victim's lungs, consider the graphs below. Each graph shows the volume of air in the victim's lungs as a function of time. The dashed lines represent the volume of air in the lungs in their normal relaxed state.

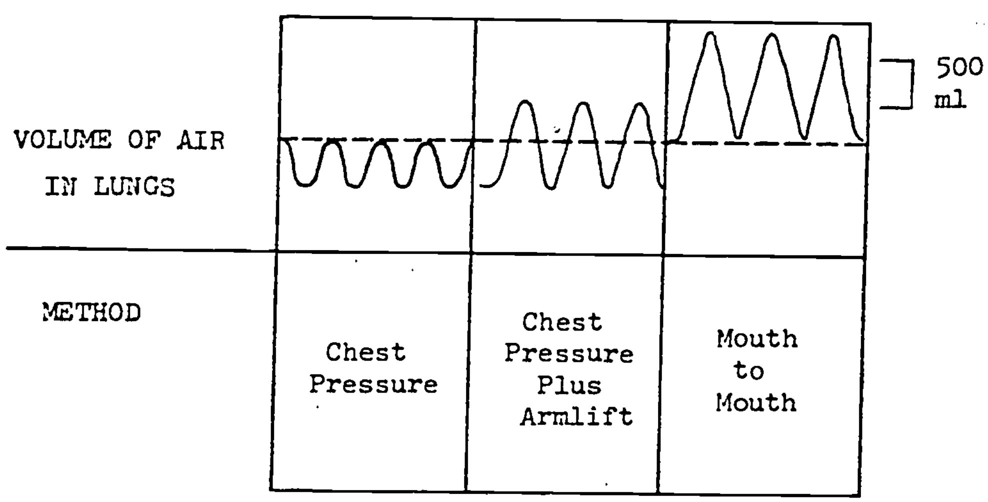


FIGURE 9: *A comparison of three methods of artificial respiration.*

Chest pressure alone (or back pressure alone) only decreases the volume of the lungs and forces air out. Lifting the victim's arms expands his lungs somewhat, but not nearly as much as the pressure created in mouth-to-mouth resuscitation does.

Hospitals have equipment which performs artificial respiration mechanically. One kind of device is the tank respirator. The older type of tank respirator, called the iron lung, is an airtight container which encloses the entire body except for the head. The modern portable type encloses only the chest. Either type uses a motor to reduce the pressure at regular intervals. The chest wall is forced to expand in a way that resembles normal breathing.

The other kind of mechanical device is the resuscitator. The resuscitator delivers air through a face mask. At regular intervals the resuscitator produces pulses of air, which increase the pressure in the lungs. The resuscitator forces air into the lungs by creating a pressure outside which is greater than atmospheric. This is in contrast to the tank respirator, which expands the chest wall, reducing the pressure in the lungs to less than atmospheric. Both devices rely on pressure outside the lungs being greater than pressure within the lungs to cause air to move into the lungs.

What general statement can be made about the attraction and repulsion of like and unlike charges?

What is the main difference between static electricity and current electricity?

When electrical current is flowing in a wire, what is actually flowing?

If no current is flowing in a wire, what can be said about the electrical charges at the two ends of the wire?

In what way is a voltage difference like a height difference in a flow of water?

Why has mouth-to-mouth resuscitation replaced other forms of artificial respiration?

How does a respirator differ from a resuscitator?

Vocabulary:

current--the movement of electric charges, usually a flow of electrons.

electric charge--the property of being able to exert electric force, i.e., electrical attraction and repulsion.

electron--a negatively charged particle of matter.

electrostatics--the study of motionless electric charges.

respirator--a device which aids breathing by applying a negative pressure outside the chest at regular intervals.

resuscitator (re-SUS-ih-TAY-tur)--a device which aids breathing by forcing air into the lungs at regular intervals.

voltage--a measure of the difference in charge between two points.

SECTION 21:

21-1 Chemistry and Biomedicine

Why study chemistry in a biomedical curriculum?

In Section 10 we considered a lung--first at the visible level and then at the microscopic or cellular level. But to understand fully what a lung is and how it works, we must consider parts of the lung that are too small to see even with the most powerful electron microscope. These small parts include water and gases and salt and very complex chemicals, and we will find that each of these substances is composed of characteristic molecules. Our bodies consist of a large number of different kinds of molecules, and the properties of molecules and ways in which they interact with one another to form other kinds of molecules is the field of chemistry. One way we can view our bodies is as a complex chemical machine.

Obviously, we can exist without a knowledge of chemistry. A person breathes even though he knows nothing about the properties of oxygen. But many of the medical advances of the past hundred years that have made our lives healthier have been based on a knowledge of chemistry. (And many of the problems of modern life, such as pollution, that threaten our health are also caused by a knowledge of chemistry.)

Knowing the chemistry of oxygen has helped us understand how oxygen is transported to the cells of our bodies and how it is used there. Understanding the chemistry of foods has added to our knowledge of nutrition. And out at the forefront of medical research, many scientists are studying cancer from the point of view of chemistry, since the disease involves complex chemical changes within the body.

But chemistry is useful not only on the frontiers of research, but also in the day-to-day treatment of common ailments. Drugs are chemicals, and not only manufacturing them but also preparing them for a patient requires a knowledge of chemistry. Laboratory tests for many types of disease involve chemistry. So chemistry is important not only in understanding more about how our bodies work, but also because of its practical use in medical professions.

21-2 Atoms and Ions

How are atoms organized?

Chemistry involves the properties and interactions of molecules, but before we deal with these we must take one step further back and consider the smaller entities of which molecules are composed.

In the preceding section we discussed electrical current and mentioned that the current with which we deal is commonly the flow of small, negatively-charged particles called electrons. Evidence for electrons was first found in the 19th century. By 1900 it was known that all electrons, no matter where they come from, are identical; each has the same mass and the same electrical charge.

In 1803, the English scientist, John Dalton, had proposed that matter was composed of small, indivisible particles that he called atoms. As time passed, however, evidence accumulated that atoms were not indivisible. In 1911, a British scientist named Ernest Rutherford performed a series of experiments which led him to propose that an atom is composed of a positively charged nucleus, surrounded by the smaller, negatively charged electrons. Rutherford proposed a model to describe what he knew about atoms.

Unlike the bell-jar model of the lung, which is a real object with working parts, Rutherford's model was a verbal description of what he believed to be the structure of the atom. In Rutherford's model, the electrons overcome the attraction of the oppositely charged nucleus by orbiting rapidly about the nucleus in much the same way that planets move around the sun. Rutherford's experiments showed that the diameter of a nucleus is only about one ten-thousandth the diameter of an atom.

A number of years later the nucleus was found to be composed of two kinds of particles. One is the proton which has a mass about 1836 times the mass of the electron and a positive charge equal in magnitude to the negative charge of the electron. The other kind of particle in the nucleus is the neutron which has a mass almost equal to the mass of a proton but has no electrical charge (see Figure 1).

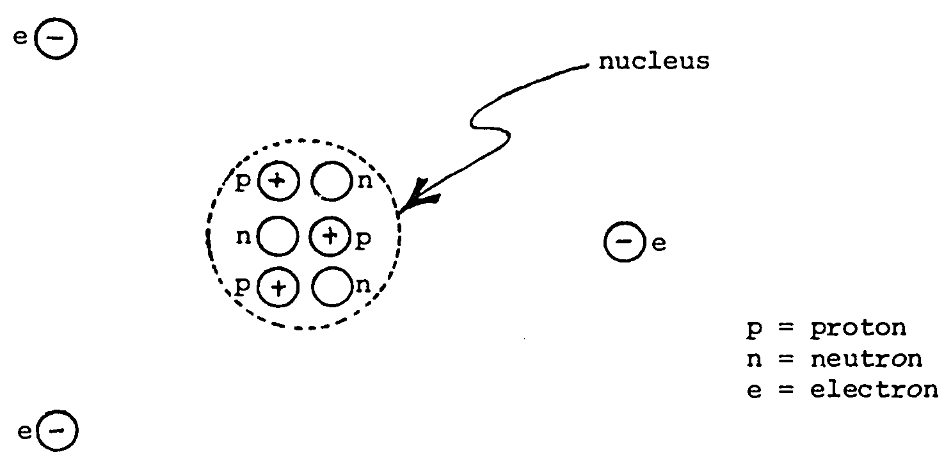
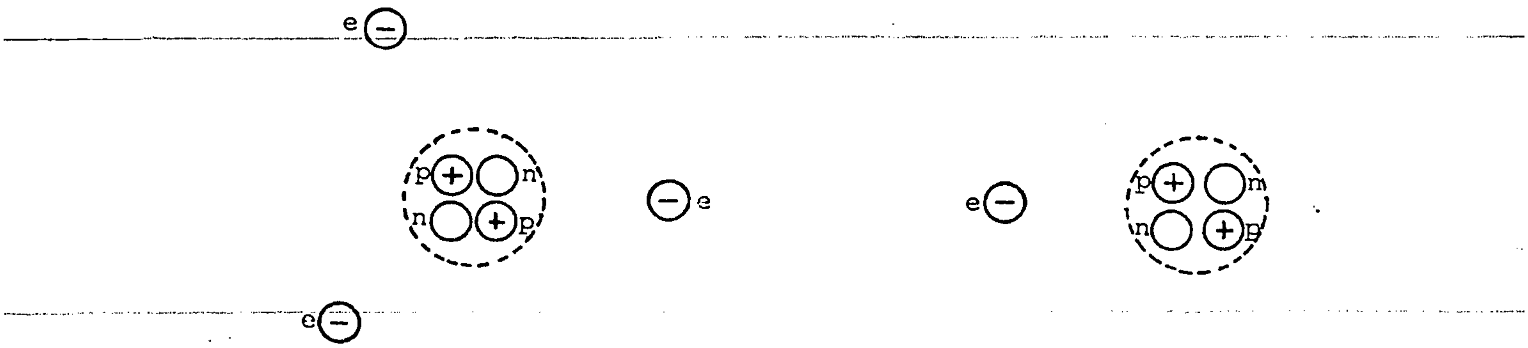


FIGURE 1: *Rutherford's model of the atom (not to scale).*

A neutral atom is one which has no net electric charge. Since the positive charge of a proton is equal in magnitude to the negative charge of an electron, a neutral atom has an equal number of protons and electrons. For example, the atom depicted in Figure 1 has three protons and three electrons, so that the net electrical charge is zero.

Atoms both within the body and without are often in a state in which they have lost or gained one or more electrons. An atom which has gained an electron has a net negative charge, while an atom which has lost an electron has a net positive charge. A charged atom is called an ion (see Figure 2). Much of the substance of our blood, muscles and bones exists as ions.



A negatively charged helium ion (two protons, three electrons).

A positively charged helium ion (two protons, one electron).

FIGURE 2: *Ions.*

Electrons are the only particles to enter or leave an atom, except in the event of a nuclear reaction. When you scuff your feet on a carpet, electrons and negative ions are transferred from the carpet to your body. The result is that the carpet contains a certain number of excess positive ions while you have an equal number of excess negative ions.

Ions may also be formed by other means. Bombardment by radiation, such as X-rays, can displace electrons from atoms, thus creating ions. Ionization by X-rays can cause harmful changes in the body. This is why X-ray technicians generally wear protective lead aprons and why patients are given minimal exposure to X-rays. A high voltage, that is, a large concentration of electrical charge, can cause ion formation (see Figure 3).

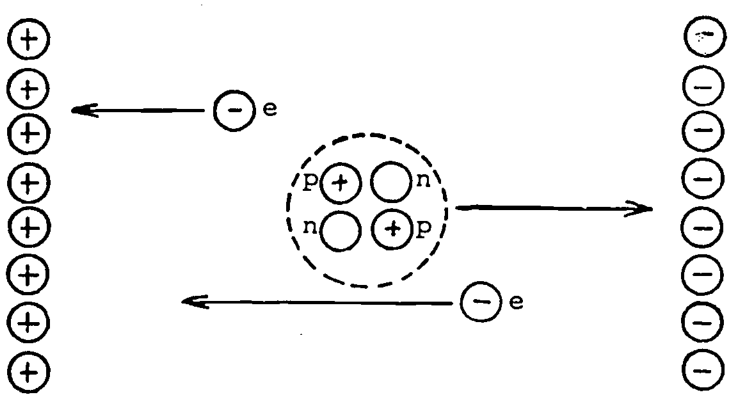


FIGURE 3: *Formation of ions.*

Air can be ionized if a sufficiently large voltage exists. If a large enough voltage occurs between a cloud and the ground, or between two clouds, the air between is ionized, and the process is seen as a lightning flash.

Electrons, being negatively charged, are attracted to a concentration of positive charge, while a positively charged nucleus is drawn toward a concentration of negative charge. And, as we will soon see, some kinds of atoms have the ability to attract electrons away from other kinds of atoms, resulting in the formation of positive and negative ions.

Many ions are present in the fluids of our bodies. For example, the quantity of one type of ion in the blood (the hydrogen ion) is important to respiration, because it is a factor in controlling the breathing rate, and certain ions have a role in drowning; we will consider these topics soon. Also, ions are involved in the transmission of nerve impulses, such as those to the respiratory center of the brain.

21-3 Elements

Different types of atoms contain different numbers of protons, neutrons and electrons. Many types of atoms are important to life. An atom which contains one proton is a hydrogen atom. An atom with six protons is a carbon atom, and an atom with eight protons is an oxygen atom. Hydrogen, carbon and oxygen are said to be elements. An element is a substance in which every atom has the same number of protons. Aluminum and iron are elements. Water is not an element because it is composed of hydrogen atoms and oxygen atoms.

The number of protons in the nucleus is called the atomic number of an atom. Atomic number distinguishes the atoms of one element from the atoms of another element. All carbon atoms have an atomic number of six; every oxygen atom has an atomic number of eight. Since in a neutral atom the number of protons is equal to the number of electrons, the atomic number is also equal to the number of electrons in a neutral atom.

The number of protons and electrons determines the main properties of an element; the number of neutrons makes only a very slight difference. Carbon atoms exist with six, seven or eight neutrons (all carbon atoms have six protons and electrons), but the behavior of the three forms of carbon is almost identical. (Each form is called an isotope of carbon, an important concept, but one that we will not treat at this time.)

The importance of mass was emphasized in Section 2. When working with chemicals in the laboratory, we often need to know the mass of one substance that will interact chemically with a certain mass of another substance. To deal with this sort of problem, we need to know the masses of the kinds of atoms involved.

Atoms are so small that if their masses were given in grams, the numbers would be awkward to work with. Therefore, another unit of mass is used, called the atomic mass unit. This unit is arbitrarily based on the mass of a carbon atom with six protons, six neutrons and six electrons being 12 atomic mass units, or 12 amu.

Most elements naturally occur as a mixture of isotopes, and chemists and biologists are usually interested in the average mass of the atoms in this mixture. This average is properly called the atomic mass of an element, but more commonly known as the atomic weight.

For example, the average mass of hydrogen atoms is about $\frac{1.008}{12}$ times that of a carbon atom with six neutrons. Thus the atomic weight of hydrogen is 1.008 amu. The atomic weight of carbon is approximately 12.01 amu (since the other isotopes must be taken into account), that of nitrogen about 14.01 amu, and oxygen has an atomic weight of about 16.00 amu.

Our bodies are composed of a large number of elements. Figure 4 shows the 12 elements that are most abundant in our bodies, although small amounts of many others are essential to health.

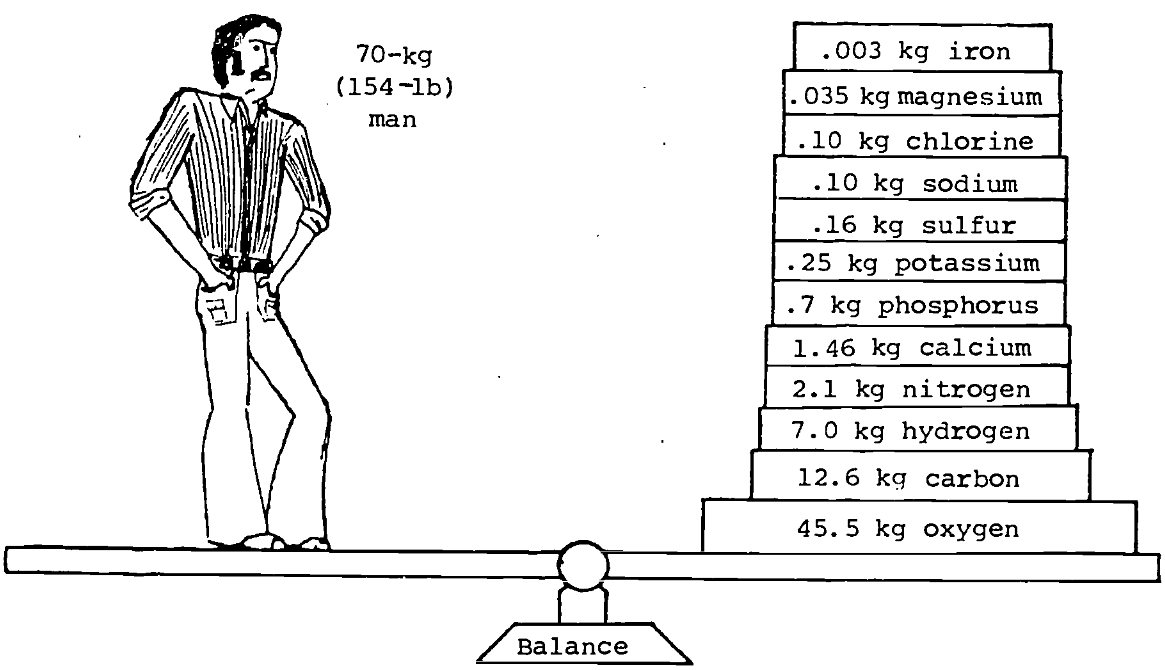


FIGURE 4: *Major elements of the human body.*

Each element has a different role in our bodies. Carbon, oxygen, hydrogen, nitrogen and, to a lesser extent, sulfur and phosphorus make up our tissues. Calcium and phosphorus are found in our bones. Sodium, potassium and chlorine exist as ions in the fluids of our bodies. Iron is a component of a very important substance which is responsible for transporting oxygen through our bloodstreams.

The elements are listed in the order of their atomic numbers in a chart called the periodic table. Each element has a standard symbol, which is used throughout the scientific world. Many symbols, such as H for hydrogen or C for carbon, seem to be appropriate; but others, such as Na for sodium and Fe for iron are not as obvious. This is because they are based on the Latin words for these elements. The periodic table gives other information on each element, such as its atomic weight.

We may immediately note a few features of the periodic table. One is that the elements that exist as gases at room temperature, such as hydrogen, helium, nitrogen and oxygen, tend to be in the upper right-hand corner of the table. The "heavier" (actually denser) elements, for example lead and gold, tend to be toward the bottom, where the atomic weights are greater.

Elements are arranged as they are in columns (above and beneath one another) because elements in the same column tend to behave chemically in a similar way. Thus, the chemical properties of sodium (11) and potassium (19) are similar, as are those of fluorine (9) and chlorine (17). This important principle makes the study and application of chemistry easier, as you will soon see.

Note that of the 12 most abundant elements in our bodies, all but iron have atomic numbers of 20 or less. For this reason we will generally restrict our discussion to the upper part of the periodic table.

21-4 Electron Orbitals

A model is useful only if facts can be explained in terms of the model. Rutherford's model was useful in many ways, but it could not explain why sodium and potassium, or fluorine and chlorine, or other elements in the same column of the periodic table have similar chemical properties.

In 1913, the Danish scientist, Niels Bohr, proposed an improvement on Rutherford's model. Within the next few years other scientists in turn improved Bohr's model to the form that we now find useful for explaining the chemical behavior of substances.

The spaces which electrons occupy or travel in are called orbitals. These orbitals are not the simple patterns of planetary orbits, but it is convenient for us to liken the arrangement of an atom to the solar system, the sun as nucleus and the planets as orbiting electrons (see Figure 5).

The Bohr model is relatively easy to visualize and helps explain many aspects of atomic structure that will be useful to know.

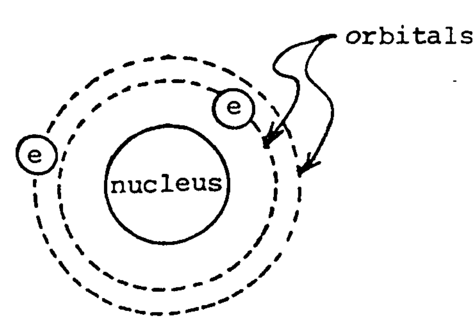


FIGURE 5: *Bohr model of atom.*

Electron orbitals occur in groups called <u>shells</u>. The first shell (in the Bohr model the first shell is the closest to the nucleus) contains two orbitals. The second shell contains eight orbitals; the third shell, 18 and the fourth shell, 32. Each orbital may contain only one electron. Thus, the first shell may have at most two electrons; the second shell, eight electrons; the third shell, 18 electrons.

Let us choose several elements from the periodic table and see which shells are occupied by electrons.

A hydrogen atom has one proton and one electron. This electron is in an orbital in the first shell (see Figure 6).

The atomic number of helium is two. Both electrons are in the first shell (see Figure 7).

Lithium is the element whose atomic number is three. Two electrons are in the first shell; the third electron is in the second shell (see Figure 8).

Next is beryllium, with an atomic number of four. Two electrons are in the first shell, two in the second shell (see Figure 9).

You are probably beginning to see a pattern. Electrons go into the first shell while there are available orbitals, then the second shell until the second shell is filled. You may suppose that electrons then fill the third shell, and you are correct, but only up to a point. But before identifying that point, we will list the electron arrangements of the elements with atomic numbers up to 18. (See the table on the next page.)

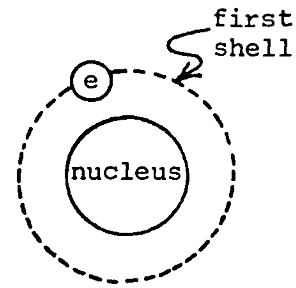


FIGURE 6: *Hydrogen atom.*

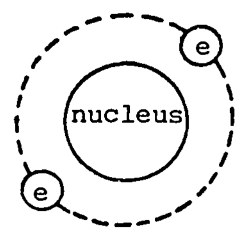


FIGURE 7: *Helium atom.*

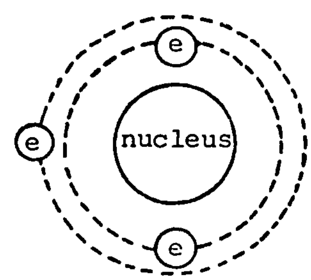


FIGURE 8: *Lithium atom.*

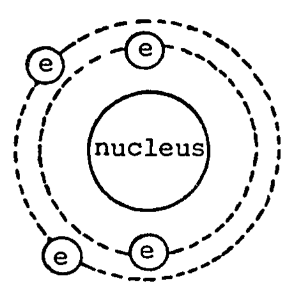


FIGURE 9: *Beryllium atom.*

The element with an atomic number of 19 is potassium. Eighteen electrons occupy the same orbitals as the electrons of argon.

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However, the other electron is not in the third shell, which has 18 orbitals, but in the fourth shell. Similarly, calcium, with an atomic number of 20, has two electrons in the first shell, eight in the second shell, eight in the third and two in the fourth.

Atomic Number	Element	Symbol	Number of Electrons		
			1st Shell	2nd Shell	3rd Shell
1	hydrogen	H	1		
2	helium	He	2		
3	lithium	Li	2	1	
4	beryllium	Be	2	2	
5	boron	B	2	3	
6	carbon	C	2	4	
7	nitrogen	N	2	5	
8	oxygen	O	2	6	
9	fluorine	F	2	7	
10	neon	Ne	2	8	
11	sodium	Na	2	8	1
12	magnesium	Mg	2	8	2
13	aluminum	Al	2	8	3
14	silicon	Si	2	8	4
15	phosphorus	P	2	8	5
16	sulfur	S	2	8	6
17	chlorine	Cl	2	8	7
18	argon	Ar	2	8	8

The rules concerning which shells are occupied by electrons become more complex as atomic number increases. However, we need not consider these rules here, because our chief concern is with those concepts of chemistry that will help to explain the chemical processes of our bodies. Recall that 11 of the 12 most abundant elements in our bodies have atomic numbers of 20 or less. So we will focus our attention on the elements with atomic numbers up to 20. This will make it easier for you to understand the principles most important to life.

One other aspect of our atomic model is directly important in our study of chemistry. Atoms tend to gain or lose electrons so as to have full or empty shells, or other special arrangements, such as eight electrons in the third shell. For our purposes in considering atomic numbers up to 20, this means that atoms tend to gain or lose electrons so as to have either zero electrons, two electrons (in the first shell), ten electrons (two in the first shell, eight in the second) or 18 electrons (two in the first shell, eight in the second, eight in the third).

It is important that you know of the tendency of atoms to attain arrangements of 0, 2, 8 or 18 electrons. This tendency is the topic of the next sections.

Vocabulary:

atom--a unit of matter composed of a nucleus of protons and neutrons surrounded by electrons.

atomic mass unit--a unit used to express the mass of an atom, based on the mass of a carbon atom with six neutrons being 12 amu.

atomic number--the number of protons in an atom.

atomic weight--the average mass of atoms of an element in atomic mass units.

chemistry--the study of the structure and properties of substances and how substances interact.

element--a substance in which every atom has the same number of protons.

ion (EYE-ahn)--an electrically charged atom.

isotopes (ICE-uh-topes)--forms of the same element which differ from one another in the number of neutrons.

neutron--an electrically neutral particle located in the nucleus of the atom.

periodic table--an arrangement of elements by order of atomic number in which elements in the same column have similar chemical properties.

proton--a positively charged particle located in the nucleus of the atom. The charge on a proton is equal in magnitude, but opposite to the charge on an electron.

shells--certain groups of orbitals.

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PROBLEM SET 21:

The following table gives the numbers of protons, neutrons and electrons in each of seven atoms.

	Protons	Neutrons	Electrons	Atomic Number	Element	Symbol
A	6	6	6			
B	6	8	6			
C	7	7	7			
D	8	8	8			
E	8	8	10			
F	10	10	10			
G	11	12	10			

1. Complete the table by giving the atomic number of each atom, the name of each element and its symbol. (Use a periodic table.)

2. Identify a pair of isotopes of the same element among the seven atoms.

3. Identify a positive ion. What is its electric charge?

4. Identify a negative ion. What is its electric charge?

5. Which of these atoms, if any, has a full outer shell?

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SECTION 22:

22-1 Ionic Bonding

How do ions combine to form ionic compounds?

We concluded the previous section by stating that atoms tend to gain or lose electrons so as to have 0, 2, 10 or 18 electrons surrounding the nucleus. It will soon be shown that electrons may transfer from one atom to another or be shared between atoms. Either process involves a chemical change. In both situations the nature of the change depends largely on the number of electrons held by the different atoms.

Turn your attention to the periodic table and the elements in the far-right column (see Figure 1).

2	He
10	Ne
18	Ar
36	Kr
54	Xe
86	Rn

FIGURE 1: *Column VIII A of the periodic table.*

Helium (He) has an atomic number of 2; thus a neutral helium atom has two protons and two electrons. The atomic number of neon (Ne) is 10, and that of argon (Ar) is 18. The atomic numbers of these elements are the numbers of electrons that provide an arrangement, or configuration that is highly stable (resistant to change).

The elements in the far-right column of the table are called the noble gases; they are too "noble" to get involved with other elements and have very little tendency to participate in chemical interactions. In fact, until quite recently no interactions had been observed involving these elements. Note the similarity in the electron configurations of the noble gases. Helium has a complete first shell. Neon has a complete second shell. Argon has 18 electrons, eight of which are in the third shell, which we stated to be a stable configuration. If a periodic table is available, you need not remember that the numbers 2, 10 and 18 represent stable electron configurations; you can find these numbers by referring to the atomic numbers of the noble gases.

We may restate the general rule by saying that atoms tend to gain or lose electrons, or share electrons, in such a way as to achieve the electron configuration of one of the elements in the far-right column of the periodic table.

Consider sodium (Na), which has two electrons in the first shell, eight in the second and one in the third. Theoretically, a sodium atom could attain the configuration of argon by gaining seven electrons, but this does not occur. There are two competing tendencies: the tendency of atoms to have the stable electron configurations of noble gases, and the attraction and repulsion of electric charges. If sodium were to gain seven electrons, the 18 electrons would repel each other, and the attraction of only 11 protons in the nucleus could not overcome this repulsion. Instead, sodium typically attains the configuration of neon by losing one electron.

Chlorine (Cl), on the other hand, has two electrons in the first shell, eight in the second but only seven in the third shell. If a chlorine atom acquires one more electron, its configuration becomes that of argon. Chlorine thus tends to gain an electron, while sodium tends to lose an electron.

When a sodium atom loses an electron, it has 11 protons and 10 electrons. It therefore has a net charge of +1 and is a positively charge sodium ion. A sodium ion is represented by the symbol Na^+. A Na^+ ion has filled first and second shells--the configuration of a stable neon atom.

One hears a lot about sodium in medicine. Sodium ions are the most common positive ions in the fluids, such as blood, outside the cells of our bodies. The amount of sodium in the blood is sometimes measured as part of a clinical analysis. Excess Na^+ may indicate several problems--a disease of the adrenal glands, severe dehydration, brain injury or diabetic coma. Too little sodium can indicate kidney disease.

A chlorine atom gains an electron to become a chloride ion. (Negatively charged ions of elements typically end in "-ide." Thus we have oxide, fluoride, sulfide and bromide ions.) A chloride ion has 17 protons and 18 electrons. Its net charge is thus -1, and it is represented by the formula Cl^-.

Cl^- ions, like Na^+ ions, are also present in large quantities in our blood; and analysis of the amount of chloride is also used to diagnose disease. High blood chloride may be a symptom of kidney disease and dehydration, while low blood chloride may indicate loss of that ion from vomiting or diarrhea or as a result of taking a diuretic (a medicine that increases urine production).

Sodium and chloride ions are thus both important chemicals in our bodies, but how do they get there?

A sodium atom may give one electron to a chlorine atom. The sodium atom becomes a positively charged sodium ion, and the chlorine atom becomes a negatively charged chloride ion.

$$Na + Cl \rightarrow Na^+ + Cl^-$$

The sodium and chloride ions are held together. What holds the ions together is the electrostatic attraction between the positively charged sodium ion and the negatively charged chloride ion. Two ions held together by electrostatic attraction are said to form an <u>ionic bond</u>.

1..:)

When bonds exist between different elements, we say they have formed a compound. The compound formed by sodium and chlorine is called sodium chloride and is represented by the formula NaCl. Sodium chloride is the chemical name of table salt.

Table salt is an important source of sodium and chloride ions in our bodies. We will discuss shortly how NaCl separates into Na^+ and Cl^-, but the need for these ions in our bodies indicates that salt has more uses to us than making some foods taste better.

Our bodies also require magnesium, which is present in bones, muscles and red blood cells.

The element magnesium has an atomic number of 12. Ten electrons are in the two inner shells; two electrons are in the outer shell. A magnesium atom becomes an ion by giving up two electrons (rather than by gaining six electrons). The loss of two electrons gives a magnesium ion the configuration of the noble gas neon. It also gives the ion a charge of +2. The symbol for the magnesium ion is Mg^{++} or Mg^{+2}.

A magnesium atom may give its outer electrons to two chlorine atoms.

$$Mg + 2\ Cl \rightarrow Mg^{++} + 2\ Cl^-$$

The ionic compound thus formed is called magnesium chloride. We may represent this compound by the formula $MgCl_2$, which indicates one magnesium atom and two chlorine atoms.

Magnesium is an important industrial metal. The main source of it is sea water. One step in the process of recovering magnesium from the sea involves converting Mg^{++} ions to $MgCl_2$, from which magnesium metal is then obtained.

22-2 Electron-Dot Formulas

The electron configuration of atoms may be conveniently shown by electron-dot formulas. Dots representing the electrons in the outermost shell of the atom are drawn around the symbol of the element. (Electrons in the inner shells do not take part in the type of chemical interactions we will be considering, so they are not shown.)

Thus hydrogen is represented as

$$H\cdot$$

and helium as

$$He:$$

Neon has two electrons in the first shell and a complete second shell of eight electrons. The two inner electrons are not shown, so neon is represented as

$$:\ddot{\underset{..}{Ne}}:$$

130

We have seen that a sodium atom has 11 electrons: two in the first shell, eight in the second shell and one in the third shell. Only the electron in the third shell is represented in the electron-dot notation.

$$\mathrm{Na}\cdot$$

Chlorine has two electrons in the first shell, eight in the second and seven in the third; the ten in the inner shells are not represented.

$$:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}\cdot$$

(It does not matter where the dots are drawn. Electron-dot formulas make no attempt to show the positions of electrons, which are in constant motion. For example, sodium's one outer electron may be placed above, below, left or right. But it pays to be neat; snowstorms of dots are difficult to interpret. And the formulas are usually easier to read with no more than two dots on each side.)

Electron-dot formulas may also represent ions. Thus the sodium ion, which has lost the only electron it had in its outer shell, is represented as

$$[\mathrm{Na}]^{+}$$

with no dots shown. A chloride ion, with one more electron than a chlorine atom, is shown as

$$[:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}:]^{-}$$

Notice that the electron-dot formulas for ions are enclosed in brackets, with the net charge outside the brackets.

The ionic compound NaCl may be represented as

$$[\mathrm{Na}]^{+}[:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}:]^{-}$$

The electron-dot formula indicates that each ion has completely filled or empty outer shells.

A magnesium atom has two electrons in its outer shell, but it may give them to two chlorine atoms. A magnesium ion and the two chloride ions are formed.

$$\mathrm{Mg}: + \cdot\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}: + \cdot\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}: \rightarrow [:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}:]^{-}[\mathrm{Mg}]^{++}[:\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Cl}}}:]^{-}$$

22-3 The Periodic Table

Why is the periodic table arranged as it is?

Sodium is the most abundant ion in the fluids of the body outside the cells, but the counterpart of sodium within cells is potassium. A potassium atom has a total of 18 electrons in its three inner shells and one in its outer shell; compare its electron-dot formula to that of sodium.

$\mathrm{Na}\cdot \quad \mathrm{K}\cdot$

How would you expect potassium to attain a stable configuration? Why, in the same way sodium does--by losing an electron. Sodium loses an electron and has the configuration of the noble gas neon; potassium loses an electron and has the configuration of argon. As a result, the chemical behavior of sodium and potassium are similar.

Note that sodium and potassium are both in the left-hand column of the periodic table. Ovserve this entire column (see Figure 2).

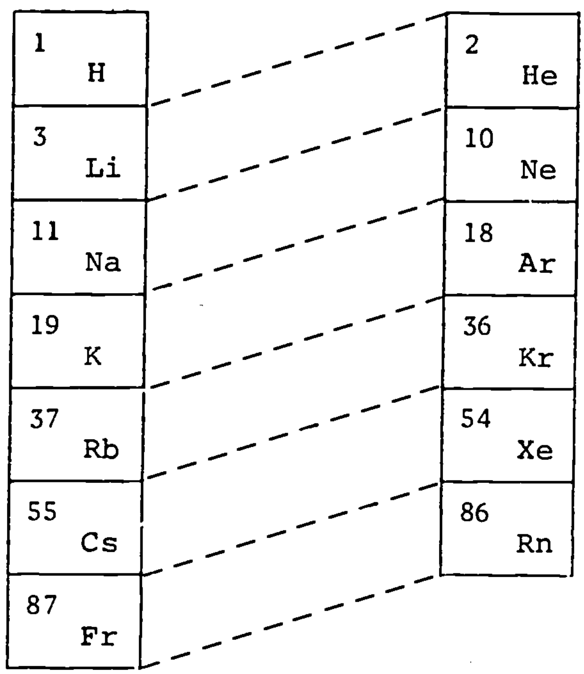


FIGURE 2: *Columns IA and VIIIA of the periodic table.*

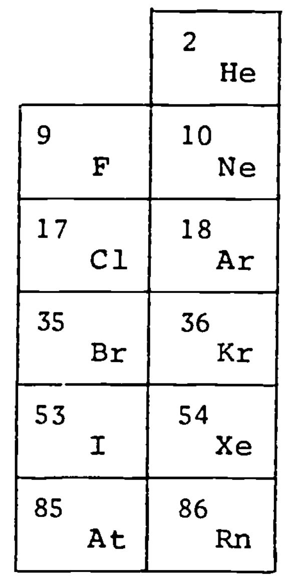
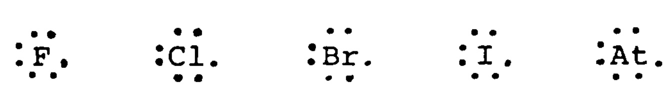


FIGURE 3: *Columns VIIA and VIIIA of the periodic table.*

Note that each element in the first column (with the exception of hydrogen) has one more electron than a noble gas. Thus each tends to form ions by losing one electron.

Now consider chlorine and the other elements in the second row from the right in the periodic table (see Figure 3).

Each of these elements lacks one electron of having a noble gas configuration.



Each may attain a stable configuration by gaining an electron and forming a negatively charged ion.

$[:\ddot{\mathrm{F}}:]^-$ $[:\ddot{\mathrm{Cl}}:]^-$ $[:\ddot{\mathrm{Br}}:]^-$ $[:\ddot{\mathrm{I}}:]^-$ $[:\ddot{\mathrm{At}}:]^-$

We are now in a position to appreciate the periodic table. As atomic number increases, the arrangement of outer electrons repeats itself in a periodic fashion. Because similar electron configurations recur periodically, similar chemical properties also recur periodically. This recurrence is reflected in the periodic table by the appearance of chemically similar elements in the same column.

About one hundred years ago, the study of chemistry involved the cataloging of the chemical properties of a large number of elements and compounds. Of the more than 60 different elements known at the time, it was recognized that certain of them had similar properties; but no one had been able to propose a scheme for their organization that was consistent with what was known about them.

Finally in 1869 the Russian scientist Dimitri Mendeleev proposed just such a scheme. In order to do so, he had to make two assumptions. One was that atomic weight was less important than chemical properties in determining how the elements should be organized. For example, he placed iodine after tellurium, even though the atomic weight of iodine is <u>less</u> than that of tellurium. By interchanging these two elements, he could show each of them in a column containing elements with similar properties.

Mendeleev's second assumption was that there were elements that had not yet been discovered, which enabled him to leave blanks in his table. In the case of six such blanks, he used his table to predict the properties of undiscovered elements. Eventually all six were found to have properties that agreed closely with the predictions; three of them were found within Mendeleev's lifetime.

It may not be obvious, but Mendeleev's table of the elements is one kind of model. Unlike the bell-jar model of the lungs or the Bohr model of the atom, the periodic table is not a model of real concrete objects, or even of a process. Instead it is a description of the <u>relationships</u> of all the elements to one another.

Keep in mind that electrons, protons and neutrons were unknown in Mendeleev's day. His model said nothing about the structure of atoms or <u>why</u> the different elements have the properties they do. Yet his model had one characteristic of great importance. It enabled him to make predictions--predictions that were subject to confirmation or denial. In Mendeleev's case the predictions were confirmed, and his model has withstood the test of time.

The periodic table has perhaps been the greatest step toward making possible a systematic and logical study of chemistry. If we know the chemical behavior of one element, we may predict the behavior of other elements, without being required to perform experiments. By knowing the behavior of chlorine, we also know approximately the behavior of fluorine, bromine and iodine.

By knowing that sodium and chlorine form an ionic compound, and by using the periodic table, we may predict that potassium and chlorine form potassium chloride (KCl).

$$[K]^+ \; [:\ddot{\underset{..}{Cl}}:]^-$$

And since fluorine and chlorine are in the same column of the periodic table, we would expect that sodium and fluorine form sodium fluoride (NaF).

$$[Na]^+ \; [:\ddot{\underset{..}{F}}:]^-$$

You may be aware that fluoride ions have a role in preventing tooth decay; drinking water is sometimes fluoridated with sodium fluoride.

22-4 Ions in Solution

What happens to sodium chloride in water?

We mentioned the fact that a positive and negative ion are held together by electrostatic attraction, and called this attraction an ionic bond. In a real situation, a large number of ions are present, and every positive ion attracts every negative ion. The result is typically a crystalline solid with each positive ion surrounded by several negative ions, and each negative ion by several positive ions. Table salt, sodium chloride, is an example. Positive sodium ions are surrounded by negative chloride ions, and chloride ions by sodium ions (see Figure 4).

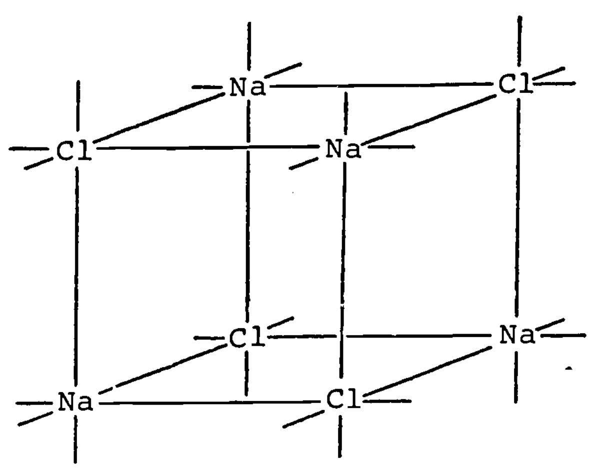


FIGURE 4: *The structure of a sodium chloride crystal.*

If you look closely at a grain of table salt, you can see the cubic shape of the crystal.

However, it is not ionic solids that concern us so much as the dissolved salts present in body fluids. So let us define a few terms relating to solutions.

When sand is dropped into water, the grains sink to the bottom. The grains are visible and retain their identity. When a small amount of salt is dropped into water, however, the salt disappears. If any grains of salt do reach the bottom, they disappear upon stirring. The salt has dissolved in the water.

