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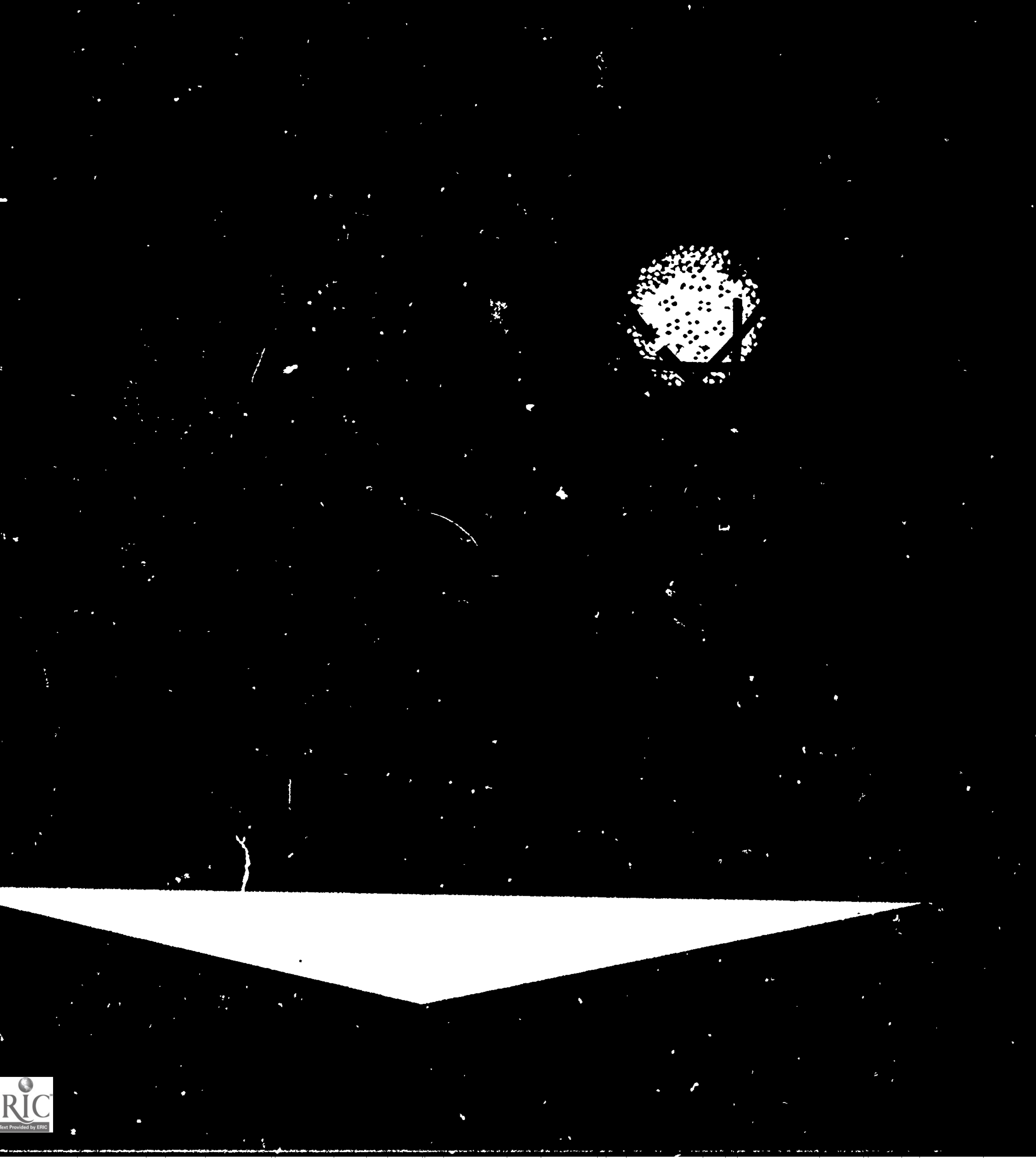
ABSTRACT

This publication is a sourcebook for science teachers. It provides guides for basic laboratory work in nuclear energy, suggesting various teacher and student demonstrations. Ideas for science clubs, science fairs, and project research seminars are presented. Problem-solving activities for both science and mathematics classes are included, as well as materials useful for social studies for training civil defense workers in the use of nuclear radiation instruments. Information is given which supplies historical data on atomic energy. An instructional unit, Protection from Radioactive Fallout, is included. A bibliography of publications embracing several aspects of the story of nuclear science and organized by grade levels is included, and a descriptive list of films is presented alphabetically by title. A chronology of steps leading to present knowledge about nuclear science is designed and presented to give teachers and students a better perspective of the whole subject of atomic energy. (EB)



NUCLEAR SCIENCE TEACHING AIDS AND ACTIVITIES

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Foreword

It takes little stretch of the imagination in this, the 20th century, to associate the continuation and expansion of our American ideals and way of living with the need for adequate numbers of people, young and old, to have the ability to interpret and take part in scientific enterprise. Bringing this fact most sharply into focus is one of the recent developments in science: nuclear energy and its military and peacetime uses.

This sourcebook of teaching aids and activities was prepared under a delegation of authority by the Office of Civil and Defense Mobilization to the Department of Health, Education, and Welfare. The Office of Education, in turn, provided technical assistance to departments of education in three State pilot centers. Teachers in these three States—California, Connecticut, and Michigan—in cooperation with Dr. Woodburn had a major part in designing and trying out the experimental instructional activities and materials reported in this publication. The work at the pilot centers has also produced three previous publications: *Significant Concepts in Nuclear Science* (California State Department of Education), *Nuclear Energy for Beginners* (Connecticut State Department of Education), and *Nuclear Science in the Classroom* (Michigan State Department of Public Instruction).

Nuclear science includes many concepts and principles of science, both natural and social. Few other topics hold as great a challenge for teachers seeking teaching techniques and activities for young people. We hope all teachers can find something in this publication which will help them strengthen their students' understanding, expand their hopes, and allay any fears which nuclear science may hold for them.

LAWRENCE G. DERTHICK,
Commissioner of Education.

Preface and Acknowledgments

The most recent science textbooks and courses of study for high schools almost without exception contain sections on nuclear science. These new publications still need, however, to be adapted to laboratory and demonstration teaching; and trained personnel are needed who could handle instruments for detecting nuclear radiation in case of a national emergency.

The present publication on laboratory and demonstration procedures has been prepared in response to the widely felt needs. Science teachers will find it a source book for the following purposes:

- To guide basic laboratory work in nuclear energy.
- To suggest teacher and student demonstrations.
- To augment projects for talented students.
- To provide ideas for science clubs, science fairs, and project research seminars.
- To afford problem-solving activities for both science and mathematics classes.
- To help train civil defense workers in the use of instruments for detecting nuclear radiation.
- To serve as material for social studies.
- To supply an historical background on atomic energy.
- To describe various aids for enrichment of study units on atomic energy.

The Office of Education acknowledges with gratitude contributions to this publication from the following persons: Roy E. Simpson, Superintendent of Public Instruction, California State Department of Education; William J. Sanders, Commissioner of Education, Connecticut State Department of Education; Lynn M. Bartlett, Superintendent of Public Instruction, Michigan State Department of Public Instruction; Frank B. Lindsay, Chief, Bureau of Secondary Education, California State Department of Education; Arthur Goldberg, Director, Civil Defense Education Project, Connecticut State Department of Education; L. Wayne Berry, Coordinator, Civil Defense Education Pilot Project, Michigan State Department of Public Instruction; and the Education and Training Staff of the Office of Civil and Defense Mobilization.

In addition, the science teachers in the three Pilot Center States should receive special mention for having developed many of the demonstrations described in the publication.

The publication was prepared under the direction of Paul MacMinn, then Chief, Civil Defense Education Project, Office of Education.

WAYNE O. REED,
Deputy Commissioner of Education.

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Chapter I
Introduction

From time immemorial, mankind has been surrounded by *chemical* reactions. Man's response to the effects of these gradually evolved from abject fear to familiarity and, eventually, utilization. Fire, a dramatic property of one chemical reaction, ceased to be something to fear and came to be recognized as a source of friendly warmth. Man learned that heat could be used to make his food taste better, to extract useful metals from their ores, and eventually propel his automobiles along the highway, or his rockets through space.

By the end of the 19th century, the phenomena that accompany chemical reactions had lost nearly all their mystery. Scientists could recognize how atoms and molecules behave in relation to each other and predict with some degree of confidence what would happen when one kind of material reacts with another. Man had learned to duplicate many useful materials heretofore produced only in nature. He understood many natural chemical processes. Even the life process was beginning to lose some of its mystery and many drugs and medicines were produced to maintain good health or cure disease.

But the end of the 19th century brought with it some events and circumstances that could not be explained in terms of the reactions of atoms and molecules. The concept of "solid, massy, hard, impenetrable, movable particles so very hard as never to wear or break to pieces," as theorized by Sir Isaac Newton, became suspect. This was so even though John Dalton had "discovered" that all bodies of sensible magnitude consist of a vast number of extremely small particles, or atoms of matter bound together by a force of attraction. Further, Dalton helped man gain a clearer picture of chemical reaction by theorizing that atoms of a pure substance are all exactly alike in size, shape, and weight and that a chemical reaction is merely reshuffling or recombining atoms involving no change in the atoms themselves.

During the 19th century, many scientists investigated the peculiar glow which accompanied the passage of electrical discharges through glass tubes. The luminous glow from evacuated tubes led some scientists to hypothesize the existence of streams of subatomic particles carrying electrical charges. The study of electricity led other scientists to believe that electricity comes in discrete units or packages. The behavior of cloud droplets caused certain scientists to strengthen the hypothesis that there is a unit of electrical charge. Eventually the electron had to be invented in order to explain these many new observations.

Near the close of the 19th century, Becquerel made his famous observations about the radiation which seemed to come from uranium salts. He saw it penetrate materials which are opaque to ordinary light. He saw it discharge the gold-leaf electroscope. Eventually, scientists realized that some of this radiation which comes naturally from the disintegration of uranium was the same as that which was produced artificially in evacuated tubes. The "indestructibility" of the atom had been destroyed.

The hundreds of individual discoveries and explorations which compose the drama of man's study of atomic structure and nuclear energy provide brilliant examples of scientists at work. They illustrate clearly how projects in natural science often originate in the curiosity of persons who see something in their natural environment that suggests the action of a scientific principle or natural law. Some authors have attempted to tell the story of nuclear science—a story to which justice cannot be done when condensed into the space available in this publication. It would be well, however, for the reader to refer to the Chronology of Steps Leading to Our Present Knowledge About Nuclear Science. This chronology indicates the scope and sequence of this research and provides perspective on the drama as a whole.

Chapter II

Visualizing Atomic Nuclei and Nuclear Reactions

Nuclear radiation consists of fragments of atomic nuclei, packets of energy emitted during nuclear activity, or fragments of the particles which make up the nuclei. The very nature of nuclear radiation makes it difficult to describe. Furthermore, many persons have an almost mystical attitude toward it. It is natural, perhaps, to fear or at least be uncomfortable in the presence of anything we do not understand, especially if it involves phenomena beyond the range of the usual sensory perception. We can neither see, hear, taste, smell, nor feel nuclear radiation. Its presence may be detected only when it produces some secondary effect.

When approaching the topic of nuclear science the teacher is faced by a 3-fold task: he must provide for his students a reasonably realistic and working picture of atoms, clarify the kinds of reactions which involve atomic nuclei, and establish a working acquaintance with the characteristics of the radiation which accompanies nuclear reactions.

A Word Picture of the Atom

A very illuminating description of an atom is given in Wolfgang Pauli's *The World of Life:*[1]

If an atom could be magnified to the size of a house, it would probably look something like a great soap bubble, except that its outlines would be so hazy and indistinct that it would be impossible to tell just where the borders of the atom were. Within the misty outer shell would appear other more or less concentric or interlocking shells, each as hazy as the outer one. Deep in the center of this shimmering mass would be a denser, more solid looking structure, the nucleus, no larger than a dot. Most impressive perhaps, would be the vast emptiness of the atom, a characteristic which it shares with all the universe around it. It is strange indeed to realize that man and all living things, the earth, and all the universe are constructed of such empty and seemingly fragile structures. It has been estimated that if all the atomic constituents of the human body could be packed together tightly, eliminating the spaces between them, they would be no larger than a grain of sand.

The planetary electrons which revolve around the nucleus must be visualized as endowed with a smashing, driving energy. Even in this house-sized atom, they would revolve in their orbits with such inconceivable speed that they would not be recognized as separate units, but would give the illusion of thin, transparent shells, as unreal as the disk described by the whirling blades of an electric fan. If their speed could be reduced so that they could be made visible, they might become vaguely outlined and intensely vibrating "objects" no larger than pinpoints: not solid, but rather, says modern physics, whirlpools of energy, foci of energy, or similar intangible units.

To Pauli's smashing, whirling picture of the atom, we must add even more activity when we consider unstable nuclei, which we are forced to do when nuclear radiation is involved. In the presence of unstable nuclei there can be a no-man's land where rifle bullets whiz by, bazooka rockets whistle about, and hand grenades are tossed around. It is difficult to associate this metaphor with "the illusion of thin, transparent shells, as unreal as the disk described by the whirling blades of an electric fan." But such is one of the purposes of this publication.

Classifying Nuclear Reactions

Just as chemistry teachers simplify the presentation of chemical reactions by classifying all chemical reactions into a few types, nuclear reactions can be classified according to the radiation or particles which they produce. These products are: alpha, beta, neutron, or other subatomic particles or gamma radiation.

Examples of each kind of nuclear reaction can be found in the history of nuclear science, or we may look for them in its more recent applications.

[1] New York: Houghton Mifflin Co., 1946, pp. 31 and 32.

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Nuclear reaction which produces alpha particles may produce a variety of disintegration products including alpha particles. An example is the natural disintegration of uranium. Just as chemists have devised a kind of shorthand to show chemical reactions, so physicists have developed a shorthand to show nuclear reactions. Thus, the disintegration of uranium can be shown as follows:

$$_{92}U^{238}\rightarrow{}_{90}Th^{234}+{}_{2}He^{4}$$

In this shorthand fashion of showing nuclear reactions the lower numbers indicate the number of protons in the nucleus and the upper numbers indicate the total number of protons and neutrons—the atomic weight of the atom. Since alpha particles are equivalent to the nucleus of the helium atom, they usually carry the He symbol.