When a substance dissolves in another substance, we have a solution. Salt dissolved in water is a solution. The substance which dissolves, such as salt, is called the solute. The substance in which the solute dissolves is the solvent. Water is the solvent in our example (see Figure 5). Root beer is a solution of sugars and other compounds (solutes) dissolved in water.

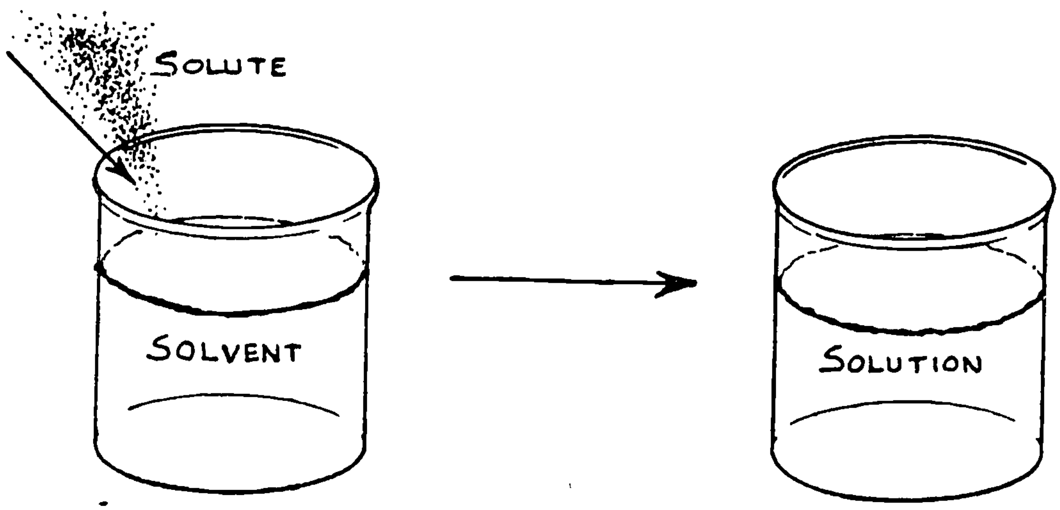


FIGURE 5: *The components of a solution.*

Various properties of ions in solution will concern us in our study of the human body. But at present we will mention just one characteristic. When an ionic compound dissolves in water, usually the ionic bonds are broken. In other words, the attraction between the ions is lost. When sodium chloride is placed in water, the water is able to separate the sodium ions from the chloride ions. The solid structure is destroyed, and the positive and negative ions exist in solution more or less independently of one another. So the salt we eat dissolves in body fluids and we are able to use the sodium and chloride ions.

What are the elements in the far-right column of the periodic table called? How likely are they to gain or lose electrons?

Does sodium tend to gain or lose electrons? How many? Which other elements have this same tendency?

What elements have the electron-dot formula $:\ddot{\underset{\cdot\cdot}{\text{Element}}}\cdot$ *?*

Lemonade is a solution containing solutes dissolved in a solvent. What is the solvent? Can you name any of the solutes?

Vocabulary:

compound--a substance composed of two or more different elements joined by chemical bonds.

dissolve--to go into solution; for example, by separating into individual ions.

electron configuration--the arrangement of electrons in various shells.

ionic bond (eye-AHN-ik)--a bond formed by the electrostatic attraction between a positive ion and negative ion.

solute (SAHL-yewt)--a substance that dissolves in another substance.

solution--a mixture of substances in which one (or more) is dissolved in the other.

solvent (SAHL-vunt)--a substance that dissolves another substance.

PROBLEM SET 22:

1. Write the electron-dot formulas of the following elements. You may use the periodic table.

Carbon (C)	Sulfur (S)	Magnesium (Mg)
Oxygen (O)	Chlorine (Cl)	Calcium (Ca)
Phosphorus (P)	Argon (Ar)	Potassium (K)

a. Which tend not to react?

b. Which tend to gain one electron?

c. Which tend to lose one electron?

d. Which tend to lose two electrons?

e. Which pairs would you expect to have similar chemical properties?

2. Write the electron-dot formulas of the following ions.

Potassium (K^+)	Bromide (Br^-)
Calcium (Ca^{++})	Oxide (O^{--})

3. You know that magnesium and chlorine form the ionic compound $MgCl_2$. Use this information and the periodic table to predict

which of the following are correct formulas for other ionic compounds.

$MgCl$ Ca_2Cl $MgBr_2$

$CaCl_2$ CaF_2 BaF_3

Draw electron-dot formulas for the compounds that you predict to exist.

4. Which compound in each group of three would you expect to exist?

a. CaO $CaHe$ $CaNe$

b. NaO NaO_2 Li_2O

c. $AlCl$ $AlCl_2$ $AlCl_3$

5. Tincture of iodine, which is used as an antiseptic on minor cuts, often contains sodium iodide. Write the correct electron-dot formula for sodium iodide.

6. Potassium bromide was once used to cure sleeplessness. Write its electron-dot formula.

7. Magnesium oxide may be used for various stomach disorders, such as excess acid accompanied by constipation. Write the electron-dot formula for magnesium oxide.

8. Mixtures of helium and oxygen are sometimes given to patients who are suffering from a disease that causes shortness of breath. Would you expect helium to cause undesirable chemical reactions in the body? Why or why not?

SECTION 23:

23-1 Covalent Bonding

What type of bond joins the atoms in a water molecule?

We have seen that a sodium atom tends to lose an electron to become a sodium ion; a chlorine atom tends to gain an electron to become a chloride ion. Sodium and chloride ions are held together in sodium chloride by electrostatic attraction; in our bodies they exist as independent ions dissolved in the body's fluids.

However, the majority of substances that are important to life do not exist as ions. The atoms in water, oxygen and carbon dioxide, for example, are joined by a different type of bond. This type of bond also enables atoms to attain the electron configuration of a noble gas, but electrons are not lost or gained. Rather, electrons are shared between two atoms. A bond formed by two atoms sharing electrons is called a covalent bond.

As an example to illustrate covalent bonding, consider hydrogen. A hydrogen atom has one electron. A hydrogen atom may achieve stability by sharing its electron with another atom. Two hydrogen atoms share their electrons to form a stable hydrogen <u>molecule</u> (see Figure 1).

$$H\cdot + H\cdot \rightarrow (H{:}H)$$

FIGURE 1: *The formation of a hydrogen molecule from two hydrogen atoms.*

Since the electrons are shared, they are in the first shell of each hydrogen atom. Two electrons in the first shell is the configuration of the noble gas helium; consequently two hydrogen atoms make a stable hydrogen molecule.

Let us consider the term "stable." A book lying on a desk is stable; it remains on the desk until someone picks it up or knocks it onto the floor. By contrast, try to stand a book on one of its corners, and you have an unstable situation. Let go of the book and it immediately falls over. A hydrogen molecule is stable in the same sense as a book lying flat. Unless acted upon from outside, it will continue to exist as hydrogen atoms bound together. However, as you will find out, hydrogen can interact (violently, in fact) with oxygen.

Hydrogen gas is extremely light and at one time was used in lighter-than-air balloons. However, it is extremely flammable; so it has been replaced by helium which, although not quite as light, has the advantage of being non-flammable.

A famous hydrogen balloon was built in Germany in the 1930's to carry passengers across the Atlantic Ocean. It was named the Hindenburg and measured 803 feet in length. On May 6, 1937, the Hindenburg was landing in New Jersey with 105 persons aboard when it suddenly caught fire. Thirty-six lives were lost.

A hydrogen molecule can be represented by the electron-dot formula

$$H{:}H$$

Electron-dot notation is especially helpful in the study of covalent bonding, because it enables us to see that every atom in a molecule has a stable electron configuration. This technique is very useful in studying the structures of the substances that make up our bodies.

It may be useful to contrast the formation of an ionic bond with that of a covalent bond. Sodium gives an electron to chlorine and the ions are attracted because they have opposite electric charges. No electrons are shared.

$$Na\cdot + :\ddot{\underset{..}{Cl}}\cdot \rightarrow [Na]^{+}\,[:\ddot{\underset{..}{Cl}}:]^{-}$$

A hydrogen atom, on the other hand, does not give its electron to another hydrogen atom. Rather, each hydrogen atom donates an electron to a covalent bond.

$$H\cdot + \cdot H \rightarrow H{:}H$$

A hydrogen atom has a stable configuration when it has two electrons, the same number of electrons as the noble gas helium. Other elements we will be concerned with have stable configurations when they have eight electrons in their outer shells. Eight electrons in an outer shell are represented by an element's symbol surrounded by eight dots; in this way an electron-dot formula makes it easier to recognize a stable configuration.

The atomic number of chlorine is 17. Two of the electrons are in the first shell, eight in the second shell and seven are in the outer shell. Remember that we can ignore the electrons in the first two shells. The electron-dot formula of chlorine is thus

$$:\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}\cdot$$

A chlorine atom is surrounded by seven dots; eight dots indicate a stable configuration as in the noble gas argon. Two chlorine atoms may combine to form a molecule of chlorine gas. Each chlorine atom shares one of its electrons with the other chlorine atom.

$$:\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}\cdot + :\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}\cdot \rightarrow :\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}:\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}:$$

Each chlorine atom in the electron-dot formula is then surrounded by eight dots, which represents a stable configuration. The two electrons that form the covalent bond are shown <u>between</u> the two atoms and are counted as part of the electrons surrounding each atom.

Chlorine molecules exist as a greenish gas that is extremely irritative to the nasal passages. Chlorine is used to treat drinking water and swimming pools.

A chlorine atom may also share an electron with a hydrogen atom. The result of this sharing is a molecule of hydrogen chloride gas.

$$H\cdot + :\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}\cdot \rightarrow :\overset{\cdot\cdot}{\underset{\cdot\cdot}{H}}:\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}:$$

The outer shell of the chlorine atom in hydrogen chloride has eight electrons, the hydrogen atom has two electrons and both have the same number of electrons as noble gases.

The situation with hydrogen chloride is more complicated than that with hydrogen or chlorine because atoms of two different elements are involved. If you are very alert, you may wonder why hydrogen and chlorine do not form an ionic compound, which would be represented as

$$H^{+}\left[:\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}:\right]^{-}$$

The fact is that to a certain extent hydrogen chloride is ionic. Nature is seldom as simple as we would like it to be, and classifying bonds as either ionic or covalent makes things a bit too simple. In some cases, the bond is partly covalent and partly ionic. Hydrogen chloride exists as a covalent molecule when it is a gas, but when it dissolves in water, it separates into H^+ and Cl^- ions. Hydrogen chloride dissolved in our stomach juices has an important role in digesting food.

But you are not expected to be able to predict whether a bond is ionic or covalent. What is important is that you understand something about the formation of bonds and, if you are told whether bonding is ionic or covalent, to be able to represent the structure of the compound.

To further illustrate covalent bonding and the use of electron-dot formulas, let us consider water. A water molecule is composed of two hydrogen atoms and one oxygen atom.

An oxygen atom has six outer electrons and may be represented in a number of ways, all being correct.

$$\cdot\ddot{\underset{\cdot\cdot}{\mathrm{O}}}\cdot \qquad \cdot\ddot{\underset{\cdot}{\mathrm{O}}}: \qquad \ddot{\underset{\cdot\cdot}{\mathrm{O}}}:$$

The oxygen atom is two electrons short of having a stable electron configuration. One way in which it may achieve stability is by sharing two electrons with two hydrogen atoms. The result is a water molecule.

$$\mathrm{H}:\ddot{\underset{\cdot\cdot}{\mathrm{O}}}:\mathrm{H} \qquad \mathrm{H}:\ddot{\underset{\substack{\cdot\cdot\\ \mathrm{H}}}{\mathrm{O}}}:$$

Both representations are correct. It is not the function of electron-dot formulas to indicate the shapes of molecules, but only to show the bonding. The electron-dot formula of water shows that an oxygen atom forms covalent bonds with two hydrogen atoms. The oxygen atom has eight electrons in its outer shell; each hydrogen atom has two.

23-2 Structural Formulas and Molecular Formulas

In what other ways may a molecule be represented?

Electron-dot formulas give information about electron configuration, but it is easier to represent a molecule by its structural formula. A structural formula represents each pair of electrons in a bond by a line. Only electrons involved in bonding are shown. The structural formulas of a hydrogen molecule, a chlorine molecule and hydrogen chloride are written in this way:

H-H   Cl-Cl   H-Cl

Structural formulas and electron-dot formulas each have advantages over the other. Structural formulas are easier to write and show bonds more clearly. However, structural formulas give no information about electron configuration, which is the key to bonding. Electron-dot formulas enable us to predict whether or not a given molecule is likely to exist.

As an example of the advantage of electron-dot formulas, suppose we know that a water molecule contains two hydrogen atoms and one oxygen atom, but do not know whether the structural formula is

H-H-O or H-O-H

We may identify the correct one by drawing electron-dot formulas for each.

H:H·Ö: H:Ö:H

Only in the second formula is the oxygen atom surrounded by eight electrons and each hydrogen atom by two electrons. The first does not exist.

Structural formulas do not represent the shape of molecules, only which atoms are bonded to which. Most molecules extend in three dimensions and their shape is difficult to show on two-dimensional paper.

The substances we have been discussing can also be expressed in terms of their molecular formulas. These formulas are a chemical shorthand that shows the numbers and kinds of atoms contained in a single molecule of each substance.

hydrogen:	H_2
chlorine:	Cl_2
hydrogen chloride:	HCl
water:	H_2O
table sugar:	$C_{12}H_{22}O_{11}$

In a molecular formula, each kind of atom is represented by its chemical symbol. Following the chemical symbol is a subscript that indicates the number of that particular kind of atom in the molecule. Thus H_2O indicates a molecule composed of two hydrogen atoms and one oxygen atom. When there is only one atom of an element present, the "1" is not written.

Molecular formulas may also be used to express the composition of ionic compounds. We know that solid sodium chloride contains Na^+ ions and Cl^- ions joined to all the ions around them by ionic bonds, and that sodium chloride dissolved in water exists as independent Na^+ and Cl^- ions. Nevertheless, it is convenient to represent sodium chloride by the formula NaCl. This formula tells us that for each sodium ion there is one chloride ion. The formula for magnesium chloride, $MgCl_2$, says that for every magnesium ion there are two chloride ions.

23-3 More Examples of Covalent Bonding

Let us consider a few more substances in terms of their electron-dot formulas, structural formulas and molecular formulas. Before reading on, refer to the periodic table and see whether you can draw the electron-dot formulas for nitrogen and carbon.

The atomic number of nitrogen is 7. Two electrons are in the first shell, while five are in the second shell. Since five electrons are in the outer shell, we may write the electron-dot structure of the nitrogen atom.

```
 ••
•N•
 •
```

Nitrogen requires three additional electrons to achieve the electron configuration of the noble gas neon. One way to do this is by sharing three of its electrons with three hydrogen atoms. At the same time each hydrogen atom shares its electron with nitrogen. The result is a molecule of ammonia gas (see Figure 2).

```
Electron-       ••          H-N-H     Structural
dot formula    H:N:H          |       formula
                ••            H
                H
```

FIGURE 2: *Ammonia.*

The molecular formula for ammonia is NH_3. All three ways of representing ammonia are used in scientific and medical writing.

A carbon atom has six electrons, four of which are in the outer shell. Four more are needed to achieve a noble gas configuration. One way of representing a carbon atom is

```
 •
•C•
 •
```

A carbon atom can achieve a stable configuration by sharing all four of its outer electrons with other atoms. Methane is the molecule formed by the combination of a carbon atom with four hydrogen atoms (see Figure 3).

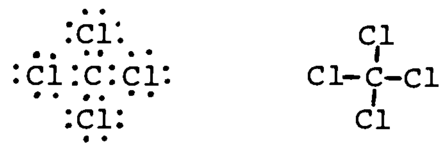
```
                H             H
Electron-       ••            |       Structural
dot formula    H:C:H        H-C-H     formula
                ••            |
                H             H
```

FIGURE 3: *Methane.*

The molecular formula of methane is CH_4. Methane is the major constituent of natural gas.

The molecular formula of carbon tetrachloride is CCl_4. (The prefix "tetra-" is from the Greek and indicates four.) The electron-dot formula shows the sharing of electrons between the carbon atom and the four chlorine atoms (see Figure 4).

Electron-dot formula



Structural formula

FIGURE 4: *Carbon tetrachloride.*

Carbon tetrachloride is a liquid that was once widely used as a cleaning agent, because it dissolves many substances that are not soluble in water. However, its vapors and the liquid itself are quite toxic, and this has limited its use in recent years.

23-4 Molecules

Earlier we used the word "molecule" to refer to the individual particles that make up gases. Now that you have been introduced to covalent bonding, we can extend our definition of molecules to include liquids and solids, as well as gases.

A hydrogen molecule is two hydrogen atoms joined by a covalent bond. A chlorine molecule is two chlorine atoms joined by a covalent bond. A molecule of hydrogen chloride is one hydrogen atom and one chlorine atom held together by a covalent bond. In general, we may say that a molecule is a group of atoms held together by covalent bonds. The definition of a molecule does not properly include groups of atoms held together by ionic bonds, but we will find it convenient to refer to the group of atoms in a formula (for example, NaCl) as a "molecule" of the ionic substance.

A substance is made up of one type of molecule. Water is composed of H_2O molecules; ammonia is composed of NH_3 molecules; table sugar is composed of $C_{12}H_{22}O_{11}$ molecules.

And each type of molecule has its own characteristic chemical properties. In fact, a molecule is the smallest quantity of matter which can exist by itself and retain all the chemical properties of the original substance.

As an example we will take a substance called hydrogen peroxide, which has the molecular formula H_2O_2 (see Figure 5).

Electron-dot formula

Structural formula

FIGURE 5: *Hydrogen peroxide.*

At room temperature it is a syrupy liquid that is used in antibacterial agents and bleaches. From a sample of hydrogen peroxide, we may remove smaller and smaller quantities of the substance which still have all of the properties of hydrogen peroxide. Eventually, however, we would reach a point at which any further removal of atoms would cause a change in the properties of what was left. This point is reached when we have just one molecule of hydrogen peroxide--two hydrogen atoms and two oxygen atoms. If we removed one oxygen atom from this molecule, we would be left with a molecule of water--a liquid with quite different properties. A H_2O molecule does not act against bacteria in the way that a H_2O_2 molecule does, nor does it have the bleaching properties of H_2O_2. The properties of a molecule are generally completely different from the parts of which it is composed.

How does a covalent bond differ from an ionic bond?

How many electrons are shared in a covalent bond?

How is a covalent bond represented in a structural formula?

What information is given by a molecular formula?

How can one tell the number of covalent bonds that an atom is capable of forming?

How can one perdict the composition of a molecule of a particular substance, knowing the kinds of atoms it contains?

Vocabulary:

covalent bond (ko-VAY-lunt)--a bond formed by the sharing of electrons by two atoms.

molecule (MAH-luh-kyool)--a group of atoms joined by covalent bonds.

SECTION 24:

24-1 Double and Triple Bonds

What kind of bonds connect the atoms in oxygen, nitrogen and carbon dioxide molecules?

The function of the respiratory system is to supply the cells of our bodies with oxygen and to remove carbon dioxide. The air from which we obtain oxygen is composed mainly of nitrogen. But we have not yet explained the bonds that connect the atoms in these three important kinds of molecules.

The oxygen molecule contains two oxygen atoms. Its molecular formula is O_2. Unlike H_2 and Cl_2, the O_2 molecule cannot be explained in terms of a covalent bond in which each atom contributes one electron to a bond with the other atom. If we attempt to represent the molecule in this way, we find that each oxygen atom is surrounded by only seven electrons.

$$:\underset{\cdot}{\ddot{O}}\cdot + \cdot\underset{\cdot}{\ddot{O}}: \rightarrow :\underset{\cdot}{\ddot{O}}:\underset{\cdot}{\ddot{O}}:$$

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Each oxygen atom has six electrons in its outer shell. Two additional electrons are required to fill the second shell.

Recall that a water molecule is formed by two hydrogen atoms each contributing one electron to bonds with the oxygen atom.

$$H\cdot + H\cdot + \cdot\ddot{\underset{..}{O}}\cdot \rightarrow H:\ddot{\underset{..}{O}}:H$$

The bond in an oxygen molecule is formed by each oxygen atom contributing two electrons to the bond. As a result, four electrons are shared.

$$\ddot{\underset{..}{O}}::\ddot{\underset{..}{O}}$$

A covalent bond in which four electrons (two pairs of electrons) are shared is called a double bond.

A double bond is represented in a structural formula by two lines. The structural formula of the oxygen molecule is

$$O{=}O$$

The molecular formula of the nitrogen molecule is N_2. The atomic number of nitrogen is 7; five electrons are in the outer shell. The electron-dot formula of a nitrogen atom is

$$:\dot{N}:$$

Two nitrogen atoms may form a nitrogen molecule if each atom contributes three electrons to the bond. Six electrons are shared by the two atoms.

$$\dot{\underset{\cdot}{N}}::\dot{\underset{\cdot}{N}}$$

The bond between the two nitrogen atoms is called a triple bond, since three pairs of electrons are shared.

Three lines are used to show a triple bond in a structural formula. The structural formula of a nitrogen molecule is

$$N{\equiv}N$$

Molecules of many other compounds of biological importance contain double and triple bonds. When you are asked to draw an electron-dot formula, you can find out whether the molecule contains double or triple bonds by trial and error. Try an electron-dot formula with all bonds drawn as single bonds. If every hydrogen atom is not surrounded by two electrons, or if every other atom is not surrounded by eight electrons, try one or more double bonds. If double bonds do not give a proper structure, try triple bonds.

We will illustrate this procedure by determining the electron-dot formula for carbon dioxide, CO_2. Before reading on see whether you can draw the correct electron-dot formula yourself by trial and error. It is known that both oxygen atoms are bonded to the carbon atom. The electron-dot formulas of carbon and oxygen atoms are

$$\cdot\underset{\cdot}{\dot{C}}\cdot \quad \text{and} \quad :\underset{\cdot}{\ddot{O}}\cdot$$

The electron-dot formula using only single bonds is

$$:\underset{\cdot}{\ddot{O}}:\underset{\cdot}{\dot{C}}:\underset{\cdot}{\ddot{O}}:$$

Each oxygen atom is surrounded by only seven electrons, while the carbon atom is surrounded by only six electrons. Clearly, this is not the correct structure for CO_2.

If we now assume double bonds and draw the electron-dot formula, we obtain

$$\underset{\cdot\cdot}{\ddot{O}}::C::\underset{\cdot\cdot}{\ddot{O}}$$

Both oxygen atoms and the carbon atom are surrounded by eight electrons. We may conclude that we have drawn the correct electron-dot formula and that the structural formula of carbon dioxide is

$$O=C=O$$

Acetylene is a gas used in welding because it burns with a very hot flame. The molecular formula of acetylene is C_2H_2. The hydrogen atoms are bound to different carbon atoms, and the carbon atoms are bound to each other. If we try to draw an electron-dot formula using single bonds, we obtain

$$H:\underset{\cdot}{\dot{C}}:\underset{\cdot}{\dot{C}}:H$$

Each carbon atom is surrounded by only six electrons.

Hydrogen atoms may not be involved in double bonds, because a hydrogen atom has only one electron to contribute to a bond and needs only two electrons to fill the first shell. If we try a double bond between the carbon atoms, we obtain

$$H:\dot{C}::\dot{C}:H$$

Each carbon atom in this structure is surrounded by seven electrons, which are still not enough.

Finally, we try a triple bond.

$$H:C\vdots\vdots C:H$$

This structure must be correct because each hydrogen atom is surrounded by two electrons and each carbon atom by eight electrons.

The structural formula of acetylene is therefore

$$H-C\equiv C-H$$

24-2 Polyatomic Ions

How can we account for ions containing more than one atom?

Now that you have been introduced to ionic bonding and single, double and triple covalent bonding, there is one other situation to consider. It is an ion composed of a group of atoms joined by covalent bonds.

In an electrolytic cell such as you used for electroplating, as well as in a storage battery or a television tube, the positively charged electrode is called the anode. The negatively charged electrode is called the cathode.

Positively charged particles are attracted to negatively charged electrodes or cathodes. Negatively charged particles are attracted to positively charged electrodes, or anodes. For this reason positively charged ions are called cations, and negatively charged ions are called anions.

The ions we have considered thus far are formed by electrons being added to or removed from a single atom. Examples are Na^+ (the sodium cation) and Cl^- (the chloride anion).

However, when sodium hydroxide (NaOH) is dissolved in water, it separates into two kinds of ions. One is a Na^+ cation, while the other is negatively charged and contains both an oxygen and a hydrogen atom. This anion is called the hydroxide ion.

We may understand the hydroxide ion in terms of its electron-dot structure, if we remember that it contains the extra electron received from the sodium atom. An oxygen atom has six electrons in its outer shell; two more are needed for a complete set of eight. One of these is obtained by sharing the electron of the hydrogen atom; the other is the electron donated by sodium. Thus we have

$$\left[H:\ddot{\underset{..}{O}}:\right]^-$$

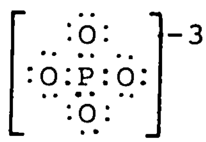
As usual, the structure is enclosed in brackets with the net charge outside. The hydroxide ion is also represented as OH^-.

The hydroxide ion is very important in chemistry, and we will soon encounter it again in the study of acids and bases and the chemical regulation of breathing.

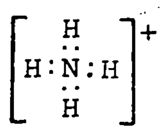
Ions composed of more than one atom, such as the hydroxide ion, are called polyatomic ions. (The prefix "poly-" is from the Greek word for "many," and means "more than one.")

Another polyatomic ion is the phosphate ion, which is an important component of bones. A phosphate ion contains a phosphorus atom and four oxygen atoms and has a net charge of -3. Its formula is PO_4^{-3}.

A phosphorus atom has five electrons in its outer shell; each oxygen also has six electrons; and since the ion has three extra electrons, the total number of electrons to be shown in an electron-dot formula is 5 + (4 x 6) + 3 = 32. The electron-dot formula shows single bonds between the phosphorus atom and each of the four oxygen atoms.



Positively charged polyatomic ions also occur. One that is often encountered is the ammonium ion (NH_4^+). The electron-dot formula shows the five outer electrons of nitrogen plus the four electrons of the four hydrogen atoms <u>minus</u> one electron (because the ion gives up one electron to acquire a positive charge). 5 + 4 - 1 = 8 electron dots.



Ammonium chloride, NH_4Cl, used in many cough syrups, is one example of a compound containing the ammonium ion.

Other polyatomic ions commonly encountered are NO_3^- (nitrate), SO_4^{-2} (sulfate), CO_3^{-2} (carbonate) and HCO_3^- (bicarbonate).

In the formulas of many substances, groups of atoms are enclosed in parentheses and followed by a subscript. An example is calcium phosphate, which is much of the structural matter in bones, and whose formula is $Ca_3(PO_4)_2$. Each Ca atom loses two electrons; a total of six electrons are lost. The six electrons are gained by two phosphate ions to give each a charge of -3. The subscript 2 shows that the molecule contains two PO_4 groups. In other words, the molecule contains two phosphorus atoms and eight oxygen atoms, as well as three calcium atoms. The formula could be written $Ca_3P_2O_8$, but the use of parentheses makes it easier to see that the compound contains phosphate ions.

24-3 <u>Tom's Case Record--Age 28</u>

The car glided along the two-lane highway leading to Lake Lodgepole. Tom leaned into the curves, powering through them, cutting corners when it was safe--indulging his old fantasy of being a race driver.

He lighted a cigarette and took a long, deep drag on it. He glanced down at the stream running alongside the road. The country looked fine. Even smelled good. He could hardly wait to get to the lake and Fred's cabin.

It had been great of Fred to invite them up for the weekend. The whole family needed the change. He had put in several hard weeks at work without a letup, and Peter had just got over chicken pox--for a couple of weeks there he had just been a three-year-old bundle of misery. And poor Kathy had been stuck in the house with him all that time, playing nursemaid when what she wanted to do was get out in the yard and play farmer.

But everything was all right now, and they were on their way to the lake. Tom pulled out of a tight outside curve with just a hint of a squeal from the tires, just enough to make it sound dangerous. He glanced down at his watch.

"Twenty more minutes," he said, "and we'll be there. Looks like we'll have time for a swim before supper."

"Good," said Kathy. She sounded like she meant it. "I could use that swim right now."

It was hot--in the mid-eighties. It was uncomfortable in the car even with all the windows down, and Peter was starting to get fussy in the back seat. But Tom wasn't bothered. Everything was going right. The kid was healthy--chicken pox didn't count, all kids get chicken pox--the job was going right, the house was all fixed up, and they were just about ready to start on the garden. It was a beautiful, early summer afternoon. All that was missing was a quick dip and a few tall, cool ones on Fred's front porch overlooking the lake.

Finally they pulled up to Fred's house. Fred had heard them coming, and he was standing out in front with his hands on his hips and a big grin on his face.

"Hey, old buddy," he shouted, "how was the trip?"

"Hot!" said Tom.

"How about a swim before dinner?" said Fred.

"I'm ready. Just point me at the water."

"Now, just a minute, you he-man athletes," said Kathy. "We've got a hungry child and a lot of baggage here. Why don't you help me unload and move this stuff into the house?"

Nobody liked the idea of work before pleasure, but they went along with it anyway. Tom and Fred lugged in the suitcases and a couple of bags of groceries, and when Kathy had finished putting the food away she warmed up some hot dogs and beans for Peter.

Meanwhile, Tom and Fred were getting into their trunks, and at last they raced down the hill toward the lake. They both hit the floating pier at the same time, and they ran right on out to the end of it and dived in.

Tom came up tingling all over and grinning from ear to ear. It was great. He swam back and forth, out beyond the end of the pier, trying out all the strokes he knew and treading water while he caught his breath between "laps." He hadn't been in the water for a while, and some of the old muscles weren't in very good shape, but he did all right.

Fred swam up behind him and pushed his head under. Tom turned around under the water, dived between Fred's legs and submarined him. They both came up laughing.

"Thought you had me, didn't you?" said Tom.

"Should've known better, shouldn't I? Hey, let's get on back and have a drink."

"Somehow I knew you were going to say that," said Tom. "You go ahead. It isn't every day I get to go for a swim. I'm going to stay in a few more minutes."

"Okay, buddy. See you." Fred raised his arms high over his head, clasped his fingers together and slapped the water hard, splashing Tom with a great sheet of water. By the time Tom could see again Fred was well out of reach, stroking for shore. Good old Fred.

Tom floated around on his back for a minute or two, watching one little white cloud right in the middle of the sky. He couldn't remember when he'd felt so good. And he had two days ahead with nothing more pressing to do than float on his back and watch clouds.

After a few minutes of that he flopped over and looked toward shore. Kathy and Peter had come down from the house. Fred and Kathy were standing on the pier, talking. Peter was sitting right on the end of the floating pier, dangling his feet in the water, watching that cloud.

Tom wondered if he could swim to the pier underwater. It looked like about fifteen yards. Peter would be delighted if he just popped out of the water right in front of him, like magic. Fifteen yards underwater should be a breeze. He took a deep breath, submerged, and started swimming toward the pier.

He swam with his eyes open, but it didn't do any good. The water was pretty muddy, and there wasn't much light, so he really couldn't see anything. He kept swimming anyway, trying to estimate how far he had left to go.

When he judged that he was just about to the dock, his air started to give out. He gave one good downward stroke with his arms and rose toward the surface, ready to gulp a lungful of air as soon as he felt his head rising into the air.

But instead of air he ran into something solid. He was under the pier.

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His lungs would burst if he didn't get some air--and there wasn't any air. He was trapped. He panicked. He felt water rushing into his nose and he tried not to breathe.

* * *

Fred saw Tom submerge. He guessed that Tom was going to swim up alongside the pier and surprise everybody with a big splash, and he waited to see where he would come up so he could jump out of the way.

He waited a few seconds, looking all around the pier for motion in the water. He didn't see any. Tom was swimming deep. He looked around some more. It was getting to about time for the old boy to surface. Where was he?

Fred had a terrible thought: maybe Tom wasn't swimming at all. Maybe he'd had a cramp out there and gone under, or maybe he'd just passed out.

Just as he yelled, "Tom's under!" and started running for the end of the dock to dive in, he saw Tom's leg in the water at the side of the pier.

"I got him!" he yelled. He dropped into the water and pulled Tom out from under the dock by the leg.

Tom wasn't struggling.

Quickly Fred put Tom's hands on top of the pier, one on top of the other. He held them there with one of his own hands as he lifted himself up out of the water and onto the pier. Then he lifted Tom out. Kathy and Peter ran up just as he was turning Tom over onto his back.

"Get up to the house and call an ambulance!" he yelled. Kathy took off, but Peter hung back, staring.

"Go with your mother!" He sounded as threatening as he could. This might turn out to be the kind of thing you don't want a little kid to watch.

Within seconds after he had Tom on the pier, he was giving him mouth-to-mouth resuscitation. It worked. By the time Kathy got back down from the house, Tom was breathing.

When the ambulance got there he didn't want to go, but the attendants put him on the stretcher and carried him up the hill to the ambulance. One of them said they would probably keep him at the hospital for observation.

Just before they closed the door and drove away, Tom looked forlornly out at them.

"Well," he said, "I guess I messed up the weekend."

Kathy reached in and patted him on the foot.

"Don't worry," she said. "I'm just glad you're all right."

"Yeah," said Fred, "we'll have plenty more weekends."

24-4 Drowning

Described below are the events which occur in a typical fresh-water drowning.

Upon submersion the victim usually starts a panicky struggle to reach the surface. Breath-holding, for various lengths of time, occurs during this stage. This is followed by inhalation and swallowing of water. Coughing and vomiting, loss of consciousness, terminal gasping with flooding of the lungs and death then follow very quickly.

Death is typically caused by circulatory failure. Large amounts of water are absorbed into the bloodstream from the lungs. The sudden and violent increase in blood volume dilutes the blood and upsets the normal balance of the blood constitutents. This causes ventricular fibrillation, which results in failure of the heart to pump any blood.

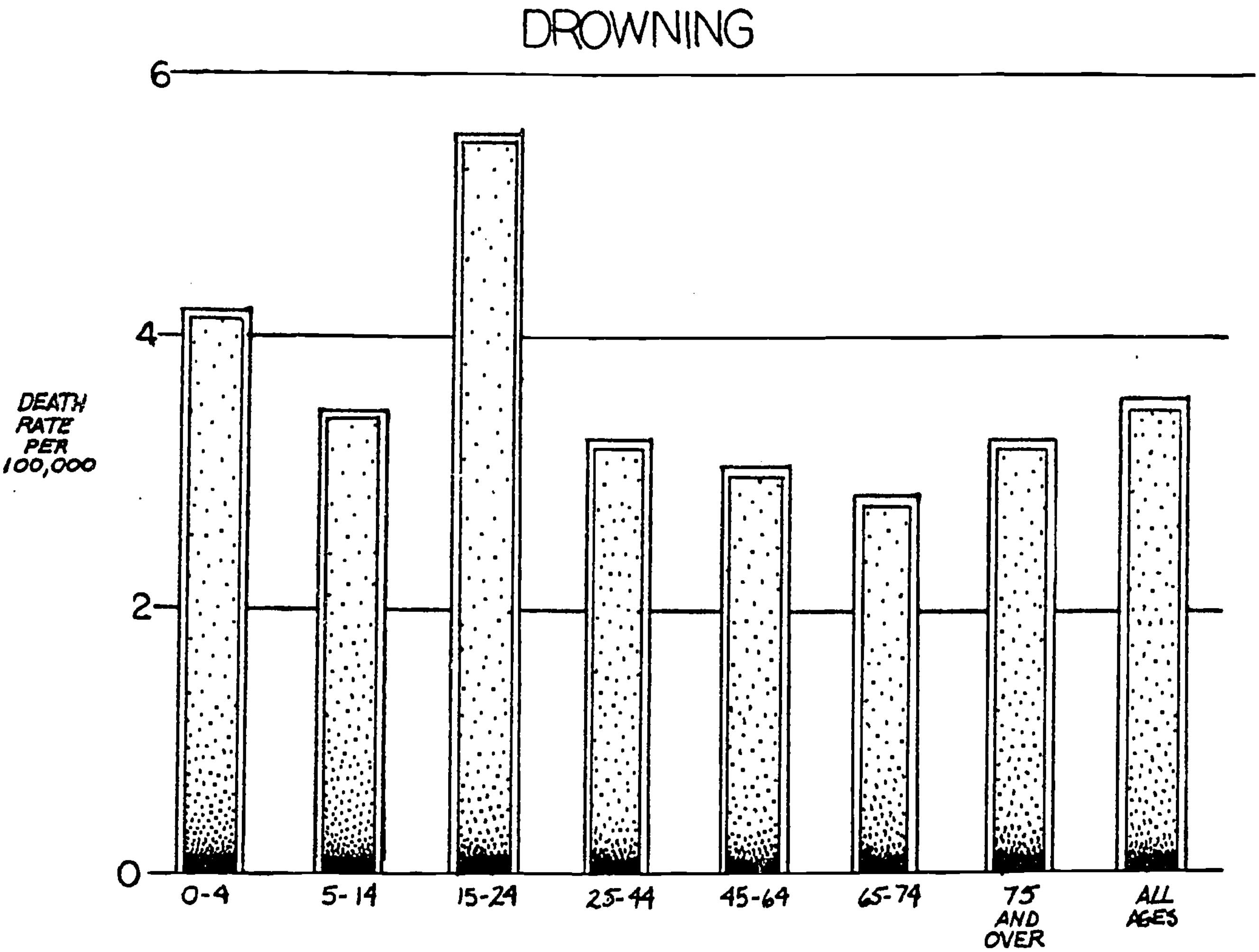
If the victim is rescued before terminal gasping sets in, spontaneous recovery may occur.

It has been estimated that in some 10 to 25 per cent of all drownings little or no water enters the lungs. In these cases a laryngospasm, or spasm of the larynx, closes the glottis to both water and air. The cause of death in this case is asphyxia, or lack of oxygen. Physicians call such cases "dry" drownings. Even after death the glottis remains closed.

A laryngospasm can also occur while a patient is under anesthesia. It may be triggered by anesthetic being administered too rapidly, by irritation of the air passageway by a gaseous anesthetic such as ether, by the accumulation of secretions, vomit or blood in the air passageway or by the disturbance of a surgical instrument in the posterior pharynx. If a laryngospasm occurs, relaxant drugs are administered. In an extreme case a tracheotomy, which is an incision into the trachea, is performed to bypass the closed glottis. A tube, called an endotracheal tube, is often inserted during anesthesia to prevent such an occurrence.

Drownings account for about 7,000 deaths each year in the United States. For every death, five to ten near-drownings occur. Statistics on drowning for different age groups are shown on the following page.

Note the large number of drownings occurring to individuals between the ages of 15 and 24. The use of common sense when engaged in water activities could reduce this statistic at least to the level of those for other ages.



How many electrons are shared in a double bond? In a triple bond?

To which electrode is a positively charged ion attracted? A negatively charged ion?

How can the net charge of a polyatomic ion be found when its structural formula is known?

Why are most drowning deaths caused by heart failure, rather than a lack of oxygen?

Explain how a person can drown without water entering the lungs. What is the cause of death in this case?

Vocabulary:

anion (ANN-eye-un)--a negatively charged ion.

anode (ANN-ode)--a positively charged electrode.

asphyxia (as-FIK-se-uh)--insufficient oxygen. Same as hypoxia.

cathode (KATH-ode)--a negatively charged electrode.

cation (CAT-eye-un)--a positively charged ion.

double bond--a covalent bond in which two pairs of electrons are shared.

laryngospasm (lah-RING-go-SPAH-zm)--spasm or contraction of the larynx which closes the glottis.

polyatomic ion (PAHL-ee-uh-TOM-ik)--an ion containing more than one atom.

triple bond--a covalent bond in which three pairs of electrons are shared.

PROBLEM SET 24:

1. The electron-dot formulas of three compounds are shown below. Nitrous oxide is an anesthetic often used in dentistry. In small doses it gives a feeling of pleasure that has earned it the nickname "laughing gas." Hydrogen cyanide, by contrast, has a bad reputation because it is extremely poisonous. Formaldehyde is a gas that, when dissolved in water, is used as a disinfectant and to preserve biological specimens.