The much-publicized decay of strontium 90 can illustrate that type of nuclear reaction in which beta particles are emitted. Strontium 90 can be one of the products of the fission of uranium 235, a reaction usually cited as an example of the type of reaction which produces gamma rays. Strontium 90 appears as the unstable product of the decay of other unstable nuclei, usually in a four-step process. The shorthand version follows:

$$_{36}Kr^{90}\rightarrow{}_{37}Rb^{90}+{}_{-1}\beta^{0}$$
$$_{37}Rb^{90}\rightarrow{}_{38}Sr^{90}+{}_{-1}\beta^{0}$$
$$_{38}Sr^{90}\rightarrow{}_{39}Y^{90}+{}_{-1}\beta^{0}$$
$$_{39}Y^{90}\rightarrow{}_{40}Zr^{90}+{}^{-1}\beta^{0}$$

An example of a nuclear reaction which yields neutrons can be found in one of the common laboratory neutron sources. If alpha particles from radium are allowed to bombard beryllium, they liberate free neutrons. The reaction is as follows:

$$_{4}Be^{9}+{}_{2}He^{4}\rightarrow{}_{6}C^{12}+{}_{0}n^{1}$$

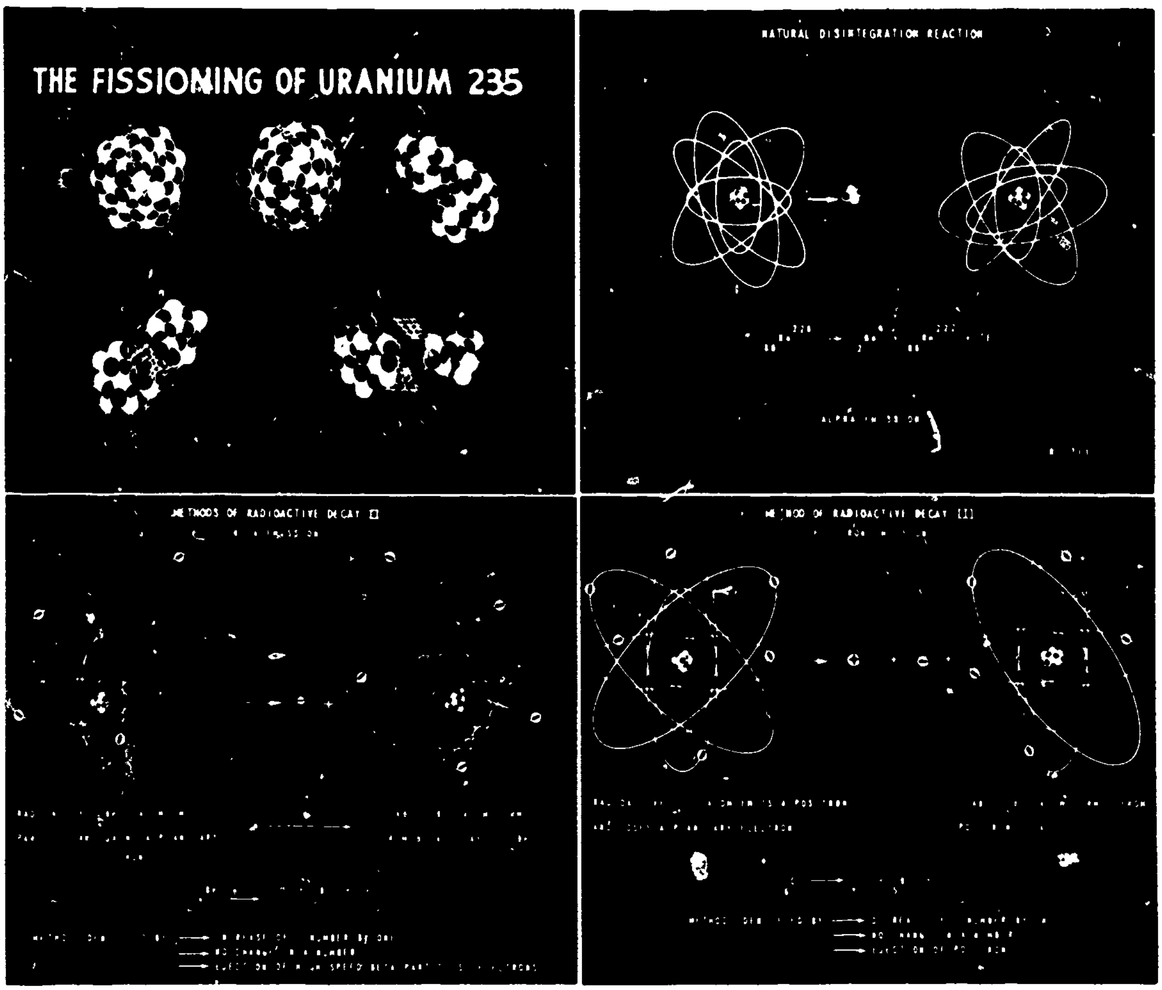

FIGURE 1.—Chalkboard sketches suggesting how nuclear reactions occur.

In preparing a neutron source, the physicist mixes finely divided radium chloride with powdered beryllium in a small capsule. One milligram of radium will yield between 6 and 12 thousand neutrons per second, depending upon the size of the radium chloride grains.

The splitting of the uranium 235 nucleus provides a good illustration of the type of nuclear reaction which produces gamma radiation. This particular reaction produces a wide variety of fission products. A representative reaction is the following:

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow {}_{42}Mo^{95} + {}_{57}La^{139} + {}_{7-1}B^0 + 2{}_0n^1$$

For example, uranium 235 + a neutron produces uranium 236, which may split into molybdenum 95 + lanthanum 139, providing 7 beta particles and 2 neutrons. It can be seen that the fission of uranium 235 also produces beta particles.

Modeling Atomic Nuclei and Nuclear Reactions

Recalling the word picture of the atom which appears earlier in this chapter and recognizing this picture may be only a first approximation

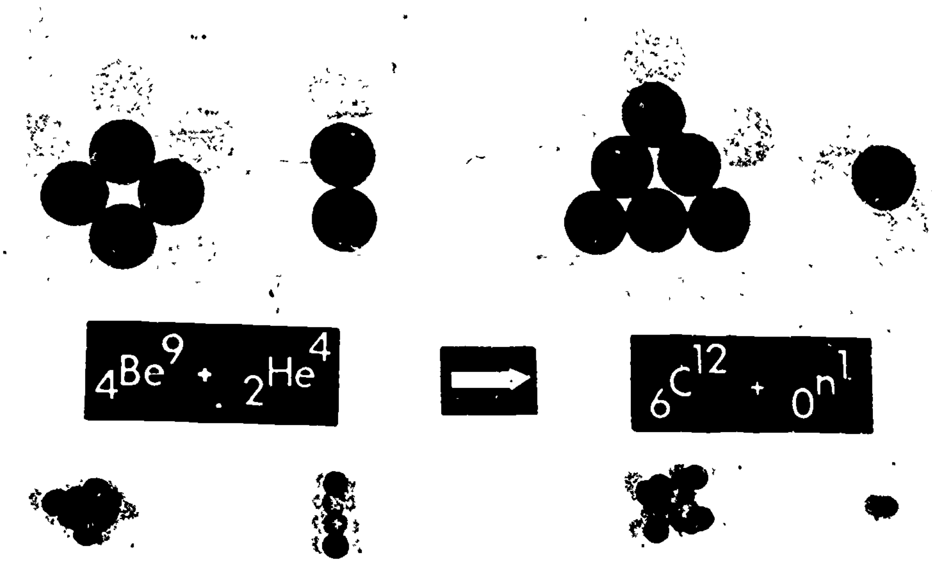

FIGURE 2.—Combining blotting paper circles and styrofoam spheres against a flannel board background to visualize a reaction which provides a source of neutrons.

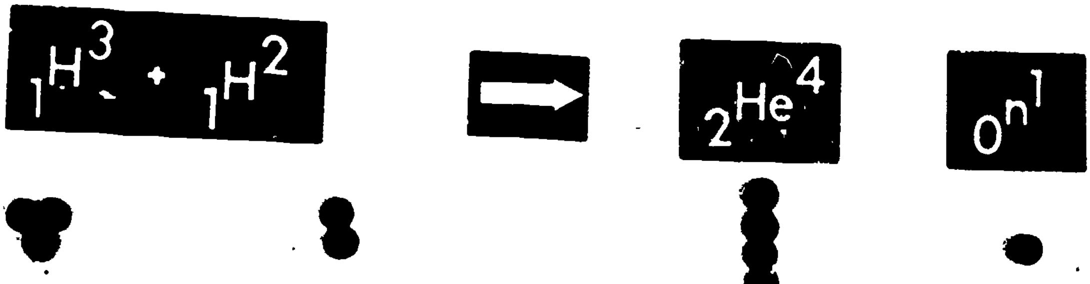

FIGURE 3.—Balls of modeling clay being used to show the last step in a hypothetical hydrogen bomb reaction.

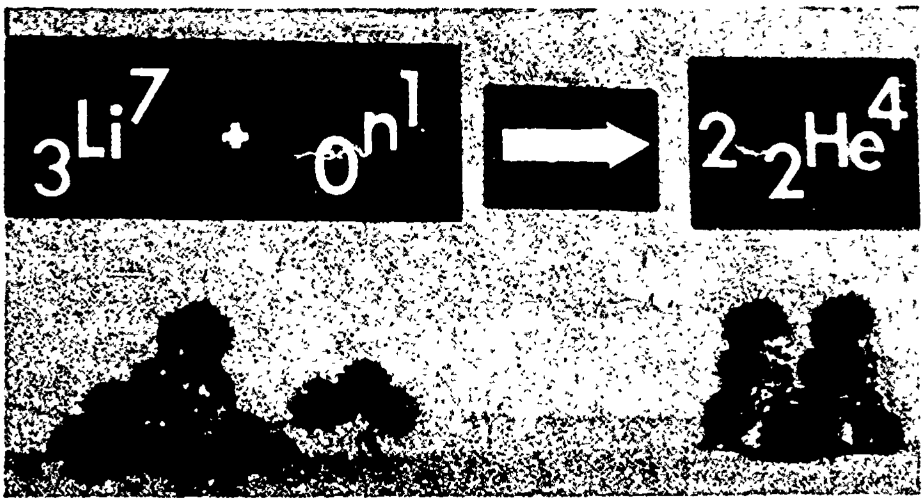

FIGURE 4.—Seed pods from sweet gum trees dipped in paint and dried are used to represent protons and neutrons. They are held together with bits of modeling clay. Would a more compact arrangement of the alpha particles produce fewer misconceptions?

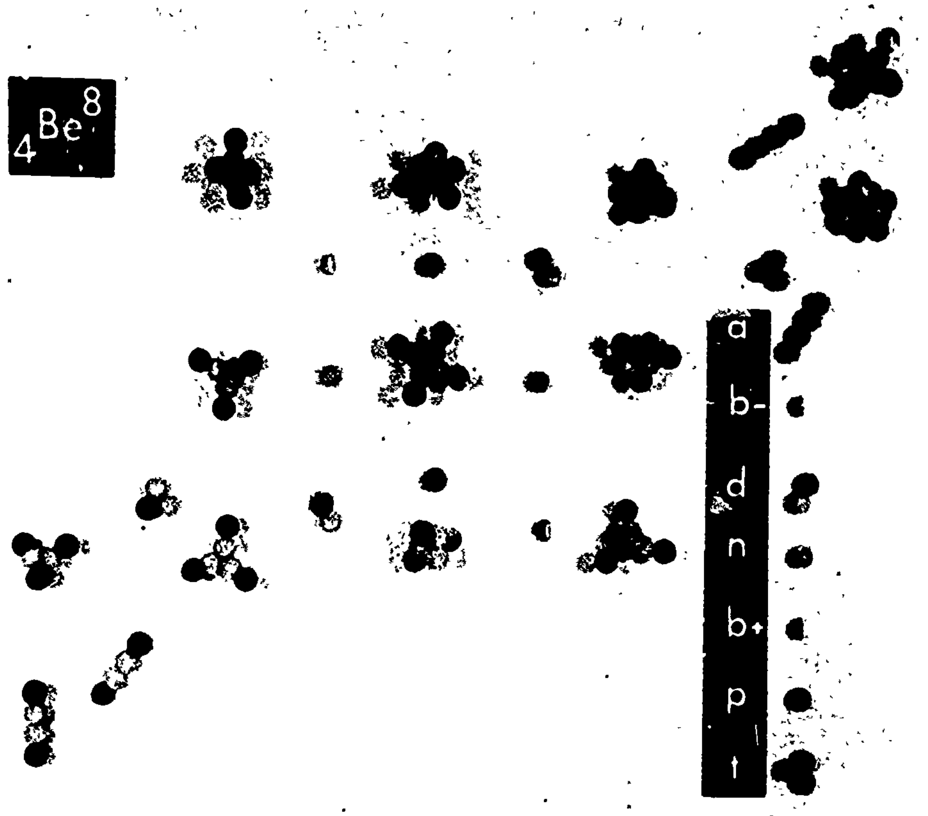

FIGURE 5.—James Stokley has summarized many nuclear reactions in his chart, *Nuclei and Isotopes.* Styrofoam balls against a flannel board background may be used to demonstrate the Stokley chart. In the example, beta emission from a beryllium 8 nucleus would produce the new nucleus found one place to the upper left diagonal. Alpha capture would produce the nucleus shown two places to the right and up two places.

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to a true description of the atom, one can appreciate that modeling atomic nuclei and their reactions carries the risk of causing many misconceptions. The limitations of the model must be kept in mind. Models can, however, clarify certain concepts and the resourceful teacher can exploit the shortcomings of the model to emphasize the more theoretical aspects of atomic structure. Efforts to visualize atomic nuclei and their reactions reflect the ingenuity of teachers and their ability to use whatever materials are at hand. Some suggestions may be gained from figures 1 through 7.

Their limitations notwithstanding, models of atomic nuclei can show that protons and neutrons form the atomic nuclei. How these units are arranged and in what form the "binding energy" or "nuclear glue" should appear,

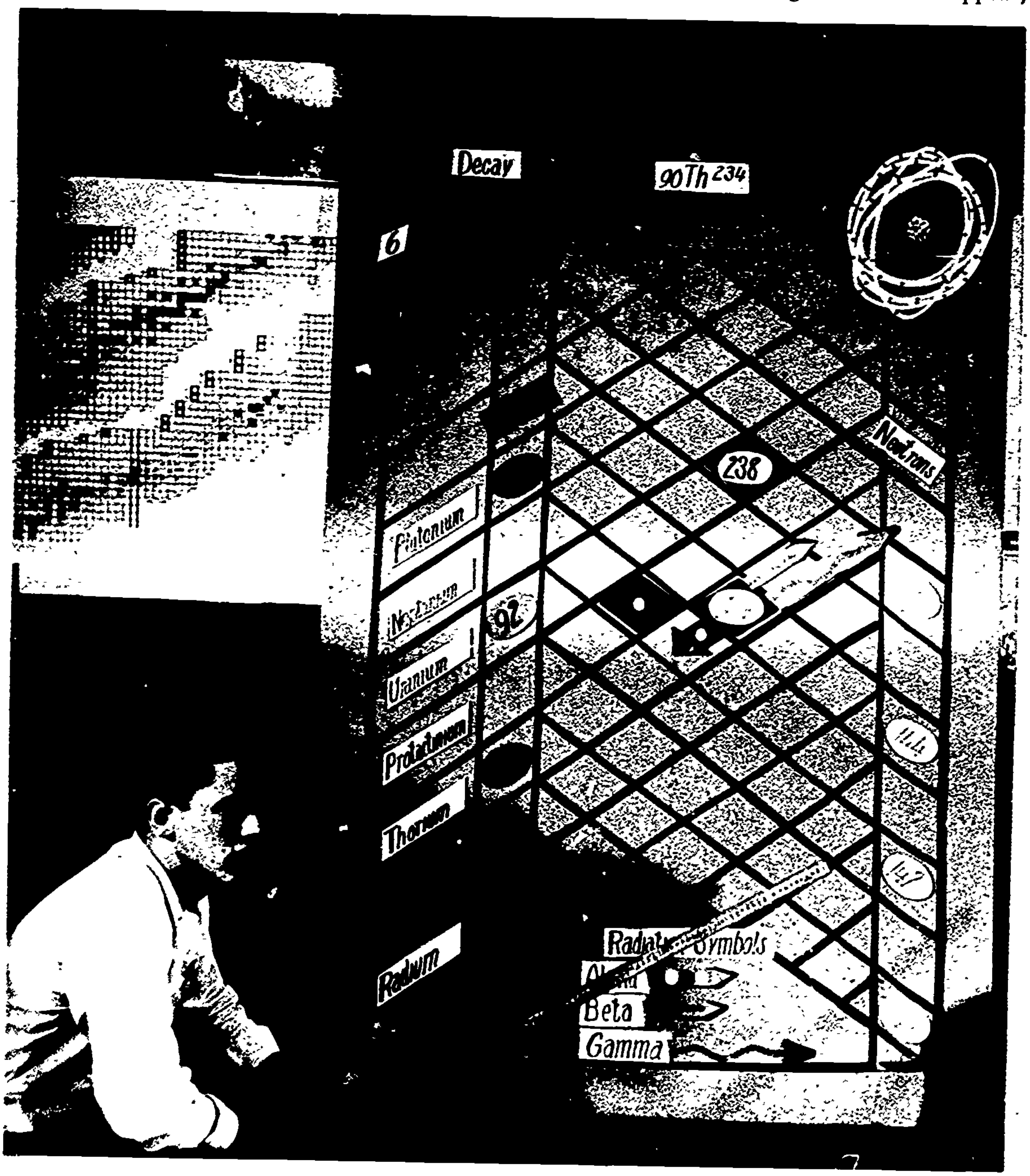


FIGURE 6.—Gordon Swicks, a student of David Schubert in the Sexton High School, Lansing, Mich., shows how the Stokley chart can be interpreted with another kind of flannel board arrangement.

however, forces one to commit himself to a single point of view regarding phenomena about which there may be many points of view. Limitations of the models impose additional restrictions. One model can show, for example, a beta particle coming from a neutron, thus forming a proton. The proton, in turn, can be shown to emit a positron. Students can now well ask how this neutron differs from the original neutron.

Styrofoam-ball models of unstable nuclei help students relate radiation to its sources—something they must succeed in doing before they can handle radioactive materials intelligently. Wires of appropriate length can be stuck into the nuclei and symbolical beta or gamma "particles" placed on the ends of the wires. Again, the limitations of the models must be kept in mind. The lengths of the wires will be completely out of scale with the size of the nucleus, but their lengths can be used to show the relative energies of the emitted particles. Visualization of the gamma rays is especially difficult. Plastic tubing or insulation slipped over the end of the wire and bent into wave form will at least suggest the wave nature of the gamma ray. Keeping the "wave" in a compact "bundle" will suggest its particulate characteristics.

Models, despite their limitations, reduce the mystery of nuclear radiation by reducing it to simple products of nuclear reactions involving either unstable nuclei or interactions between nuclei or portions of nuclei. As the student advances toward a more sophisticated stage, models bring sharply into focus many questions regarding the arrangement of nuclear particles and the maintenance of stability or instability.

Additional ideas of modeling nuclei and nuclear reactions appear in the bibliography.

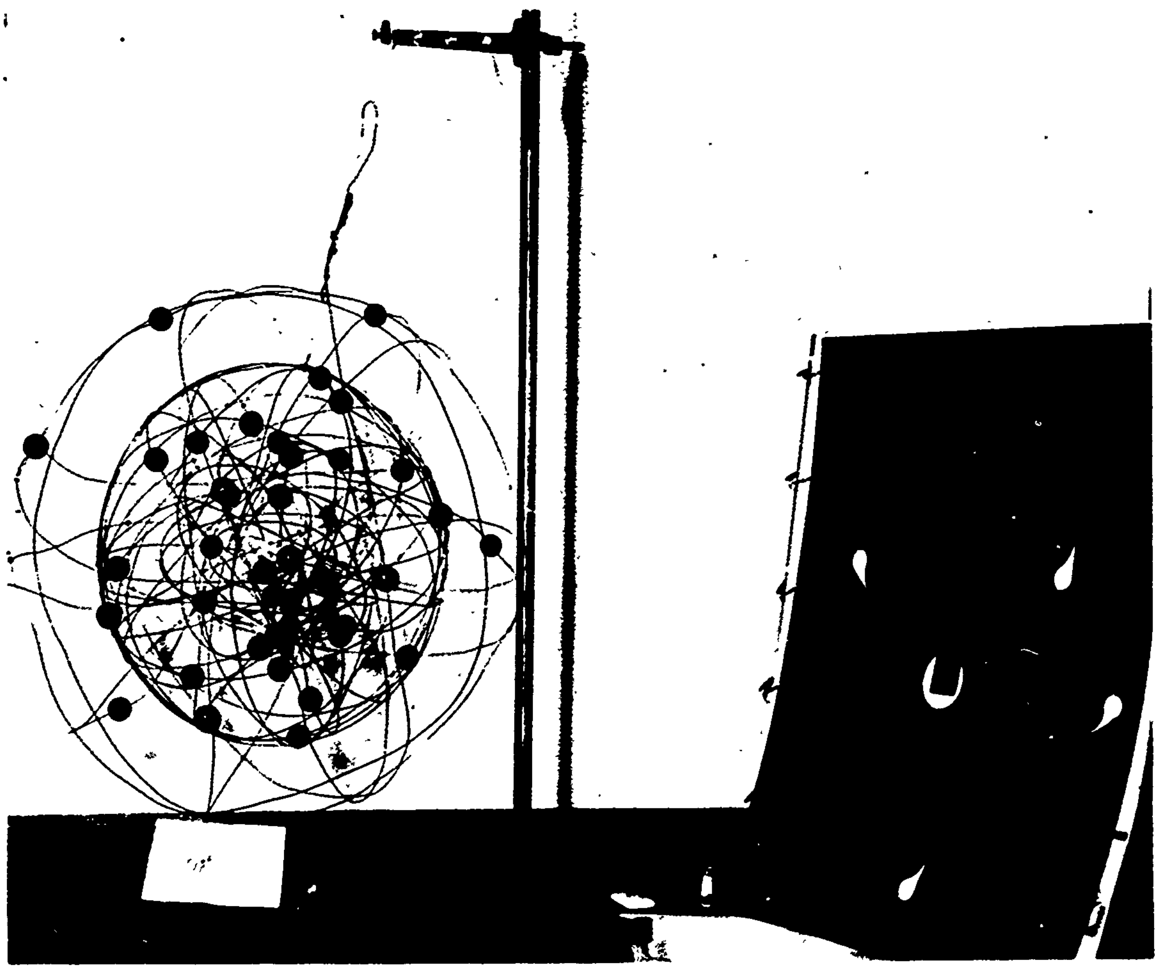


FIGURE 7. —Two students at the T. L. Handy High School, Bay City, Mich., turned out on a lathe wooden balls to portray the krypton 82 atom. This portrayal includes the orbital electrons.

Chapter III

Getting Acquainted With Nuclear Radiation

We need to call upon no scientific principle more complex than the simple conservation of energy to realize that alpha, beta, gamma, and other nuclear radiation tends to transfer energy to atoms with which it comes into close contact or collides. By recalling our earlier word picture of the atom, we can easily understand why most of the phenomena associated with the collisions involve the orbital electrons. Atoms whose orbital electrons have been removed exhibit the properties of ionization. Thus our problem of becoming acquainted with nuclear radiation brings us, for the most part, to an understanding of ions and ionization.

If a phenomenon depends upon atoms being combined in molecules by ionic processes, we can expect that phenomenon to be affected by the presence of nuclear radiation. Many of the biological effects of radiation are so originated. Similarly, we would expect nuclear radiation to affect a photographic emulsion if the chemical compounds in the emulsion are sufficiently unstable to be affected by ionizing radiation.

When we work with nuclear radiation, we may expect to recognize each of the characteristics of ions. Electrical fields produce ion movement. Their energy is converted into some other form. They may serve as condensation nuclei in cloud or bubble chambers. These and other effects can be traced to disturbances in the arrangement of the orbital electrons around an atom.

The accompanying sketches (figure 8) show one artist's attempt to illustrate nuclear radiation and the production of ionized atoms.

Sources of Nuclear Radiation

The widespread use of radioactive isotopes for tracers and other peacetime purposes has resulted in a wide variety of unstable nuclei being available from commercial laboratories. No special licensing is required to purchase small quantities of many of these isotopes. Several suppliers have indicated willingness to sell them and each shipment usually includes a copy of the regulations governing distribution and handling of radioactive material.

To work comfortably, confidently, and in-

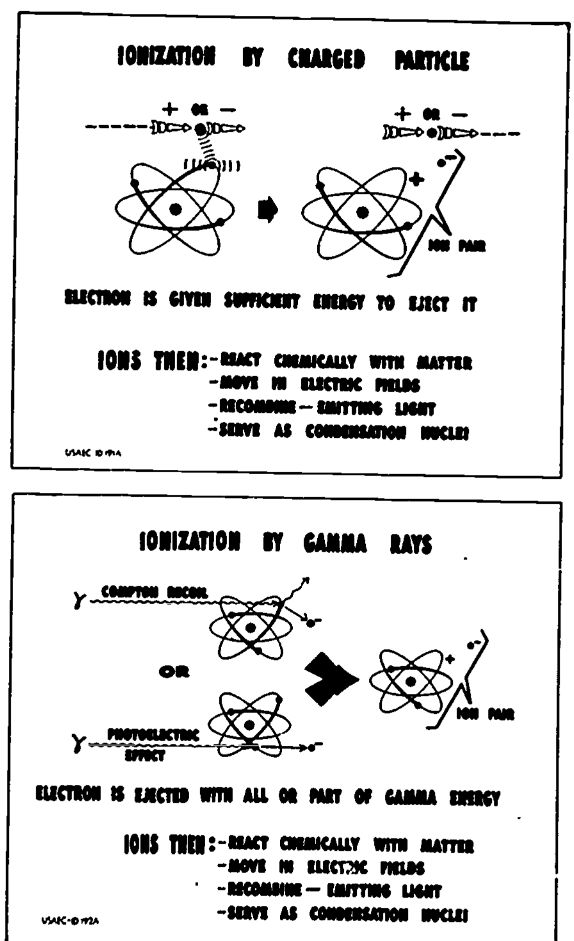


FIGURE 8.--A set of instructional charts prepared by the U. S. Atomic Energy Commission.

telligently with nuclear radiation, one needs answers to the following questions:

- What nuclear reaction is producing the radiation?
- How much of the reacting material am I responsible for and where is each bit of it?
- What are the characteristics of the specific radiation with which I am working?
- How can it be used to do something worth doing?
- How can I keep to a minimum the chances that this radiation will do something that should not be done?

One commercial supplier who provides small quantities of radioactive materials for classroom demonstration or experimental purposes features nine isotopes in a small pack ("jumbo" pack). The isotopes are selected so as to provide a range of half-lives, a range in the energies of the particles emitted, and a variety of radiation.

Radioactive Materials

Quantities of radioactive material are usually expressed in terms of microcuries, millicuries, or curies. A microcurie quantity of any radioactive material contains enough unstable nuclei to allow 3.7×10^4 (37,000) disintegrations per second. In other words, a 10-microcurie quantity of phosphorus 32 would have 370,000 phosphorus 32 atoms disintegrating per second. No one can proceed intelligently with the handling of any radioactive material if he does not know precisely its microcurie rating. This fact becomes especially apparent when one is using luminous dials or other casually obtained sources of radiation.

Various charts and handbooks summarize the type and characteristics of radiation emitted from all known unstable nuclei. An example is the Table of Isotopes by D. Strominger, J. M. Hollander, and G. T. Seaborg.[1]

Iodine 131 has a relatively short half-life, 8 days. It emits 0.60 and 0.32 Mev maximum energy beta particles and gamma rays with energies approaching 0.08 and 0.64 Mev. These energies are in the medium range of radiation produced by the more commonly available isotopes. Phosphorus 32 (half-life of 14.3 days) emits only beta particles with a maximum energy of 1.7 Mev. These are relatively high energy beta particles. Sulfur 35 (87 days half-life), emits 0.17 Mev beta particles. These are relatively low energy betas. In fact, beta particles with much less energy are scarcely adequate to expose photographic emulsions unless in high concentrations or by very long exposures. Zinc 65 (250 days half-life) decays by electron capture, producing 0.32 Mev positive beta particles and 1.11 Mev gamma rays.

The data given above are representative of the information one needs to plan experiments using radioactive materials. Unless the information is well in hand before ordering isotopes, especially the short-lived ones, the material may decay before the experiments are underway or may lack the characteristics necessary to insure success for the experiments. The tendency of nuclear radiation to transfer energy to atoms with which it collides causes it to be potentially dangerous, but it is this characteristic that makes it useful and which is the basis of design of instruments or techniques of radiation study. Nuclear radiation, for example, is detected by its ability to register on photographic film or to affect specially designed instruments. Autoradiography is an example of the first process.

Principles of Autoradiography

The basic idea of autoradiography is to bring a sample, such as thin slices of biological materials, smears of fluid tissue, organs, organisms, or other objects containing radioactive isotopes into contact with a photographic emulsion which, after suitable exposure, is developed and fixed. The origin of the process can be traced directly to Becquerel's accidental discovery that a fragment of uranium ore lying near a photographic plate caused darkening of the plate even though the latter had been protected from light by opaque paper. As the accompanying photograph indicates, it did not take long for scientists to apply this new technique in their investigations (fig. 9).

The basic principle underlying autoradiography is that alpha particles, beta particles, gamma rays, or other nuclear radiations ionize molecules along their paths. This ionization leads to the chemical reduction of silver atoms in halogen compounds contained in the photographic emulsion in about the same way light acts on silver salts. Each silver atom struck by a "bullet" from a radioactive isotope parts company from its bromine or other halogen

[1] Published in the American Institute of Physics' *Review of Modern Physics*, 30: 2: 585, April 1958.

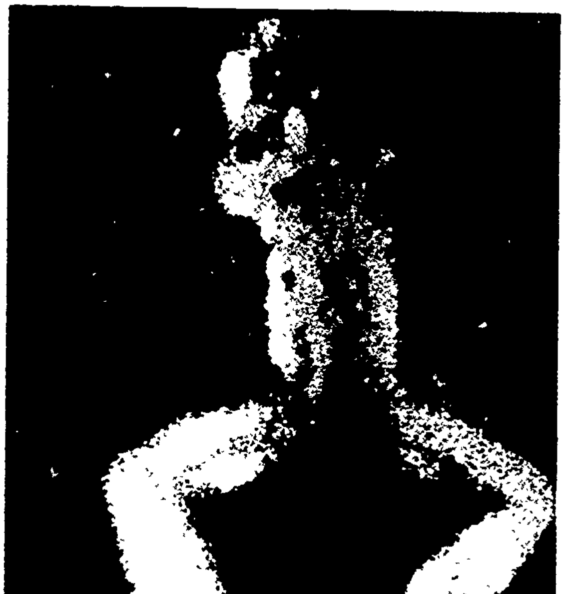


FIGURE 9.—Radioautograph of biological application of Becquerel's discovery (radioactivity of uranium salts). A frog, placed in a hermetically sealed jar to which was connected a tube of radium, was exposed to its vapors and on the 12th day died and was photographed.

atom and becomes an atom of free silver. Each of these free silver atoms, during the developing process, tends to accumulate crystals of silver around it. Thus, during this same developing process, those silver atoms which were missed by the alpha, beta, gamma, or neutron "bullets" are washed from the photographic plate. They will not thereby be reduced to free silver if the plate is exposed to light, a process that is necessary if we are to look at our radiographs. The silver atoms which were hit by "bullets," on the other hand, will remain on the plate to show us where the "shooters" found their targets. These targets form opaque silhouettes on the photographic film. A more advanced version of this process, in *Radiation Dosimetry*,[2] is the following:

The exposing agent transfers some of its energy to the silver bromide crystal, thereby raising the energy of one or more electrons into the conduction energy band of the crystal. These electrons then travel through the crystal until trapped in sensitivity centers, which might consist of impurities or deformities in the crystal lattice. The electrostatic potential set up about these centers brings into action a second process. A certain very small fraction of silver ions in the crystal is free to migrate through the crystal, the fraction depending largely on the temperature. These ions are attracted to the trapped electrons and neutralized to form silver atoms. Under continuing exposures these two processes continue until a group of silver clumps, containing one to several silver atoms each, are distributed throughout and on the surface of the crystal. These clumps constitute the latent image and catalyze, during the development process, the chemical reduction of the remainder of the ionic silver in the grain.