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                                                 :O:
 ..   ..                                         ::
 N::N::O              H:C:::N:                  H:C:H
 ..   ..
```

nitrous oxide | hydrogen cyanide | formaldehyde

a. Identify each bond as a single, double or triple bond.

b. Write the structural formula of each compound.

c. Write the molecular formula of each compound.

2. Determine which of the following compounds have double or triple bonds by drawing an electron-dot formula. Then draw the correct structural formula.

a. CS_2--carbon disulfide, which was once used as a cleaning fluid, but is now considered too irritating and toxic to be used for this purpose.

b. H_2S--hydrogen sulfide, a pollutant with the odor of rotten eggs.

c. CO--carbon monoxide, a toxic gas that is emitted in automobile exhausts and is the most common air pollutant in this country.

d. SO_2--sulfur dioxide, a common pollutant, produced by the combustion of coal and oil, that affects the respiratory system. (Both oxygen atoms are bonded to the sulfur atom.

e. C_2H_4--ethylene, a stronger gaseous anesthetic than nitrous oxide; it is flammable.

3. Draw electron-dot formulas for the following polyatomic ions. Then draw the structural formula of each. Be on the lookout for double bonds. (You will need the clue that none of these ions have oxygen atoms bonded to other oxygen atoms.)

a. nitrate--NO_3^-

b. sulfate--SO_4^{-2}

c. carbonate--CO_3^{-2}

d. bicarbonate--HCO_3^- (Hint: the hydrogen atom is not bonded to the double-bonded oxygen atom.)

4. a. Sodium bicarbonate is used in many common remedies for indigestion. Use your knowledge of chemistry to determine which of the following is the correct formula for sodium bicarbonate.

Na_2HCO_3 $NaHCO_3$ $Na(HCO_3)_2$

b. Milk of magnesia, a laxative, is magnesium hydroxide. Determine the correct formula for magnesium hydroxide.

SECTION 25:

25-1 Chemical Reactions

How are chemical reactions represented? What is a balanced equation?

The past few sections have been devoted to the structure of molecules and ions, but this is only one part of chemistry. The subject of chemistry also includes the study of how structures change when chemicals interact with one another. The chemicals in our bodies are constantly changing. If we could follow a molecule of sugar that we eat, we would see the atoms arranged in one structure after another, until eventually they formed carbon dioxide and water. Many diseases are associated with the chemical changes of the body. In disease, such changes may not occur, or they may occur too rapidly or too slowly.

Each time a chemical change occurs, bonds are formed, broken or both formed and broken. When a chemical bond of either type, covalent or ionic, is formed, or when a bond is broken, we say that a chemical reaction has taken place. An example of a chemical reaction is the formation of water from hydrogen and oxygen.

The substances which react are called the reactants, while the substances which are formed by the reaction are called the products. In the formation of water, hydrogen and oxygen are the reactants, while water is the product.

A chemical reaction may be described by a chemical equation. For example,

$$HCl + NaOH \rightarrow NaCl + H_2O$$

Such an equation may be read aloud in several ways, all of which mean the same thing. One reading might be, "Hydrogen chloride plus sodium hydroxide yields sodium chloride plus water." Another possible reading is, "Hydrogen chloride and sodium hydroxide react to form sodium chloride and water." A third reading is, "One molecule of HCl and one molecule of NaOH react to form one molecule of NaCl and one molecule of H_2O." Note the direction of the arrow in the preceding equation. It tells us the direction in which the reaction proceeds--in other words, which side contains the reactants and which side the products.

An important principle of chemical reactions is that the number of atoms of each element does not change during the reaction. For example, if the reactants contain 18 carbon atoms, the products must contain 18 atoms of carbon. An equation which shows the same number of atoms of each element on both sides of the arrow is said to be a balanced equation.

In order to balance an equation, we first write it showing one molecule of each substance.

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

To determine whether the equation is balanced, we count the number of atoms of every element on each side of the equation. On the left side are one carbon atom, four hydrogen atoms and two oxygen atoms. On the right side are one carbon atom, two hydrogen atoms and three oxygen atoms. The equation is not balanced.

The right side is short two hydrogen atoms, so let us put the coefficient "two" before the formula H_2O and recheck to see whether the equation is balanced.

$$CH_4 + O_2 \rightarrow CO_2 + 2\ H_2O$$

The right side of the equation now has one carbon atom, four hydrogen atoms and four oxygen atoms.

The only difficulty remaining is that the left side has two fewer oxygen atoms than the right side, but this is easily fixed by having two oxygen molecules on the left side.

The balanced equation is therefore

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Observe that both sides of the equation have the same number of carbon atoms, hydrogen atoms and oxygen atoms. The equation is now balanced.

A balanced chemical equation tells us the relative numbers of each type of molecule involved in a chemical reaction. And as we will soon see, it also can help us to calculate the quantities of each substance taking part in the reaction.

25-2 Reversible Reactions

How are reactions that may go in either direction represented?

Many reactions may go in either direction, depending on conditions. In bottling plants, soft drinks are carbonated by adding carbon dioxide, which reacts with water to form H_2CO_3 (carbonic acid).

$$CO_2 + H_2O \rightarrow H_2CO_3$$

This is done under pressure because more CO_2 reacts when the pressure is greater. If you shake a bottle of a carbonated drink and remove the cap, the reverse reaction occurs. Carbonic acid splits into water and carbon dioxide.

$$H_2CO_3 \rightarrow H_2O + CO_2$$

Reactions that may go in either direction are called reversible reactions and are indicated by arrows pointing each way ($\rightleftarrows$). The reaction of carbon dioxide and water to form carbonic acid is an example of a reversible reaction.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftarrows \underset{\text{carbonic acid}}{H_2CO_3}$$

25-3 Reactions Involving Ions

The reactions we considered in Section 25-1 all involved molecules. Other reactions, however, may involve ions. Consider, for example, the separation, or dissociation, of copper sulfate in water. Copper sulfate dissociates into positively charged copper ions and negatively charged sulfate ions. The dissociation may be represented by the following equation.

$$CuSO_4 \rightarrow Cu^{+2} + SO_4^{-2}$$

Note that the equation is balanced with respect to atoms. Both sides include one copper atom, one sulfur atom and four oxygen atoms. Observe also that the equation is balanced with respect to net electric charge. There is no net charge on the left side; on the right side are two positive charges and two negative charges, which add to a net charge of zero (+2 - 2 = 0). The number of electrons and protons represented on the left side is the same as the number represented on the right side. Electrons and protons are neither created nor destroyed during a chemical reaction; they can only be brought together or separated.

Hydrogen gas is commonly prepared in the laboratory by adding zinc to a solution of hydrogen chloride dissolved in water, which is called hydrochloric acid. HCl dissociates in solution into H^+ and Cl^- ions, so the equation for this reaction is

$$Zn + 2\ H^+ + 2\ Cl^- \rightarrow Zn^{+2} + H_2 + 2\ Cl^-$$

But the two chloride ions in this equation take no part in the reaction and appear on both sides of the equation. Therefore, we may omit these chloride ions that are only "spectators" to the reaction, and write

$$Zn + 2\ H^+ \rightarrow Zn^{+2} + H_2$$

This second equation does not imply that the solution has a positive charge; the negative charge of the chloride anions that are not shown is equal in magnitude to the positive charge of the hydrogen and zinc cations. Both equations are correct, and either may be used to represent the reaction of zinc with hydrochloric acid.

Remember that net electric charge must be the same on both sides of a balanced equation. For this reason the following equation is not correct, even though it is balanced with respect to the atoms on both sides.

$$2\ Zn + 2\ H^+ \rightarrow 2\ Zn^{+2} + H_2$$

Two zinc atoms and two hydrogen atoms appear on each side of the equation. However, the net charge on the left side is 2(+1) = +2, while on the right side the net charge is 2(+2) = +4. For this equation to be correct, protons would have to be created or electrons destroyed. Since this does not happen, this equation is not correct.

What two factors must be considered in determining whether a chemical equation is balanced?

What is indicated by the arrow in a chemical equation?

Is it possible for an equation to be balanced with respect to net charge and yet not balanced with respect to atoms?

Vocabulary:

balanced equation--a chemical equation in which the same numbers of atoms of each element appear on each side, and the net electric charge is the same on each side.

chemical reaction--the rearrangement of chemical bonds, by breaking old bonds and/or forming new bonds.

dissociation (dis-SO-see-A-shun)--separation of a substance into smaller molecules or ions.

product--a substance that results from a chemical reaction.

reactant--a substance that takes part in a chemical reaction.

reversible reaction--a chemical reaction that may go in either direction depending on the conditions.

PROBLEM SET 25:

1. Plants make simple sugars such as glucose, $C_6H_{12}O_6$, from carbon dioxide and water by the process called photosynthesis. Oxygen is given off as a by-product.

$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$$

a. Count the numbers of C atoms, H atoms and O atoms on each side of the equation. If the same number of each type of atom appears on both sides, the equation is balanced. Is the equation balanced?

b. If more C atoms are on one side than the other, write a number before either the formula CO_2 or $C_6H_{12}O_6$ so that equal numbers of C atoms are on each side.

c. Count the number of H atoms on each side again. If more H atoms are on one side than the other, place a number before either H_2O or $C_6H_{12}O_6$ so that equal numbers of H atoms are on each side.

d. Count the number of O atoms on each side again. If more O atoms are on one side than the other, write a number before O_2 so that equal numbers of O atoms are on each side.

e. Check to see whether you have a balanced equation by counting the numbers of C, H and O atoms again. If the equation is balanced, stop; if not, keep adjusting numbers of molecules until it is.

2. When HF (hydrogen fluoride) is dissolved in water, it has the unusual ability to react with SiO_2. Silicon dioxide is the main component of sand and of glass, so HF is used to etch glass. The products are SiF_4 (silicon tetrafluoride) and water.

$$SiO_2 + HF \rightarrow SiF_4 + H_2O$$

a. Determine whether the equation is balanced by counting the numbers of Si, O, H and F atoms on each side.

b. If the equation is not balanced with respect to Si, write the appropriate numbers before SiO_2 and/or SiF_4 until it is.

c. If the equation is now not balanced with respect to O, write appropriate numbers before SiO_2 or H_2O until it is.

d. Now see whether the equation is balanced with respect to H. If not, write appropriate numbers before HF or H_2O.

e. Finally, see whether the equation is balanced with respect to F. If not, write appropriate numbers before HF or SiF_4.

f. Check the numbers of each type of atom on both sides of the equation. If the equation is not balanced, keep trying until it is.

g. What does this reaction tell you about storing HF solutions in bottles?

3. Copper sulfate exists in solution as Cu^{+2} ions and SO_4^{-2} ions. If an iron nail is placed in a copper sulfate solution, copper plates on the nail, while iron goes into solution as Fe^{+3} ions.

$$Cu^{+2} + SO_4^{-2} + Fe \rightarrow Cu + SO_4^{-2} + Fe^{+3}$$

a. Is this equation balanced?

b. What is the net charge on the left side? What is the net charge on the right side? Is the equation balanced? If not, write a balanced equation.

c. Which ion takes no part in the reaction and therefore can be omitted from the equation?

d. Which of the following equations, in which the ion that does not take part in the reaction has been omitted, is correct?

$$Cu^{+2} + Fe \rightarrow Cu + Fe^{+3}$$

$$3\ Cu^{+2} + 2\ Fe \rightarrow 3\ Cu + 2\ Fe^{+3}$$

$$Cu^{+2} + SO_4^{-2} \rightarrow Cu + SO_4^{-2}$$

$$2\ Fe + 3\ SO_4^{-2} \rightarrow 2\ Fe^{+3} + SO_4^{-2}$$

4. The previous examples illustrate the techniques used to balance some types of equations. Often, however, you must use your ingenuity. Balance the equations in each of the following situations.

a. The energy used to move an automobile is obtained by the oxidation of gasoline. Gasoline is a mixture of compounds containing hydrogen and carbon, called hydrocarbons. One component of gasoline is octane, C_8H_{18}. The products of oxidation are carbon dioxide and water.

$$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$$

b. Your body also obtains energy from an oxidation reaction--the oxidation of glucose, $C_6H_{12}O_6$, to carbon dioxide and water.

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$$

c. As you may recall, hydrogen peroxide is used as an antibacterial agent and as a bleach. H_2O_2 dissociates into oxygen and water.

$$H_2O_2 \rightarrow H_2O + O_2$$

d. In Laboratory Activity 17, carbon dioxide was absorbed by soda lime. Soda lime is composed of sodium hydroxide and calcium hydroxide; the calcium hydroxide reacts with CO_2 to form calcium carbonate and water.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

e. Ethyl alcohol is oxidized in the body to carbon dioxide and water, as expressed by the equation

$$C_2H_6O + O_2 \rightarrow CO_2 + H_2O$$

f. Much of the structure of bones is calcium phosphate, which may be formed by the reaction of calcium ions and phosphate ions.

$$Ca^{+2} + PO_4^{-3} \rightarrow Ca_3(PO_4)_2$$

5. The detection of poisons often involves chemical analysis. The following examples are chemical reactions used to determine the presence of toxic substances. In each case balance the equation.

a. Carbon monoxide may be detected by its reaction in a water solution with palladium chloride, which forms palladium metal as a silver-black film on the surface of the solution. HCl and CO_2 are also formed in the reaction.

$$PdCl_2 + CO + H_2O \rightarrow Pd + CO_2 + HCl$$

b. Arsenic is not a common poison, but it does enjoy some favor with murderers. It may be detected by its reaction with copper. Copper goes into solution as copper ions. Arsenic deposits on the copper as a dark film.

$$Cu + As^{+3} \rightarrow Cu^{+2} + As$$

c. Ethyl alcohol is not considered a poison if taken in ordinary amounts. Yet it may cause death if taken in large enough quantities. Many tests have been devised for measuring alcohol in blood. One involves the reaction of C_2H_6O (ethyl alcohol) with $Cr_2O_7^{-2}$ (dichromate ions), which are yellow, and hydrogen ions. The products are $C_2H_4O_2$ (acetic acid), green chromium ions and water. The color change from yellow to green indicates the presence of alcohol.

$$C_2H_6O + Cr_2O_7^{-2} + H^+ \rightarrow C_2H_4O_2 + Cr^{+3} + H_2O$$

6. In each of the following situations write an equation for the chemical reaction, and balance the equation.

a. The sulfur contained in coal and oil is oxidized to SO_2 (sulfur dioxide), an air pollutant.

b. NaOH (sodium hydroxide) dissociates in solution into sodium ions and hydroxide ions.

c. A small amount of O_3 (ozone) in the upper atmosphere shields us from much of the ultraviolet radiation coming from the sun. Ozone forms from oxygen gas, but recent evidence indicates that certain pollutants cause ozone to revert to oxygen. Write these two processes as one balanced equation.

SECTION 26:

26-1 Molecular Weights

How is the molecular weight of a substance determined?

If the only purpose of a chemical equation were to indicate what products were formed from what reactants, balancing an equation would not be necessary. However, we frequently wish to know how much of a product is formed from specified amounts of reactants, or how much of a reactant is needed to make a certain quantity of a product. (For instance, abnormal amounts of reaction products in our blood or urine are often signs of a disease.) These types of problems may be solved using balanced equations, if the masses of the various molecules taking part in the reaction are known.

A molecule is composed of a specific number of atoms of one or more elements. The sum of the atomic weights of the atoms in a molecule is called the molecular weight of the substance. (Just as with atomic weights, a molecular weight is actually a mass. The term "weight" continues to be used because of long tradition.)

The molecular weight of a substance is determined by summing the atomic weights of the individual atoms. We will demonstrate this by calculating the molecular weight of water, which has a molecular formula of H_2O. From the periodic table we find that each of the two hydrogen atoms has an atomic weight of approximately 1.0 amu and that the oxygen atom has an atomic weight of approximately 16.0 amu. The molecular weight of water is therefore approximately

$$2(1.0) + 16.0 = 18 \text{ amu}$$

A molecule of an ionic substance is taken to be the group of atoms in the formula. The molecular weight of an ionic substance is the sum of the atomic weights of the atoms in the formula. As an example, the formula of sodium chloride is NaCl. The molecular weight of NaCl is the sum of the atomic weights of sodium and chlorine.

$$22.99 + 35.45 = 58.44 \text{ amu}$$

The molecules we are considering are relatively simple. Some molecules in the body are extremely complex, and as a result have very large molecular weights.

	Molecular Weight, amu
Insulin	about 5,734
Hemoglobin	about 65,000
Deoxyribonucleic acid	over 1,500,000

The idea of molecular size will become important when we consider how molecules are transported from one part of the body to another.

We have expressed atomic weights and molecular weights in atomic mass units, or amu's. But we can't weigh individual atoms and molecules with a balance. For this reason, chemists often find it more convenient to use gram atomic weights and gram molecular weights. The gram atomic weight of an element is the same number as the atomic weight, but has units of grams. Thus the atomic weight of oxygen is approximately 16.00 amu; its gram atomic weight is approximately 16.00 grams. The gram molecular weight is the same number as the molecular weight, but with units of grams. The molecular weight of H_2O is approximately 18.0 amu, while the gram molecular weight is approximately 18.0 grams.

You may have noticed in the preceding examples that we used rounded values of atomic weights to calculate molecular weights. For water we rounded to the nearest 0.1 amu, while for sodium chloride we rounded to the nearest 0.01 amu. In the following example, the molecular weight of $MgCl_2$ (magnesium chloride) has been calculated in four different ways.

Nearest Whole amu	Nearest 0.1 amu	Nearest 0.01 amu	Nearest 0.001 amu
24	24.3	24.31	24.312
35	35.5	35.45	35.453
35	35.5	35.45	35.453
94 amu	95.3 amu	95.21 amu	95.218 amu

Notice that the sum increases in accuracy from left to right. How accurate one needs to be in such calculations depends upon what the sum is to be used for. For example, if one needed to weigh out a gram molecular weight of $MgCl_2$, and it was important to be accurate to the nearest 0.01 gram, then one would have to use the sum shown at the far right rounded to 95.22.

26-2 Quantities in Chemical Reactions

How are molecular weights used to find the amounts of reactants and products in a chemical reaction?

The amount of sodium and chloride ions in our blood indicates many things about the state of our bodies. For instance, a greater-than-normal quantity of salt in a blood sample is a symptom of dehydration.

The presence of a substance can be tested for by making use of some special property of the substance. When silver and chloride ions are present in the same water solution, they form AgCl (silver chloride), which is not soluble in water and settles to the bottom as a white precipitate.

$$Ag^{+} + Cl^{-} \rightarrow AgCl$$

In most situations the other anions present do not react with silver in this way. Therefore, the formation of a white precipitate indicates the presence of chloride ions. (Silver chloride, incidentally, has the interesting property of turning dark when exposed to light. This property has made AgCl useful in photography; films coated with AgCl turn dark when light is let into the camera.)

Suppose that we want to know how much sodium chloride is present in a solution. We can add silver nitrate as long as a white solid continues to precipitate. Note that the following equation of this reaction is balanced.

$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$

We can then collect the AgCl, dry it and weight it. How does the balanced equation help us determine how much sodium chloride was in the solution?

The equation tells us that for every molecule of NaCl originally present in the solution, one molecule of AgCl precipitates.

The mass of one molecule of silver chloride is the molecular weight of AgCl. The atomic weights of Ag and Cl are approximately 107.87 amu and 35.45 amu, respectively, so the molecular weight of AgCl is approximately

$$107.87 + 35.45 = 143.32 \text{ amu}$$

One molecule of AgCl is the product of the reaction of one molecule of sodium chloride. The molecular weight of NaCl is approximately 22.99 + 35.45 = 58.44 amu. 143.32 amu of AgCl are the result of the reaction of 58.44 amu of NaCl.

The gram molecular weight of AgCl is 143.32 grams, and the gram molecular weight of NaCl is 58.44 grams. Therefore, 143.32 grams of AgCl are formed from 58.44 grams of NaCl.

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Twice 143.32, or 286.64 grams of AgCl are formed from 2 x 58.44 = 116.88 grams of NaCl. The quantity of AgCl produced is proportional to the quantity of NaCl reacting.

One gram of AgCl is produced by $\frac{58.44}{144.32}$ grams of NaCl. Therefore, we may use $\frac{58.44 \text{ g NaCl}}{143.32 \text{ g AgCl}}$ as a conversion factor. The quantity of NaCl reacting is equal to the amount of AgCl formed multiplied by the conversion factor.

$$\cancel{\text{g AgCl}} \times \frac{58.44 \text{ g NaCl}}{143.32 \cancel{\text{ g AgCl}}} = \text{g NaCl}$$

Note that the units are the same on each side of the equation. Grams of AgCl appear in both the numerator and denominator on the left side, thus canceling, and leaving grams of NaCl as the one unit on each side.

Suppose that in the analysis of a certain NaCl solution 20 grams of AgCl were precipitated. The amount of NaCl present in the solution can be determined using the conversion factor.

$$20 \cancel{\text{ g AgCl}} \times \frac{58.44 \text{ g NaCl}}{143.32 \cancel{\text{ g AgCl}}} = \frac{20(58.44)}{143.32} \text{ g NaCl}$$

$$\approx 8 \text{ g NaCl}$$

If 20 grams of AgCl precipitated, then about eight grams of NaCl must have been in the original solution.

How does the total mass of reactants compare with the total mass of products? In order to answer this question, it is necessary to calculate the molecular weights of $AgNO_3$ and $NaNO_3$. You may wish to test your ability to calculate molecular weights and gram molecular weights by showing that 169.88 grams of $AgNO_3$ are needed to form 143.32 grams of AgCl, and that 85.00 grams of $NaNO_3$ are also formed ($NaNO_3$ remains in solution as Na^+ and NO_3^- ions).

$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$

$$169.88 \text{ amu} + 58.44 \text{ amu} \rightarrow 143.32 \text{ amu} + 85.00 \text{ amu}$$

$$169.88 \text{ g} + 58.44 \text{ g} \rightarrow 143.32 \text{ g} + 85.00 \text{ g}$$

$$228.32 \text{ g} = 228.32 \text{ g}$$

Note that the total mass before and after the reaction is the same. This is to be expected since the reaction involves only the rearrangement of atoms, not the creation or destruction of matter.

One molecule of silver chloride forms from one molecule of sodium chloride, but frequently the numbers of molecules of products and reactants are not equal. For example when octane (C_8H_{18}), the main component of gasoline, is burned in an engine, one of the products is CO (carbon monoxide), this country's leading air pollutant.

$$2\ C_8H_{18} + 17\ O_2 \rightarrow 16\ CO + 18\ H_2O$$

Two molecules of octane produce 16 molecules of CO.

The molecular weight of C_8H_{18} is 114.23 amu; the molecular weight of CO is 28.01 amu. (You may wish to calculate these yourself to see whether you know how to determine molecular weights. You will need to use the nearest 0.001 amu for C and H to obtain our result for octane.) Two molecules of C_8H_{18} then have a mass of 2 x 114.23 = 228.46 amu; 16 molecules of CO have a mass of 16 x 28.01 = 448.16 amu. The balanced equation then tells us that the burning of 228.46 amu of C_8H_{18} produces 448.16 amu of CO, and that burning 228.46 grams of C_8H_{18} results in 448.16 grams of CO. In summary,

$$2\ C_8H_{18} + 17\ O_2 \rightarrow 16\ CO + 18\ H_2O$$

$$2 \text{ molecules } C_8H_{18} \rightarrow 16 \text{ molecules CO}$$

$$2 \times 114.23 = 228.46 \text{ amu} \rightarrow 16 \times 28.01 = 448.16 \text{ amu}$$

$$228.46 \text{ g } C_8H_{18} \rightarrow 448.16 \text{ g of CO}$$

The conversion factor that relates the quantity of octane burned to the quantity of carbon monoxide produced is

$$\frac{228.46 \text{ g } C_8H_{18}}{448.16 \text{ g CO}}$$

Once this conversion factor has been determined, it can be used to solve two different kinds of problems, as the following examples will show.

EXAMPLE 1:

How much octane does it take to form 250 grams of CO?

SOLUTION:

$$250 \cancel{\text{ g CO}} \times \frac{228.46 \text{ g } C_8H_{18}}{448.16 \cancel{\text{ g CO}}} = \frac{250(228.46)}{448.16} \text{ g } C_8H_{18}$$

$$\simeq 127 \text{ g } C_8H_{18}$$

EXAMPLE 2:

How much CO is formed when 100 grams of octane are burned?

SOLUTION:

Note that in this case the conversion factor needs to be inverted. Since we start with 100 g C_8H_{18}, the units of g C_8H_{18} must be in the denominator of the conversion factor. Otherwise, these units could not be canceled to leave only g CO in the answer.

$$100 \cancel{g\ C_8H_{18}} \times \frac{448.16\ g\ CO}{228.46\ \cancel{g\ C_8H_{18}}} = \frac{100(448.16)}{228.46}\ g\ CO$$

$$\simeq 196\ g\ CO$$

Under what circumstances is it necessary to balance a chemical equation?

What is the difference between a molecular weight and a gram molecular weight?

Is a gram molecular weight actually a weight or a mass?

What steps must be taken in order to determine the mass of a product that will be formed from a given mass of a reactant? Assume that you start with an unbalanced equation.

Vocabulary:

gram atomic weight--the atomic weight of an element expressed in grams, rather than amu's.

gram molecular weight--the molecular weight of a substance expressed in grams, rather than amu's.

molecular weight--the mass of a molecule in atomic mass units; the sum of the atomic weights of the atoms in a molecule.

precipitate (pre-SIP-ih-TATE)--a solid formed by a reaction in a solution. Also, the act of forming such a solid.

PROBLEM SET 26:

All calculations for the following problems may be based on atomic weights rounded to the nearest 0.01 amu.

1. Determine the molecular weight of carbon dioxide, CO_2.

   a. Find the atomic weights of C and O in the periodic table.

   b. A CO_2 molecule contains one C atom and 2 O atoms. Therefore, the molecular weight of CO_2 is

   atomic weight of C + 2 x atomic weight of O = ?

2. Determine the molecular weights of the following substances.

   a. oxygen gas--O_2

   b. carbon monoxide--CO

   c. ammonia--NH_3

d. methyl alcohol--CH_4O

e. glucose--$C_6H_{12}O_6$

3. The substance that gives vinegar its sour taste is acetic acid, $C_2H_4O_2$. Acetic acid may be made by the reaction of ethyl alcohol and oxygen in the presence of certain bacteria.

$$C_2H_6O + O_2 \xrightarrow{\text{bacteria}} C_2H_4O_2 + H_2O$$

"Bacteria" is written above the arrow to indicate their role in making the reaction occur. Use the following steps to determine how much acetic acid can be made from 100 grams of ethyl alcohol.

a. Calculate the molecular weight of ethyl alcohol.

b. Calculate the molecular weight of acetic acid.

c. How many molecules of acetic acid are formed from the reaction of one molecule of ethyl alcohol?

d. Write a conversion factor that gives the grams of C_2H_4O formed per grams of C_2H_6O reacting.

e. Use the conversion factor to determine the quantity of acetic acid that can be produced from 100 grams of ethyl alcohol.

4. A painful condition occurs when a "stone," develops in the kidney, gall bladder or urinary bladder. Some stones are formed by the precipitation of calcium oxalate; too much calcium in the diet is thought to be a possible contributing factor.

$$Ca^{+2} + C_2O_4^{-2} \rightarrow CaC_2O_4$$

What is the mass of a stone produced from 8.0 grams of calcium ions? (Electrons have so little mass in relation to the mass of an atom that they may be ignored in determining atomic or molecular weights.)

5. Alcoholic beverages are made by the fermentation of the starch in corn, molasses, potatoes and other plants. Fermentation is the action of yeast to first convert the starch to maltose, $C_{12}H_{22}O_{11}$, and finally to ethyl alcohol.

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{yeast}} C_2H_6O + CO_2$$

a. Balance this equation.

b. How many molecules of ethyl alcohol are produced by the fermentation of one molecule of maltose?

c. How many grams of ethyl alcohol are produced by the fermentation of 200 grams of maltose?

d. The density of ethyl alcohol is about 0.8 gram per milliliter. What is the volume of ethyl alcohol produced from 200 grams of maltose?

SECTION 27:

27-1 Tom's Case Record--Age 33

"Happy birthday to you,
Happy birthday to you,
Happy birthday dear Kristi,
Happy birthday to you!"

"And many mo-o-ore," added Peter, off-key.

Kristi stood up on her chair, took a deep breath and blew out all five candles on the white birthday cake. She grinned from ear to ear.

"Let's eat it now and do the presents later," said Peter, with a malicious grin at his little sister.

"Oh, Mom, where is he?" she said. "Where is he? You promised! You promised!"

Kathy beamed as she lifted the furry little ball out of the box she had been hiding on her lap.

"Here he is, Darling," she said. "One tailless Manx kitten."

Kristi squealed with delight as she reached out with both hands and carefully took hold of the little animal.

"I'll call him Detail, too," she said, "just like Aunt Peggy's kitty!"

Tom leaned back in his chair with a big smile on his face. He'd taken the whole afternoon off for this party, and he was enjoying it. Watching Kristi hug Detail, he even felt his eyes begin to water. He didn't usually cry over things like that. Must be something about a little girl with a kitten, he thought.

"Bring on the ice cream!" shouted Peter.

"Second the motion!" said Tom.

"Double scoop for me," said Peter.

"And triple for me!" said Tom.

Peter held his belly with both hands, stuck out his tongue and crossed his eyes.

"Triple?" he said.

Tom laughed. Ordinarily he would have been upset with such a display at the table, but this was a party.

"Here, Daddy," said Kristi, "he wants you to pet him."

"Okay. Here, kitty. Here, Detail. Ouch! He has claws!"

Tom took the cat and gave it a soft hug while Kristi smiled a motherly smile at it. As he fondled the kitten, his eyes began to itch. He handed the little furball back to Kristi and rubbed his eyes, but they kept itching.

"I've got something in my eyes," he said. He got up and went into the bathroom to splash some water on his face. The cold water felt good, and it seemed to make the itching stop, so he dried his face and started back to the party. But by the time he was halfway there, the itching had started again. He decided to sit down in the living room until it had passed.

The kitten was exploring its new home, and when it saw Tom sit down in his easy chair it jumped up on his lap for more petting. By this time Tom had a tight feeling in his chest, and he was having trouble breathing. The itching around his eyes was getting worse, and his nose was beginning to itch too. He blew his nose several times, but the itching didn't stop. It was getting harder and harder to breathe. He heard a wheezing sound each time he exhaled.

He got up from his chair to get a cigarette. The startled cat leaped to the floor and ran to hide under the couch. As Tom walked into the kitchen he began to cough. When he wasn't coughing, he felt like he was choking. When he exhaled he couldn't seem to get enough air out of his lungs.

"What the devil is happening to me?" he cried, between wheezing breaths.

"What's the matter?" said Kathy. "You're sweating!"

Tom tried to answer, but he started coughing again. The coughing went on for several seconds. Finally he managed to stop coughing.

"I can't breathe," he wheezed. "Call the doctor!"

Kathy jumped up and dialed the doctor's number. Soon she was describing his symptoms. Then she listened as the doctor said something.

"Has it ever happened before?" she asked Tom.

Tom shook his head no. He didn't want to risk trying to talk and starting another coughing fit.

"No," said Kathy to the doctor. She listened a moment more, then said, "Okay," and hung up.

"Come on," she said. "He wants to see you right away." She pulled him up from the chair.

Tom followed her out to the car.

"He says it sounds like an asthmatic attack," said Kathy. "He heard you wheezing over the telephone." She drove much too fast, but they made it to the doctor's office.

The receptionist showed them into an examination room, and soon the doctor came in. He quickly examined Tom, then gave him a shot.

"What's that?" said Tom in his wheezing voice.

"Epinephrine," said the doctor. "Also known as adrenalin. It'll fix you up in a few minutes."

"I hope so," said Tom.

The doctor went out of the room to see another patient while Tom waited for the drug to take effect. Sure enough, within a few minutes he was breathing easily. The only ill effect he felt was a slight soreness in his chest.

When the doctor came back into the room, he wanted to know what Tom had been doing when the attack started. Tom described the birthday party, and before long the doctor figured out that the most likely cause of Tom's attack was an allergic reaction to the kitten's fur.

That made sense, except for one thing. Tom had always had cats when he was a child, and nothing like this had even happened to him before. He asked the doctor how he could be allergic to cats now, if he wasn't allergic to them before.

"It's not unusual," said the doctor. "In fact, it's typical of acute allergic reactions. Early in life, you have a continuous association with the offending agent, whatever it may be--in your case, apparently cat dander."

"Dander?"

"Little flakes," said the doctor. "They come off the cat's fur and fly around in the air, and you get them in your nose and bronchial tubes when you breathe."

"Oh."

"During this early period you don't have any symptoms, but you become sensitized to the agent--the dander."

"So those cats we had around the house when I was little were just setting me up for this allergic reaction?"

"Right. For an acute reaction to occur, there is usually a long period after you're sensitized during which there is no exposure at all. I'd wager that you, for example, haven't held a cat in your lap for a long time, up until this afternoon."

"That's right," said Tom. "Not since I was in--oh, about the sixth grade. I can't even remember the last time I petted a cat."

"Well," said the doctor, "that's all it takes for some people. A period when you're being sensitized, then a long period when you have no exposure. After that, you pet a cat just once--or even get close to one--and you may have an acute allergic reaction."

"Well," said Tom, "I guess that's that." The only problem left was, of course, what to do about it. He'd hate to make Kristi give up her little kitten. On the other hand, he enjoyed breathing too much to put up with an allergic reaction every evening after work. He asked the doctor what could be done.

Getting rid of the cat was, of course, the simplest solution. The other solution was for Tom to get a series of desensitizing injections. Tom promised he would think it over.

Kathy was quiet as they drove back home. Finally she spoke.

"Kristi will be broken-hearted if we have to get rid of the cat," she said. "Do you think you'd mind getting the shots?"

Tom didn't like shots, but he guessed it was worth a try.

"If it doesn't work," he said, "out goes the cat."

"Okay," said Kathy.

"And until I get the shots, he's going to have to stay outside."

"Oh, the poor little thing! But it's so cold!"

"Well," said Tom, "it's him or me. Take your pick."

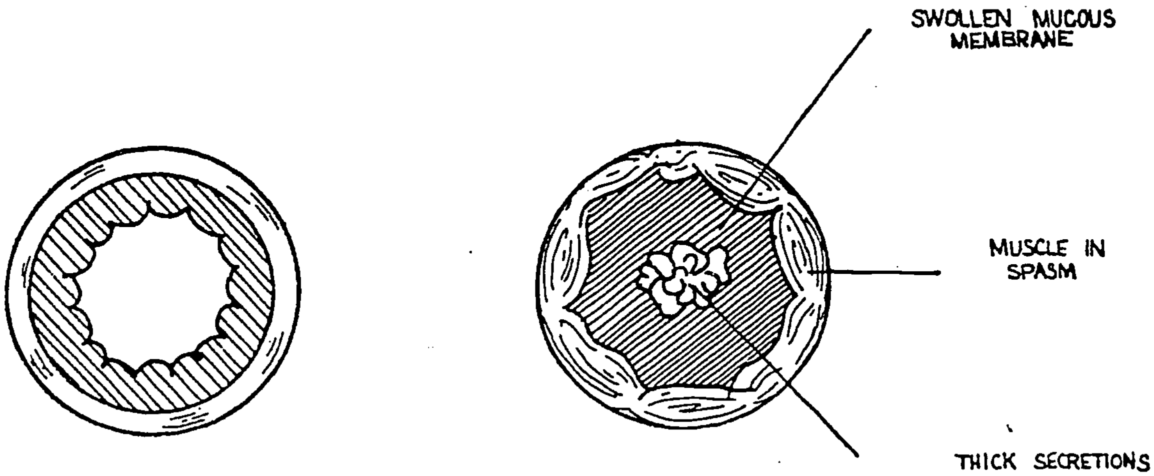
"Okay," said Kathy. "The cat stays outside."

27-2 Asthma

What is happening inside the lungs during an asthma attach?

The air passageways in the bronchioles of some people become partially constricted or blocked in the presence of plant pollens, animal fur, dust or other substances. The constriction or blocking is an allergic reaction to the substance, and the condition is given the name asthma. Asthma can also be caused by irritants such as smoke or air pollutants. It is more likely to occur when the respiratory passages are infected, and is also influenced by emotional states.

Constriction of air passageways during an asthmatic attack may be caused by three reactions. One reaction is spasms in the muscles surrounding bronchioles. A second is swelling of the mucous membranes that line bronchial passages. A third reaction is thick secretions from the mucous membranes. Any one of these reactions can cause constriction of air passageways, or more than one may combine to block the passageways. The illustration on the following page shows all three factors occurring simultaneously.



NORMAL BRONCHIOLE

OBSTRUCTED BRONCHIOLE

ENLARGED CROSS—SECTION

Bronchioles normally enlarge during inspiration and contract during expiration. For this reason constriction of bronchioles interferes more with expiration than with inspiration. A person who suffers from asthma over a long period of time may develop an enlarged chest because of over-inflation of his lungs.

Asthma may occur as <u>acute</u> attacks or in a milder continuous or <u>chronic</u> form. Acute attacks are sudden and severe, and may come at any time and last for minutes, hours or even days. A person having a severe asthma attack feels as if he is choking, as if he cannot get enough air out of his lungs. His breathing is accompanied by wheezing, and [illegible] coughs frequently, spitting up a white mucus. Acute attacks are caused by spasms of the muscles surrounding bronchioles, and treatment is aimed at relaxing these muscles. An asthmatic attack causes the body to release its own supply of adrenalin, which tends to relax the muscles, but injections of adrenalin to supplement the body's supply are given to bring immediate relief.

Milder, chronic asthma is caused by swelling of the mucous lining of the bronchioles and secretion of thick mucus into the passageways. Symptoms include a tightness in the chest and labored breathing, as well as itching around the eyes and nasal passages. Treatment of chronic asthma is intended to reduce swelling and mucus production. One drug which is used to treat chronic asthma is ephedrine, which caused a gold medal to be withdrawn from a swimmer during the 1972 Olympic Games.

If asthma attacks are caused by reaction to a specific substance, the substance can often be identified by skin tests. The skin is scratched, the substance applied, and the reaction observed. Usually asthma is caused by more than one substance. When the cause is known, avoiding the substance usually prevents further attacks. Injections are successful in preventing attacks in perhaps half of all asthma cases.

Hay fever is an allergic reaction similar to allergic asthma, except that the region affected is confined to the eyes and the nasal passages.

27-3 Units for Chemical Quantities

A method commonly used to measure the amount of chloride in a body fluid, such as blood or urine, takes advantage of the fact that mercury ions react with chloride ions to form mercuric chloride.

$$Hg^{+2} + 2\ Cl^- \rightarrow HgCl_2$$

$HgCl_2$ is soluble, but the mercury remains bonded to the chloride and is not available to take part in other reactions.

Mercuric nitrate, $Hg(NO_3)_2$, which is soluble in water and provides mercury ions, can be added a small amount at a time to a chloride solution. At first, the Hg^{+2} ions react with the Cl^- ions, but eventually the chloride has all reacted, and the mercury ions can take part in another reaction. This reaction is with a certain red substance that changes color when it reacts with mercury.

When the solution is no longer red, the technician making the test knows that all the chloride has reacted. He knows how much mercuric nitrate he has added, and he knows the equation for the reaction of Hg^{+2} and Cl^-. From these he can determine how much chloride was present in the solution.

The equation tells him that one Hg^{+2} ion reacts with two Cl^- ions to produce one $HgCl_2$ molecule.

$$1\ Hg^{+2}\ \text{ion} + 2\ Cl^-\ \text{ions} \rightarrow 1\ HgCl_2\ \text{molecule}$$

The technician could express the amount of mercury added in terms of numbers of ions. But even one milliliter of blood might normally contain 3.6×10^{19} chloride ions, which react with $\frac{1}{2} \times 3.6 \times 10^{19} = 1.8 \times 10^{19}$ mercury ions to produce 1.8×10^{19} $HgCl_2$ molecules.

These numbers are so large that they are inconvenient to work with. And ions, as well as atoms and molecules, are so small that the technician cannot count them directly. Therefore, chemical quantities are rarely expressed in terms of numbers of atoms, ions or molecules.

The technician can express the quantities of Hg^{+2} and Cl^- ions in terms of mass, as we did in Section 26. The atomic weight of mercury is 200.59 amu, and the atomic weight of chlorine is 35.45 amu. Thus 200.59 amu of Hg^{+2} react with 2×35.45 amu = 70.90 amu Cl^- to form $200.59 + 70.90 = 271.49$ amu $HgCl_2$.

$$200.59\ \text{amu}\ Hg^{+2} + 70.90\ \text{amu}\ Cl^- \rightarrow 271.49\ \text{amu}\ HgCl_2$$

Or we can write the same equation using gram atomic weight.

$$200.59 \text{ g } Hg^{+2} + 70.90 \text{ g } Cl^{-} \rightarrow 271.49 \text{ g } HgCl_2$$

Since 70.90 grams of Cl^{-} react per 200.59 grams of Hg^{+2},

$$\left[\frac{70.90 \text{ g } Cl^{-}}{200.59 \text{ g } Hg^{+2}}\right]$$

may be used as a conversion factor. If the amount of Hg^{+2} that reacts is known, the amount of Cl^{-} can be calculated from the formula

$$\text{g } Cl^{-} = \left[\frac{70.90 \text{ g } Cl^{-}}{200.59 \text{ g } Hg^{+2}}\right]\left[\text{g } Hg^{+2}\right]$$

Note that the units "g Hg^{+2}" in the numerator and denominator cancel, leaving "g Cl^{-}" as the units on both sides of the equation.

If 2.05 g Hg^{+2} react with the chloride in a blood sample, the sample contains

$$\left[\frac{70.90 \text{ g } Cl^{-}}{200.59 \text{ g } Hg^{+2}}\right]\left[2.05 \text{ g } Hg^{+2}\right] \approx .72 \text{ g } Cl^{-}$$

A disadvantage to expressing chemical quantities in mass units is that conversion factors such as

$$\left[\frac{70.90 \text{ g } Cl^{-}}{200.59 \text{ g } Hg^{+2}}\right]$$

make the arithmetic difficult. We would like to be able to use a unit that makes the arithmetic as easy as possible. We would like to avoid huge numbers such as 1.8×10^{19} and awkward conversion factors as well.

27-4 The Unit Called the Mole

How did the mole get out of his hole in the ground and into the laboratory?

The atomic weight of an element is the mass of one atom. 200.59 atomic mass units is the mass of one mercury atom (or ion). But how many mercury atoms have a total mass of 200.59 grams?

Modern instruments have made it possible to determine the masses in grams of single atoms. The mass of a single mercury atom is approximately 3.332×10^{-22} grams. Therefore, the number of mercury atoms in 200.59 grams is

$$\frac{200.59 \text{ g}}{3.332 \times 10^{-22} \text{ g/atom}} \approx 6.02 \times 10^{23} \text{ atoms}$$

For convenience, let us round this number to 6×10^{23}. The mass of one Hg atom is 200.59 amu; the mass of 6×10^{23} Hg atoms is 200.59 grams.

Since one Hg^{+2} ion reacts with two Cl^- ions, 6×10^{23} Hg^{+2} ions react with $2(6 \times 10^{23}) = 12 \times 10^{23}$ Cl^- ions to produce 6×10^{23} $HgCl_2$ molecules.

$$1\ Hg^{+2} \text{ ion} + 2\ Cl^- \text{ ions} \rightarrow 1\ HgCl_2 \text{ molecule}$$

$$6 \times 10^{23}\ Hg^{+2} \text{ ions} + 12 \times 10^{23}\ Cl^- \text{ ions} \rightarrow 6 \times 10^{23}\ HgCl_2 \text{ molecules}$$

The mass of 6×10^{23} Hg^{+2} ions is 200.59 grams. Since we know that 6×10^{23} Hg^{+2} ions react with 12×10^{23} Cl^- ions, and also react with 70.90 grams of Cl^- ions, the mass of 12×10^{23} Cl^- ions must be 70.90 grams.

Therefore, the mass of 6×10^{23} Cl^- ions is $\frac{1}{2} \times 70.90 = 35.45$ grams. The mass of 6×10^{23} Hg^{+2} ions is equal to the gram atomic weight of mercury, and the mass of 6×10^{23} Cl^- ions is equal to the gram atomic weight of chlorine.

The product of the reaction of 6×10^{23} Hg^{+2} ions and 12×10^{23} Cl^- ions is 6×10^{23} $HgCl_2$ molecules. This is equivalent to the statement that 200.59 grams of Hg^{+2} and 70.90 grams of Cl^- react to form 271.49 grams of $HgCl_2$. Thus the mass of 6×10^{23} $HgCl_2$ molecules is 271.59 grams, which is the gram molecular weight of $HgCl_2$.

The mass of 6×10^{23} Hg^{+2} ions or 6×10^{23} Cl^- ions is equal to the gram atomic weight of those elements, and the mass of 6×10^{23} $HgCl_2$ molecules is equal to the gram molecular weight of $HgCl_2$. But none of this helps the technician analyzing a blood sample for its chloride content, who certainly cannot count 6×10^{23} ions.

Therefore, we define a unit called the <u>mole</u>. <u>One mole of a substance is 6×10^{23} molecules of that substance</u>. 6×10^{23} $HgCl_2$ molecules is one <u>mole</u> of mercuric chloride.

The word "mole" is intended to remind us of the word "molecule," but we also may speak of moles of atoms and moles of ions. 6×10^{23} Hg^{+2} ions is one mole of mercury ions and 6×10^{23} Cl^- ions is one mole of chloride ions.

Since the mass of 6×10^{23} molecules is equal to the gram molecular weight of a substance, we have an important principle that makes units of moles useful in solving many problems. <u>The mass of one mole of a compound is equal to its gram molecular weight, and the mass of one mole of atoms is equal to the gram atomic weight of the element</u>. The mass of one mole of $HgCl_2$ is 271.49 grams, and the mass of one mole of mercury ions is 200.59 grams.

6×10^{23} Hg^{+2} ions react with 12×10^{23} Cl^- ions to form 6×10^{23} $HgCl_2$ molecules. This fact may be also expressed by stating that one mole of Hg^{+2} and two moles of Cl^- react to produce one mole of $HgCl_2$. The follwoing three equations express the same quantities, but in different units.

$$200.59 \text{ g } Hg^{+2} + 70.90 \text{ g } Cl^- \rightarrow 271.49 \text{ g } HgCl_2$$

$$6 \times 10^{23}\ Hg^{+2} + 12 \times 10^{23}\ Cl^- \rightarrow 6 \times 10^{23}\ HgCl_2$$

$$1 \text{ mole } Hg^{+2} + 2 \text{ moles } Cl^- \rightarrow 1 \text{ mole } HgCl_2$$

Note that using units of moles makes the numbers easiest to work with.

EXAMPLE:

After .011 moles of Hg^{+2} have been added to a blood sample, red indicator changes color. How many moles of chloride ion did sample contain?

SOLUTION:

Two moles of Cl^- react per mole of Hg^{+2}. Therefore,

$$\left[\frac{2 \text{ moles } Cl^-}{1 \text{ mole } Hg^{+2}}\right]$$

may be used as a conversion factor.

The moles of Cl^- in the sample may be calculated using the expression

$$\text{moles } Cl^- = \left[\frac{2 \text{ moles } Cl^-}{1 \text{ mole } Hg^{+2}}\right]\left[\text{moles } Hg^{+2}\right]$$

$$= \left[\frac{2 \text{ moles } Cl^-}{\cancel{1 \text{ mole } Hg^{+2}}}\right]\left[\cancel{.011 \text{ moles } Hg^{+2}}\right]$$

The "moles Hg^{+2}" in the numerator cancel those in the denominator, leaving the expression

$$\text{moles } Cl^- = 2 \times .011 \text{ moles } Cl^-$$

$$= .022 \text{ moles } Cl^-$$

The blood sample contains .022 moles of chloride.

27-5 Converting Between Units of Mass and Moles

How does the technician prepare a solution containing a given number of moles of Hg^{+2}? How many grams of Cl^- are in the sample that contains .022 moles of Cl^-?

Moles are such a convenient unit to use in many situations that the amount of a solute in solution is commonly expressed in moles.

In the next few sections we will be concerned with solutions and will express quantities in moles. And in a later section we will return to our study of gases and find moles useful for expressing quantities of gases.

The technician may have a bottle on the shelf labeled with the amount of mercuric nitrate in solution in moles, but someone had to prepare the solution. And the solution was prepared by weighing out a certain mass of $Hg(NO_3)_2$; a balance does not measure in units of moles. [Remember that moles are not units of mass, but of numbers of molecules. A mole of $Hg(NO_3)_2$ has a different mass than a mole of NaCl.]

Therefore, it is necessary in preparing solutions or other samples to determine the number of moles in a given mass of the substance. For example, in preparing a mercuric nitrate solution, a certain amount of $Hg(NO_3)_2$ is weighed out; then the mass of $Hg(NO_3)_2$ is converted to moles.

This is done by using the fact that the mass of one mole of a substance is equal to its gram molecular weight. The mass of one mole of $Hg(NO_3)_2$ is equal to the gram molecular weight of $Hg(NO_3)_2$, so we may use the conversion factor

$$\frac{1 \text{ mole } Hg(NO_3)_2}{\text{gram molecular weight of } Hg(NO_3)_2}$$

The gram molecular weight of $Hg(NO_3)_2$ is

1 x 200.59 =	200.59	(mercury)
2 x 14.01 =	28.02	(nitrogen)
6 x 16.00 =	96.00	(oxygen)
	324.61 g	

The mass of one mole of $Hg(NO_3)_2$ is 324.61 grams.

Therefore, the number of moles in a given mass of mercuric nitrate may be determined using the expression

$$\text{moles } Hg(NO_3)_2 = \left[\frac{1 \text{ mole } Hg(NO_3)_2}{324.61 \text{ g } Hg(NO_3)_2}\right]\left[\text{g } Hg(NO_3)_2\right]$$

EXAMPLE:

A solution is prepared for a laboratory analysis containing 85.0 grams of mercuric nitrate. How many moles of $Hg(NO_3)_2$ does the solution contain?

SOLUTION:

$$\text{moles } Hg(NO_3)_2 = \left[\frac{1 \text{ mole } Hg(NO_3)_2}{324.61 \text{ g } \cancel{Hg(NO_3)_2}}\right]\left[85.0 \text{ g } \cancel{Hg(NO_3)_2}\right]$$

The units "g $Hg(NO_3)_2$" in the numerator and denominator cancel. The result is

$$\text{moles } Hg(NO_3)_2 = \frac{85.0}{324.61} \text{ moles } Hg(NO_3)_2$$

$$\simeq .26 \text{ moles } Hg(NO_3)_2$$

In the example in Section 27-4, a blood sample was found to contain .022 moles of chloride ion. But the technician may be asked to report his results in mass units rather than in moles. He must convert moles to grams, using the fact that the mass of one mole of chloride ions is the gram atomic weight of chlorine, which is 35.45 grams. The conversion factor is thus

$$\left[\frac{35.45 \text{ g } Cl^-}{1 \text{ mole } Cl^-}\right]$$

EXAMPLE:

A blood sample contains .022 moles of chloride ion. Express this quanitty in units of grams.

SOLUTION:

$$\text{g } Cl^- = \left[\frac{35.45 \text{ g } Cl^-}{\cancel{1 \text{ mole } Cl^-}}\right]\left[\cancel{.022 \text{ moles } Cl^-}\right]$$

$$= 35.45 \times .022 \text{ g } Cl^-$$

$$\simeq .78 \text{ g } Cl^-$$

Is the mole a unit of mass, volume, number of molecules or molecular weight?

The gram molecular weight of O_2 is 32.00 grams. How many molecules are in one mole of oxygen? What is the mass of one mole of oxygen?

What are some of the causes of asthma? How is it treated?

How does the constriction of air passageways during an asthma attack come about?

Vocabulary:

acute (uh-KEWT)--occurring suddenly, and of short duration.

asthma (AZ-muh)--the constriction or blockage of air passages as a result of allergy.

chronic (KRON-ik)--existing over a period of time.

mole--6 x 10^{23} molecules of a substance or 6 x 10^{23} atoms or ions; equivalent to a gram molecular weight or gram atomic weight.

PROBLEM SET 27:

1. Methane, the main component [illegible]ural gas, reacts with oxygen to form carbon dioxide and water. [illegible]he equation for this reaction is

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Answer the [illegible]wing questions about this reaction.

a. How many molecules of O_2 react with one molecule of CH_4? How many molecules of CO_2 and how many molecules of H_2O are formed when one molecule of CH_4 reacts?

b. How many molecules of O_2 react with 6×10^{23} CH_4 molecules? How many CO_2 molecules and how many H_2O molecules are formed?

c. 6×10^{23} molecules of CH_4 is how many moles of CH_4? How many moles of O_2 react with 6×10^{23} CH_4 molecules? How many moles of CO_2 and how many moles of H_2O are formed?

d. Write a conversion factor expressing the number of moles of O_2 that react with one mole of CH_4. Also write conversion factors for the number of moles of CO_2 and H_2O formed per mole of CH_4 reacting.

e. Use these conversion factors to determine the numbers of moles of O_2, CO_2 and H_2O involved in the reaction of .62 moles of CH_4.

2. The oxidation of glucose ($C_6H_{12}O_6$) provides the energy our bodies need. Carbon dioxide, which is removed by the respiratory system, and water are the products of the reaction.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

a. How many moles of O_2 react with one mole of $C_6H_{12}O_6$?

b. Write a conversion factor expressing the moles of O_2 consumed per mole of glucose oxidized.

c. A typical adult might oxidize 4 moles of glucose per day. How many moles of O_2 are required for the oxidation of 4 moles of $C_6H_{12}O_6$?

d. How many moles of CO_2 are produced by the oxidation of 4 moles of $C_6H_{12}O_6$?

3. A small amount of ozone is formed from oxygen gas by an electric spark, such as lightning.

$$3\ O_2 \rightarrow 2\ O_3$$

How many moles of O_3 are formed from .006 mole of O_2?

4. Sodium chloride solutions are used in many biological studies to simulate body fluids. Suppose that you are asked to weigh out .6 mole of NaCl that will be used to prepare a solution. You must determine the mass of .6 mole of NaCl.

a. What is the molecular weight of NaCl?

b. What is the gram molecular weight of NaCl?

c. What is the mass of one mole of NaCl?

d. Write the mass of NaCl per mole as a conversion factor.

$$\frac{\_\_\_\_\ \text{g NaCl}}{\text{1 mole NaCl}}$$

e. Use this conversion factor to determine the mass of .6 mole of NaCl.

$$\text{g NaCl} = \left[\frac{\_\_\_\_\ \text{g NaCl}}{\text{1 mole NaCl}}\right]\left[\_\_\_\_\ \text{mole NaCl}\right]$$

5. The chemical name of table sugar is sucrose and its formula is $C_{12}H_{22}O_{11}$. A sample of sucrose, to be used for preparing a laboratory solution, has a mass of 68.4 grams. It is desired to express the quantity in units of moles.

a. What is the gram molecular weight of $C_{12}H_{22}O_{11}$?

b. What is the mass of one mole of $C_{12}H_{22}O_{11}$?

c. Write a conversion factor that may be used to convert grams of sucrose to moles of sucrose.

$$\frac{\text{1 mole } C_{12}H_{22}O_{11}}{\_\_\_\_\ \text{g } C_{12}H_{22}O_{11}}$$

d. How many moles are 68.4 grams of sucrose?

6. The fermentation of maltose, which like sucrose has the formula $C_{12}H_{22}O_{11}$, produces ethyl alcohol (see Problem Set 26, Problem 5).

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{yeast}} 4\ C_2H_6O + 4\ CO_2$$

a. How many moles of ethyl alcohol are produced by the fermentation of .32 mole of maltose?

b. How many grams of ethyl alcohol are produced by the fermentation of .32 mole of maltose?

7. Hydrogen peroxide dissociates into water and oxygen (see Problem Set 25, Problem 4c).

$$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$$

How many moles of H_2O_2 produce 96 grams of O_2?

SECTION 28:

28-1 The Concentration of a Solution

How is the amount of solute per unit volume of solution expressed?

The idea of using moles as units for chemical quantities was presented in the previous section. We illustrated the idea with a test for the amount of chloride in a blood sample. The quantity of chloride was determined by its reaction with mercury ions, but we omitted an important piece of information. We never specified the size of the sample. Obviously, the quantity of chloride in a blood sample depends upon the amount of sample used. A sample twice as large as another contains twice as much of each ion.

The amount of solution can be expressed in terms of mass or volume; we will restrict ourselves to the latter, because the volume of a solution is easy to measure. Thus we work with milliliters of blood, or liters of sodium chloride solution.

The quantity of solute in a given amount of solution is the concentration of the solute in the solution. Concentration may be expressed in terms of mass per unit volume of solution. For example, the normal amount of chloride in one liter of human blood is approximately five grams. Thus the concentration of chloride in blood is about five grams per liter.

When we are involved with chemical reactions in solution, it is more convenient to express concentration in terms of moles per unit volume of solution. Since one liter of blood contains five grams of chloride and the gram atomic weight of chlorine is 35.45 grams, the number of moles in one liter of blood is

$$(5\ g)\left(\frac{1\ \text{mole}}{35.45\ g}\right) \approx .14\ \text{mole}\ Cl^-$$

The concentration of chloride in blood is approximately .14 mole per liter. Rather than say that the concentration is .14 mole per liter, we say that it is a .14 molar (or .14 M) solution. The molar concentration, or molarity, of a solution is its concentration expressed in moles of solute per liter of solution.

It is important to note that molar concentration is based on one liter of solution, not one liter of solvent. To make a one molar aqueous (or water) solution, you do not add one liter of water to one mole of solute; you add water to the solute until the volume of the solution is one liter.

Workers in many health professions are frequently required to prepare solutions with a certain molar concentration. For example, to simulate blood it might be necessary to make up a .14 molar aqueous sodium chloride solution. If one liter of solution were required, .14 mole of NaCl could be measured into a one-liter flask and water added to make a total volume of one liter. The one calculation the technician would be required to make would be to determine the mass of .14 mole of NaCl.

The gram molecular weight of NaCl is 22.99 + 35.45 = 58.44 grams. Therefore a .14 M NaCl solution contains

$$(.14\ \frac{\text{mole}}{\text{liter}})(\frac{58.44\ \text{g}}{1\ \text{mole}}) \approx 8.18\ \frac{\text{g}}{\text{liter}}$$

One liter of .14 M NaCl solution contains approximately 8.18 grams.

Note the use of dimensional algebra. Using the equivalence between 58.44 grams NaCl and one mole NaCl to make a conversion factor, the numerator contains units of moles and grams, while the denominator has liters and moles. The moles in the numerator and denominator cancel, leaving the answer in units of grams per liter.

Dimensional algebra is even more useful when the volume of solution being prepared is not one liter. Suppose that 2.5 liters of a .14 M NaCl solution is to be prepared. This solution contains 2.5 times the quantity of sodium chloride that one liter of .14 M NaCl does.

$$(.14\ \frac{\text{mole}}{\text{liter}})(\frac{58.44\ \text{g}}{1\ \text{mole}})(2.5\ \text{liters})$$

Observe that the units of moles and liters each occur in the numerator and denominator and therefore cancel; the answer is in units of grams.

$$(.14\ \frac{\text{mole}}{\text{liter}})(\frac{58.44\ \text{g}}{1\ \text{mole}})(2.5\ \text{liters}) \approx 20.45\ \text{g}$$

This solution may be prepared by weighing out 20.45 grams of NaCl and adding water until the volume of the solution is 2.5 liters.

Frequently in the laboratory you will be preparing solutions of a given molar concentration, and it is important to be able to perform the type of calculation that we just did. Therefore, another example of this type of calculation follows. In the solution to the problem the answer to each step is on the right-hand side. This is done so that you may test yourself by covering the right-hand side of the page as you try each step. Check your answer to each step by lowering your cover one step at a time after you have completed that step. If your answer is correct, go on to the next step.

EXAMPLE:

You are working in a laboratory that is testing the effectiveness of ammonium chloride (NH_4Cl) in cough syrups. How would you prepare 12 liters of a .8 M NH_4Cl solution? (Whenever the solvent is not specified, assume it is water.)

SOLUTION:

1. Calculate the molecular weight of NH_4Cl.

1. $1 \times 14.007 = 14.007$ (N)
$4 \times 1.008 = 4.032$ (H)
$1 \times 35.453 = \underline{35.453}$ (Cl)
53.492
≈ 53.49 amu

2. What is the gram molecular weight of NH_4Cl?

2. 53.49 g

3. One mole of NH_4Cl is equivalent to ______ grams of NH_4Cl. Express this fact as a conversion factor.

3. $\frac{53.49\ g}{1\ mole}$

4. Using this conversion factor, write an expression for the quantity of NH_4Cl in one liter of a .8 M solution.

4. $(.8\ \frac{mole}{liter})(\frac{53.49\ g}{1\ mole})$

5. Now write an expression for the mass of NH_4Cl in 12 liters of a .8 M solution.

5. $(.8\ \frac{mole}{liter})(\frac{53.49\ g}{1\ mole})(12\ liters)$

6. Which units appear in both the numerator and the denominator, and thus cancel?

6. moles and liters

7. Use the expression obtained in Step 5 to calculate the mass of NH_4Cl in the desired solution. Include units in your answer.

7. 513.50 grams

8. How would you prepare 12 liters of .8 M NH_4Cl solution?

8. Weigh out 513.50 grams of NH_4Cl. Add water until total volume is 12 liters.

If you have learned to convert between molar concentrations and mass, you have earned a vacation of sorts. In the next section, in which you are introduced to certain classes of substances called acids, bases and salts, there will be no conversions between mass and moles. We will express all quantities in moles and show how this makes easier the calculation of quantities involved in chemical reactions that take place in solution.

Which is the correct method for preparing .5 liter of a 6 M potassium chloride solution?

a. Add 6 moles of KCl to .5 liter of water.

b. Add .5 liter of KCl to 6 moles of water.

c. Add water to 6 moles of KCl until the total volume is .5 liter.

d. Add .5 liter of water to 6 moles of KCl.

Vocabulary:

aqueous solution (A-kwee-us)--a solution in which water is the solvent.

concentration--the quantity of a solute in a given amount of solution.

molar concentration (or molarity)--the number of moles of solute in one liter of solution.

PROBLEM SET 28:

1. Mercuric nitrate is used to test for the quantity of chloride in various biological samples, such as blood and urine (Section 27). It is desired to have available on a laboratory shelf one liter of a .1 M $Hg(NO_3)_2$ solution. How would you prepare this solution?

2. How would you prepare .8 liter of a 3 M NaCl solution?

3. Patients being fed intravenously are given glucose ($C_6H_{12}O_6$) solution. How would you prepare 10 liters of .3 M glucose solution? (Be careful with your arithmetic; a misplaced decimal point could kill a patient.)

4. A five per cent solution of hydrogen peroxide contains five grams of H_2O_2 per 100 grams of solution, or about five grams of H_2O_2 per 100 ml of solution. How many moles of H_2O_2 are in 500 ml of five per cent solution? (Watch out: this problem is not like the others. You may find dimensional algebra a big help.)

REVIEW SET 28:

1. Suppose that you walked across a rug, then touched a door knob and felt a slight shock. What is the cause of the shock?

2. A negatively charged object is brought near a second charged object. What is the charge on the second object if

a. the two objects attract one another?

b. the two objects repel one another?

3. Carbon dioxide plays an important role in respiration.

a. Use information from the periodic table to show the Bohr models for the two kinds of atoms that make up carbon dioxide.

b. How many protons, electrons and neutrons are present in each of these atoms?

c. Would these numbers be the same if you were describing ions rather than atoms? Explain.

4. a. Write the electron-dot formulas for Na^+, Mg^{++}, F^- and S^{--} and the compounds that can be made with these ions.

b. Is the bonding in these salts ionic or covalent? Explain.

5. Carbon forms covalent bonds with both bromine and oxygen.

a. Write an electron-dot formula and a structural formula for CBr_4 and for CO_2.

b. Explain the difference between a covalent and an ionic bond.

6. Ethyl alcohol, C_2H_6O, is the kind of alcohol found in "alcoholic" beverages such as beer and wine. Large amounts of ethyl alcohol can have harmful effects. Human cells can break the alcohol down to carbon dioxide and water which can then be excreted. The ethyl alcohol reacts with oxygen to form carbon dioxide and water.

a. Write the equation for this reaction.

b. Balance the equation.

c. If this reaction were reversible, how could this be indicated?

d. Determine the molecular weights of the reactants and products to the nearest 0.1 amu.

e. If 4.6 g of ethyl alcohol and 9.6 g of oxygen react, how many g of carbon dioxide and of water will be produced?

f. How many moles of C_2H_6O reacted in Part e?

g. If only 9.22 g of ethyl alcohol reacted with oxygen, how many moles would that have been?

7. Lactose is a sugar with the formula, $C_{12}H_{22}O_{11}$. Explain how you would make up 2 liters of 0.5 M lactose solution. Show all calculations.

SECTION 29:

29-1 Tom's Case Record--Age 37

Kathy peeked into the oven at the casserole. It was just about done, nice and brown. Smelled great.

She straightened up and looked around the kitchen. Everything was in order. She'd been working all day to get ready for a nice, quiet, pleasant dinner with her husband. She'd gone out and bought candles and a new tablecloth, straightened up the kitchen, and put in a couple of hours on a new casserole recipe. And the kids were out of the house--transistor radios and all--on a four-day camping trip with the neighbors.

"Dinner's ready," she called to Tom. She lighted the candles, turned out the light, and put the casserole on the table. It looked so nice in the candlelight that she hated to cut into it.

"Hey, it's dark in here," said Tom. "Oh--candles." He sat down at the table and looked at the casserole. Kathy had a horrible feeling that he was going to ask her what it was.

"What is it?" he asked.

Kathy felt like saying that if he didn't like it he could go out and get a plasticburger, but she caught herself in time. She told him what it was, and served him some. He grunted and poked it with his fork.

Tom had been in a bad mood for several days. He hadn't eaten much, and he hadn't been sleeping well. Kathy knew he was just worried. He was due for a promotion, but he wasn't sure he would get it. He was getting ready to buy a new home, but the down payment always seemed to stay just ahead of the family savings. And then there were all the ordinary expenses of running a home--and raising kids. Sometimes she felt like it was all her fault, but of course that was silly. Still, she had decided to keep things quiet around the house during the long weekend and be as loving and patient as she could, so that Tom could at least worry in peace. This special dinner was the grand opening of a surprise second honeymoon.

It wasn't working too well. He wasn't eating. He had taken a couple of bites, but now he was just sitting there, staring out the window.

"What's the matter?" said Kathy. Maybe it would help him to talk about it.

He sat there a moment longer, staring out the window.

"Mr. Brink has been very distant lately," he said. Mr. Brink was the man in charge of promoting people--or not promoting them.

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Kathy tried to think of something encouraging to say. Maybe Mr. Brink was beginning to treat him as an equal. No, that was wrong. Even if he got promoted he wouldn't be anywhere near equal to Mr. Brink. Kathy chewed her bite of casserole. It had lost its flavor, somehow. Tom sat.

"We got a bill from the dentist today," he said. "Did you see that?"

"Yes."

"I mean the number. Did you see the number?"

"Yes." She'd seen it. It was scary. Hundreds of dollars, and there was more work to be done.

Tom picked up a bite of casserole on his fork. Looked at it. Put it back down on the plate.

"We don't have enough for the down payment on the house, either," he said.

He sure was worried about that promotion. Worried about money. She tried to remember a time when he hadn't been worried about money. Before they'd got married--then he'd been rich, relatively speaking. But ever since then they'd been on a tight budget. She wondered if there ever would be a time when Tom didn't have to worry about money. But that was depressing, so she put it out of her mind.

Tom sat up very straight and took a big, deep breath, and then he gave a huge sigh and his shoulders sagged.

He put his napkin on the table and pushed his chair back.

"'Scuse me," he said.

He poured himself another highball--his third that evening--and went into the living room. Kathy watched him as he turned on the the television and stood there in front of it adjusting the dials. Then he went to the other end of the room, where she couldn't see him. She heard him plop into his chair.

Kathy looked at the wounded casserole. It was already cold. One of the candles was dripping on the tablecloth. She had a plate full of food in front of her, but she wasn't the least bit hungry. So much for the quiet, pleasant dinner.

She should have made Kristi stay home. At least she would have had somebody to talk to.

"Oh, damn," said Tom in the living room. "Do I have any more cigarettes in there? This pack is empty."

She wanted to say something nasty, like "That isn't all that's empty around here," but she didn't. After all, he was worried, and they would be in bad shape if he didn't get promoted.

She got up and pulled Tom's carton of cigarettes out of the cupboard. There was only one pack. She took it into the living room, opened it and lighted one for him.

"You've smoked up that whole carton in five days," she said. "That's two packs a day."

Tom waved his hand with the cigarette in it.

"Yeah, yeah, I know. I have to cut down. Soon as this promotion business is out of the way so I can relax. Smoking and drinking are the only things that help me relax. Listen, I want to hear what this guy is saying. It's about home loans."

Kathy went back into the kitchen. She turned on the light and blew out the rest of the candles. There was nothing romantic about the table any more. Just a mess. But at least it wasn't a very big mess.

The man on the television was talking about interest rates. Kathy listened as she moved around the kitchen, putting things away and stacking the dishes in the sink. Interest rates were expected to go up again by the end of the week. She didn't know whether that was bad or good. Applicants who did not have a substantial income would find it more difficult to get a loan. Uh-oh. That was bad. The man said that the advice of somebody-or-other to prospective home buyers was to close any deals now, before money got any tighter.

Then there was the beginning of a commercial for pills that calm you down so that you won't shout at your loved ones. Kathy turned on the water and started washing the dishes.

Suddenly Tom yelled: "Kathy!"

She cringed. He was about to have a blowup about the interest rates.

"Kathy! I can't get enough breath!"

She dropped the plate and ran into the living room. Tom was breathing hard. He looked terribly distressed, and she could tell that he was frightened.

"Is it your asthma?" she said.

"I don't know. I'm numb." He gasped for breath. He was twitching. "I'm so weak I can hardly move." He gasped again. "I think I'm going to pass out." Suddenly grabbed his chest. "Maybe it's a heart attack," he said. "Call the doctor quick!"

Kathy was shaking like a leaf, but she managed to get to the phone and dial the doctor's number. He answered, and she quickly described what was happening to Tom as best she could.

"Is it his asthma?" she said.

"I don't think so," came the doctor's voice from the telephone. "You said he thought he was going to pass out?"

"Yes," said Kathy.

"Is he wheezing?"

"Wheezing? Uh--Tom, are you wheezing?"

"You would hear it if he were. Like when you got the cat, remember?"

"Oh, yes. No. I mean yes, I remember. No, he isn't wheezing."

"Okay," said the doctor. "Now, listen. Here's what you do. Get a small grocery bag, you know? Like a lunch bag."

"Right." She didn't have any idea what that had to do with Tom.

"Get a paper bag and have Tom breathe in and out of it. Got it?"

"Yes--is that all?"

"That's all. Have him breathe in and out of the bag, so that he's rebreathing the same air over and over again. Call me back if he's not much better in about ten minutes. And have him come in tomorrow so I can look him over."

"Okay," said Kathy. "Good-bye." She hung up, ran into the kitchen for a bag and brought it back. She opened it and blew it up, then held it over Tom's mouth.

"Breathe in and out," she said.

Tom looked at her like she was crazy. She wasn't too sure herself, but she had heard the doctor.

"He says you have to breathe in and out of a paper bag. Go on. Breathe."

He breathed. In and out, in and out, in and out.

It worked. Within a few minutes, all the symptoms were gone. He was a little sweaty, but he had stopped twitching and gasping for breath.

"How do you feel?" said Kathy.

"All right, I guess," said Tom. He looked down at his chest, as though waiting for it to start again. "A little weak, but all right."

"He said you should go in tomorrow so he can look you over."

"That's all?"

"Yep."

Tom looked down at his chest again and then up at Kathy.

"What do you suppose was wrong with me?"

"I don't know," she said. "I guess you'll just have to go see the doctor tomorrow and ask him."

29-2 <u>Acids</u>

What substances produce hydrogen ions in solution?

We have shown some general biomedical applications of chemistry, but have not yet related chemistry directly to the process of respiration. But the substances involved in the respiration process have chemical properties, and the properties of one of these substances, carbon dioxide, is related to Tom's problem. So before discussing Tom's ailment, we will consider some additional chemistry. This chemistry involves the properties of hydrogen ions.

When hydrogen chloride is a gas it exists as a covalent molecule.

$$H:\ddot{\underset{\cdot\cdot}{Cl}}:$$

But when it dissolves in water it dissociates into a positive hydrogen ion and a negative chloride ion.

$$[H]^+ \qquad [:\ddot{\underset{\cdot\cdot}{Cl}}:]^-$$

$$\underset{\text{hydrogen chloride}}{HCl} \rightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{chloride ion}}{Cl^-}$$

A solution of hydrogen chloride in water is called hydrochloric acid, and is typical of a class of substances called <u>acids</u>. We define an acid as a substance that produces hydrogen ions in solution.

A small amount of water itself dissociates to give hydrogen ions and hydroxide ions.

$$H_2O \rightarrow H^+ + OH^-$$

The concentration of H^+ ions in pure water is 10^{-7} M. A solution in which the concentration of hydrogen ions is greater than 10^{-7} M is said to be <u>acidic</u>.

The acidic properties of hydrochloric acid are important in the digestion of food in the stomach.

Acids have several characteristic properties. They have a sour taste. For instance, lemons owe their sour taste to citric acid. Some concentrated acids characteristically dissolve metals and burn skin and body tissue, which is a very good reason for not testing a solution for acidity by tasting it.

Other acids commonly used in laboratory work are nitric, HNO_3; sulfuric, H_2SO_4; and phosphoric, H_3PO_4. Nitric acid dissociates to hydrogen ions and nitrate ions, sulfuric acid to hydrogen ions and sulfate ions, and phosphoric acid to hydrogen ions and phosphate ions.

$$HNO_3 \rightarrow H^+ + NO_3^-$$

$$H_2SO_4 \rightarrow 2\ H^+ + SO_4^{-2}$$

$$H_3PO_4 \rightarrow 3\ H^+ + PO_4^{-3}$$

Low concentrations of boric acid, H_3BO_3, are used as an eyewash. Other acids are found in biological systems. A few of these are given in the following list.

Name	Formula	Where Found
Citric acid	$H_3C_6H_5O_7$	lemons, oranges, limes, grapefruits