Tracers are so convenient to use whenever one wants to keep track of some element and watch what it does and where it goes that recent issues of many scientific journals report new examples of autoradiography in solving problems. Autoradiography, in turn, provides a permanent record of the tracing investigations. Some examples follow:

Using material from a patient poisoned by radium, Gettler and Norris in 1933 placed bone and other tissue ashes on photographic film which had been wrapped in black paper. The bones were found to be strongly radioactive, whereas the soft tissues were only weakly so.

Behrens and Baumann in 1933 sanded smooth one side of normal and pathologically changed bones and exposed the smooth side to film. They found that radioactive lead seemed to deposit itself in the bone depots where calcium tends to collect.

Arnon and coworkers in 1940, using radioactive phosphorus, traced the metabolism of inorganic phosphates in the leaves and fruits of the tomato plant. Leaves and slices of the tomato fruit, 2 to 4 millimeters thick, were placed on paraffined paper on top of X-ray films wrapped in black paper. A heavy glass plate held the samples close to the film. The developed films showed that radiophosphorus was accumulated in the seeds of green fruit, whereas only traces were found in ripe fruit and no concentration was found in ripe seeds. Also the conducting system of the leaves accumulated a large amount of radiophosphorus.

Pecher in 1942 used autoradiographs to show the accumulation of phosphorus 32 in the skeleton and soft tissues and of strontium 90 in the skeleton of whole mice. Thick slices cut from frozen animals were placed on film covered with cellophane, and the whole set-up kept in the refrigerator during the exposure.

Reinhardt in 1942 used autoradiography to determine the completeness of thyroidectomy. Tissue masses from animals which supposedly had had their thyroids removed and had been injected with radioiodine were

[2] Lane, Carroll J and Brownell, Gordon L., ed. New York 10 Academic Press, 1956.

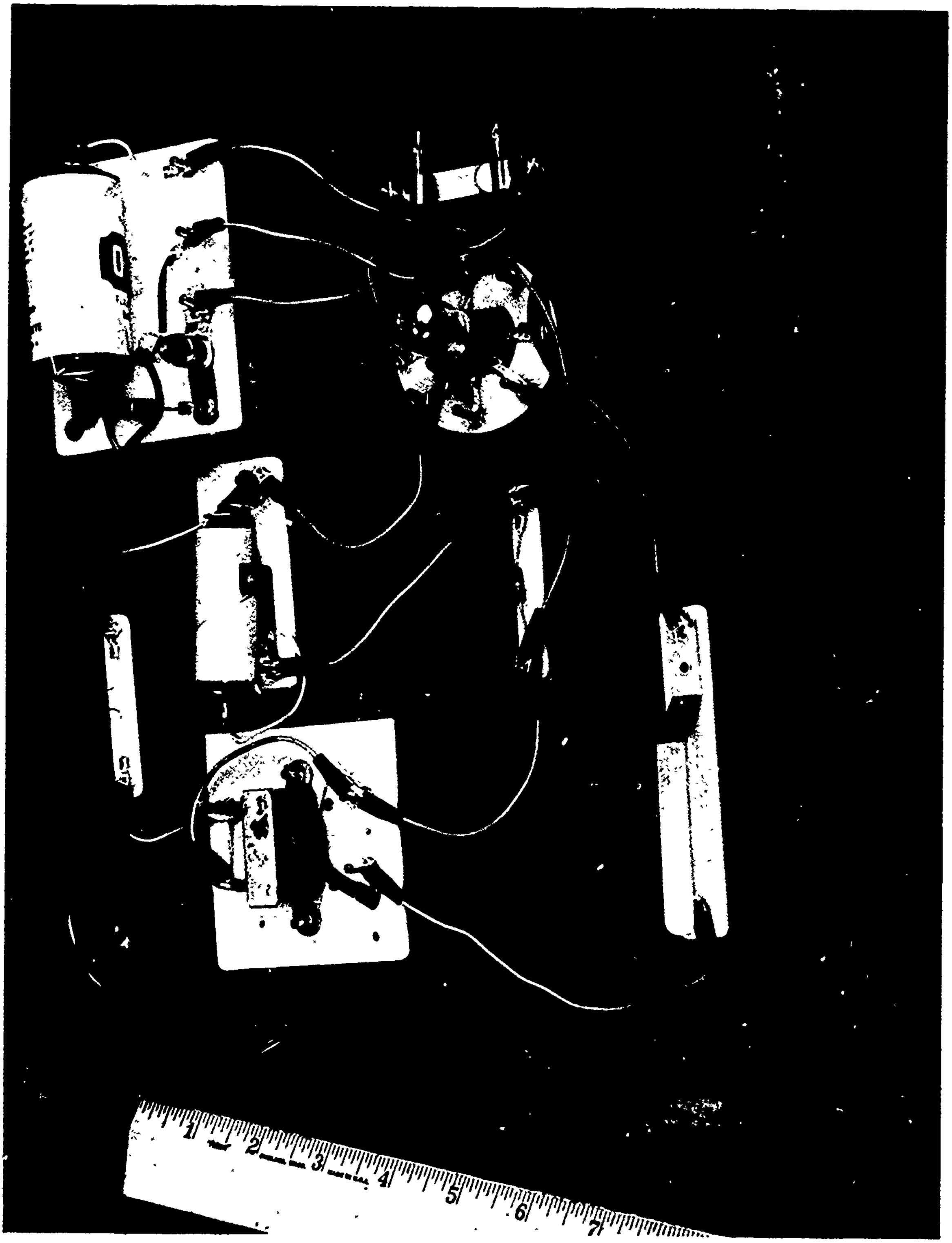


FIGURE 10.—Pegboard-model Geiger counter assembled by clothes-pin type connectors. Telegraph sending key makes and breaks current from battery pack, causing transformer to charge condenser, which maintains 300-volt charge on GM tube. Ionizing radiations entering tube release electrons to amplifying tube circuit sufficient to cause a click in earphone. (Circuit could be improved by moving GM tube near edge of baseboard and attaching rule or scale, thus placing sample to be counted at measured distance from tube. Stop-watch needed to tally count.)

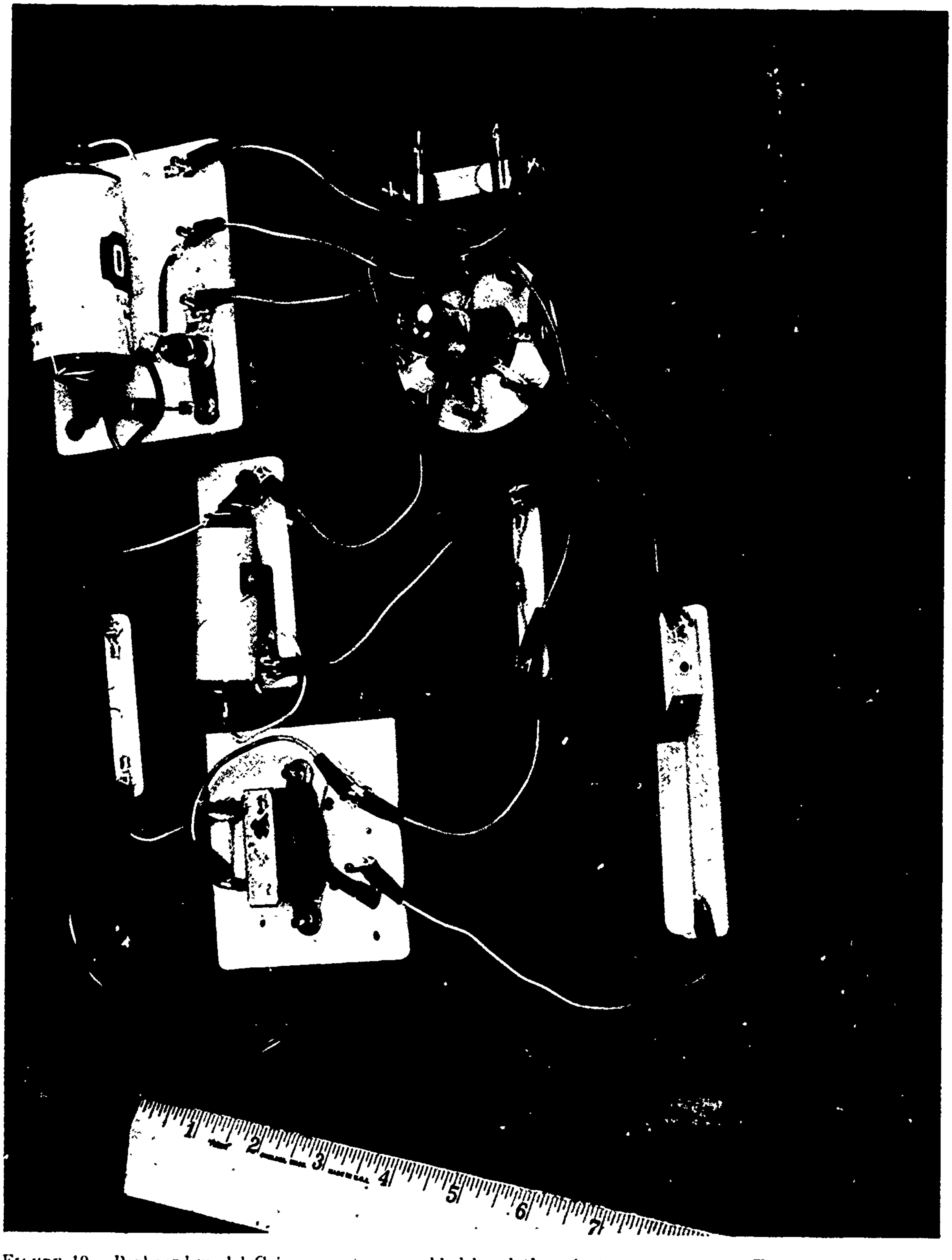


FIGURE 10.—Pegboard-model Geiger counter assembled by clothes-pin type connectors. Telegraph sending key makes and breaks current from battery pack, causing transformer to charge condenser, which maintains 300-volt charge on GM tube. Ionizing radiations entering tube release electrons to amplifying tube circuit sufficient to cause a click in earphone. (Circuit could be improved by moving GM tube near edge of baseboard and attaching rule or scale, thus placing sample to be counted at measured distance from tube. Stopwatch needed to tally count.)

keeping track of nuclear radiation with the use of a Geiger counter. Intelligent use of a Geiger counter, however, requires an understanding of the basic principles of its operation. One of the most effective ways to acquire an understanding of these basic principles is to put together some of the simple circuits described in science teachers' magazines or the semipopular electronics journals. For example, Orin Rodewald reports that one of his students in the Muskegon, Mich., High School achieved very satisfying results by following the suggestions which appear in an electronics magazine.[3] This circuit calls for a 300-volt Geiger tube, 1½-volt flashlight battery, a CK722 transistor, and other low-cost components. The accompanying photographs show two commercially available kits which suggest the types of "do-it-yourself" Geiger counters currently available.

Classroom models of Geiger counters designed especially for instructional purposes are available. The addition of such an instrument to the science laboratory equipment will make possible many interesting and effective teaching activities.

In connection with its efforts to provide the Nation with a group of people who are able to serve as radiation monitors in time of national emergency, the Office of Civil and Defense Mobilization cooperates with school people by making available the Geiger counters used to train radiation monitors. Not only are these instruments extremely rugged, but they are readily adaptable to classroom use. Several photographs throughout this publication show how the civil defense Geiger counter can be used in the classroom.

In many cases, teachers must learn to use a Geiger counter. The instrument guide sheet which follows may help accomplish this purpose.

[3] *Popular Electronics*, 4:90–93, June 1956.

Geiger Counter Instrument Guide Sheet

The heart of this instrument is a Geiger tube—a glass or metal cylinder which may be from a few inches to several feet in length and with a diameter less than that of a pencil to an inch or more. (Geiger counters designed for the detection of alpha radiation must have an extremely thin window. Mica usually is used for this purpose.) Two or three wires enclosed in an insulating and protective cable connect the Geiger tube to something that will change each count to clicks in an earphone, activate

FIGURE 11.—Commercial kit in assembled and unassembled form. The transformer relies upon an air gap to charge the condenser.

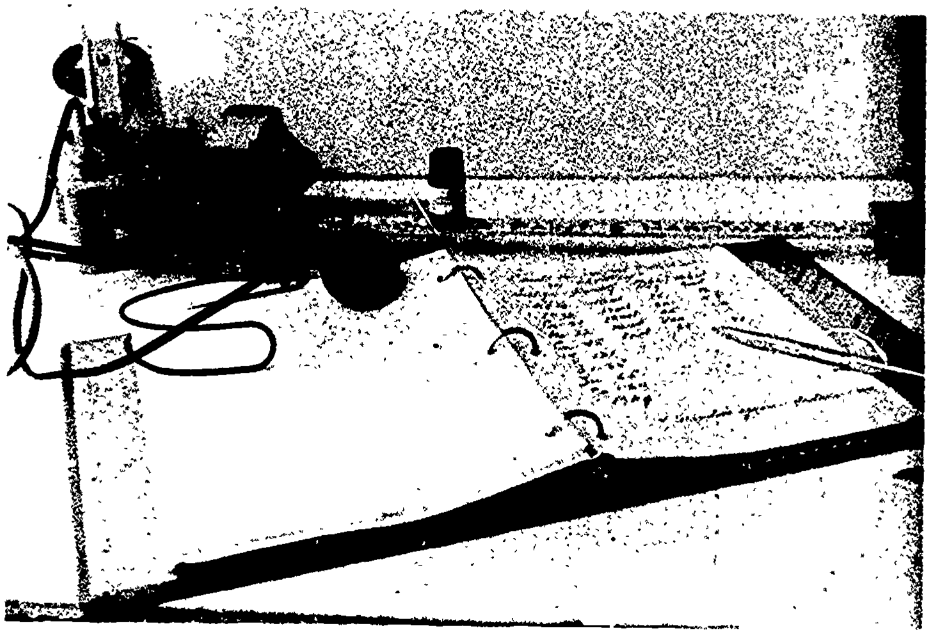


FIGURE 12.—Civil defense Geiger counter: probe taped to a wooden block fastened to a yardstick. Purpose: to estimate number of gamma rays from bottle of 10 microcuries of iodine 131.