Acetic acid	$HC_2H_3O_2$	vinegar
Carbonic acid	H_2CO_3	carbonated beverages
Lactic acid	$HC_3H_5O_3$	sour milk
Tartaric acid	$H_2C_4H_4O_6$	grapes
Butyric acid	$HC_4H_7O_2$	rancid butter, limburger cheese, perspiration
Acetylsalicylic acid	$HC_9H_7O_4$	aspirin

The hydrogen atoms that are capable of dissociating to become H^+ ions are usually placed first in the formula to indicate an acid. Thus in $HC_2H_3O_2$, one hydrogen atom can become an ion; the other three remain part of an acetate ion ($C_2H_3O_2^-$).

Proteins are built by our bodies from substances called amino acids, and genetic information is passed on by extremely large molecules called nucleic acids.

29-3 Bases

What substances produce hydroxide ions in solution?

Soda lime, used in Laboratory Activity 17 to absorb carbon dioxide, is a mixture of sodium hydroxide, NaOH, and calcium hydroxide, $Ca(OH)_2$. Both of these substances dissociate in water to produce hydroxide ions.

$$NaOH \rightarrow Na^+ + OH^-$$

$$Ca(OH)_2 \rightarrow Ca^{+2} + 2\ OH^-$$

A solution of sodium hydroxide or calcium hydroxide or any other substance which produces hydroxide ions is called a base. A solution containing more than 10^{-7} hydroxide ions per liter, the concentration in pure water, is said to be basic. A basic solution is also frequently called alkaline.

A basic solution feels slippery or soapy. Its taste is bitter, although taste is never used as a test because some bases can cause severe burns.

Bases rarely occur in nature; what few bases do occur tend to be poisons. However, bases such as sodium hydroxide and calcium hydroxide are common laboratory chemicals. Their importance lies in their reaction with acids.

29-4 Neutralization and Salts

What is the product of the reaction of an acid and a base?

A hydrogen ion may combine with a hydroxide ion. The positive charge of the hydrogen ion cancels the negative charge of the hydroxide ion. The hydrogen ion combines with the hydroxide ion to form a water molecule.

H^+	+	OH^-	$\rightarrow$	H_2O
hydrogen ion		hydroxide ion		water

If an equal number of hydrogen ions and hydroxide ions are added to a solution, the two types of ions neutralize each other and form water. A solution with neither an excess of hydrogen ions nor an excess of hydroxide ions is said to be neutral.

If a base is added to an acid, the base destroys the acidic properties of the solution because the hydroxide ions react with the hydrogen ions to form water. For example, when HCl and NaOH solutions are mixed, the following reaction occurs.

$$H^+ + Cl^- + Na^+ + OH^- \rightarrow H_2O + Na^+ + Cl^-$$

Whether the mixture is acidic, neutral or basic depends on the relative amounts of HCl and NaOH. If the solution contains more moles of HCl than NaOH, more H^+ ions are formed than OH^- ions. Not all H^+ ions react with OH^- ions, and the excess H^+ makes the solution acidic.

If equal numbers of moles of HCl and NaOH are put into solution, the number of H^+ ions is equal to the number of OH^- ions. Except for the 10^{-7} moles of OH^- and 10^{-7} moles of H^+ that remain dissociated in a liter of water, every OH^- reacts with an H^+ and the solution is neutral.

The neutral solution contains an equal number of Na^+ and Cl^- ions. In other words, it is a solution of sodium chloride, and if the water evaporated, table salt would remain.

Sodium chloride is only one of a class of substances known as <u>salts</u>. A salt is any ionic substance that can be formed when an acid and base neutralize one another. For example, the formula of Epsom salt, which is used as a laxative, is $MgSO_4$. Magnesium sulfate is formed when sulfuric acid is neutralized with magnesium hydroxide.

$$Mg(OH)_2 + H_2SO_4 \rightarrow 2\ H_2O + Mg^{+2} + SO_4^{-2}$$

If a solution contains a larger number of moles of OH^- than H^+, essentially all the H^+ ions are neutralized, and excess OH^- ions remain. This solution is therefore basic.

The concentrations of acids and bases are commonly expressed as molar concentrations. Expressing concentrations in moles per liter makes many types of problems easier to solve, as illustrated by the following examples.

<u>EXAMPLE</u>:

One liter of 2 M HCl is mixed with one liter of .5 M NaOH. Is the resulting solution acidic, neutral or basic?

<u>SOLUTION</u>:

A 2 M HCl solution contains 2 moles of HCl per liter. One liter of this solution thus contains 2 moles HCl. One liter of .5 M NaOH contains .5 mole of NaOH. The mixture of these two solutions contains more H^+ ions than OH^- ions and is therefore acidic.

<u>EXAMPLE</u>:

1.2 liters of .6 M HCl are mixed with .8 liter of .9 M NaOH. Is the resulting solution acidic, neutral or basic?

<u>SOLUTION</u>:

The number of moles in the HCl solution is given by the following formula.

$$\text{moles HCl} = \left(\frac{\text{moles HCl}}{\text{liter of solution}}\right)(\text{liters of solution})$$

$$= \left(\frac{.6 \text{ mole HCl}}{\cancel{\text{liter}}}\right)(1.2 \cancel{\text{liters}})$$

$$= .72 \text{ mole}$$

The number of moles in the NaOH solution is given by the formula

$$\text{moles NaOH} = \left(\frac{\text{moles NaOH}}{\text{liter of solution}}\right)(\text{liters of solution})$$

$$= \left(\frac{.9 \text{ mole NaOH}}{\cancel{\text{liter}}}\right)(.8 \cancel{\text{liter}})$$

$$= .72 \text{ mole}$$

An equal number of moles of H^+ and OH^- are added. Therefore the resulting solution is neutral. Note how much easier this type of problem is when quantities are expressed in moles rather than grams.

EXAMPLE:

160 grams of NaOH are added to two liters of 1.5 M HCl. Is the resulting solution acidic, neutral or basic?

SOLUTION:

In this example the quantity of NaOH is given in grams, so we must convert it to moles. The gram molecular weight of NaOH is 22.99 + 16.00 + 1.01 = 40.00 grams.

The number of moles in 160 grams of NaOH is given by the formula

$$\text{moles NaOH} = (160 \cancel{g})\left(\frac{1 \text{ mole}}{40 \cancel{g}}\right)$$

$$= 4 \text{ moles}$$

The number of moles of HCl in two liters of a 1.5 M solution is

$$(2 \cancel{\text{liters}})\left(\frac{1.5 \text{ moles}}{\cancel{\text{liter}}}\right) = 3 \text{ moles}$$

The solution contains an excess of OH^- ions and is therefore basic.

29-5 Indicators and Titration

How can one tell whether a solution is acidic or basic? How can one determine the concentration of H^+ ions in a solution?

Certain chemicals by their color indicate the presence, absence or concentration of some other substance. These chemicals are called indicators. We encountered an indicator in Section 27: it is red in the absence of Hg^{+2} ions but it changes color when it reacts with Hg^{+2} ions.

The color of certain other indicators depends on the concentration of H^+ ions in a solution, and may be used to indicate whether a solution is acidic or basic. One dye commonly used as an indicator is litmus. Litmus is red in acidic solutions and blue in basic solutions. Another indicator is phenolphthalein. This dye is colorless in acidic solutions but pink in basic solutions.

The molar concentration of H^+ ions (or OH^- ions) in a solution may be determined using an indicator and a technique called titration.

As an illustration of the use of titration, consider the following situation. The diagnosis and treatment of certain stomach disorders, such as an ulcer, depends on the concentration of hydrochloric acid in the stomach juices. A sample is withdrawn from the stomach of the patient and titrated with sodium hydroxide. An indicator dye, such as phenolphthalein, is added to the HCl solution. NaOH is added one drop at a time until the solution just turns pink. This indicates that the last drop turned the solution from being slightly acidic to being slightly basic, and that the number of OH^- ions added is approximately equal to the number of H^+ ions that were present in the HCl solution to start with.

The following example shows the method of determining molar concentrations from a titration.

EXAMPLE:

.002 M NaOH solution is added a drop at a time to 12 ml (.012 liter) HCl solution until an indicator just changes color. The amount of NaOH added is 30 ml (.03 liter). What was the molar concentration of the HCl solution?

SOLUTION:

$$\text{moles NaOH} = \left(\frac{\text{moles NaOH}}{\text{liter of solution}}\right)(\text{liters of solution})$$

$$= \left(\frac{.002\ \text{mole}}{\cancel{\text{liter}}}\right)(.03\ \cancel{\text{liter}})$$

$$= 6 \times 10^{-5}\ \text{mole}$$

$$\text{moles } OH^- = \text{moles NaOH} = 6 \times 10^{-5}\ \text{mole}$$

$$\text{moles } H^+ = \text{moles } OH^- = 6 \times 10^{-5}\ \text{mole}$$

$$\text{moles HCl} = \text{moles } H^+ = 6 \times 10^{-5}\ \text{mole}$$

$$\text{molar concentration} = \frac{\text{moles HCl}}{\text{liters of solution}}$$

$$= \frac{6 \times 10^{-5}\ \text{mole HCl}}{.012\ \text{liter of solution}}$$

$$= 5 \times 10^{-3}\ \frac{\text{mole HCl}}{\text{liter of solution}} = .005\ \text{M}$$

The HCl solution contains .005 mole HCl per liter of solution.

When ammonia dissolves in water, each NH_3 *molecule reacts with an* H_2O *molecule to form ammonium hydroxide.*

$$NH_3 + H_2O \rightarrow NH_4OH$$

Ammonium hydroxide, which is also called ammonia water, can dissociate to an ammonium ion and a hydroxide ion.

$$NH_4OH \rightarrow NH_4^+ + OH^-$$

NH_4OH *is harmful if swallowed because of its basic properties. The label may suggest using vinegar or lemon juice if ammonia water is swallowed. Why? Write equations for the reactions between ammonium hydroxide and acetic acid and between ammonium hydroxide and citric acid.*

Vocabulary:

acid--a substance that produces H^+ ions in solution.

acidic (uh-SID-ik)--containing a greater concentration of H^+ ions than pure water.

alkaline--see basic.

base--a substance that produces OH^- ions in solution.

basic--containing a greater concentration of OH^- ions than pure water.

indicator--a chemical that indicates by its color the presence, absence or concentration of some other substance.

neutral--containing an equal number of H^+ and OH^- ions.

neutralize--cause a solution to have an equal number of H^+ and OH^- ions.

salt--any ionic substance that may be formed during a neutralization reaction.

PROBLEM SET 29:

A. After each of the following pairs of solutions is mixed, is the resulting solution acidic, neutral or basic?

1. 1 liter of 2 M nitric acid (HNO_3) and 1 liter of 3 M sodium hydroxide (NaOH).

2. 1 liter of .5 M hydrochloric acid and 1 liter of .3 M potassium hydroxide (KOH).

3. 1 liter of 2 M nitric acid and 2 liters of .5 M potassium hydroxide.

4. .3 liter of .4 M hydrochloric acid and .2 liter of .6 M sodium hydroxide.

5. 1.5 liters of 2 M HNO_3 and 112.2 grams of KOH.

B. Determine the molar concentration of the acid solutions in each of the following situations.

1. .5 M KOH solution is added to 1 liter of HNO_3 solution. The indicator changes color when 40 ml of KOH solution have been added.

a. Determine the number of moles in 40 ml of .5 M KOH.

b. How many moles of HNO_3 are in the solution?

c. Determine the molar concentration of HNO_3 from the number of moles in 1 liter of solution.

2. .1 M NaOH is added to 80 ml of HCl solution. Phenolphthalein indicator turns pink when 25 ml of NaOH have been added.

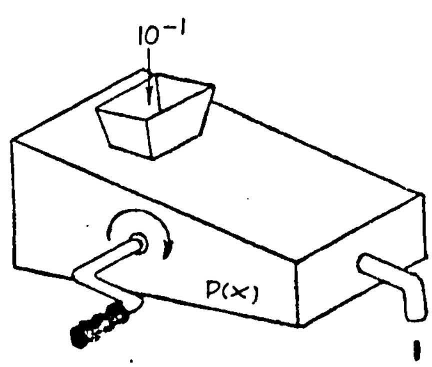
SECTION 30:

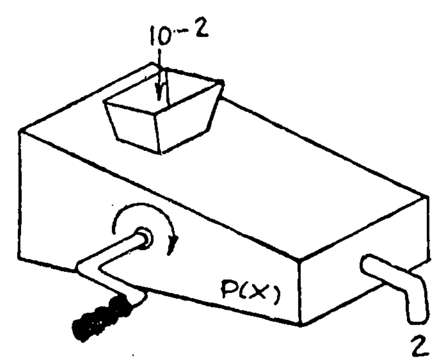
30-1 pH as a Measure of Acidity

What is the difference between a strong acid and a weak acid?

We discussed in Section 28 how the concentrations of solutes in solutions may be expressed in units of moles per liter. If a solution contains 3 moles per liter of a solute, we say that it is a 3 molar or 3 M solution.

The molarity of many solutions is very small. The hydrogen ion concentration in the blood, for instance, is extremely important to health and is normally between 10^{-7} M and 10^{-8} M. To make concentrations such as this easier to express, scientists use a function called the p function. The operation of the p function may be deduced from the operation of its function machine on a few numbers.





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If 10^{-1} is put into the machine, the output is 1. If 10^{-2} is the input, 2 is the output. If $x = 10^{-3}$, $p(x) = 3$. Writing these observations in function notation,

$$p(10^{-1}) = 1$$

$$p(10^{-2}) = 2$$

$$p(10^{-3}) = 3.$$

From these examples we deduce that, if $x = 10^{-n}$,

$$p(10^{-n}) = n$$

Because the acidity of a solution has an effect on many chemical reactions, and because many functions of the body are extremely sensitive to changes in acidity, the p function is most commonly used to express the concentration of hydrogen ions in a solution. When expressing hydrogen ion concentration, the function is written pH, although "p(H)" would be more consistent with function notation. The statement, "The pH of the solution is 3," is equivalent to the statement, "The concentration of hydrogen ions in the solution is 10^{-3} moles per liter."

The behavior of an acid in solution may be studied by putting a known amount of the acid into solution and measuring the pH of the solution. We will examine the contrasting behavior of two acids. One is nitric acid, which is said to be a strong acid; and the other is boric acid, said to be a weak acid.

The following table shows the measured pH of four nitric acid solutions, each of which has a different concentration.

Nitric Acid

Concentration	pH
10^{-1} M	1
10^{-2} M	2
10^{-3} M	3
10^{-4} M	4

We determine the values of p(concentration) for each solution using the equation we deduced from the operation of the function machine.

$$p(10^{-n}) = n$$

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The results are tabulated below.

Nitric Acid

p(concentration)	pH
1	1
2	2
3	3
4	4

The pH values of boric acid solutions of varying concentrations are shown in the next table.

Boric Acid

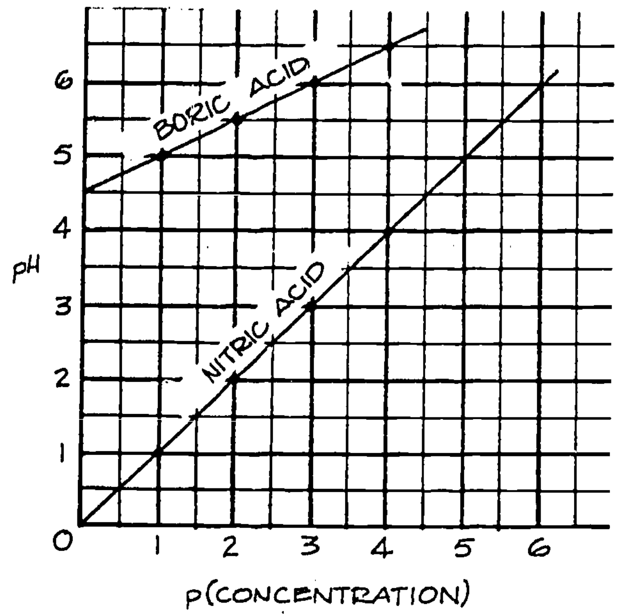
Concentration	pH
10^{-1} M	5
10^{-2} M	5.5
10^{-3} M	6
10^{-4} M	6.5

Again we determine the value of p(concentration) for each solution and tabulate the results.

Boric Acid

p(concentration)	pH
1	5
2	5.5
3	6
4	6.5

Let us graph pH as a function of p(concentration) for each acid. Both lines are shown on the same graph on the following page.



The graph may be used to find the equation of each line. Remember that since the lines are straight, the equations are of the form $y = mx + b$, where m is the slope and b the y-intercept. The slope of the nitric acid line is 1, and the y-intercept. The slope of the nitric acid line is 1, and the y-intercept is 0. Therefore, the equation for nitric acid is

$$pH = p(\text{concentration})$$

The slope of the boric acid line is $\frac{1}{2}$, and the y-intercept is $4\frac{1}{2}$. Therefore, the equation for boric acid is

$$pH = \frac{1}{2}\, p(\text{concentration}) + 4\frac{1}{2}$$

When the p(concentration) of nitric acid is decreased, the pH decreases equally. (Remember that an <u>increase</u> in hydrogen ion concentration is associated with a <u>decrease</u> in pH.) This indicates that essentially every molecule of nitric acid added to the solution dissociates to give a hydrogen ion. Complete dissociation is a property of a strong acid.

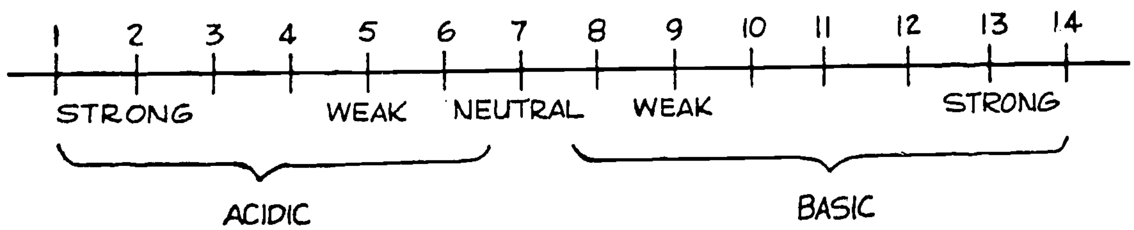
When the p(concentration) of boric acid is decreased by one unit, however, the pH decreases by only half a unit. This means that only part of the boric acid molecules added dissociate to give hydrogen ions. Incomplete dissociation is a property of a weak acid.

Observe that over the range shown at any given acid concentration, the pH is greater for boric acid than for nitric acid. In other words, a nitric acid solution of a given concentration is more acidic than a boric acid solution of the same concentration.

Pure water dissociates slightly, into hydrogen ions and hydroxide ions.

$$H_2O \rightarrow H^+ + OH^-$$

In pure water the concentration of H^+ ions is equal to the concentration of OH^- ions, which is 10^{-7} M. Thus the pH of pure H_2O is 7. A pH value lower than 7 refers to an acidic solution. The lower the pH, the more acidic the solution. The pH of a basic solution is greater than 7. The stronger the base, the larger the pH value.



What does the degree of dissociation in solution have to do with the strength of an acid?

The pH of a certain solution is 0. What is the molar concentration of H^+ ions in the solution?

NaOH dissociates completely in solution. Is it a weak base or a strong base?

Two solutions have respective pH's of 2 and 3. Which is the more acidic?

Two solutions have respective pH's of 13 and 14. Which is the more basic?

Why is pure water called a neutral solution?

Vocabulary:

pH--when the hydrogen ion concentration is expressed in the form 10^{-n} moles per liter, pH is equal to n.

strong acid--an acid that dissociates completely in solution.

weak acid--an acid that dissociates only partially in solution.

SECTION 31:

31-1 Carbon Dioxide and the pH of Blood

How does dissolved CO_2 lead to the production of H^+ ions?

If you measure the pH of the water coming from a tap, or even of distilled water, you will find the pH is less than 7. This is because of dissolved carbon dioxide in the water.

Part of the dissolved carbon dioxide combines with water to form carbonic acid.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftarrows \underset{\text{carbonic acid}}{H_2CO_3}$$

The reaction may also proceed in the opposite direction: carbonic acid dissociating to carbon dioxide and water. Carbonic acid is the source of the carbon dioxide gas which forms bubbles in soft drinks.

Carbonic acid is a weak acid and partially dissociates to hydrogen ions and bicarbonate ions, which have the formula HCO_3^-.

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

When oxygen is used by the cells of the body to produce energy, carbon dioxide is produced in the chemical reaction. The carbon dioxide is released by the cells into the blood. Carbon dioxide leaves the blood by moving from the pulmonary capillaries into the lungs.

If the amount of carbon dioxide in the blood increases, the amount being converted to carbonic acid increases. And if the amount of carbonic acid increases, the amount dissociating to hydrogen ions increases. Therefore, the greater the amount of CO_2 in the blood, the more acidic is the blood (and the lower is its pH).

Conversely, if the concentration of carbon dioxide in the blood is decreased, the pH of the blood increases as the blood becomes less acidic and more basic.

31-2 The Chemical Regulation of Breathing

How does blood pH affect the respiratory center in the brain?

In Section 17 we discussed the respiratory center, located in the brain. We stated that the neurons in the respiratory center could be stimulated by a variety of sources.

We will now explain how chemical changes in the blood stimulate the respiratory center.

Any change in the H^+ ion concentration of the blood is quickly followed by a similar change in the fluid of the brain. This fluid is called the cerebrospinal fluid. In the respiratory center and in the region near it are located certain special cells called chemoreceptors. They have this name because they monitor the chemical composition of the fluid surrounding them. The chemoreceptors in and near the respiratory center monitor the concentration of H^+ ions in the cerebrospinal fluid.

If the H^+ concentration is too high, the respiratory center responds by sending signals to the lungs that increase breathing. This is the main cause of the breaking point when we hold our breath.

If you deliberately hold your breath, your cells nevertheless continue to put carbon dioxide into the blood, but none is lost through your lungs. The concentration of CO_2 in your blood increases, and the H^+ ion concentration increases. You grow increasingly uncomfortable, and eventually your respiratory center takes control and forces you to breathe. You breathe rapidly until enough CO_2 is expelled that the H^+ ion concentration is again normal.

If the H^+ concentration of the cerebrospinal fluid is too low, the respiratory center responds by sending signals to the lungs that decrease breathing.

If a person intentionally overbreathes, the H^+ ion concentration of the blood falls because of the increased loss of CO_2 from the lungs. However, this soon causes a response in the respiratory center which depresses breathing until the H^+ ion concentration returns to normal.

Other chemoreceptors monitor the H^+ concentration of the blood. They are located just above the heart. Blood being pumped into the body by the heart begins its journey from the heart in a large artery called the aorta. The first part of the aorta leads upward, but it then arches downward. From the arch of the aorta come other arteries which lead upward and out to the sides.

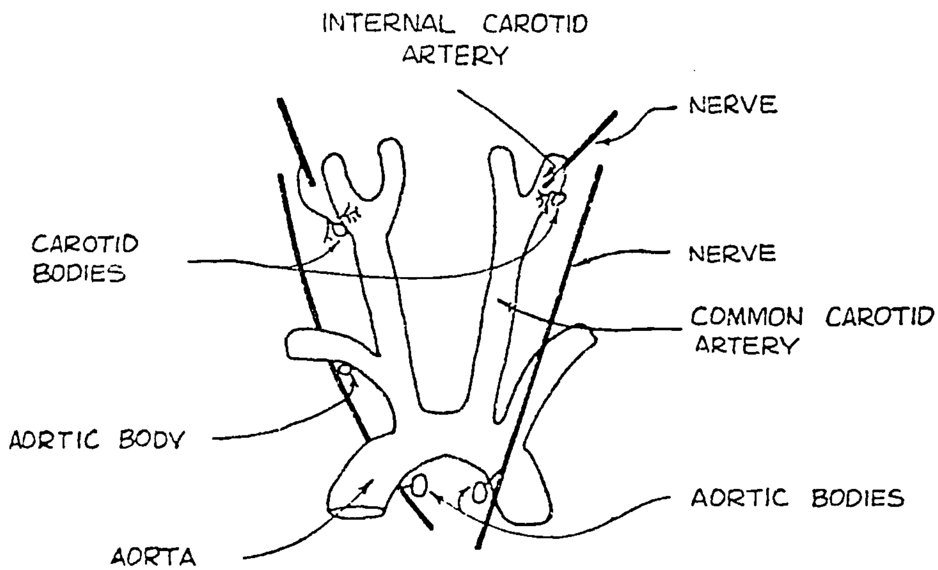


FIGURE 1: *Location of the aortic and carotid bodies.*

As you can see from Figure 1, there are two types of special structures in this region. There are two or more aortic bodies near the arch of the aorta, and there are two carotid bodies higher up along the carotid arteries. Both types of bodies contain chemoreceptors that function in the same way. One of their functions is to monitor the H^+ concentration of the blood and to send signals, along nerve pathways, to the respiratory center.

The signals from the carotid and aortic bodies concerning the H^+ concentration of the blood, however, have a much smaller effect on the respiratory center than the H^+ concentration of the cerebrospinal fluid.

A more important function of the carotid and aortic bodies is the monitoring of the concentration of oxygen dissolved in the blood. The monitoring of oxygen does not occur anywhere else in the body. When the oxygen concentration falls below normal, the monitoring bodies send signals to the respiratory center to increase breathing. The response of the respiratory center to these signals is rather strong, but it is still not as strong as the response to changes in the H^+ ion concentration of the cerebrospinal fluid.

This fact becomes important when we ascend rapidly to high altitudes. The lowered concentration of oxygen in the air at high altitudes leads to a lowered concentration of oxygen in the blood. The decreased amount of oxygen in the blood is monitored by the aortic and carotid bodies. They in turn stimulate the respiratory center to increase the rate of breathing.

However, the increased rate of breathing eliminates more carbon dioxide through the lungs. The decreased concentration of CO_2 leads to a decrease in the H^+ ion concentration both in the blood and in the cerebrospinal fluid. This stimulates the respiratory center to decrease the breathing rate.

Thus the effect of low oxygen concentration is opposed by the effect of low H^+ concentration. The result is that the increase in breathing is limited to about 65 per cent greater than normal. In acclimatized individuals, changes in the activity of the kidneys return the H^+ ion concentration toward normal, even though the concentration of CO_2 remains low. This permits further increases in the breathing rate.

31-3 Respiratory Alkalosis

What is the relation between blood pH and Tom's condition?

The concentration of carbon dioxide in the blood depends upon the amount produced by the cells and the amount being exhaled into the air. Normally the quantity of CO_2 produced by the cells is equal to the quantity given off through the lungs, and the pH of the blood remains constant.

When an individual is exercising vigorously, the pH of his blood is maintained near its proper value by one effect compensating for another. When a person exercises, his cells consume more oxygen than when he is still. This leads to a greater production of CO_2 in the cells, and thus a greater amount of CO_2 enters the blood.

But when an individual is exercising, he breathes more deeply and more frequently. Breathing deeply and frequently causes us to give off more CO_2 through the lungs. Therefore, when a person is exercising, the amount of CO_2 produced by the cells increases, but is balanced by the increased removal of CO_2 through the lungs. The pH of the blood remains reasonably constant.

If a person experiences extreme anxiety or panic, the respiratory center of his brain is stimulated. He breathes far more deeply ~~and frequently than his level of activity requires. The condition~~ of overbreathing is given the name hyperventilation. (The prefix "hyper-" means "too much," while the word "ventilation" means "breathing.")

When hyperventilation occurs, the amount of carbon dioxide produced by cells does not increase. However, the increased rate and depth of breathing causes an increased loss of CO_2 through the lungs. The result is a decrease in the concentration of CO_2 in the blood and a rise of the pH.

Normally, an increase in the pH of the cerebrospinal fluid causes the respiratory center to respond by signaling the lungs to decrease breathing. In Tom's case, though, this response was overridden by the effects of panic an anxiety on the respiratory center.

An abnormally high blood pH causes a condition known as respiratory alkalosis. (The word "alkaline" we mentioned as a synonym for basic. The suffix "-osis" means an abnormal increase. Thus alkalosis is an abnormal increase in basicity or pH.) Among the symptoms of respiratory alkalosis are dizziness, numbness, weakness, and twitching. All of these symptoms arise either because of the lowered concentration of CO_2 in the blood or its increased pH. If treatment is not given, the individual may eventually lose consciousness. Loss of consciousness leads to a reduction of the breathing rate, and the pH of the blood returns to normal.

Treatment involves decreasing the amount of CO_2 lost through the lungs. An effective treatment is to have the patient hold his breath, if he is capable of doing so. Tom was made to breathe in and out of a paper bag. Expiring into the bag filled the bag with air rich in CO_2. Inspiring the CO_2-rich air decreased the rate at which CO_2 moved from the blood into the air. Thus Tom's blood pH returned to normal.

The sequence of events in Tom's respiratory alkalosis are shown in Figure 2 on the following page. Note that the symptoms themselves caused further panic, which reinforced the original stress.

In healthy persons, the pH of the blood is "automatically" taken care of and no problems arise (except for cases such as Tom's). However, many medical conditions may affect blood pH. In some kinds of lung disease, for example, CO_2 is not properly expelled from the lungs. As a result, the CO_2 concentration in the blood gradually rises. This condition is known as respiratory acidosis. If such a patient is mistakenly given oxygen, the respiratory center may cause the breathing rate to decrease, leading to even less elimination of CO_2 and death from acidosis.

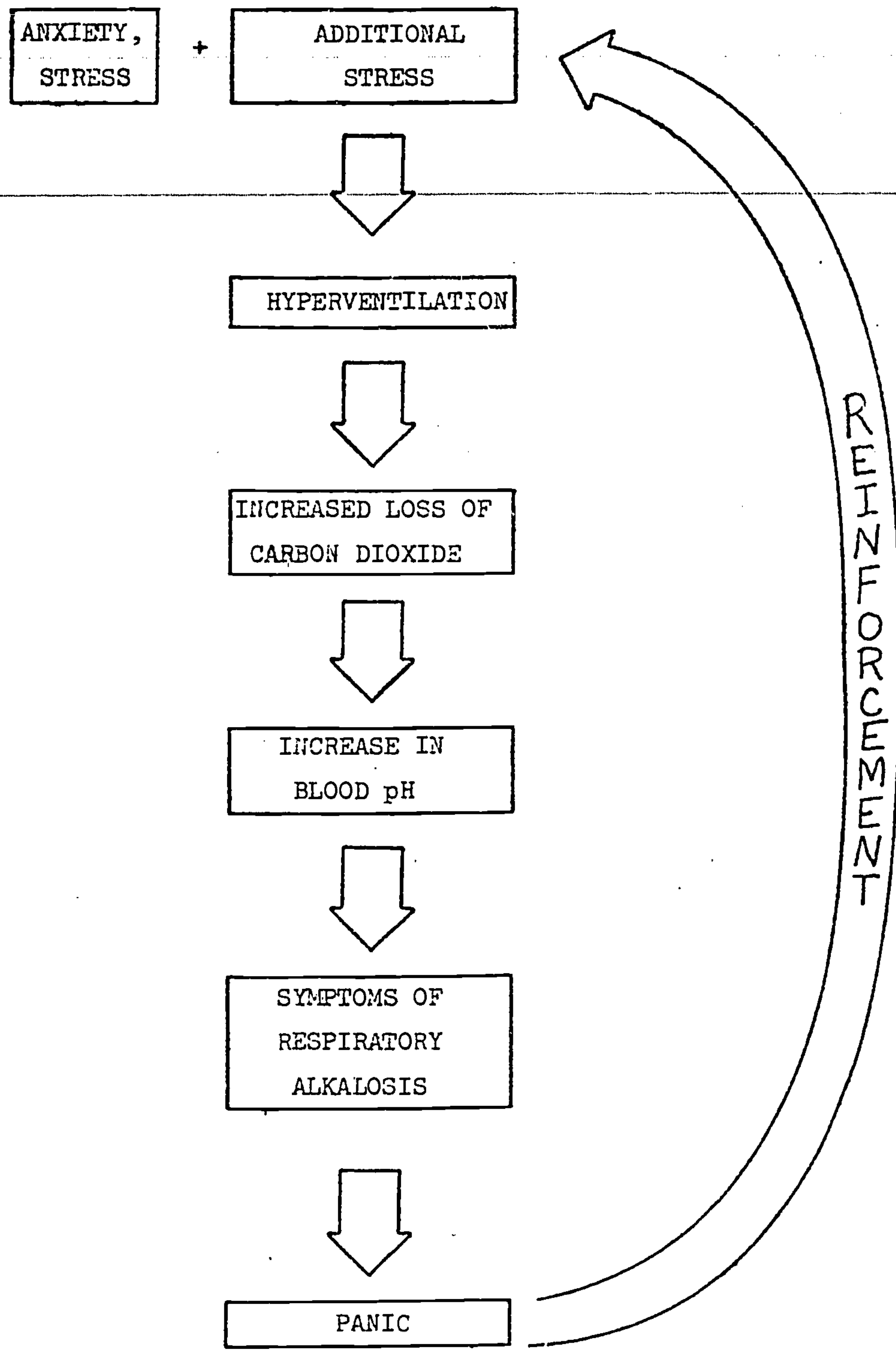


FIGURE 2: *The events which produced Tom's respiratory alkalosis.*

In untreated diabetics, acidic substances other than CO_2 may build up in the blood. The lowered pH of the blood stimulates an increase in the breathing rate, which can reduce the CO_2 concentration of the blood to abnormally low levels. Again, death may result from acidosis if the condition is not treated.

A clinical determination of the blood pH, along with its CO_2 concentration, is a very helpful tool in pinpointing the underlying cause of acidosis or alkalosis so that proper treatment can be given.

What is the relation between H^+ concentration and pH?

What effect does CO_2 concentration have on the H^+ concentration of the blood?

What effect does CO_2 concentration have on the pH of the blood?

What is the normal response of the respiratory center to decreased blood pH?

What is the normal response of the respiratory center to increased blood pH?

Why did this mechanism fail in Tom's case?

Vocabulary:

acidosis (ASS-ih-DOH-sis)--abnormal increase in acidity.

alkalosis (AL-kuh-LOW-sis)--abnormal increase in basicity.

aortic body (a-OR-tik)--a small mass of chemoreceptors that monitor the concentration of oxygen and H^+ ions in the blood.

carotid body (kah-ROT-id)--a small mass of chemoreceptors that function similarly to those of an aortic body.

chemoreceptors (KEE-mo-re-SEP-tors)--cells which monitor the chemical composition of the fluid surrounding them.

hyperventilation (HY-pur-VEN-til-A-shun)--overbreathing.

SECTION 33:

33-1 Alveoli

How are gases exchanged between the lungs and the bloodstream?

The oxygen we inhale must somehow get from the lungs to all parts of the body. Every cell is dependent on oxygen for its survival. The subject of this section is the transport of oxygen from the lungs to the cells of the body and the movement of carbon dioxide from the cells to the lungs. In order to understand this transport of gases, it is necessary to understand the process of diffusion. But before considering diffusion, let us review the anatomy of alveoli and blood capillaries.

The alveoli are the thin-walled structures attached to air sacs at the end of bronchial tubes. Alveoli have a clustered appearance, similar to a bunch of grapes. The walls of alveoli are very thin, being in most places only about 0.001 millimeter thick.

Gas molecules can pass through the thin walls of the alveoli. On the other side of the walls are pulmonary blood capillaries. The walls of these capillaries are as thin as the walls of alveoli, and gas molecules can pass through these walls and enter the blood system.

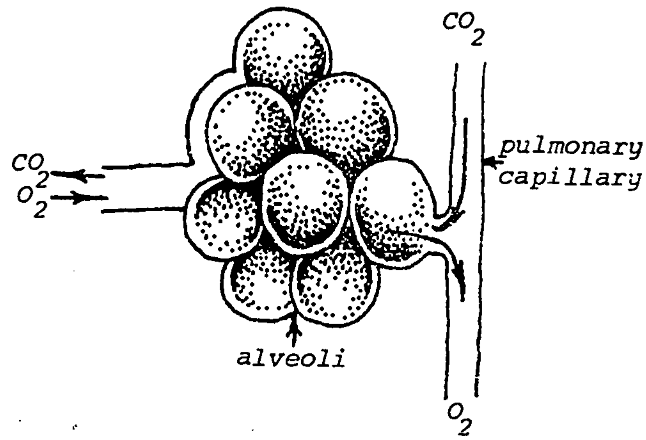


FIGURE 1: *Gas exchange between the alveoli and the pulmonary capillaries.*

The diameter of the pulmonary capillaries is just large enough to permit one red blood cell to pass at a time. The red blood cells acquire oxygen from the lungs and give up carbon dioxide. The thin walls make possible a rapid exchange of gas between the alveoli and the blood. When a person is at rest, red blood cells spend 0.75 second passing through the pulmonary capillaries, but when a person is active, the red blood cells pass through in 0.30 second or less.

The process by which oxygen and carbon dioxide pass through the walls of the alveoli and capillaries is diffusion. Diffusion is important to so many functions in all living things that we will examine it now in detail. To make it easier to understand, we will temporarily consider diffusion as it takes place in laboratory glassware.

33-2 Diffusion

What factors control the rate of diffusion?

If a piece of a soluble salt which has color is dropped into a beaker of water, the color slowly spreads through the water as the salt dissolves. Copper sulfate ($CuSO_4$) is a good salt for this experiment. $CuSO_4$ dissociates in solution into a blue copper (Cu^{+2}) ion and a sulfate (SO_4^{-2}) ion. The blue color spreads as copper ions travel through the solution (see Figure 2 on the next page). The ions do not move through the solution as rapidly as molecules through a gas, because gas molecules have a greater speed and travel farther between collisions with other molecules.

The spread of copper ions throughout the solution is called diffusion. If one part of the solution has a greater concentration of copper ions than another part, copper ions diffuse from the area of high concentration to the area of low concentration. Eventually the blue color is uniform throughout the solution.

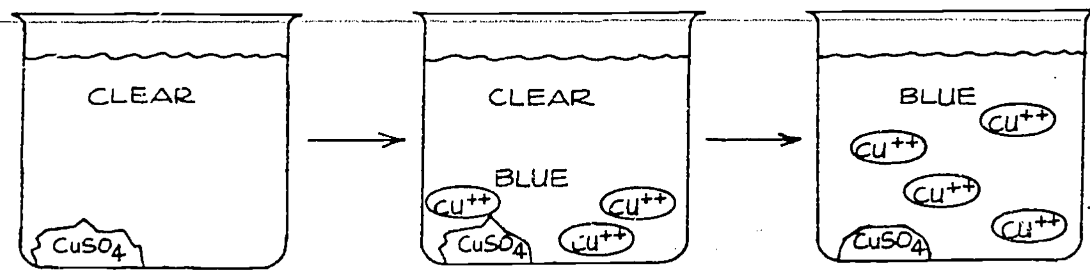


FIGURE 2: *The spread of copper ions in solution.*

One important principle of diffusion is that substances diffuse from regions of high concentration to regions of low concentration.

Our example with copper sulfate concerned diffusion through a single solution. Let us now consider diffusion through a partition that separates one solution from another. Such a partition must allow the diffusing substance to pass through. If a substance can pass through, we sa, the partition is permeable to that substance.

Suppose that a one-liter solution containing 40 grams of a red dye is separated from another one-liter solution, which contains 20 grams of the red dye, by a partition permeable to the dye. (See Figure 3.)

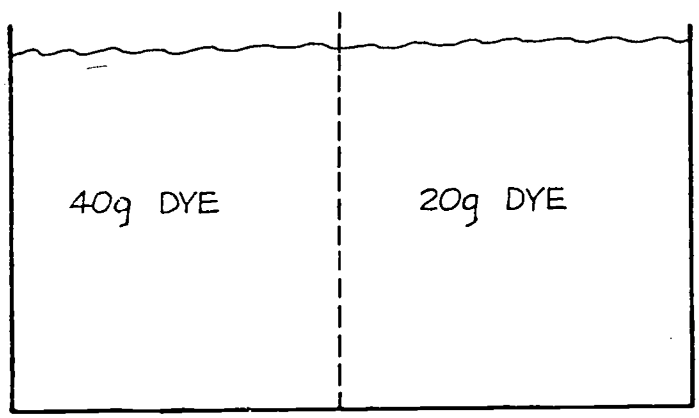


FIGURE 3: *Different concentrations of dye on two sides of a permeable partition.*

Initially the solution on the left is colored a deeper red. Dye passes through the barrier until the concentration of dye on both sides of the barrier is the same. That occurs when 10 grams of dye has passed from the left side to the right side; each side then contains 30 grams of dye, and the colors on the two sides are identical.

The rate at which diffusion occurs is critical to the process of respiration and depends on several factors. One is the difference in concentration between the two sides; in our example, the greater the dye concentration on the left side and the smaller the concentration on the right side, the faster the rate of diffusion. A second factor is the surface area of the barrier; the larger the area of barrier, the faster the rate of diffusion. A third factor is the thickness of the barrier; if the barrier is thinner, the rate of diffusion is greater.

33-3 The Transport of Oxygen from the Lungs to the Body

How does oxygen get from the lungs to the cells of the body?

How is carbon dioxide removed from the body?

In the transport of oxygen from the lungs to the body cells, as well as in the transport of carbon dioxide from the cells to the lungs, diffusion takes place at several points. The first surface through which oxygen diffuses is the walls of alveoli. It then diffuses through the walls of blood capillaries and enters the fluid portion of the blood. Our discussion of diffusion concerned the passage through a barrier from one liquid to another, and we spoke in terms of concentrations. When a substance diffuses from a gas to a liquid, the idea of concentrations is somewhat changed, but that need not concern us. The basic principles of diffusion are the same. The greater the concentration of oxygen in the lungs, the greater the rate of diffusion into the blood. And the greater the surface area for diffusion, the greater the amount of oxygen diffusing.

The fluid portion of the blood is called the plasma. Oxygen is not very soluble in plasma, and plasma can carry only enough oxygen to supply the body for about 4.5 seconds. However, the blood contains erythrocytes, which are also called red blood cells; and erythrocytes carry hemoglobin. A hemoglobin molecule contains four iron atoms, and each iron atom can bind one oxygen molecule. Therefore, since an oxygen molecule is two oxygen atoms, each hemoglobin molecule can carry eight oxygen atoms. The compound formed is called oxyhemoglobin. The hemoglobin molecules in our erythrocytes can carry enough oxygen to supply the body's needs for about five minutes.

The next diffusion of oxygen then is across the membrane of an erythrocyte. Again concentrations determine the rate of diffusion. As more oxygen enters the blood plasma, the concentration of oxygen in the plasma increases and the rate of diffusion across walls of erythrocytes increases (see Figure 4 on the next page).

When oxygen is taken up by body cells, the opposite process occurs. Oxygen diffuses from the plasma to the cells. This reduces the concentration of oxygen in the plasma, so oxygen leaves hemoglobin molecules and diffuses into the plasma (see Figure 5 on the following page).

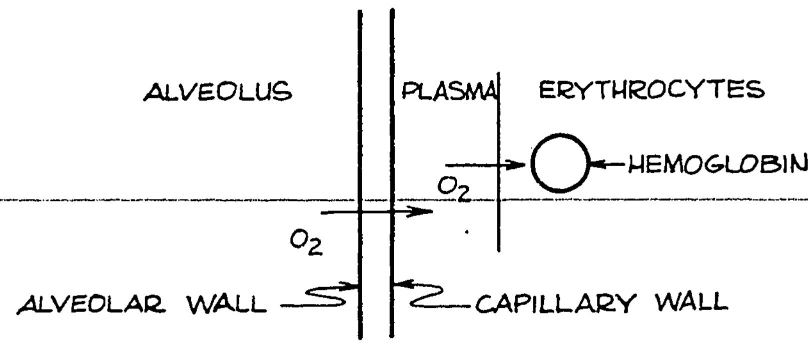


FIGURE 4: *Diffusion of oxygen from the alveoli to the erythrocytes.*

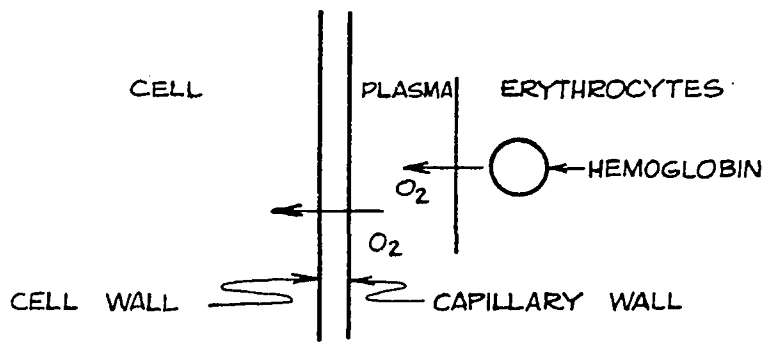


FIGURE 5: *Diffusion of oxygen from the erythrocytes into the cells.*

The transport of carbon dioxide occurs by the process opposite to the transport of oxygen. Carbon dioxide diffuses across the cell wall and capillary wall into the blood plasma. Most of the CO_2 that enters the blood plasma enters erythrocytes. Here most of it undergoes a chemical reaction with water to form carbonic acid (H_2CO_3).

$$H_2O + CO_2 \rightarrow H_2CO_3$$

In erythrocytes, carbonic acid dissociates into hydrogen ions and bicarbonate ions (HCO_3^-).

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

Hydrogen ions combine with hemoglobin, but bicarbonate ions diffuse back into the plasma. (See Figure 6 on the next page.)

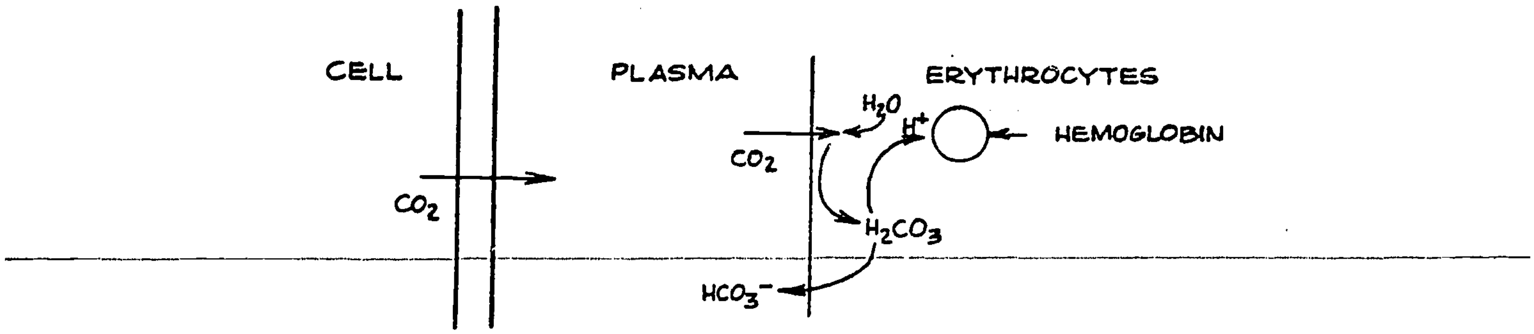


FIGURE 6: *Pathway of CO_2 leaving the cells.*

About 67 per cent of the CO_2 is carried to the capillaries in the lung in this form. Another 25 per cent of the CO_2 reacts directly with hemoglobin and is carried in that form. The remaining 8 per cent of the CO_2 remains dissolved in the plasma and the erythrocytes and is carried in that form.

At the pulmonary capillaries the hemoglobin releases its CO_2 and H^+ ions and takes up oxygen. The H^+ ions combine with HCO_3^- ions to form carbonic acid. The carbonic acid in turn dissociates to carbon dioxide and water.

$$H^+ + HCO_3^- \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$$

Finally, carbon dioxide diffuses through capillary walls and alveolar walls into the lungs. (See Figure 7.)

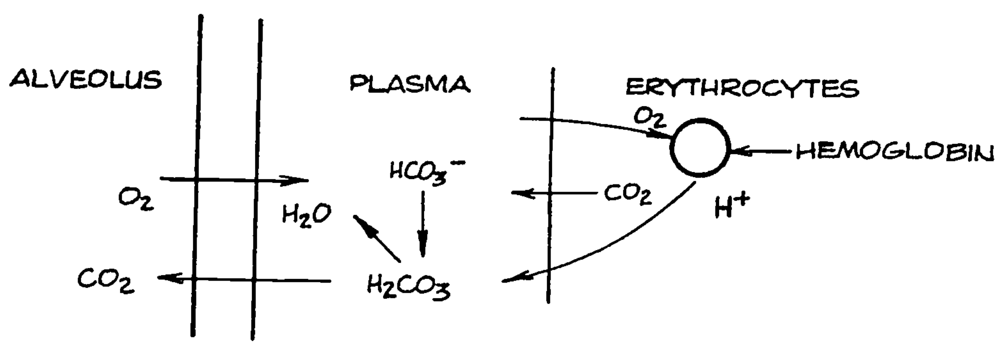


FIGURE 7: *Interchange of gases at the alveoli.*

List three factors upon which the rate of diffusion depends.

List the surfaces across which O_2 diffuses on its way from the lungs to the body cells, and across which CO_2 diffuses when being removed from the body.

Vocabulary:

diffusion (dih-FEW-shun)--the movement of a substance from a region of high concentration to a region of low concentration.

erythrocyte (eh-RITH-row-SITE)--a red blood cell.

hemoglobin (HE-mo-GLO-bin)--a molecule within the red blood cell which facilitates the transfer of oxygen and carbon dioxide between the lungs and the cells of the body.

permeable (PUR-me-uh-bl)--permitting the passage of substances.

plasma (PLAZ-muh)--the fluid portion of the blood.

SECTION 34:

34-1 Bumps, Runny Noses and the Movement of Water

Why do noses run during a cold?

In the last section we discussed how substances move from regions of high concentration to regions of low concentration. This is called diffusion. Now we will focus on the movement of a very special substance: water. You might wonder why we say water is so special.

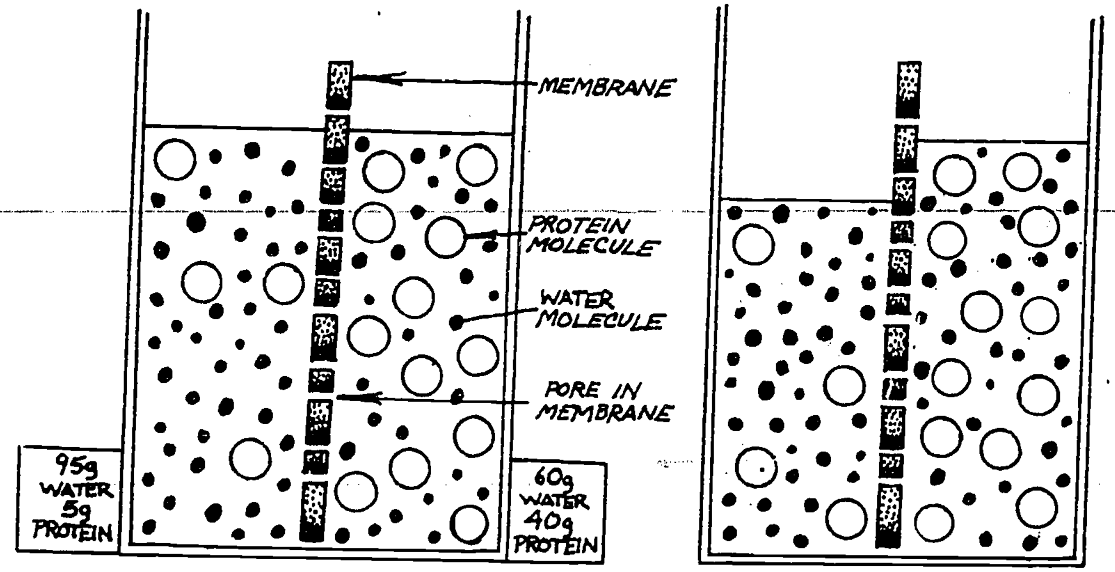
For one thing, about 55 to 60 per cent of the body is made of water. The movement of water is also an important response to injury. . Consider what happens when you hit your head; in ten minutes the's a swelling or a bump. Or consider a watery nose during a cold. Or consider Tommy's case of croup in Section 10. One of his symptoms was swelling in the larynx.

All of these have one thing in common: the movement of water. Water and protein move into a bumped area to produce swelling. Water and other materials are secreted by the soft tissues lining the nose in response to invasion by cold viruses. And water and special cells moved into the tissues of Tommy's larynx to produce swelling in response to the bacteria that cause croup. When bacteria invade the lungs, water can even collect in the alveoli, and block the respiratory exchange of oxygen and CO_2. What makes water act like this?

34-2 Osmosis and the Movement of Water

What causes water to move?

To answer this question about water, we need to consider a phenomenon called osmosis. Examine the membrane shown in Figure 1A on the next page. It lies between two water compartments. On the left side of the membrane is a solution that is very watery--95 g of water mixed with 5 g of protein. On the right side of the membrane there is a solution with much less water--only 60 g of water mixed with 40 g of protein. Protein molecules are generally too large to pass through the pores of a membrane, as you can see in the figure. Water molecules, however, are small enough to pass through the membrane.



1A

1B

FIGURE 1: *The movement of water, from where there is a high concentration of water to where there is a low one.*

What will happen? Water is just like any other substance. It moves from where it's in high concentration to where it's low. We can easily calculate the percentage of water on each side of the membrane in Figure 1A.

LEFT SIDE OF MEMBRANE	RIGHT SIDE OF MEMBRANE
95 g water	60 g water
5 g protein	40 g protein
100 g solution	100 g solution
$\frac{95\ g}{100\ g}$ = 95 per cent water	$\frac{60\ g}{100\ g}$ = 60 per cent water

Water moves from where there is 95 per cent water toward where there is only 60 per cent water--from high to low concentration. You can see the result in Figure 1B; the water level rises on the right side of the membrane and falls on the left.

This flow of water is known as osmosis. Osmosis is defined as the movement of water molecules (or other solvent) from a region of high water concentration to a region of low water concentration across a membrane which cannot be crossed by substances dissolved in the water. Such a membrane is said to be semipermeable.

We can see that osmosis is much like diffusion if we think about the concentration of water on the two sides of the membrane rather than the concentration of protein.

34-3 Osmosis in Cells and Tissues

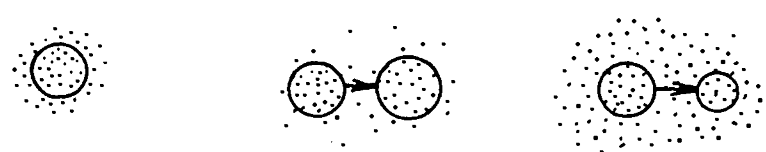
How does osmosis cause cells to burst?

Now we may return to our original question. What makes water move into an area to cause swelling?

We must consider the effects of injury. Cells may be injured by bacteria, viruses, chemicals or mechanical injury, such as banging them. Most cells and tissues in the body contain a lot of protein. These injuries alter cells so that they leak protein into the fluid around them. The effect of injury, then, is to add more protein to the fluid that surrounds cells.

All around this high-protein fluid is the normal fluid of the uninjured cells and tissues that are located around the injured area. By osmosis, water moves out of this normal fluid into the high-protein fluid, just as in Figure 1. This produces swelling of the injured area. This happened in Tommy's croup, and it happens with a bump on the head. And when the lining inside the nose is injured in a cold, water moves into it to cause running. The water helps to wash out bacteria and viruses and to protect injured cells.

Cells have to have just the right concentration of protein and salts in the fluid around them. If there is too little salt outside, osmosis will cause water to move through the cell membrane into the cell and fill it up. The cell then swells and may even burst. If there is too much salt outside, osmosis goes the other way. Water moves out of the cell to the outside and the cell shrinks (see Figure 2).



Normal amount of salt outside.	Too little salt outside: water enters cell.	Too much salt outside: water leaves cell.

FIGURE 2: *The effect of different salt concentrations around a cell.*

Osmosis is an important factor in deaths from drowning. If large quantities of fresh water enter the lungs, water is absorbed from the alveoli into the blood by the process of osmosis. This dilutes the blood, which has disastrous effects on the blood chemistry and the heart. It is this that causes death, rather than a lack of oxygen.

In salt-water drownings osmosis works in the opposite direction, because the concentration of water is higher in the blood than in sea water. Also, the concentration of salts is lower in the blood than in seawater. Thus salt water in the lungs causes a loss of water from the blood and an increase in the quantity of salts dissolved in it. This, too, causes death more rapidly than would occur from a lack of oxygen alone.

In what ways is the process of osmosis like the process of diffusion? How do the two processes differ?

Explain, in terms of water concentrations, why a cell with too little salt outside it swells up.

How do the events leading to death differ in fresh-water drownings and salt-water drownings?

Vocabulary:

osmosis (oz-MO-sis)--the movement of water or other solvent through a semipermeable membrane, from the side of higher water concentration to the side of lower water concentration

semipermeable--permitting passage of some substances and not others.

SECTION 35:

35-1 Avogadro's Principle

What determines the volumes of gases that take part in chemical reactions?

In Problem Set 27, we stated that an adult might typically oxidize 4 moles of glucose in one day for his or her energy needs. The reaction is

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

How much oxygen is required to oxidize 4 moles of glucose?

One answer to this question is 4 x 6 = 24 moles of oxygen. Or we could calculate the mass of the required oxygen. 24 x 32 = 768 grams of oxygen.

Similar answers could be given for the amount of CO_2 produced from the oxidation of 4 moles of glucose. 4 x 6 = 24 moles of CO_2 and 24 x 44 = 1056 grams of CO_2.

All of these are valid answers to the questions raised. But if we needed to supply this quantity of oxygen to a patient or were concerned about disposal of the CO_2 (such as in a submarine), we might be far more interested in the volumes that these quantities of gas would occupy.

How such volumes may be determined is the topic of Section 35-2, but before considering this problem, we need to describe a series of observations that may be made about chemical reactions involving gases. Some of these observations were first made in the early years of the nineteenth century, before electrons or orbitals or covalent bonds had been thought of. They gave support to the theory that matter is composed of atoms and led to the idea that molecules are made up of groups of atoms.

One of these observations is that an electric current passed through water causes water to be separated into its components. The process is called electrolysis. Hydrogen may be collected at one electrode and oxygen at the other electrode as shown in Figure 1.

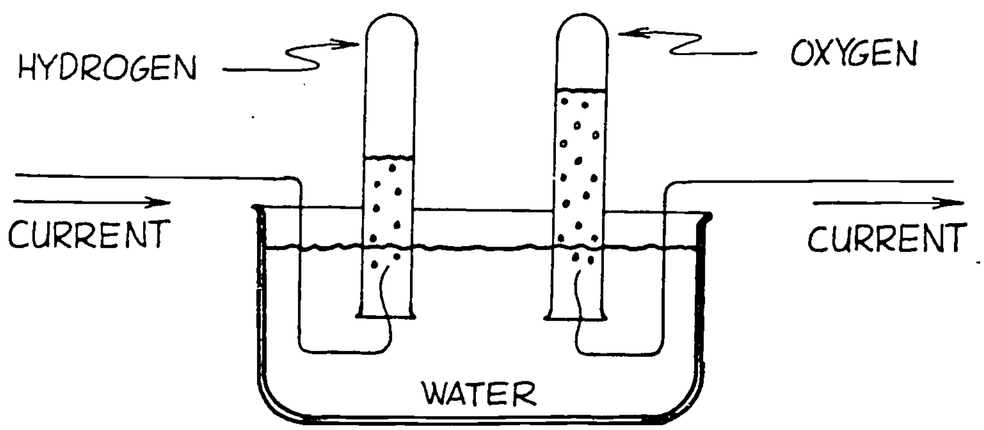
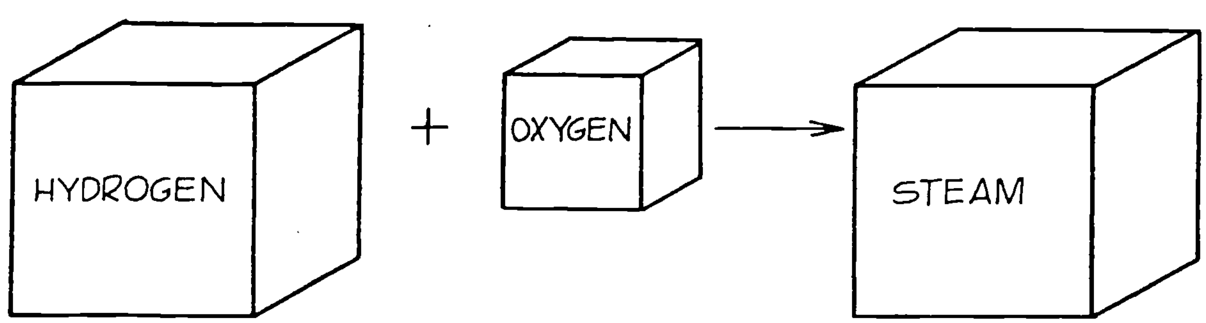


FIGURE 1: *The electrolysis of water.*

In this process the volume of hydrogen collected is always twice the volume of oxygen collected.

In a second experiment, a volume of oxygen is mixed with twice that volume of hydrogen and the mixture is ignited at a temperature above 100 °C. The product is a volume of steam twice the volume of oxygen (see Figure 2).



2 volumes hydrogen + 1 volume oxygen → 2 volumes steam

FIGURE 2: *Volumes for the reaction of H_2 and O_2.*

Likewise, when hydrogen gas reacts with chlorine gas to form hydrogen chloride gas, the volume of hydrogen reacting is always equal to the volume of chlorine reacting, and the volume of hydrogen chloride produced is always twice the volume of hydrogen or volume of chlorine reacting.

1 volume hydrogen + 1 volume chlorine → 2 volumes hydrogen chloride

Simple whole-number ratios between the volumes of reactants and products are also observed when nitrogen gas and hydrogen gas react to form ammonia gas. The volume of hydrogen reacting is always three times the volume of nitrogen reacting, and the volume of ammonia formed is always twice the volume of nitrogen reacting.

1 volume nitrogen + 3 volumes hydrogen → 2 volumes ammonia

(The volumes of all of the gases we have been discussing are measured at the same pressure and temperature, because the volume of a gas changes as pressure or temperature change.)

In 1811, an Italian scientist named Amadeo Avogadro made two assumptions to explain the combining volumes of gases; both assumptions later proved to be correct. The first is by now well known to you: that matter can exist as molecules in which atoms are joined in specific arrangements. The second assumption is that <u>equal volumes of gases at the same temperature and pressure contain the same number of molecules</u>. Avogadro's assumption was later confirmed by a large amount of experimental evidence. What was once a hypothesis has since become known as <u>Avogadro's Principle</u>.

Avogadro's Principle explains the observations regarding volumes of gases. Two water molecules decompose to form two hydrogen molecules and one oxygen molecule

$$2\ H_2O \rightarrow 2\ H_2 + O_2$$

Twice as many H_2 molecules are formed as O_2 molecules; therefore hydrogen gas occupies twice the volume of oxygen gas.

Two hydrogen molecules and an oxygen molecule combine to produce two H_2O molecules.

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Two H_2 molecules occupy twice the volume of an O_2 molecule and the same volume as two H_2O molecules (in the form of steam).

The fact that one volume of hydrogen gas and one volume of chlorine gas combine to form two volumes of hydrogen chloride gas can also be explained by the chemical equation and the application of Avogadro's Principle.

$$H_2 + Cl_2 \rightarrow 2\ HCl$$

Equal numbers of molecules of H_2 and Cl_2, and therefore equal volumes of H_2 and Cl_2 gas, react to form twice the number of molecules and therefore twice the volume of HCl gas.

Avogadro's Principle enabled Avogadro and other nineteenth-century scientists to deduce the molecular formulas of many compounds from observations about combining volumes of gases. However, we generally know molecular formulas and wish to predict combining volumes, so we use reasoning the reverse of Avogadro's.

For example, the equation for the formation of ammonia from nitrogen and hydrogen is

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3$$

This enables us to predict that one volume of N_2 and three volumes of H_2 react to form two volumes of NH_3. This prediction agrees with the experimental result mentioned earlier.

One further example illustrates the use of Avogadro's Principle.

EXAMPLE:

Nitric oxide is an air pollutant given off by automobiles. It reacts with oxygen in the air to form nitrogen dioxide, which is an even worse pollutant. The equation for this reaction is $2\ NO + O_2 \rightarrow 2\ NO_2$. How many liters of O_2 gas react with 6 liters of NO gas, and how many liters of NO_2 are formed?

SOLUTION:

Two molecules of NO react with 1 molecule of O_2. Therefore, according to Avogadro's Principle, 2 volumes of NO react with 1 volume of O_2. The volume of O_2 reacting is thus

$$\frac{1}{2} \times 6 = 3 \text{ liters}$$

Two molecules of NO produce 2 molecules of NO_2. Consequently, 6 liters of NO produce 6 liters of NO_2.

35-2 The Volume of One Mole of Gas

According to Avogadro's Principle, equal volumes of gas (at the same pressure and temperature) contain the same number of molecules. By definition, one mole of any substance is 6.02×10^{23} molecules.

If we reword Avogadro's Principle to say that an equal number of gas molecules occupy the same volume, we see that 6.02×10^{23} molecules of any gas (at the same pressure and temperature) occupy the same volume. Or, in other words, a mole of any gas occupies the same volume. But what is the volume of a mole of gas?

Since gas volume varies with pressure and temperature, scientists have established standard conditions of pressure and temperature. For convenience, standard pressure is taken as exactly 1 atmosphere, and standard temperature as 0 °C. We want to know the volume of one mole of gas at 1 atm and 0 °C.

We cannot count 6.02×10^{23} gas molecules, but we can determine the mass of 6.02×10^{23} gas molecules. Recall that the mass of 6.02×10^{23} molecules, or 1 mole, is the gram molecular weight.

The volumes of gram molecular weights of various gases have been determined experimentally. In each case, the result is 22.4 liters. In other words, the volume of one mole of any gas at 1 atm and 0 °C is 22.4 liters.

Consider how knowing the volume of a mole of gas applies to a specific reaction, for example, the formation of hydrogen chloride from the reaction of hydrogen gas and chlorine gas.

$$H_2 + Cl_2 \rightarrow 2\ HCl$$

The following statements are all equivalent ways to interpret this equation.

$$1 \text{ molecule } H_2 + 1 \text{ molecule } Cl_2 \rightarrow 2 \text{ molecules } HCl$$

$$6.02 \times 10^{23} \text{ molecules } H_2 + 6.02 \times 10^{23} \text{ molecules } Cl_2 \rightarrow 12.04 \times 10^{23} \text{ molecules } HCl$$

$$1 \text{ mole } H_2 + 1 \text{ mole } Cl_2 \rightarrow 2 \text{ moles } HCl$$

$$22.4 \text{ liters } H_2 + 22.4 \text{ liters } Cl_2 \rightarrow 44.8 \text{ liters } HCl$$

Observe that the last three equations are equivalent ways to express the same quantities, because 6.02×10^{23} molecules are one mole and, at standard conditions, occupy 22.4 liters.

We now have the information needed to solve the problem posed at the beginning of this section. What volume of oxygen is required to oxidize 4 moles of glucose, and what volume of CO_2 is produced?

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

Four moles of glucose react with 24 moles of O_2, and 24 moles of CO_2 are produced. Since one mole of any gas occupies 22.4 liters (at standard conditions), the oxygen requirement is $24 \times 22.4 = 537.6$ liters. The volume of CO_2 produced is the same.

Remember that these results are for standard conditions. If we wished to know the volumes at room temperature or body temperature, we could apply the Charles' Law equation.

EXAMPLE:

Ethyl alcohol reacts with oxygen to form carbon dioxide and water.

$$C_2H_6O + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$$

How many liters of CO_2 are formed by the oxidation of 9.21 grams of C_2H_6O at atmospheric pressure and 0 °C?

SOLUTION:

The first step is to convert 9.21 grams of C_2H_6O to units of moles.

$$\text{moles } C_2H_6O = \frac{\text{grams } C_2H_6O}{\text{gram molecular weight } C_2H_6O}$$

$$= \frac{9.21}{46.07}$$

$$\simeq .2 \text{ mole}$$

One mole of C_2H_6O forms 2 moles of CO_2; therefore, .2 mole of C_2H_6O form .2 x 2 = .4 mole of CO_2. One mole of CO_2 occupies 22.4 liters at standard conditions. Consequently, .4 mole occupies .4 x 22.4 = 8.96 liters.

Vocabulary:

Avogadro's Principle (AH-vo-GOD-row)--the statement that equal volumes of gases at the same temperature and pressure contain the same number of molecules.

electrolysis (Eh-lek-TRAHL-ih-sis)--the decomposition of a compound by means of electricity.

PROBLEM SET 35:

1. Sulfur dioxide reacts with oxygen to produce sulfur trioxide.

$$2\ SO_2 + O_2 \rightarrow 2\ SO_3$$

a. How many liters of O_2 gas react with 7 liters of SO_2 gas?

b. How many liters of SO_3 gas are formed by the reaction of 3.8 liters of SO_2 gas?

2. Ozone in the upper atmosphere is important in shielding the earth from ultraviolet radiation. However, some scientists fear that certain pollutants are causing O_3 to decompose into oxygen gas.

$$2\ O_3 \rightarrow 3\ O_2$$

a. How many liters of O_2 are formed by the decomposition of 12 liters of O_3?

b. How many grams of O_2 are formed from 53.8 grams of O_3?

3. Methyl alcohol reacts with oxygen to form carbon dioxide and water.

$$CH_4O + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

a. What is the molecular weight of CH_4O?

b. How many moles are 16.02 grams of CH_4O?

c. How many moles of CO_2 are formed in the oxidation of 16.02 grams of CH_4O?

d. How many liters of CO_2 ($P = 1$ atm, $T = 0$ °C) are formed by the oxidation of 16.02 grams of CH_4O?

e. How many liters of O_2 ($P = 1$ atm, $T = 0$ °C) are required to oxidize 16.02 grams of CH_4O?

4. Zinc metal reacts with hydrochloric acid to release hydrogen gas. The zinc dissolves as Zn^{++} cations.

$$Zn + 2\ HCl \rightarrow H_2 + Zn^{++} + 2\ Cl^-$$

How many liters of H_2 are produced by the reaction of 6.54 grams of zinc at standard conditions?

5. A female hospital patient might be fed intravenously at the rate of 0.11 mole of glucose per hour.

a. What volume of oxygen (at standard conditions) would the patient need to oxidize this quantity of glucose? (The chemical equation is given in Section 35-1.)

b. Use Charles' Law to find the volume occupied by this quantity of oxygen at 25 °C.

c. At 25 °C, what volume of oxygen would the patient need per day?

SECTION 36:

36-1 The Universal Gas Law

How can we combine all of our information on gases into a single expression?

Charles' Law states that the volume of a gas is proportional to its absolute temperature. This statement may be represented by the following expression, in which k is the proportionality constant.

$$V = kT \quad \text{(at constant pressure)}$$

If the absolute temperature of a gas is doubled, the volume doubles. If the absolute temperature is halved, the volume is halved.

According to Boyle's Law, the volume of a gas is proportional to the reciprocal of the pressure.

$$V = k_1(\frac{1}{P}) \qquad \text{(at constant temperature)}$$

This proportionality constant is not the same as the one in the Charles' Law expression, so we use k_1 to distinguish it from k. If the pressure of a gas doubles, its volume is halved; if pressure is halved, volume doubles.

Charles' Law shows how volume varies with temperature. Boyle's Law relates volume changes to pressure changes. But what happens to volume when both temperature and pressure change?

Suppose that we have a gas at a pressure of one atmosphere. Its volume is given as a function of temperature by the expression

$$V = kT$$

Now suppose that the pressure of this gas is doubled to two atmospheres. According to Boyle's Law, doubling the pressure decreases the volume to one-half the original volume.

$$V \text{ (when } P = 2 \text{ atm)} = \frac{1}{2} V \text{ (when } P = 1 \text{ atm)}$$

$$= \frac{1}{2} kT$$

If pressure is now increased to three atmospheres, the volume is reduce to one-third volume at one atmosphere pressure.

$$V \text{ (when } P = 3 \text{ atm)} = \frac{1}{3} \text{ (when } P = 1 \text{ atm)}$$

$$= \frac{1}{3} kT$$

Note that in each situation the volume may be expressed as

$$V = \frac{1}{P} kT$$

$$\text{when } P = 1 \text{ atmosphere, } V = \frac{1}{1} kT = kT$$

$$\text{when } P = 2 \text{ atmospheres, } V = \frac{1}{2} kT$$

$$\text{when } P = 3 \text{ atmospheres, } V = \frac{1}{3} kT$$

You may test this generalization for other pressures if you wish.

We based our argument on a situation in which the original pressure is one atmosphere. But we could use a similar argument for any other initial pressure. We would only have to change the proportionality constant to some other value that we will call k_2. We can show that in general

$$V = kT\left(\frac{1}{P}\right) \qquad \text{or} \qquad V = \frac{k_2T}{P}$$

This expression illustrates the fact that if a quantity (in this case, volume) is proportional to each of two other quantities (temperature and reciprocal of pressure) it is proportional to their product.

The volume of a gas is also related to the quantity of gas. Avogadro's Principle states that equal numbers of molecules of any gas at the same temperature and pressure occupy the same volume. We reasoned that since one mole of any compound is 6.02×10^{23} molecules, Avogadro's Principle states also that equal numbers of <u>moles</u> of any gas at the same temperature and pressure occupy the same volume. At a pressure of one atmosphere and a temperature of 0 °C, the volume of one mole of any gas is 22.4 liters.

If the volume of one mole of a gas is 22.4 liters, the volume of two moles of the gas is 22.4 x 2 = 44.8 liters. In other words, the volume of a gas is proportional to the number of moles. Let us use the proportionality constant k_3 to distinguish it from the constants relating pressure and temperature to volume. We may symbolize number of moles by n, and relate n to the volume of a gas by

$$V = k_3n$$

We now have volume proportional to each of two different quantities. One of these quantities is the product of temperature and the reciprocal of pressure; the other is the number of moles.

$$V = \frac{k_2T}{P} \qquad \text{and} \qquad V = k_3n$$

By the same reasoning used earlier, we can state that volume is proportional to the product of these two quantities. The proportionality constant for this combined expression is, by convention, designated R.

$$V = \frac{RnT}{P}$$

This equation, which is known as the <u>Universal Gas Law</u>, is usually written in the equivalent form

$$PV = nRT$$

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It is extremely important in chemistry and physics, because it relates the volume of a gas to the pressure, temperature and number of moles.

It is only necessary to know the constant R. Since R has a single value for all gases under all conditions, if we can determine R for one set of conditions, we know it for all other conditions.

It turns out that we have the information to calculate R at standard conditions. We know that one mole of gas at 0 °C (273 °K) and 1 atmosphere pressure occupies 22.4 liters. So we substitute n = 1 mole, T = 273 °K, P = 1 atm and V = 22.4 into the Universal Gas Law expression.

$$(1 \text{ atm})(22.4 \text{ liters}) = (1 \text{ mole})(R)(273\ ^\circ K)$$

By rearranging, we obtain

$$R = \frac{(22.4 \text{ liters})(1 \text{ atm})}{(1 \text{ mole})(273\ ^\circ K)}$$

$$= \frac{22.4}{273} \frac{\text{liter-atm}}{\text{mole-}^\circ K}$$

$$= .082 \frac{\text{liter-atm}}{\text{mole-}^\circ K}$$

When volume is in units of liters, pressure in atmospheres, n in moles and temperature in degrees Kelvin, the constant R has the value .082.

EXAMPLE:

What volume is occupied by 5 moles of gas at 300 °K and a pressure of 1.2 atmospheres?

SOLUTION:

$$n = 5 \text{ moles}$$

$$T = 300\ ^\circ K$$

$$P = 1.2 \text{ atm}$$

$$R = .082 \frac{\text{liter-atm}}{\text{mole-}^\circ K}$$

$$V = ?$$

$$PV = nRT$$

$$V = \frac{nRT}{P}$$

$$= \frac{(5)(.082)(300)}{1.2}$$

$$= 102.5 \text{ liters}$$

PROBLEM SET 36:

1. The body of an active adult might require roughly 40 moles of oxygen per day. How many liters of O_2 is this at 20 °C (remember to convert to absolute temperature) and 1.2 atmospheres pressure?

2. A normal breath contains approximately .1 liter of O_2. At 37 °C and 1 atmosphere pressure, how many moles are contained in .1 liter?

3. A basketball has a volume of 8.6 liters and is inflated to 1.5 atmospheres total pressure. In a warm gym (27 °C) how many moles of air does a basketball hold?

SECTION 37:

37-1 Partial Pressure

What is the pressure exerted by oxygen alone in a sample of air?

Suppose for simplicity that air is 80 per cent nitrogen and 20 per cent oxygen. A sample of air that is a mixture of these two gases obeys the Universal Gas Law, PV= nRT, where n is the total number of moles of N_2 and O_2.

But it is also possible to consider each component separately. We may consider the pressure exerted by just the N_2 molecules or just the O_2 molecules. These pressures are called partial pressures: the partial pressure of nitrogen and the partial pressure of oxygen. As we shall see, the partial pressure of oxygen is what determines how much of this gas is transported to our cells. And rapid changes in the partial pressure of nitrogen can cause severe injury, or even death.

There is no way to measure partial pressures directly, since the walls of a container are bombarded by a large number of each kind of molecule. But the Law of Partial Pressures gives us a means for determining partial pressures.

According to the Law of Partial Pressures, each gas exerts the pressure that it would exert if it alone occupied the space. To illustrate this principle, consider a 20-liter container occupied by .8 moles of N_2 and .2 moles of O_2, at 27 °C. (See Figure 1 on the next page.)

The nitrogen molecules exert the same pressure on the walls that they would if the O_2 were not present. (See Figure 2 on the following page.)

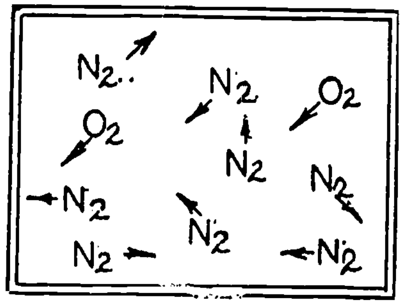


FIGURE 1: *A mixture of nitrogen and oxugen.*

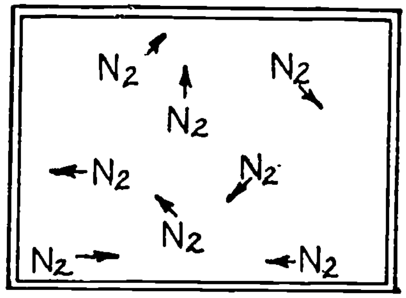


FIGURE 2: *Nitrogen alone, occupying the same volume.*

We can use the Universal Gas Law to calculate the pressure exerted by the nitrogen, by the oxygen and by the mixture of the two.

$$PV = nRT$$

$$P = \frac{nRT}{V}$$

NITROGEN	OXYGEN	TOTAL MIXTURE
$p = \frac{.8(.082)(300)}{20}$	$p = \frac{.2(.082)(300)}{20}$	$p = \frac{1(.082)(300)}{20}$
$= .984$ atm	$= .246$ atm	$= 1.230$ atm

Note that $.984 + .246 = 1.230$. This confirms the second part of the Law of Partial Pressures, which states that the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of the individual gases.

In the three preceding calculations, R, T and V all remained constant. If we had known the total pressure to start with, a much simpler calculation would have been possible. Since the mixture was 80 per cent nitrogen and 20 per cent oxygen, the pressure exerted by the oxygen was 20 per cent of the total pressure.

partial pressure of $N_2 = .8(1.23) = .984$ atm

partial pressure of $O_2 = .2(1.23) = .246$ atm

In other words, the partial pressure exerted by each gas is equal to the percentage or fraction of molecules of that gas in the mixture times the total pressure.

EXAMPLE:

A mixture of oxygen and carbon dioxide consists of 1.50 moles of O_2 and .25 moles of CO_2. The total pressure is 3.5 atmospheres. What are the partial pressures of O_2 and CO_2 in this mixture?

SOLUTION:

$$\text{total moles of gas} = \text{moles } O_2 + \text{moles } CO_2$$

$$= 1.50 + .25$$

$$= 1.75 \text{ moles}$$

$$\text{fraction that is } O_2 = \frac{1.50}{1.75} = \frac{6}{7}$$

$$\text{fraction that is } CO_2 = \frac{.25}{1.75} = \frac{1}{7}$$

$$\text{partial pressure of } O_2 = \frac{6}{7}(3.5) = 3.0 \text{ atm}$$

$$\text{partial pressure of } CO_2 = \frac{1}{7}(3.5) = 0.5 \text{ atm}$$

Note that the sum of partial pressures of O_2 and CO_2 equal the total pressure. Note also that we could solve this problem without knowing the volume or temperature.

37-2 Decompression Sickness, or "The Bends"

How are the bends related to partial pressure?

The solubility of a gas in a liquid depends on the partial pressure of the gas above the solution. The greater the partial pressure, the greater the solubility. You are probably most familiar with this phenomenon in relation to carbonated beverages. Carbonation is obtained by dissolving carbon dioxide in the beverage. Bottling is done with a high partial pressure of CO_2. The high partial pressure increases the solubility of CO_2.

When the bottle is opened, the CO_2 partial pressure above the beverage decreases to that of the normal atmosphere. Thus the partial pressure of CO_2 diminishes, the solubility is less and CO_2 escapes from solution as bubbles.

A certain amount of nitrogen dissolves in blood and body tissues. At atmospheric pressure about 1.5 liters of N_2 are dissolved in the body. But the solubility of N_2 increases as its partial pressure increases. At atmospheric pressure the partial pressure of N_2 is approximately .77 x 1 = .77 atmosphere.

However, as total pressure increases, nitrogen partial pressure increases. This happens, for instance, below the surface of the ocean. At a depth of 10 meters the pressure is 2 atmospheres, and N_2 partial pressure is .77 x 2 = 1.54 atmospheres.

As N_2 partial pressure increases, the solubility of N_2 increases more or less proportionally. At a depth of 10 meters, approximately twice as much nitrogen will dissolve in the body as at atmospheric pressure. The dissolved nitrogen causes no problems--until the diver returns to the surface and atmospheric pressure.

At atmospheric pressure the partial pressure of nitrogen is less than it is below the surface. Therefore, less nitrogen can dissolve in the blood and tissues of the body. If the diver returns quickly to the surface, nitrogen escapes from solution, as bubbles, just as carbon dioxide bubbles escape from carbonated beverages when the CO_2 partial pressure is reduced. Fortunately, nitrogen dissolves at a slow rate, so that lengthy exposure is usually necessary for a dangerous amount to dissolve.

The nitrogen bubbles cause a very painful condition known as decompression sickness. This is the condition commonly called "the bends," due to the pain felt in the arms and legs. Bubbles in the heart and pulmonary vessels may cause a feeling of asphyxiation known to divers as "the chokes." An even more serious symptom of decompression sickness is paralysis, which may occur if bubbles affect the spinal column. Death can occur if the damage done by the bubbles is severe enough.

Decompression sickness is prevented by returning slowly from high pressure to atmospheric pressure. In this case, the nitrogen is slowly released from the blood through the lungs, and bubble formation is avoided.

Once decompression sickness has occurred it is treated by recompression, that is, by placing the patient in a pressure chamber. This increases the N_2 partial pressure, causing the bubbles to redissolve. Proper decompression may then be done by reducing the pressure slowly over a period of perhaps hours.

37-3 Partial Pressure, Gas Transport and Altitude

When gases are dissolved in a liquid they still exert a pressure. For example, oxygen, carbon dioxide and nitrogen each exert a partial pressure in the bloodstream. Partial pressures in the blood are of critical importance because the behavior of the hemoglobin molecules in the red blood cells depends on them.

When the concentration or partial pressure of oxygen is high in the fluid portion of the blood, almost all of the hemoglobin molecules pick up and carry oxygen molecules. This is what happens in the pulmonary capillaries where new supplies of oxygen are continually arriving from the alveoli.

When the blood arrives at places where oxygen is needed, the first thing that happens is that dissolved oxygen leaves the blood and enters the cells in that region. This lowers the partial pressure of oxygen in the blood. The hemoglobin molecules respond to the lowered partial pressure of oxygen by giving up the oxygen molecules they have been carrying.

The transport of CO_2 works just in reverse. At the cells, the partial pressure of CO_2 is high, which causes the hemoglobin to attach to them. When the CO_2 arrives at the pulmonary capillaries, the hemoglobin releases it, because the partial pressure of CO_2 is low there (because it is diffusing out of the bloodstream and into the alveoli).

With this information, we can understand more fully what happens when we ascend rapidly to high altitudes. At sea level the partial pressure of the oxygen in the air we breathe is about $.21 \times 1 = .21$ atm, and just about all of our hemoglobin is carrying oxygen. Non-smokers in good health can ascend rapidly to about 8,000 feet before they notice any significant effect. At 8,000 feet the total air pressure is about .75 atm. The oxygen partial pressure is about $.21 \times .75 \approx .16$ atm, and about 93 per cent of the hemoglobin is still carrying oxygen.

But above 8,000 feet the situation gets worse rapidly. By the time one gets to 23,000 feet (for example, in an unpressurized airplane), only half the hemoglobin molecules are carrying oxygen. At this stage an unacclimatized person would lose consciousness and die of hypoxia soon thereafter.

Why does decompression sickness occur only if a diver ascends too rapidly?

How are partial pressures related to the transport of oxygen and carbon dioxide in our bodies?

How is partial pressure connected with altitude sickness?

Vocabulary:

decompression sickness--a condition caused by the formation of nitrogen bubbles in the blood and tissues, as a result of a rapid decrease in the partial pressure of nitrogen.

partial pressure--the pressure exerted by a single gas in a mixture of gases.

PROBLEM SET 37:

1. The air you exhale contains about 5.3% CO_2. What is the partial pressure of CO_2 when the total pressure is 1 atmosphere?

2. On top of Mt. Whitney, the air pressure is only about .6 atmosphere. Assuming air to be 21% oxygen, what is the partial pressure of O_2 there?

3. A sample of air in a 30-liter container is composed of .772 mole of N_2, .207 mole of O_2, .012 mole H_2O vapor, and .009 mole of argon. The temperature is 27 °C. What is the partial pressure of each gas and what is the total pressure?

4. Anesthesiologists often specify concentrations of gaseous anesthetics in terms of partial pressures. Halothane is commonly used in concentrations of 3%. What is the partial pressure of halothane when total pressure is .95 atmosphere?

5. At a depth of 20 meters beneath the sea, the pressure is approximately 3.0 atmospheres. If air is 77% N_2, what is the partial pressure of N_2 20 meters below the surface of the sea?

REVIEW SET 37:

1. What would happen if deep sea divers carried pure oxygen in their tanks?

2. What are the symptoms of respiratory alkalosis? What is the treatment for this condition?

3. Give at least three characteristics of acids.

4. Give at least five characteristics of bases.

5. What is a salt?

6. Tommy's aunt is boiling red cabbage for dinner. She looks in the pot and notices that the cabbage has turned a blueish color which is not at all appetizing. She remembers an old cook's trick and adds vinegar a little at a time until the cabbage turns red again. Was the water in the pot that caused the blue color acidic or basic? What is a substance called that changes color with a change in pH?

7. What does "pH" mean? What does the pH of a solution tell you about that solution?

8. How is the breathing rate affected by carbon dioxide and oxygen in the bloodstream?

9. Name two different chemoreceptors. Describe their functions and how they function.

10. What is the blood pH (high or low) of a person who is hyperventilating? What is another term for this condition of the blood?

11. Compare and contrast diffusion and osmosis. Give an example of each process in the body.

12. Does hemoglobin transport oxygen exclusively? Explain.

13. Contrast the events of fresh-water drownings and salt-water drownings.

14. State Avogadro's Principle.

15. Give the volume of 1 mole of a gas. Include the pressure and temperature conditions needed for your statement to be true.

16. State Charles' Law in words. State it in equation form.

17. State Boyle's Law in words and in equation form.

18. State the Universal Gas Law in words and in equation form.

19. State the Law of Partial Pressures.

20. What is the cause of decompression sickness?

21. What would happen in your body if you ascended to a high altitude quickly in an unpressurized airplane? What would you feel as these changes took place in your body?

SECTION 38:

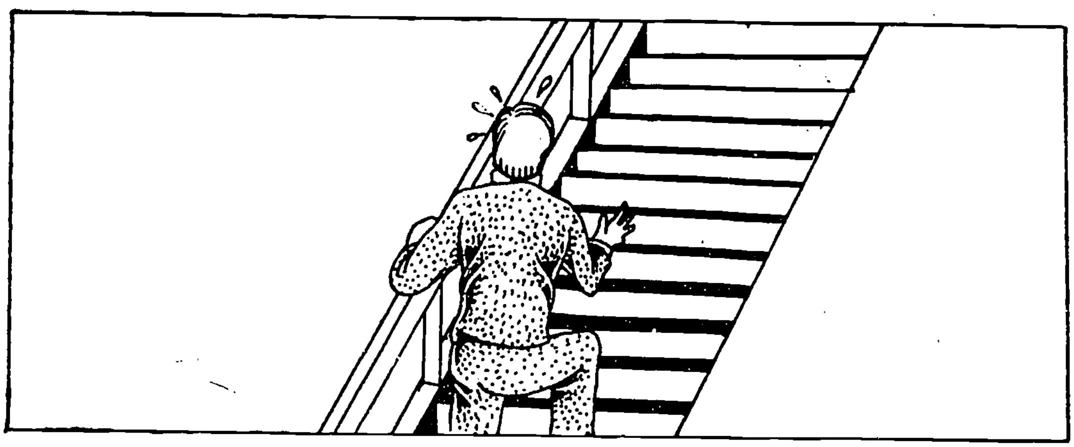
38-1 Tom's Case Record--Age 42

Tom pushed the "up" button for the elevator, but nothing happened. No lights, no bells, nothing. He looked at the stairway. Two flights up to the payroll office. He turned back to the elevator and pushed the button again. Nothing.

Somebody walking by behind him spoke.

"It's broken, Mr. Young. Have to work for our money this week." The young man who had spoken to him strode over to the stairs and started up them, two at a time.

Tom gave the button one last nudge, without much hope, and started for the stairs. He started off taking them two at a time, but after three leaps through the air he decided that such behavior was undignified for a man of his age and position. Besides, it hurt his legs.



When he reached the second floor he decided to take his time on the next flight to the third floor, where the payroll office was. He didn't remember having this much trouble climbing stairs before, but then it had been a long time since he'd climbed anything higher than his front porch. He hoped the elevator wouldn't be out of service long.

As he reached the top of the stairs, the young man who had spoken to him below came out of the payroll office, already tucking his pay-check into his shirt pocket. He seemed surprised to see Tom just arriving, but he didn't say anything. He rounded the corner and clattered down the stairs.

When Tom entered the payroll office, he realized that he was still out of breath--much more so than ever before, especially after climbing only two flights of stairs. Must be old age creeping up on him, he decided. He presented his ID card and then lit a cigarette while he waited for the clerk to bring his check.

Back on the ground and outside, Tom was joined on the way to the parking lot by his bowling teammate, Joe. They exchanged small talk about work and the bowling league and their families. When they reached Tom's car, Joe looked at Tom seriously.

"That's a bad cough you've got, Tom."

"It is?" said Tom. He had coughed a couple of times on the way out to the car, but he didn't think it was as bad as Joe had implied.

"Sounds bad to me," said Joe.

"Well, I had a pretty bad chest cold last month, and the cough is hanging on. Can't seem to get rid of it."

"Why don't you try some Suppress-It?" said Joe.

"What's that? Cough syrup?"

"Yeah. I've used it several times. It always seems to work."

"Okay," said Tom. "Thanks. See you." He got into his car, started it up and headed for home.

He thought about Joe's advice. That particular morning had been worse than most. He'd had to cough for several minutes before he finally got all the stuff out of his windpipe. He decided to stop at the drugstore on the way home and buy a bottle of that cough syrup.

* * *

A week later, he was still coughing. He had bought the cough syrup, and he had taken it faithfully four times a day, but it hadn't had much effect on the cough. He had had several bad mornings, and Kathy had started coaxing him to go to the doctor. Finally he decided she was right, and one afternoon he called the doctor's office and made an appointment. The doctor had an opening late that afternoon, and Tom took it.

The doctor asked a lot of questions. As Tom answered them, he realized that he had had quite a few of those "bad chest colds" in the past few years, some of them serious enough to make him lose time from work. He always coughed a lot when he had these colds, and the cough was always persistent. Sometimes it lasted months after all the other cold symptoms were gone. Then there were cats. He always felt breathless and started wheezing whenever there was a cat around.

Finally, after a long question-and-answer session, the doctor recommended that Tom have a respiratory function test.