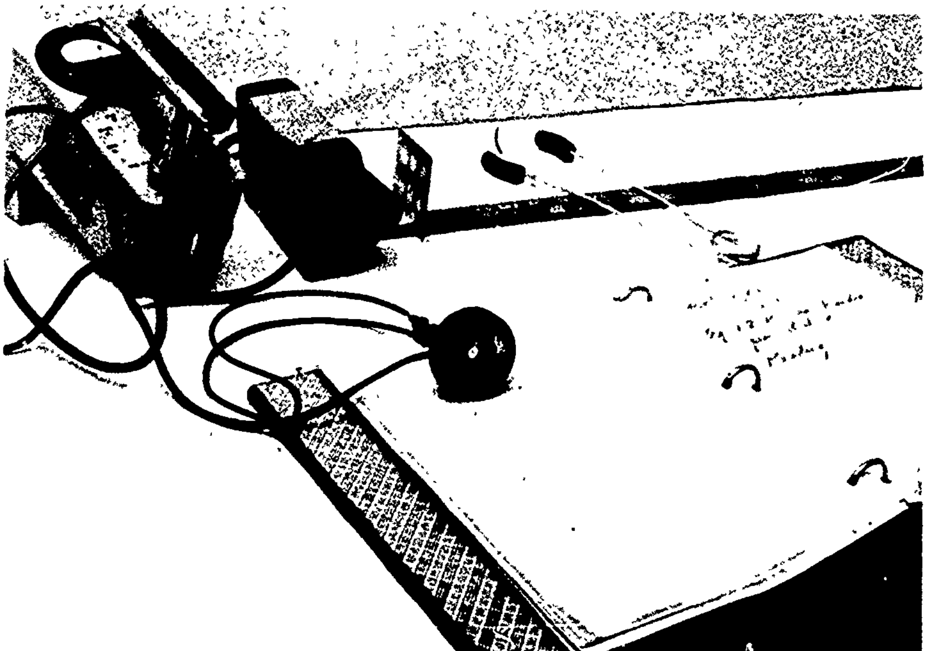


FIGURE 13.—Civil defense Geiger counter for observing the count from a test card on which are paper disks soaked with equal quantities of two isotopes of different half-lives.

21

a meter, or operate a mechanical counter. Portable instruments, more commonly used in monitoring radiation for radiological defense and other purposes, show a reading on a scale rather than activating ear phones, lights, or mechanical counters. The tube of a Geiger counter is usually mounted in a protective metal cylinder called a probe. The power source in portable models is made up of two or more 45- and 1.5-volt batteries. Newly developed transistorized Geiger counters use 1.5-volt batteries only. Usually the power source and indicating mechanism are put in the same container.

The Geiger counter will respond to any kind of radiation that has enough energy to dislodge electrons from the wall or window of the tube and ionize the gas molecules within the tube. The newly formed electrons pick up additional energy causing further ionization, and thereby forming more electrons in a continuous process. Finally, a large number of electrons is collected by a strongly positively charged wire in the center of the tube. Upon reaching the wire, the negative ions give up enough electrons to form a pulse of current in an outside circuit leading to an amplifier. The amplifier, in turn, operates a blinking light, headphones, or a mechanical counter. In some models, an ammeter reads the amount of the amplified current which, in turn, can be converted into equivalent counts per minute.

Questions and Answers

1. *Q. What happens when I turn the Range Control switch to the 1X position?*

   A. A positive charge of about 1,000 volts is applied to the collecting wire in the Geiger tube and the batteries begin to deliver voltage to the amplifying circuit.

2. *Q. Actually, what makes the needle move across the scale?*

   A. When any kind of ionizing particle enters the Geiger tube, a surge of electrical current flows through a small coil of wire that is in a magnetic field. The newly created magnetism within the coil is opposed by another magnetic field which causes the coil to turn. The indicating needle is fastened to this coil.

3. *Q. What fundamental principle is applied in the design of the Geiger counter?*

   A. There are several principles involved, but the most important one is that unattached electrons and/or gamma rays whizzing past gas molecules may ionize the molecules by removing one or more electrons or by being taken up by neutral atoms.

4. *Q. Will the Geiger counter wear out?*

   A. Yes, for two reasons among others. First, the batteries have a limited life; and second, the gas molecules within certain types of tubes can form only so many ions. Halogen tubes, however, are said to have an unlimited life.

5. *Q. Will each beta or gamma ray that impinges on the walls of the probe trigger a count?*

   A. If a beta particle has enough energy to dislodge electrons from the walls of the Geiger tube, it is almost sure to trigger a count. Not much more than one percent of the gamma radiation that passes through the tube, however, will interact with the molecules of the tube wall or of the gas in such a way as to produce a count.

6. *Q. Does each click of the counter mean that a beta or gamma ray has entered the counter?*

   A. No, the count could have been caused by a cosmic ray.

7. *Q. How can I tell whether a count was caused by a beta particle or a gamma ray?*

   A. Close the shield on the probe. Beta particles can't penetrate the thick metal shield.

8. *Q. When the shield is open, how can I tell a beta ray count from a gamma ray?*

   A. You can't. Nor can you be sure it wasn't a cosmic ray.

9. *Q. Provided the switch is on, is the Geiger counter always ready to count a beta or gamma ray?*

   A. Not quite. Most counters need a split second to register one count and recover for the next. For example, a ray that enters one type of counter less than 0.001 second after one that is being registered will escape recognition.

10. *Q. If I know how long it takes my counter to register a count and recover, can I correct readings accordingly?*

    A. Yes, use the following formula:

$$n_t = \frac{n_o}{1 - n_o t_r}$$

n_t—true count
n_o—observed count
t_r—resolving time

    For example, in the situation in Question 9, a reading of 100 counts per second would mean that the tube would have been "busy" 100 times during the second for a total time of 0.1 sec. During this time it would have missed about 11 counts.

11. *Q. What happens if I turn the switch to the 10X position?*

    A. Ten pulses are piled up on a condenser and only a proportional amount of current flows through the meter.

12. *Q. How about the 100X position?*

    A. Same story except this condenser holds 100 ordinary pulses.

13. *Q. What does it mean if my counter reads 0.04 mr/hr on the 10X scale but doesn't read 0.4 mr/hr on the 1X scale?*

    A. There are several possibilities. Perhaps one of the condensers is losing its original characteristics.

14. *Q. Can I still use my counter?*

A. Yes. You must, however, calibrate each scale separately.

15. *Q. How do I calibrate a Geiger counter?*

A. By recording some readings when you know or can calculate what it should read. A graph of these values will allow you to change any meter reading to the correct value.

16. *Q. How can I tell or calculate what my meter should read?*

A. Obtain a source of known intensity and use the inverse square law.

17. *Q. What is the inverse square law?*

A. The intensity of the radiation received from a point source (assuming none is lost on the way) decreases as the square of the distance increases.

18. *Q. Give me an example.*

A. If you move 4 times as far from a source, you will receive 1/16 as much radiation.

19. *Q. Where can I get a source of known strength?*

A. Accurately calibrated sources are hard to obtain. Check with your local civil defense office or university or industrial research radioisotope laboratory.

20. *Q. What does a source look like?*

A. There are several kinds. Some are small metal capsules shaped like pencil erasers, some are like metal buttons or slugs, and some are liquids or evaporated residues in small bottles. In any case, the supplier gives you the strength in curies at the time the source was made.

21. *Q. Why does the time make a difference?*

A. Because after each ray or particle is emitted there remain fewer rays or particles to be emitted. This process is called radioactive decay.

22. *Q. What do you mean "strength in curies?"*

A. The curie is the unit for measuring radioactivity. One curie is equivalent to 3.7×10^{10} disintegrations per second; about the number of disintegrations per second from one gram of radium.

23. *Q. Aren't there smaller units?*

A. Yes, millicuries and microcuries, the first equivalent to 3.7×10^{7} counts per second and the latter 3.7×10^{4}.

24. *Q. About what should my counter read if I hold it 1 foot from a 10-millicurie source?*

A. This depends on the kind and energy of the radiation the source produces.

25. *Q. How can I know that?*

A. Each element or isotope emits characteristic radiation. For example, P^{32} emits beta rays only, I^{131} emits both beta and gamma rays, and U^{238} emits alpha particles. This information is in handbooks and reference books.

26. *Q. Do all radioactive materials decay at the same rate?*

A. No. This too depends on the element or isotope involved. For example, the half-life of P^{32} is 14.3 days; for I^{131} it is 8 days, and for Co^{60} it is 5.3 years.

27. *Q. What does "half-life" mean?*

A. The time it takes for a source to decay to one-half its original strength.

28. *Q. Why use such an awkward unit as that to express the decay rate of radioactive materials?*

A. It's less awkward than any other unit when you realize that any atom is as likely to decay as any other atom of the same element or isotope. The life of a radioactive atom is not at all the same idea as the life of a plant or animal. Among living things we know that the older one of them becomes, the more likely it is to "decay." Physicists have no way to tell which atom in a group of atoms will be the next one to decay.

29. *Q. Does this mean that a 10-microcurie source of P^{32} would be less than one of 5 microcuries about 15 da[illegible] after it had been prepared?*

A. Yes.

30. *Q. Coming back to Question 24: Should my Geiger counter read 1.35×10^{4} counts per second if I use a 10-microcurie source of P^{32} that is 15 days old?*

A. Try it and see. But remember that you will have to collect all the beta rays being emitted.

31. *Q. How do I do that?*

A. You can't—a Geiger counter isn't built that way.

32. *Q. I still want an answer to Question 24.*

A. The answer depends on several things. Some of the beta particles spend their energy ionizing air molecules along the way and never reach or enter the window of your counter. If the P^{32} is a point source, its beta particles fly out evenly in all directions through a sphere that becomes larger and larger as you move from the source. One foot from the source, for example, the particles would be distributed more or less evenly over a sphere with an area of about 290 square inches. If the window of your counter is only about 1½ square inches in area, it should collect only about 1/200 of the beta rays being emitted.

33. *Q. You mean my question can't be answered.*

A. At least we can say that it won't be more than 68 counts per second.

34. *Q. That's not much help. Let's put it this way: If I were to have to run through a no-man's land where rifle slugs are whizzing by, bazooka rockets whistling about, and hand grenades being tossed around, I would like to know my chances of getting through alive.*

A. Right. And in your no-man's land, as in a radioactive field, it would be risky business to go in and actually count the things that worry you.

35. *Q. Even trying to judge how dangerous the place is by going in there for a brief sampling also would be too dangerous, wouldn't it?*

A. You're right; so let's try the indirect approach. If you know how much noise a given number of rifle shots, rocket, and grenade explosions make, you could estimate the danger in the no-man's land by safely standing on the sidelines and just listening.

36. Q. *Let's come back to gamma, beta, and alpha particles: we can't hear them.*

A. No, but we do know how to get them to develop electrical currents. Put your Geiger counter in some radiation field where you know how many beta and gamma rays are whizzing by, record the readings on your meter, and from then on you can exchange your readings for estimates of the numbers of gamma and beta rays actually present.

37. Q. *Give me an example.*

A. Suppose you have a 10-millicurie source of Co^{60}. Handbooks show that 1 millicurie of this isotope produces 1.59 milliroentgens per hour at 1-yard distance. Your 10-millicurie source would produce 15.9 mr/hr at 1-yard distance. Using the inverse square law you can calculate the values expected at other distances. You can then exchange whatever your meter reads for what you know it should read.

38. Q. *Wait a minute. Why did you switch from curies and disintegrations per second to milliroentgens per hour?*

A. First, that is the way the meters on some counters read. This is so because civil defense workers and research scientists need to know the effects of gamma and beta radiation. Since these effects are almost identical to those of X-rays, the X-ray measuring unit, the roentgen, is used.

39. Q. *But what would the reading 15.9 mr/hr really mean?*

A. A roentgen is defined as the quantity of gamma or X-radiation needed to produce a specific number of ions in air. If a chest X-ray calls for an exposure of 1 roentgen, the technician may adjust the machine to deliver 7,200 r/hr and give a ½-second exposure. A civil defense worker who had to stay in a radiation area of 15.9 mr/hr intensity would accumulate .159 roentgen if he worked there for 10 hours.

40. Q. *Now suppose that my counter reads 32 mr/hr when I hold it 1 yard from a 20-millicurie source of Co^{60}. What does this mean?*

A. First, we know that there are about 74,000,000 disintegrations per second in a 20-millicurie source of Co^{60}. Second, the formula

$$\text{mr/hr}=\frac{1.59 \text{ mc. of } Co^{60}}{(\text{distance in yds})^2}$$

tells us that a 20-millicurie source should produce 31.8 mr/hr at a distance of 1 yard. Combining these two facts, we can say that of all the gamma rays that shoot from the Co^{60}, at a distance of 1 yard they are dense enough to cause a radiation intensity of 31.8 mr/hr.

41. Q. *But my meter reads 32 mr/hr. Where did the other 0.2 mr/hr come from?*

A. This may be caused by a number of things. Perhaps your counter simply reads too high. It could be picking up stray radiation. Perhaps the source was actually stronger than the label indicated.

42. Q. *Is there any way to adjust my counter to make it read what it is supposed to?*

A. Yes. See your Instruction Manual.

43. Q. *If I want to check something that may or may not be radioactive, how do I know that my counter is working?*

A. Hold the probe close to a luminous watch dial. There is also a beta radiation source under the nameplate on some Geiger counters.

44. Q. *What do I do if my counter isn't working?*

A. Follow the suggestions under Preventive and Corrective Maintenance in your Instruction Manual. Remember, however, that this is a poor instrument to use to learn how to be an electronics expert.

Understanding Electronic Circuits

Electronic circuits are difficult for some students to understand; and students progress slowly in the use of any electronic instrument until its circuits *are* understood. Charles A. Culver provides some material[4] that has been adapted to a teaching aid that holds promise of helping students understand electronic circuits. The aid follows:

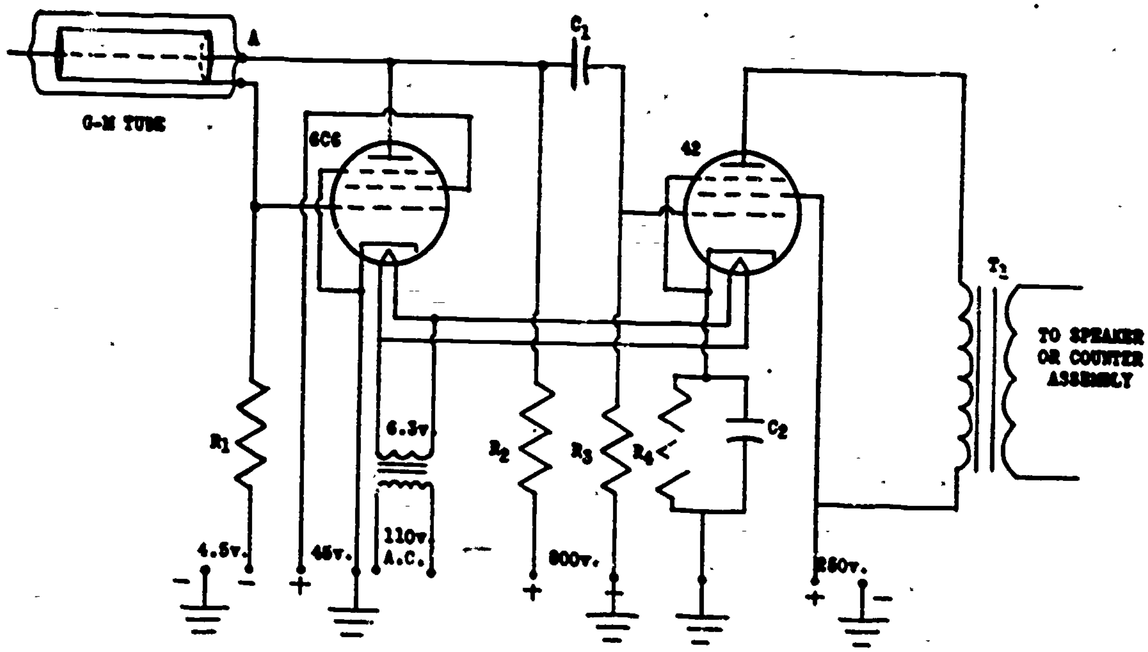
The first time one sees a diagram of an electronic circuit he is likely to be frightened by how complicated it seems. Even an electronics engineer might feel the same way upon seeing for the first time a woman's kitchen recipe or a set of blueprints for making a rose trellis or even the plans for a model airplane. Each of these is simply a shorthand way of showing how something is put together. As soon as you know what each symbol means it is quite easy to see how the parts go together.

To gain practice in understanding an electronic circuit, let's look at a typical example of the kind of wiring and the parts needed to make a Geiger counter tell us whether it is near a source of beta, gamma, or other radiation to which it can respond (see fig. 14).

Before we try to decipher what this all means, let's recall briefly what a Geiger counter does. In general, it simply picks up very tiny bits of electricity and then multiplies each into a large enough package to cause clicks in earphones or a loudspeaker.

Now let's look at the Geiger counter circuit, a part at a time. Try to follow some imaginary electrons from the junction marked "A" through the circuit and back to the starting point. Do you see how they could be "pulled" by the battery down the circuit, through the battery, through the ground, and back up to the Geiger tube? Do you also see that they would have to pass through the two resistances, R_1 and R_2 and jump the gap between the central wire and surrounding cylinder in the Geiger tube? It is this gap that is the heart of the Geiger counter. The battery places a charge on the central wire that is just about, but not quite, strong enough to allow electrons to jump the

[4] In an article, "Construction and Use of a Geiger-Mueller Counter Assembly," *Science Counselor*. 12:3:87-89; 104, September 1949.



R_1 - 2 to 10 x 10^6 ohms, 1 watt

R_2 - 2 x 10^6 ohms, 2 watts

R_3 - 0.5 x 10^6 ohms, 1/2 watt

R_4 - 400 ohms, 2 watts

C_1 - 50 to 100 mmf, high voltage

C_2 - 10 to 25 mf at 25 to 50 volts

V - DC counter threshold + 100 v.

T_1 - Output transformer

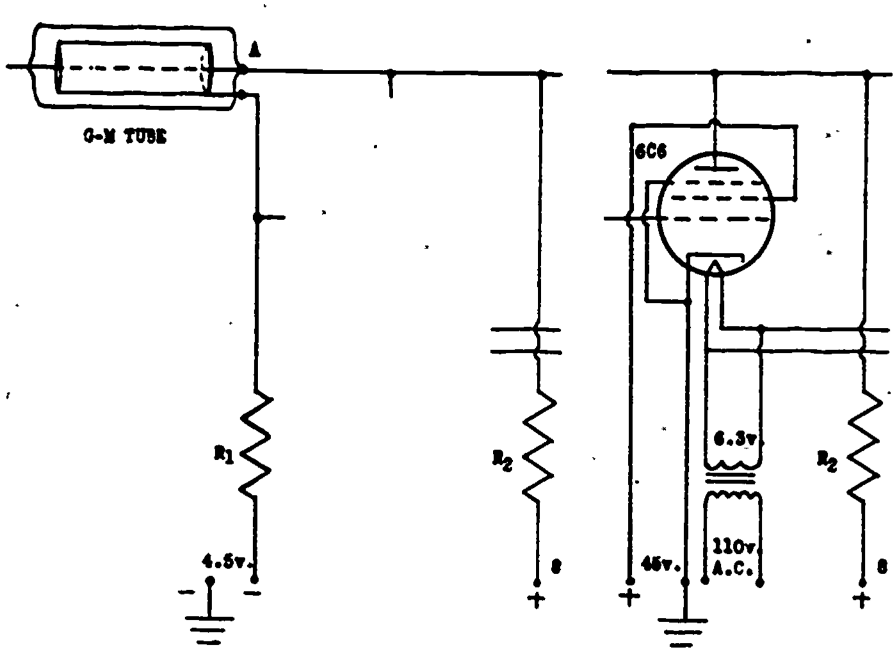


FIGURE 14.— The complete circuit of a Geiger counter can be more easily studied if broken down into portions.

gap. When any charged particle or ionizing ray enters the tube, a whole surge of electrons will jump the gap.

When this surge of electrons begins to flow through the Geiger tube, why doesn't it continue? The answer is that the electrical discharge through the tube is terminated by action of the quenching gas—either organic vapor or halogen gas—in the tube. The exact manner in which the quenching action is performed is not known.

Now let's look at the 6C6 tube in figure 14. When the current from the 6.3-volt source heats the tube's filament and electrons are boiled off, do you see why they don't jump directly to the positive plate? Do you see how the negative grids would repel them? Do you also see how the negative grids would become less of a barrier while the surge of current discussed in the previous paragraph was flowing? On this basis, the 6C6 tube serves as a valve that allows a larger pulse of electrons to flow through the circuit each time one of the smaller pulses comes from the Geiger tube. Not only do these larger pulses help quench the flow of electrons through the tube but they can also be fed into an amplifier tube, eventually to operate a loudspeaker or a set of earphones.

These larger surges of current from the 6C6 tube pass through the condenser C_1 and on to the grid of the 42 tube. Do you see how this grid can now serve as a gate or valve for even larger currents between the filament and plate of the 42 tube? In this case a 250-volt source is forcing electrons through the tube and, once the negative grid in the tube no longer blocks their flow, they will pass through the coil of a transformer and be stepped up enough to operate a loudspeaker or some kind of counting machine.

With this much of a start, see whether you can trace the various paths electrons might follow throughout the Geiger counter circuit. Keep in mind what would be most likely to happen to them as they encounter each resistance, condenser, filament, grid, or other part.

Adapting Geiger Counters

Continued use and increasing familiarity will allow teachers to adapt Geiger counters to whatever needs they encounter in their own classrooms. For example, Clifford Malone, a teacher in the West Side Junior High School at Groton, Conn., has converted the civil defense Geiger counter to produce audible and visual signals for group demonstrations. He disconnected the earphones from the cord leading to them and attached the cord to the microphone jack and plug of a record player, tape recorder, public address system, or movie projector. With the tape recorder, for example, in recording position, the glow bulb gave a strong flash each time the Geiger counter clicked.

Isotopic Effects on Films and Geiger Counters

This is an effective exercise in teaching students to handle small quantities of radioactive materials and to acquaint them with the characteristics of their radiation. Get freshly calibrated 1-, 10-, or 50-microcurie quantities of such isotopes as phosphorus 32, iodine 131, cobalt 60, sodium 22, calcium 45, sulfur 35, or other generally licensed isotopes. All isotopes should be in solution and diluted to uniform activity per milliliter solution. If they are delivered in dry form, use a dilution of one microcurie per milliliter solution. Most teachers will have to be satisfied with an approximation of this factor.

Radioactive Materials From Precalibrated Sources

If the available isotopes are of different half-lives and are not freshly calibrated, simplify the calculations required to equalize quantities of radioactive materials by using the table[5] below. Two problems and their solutions are given after the table.

TABLE 1.—*Data to simplify calculations for equalizing quantities of radioactive materials*

Time expressed as percent of half-life	*Percent remaining*	*Reciprocal*
0. 05	0. 965	1. 035
. 10	. 933	1. 072
. 15	. 900	1. 109
. 20	. 870	1. 149
. 25	. 841	1. 188
. 30	. 811	1. 231
. 35	. 784	1. 275
. 40	. 759	1. 318
. 45	. 732	1. 365
. 50	. 706	1. 415
. 55	. 684	1. 464
. 60	. 660	1. 515
. 65	. 637	1. 570
. 70	. 616	1. 624
. 75	. 595	1. 682
. 80	. 574	1. 741
. 85	. 554	1. 802
. 90	. 535	1. 866
. 95	. 516	1. 933
1. 00	. 500	2. 000
1. 2	. 435	2. 298

[5] Set up by G. H. Rees.

TABLE 1.—*Data to simplify calculations for equalizing quantities of radioactive materials*—Continued

Time expressed as percent of half-life	*Percent remaining*	*Reciprocal*
1.4	0.379	2.641
1.6	.330	3.034
1.8	.287	3.490
2.0	.250	4.000
2.25	.210	4.759
2.50	.177	5.641
2.75	.148	6.753
3.0	.125	8.000
3.5	.088	11.36
4.0	.062	16.00

Problem: The half-life of Na^{24} is 15 hours. A 100-microcurie sample will have what activity after 3 hours?

Solution: 3 hours = 3/15 or 0.2 half-life. Opposite 0.2 in the first column, find the percent remaining = 0.87. The activity of the sample is 100 × 0.87 = 87 microcuries.

Problem: A sample of Na^{24} has a count rate of 1,000 counts per minute at 3 p. m. What was its count rate at 9 a. m. the same day?

Solution: The time elapsed was 6 hours or 6/15=0.4 half-life. Opposite 0.4 in the first column, find 1.318 in the reciprocal column. (Since we are figuring back to an earlier time, the factor must be larger than 1.0.) The count rate is 1,000 × 1.318 = 1,318 counts per minute.

As soon as the uniform activity solutions are ready, prepare low-level dry sources of each solution by soaking small paper disks in the solutions. Dry each disk, paste it to a larger labeled cardboard, and then wrap the cardboard with transparent plastic. It is well to prepare several disks from each solution at the same time. Each disk can be placed separately at an appropriate distance from the Geiger counter tube to observe its effects on the Geiger counter.

To compare the effects of the various isotopes on film, mount several different kinds of disks on a test card and then wrap the test card with transparent plastic. A piece of photographic film, cut to just cover the test card, can then be placed over the test card, the preparation wrapped with lightproof paper, placed between the pages of a book to provide adequate contact pressure, and left for an appropriate exposure time.

There are advantages to be gained from using paper disks from an ordinary punch for notebook paper. The disks are small and can be mounted on a 35-millimeter card so that the individual pieces of film, after exposure and development, can be framed with ordinary 2″ x 2″ slide binders for classroom projection purposes.

Additional information about this exercise can be obtained from the captions of the accompanying photographs (figs. 15 and 16).

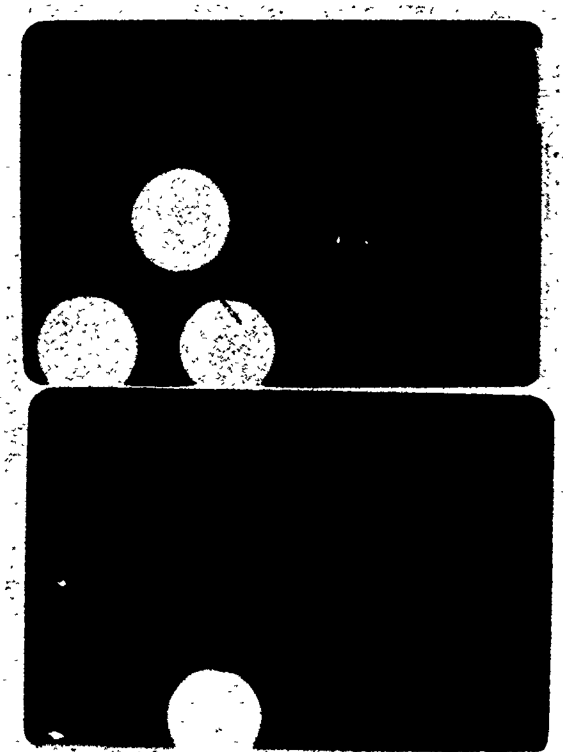


FIGURE 15.—Paper disks were soaked in 1 microcurie per milliliter solutions of 9 different isotopes. After drying, the individual disks were glued to a 35-millimeter card, wrapped with transparent plastic, and placed in contact with no-screen X-ray film for 11 hours. The top print shows the effect on the film 4 days after the isotopes were calibrated. The bottom print shows the effect of the same test card on a new piece of film 45 days after calibration of the isotopes. Development procedures were approximately equal in both cases to insure equal film densities. The 9 isotopes from top left to bottom right were calcium 45, chromium 51, cobalt 60, iodine 131, phosphorus 32, rubidium 86, sodium 22, sulfur 35, and zinc 65. (NOTE: There are reasons to believe that the chromium 51 used in this exercise was not accurately calibrated.)

How Radiation Passes Through Materials

Paper disks and test cards similar to those in the previous exercise are useful in the observation of the shielding effects which various

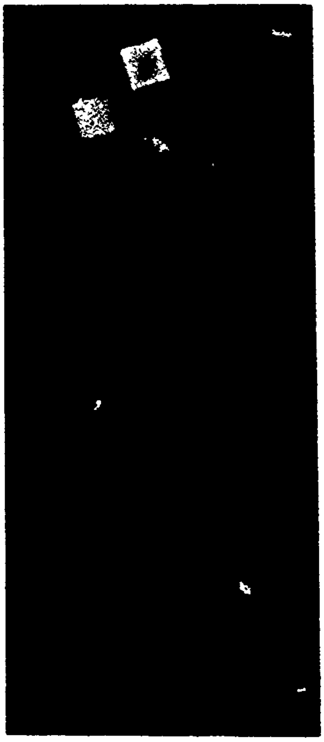


FIGURE 16.—Small squares of blotting paper were soaked in 1 microcurie per milliliter solutions of 9 isotopes. The squares were dried, pasted to a 2¼″ x 2¼″ test card, and wrapped with transparent plastic. The test card, in turn, was mounted over the film opening in a box camera. The camera was loaded with Kodak Tri-X film and the various frames rolled by for increasing exposure times. The top print is from a 60-hour exposure and the bottom print from a 13-hour exposure. Beginning at the bottom right and working up around and back down are the isotopes, iodine 131, chromium 51, cobalt 60, calcium 45, sodium 22, phosphorus 32, rubidium 86, sulfur 35, and zinc 65.

materials have on nuclear radiation. Known thicknesses of various materials can be simply inserted between the test cards and a Geiger counter tube. The lead foil that comes in dental film packs is approximately 0.06 millimeter thick and weighs 0.07 gram per square centimeter. Ordinary lightweight kitchen aluminum foil is approximately 0.0007 inch thick and runs about 0.0046 gram per square centimeter. Plumber's lead comes in sheets approximately one-sixteenth of an inch thick and runs 4 pounds per square foot.

The accompanying photographs show how photographic film can be used to observe the shielding effects of various materials (see figs. 17 and 18).

Nuclear radiation's loss of energy as it passes through the air, becomes complicated by the inverse square manner in which its density is reduced as it travels farther from the source. Using a Geiger counter under a partial vacuum becomes something of a problem, but one which an ingenious person may be able to solve. The accompanying photographs show how film can be used to observe the effects of increasing lengths of air paths. This procedure may yield very interesting results when repeated under a partial vacuum and the effects compared with those obtained under ordinary conditions.

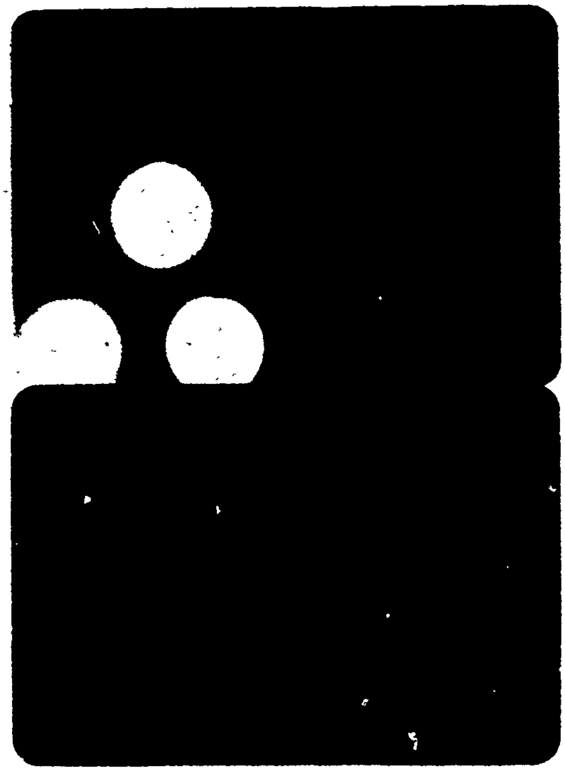


FIGURE 17.—A test card similar to that used in figure 15 separated from no-screen X-ray film by 13 sheets of lead foil. The top print shows the effect of a test card without lead shielding. The bottom print shows the effect of 16-hour exposure with three sheets of lead foil between the test card and the film. The high energy beta particles from the phosphorus 32, rubidium 86, and sodium 22 were able to penetrate the lead foil This shows clearly, however, that the beta particles from these isotopes have a range of energies with only the very highest energy particles getting through the lead foil.