"Perhaps you have a breathing problem," he said.

"I just had a physical at the plant six months ago," said Tom, "and they said I was in fine shape."

"Those tests don't always pick up breathing problems," said the doctor, "because of the tremendous reserve capacity of your lungs. You can lose some of your breathing capacity and not notice any difference in your breathing at all. In fact, you can lose a great deal of it and still not notice anything when you're at rest."

"I didn't really notice anything until that day when I had to climb two flights of stairs," said Tom.

"That was a warning," said the doctor. "People with breathing problems usually make adjustment. They learn to live with it, even if it's severe. They don't notice anything unless they happen to get into an unusual situation that requires some exertion--like climbing two flights of stairs when you're used to taking the elevator."

Tom took two tests. One measured his total vital capacity: the maximum amount of air that he could expel from his lungs after breathing in as deeply as he could. The second test measured the amount of air he could expel in one second.

The doctor explained the reason for these tests. If a person is not able to expel more than about three-fourths of his vital capacity in one second, it may indicate an obstruction of his airways or a reduction in his lung elasticity.

The doctor told Tom the results of his two tests: 3.6 liters for total capacity and 2.2 liters for the one-second test. He said these results indicated a definite lung impairment, and his diagnosis was chronic bronchitis, with other factors possibly involved.

He told Tom how it could happen.

"The air tubes can be clogged by several things. Unwanted materials, such as too much mucus or foreign matter from the air. Swelling due to infection or some other irritation. Muscle spasms can do it too. And smoking. Your smoking is interfering with your lungs' cleaning system. It also reduces the moisture level in your lungs."

Tom was beginning to be frightened.

"What can I do?" he said.

The doctor prescribed an antibiotic for the infection. He also told him to stop smoking.

"If you stop now," he said, "you'll have less trouble breathing in a few days. A few weeks at most."

Tom stopped at the drugstore on the way home and picked up the antibiotic the doctor had prescribed. As he was getting out his wallet to pay for the drug, he slapped his shirt pocket automatically to check his supply of cigarettes. Empty.

"Oh, and give me a -- "

"Yes, sir? A what?"

"Uh--candy bar. Do you have candy bars?"

"Right in front of you, sir."

"Oh. Yeah." He grabbed a handful of candy bars and gave the girl his money. She dropped the candy into the bag with the drug and gave him his change.

"Thank you," she said.

"Yes," said Tom. "Thank you."

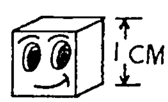
* * *

A week later, Tom's breathing was a lot closer to normal. The doctor had been right. Tom hadn't had a cigarette since the doctor had told him to quit. A lot of candy bars, but no cigarettes. And he wasn't only having an easier time breathing. Candy bars tasted better, too.

38-2 Surface Area and Respiration

How are surface area and volume related in our lungs?

Somewhere in the world, and it does not matter where, we will pretend there lives a small, one-celled species of animal called the cubeast. The cubeast has the shape of a cube and measures one centimeter on each edge.

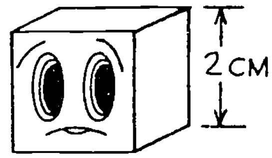


The cubeast, like real animals, requires oxygen. As with other primitive beings, oxygen diffuses directly through the cubeast's surface, which is not skin but the cell membrane.

The amount of oxygen diffusing through its surface is proportional to the area of the surface. The surface of the cubeast is six squares, each with sides of a length of 1 centimeter. The surface area is therefore $6 \times 1^2 = 6$ square centimeters.

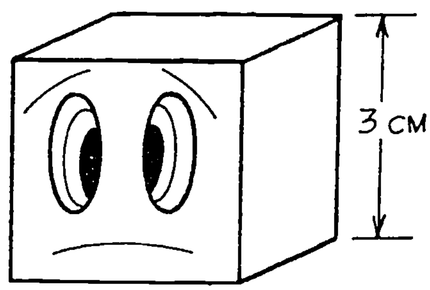
The amount of oxygen required by the body of the cubeast is proportional to its size, as it is with real animals. The volume of the cubeast is 1 cubic centimeter. The ratio of surface area to volume is consequently 6:1. Six square centimeters of surface supply oxygen to the one cubic centimeter of cubeast.

The cubeast happens to float to a location rich in nutrients and begins to grow. Soon he is a cube whose edges measure two centimeters.



The surface of the cubeast is now six squares, two centimeters long on each edge. The surface area is $6 \times 2^2 = 24$ square centimeters, so the cubeast obtains four times as much oxygen as he did when he was a one-centimeter cube. However, his volume has increased to $2^3 = 8$ cubic centimeters, with the result that his need for oxygen is 8 times what it was before he grew. The ratio of surface area to volume is now only 24:8 or 3:1. Each cubic centimeter of cubeast is now being supplied O_2 by only three square centimeters of surface. He is receiving less oxygen, relative to the needs of his body, than when he was smaller.

If the cubeast continues to grow, he will have increasing difficulty obtaining sufficient oxygen for the needs of his body. If he grows to a cube with edges 3 centimeters in length, his surface area will be $6 \times 3^2 = 54$ square centimeters, and his volume will be $3^3 = 27$ cubic centimeters. The ratio of surface area to volume will be only 54:27 = 2:1. Now each cubic centimeter obtains only as much oxygen as can diffuse through two square centimeters of surface.



What is true of cubes is also true of other three-dimensional shapes. As a sphere or cylinder or any other solid object becomes larger, the ratio of surface area to volume decreases. The surface area to volume ratio of a sphere with a radius of 1 centimeter is 3:1, while for a sphere of radius of 2 centimeters, the ratio is only 3:2. When comparing objects of the same shape, the ratio of surface area to volume is always greater for the smaller objects. This is the reason why the only organisms that obtain oxygen through their outside surface are small organisms.

What is true for objects of the same shape is not necessarily true for objects with different shapes. For example, flat objects tend to have more surface area for a given volume than round objects. This piece of paper has an extremely large surface area for its small volume. And in the animal kingdom, the largest animals which get oxygen through their outside surfaces tend to be flat: flatworms and earthworms are examples.

A planarian is a type of flatworm which gets oxygen directly through its out surface, as shown in Figure 1. Oxygen enters the inner cells of a planarian, and carbon dioxide passes out, through an outer covering and a muscle layer.

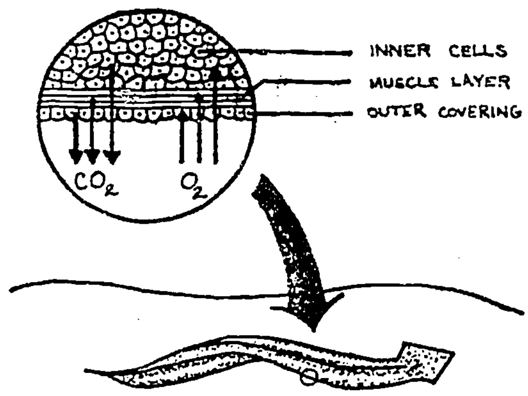


FIGURE 1: *Gas exchange in the flatworm.*

But larger and more complex forms of life cannot use such a simple system. Most of the cells are in the interior, so that oxygen cannot reach these cells directly from the outside air. And as size increases, the ratio of outside surface to the volume of the organism becomes increasingly smaller. So large, complex animals have special ways of obtaining oxygen.

The planarian and the cubeast have closed surfaces, with no openings into their interiors. But, if the cubeast were hollow and could open his mouth, rather than using it merely to express emotion, he would have perhaps twice as much surface area available for obtaining oxygen.

All higher forms of animal life use an internal surface for breathing. Insects possess tracheal tubes that lead to air sacs, where oxygen diffuses into their bodies (see Figure 2).

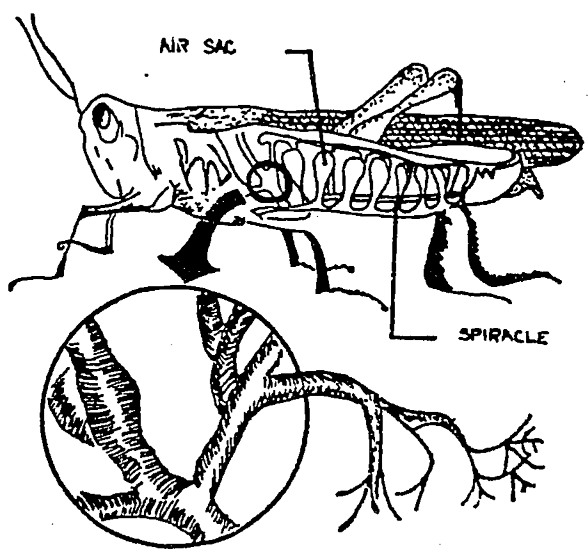


FIGURE 2: *Gas exchange in the insect.*

Fish and most other animals living in the water use oxygen dissolved in the water. Water enters through their mouths, passes by membranes called gills, where oxygen is absorbed into the body, and leaves through slits behind the gills (see Figure 3).

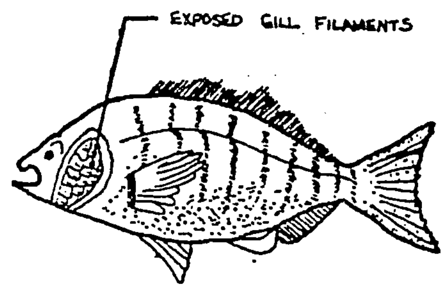


FIGURE 3: *Gas exchange in fishes.*

Mammals, birds and reptiles have lungs for respiration (see Figure 4).

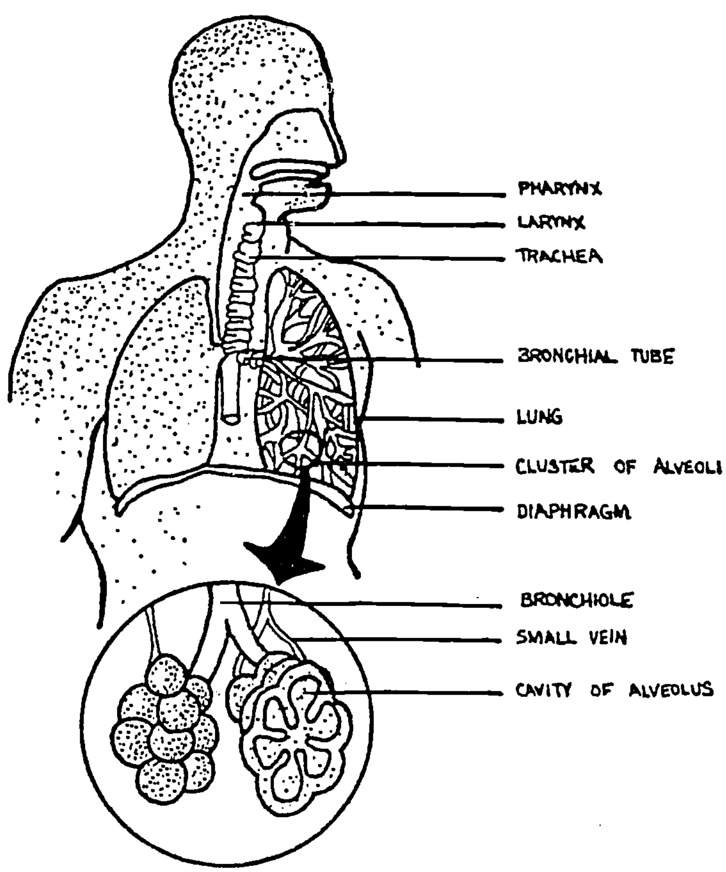


FIGURE 4: *Gas exchange in mammals, birds and reptiles.*

In the human respiratory system, the surface for oxygen diffusion is provided by alveoli. The shape of alveoli is such as to provide maximum surface area. This can be seen by comparing the following two illustrations in Figure 5.

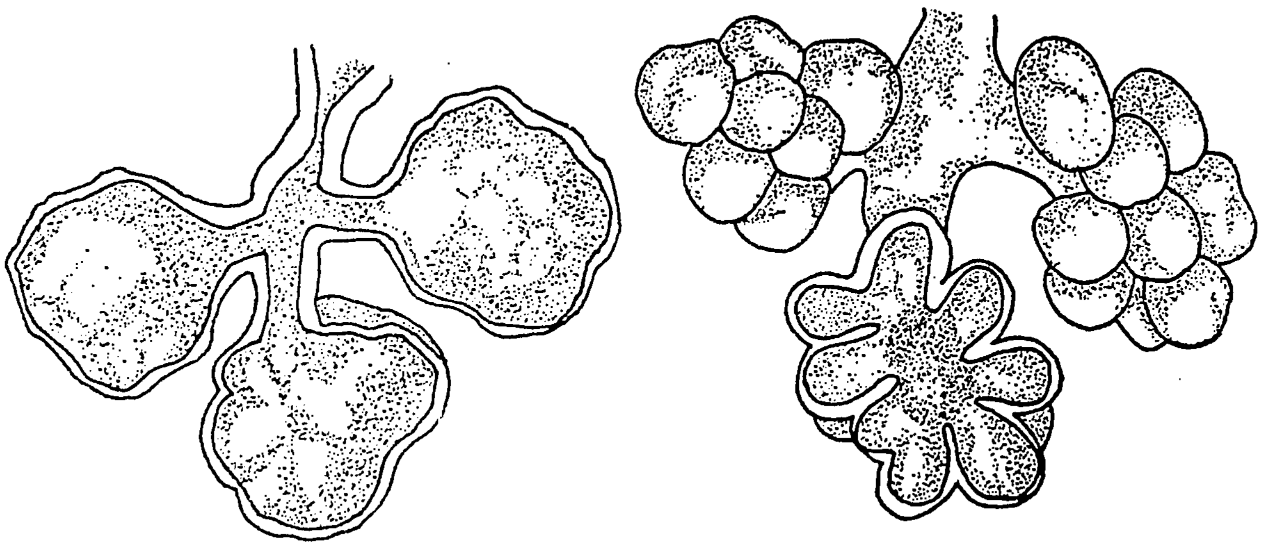


FIGURE 5: *A comparison of surface area for two different structures.*

The structure on the left contains just three spheres. The structure on the right, which represents alveoli, contains many small spheres and has far greater surface area than the three larger spheres.

The number of alveoli in a pair of human lungs has been estimated to be 300 million. If each alveolus had its own tube bringing it air from outside, the lungs would contain 300 million tubes. These tubes, or bronchioles, would occupy a large part of the chest cavity. A more efficient use of the space available is the system of branching. One trachea branches into two bronchi, which in turn branch into smaller bronchioles. The bronchioles ultimately divide into more than a million tubes which end in the air sacs connected to the alveoli. The result is that the surface area of the lungs is 40 times greater than the exterior area of the entire body.

38-3 Chronic Bronchitis

What are the causes of bronchitis? How is it treated?

In certain respiratory diseases, the surface area in the lungs available for gas diffusion is drastically reduced. One of these diseases is chronic bronchitis, which Tom was suffering from.

Bronchitis is an inflammation of the lining of the bronchial tubes. Breathing is labored. Heavy mucus or phlegm is produced and is usually coughed up.

The word chronic is used often in medicine. Chronic means occurring over a long period of time. A chronic distress is contrasted to an acute distress. An acute distress may be serious, but lasts only a short time.

Bronchitis is considered chronic if the victim has symptoms for several months over a two-year period. The main symptom is a cough in which sputum is coughed up. Sputum is a mixture of fluid from the blood which normally escapes into the alveoli, mucus from cells lining the bronchi and bronchioles, pus and bacteria from infections, and any objects trapped in this mixture. The cough is a reflex which removes this sputum from the bronchial passages.

Some of the cells lining the bronchi and bronchioles secrete mucus, and others have cilia. Cilia are tiny things which resemble hairs and are able to move back and forth. Cilia in the bronchi move in such a way as to sweep mucus, plus any foreign matter collected in the mucus, upward to the pharynx, where it may be swallowed without conscious effort.

In the bronchial tubes of bronchitis victims, the cells which secrete mucus are usually abnormally large and an abnormally large amount of mucus is produced. At the same time the movement of the cilia is impaired. The result of increased mucus production and diminished movement of the cilia is that mucus is not removed from the bronchial passages.

When mucus accumulates in the bronchial passages, it provides a good place for bacteria and viruses to grow. Inflammation from bacteria destroys ciliated cells, and these cells are replaced by cells without cilia. This means even less removal of mucus, and greater inflammation by bacteria.

Accumulated mucus may obstruct the breathing passages to the extent that the victim feels short of breath. Mucus may also accumulate in alveoli and prevent gas diffusion there.

Bronchitis is treated by destroying the bacteria with antibiotics. However, these drugs do not cure chronic bronchitis. If cilia have been destroyed, they are not replaced, and the lungs therefore tend to become infected again. The best that can be done is to eliminate sources of irritation and infection.

Air pollution and smoking are important causes of lung irritation. Cigarette smoke both destroys ciliated cells and causes increased mucus production. Consequently smoking encourages bacterial infection in the lungs. If a person gives up smoking, the destroyed cilia are not replaced, but mucus production returns to normal. This decreases bacterial infection and his "smoker's cough" should disappear. However, once the cilia have been destroyed, that person is more susceptible to lung infection than someone who has never smoked.

How is the ratio of surface area to volume affected by an increase in size?

Why can't large animals exchange gases through their outer surfaces?

What is the advantage of the branching arrangement of the human lungs?

What is bronchitis? What are its symptoms?

How is acute bronchitis treated? How can chronic bronchitis be avoided?

Vocabulary:

acute (uh-KEWT)--occuring over a short period of time.

bronchitis (bron-KY-tis)--inflammation of the lining of the bronchial tubes.

chronic (KRON-ik)--occuring over a long period of time.

cilia (SILL-e-uh)--tiny, hairlike projections which move in such a manner as to sweep mucus and foreign matter from the bronchial tubes toward the throat.

sputum (SPEW-tum)--material discharged from the respiratory passages and throat.

SECTION 39:

39-1 Air Pollution

Is there a relation between air pollution and health?

It should be apparent that we think Tom's habit of smoking cigarettes is bad for his health. Each cigarette he smokes produces 20 milligrams of tar. If three-fourths of this tar remains in his lungs, he receives 15 milligrams per cigarette.

However, Tom also lives in a city, and if the air that he breathes is average for a city, he takes in about 2 milligrams of pollutants from the air each day. What effect does this air pollution have on Tom's health?

Can you give any specific examples of illness which has resulted directly from air pollution? Probably not. There are few examples that have been documented showing a direct cause-and-effect relationship between contaminated air and disease.

This does not mean, however, that there is no relation between air pollution and health. Many studies have shown that polluted air definitely does have an effect on many functions of the body.

One study, as an example, was done by two scientists named Holland and Reid. They studied several hundred post office employees who had similar jobs in London and in rural towns. These two groups were chosen so that the London employees could be compared to people who were as similar to them as possible in every way except the air they breathed. Holland and Reid found that the men in London coughed far more frequently, their mucus production was greater, and shortness of breath was more common than in their country cousins.

Another study found that during the worst week of the London smog episode in 1952 the death rate of new-born babies and infants less than a year old doubled.

Air pollution is included in our study of respiration because exposure to pollution contributes to respiratory disease. In this section and ones to follow we will examine air pollution, its sources, its effects, and possibilities for its prevention.

39-2 Air Pollutants

What are the sources of air pollution? What chemicals are major air pollutants?

Let us start by defining what we mean by an air pollutant. Must an air pollutant have a bad odor? No, carbon monoxide is a major pollutant in the United States, yet it has no odor. Must a pollutant be visible? No, carbon monoxide and many other pollutants cannot be seen. The one attribute shared by all pollutants, though, is that they are harmful to some form of life. Let us define an air pollutant then as any substance which makes the air less able to support life, or capable of causing some degree of harm to living things.

Definitions have a tendency to be imperfect, and we find that certain substances are pollutants in some circumstances but not in others. For instance, ozone in the lungs is harmful, but ozone in the upper atmosphere protects us from most of the sun's ultraviolet radiation. Another example is carbon dioxide. Carbon dioxide is essential to green plants, yet excessive carbon dioxide is harmful to humans and other animals.

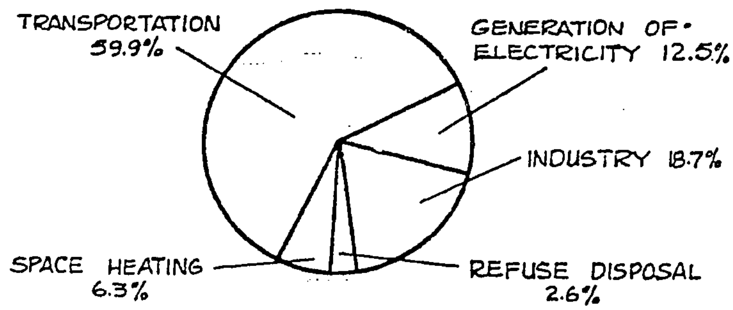
Air pollutants were part of the earth's atmosphere long before man appeared. From the time of the formation of the earth, volcanoes have been filling the air with sulfur gases and smoke. Wind storms have always blown dust into the air. Lightning causes fires, which give off smoke, carbon monoxide and carbon dioxide. Ozone is formed by lightning and by the action of sunlight on oxygen in the upper atmosphere. And hydrogen sulfide, methane and oxides of nitrogen are created in the decay of plant and animal matter.

With all this natural pollution that has always been around, why the special concern about the air in recent years? Because natural air pollution has always been balanced by the cleansing action of the atmosphere. Dust eventually settles or attaches itself to falling raindrops. Gases convert to less harmful substances or become absorbed by particles.

But man has disturbed the balance. Technical advances have resulted in an increase in the quantity and types of pollutants. Great numbers of people living closely together in our industrialized society are able to cause more pollution than the natural cleansing action of the air can remove. Each day automobiles, factories, households and power plants emit tons of pollutants into the atmosphere.

Although the causes of air pollution are many, most of it results from burning or combustion of various materials. Much of this combustion is in direct support of our daily lives.

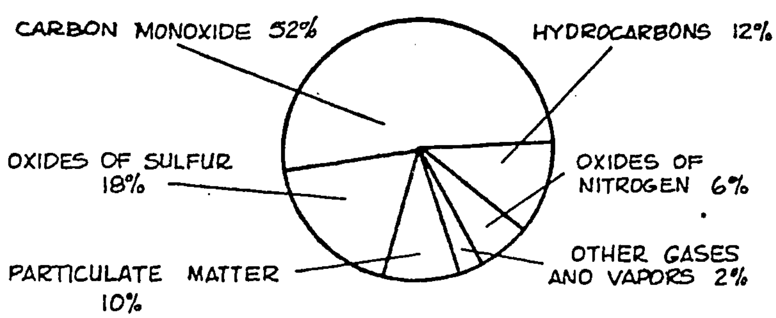
SOURCE OF POLLUTANT



Electric lights use electric power, and most electric power is generated by burning fuels which give off air pollutants. Stoves and hot water heaters burn natural gas and create pollutants. Automobile engines burn gasoline, and exhaust fumes from automobiles are the largest source of air pollution in most cities. When we are finished with a product and throw it away, it may be burned in an incinerator. So when we ask who pollutes the air, the answer is that we all do. We all share the responsibility for the quality of the air we breathe. If you enjoy cruising around town in your automobile, don't blame the oil refineries.

We have identified combustion of various materials as the principal source of pollution, but what specifically are the pollutants? We have already mentioned several as examples, but let us now identify some important types of pollutants. In Section 42 we will discuss the effect of these pollutants on our health.

TYPE OF POLLUTANT



Of the 125 million tons of pollutants emitted into America's air each year 52 per cent is carbon monoxide (CO). Carbon monoxide is an odorless, invisible gas. It is produced in the incomplete combustion

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of hydrocarbons. (A hydrocarbon is a compound containing only carbon and hydrogen. Gasoline is a mixture of certain hydrocarbons.) Complete combustion of hydrocarbons forms carbon dioxide, but if the supply of oxygen is short, the product is carbon monoxide. This can be seen from the two equations we can write for the combustion of methane.

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

$$2CH_4 + 3O_2 \rightarrow 4H_2O + 2CO$$

The formation of CO_2 requires two molecules of oxygen per molecule of methane, while the formation of CO consumes only 1.5 oxygen molecules for each methane molecule.

Carbon monoxide seldom occurs in the atmosphere in lethal concentrations. However, it is often found in concentrations sufficient to affect judgment, coordination and reaction time.

About 18 per cent of the pollution in the air is oxides of sulfur. These include SO_2 (sulfur dioxide), SO_3 (sulfur trioxide) and H_2SO_4 (sulfuric acid). Sulfuric acid is formed by sulfur trioxide reacting with water.

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Oxides of sulfur are products of the combustion of the "fossil fuels," coal and oil, which contain small amounts of sulfur. Sulfur dioxide has been identified as a most important pollutant in many of our cities in terms of its effect on the respiratory system. New York and London are cities with high concentrations of SO_2.

Another sulfur compound, H_2S (hydrogen sulfide), is produced largely by oil refineries. It has the odor of rotten eggs and can also be detected near sewage treatment plants.

Nitrogen forms several compounds with oxygen. Two of the oxides of nitrogen, NO (nitric oxide) and NO_2 (nitrogen dioxide) are important air pollutants. Nitric oxide is another colorless and odorless gas. It is a product of high-temperature combustion and is found in the exhaust gas of automobiles.

Nitric oxide itself is relatively harmless, but it can react with oxygen in the air to form nitrogen dioxide.

$$2NO + O_2 \rightarrow 2NO_2$$

This reaction occurs to any significant extent only in sunlight. Nitrogen dioxide is the one important gaseous pollutant which can be seen. It has a brownish color and as a result can affect visibility. It also has a sweet pungent odor which can be detected even at low concentrations.

Many hydrocarbons, as well as compounds containing hydrogen and carbon in combination with other elements, are emitted into the atmosphere. The automobile can once again be blamed, but these gases are also released into the atmosphere when paints, solvents and gasoline evaporate.

Hydrocarbons are important as pollutants because of their reaction in the atmosphere with the oxides of nitrogen. This reaction requires the energy supplied by ultraviolet radiation from the sun. Reactions dependent on light are called photochemical reactions. The product of the photochemical reaction of hydrocarbons and oxides of nitrogen is called photochemical smog.

The word smog originally referred to the combination of smoke and fog which is common in London. The word was then applied to the haze over Los Angeles, before it was discovered that Los Angeles pollution is not smoke but automobile emissions. The word smog may refer to either type of pollution.

The products of the reaction of hydrocarbons and nitrogen oxides, the ingredients of smog, are ozone and peroxyacetyl nitrate, commonly called PAN.

Although the sources of smog produce pollutants at a rather steady rate, the amount of pollution in the air varies widely from day to day. These differences depend entirely upon the weather. You may be unaware of the pollution in your area until weather conditions allow air to remain in one place for several days. Those weather conditions are the topic of the next section.

What is the major pollutant in the air of the United States?

Which pollutants are emitted into the air by automobiles?

Vocabulary:

photochemical--describing a chemical reaction requiring the energy from light or some other form of radiation.

pollutant (puh-LOO-tant)--a substance capable of harming living things, or making the environment (for instance, the air) less able to support life.

smog--combination of smoke and fog; also applies to pollution caused by automobile emissions.

PROBLEM SET 39:

1. As a review of our introduction to chemistry, draw the electron-dot formulas and structural formulas of the following pollutants.

CO_2--carbon dioxide SO_3--sulfur trioxide

CO-carbon monoxide O_3--ozone

SO_2--sulfur dioxide CH_4--methane

(Interestingly, NO and NO_2 are two of the very few compounds whose electron-dot formulas violate the rule that each atom be surrounded by a complete shell of electrons. Try, if you are curious.)

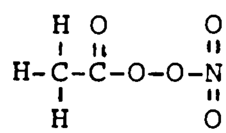
2. Balance the equations for the complete oxidation of octane (the main constituent of gasoline) to form carbon dioxide and water, and the incomplete oxidation of octane to carbon monoxide and water.

$$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$$

$$C_8H_{18} + O_2 \rightarrow CO + H_2O$$

Does it require more O_2 to oxidize octane to CO or to CO_2? Would you expect CO to be formed if too much oxygen were available or if too little oxygen were available?

3. The structural formula of peroxyacetyl nitrate (PAN) is



a. Write the electron-dot formula of PAN.

b. Write the molecular formula of PAN.

c. Determine the molecular weight of PAN.

d. What is the mass of .4 moles of PAN?

SECTION 40:

40-1 The Movement of Air

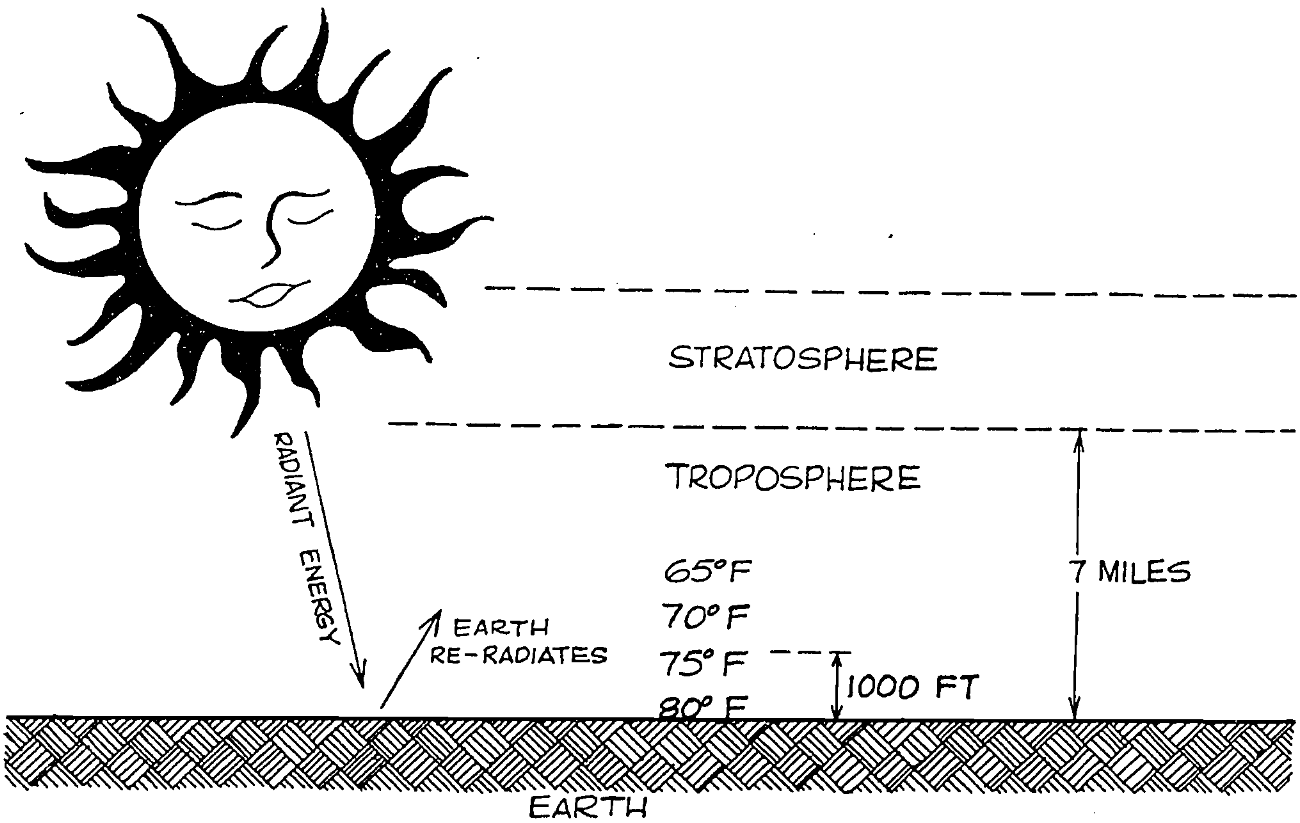
Why does warm air rise?

An air pollution problem exists whenever the contaminants in the air are not removed by natural processes. The most important natural process is air movement. Air movement results in the replacement of polluted air with fresh, clean air.

Air may move in a horizontal direction, or it may move in a vertical direction. Our familiar winds are air moving horizontally. Winds are caused by variations in temperature and air pressure, and by the rotation of the earth on its axis. Winds are important in removing polluted air from a location, but what we are interested in here is the vertical movement of air.

About 95 per cent of the earth's air lies below an altitude of 12 miles. The atmosphere consists of several layers. The lowest layer is the troposphere, which in our latitudes extends from the ground to an altitude of about seven miles. The troposphere contains the cloud formations. Above the troposphere is the stratosphere.

Little radiation from the sun heats the troposphere directly. Instead the radiation passes through the atmosphere and is absorbed by the earth. The earth then re-radiates much of this energy into the atmosphere as heat. The air closest to the earth obtains the most heat. As a very approximate rule, temperature drops 3 °C (or 5 °F) for each increase of 1000 feet in altitude.



The heat from the earth raises the temperature of the air. As we know from Charles' Law, one effect of heating a gas is to increase its volume. And as the gas expands, its density becomes less. Since density is mass per unit volume, and the mass of the gas doesn't change, the density must decrease.

Less dense substances rise above denser substances. Air bubbles rise through water. Wood floats on water. Stones sink in water. And warmer air rises above colder air, because warm air is less dense than cold air.

The fact that warmer air rises above cooler air has a great importance in the movement of air in the troposphere. Recall that the heating of the atmosphere by the earth results normally in a 5 °F decrease in temperature for each thousand feet increase in altitude. Thus, in a normal situation, the lower air is warmer than the upper air.

Warmer air, as we have seen, is less dense than cooler air, and less dense substances tend to rise. Thus, the warm air of the lower atmosphere rises and is replaced by denser, cooler air. This cooler air is in turn warmed by the earth, expands, and in its turn rises. Thus the air in the atmosphere is continuously circulating. This flow of air is called a convection current. The same principle is used in heating many homes. Hot air enters a room through a vent near the floor. The hot air rises and displaces cold air which travels down the walls and across the floor to a second vent that returns air to the heater.

The result of convection currents in the troposphere is that large volumes of air are continuously being mixed. By this process, pollutants that enter the air at ground are dispersed into the atmosphere.

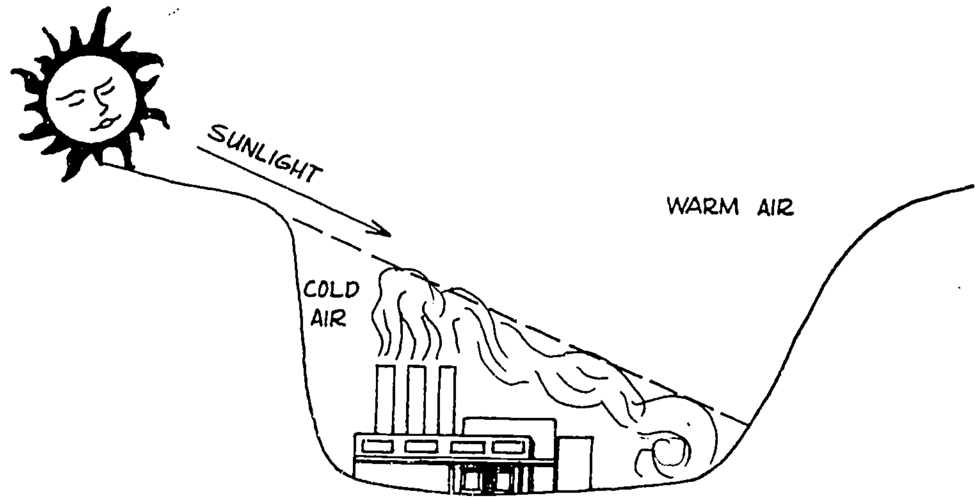
40-2 Inversions

Why don't convection currents always keep our air clean?

The trouble is that the troposphere does not always work this way. The lower air is not always warmer than the upper air. When the air near the earth's surface is cooler than the air above, a situation exists called a thermal inversion. The lower air is denser than the upper air and cannot rise. We say that the troposphere is then stable.

Inversions occur regularly at night. The ground loses its heat, and the air near the surface is cooled by the ground. This kind of inversion, however, is ended by the morning sun. The ground receives radiation, the lower air is warmed and the circulation of air again begins.

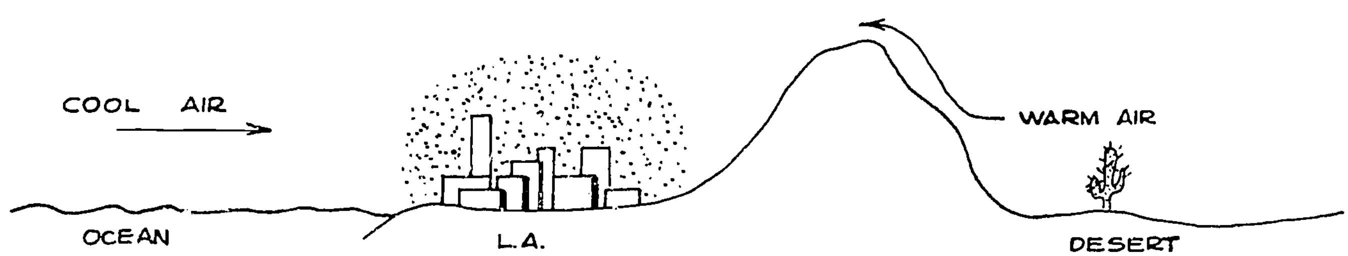
This type of inversion may be more serious in a valley. At night, cool air flows down the hillsides into the valley. In the morning, sunlight may not reach the valley floor for several hours, especially during the winter, when the sun is lower in the sky. The inversion remains until the air near the ground is heated and is warmer than the upper air (see figure on the following page).



The Rocky Mountains rise 8,000 feet above the city of Denver, Colorado. Every night cold air flows down the mountainsides to the city. Inversions occur frequently in Denver. During the winter, when the sun is never high in the sky, over half the inversions in Denver last throughout the day.

If fog is present, an inversion may last for several days. Fog prevents sunlight from reaching the ground, and thus cold air near the surface is not heated. Two of the worst pollution disasters of this century occurred in the Meuse Valley of Belgium and Donora, Pennsylvania. Both are in valleys of heavy industry. Both disasters occurred during the winter, and in both situations fog covered the area for several days, while pollutants accumulated in the colder air near the ground. Sixty people died from pollution in the Meuse Valley; in Donora almost half the population became ill.

The Los Angeles problem is slightly different. To the east of Los Angeles are mountains, and beyond the mountains is the desert. To the west is the ocean. Warm air from the desert moves over the mountains and forms a layer 2000 to 3000 feet thick. Cooler air moves in from the ocean at a lower altitude.



The inversion remains over Los Angeles until the breezes from the ocean are sufficient to blow the warm air away.

Let us summarize what we know about inversions. An inversion exists when cooler air is beneath warmer air. An inversion remains until the lower air becomes warmer than the upper air, or until the upper warm air is blown away. Heating the cold lower air depends on sunlight reaching the ground. Surrounding hillsides, the low sun in midwinter, and the presence of fog all may prevent sunlight from reaching the ground and cause an inversion to remain for a longer time.

How is air temperature normally related to altitude in the daytime?

Why is cold air more dense than warm air?

Why do inversions regularly occur at night?

How do inversions in Denver and Los Angeles differ in their causes?

Vocabulary:

convection (kon-VEK-shun)--the transfer of heat by the interchange of warm and cold air.

stratosphere (STRAT-uh-SFEER)--the layer of the earth's atmosphere lying above the troposphere.

thermal inversion--a condition in which the air near the earth's surface is cooler than the air above it.

troposphere (TROP-us-SFEER)--the lowest layer of the earth's atmosphere.

SECTION 41:

41-1 Tom's Case Record--Age 45

Tom clicked the lawn chair back to the level position and stretched out in the sun. It was the first warm day of spring, and he was grateful for it.

The winter had been hard. The many colds, and the persistent coughs that always came with them and lasted long after the colds had subsided, had exhausted him. He had just about used up his sick leave, and he had had to cut down on his workload at the plant. Altogether, it had been very depressing.

But now it was spring. The cold season had passed, so maybe he would be able to go a month or two without a siege of coughing and wheezing.

"Hey, Dad! Wanta catch a few?"

Peter came bounding out of the house with his old baseball, bat and glove. He threw the glove to Tom and sauntered down to the other end of the yard to pepper a few at his old man.

Tom hoisted himself off the lawn chair and watched his son. He was proud of Peter. The boy had put himself through junior college with a straight "A" average and won a scholarship to the university. He was home now for the spring break, after his first semester in the "big leagues," as he called it. He had found the going a little rougher there than in the "minors"--the local JC--but Tom knew he would pull it out of the fire and go all the way.

Peter popped a high one right to him, but he bobbled it. He bent down and picked it up and threw it back to Peter, who one-handed it, tossed it up and popped it back to him, all in one motion, without giving him a chance to rest. It was right to him again, and this time he caught it.

"That's a little better," called Peter.

"Just warming up," said Tom. "Give an old man a chance."

Peter laughed at that as Tom lobbed the ball back to him, but Tom didn't think it was funny. He was out of breath already. Being an "old man" wasn't a joke any more.

Peter popped him a couple more, and Tom got more and more out of breath. This wasn't the first time this had happened. The slightest exertion would have him puffing and blowing. Sometimes the breathlessness would last most of the day.

Tom lobbed the ball back to Peter and then sat down quickly, before Peter had the chance to hit it again.

"Hey, you can't quit now. I'm just getting started."

"Sorry," said Tom. "Too hot for me, I guess."

Peter stood there, looking at him.

"Yeah, I guess so," he said, finally. "It's pretty warm, all right." He didn't sound like he believed that, but Tom was grateful to him for saying it anyway. Peter came over and picked up the glove and ambled back into the house.

Tom lay back on the lawn chair. It wasn't that hot. The sun felt good, in fact, after the long winter. It was just that he was out of breath. Old, tired and out of breath. It was depressing. He wished he hadn't started playing ball with Peter in the first place. He should have known he wouldn't be able to keep up with the kid.

He reached for a cigarette, lighted it, and took a puff. It didn't taste good. They never had tasted good, but he kept smoking them anyway. Oh, he'd stopped for a while, a few years ago, when the doctor had told him it was causing his bronchitis. But after a few setbacks at work he'd bought a pack and chain-smoked them, just to relieve the tension. Then of course there were parties. He never had been able to enjoy drinking without smoking. And then there was the fact that he was getting fat, which he figured was due to eating too much. Smoking helped him cut down on snacks.

He had all kinds of reasons for smoking. He took another puff and thought about the real reason, which was that he couldn't quit. It made him angry that he couldn't, but then it made him very uncomfortable when he tried. The only times he'd been able to lay off were the times when he had those awful chest colds and coughs. The doctor would give him an antibiotic for the infection and tell him to quit, and he would quit, partly because it hurt to smoke when he had the cough, but mostly because he was scared.

But then the antibiotics would knock out the infection, finally --it seemed to take longer each time--and it wouldn't hurt any more, and he wouldn't be scared. Then all it took was a little bit of a tight situation at work, or a party, or a child's overheard remark about "that fat man," and he would be off and puffing again.

He took another puff. It tasted awful. And it was insulting. The cigarette was insulting him. That little tube of paper with the leaves inside was more powerful than he was. When he thought about it that way he always quit, at least for a few hours. He stubbed the cigarette out in the grass and lay back on the lawn chair in the sun.

He heard the door open and close, and Kathy's footsteps. He closed his eyes and ignored her. She was coming to tell him that it was time to go to the doctor's. The doctor had called the night before and told him to come down for the results of his latest pulmonary function test. It was getting ridiculous, the number of times the doctor had told him to quit smoking, and the number of times he had said "Okay" and then quit, only to start again a few weeks later.

"It's time to go to the doctor's," said Kathy.

"Oh, is it that late already?"

"Yes. Come on, I'll drive you."

"Maybe I'd better take a shower, in case he wants to examine me. I've been playing ball with Peter and I smell terrible."

"You didn't play ball long enough to work up a sweat. Besides, he doesn't want to examine you. Come on. We're late already."

They got into the car, and Kathy drove to the doctor's office. When they got into the waiting room, the receptionist stood up and opened the door to the doctor's study.

"Step right in, please," she said. "Doctor has been expecting you."

Doctor has been drumming on his desk, wondering if we were ever going to show up, said Tom to himself. It always amazed him how polite doctors' receptionists were.

"Come right in," said the doctor. He indicated chairs and sat down behind his desk. "Tom, I'm afraid the lab results aren't very good."

He got out a file folder from somewhere and opened it up.

"Your respiratory function test score is much lower than before." He ran his finger down a paper in the folder and then looked up over the top of his glasses. "You could exhale only thirty percent of your total vital capacity in one second."

He got up from his chair and came around to the front of the desk, closer to the chair where Tom and Kathy were sitting. He hitched up one pants leg and sat casually on the corner of the desk.

"Everything considered," he said, "I've arrived at the following diagnosis. The persistent coughing is your body's way of trying to get rid of excess mucus, which is accumulating in the air passageways in your lungs." He paused to let that sink in. "The excess mucus is caused by irritation of the tissue that lines these passageways." Another pause. "The irritation is most likely caused by tobacco smoke."

He walked back around to the other side of the desk while th message sank in. It wasn't news. He'd said the same thing befo. But Tom had kept smoking, of course, and so now he was saying it a

"The mucus does more than make you cough," said the doctor. "It reduces the movement of air out of your lungs. It also makes a fine place for germs to settle and develop. That, of course, accounts for the many chest colds you've had."

The doctor paused again, frowning down at the papers in the folder.

"Besides those things," he said, "--besides the mucus, the colds, the coughing--some of the tissues that make up your lungs have lost their elasticity. As a result of that, you cannot perform a complete exhalation. Your chest is overinflated because of the extra air that's trapped in your lungs."

The doctor opened a drawer in his desk and pulled out a chart of the lungs. He held it up and pointed at some bumpy little bags in a blown-up section of the diagram.