Atomic and Subatomic Dimensions

To gain a realistic and working knowledge of the radiation which accompanies disintegration of unstable nuclei, one must expand his ability to grasp exceedingly small and exceedingly large dimensions. Wolfgang Pauli [6] shows how easily our concept of dimensions can influence our understanding of things in our environment.

To try to visualize some of these things, imagine a person standing on the sand at the edge of a pond, then shrinking to about 1/250 of an inch. As he shrinks, the treetops fade from sight, the pond becomes a sea, the sand becomes a plain of boulders, each over a thousand feet high—and he is standing on one of them. He tries to walk, but the air would seem thick, almost fluid, as if he were walking in water. At the edge of his boulder, he tries to drop a stone to test the depth of the pit but the stone floats in the air until a gust whisks it away. He may find that he stops breathing, because he is absorbing all the oxygen he needs for his reduced volume through his skin. But he becomes intolerably thirsty, since his increased relative surface loses moisture at many times the normal rate. Actually, he would become a desiccated mummy, but we may compromise by assuming that he is merely thirsty. Reasoning from the behavior of the stone, he figures he too can float down to the water to get a drink—and he does. But try as he will, he cannot break through the tough surface membrane of the water, on which he slips and slides as on elastic ice. So he comes ashore again and finds a mountainous dewdrop which he tries to pierce with a straw. If he succeeds in doing so, the water might at once suck the straw and the man into its crystal interior, holding him helplessly captive, too weak to cope with molecular forces.

[6] In his *World of Life*, p. 25. New York: Houghton Mifflin Co., 1946.

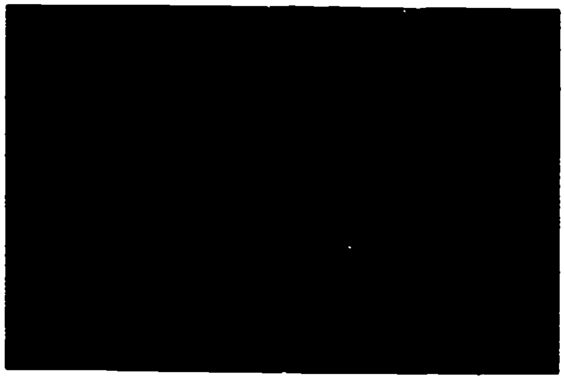


FIGURE 19.—A small ball of cotton fastened to a toothpick was dipped in phosphorus 32 and mounted on insulating wall-board in the bottom of a shoebox. Pieces of film behind sheets of lead containing three holes were mounted at increasing distances from the phosphorus 32. The two prints show the effects of the beta particles on the film at distances of 1 inch and 4 inches through a 48-hour exposure.

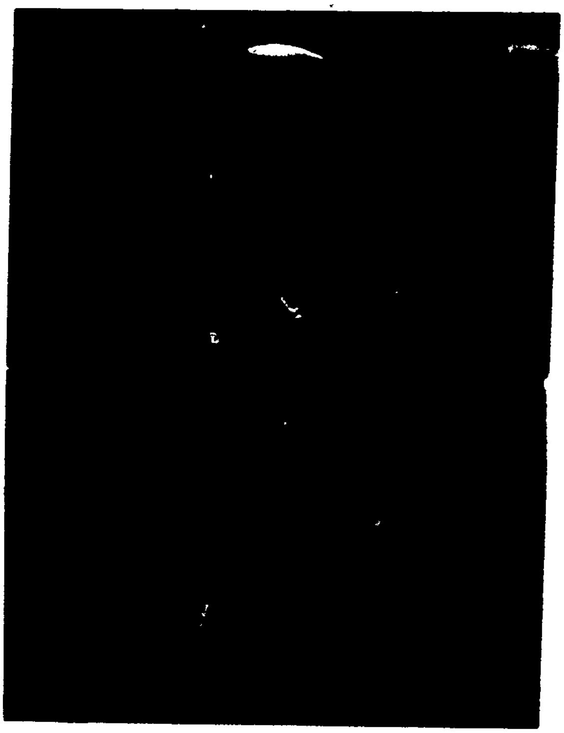


FIGURE 18.—Paper disks soaked in sulfur 35, calcium 45, and phosphorus 32 represented low, medium, and high energy beta-emitting isotopes. For the top print, the paper disks were allowed to project over the edge of a pack of lead foils which separated the paper disks from a piece of film. The film was exposed for 23½ hours. The 1 microcurie per milliliter solutions of the isotopes were 30 days old. In the bottom print, the paper disks were separated from the film by 10 sheets of aluminum foil and given a 12-hour exposure.

It was only by developing a realistic concept of the dimensions of atoms and subatomic particles that physicists were able to develop a concept of atoms. A good example is found in the work of E. Rutherford, in 1906. Two of his students, Geiger and Marsden, tried to determine the number of alpha particles expelled from one gram of radium. While experimenting, they were puzzled to see "some of the alpha particles can be turned within a layer of 6×10^{-5} centimeters of gold to an angle of 90 degrees, and even more." Familiar as he was with the high velocity and mass of alpha particles, to Rutherford this was "about as credible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you." This led him to abandon the idea that the particles making up an atom were evenly distributed throughout the atom. He came to see the atom as containing "a central charge distributed through a very small volume." Thus we can understand that the concept of an atomic nucleus reflects Rutherford's ability to think in atomic particle dimensions. Furthermore, many of the phenomema of nuclear science are totally confusing unless students understand the relation between actual particles and space in the structure of material.

How can we explain to the student that gamma rays, beta particles, or other atomic radiation can go through what is apparently solid stuff and not, necessarily, leave a hole? First, what do we mean by "leaving a hole?" For example, to make a hole in a flock of flying geese, must a bullet actually hit a goose? Let's assume that is what we mean. All we have to do is convince our student that the atoms which make up his body are actually flocks of very small geese flying around in very, very large flocks. For an average atom, about one ten-trillionth of it is actually material and the rest is simply space bounded by rapidly moving particles. In other words, for each goose in a flock, there would be room for about 9,999,999,999,999 other geese. This means that if we were to shoot a goose-sized bullet at the exact center of such a flock of geese we would have one chance in about 10 trillion of hitting a goose.

We must recognize, however, that many atomic bullets do not pass through the materials they encounter just as all the hunter's bullets don't miss the flying geese. Atomic bullets that are "near misses" can dislodge electrons from the outer orbits of atoms, losing a little energy in the process. The hunter's bullets can knock feathers from a goose without actually penetrating the goose's body. The goose that has lost some feathers will, of course, feel and behave differently from one that has not had such a close call. Atoms that have lost electrons are called "ions" and they, too, behave in a manner different from that of normal atoms.

Laboratory exercises of the type discussed in this chapter help one realize atomic and subatomic dimensions. Consider, for example, figure 15. One can see how the high energy beta particles from phosphorus 32 range far from the paper disk, causing a fuzzy spot to appear on the film. Low energy beta particles, such as those from sulfur 35, either fail to get out of the paper disk or fail to penetrate the transparent film between the paper disk and the film. In no case do they range far into the emulsion of the film.

Ionizing Effects of Nuclear Radiation

To handle radioactive materials intelligently, confidently, effectively, and safely, we must forever keep in mind that the radiation which they produce is capable of ionizing atoms. Chemists, especially biochemists, realize that ionized atoms and ionized portions of molecules are quite different from nonionized materials. Molecules which exist in one form in the body may exist in an entirely different form if they are broken up by ionizing radiation and allowed to recombine. If the newly formed compounds are physiologically significant and exist in large enough concentrations, the radiated individual will show symptoms of radiation sickness. The nature of these symptoms will depend upon what body tissues and organs have been affected, how seriously they have been affected, and the function they perform in the total body process. Since nuclear radiation can demolish or rearrange the structure of almost any molecule, to the extent that future physiological processes depend on gene-controlled hormone or enzyme production, the effects of radiation on any individual may show some time after exposure to it. Repetitive doses may show more marked accumulated effects on some physiological processes than on others.

The widely publicized genetic effects of nuclear radiation carry additional importance. To the extent to which individual genes and/or complete chromosomes within the germ plasm are demolished, damaged, or rearranged, variations in the functional or anatomical traits carried by these genes or chromosomes will occur in offspring inheriting the changed gene or chromosome.

It is very difficult to predict the quantity of abnormal molecules that will be produced as a result of ionizing radiation or to predict physiological effects of the newly formed materials. At the time of preparing this publication, there is widespread disagreement among scientists on these matters. When faced with this situation a teacher sometimes can meet his responsibilities to his students by helping them analyze data available from experimental studies. Two examples of how this may be done follow:

The first is an account of Johanna Blumel's research on the action of radioactive phosphorus in Drosophila. It is followed by an interpretation-of-data study exercise. The second experimental study, reported here in tabular form, compares the number of offspring produced by female rabbits mated to control, versus irradiated, males. It, too, is followed by an interpretation-of-data study exercise for students.

How large doses of beta radiation affect fruit fly offspring.—The purpose of Johanna Blumel's study was to determine what happens to the offspring of fruit flies that have been given large doses of beta radiation. She found some most unusual and interesting mutations among the second generation.

Pairs of mature flies from stock bottles were placed in shell vials containing a radioactive medium. This culture medium had been prepared by adding approximately 3.2 milliliters of radioactive H_3PO_4 (containing about 1.54 microcurie/milliliters at the time of its use) to 300 milliliters of the standard Drosophila culture medium. The radioactivity of the original volume was determined with a Geiger counter, and was found to be 265,000 counts per minute/milliliter. The medium was distributed among 50 vials, each containing approximately 6 milliliters. Twenty-five vials were used to test D. melanogaster, and 25 to test D. virilis.

All 25 vials of D. virilis were fertile and produced the average number of pupae. However, only 39 females and 25 males hatched. Without exception, these imagines were morphologically abnormal. The abnormality pertained mostly to the eyes, legs, abdomen, wings, and genitals. Twenty-one females and 17 males survived to be tested for fertility to untreated flies. Of these only 7 females were found fertile.

The low hatch was obviously caused by the lack of ability of the treated imagines to emerge. Dissections of unhatched pupae showed fully formed flies with similar or more extreme abnormalities than those just described.

The number of adult offspring from the seven treated D. virilis females was very low.

The D. melanogaster flies were not tested for mutations. Of the treated flies tested for fertility, 78 out of 130 females and 56 out of 109 males were fertile in pair matings to nonirradiated flies. These produced the normal number of progeny.

Beta radiation proved to be an excellent source of irradiation for Drosophila virilis. The mutations obtained from this treatment are as follows: an eye color, either apricot or an allele of apricot (sex-linked); a wing character, cut or cutlike (sex-linked); scute: extra scutellar bristles; a wing character with unusual venation; another wing character (sterile) in which the wings were folded and rotated 90°; extremely knobby eyes (both males and females also sterile). Several different mutations of the same general type produced flies with extended wings and added effects causing sterility. Among the progeny of yet another tube was a male with one apricot-like eye and the other eye a mosaic of areas respectively normal and apricot-like; when mated, no progeny was obtained.

Perhaps the most unusual and interesting mutation found was of aristapedia-like character. The 10 mutant flies examined (5 males and 5 females) had leg-like aristae, extended wings, crippled legs, and all bristles reduced to the size of hairs. They were nonviable and died soon after emergence.

The mutant is retained by crossing the heterozygotes. Cytological examination of the salivary gland chromosomes of such heterozygotes showed an inversion in the second chromosome. Whether or not this rearrangement is independent of the mutation has not been determined. The spineless aristapedia locus in D. melanogaster is located in the right arm of chromosome 3, which is analogous to chromosome 2 in D. virilis. This coincidence of mutation and rearrangement in the same chromosome suggests that there is a connection between the mutation and the rearrangement.

The present investigation indicates that radioactive P^{32} not only produces mutations in Drosophila virilis, but also chromosomal rearrangements. The tolerance to irradiation with radioactive P^{32} during development is high.

Interpretation-of-data study exercise.—Use the following key (A, B, C) to show that you understand and can interpret Johanna Blumel's study. Decide for yourself what are some of its implications.

A. The statement agrees with the report of the experiment.

B. The statement disagrees with the report of the experiment.

C. The statement neither agrees nor disagrees with the report.

1. During the growth of the experimental flies, the eggs, larva, pupae, and adults would be subjected to beta radiation from both outside and inside their bodies.
2. Mixing radioactive phosphorus in the culture medium used to raise fruit flies tends to cause the flies to become sterile.
3. Radioactive phosphorus seems to affect fruit fly pupae more seriously than it does the larvae or adults.
4. Any genetic effects produced by radioactive phosphorus on adult flies do not show up until the second generation of their offspring.
5. The aristopedia-like mutation must be a dominant trait.
6. The character involving one apricot-like eye and one mosaic eye must be a sex-linked, recessive trait.
7. It would have been much more difficult to inter-

pret the results from this experiment if Blumel had used ordinary fruit flies collected from an overripe melon or other place where these flies gather.

8. The beta radiation from phosphorus 32 seems to affect whole chromosomes just about as often as they affect single genes.
9. It was very probable that similar degrees of exposure to beta radiation would produce as many mutations in other species of animals or plants.

Do X-rays affect the fertility of rabbits?—The following two tables on fetal mortality and fertility in normal female rabbits mated to control males versus irradiated males present data based on experiments by R. L. Murphree, W. M. Whitaker, J. L. Wilding, and J. H. Rust. After the tables is an exercise to give practice in gleaning information from data presented in the form of a table.

TABLE 2.—*Fetal mortality in normal female rabbits mated to control males versus irradiated males*

Treatment of males	Number of matings	Corpora lutea		Fetuses			Percentage of eggs missing	Percentage fetal loss
		Number	Average per female	Number alive	Average number in potential litter [1]	Number dead		
1	2	3	4	5	6	7	8	9
Control	7	74	10. 6	59	8. 4	0	20. 3	0. 0
All irradiated males	26	318	12. 2	146	5. 6	71	31. 8	32. 7
100 r	6	92	15. 3	46	7. 7	18	30. 4	28. 1
200 r	14	163	11. 6	74	5. 3	34	33. 8	31. 5
300 r	6	63	10. 5	26	4. 3	19	28. 6	42. 2

[1] If all live to birth.

TABLE 3.—*Fertility in normal female rabbits mated to control males versus irradiated males*

Treatment of males	Number of matings	Fertile matings		Litters					Young	
		Number	Percent of total matings	Number born	Number resorbed	Average number	Number born alive	Number born alive per mating	Number born	Number born alive
1	2	3	4	5	6	7	8	9	10	11
Control	34	31	91. 2	30	1	7. 7	7. 4	6. 6	233	233
Irradiated	57	47	82. 5	38	9	6. 4	5. 7	3. 8	244	218
100 r	15	12	80. 0	10	2	6. 0	5. 1	3. 4	60	51
200 r	26	23	88. 5	19	4	6. 4	6. 1	4. 5	122	116
300 r	16	12	75. 0	9	3	6. 9	5. 7	3. 2	62	51

Interpretation-of-data study exercises.—Use the following key (A, B, C) to show whether or not the statements below are supported by the data in the two tables.