"See these little air sacs?" he said. "They're called alveoli. It's through the walls of these little sacs that oxygen gets from the air in your lungs into your bloodstream. Now, your breathlessness results from a shortage of oxygen. What has probably happened is that the walls of some of these little sacs in your lungs have broken down. That means there is less surface area for oxygen to pass through on the way to your bloodstream. And that, of course, means that your body can't get enough oxygen."

The doctor put the chart away and sat down in the chair behind his desk. He folded his hands on top of the file folder and looked at Tom.

"Based on your history of chronic coughing, the fact that you are a heavy smoker, the lab analysis of your sputum sample, the X-rays of your chest, the results of the pulmonary function test, and my physical examination--I believe that you have a lung impairment which is a form of emphysema."

Tom looked at the doctor's face. He had a wild impulse to crack a joke, to try to relieve the tension. He didn't believe the doctor. He wanted to leave. There must be some mistake. What had he done to deserve this? What would he tell Peter? What would happen to Kristi? Kathy--

Kathy was crying. When he looked at her, he believed it. He sank back in the chair, weak as a kitten.

"How--" he said.

"How--"

He was trying to say, "How long?" but he couldn't get it out. The doctor came out from behind his desk and offered Kathy a tissue. She wiped her nose and straightened up. The doctor went back to his chair.

"It isn't quite that hopeless," he said. "There are a number of things we can do to help you. We can continue to give you antibiotics for infections. We can give you drugs to relieve bronchial spasms. There are breathing exercises, as you know. There is nothing that can be done to restore your damaged lung tissues. But, in some cases, the progress of the disease can be slowed down to a crawl. An important factor here is your smoking. And that decision is up to you...no one else."

The doctor stopped. Tom realized he wasn't going to say any more. But he should say more. There should be research going on about this. They might come up with something at any time, next week, tomorrow. The doctor should tell him about these things if they were true. But the doctor wasn't telling him anything, so they must not be true. The doctor wasn't saying any more, so there must not be any more to say.

41-2 <u>Emphysema</u>

What happens to the bronchioles and the alveoli in cases of emphysema?

Breathing involves the passage of air through bronchial tubes and its diffusion through alveoli into the blood system. If the structure of either the bronchial tubes or the alveoli is changed, the process of breathing is affected. The word emphysema refers to damage to the structure of the bronchioles and alveoli such that they do not function properly.

Emphysema is apparently caused generally by the same prolonged irritation of the bronchial passages that causes chronic bronchitis. Bronchial tubes may be injured by bacterial or viral infections or they may be irritated by dust or pollutants. Cigarette smoking is known to cause emphysema, although scientists are still seeking the exact mechanism.

Certain tissues give the air passageways and alveoli their structure. It is this tissue which prevents bronchial tubes from collapsing completely during expiration. If this tissue is destroyed, the passageways may expand or contract freely. During inspiration the passageways of an emphysema victim expand normally, because of the negative pressure of the pleural space. However, during expiration the passageways partially collapse, reducing the amount of air that can leave the lungs.

A normal amount of air is inhaled, but it is not exhaled in a normal manner. Consequently, air accumulates in the alveoli and exerts pressure against the membranes of the alveoli. Eventually these walls break down and the shape of the alveoli changes. The many small air spaces are replaced by a few large spaces.

As we saw in Section 38, a few large air spaces have much less surface area than many small spaces. Consequently, the diffusion of oxygen into the blood and carbon dioxide out of the blood is severely diminished.

Victims of emphysema typically become "barrel-chested," because of chronic over-inflation of the lungs. The important symptoms, however, are the victim's cough, the fact that he is easily tired, and his shortness of breath. As emphysema progresses, the victim may be totally incapacitated.

The problems of emphysema are not limited to the bronchial tubes and alveoli. The circulation of blood through the lungs is also affected. The small blood capillaries through which oxygen enters the blood system from the alveoli develop a greater resistance to the flow of blood. This leads to two undesirable results. One is that blood tends to bypass the capillaries offering resistance and consequently to not obtain oxygen. The other is that the increased resistance of the capillaries causes the blood pressure in the pulmonary system to increase. The right ventricle of the heart is designed to pump a large volume of blood at a low pressure, and changing that condition can lead to heart failure.

Diagnosis of emphysema is based on the patient's history of coughing, an analysis of his sputum, a chest X-ray, and a pulmonary function test in which the one-second vital capacity is compared to the total vital capacity (the ratio of FEV_1 to FEV_T).

Emphysema cannot be cured, because what is destroyed cannot be replaced. The object of treatment is to slow the progress of the disease as much as possible and to make the patient as comfortable as possible. The progress of emphysema is retarded by avoiding anything that can irritate or infect the lungs. This includes colds, allergies, dusts and of course cigarettes.

Equally important are breathing exercises. The object of these exercises is to make the mechanism of breathing as effecient as possible. The key to proper breathing is use of the diaphragm, and the exercises are designed to strengthen the diaphragm and to encourage its use.

Why does the emphysema patient have more difficulty in getting air out of his lungs than in?

What is the direct cause of the destruction of alveoli in emphysema?

What evidence is used in making a diagnosis of emphysema?

How can emphysema lead to heart failure?

What forms of treatment are available for emphysema patients?

Vocabulary:

emphysema (EM-fih-SEE-muh)--a condition involving damage to the structure of the bronchioles and alveoli and the accumulation of abnormal amounts of air in the alveoli.

SECTION 42:

42-1 Air Pollution and Health

What is known about the health hazards of specific air pollutants?

In Section 39, we described two studies in England which demonstrated that air pollution is related to health in a general way. However, these studies give no other information. London smog is composed of a variety of pollutants, and the specific respiratory distresses suffered by the people being studied are not identified. To determine the specific role of a pollutant as a health hazard, scientists must know the exact concentration in the air of that pollutant, and how long a person was exposed to the pollutant. Ideally only one pollutant should be present in the air. They must then determine the exact nature of the distress.

Testing a sample of air is difficult. One sample will differ from another sample taken ten feet higher, one block away, or at a different time of day. A second difficulty is that people are not alike in their reaction to pollutants. A third problem is that two chemicals together may cause the body to react more strongly than it would to the chemicals acting independently. Or one pollutant may cancel the effect of another.

Nevertheless, scientists are able to do meaningful studies of the health problems associated with air pollution. They may study epidemics in communities as a whole, as was done in London. They may perform experiments on animals. They may analyze the victims of pollution accidents. These studies have produced much information. The specific mechanism by which a pollutant affects the body is known for many pollutants. It is now often possible to predict how a given concentration of an air pollutant will affect a particular individual.

Carbon monoxide, for example, hinders oxygen transport by the blood. Oxygen is carried by hemoglobin molecules, but if carbon monoxide is present in the blood, hemoglobin carries it in preference to oxygen.

The symptoms of carbon monoxide poisoning depend on the proportion of hemoglobin which is carrying CO. This depends on the concentration of carbon monoxide in the inhaled air. If the concentration of CO in the air is 300 to 400 parts per million, 30 to 40 per cent of the hemoglobin molecules will be carrying CO. If the concentration of CO in the air is 100 parts per million, it will be attached to as much as 20 per cent of the hemoglobin molecules.

CO concentrations greater than 1000 parts per million kill quickly. Concentrations of 300 to 400 parts per million cause severe headache, dim vision, nausea and may cause the victim to collapse.

Individuals exposed to lesser amounts of carbon monoxide for longer periods of time also exhibit symptoms of poisoning. Some people living near industries which emit carbon monoxide have been found to have chronic headaches, poor appetites and to tire easily.

Fifty parts per million is suggested as an upper limit for workers exposed to CO for eight hours. But even this amount may be a health hazard, since it results in about five per cent of the body's hemoglobin carrying CO. This concentration of CO has been shown to affect vision and to influence judgment.

The concentration within automobiles in city traffic has been found to vary from 7 ppm to 77 ppm. Concentrations often exceed 100 ppm in garages and tunnels and directly behind automobiles.

The oxides of sulfur irritate the respiratory system. They affect the sense of smell and constrict respiratory passageways. Most people show increased constriction in the airways at a concentration of 0.5 parts per million of sulfur dioxide. When 0.25 parts per million of SO_2 is present with smoke, British studies suggest that the death rate increases. When that concentration occurred in the air in New York, the number of visits to emergency clinics increased.

Nitric oxide (NO) has not been shown to be harmful to humans, but it is converted in the air to nitrogen dioxide (NO_2), which is harmful. Nitrogen dioxide is a strong irritant which, like carbon monoxide, combines with hemoglobin and thus reduces the capacity of the blood to transport oxygen. Experiments with animals indicate that NO_2 causes changes in lung tissue similar to emphysema. Experiments were also done in which humans were exposed to 4 to 5 parts per million of NO_2 for ten-minute intervals every two weeks. This exposure to nitrogen dioxide caused increased resistance to air flow into and out of the lungs.

The study of epidemics involving nitrogen oxides is difficult because sulfur dioxide and other pollutants usually are also present. However, a situation occurred in Chattanooga, Tennessee, which made possible a study of the effects of NO_2. A TNT plant emitted a large amount of NO_2 and little of any other pollutant. The study revealed that families living near the factory had respiratory ailments 19 per cent more frequently than a comparable group in a different part of town. Especially high was the rate of occurrence of bronchitis in young children. It is interesting that the concentration of NO_2 which was found to contribute to disease is present in over half the cities in the United States with populations between 50,000 and 500,000.

Ozone irritates the nose and throat, and it also causes damage to lung tissue. Short-term exposure to small amounts causes lowered vital capacity measurements. These concentrations are similar to those encountered in Los Angeles traffic. Higher concentrations of ozone cause fatigue and loss of coordination.

Particles in the air affect health in a variety of ways. Particles affect the respiratory system by slowing the movement of the cilia, the hair-like structures along the airways which move mucus and bacteria along. Particles also can retard the flow of mucus. Of course, the particles themselves may be toxic, or they may carry other toxic substances.

Certain diseases are related to specific kinds of solid particles. Two such diseases are asbestosis, which results from the inhalation of tiny fibers of asbestos and silicosis, which is caused by the inhalation of silica dust. Asbestosis has been associated with lung cancer, while silicosis causes not only shortness of breath but increased susceptibility to tuberculosis.

42-2 Self-Induced Air Pollution

What about cigarette smoke?

Sources of air pollution we have discussed include means of transportation, generation of heat and manufacture of goods. Most pollutants are the product of combustion. They create a hazard for the entire community that breathes the air.

A source of air pollution that we have not mentioned is perhaps the most serious of all. It involves the products of combustion, but unlike the other sources, the harm is done primarily to the person creating the pollution. We are referring to cigarette smoking.

The average cigarette produces 20 milligrams of tar. If a person smokes 20 cigarettes a day, he inhales $20 \cdot 20 = 400$ milligrams of tar. If he inhales deeply he may retain in his lungs approximately 75 percent of this tar, or 300 milligrams. By contrast, a person breathing average city air takes in only about 2 milligrams of pollutants each day.

One constituent of cigarette smoke is carbon monoxide. Smoking increases the number of hemoglobin molecules carrying carbon monoxide by up to 6 or 7 per cent. This means that the blood is able to carry 6 to 7 per cent less oxygen.

The long-term effects of smoking can be seen by examining the chart below.

Life Expectancy in Years for Men of Different Ages

Age	Non-smoker	Smoker: No. of cigarettes smoked daily 1-9	10-19	20-39	40+
25	48.6	44.0	43.1	42.4	40.3
30	43.9	39.3	38.4	37.8	35.8
35	39.2	34.7	33.8	33.2	31.3
40	34.5	30.2	29.3	28.7	26.9
45	30.0	25.9	25.0	24.4	23.0
50	25.6	21.8	21.0	20.5	19.3
55	21.4	17.9	17.4	17.0	16.0
60	17.6	14.1	14.1	13.7	13.2
65	14.1	11.3	11.2	11.0	10.7

(From American Cancer Society Survey)

The chart compares the life expectancy of male smokers and non-smokers. It gives the number of years people of various ages may expect to have left in their lives. For instance, the average 25-year-old non-smoker will live 48.6 more years, or until he is $25 + 48.6 = 73.6$ years old. By contrast, a 25-year-old male who smokes 40 cigarettes a day is expected to live only to the age of $25 + 40.3 = 65.3$ years. Thus his smoking habit will take $73.6 - 65.3 = 8.3$ years off his life.

Cigarette smoking must be considered as a major air pollution problem, because smoking is responsible for the early deaths of 300,000 Americans each year.

42-3 <u>What Can Be Done About Air Pollution?</u>

At first the solutions to the problem of air pollution seem simple. People can drive their automobiles less often. Ride on buses or trains. Walk or ride bicycles. Automobiles can have smog control devices and be maintained in proper running condition. Factories which emit pollutants can be made to install equipment to prevent pollution or be made to close down.

But if we examine these solutions more closely, they begin to appear not so simple. If your community suffers from smog, are you willing to drive your automobile less frequently? Even if everyone else in your town agrees to cut their driving in half, would you be happy to go along with them?

One problem is that most efforts to control pollution cost money. To provide electricity for your home, the electric company probably burns a fuel. Combustion of the fuel may put pollutants, such as sulfur dioxide, into the air. The amount of sulfur dioxide being emitted can be reduced in two ways. Fuel containing less sulfur compounds may be used, but such fuel costs more. Or devices to absorb or destroy the pollutants may be installed, but these devices also cost money. The question is who should pay the money.

The money can come from one of three places: the industry, the consumer, or the government. You may think that the company polluting the air has the obligation to remove the pollutants. You have no doubt been taught to clean up after yourself. Why can't industry do the same? But a company also has an obligation to make the maximum profit for its shareholders. If a company installs costly pollution-control equipment, its profits will be reduced. It is a matter of economics.

Of course, the company can remedy low profits by raising its prices. They are then passing on the cost of reducing pollution to the consumer. But if one company reduces pollution and raises its prices, while its competitor continues to pollute and sells for a lower price, who will buy the more expensive product? Would you? Would you buy the more expensive product if it meant that the air in your community were cleaner? What if it meant that the air in a community 1000 miles away were cleaner? If a company in your community went out of business because of the economics of reducing pollution, would it benefit the community?

When the government pays a company to reduce pollution, the cost is passed on to the taxpayer. Since taxes are paid by the entire community, this solution makes the people who breathe the air pay for its cleanliness. To some this may seem fair. But if there is an industry near your home which makes a product you never use, do you want to pay because they pollute the air?

As you can see, reducing air pollution in an industrialized country of 200 million individuals is not simple. Two things are required, and these two things are not always easy to get. One is a willingness to pay for better air. This means higher prices for consumers, higher taxes for taxpayers and lower profits for stockholders. The second thing required is a spirit of cooperation. If you expect someone to care about your pollution problem, you must also care about his problem. The old problem of citizenship.

Citizenship would be easier to practice if we lived in a small community in which we knew everyone and which was a hundred miles from the nearest other community. Then we could decide how little pollution we desired in our air and how much we were willing to pay for it.

But we are citizens of a larger community, in a sense the whole world, since winds blow across national boundaries. And in a nation of 200 million diverse individuals, problems must be solved by laws. As a citizen of this nation, what you can do about pollution is to inform yourself about the problems, help see that proper laws are written, and see that the laws are fairly enforced.

What are proper laws is what you as an individual and everyone else must decide. To do so, you must first answer two questions. Who should pay for the reduction of air pollution? And how much are you willing to pay for clean air? We cannot answer these questions for you; you will have to seek the answers yourself.

Why is it difficult to determine the effect of specific air pollutants on health?

What are some of the symptoms of carbon monoxide poisoning?

What are some of the effects of oxides of sulfur, of NO_2 and of ozone?

How does cigarette smoking affect life expectancy?

SECTION 43:

43-1 Tom's Case Record--Epilogue

Dr. Garvin pulled into the "RESERVED" space in the parking lot and switched off the ignition. He sat there, staring at the back entrance to his office. It wasn't the first time and it wouldn't be the last. But he wasn't used to it yet, and he wasn't sure he ever would be.

"Losing a patient," they called it. You did what you could to prevent it, to make the patient comfortable and get him to take care of himself. You tried to prepare the family without unduly discouraging them. Then the time came, nobody was prepared, and there was nothing you could do but watch. That's what it was. You didn't just "lose a patient." You had to watch somebody die.

Dr. Garvin got out of the car and climbed the stairs to the rear entrance of his office. He pushed the key into the lock and turned it, pushed the door open and stepped inside. It was quiet. Mrs. Wilson was up front in the reception room, typing statements. He walked up the hallway to his consulting room and opened the door. The typing stopped.

"Doctor?"

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"Yes."

He took off his hat and coat and sat down. Mrs. Wilson padded down the hallway and looked in.

"Can I get you anything?"

"Coffee."

Mrs. Wilson stepped into the little kitchen across the hall, poured a cup of coffee and brought it in.

"Thank you."

"Welcome." Mrs. Wilson looked at him a moment. "You look awfully tired," she said.

The doctor allowed that he probably didn't look any worse than he felt.

"Was it Tom Young?"

The doctor nodded.

"Did he--I mean, did you lose him?"

The doctor stared at the steam rising from the coffee cup.

"Yes," he said. "He died."

"Oh, dear. That poor family."

"Yes," said the doctor, "that's about all one can say, isn't it? Bring me his record, will you please?"

Mrs. Wilson padded off down the hall.

There was nothing left to do with the record but fill in the last line. He could have filled it in three years ago, except for the date and the time of day. And of course all the steps along the way had to be filled in too. More and more visits to the office. More and more frequent hospitalizations. Bigger and bigger dosages of drugs and medications. The record for the last year was that of a total invalid. The last line was inevitable. It was just a question of the date and time.

"Here you are, Doctor."

"Thank you." He looked through the pages. "You know those bad dreams children have, the ones that keep coming back? Where the same monster backs them into the same corner every night, and gets them every time?"

It was Mrs. Wilson's turn to nod.

"Well," said the doctor, "that's what this is like. This record. I've read it before, so many times. The name is different, the time of day, the immediate cause. Sometimes they go on a few years longer or stop a few years earlier. But it's the same record, really. I've been reading it more and more often. It's just like one of those bad dreams. Only it isn't a dream, of course. It's real."

"What will happen to them? To the family?"

"I don't know," said the doctor. "A lot of it has happened already. Tom's son, Peter, quit school two years ago, right after he graduated. He was all set up to go to graduate school, with a fellowship and everything. But he had to go to work, get money, support his mother and sister. And father. His sister, Kristi, she never got to go to school at all. She'd just graduated from high school when Tom had to stop working. She had a scholarship all lined up, too, but it wasn't enough to pay for everything. Tom had saved up a couple of thousand for her, but he used it to pay his bills when he quit working. I don't know what Kristi will do. She's been working in the dime store. I guess she'll get married."

The doctor sipped his coffee. It was getting cold. He was talking too much. He opened the record to the last page and filled in the bottom line. Then he closed the folder and dropped it in the "out" basket.

"What about the mother?" said Mrs. Wilson. "Does she have any income?"

"Hasn't worked a day in her life, as far as I know. When Tom quit work he said something about how he hated for her to have to go to work. She was looking for jobs then, but I don't think she ever found one. Anyway, she's spent the last couple of years just looking after Tom. Hasn't had time to work. Even with that visiting nurse coming in three or four times a week it was all she could do to keep the household from falling apart."

"Well," said Mrs. Wilson, "she seems like an awfully nice person. Maybe she'll remarry."

"Maybe. I don't know. That or menial labor. Or live off her kids. Maybe all three. But that isn't what gets me--what will happen to the family now that it's over. What gets me is that Tom never thought about that before it was over. I told him six years ago that he had bronchitis, and he didn't do anything different. Stopped smoking for a week, I think. Three years ago it was emphysema. That, of course, was his problem to start with. Two years ago he was coming in here once every two or three weeks with some kind of attack and he still didn't do anything. Do you know when he stopped smoking? Do you?"

"When he had to quit work?"

"No. Not when he quit work. Not six months later when his kids had to drop out of school and go to work to support him. Not six months after that when he was coming in here twice a month, just like the drug salesmen, and spending more of his time just sitting in bed trying to breathe. No, it was six months after that--when he couldn't get out of the bed to go get the cigarettes. That's when he quit."

The doctor realized he was shouting.

"I'm sorry," he said.

"It's all right," said Mrs. Wilson.

The bell rang in the reception room. The doctor looked at his watch. It was only 4:30 in the afternoon. Lots more people could get sick before the day was over.

"Excuse me," said Mrs. Wilson, and she headed for the reception room.

In a few moments she was back, with another record.

"It's Mr. Albert," she said. "He dropped an anvil on his foot."

"In pain?"

"No, groggy. They gave him something at work."

"Okay. Get me another cup of coffee. Get him in the operating room and wash it off. Call the hospital and tell them to be ready in case I can't handle it. Oh, and call the factory and find out what they gave Mr. Albert. The way they run that infirmary down there, I wouldn't be surprised if it was a shot of bourbon and a pat on the back."

Mrs. Wilson quickly brought another cup of coffee and then went off down the hall again. The doctor swallowed a few mouthfuls and went into the other room to wash up. Mr. Albert dropped an anvil on his foot. Well, that sounded pretty stupid, but then most industrial accidents did. It might be minor or it might keep him out of work for a while. All those little bones, all those intricate connections. The foot was actually a marvelous machine, though of course nobody ever thought of it that way. If it was badly smashed it could cause a lot of pain and trouble. It might take a specialist to do a really thorough job on it, and even then it might take a long time to heal and cost a lot of money.

But in a way it was a relief, Mr. Albert's foot. No matter how bad it was right now, he would be up and around in a week or two, and he'd be back on the job in a couple of months at the very worst. The doctor could fix Mr. Albert's foot, if he had to, all by himself. Bones always heal. You just have to put them back together right. That was the big difference between Mr. Albert's foot and Tom Young's lungs. All any doctor could do for Tom, when it came right down to it, was watch him fight for breath.

Maybe that was the worst part about it. Not watching him die, because everybody dies sooner or later. Maybe the worst part was watching him gasp for air. Seeing the look on his face, in his eyes, when he couldn't get any, and knew what was about to happen to him.

"Ready, Doctor. 75 mg Demerol, IM, a half-hour ago."

"Thank you." The doctor went in to see the patient.

"Hi, Doc. How's it look?"

"Hello, Mr. Albert." He looked at the foot. "It doesn't look too bad. Tell me something, Mr. Albert."

"Sure, Doc."

"Do you smoke?"

"No."

"Good. Don't ever start."

"I don't plan to. But what does that have to do with my foot?"

"Nothing, Mr. Albert. Nothing at all."

SAMPLE COPY

DECEDENT IS FICTITIOUS

CERTIFICATE OF DEATH

26847987
STATE FILE NUMBER

DEPARTMENT OF PUBLIC HEALTH

PDL - 1723 - 17524
LOCAL REGISTRATION DISTRICT AND CERTIFICATE NUMBER

DECEDENT PERSONAL DATA

1A. NAME OF DECEASED—FIRST NAME: Thomas	1B. MIDDLE NAME: Arwen	1C. LAST NAME: Young	2A. DATE OF DEATH—MONTH, DAY, YEAR: March 17, 19 ___ / 2B. HOUR: 1
3. SEX: M / 4. COLOR OR RACE: Cauc.	5. BIRTHPLACE (STATE OR FOREIGN COUNTRY): California	6. DATE OF BIRTH: Nov. 27, 19 ___	7. AGE (LAST BIRTHDAY): 48 YEARS / IF UNDER 1 YEAR / IF UNDER 24 HOURS
8. NAME AND BIRTHPLACE OF FATHER: John Young - Indiana		9. MAIDEN NAME AND BIRTHPLACE OF MOTHER: Evette Arwen - Ohio	
10. CITIZEN OF WHAT COUNTRY: U.S.A.	11. SOCIAL SECURITY NUMBER: 123-45-6789	12. MARRIED, NEVER MARRIED, WIDOWED, DIVORCED (SPECIFY): Married	13. NAME OF SURVIVING SPOUSE (IF WIFE, ENTER MAIDEN NAME): Kathleen Wankel
14. LAST OCCUPATION: Tool Maker	15. NUMBER OF YEARS IN THIS OCCUPATION: 30	16. NAME OF LAST EMPLOYING COMPANY OR FIRM (IF SELF EMPLOYED, SO STATE): Strong Steel Corp.	17. KIND OF INDUSTRY OR BUSINESS: Tool Manufacturing

PLACE OF DEATH

18A. PLACE OF DEATH—NAME OF HOSPITAL OR OTHER IN-PATIENT FACILITY: Community Hospital	18B. STREET ADDRESS—(STREET AND NUMBER, OR LOCATION): 987 Fairview Drive		18C. INSIDE CITY CORPORATE LIMITS (SPECIFY YES OR NO): Yes
18D. CITY OR TOWN: Center City	18E. COUNTY: Morgan	18F. LENGTH OF STAY IN COUNTY OF DEATH: 48 YEARS	18G. LENGTH OF STAY IN CALIFORNIA: 48 YEARS

USUAL RESIDENCE (IF DEATH OCCURRED IN INSTITUTION, ENTER RESIDENCE BEFORE ADMISSION)

19A. USUAL RESIDENCE—STREET ADDRESS (STREET AND NUMBER OR LOCATION): 123 Tule Lane		19B. INSIDE CITY CORPORATE LIMITS (SPECIFY YES OR NO): Yes	20. NAME AND MAILING ADDRESS OF INFORMANT: Kathleen Young
19C. CITY OR TOWN: Center City	19D. COUNTY: Morgan	19E. STATE: California	Same address

PHYSICIAN'S OR CORONER'S CERTIFICATION

21A. CORONER: I HEREBY CERTIFY THAT DEATH OCCURRED AT THE HOUR, DATE AND PLACE STATED ABOVE FROM THE CAUSES STATED BELOW AND THAT I HAVE HELD AN INQUEST OR INVESTIGATION ON THE REMAINS OF DECEASED AS REQUIRED BY LAW	21B. PHYSICIAN: I HEREBY CERTIFY THAT DEATH OCCURRED AT THE HOUR, DATE, AND PLACE STATED ABOVE FROM THE CAUSES STATED BELOW AND THAT I ATTENDED THE DECEASED FROM (ENTER MONTH, DAY, YEAR): 4/11/ TO (ENTER MONTH, DAY, YEAR): 3/17/ AND LAST SAW THE DECEASED ALIVE ON (ENTER MONTH, DAY, YEAR): 3/17/	21C. PHYSICIAN OR CORONER—SIGNATURE AND DEGREE OR TITLE: [signature] M.D. / 21E. ADDRESS: 1117 Potelho Ave.	21D. DATE SIGNED: 3/18/ / 21F. PHYSICIAN'S LICENSE NUMBER: 135531

FUNERAL DIRECTOR AND LOCAL REGISTRAR

22A. SPECIFY BURIAL, ENTOMBMENT OR CREMATION: Cremation	22B. DATE: Mar. 21	23. NAME OF CEMETERY OR CREMATORY: Alden Glade	24. EMBALMER—SIGNATURE (IF BODY EMBALMED) LICENSE NUMBER: [signature] 246642
25. NAME OF FUNERAL DIRECTOR (OR PERSON ACTING AS SUCH): P.S. Brackett	26. IF NOT CERTIFIED BY CORONER WAS THIS DEATH REPORTED TO CORONER? (SPECIFY YES OR NO): Yes	27. LOCAL REGISTRAR—SIGNATURE: [signature]	28. DATE ACCEPTED FOR REGISTRATION BY LOCAL REGISTRAR: Mar. 27

CAUSE OF DEATH

29. PART I. DEATH WAS CAUSED BY: ENTER ONLY ONE CAUSE PER LINE FOR A, B, AND C

		APPROXIMATE INTERVAL BETWEEN ONSET AND DEATH
IMMEDIATE CAUSE (A)	Respiratory Failure	1 hr.
CONDITIONS, IF ANY, WHICH GAVE RISE TO THE IMMEDIATE CAUSE (A), STATING THE UNDERLYING CAUSE LAST — DUE TO, OR AS A CONSEQUENCE OF (B)	Pneumonia	1 day
DUE TO, OR AS A CONSEQUENCE OF (C)		

30. PART II: OTHER SIGNIFICANT CONDITIONS—CONTRIBUTING TO DEATH BUT NOT RELATED TO THE IMMEDIATE CAUSE GIVEN IN PART I: Emphysema, Chronic Bronchitis	31. WAS OPERATION OR BIOPSY PERFORMED FOR ANY CONDITION IN ITEMS 29 OR 30? (SPECIFY OPERATION AND/OR BIOPSY): No	32A. AUTOPSY (SPECIFY YES OR NO): No	32B. IF YES WERE FINDINGS CONSIDERED IN DETERMINING CAUSE OF DEATH? (SPECIFY YES OR NO)

INJURY INFORMATION

33. SPECIFY ACCIDENT, SUICIDE OR HOMICIDE	34. PLACE OF INJURY (SPECIFY HOME, FARM, FACTORY, STREET, OFFICE BUILDING, ETC.)	35. INJURY AT WORK (SPECIFY YES OR NO)	36A. DATE OF INJURY—MONTH, DAY, YEAR / 36B. HOUR
37A. PLACE OF INJURY (STREET AND NUMBER OR LOCATION AND CITY OR TOWN)	37B. DISTANCE FROM PLACE OF INJURY TO USUAL RESIDENCE (ITEM 19) MILES	38. WERE LABORATORY TESTS DONE FOR DRUGS OR TOXIC CHEMICALS? (SPECIFY YES OR NO)	39. WERE LABORATORY TESTS DONE FOR ALCOHOL? (SPECIFY YES OR NO)

40. DESCRIBE HOW INJURY OCCURRED (ENTER SEQUENCE OF EVENTS WHICH RESULTED IN INJURY. NATURE OF INJURY SHOULD BE ENTERED IN ITEM 29)

STATE REGISTRAR

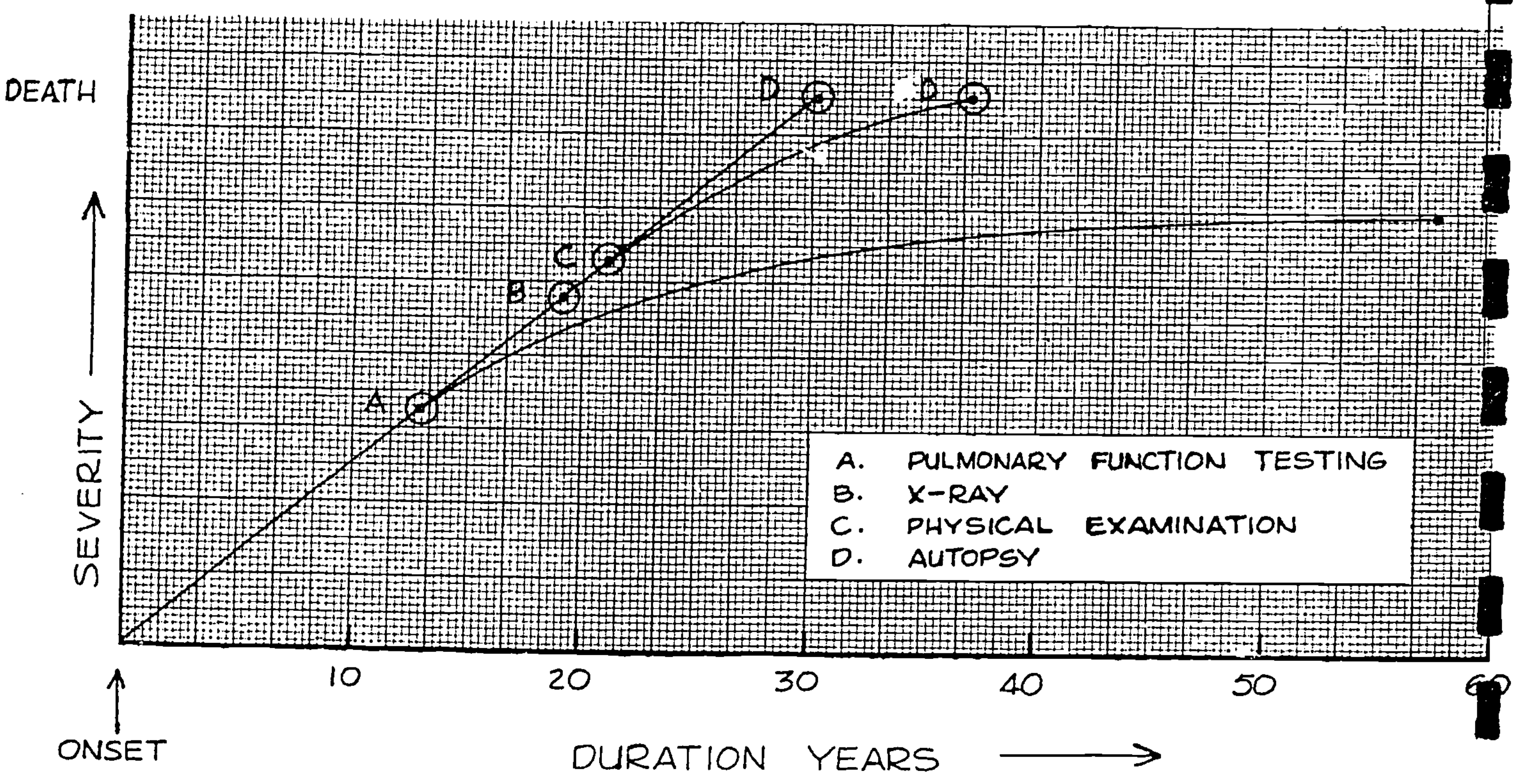
A.	B.	C.	D.	E.	F.

43-2 Tom's Death

Note that the cause of Tom's death is given on the death certificate as pneumonia. Although the immediate cause of death was in fact pneumonia, his failure to survive pneumonia was a result of emphysema.

A more difficult question is whether smoking was the cause of Tom's early death. We cannot answer with certainty. People who never smoke can get emphysema. However, the chances of someone who does smoke getting emphysema are much greater, and we can say definitely that smoking accelerated the progress of the disease in Tom.

The following graph represents the progress of chronic bronchitis or emphysema (or both) in a person who smokes.



The horizontal axis represents time, while the vertical axis represents the severity of the disease. Point A is the first point at which pulmonary function testing would show an impairment. If the individual, for instance Tom, quit smoking permanently at that point, the progress of the disease would be slowed to the rate shown by the lower curve, and he would live a normal life span. If he continued to smoke, however, bronchitis or emphysema would progress at the same rate as before diagnosis. When the disease had progressed to Point B it would show on a chest X-ray. Point C is the stage at which emphysema can be identified by means of a physical examination. If Tom had stopped smoking for good at this point, he might have lived perhaps an extra seven or eight years, although by then the outcome was inevitable.

The following chart is a cost analysis of Tom's last three years, showing the increasing loss of money as his emphysema progressed. By the time he was a total invalid, emphysema was costing his family over $15,000 a year. The figure $15,000 represents his medical expenses plus the money he lost by not being able to work.

COST ANALYSIS OF TOM'S INVALID PHASE (AGE 45 TO 48)

(I) Medical Attention Phase

Age: 45-46	
15 doctor visits $20/call	$ 300
Drugs/Medicine $15/mo	180
1 hospitalization (4 days at $150/day)	600
Total medical	1080
Work loss	8000
Total money loss	$ 9080

(II) Increased Medical Attention Phase

Age: 46-47	
24 doctor visits $20/call	$ 480
Drugs/medicine $20/mo	240
3 hospitalizations (4 days each)	1800
Total medical	2520
Work loss	16000
Total money loss	$18520

(III) Total Invalid Phase

Age: 47-48	
36 doctor visits $20/call	$ 720
Drugs/medicine $35/mo	420
8 hospitalizations	4800
Hospital bed rental $100/mo	1200
156 nurse visits $12/visit	1872
Breathing device $32/mo	384
Oxygen $18/mo	216
Total medical	9612
Work loss	16000
Total money loss	$25612

43-3 Emphysema Statistics

A recent national health survey estimated that 923,000 Americans have been diagnosed as suffering from emphysema. Many more have not yet been diagnosed. Most emphysema victims are older men, yet women and younger people also suffer.

The following table gives the death rate for the fifteen leading causes of death. Emphysema is listed as the tenth leading cause, being responsible for 1.3 per cent of all deaths in this country.

Rank	Cause of death	Number of deaths per year	Death rate per 100,000 population	Percent of total deaths
1	Diseases of Heart	744,658	372.6	38.6
2	Cancer	318,547	159.4	16.5
3	Stroke (Cerebrovascular Diseases)	211,390	105.8	11.0
4	Accidents	114,864	57.5	6.0
	Motor-Vehicles Accidents	54,862	27.5	2.8
	All Other Accidents	60,002	30.0	3.2
5	Influenza and Pneumonia	73,492	36.8	3.8
6	Certain Diseases of Early Infancy	43,840	21.9	2.3
7	Diabetes Mellitus	38,352	19.2	2.0
8	Arteriosclerosis	33,568	16.8	1.7
9	Cirrhosis of Liver	29,183	14.6	1.5
10	Emphysema	24,185	12.1	1.3
11	Suicide	21,372	10.7	1.1
12	Congenital Anomalies	16,793	8.4	0.9
13	Homicide	14,686	7.3	0.8
14	Peptic Ulcer	9,460	4.7	0.5
15	Infections of Kidney	9,395	4.7	0.5
	Other and Ill-Defined	226,297	113.3	11.5
	All causes	1,930,082	965.8	100.0

Source: Vital Statistics of the United States, 1968.

Actually emphysema is responsible for even more deaths. The people who compile such statistics list only the immediate cause of death, the cause given on the death certificate. Remember that the cause of Tom's death was given as pneumonia. It is estimated that in as many as 75 per cent of deaths listed as caused by pneumonia or influenza, as well as in 2 percent of heart disease deaths, emphysema was the underlying problem. If these estimates are taken into consideration, emphysema is approximately the fifth leading cause of death.

The incidence of emphysema is increasing rapidly throughout the United States. One of the tasks confronting medical researchers is to determine the cause of this rapid increase.

Why did Tom's death certificate list pneumonia as the cause of death?

Did smoking cause Tom to get emphysema?

What might have happened if he had quit smoking?

How important is emphysema in relation to other causes of death?

REVIEW SET 43:

1. What happens to the ratio of surface area to volume as the size of an object increases?

2. What is the difference between a chronic condition and an acute condition?

3. What are the symptoms of bronchitis? How is it treated? What preventive measures can be taken to avoid chronic bronchitis?

4. What are the major sources of air pollution? Which of these exist in your community?

5. What are some of the effects of air pollutants on health?

6. What is a thermal inversion?

7. Describe two different situations in which an inversion occurs.

8. How do inversions create air pollution problems?

9. a. What changes have occurred in the lungs of a person with emphysema?

b. What symptoms does a person with emphysema have?

c. What are causes of emphysema?

d. What treatments and means of prevention are there for emphysema?

10. Can cigarette smoking be considered a major air pollution problem? Explain.

UNIT REVIEW SET:

1. Make a diagram (or obtain a diagram) of the respiratory system. Label all the structures passed by oxygen from its entry into the body until it reaches the bloodstream.

2. Look at a labeled diagram of the respiratory system. For each incident in Tom's case record, name or describe the condition and the part(s) of the system involved. Include the cause, the symptoms, the treatment and prevention wherever possible.

3. Describe the cause of gas pressure. What is the importance of different pressures in the functioning of the respiratory system?

4. Describe the atomic structure of matter. (Use diagrams). Explain how atoms can combine to form molecules.

5. What is a chemical reaction? Give one or more examples of reactions that are of basic importance to human respiration.

6. What is a mole? When is the concept of a mole useful in chemistry to simplify problem solving?

7. What steps could be taken to reduce the incidence of death and disease from lung ailments in general?