A. The statement is supported by the data.
B. The statement is contradicted by the data.
C. The statement is neither supported nor contradicted by the data.

____ 1. When normal rabbits are mated, at least 95 percent of all mature eggs are fertilized.

____ 2. The greater the amount of radiation to which the male rabbits were exposed, the greater the chances that the resultant fetuses will die.

____ 3. Male rabbits which received 200 roentgens produced larger litters than were produced by the control males.

____ 4. If some of the males in a population of rabbits were exposed to doses of X-rays as great as 300 roentgens, the total population would decrease in later generations.

____ 5. The reduced fertility of X-radiated rabbits tends to wear off in time.

____ 6. Some females mated to irradiated males produced normal size litters of live young.

____ 7. Individual male rabbits receiving the same amount of X-radiation may be affected quite differently as far as producing live litters is concerned.

____ 8. Female rabbits subjected to X-rays tend to produce dead fetuses.

____ 9. The effect of X-rays on the fertility of male rabbits seems to be more a case of weakening the embryo than failing to fertilize the eggs.

____ 10. Radiation exposures less than 100 roentgens have no effect on the fertility of male rabbits.

Teachers may want to review with their students the fact that ionized materials differ chemically from nonionized materials. For example, if paper moistened with a solution of potassium iodide is touched with the two wires connected to a source of direct current, a brown stain appears at one of the points of contact. Similarly, anhydrous copper sulfate, copper bromide, and copper chloride in crystalline form are respectively white, brown, and green. When water is added, blue colors appear which suggest the formation of cupric ions.

One can show that the air in the immediate vicinity of a source of radioactivity is ionized. Arnold Rubin and T. H. Diehl have shown that a radium button will allow a spark to pass in a circuit connected to a spark coil which is being energized by a 3-volt battery. It would be interesting to compare the degree to which paper disks soaked in uniform activity solutions of a variety of isotopes would produce this effect. The discharging of electroscopes by nuclear radiation has been applied in the design of small meters to be worn in the pockets of people who work in radiation fields. The total amount of radiation to which the worker has been exposed is recorded. These pocket dosimeters are similar to the Lauritsen electroscope (fig. 20).

Before a pocket dosimeter is used, the quartz fiber is bent away from its normal position by being subjected to a voltage of approximately 160. This electrical charge is effectively trapped and cannot be neutralized until ionizing radiation dislodges electrons from the walls of the ion chamber. As the fiber moves closer to the frame, a hairline image of the fiber moves across a scale recording the total amount of radiation to which the ion chamber has been exposed. Teachers may demonstrate the fundamental characteristics of the dosimeter by using an ordinary electroscope and paper disks which have been soaked in one microcurie per milliliter solutions of gamma-emitting isotopes.

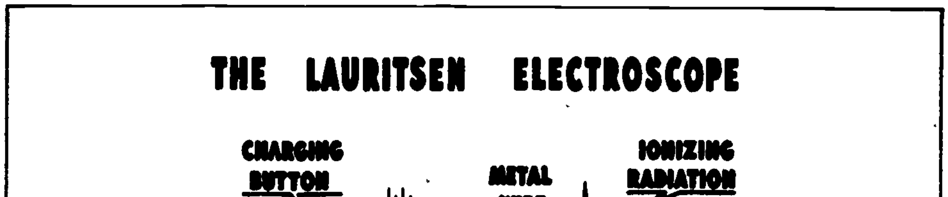


FIGURE 20.—Pocket dosimeters are special adaptations of the Lauritsen electroscope.

How ions may serve as condensation nuclei is clearly known to everyone who has seen vapor trails left by high flying aircraft. This phenomenon is also applied in the design of the Wilson cloud chamber. Descriptions of homemade cloud chambers are already in the literature. A photograph of one type appears here (fig. 21).

Cloud chambers have played such an active rọle in helping physicists identify and describe the characteristics of nuclear particles that teachers may want to give their students some exercise in the interpretation of cloud chamber tracks. Perhaps the diagrams in figure 22 could be reproduced on the chalkboard and questions, such as those indicated in figure 22, could be used to lead the class discussion.

As demonstration that a stream of electrons is equivalent to a beam of beta particles, a student of Fred Moore, a science teacher in Michigan's Owosso High School, removed the horizontal and deflecting plates from a small TV tube so that when it was turned on it gave a brief spot of light in the middle of the screen. The tube and its original power supply were mounted on a breadboard. After the spot of light became visible to the class, a magnet, moved around the forward portion of the neck of the tube, caused the spot of light to move.

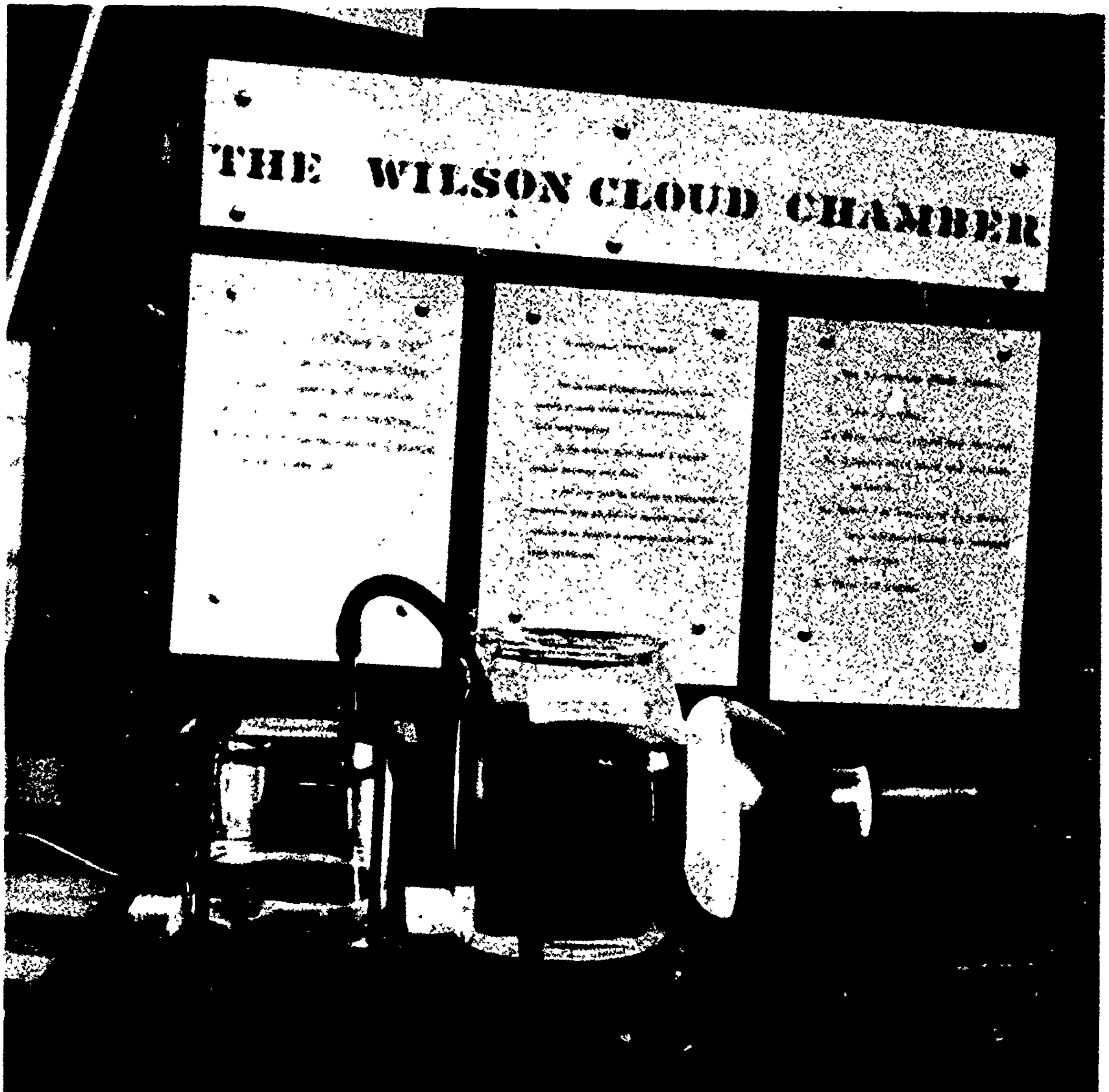


FIGURE 21.—Student-made cloud chamber.

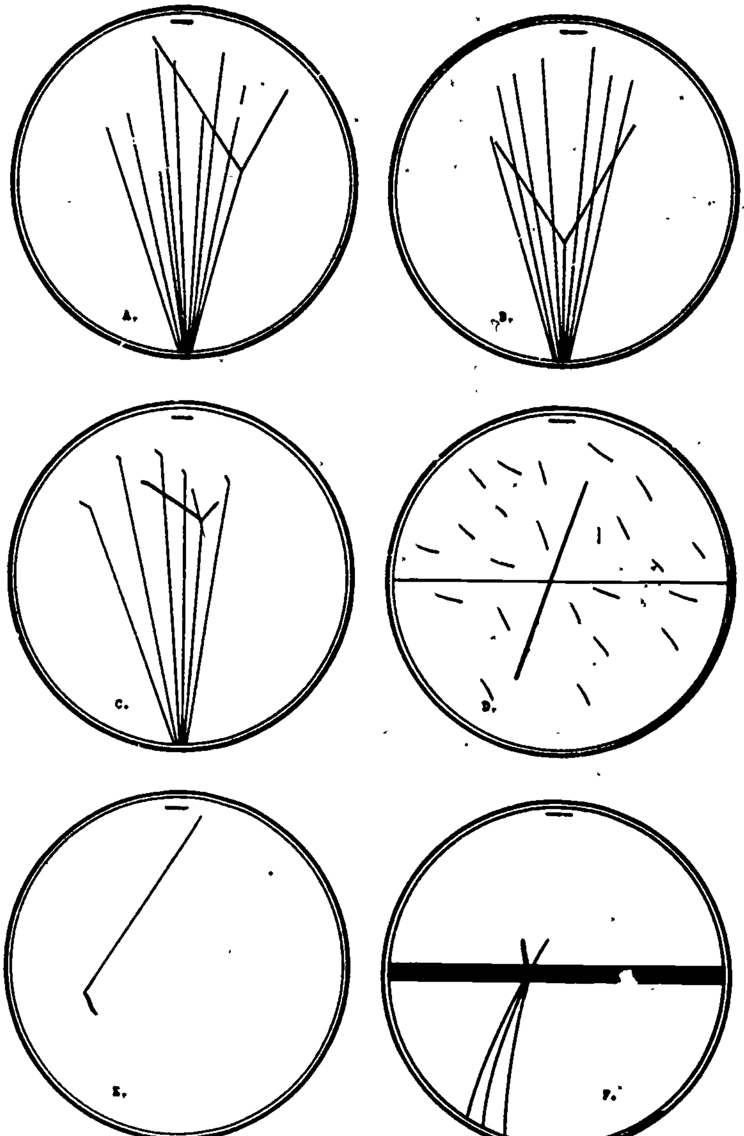


FIGURE 22.—Reading Cloud Chamber Tracks. *A.* Alpha particles are shown streaming through a cloud chamber. What kind of a particle must have been hit and knocked out of the way toward the left? Would it be lighter or heavier than the alpha particle that hit it? Would it have the same or opposite charge as the alpha particle? *B.* One of the alpha particles streaming across this cloud chamber has struck a helium nucleus. How must the mass of the alpha particle compare with the mass of a helium nucleus? Do the two particles carry the same charge? Was the helium nucleus charged before it was struck by the alpha particle? *C.* In this case, an alpha particle has collided with an atom of some element. After the collision the alpha particle glanced off toward the top left and the atom it hit recoiled to the right. Was the atom heavier or lighter than the alpha particle? Did the atom become a positive or a negative ion? Could it have been an oxygen atom that the alpha particle hit? *D.* An atom of uranium was apparently at rest in the thin foil that stretches across the cloud chamber, then it was "triggered off" by a passing neutron. Were the two fission products of equal mass? What two elements might have been formed by the fission of the uranium atom? Are the fission products ionized? Were any new neutrons produced? *E.* Some kind of a collision has produced a light particle that streams toward the negatively charged plate and a much heavier particle that recoiled in an almost opposite direction. If it was a nitrogen atom that was hit, what kind of particle must have hit it? Was the projectile charged? Was it heavier than the two particles which left the tracks? *F.* The particle which produced the heavy track in this photograph had passed through a thick block of lead and was near the end of its path. It showed a slight curve toward the negative plate but other photographs showed a similar curvature toward the positive plate. How must this projectile differ from alpha, beta, or gamma rays?

If the students already know the relationship between magnetism and electricity, it is easy for them to see that beta particles might have magnetic properties which are influenced by the electrical field. Quoting Moore:

> This helps the students to see that the invisible particles we talk so much about are really there and that they are electrical.

Phosphorescence and Fluorescence

The phenomena of phosphorescence and fluorescence may be brought to the student's attention by luminous instrument dials. The paint used to print these dials may contain a phosphorescent or fluorescent compound. Either will glow in the dark. Fluorescent materials, however, will glow only when atomic particles or rays are striking them. Phosphorescent materials can store up such rays, so to speak, and then give them back slowly in the form of a soft glow. On fluorescent luminous dials, the paint contains a mixture of radium and fluorescent compounds. Particles from the radium continually bombard the fluorescent material and cause it to glow. Phosphorescent dials contain no radium.

Directions for making spinthariscopes have already been widely distributed and several toy models are readily available. Similar observations can be made simply by looking at a radium watch dial with a magnifying glass in a totally dark room. Perhaps students can appreciate the starlike flashes more readily if they look upon whizzing atomic particles as carrying energy just as a baseball does when it leaves a bat. They know that the baseball can do things to their hands when they try to stop it. Its energy of motion can be changed into heat or other forms of energy. The whizzing atomic particles can do things to the atoms of the fluorescent material on the screen. Perhaps they rub their energy off onto some of the electrons that surround the nuclei of these atoms and thereby boost them into higher energy levels. As soon as the whizzing particle passes by or settles down, the high energy orbital electrons return to the level they ordinarily occupy and give up the newly acquired energy as a flash of light.

Phosphorescent materials are similar in some ways and different in others. Their electrons can also be boosted up into high energy levels, but some of them stay there for a time after the atomic particle or ray has acted upon them. For this reason, phosphorescent materials glow more slowly for a longer time after being subjected to bombardment than fluorescent materials.

Chapter IV

Classroom Demonstrations and Laboratory Exercises Involving Nuclear Radiation

There are several reasons why teachers may want to increase the emphasis on nuclear science in their classrooms. Many of the concepts in high school biology, chemistry, and physics are very closely related to atomic structure, nuclear energy, and nuclear radiation.

To the extent that students bring into the classroom questions prompted by their everyday reading, radio listening, and television watching, teachers can expect an increasing number of questions dealing with nuclear energy.

More than 35,000 laboratories in the United States are licensed to work with radioactive materials. In effect, each of these laboratories becomes a potential employer for young people trained and oriented in handling radioactive materials.

So long as a possibility exists that our Nation can be involved in atomic warfare and fallout hazards, there is a great need for everyone to understand the fundamentals of atomic energy. The Nation needs a corps of people trained to predict the areas of radiological contamination resulting from fallout, determine the actual areas and concentration of radioactive contamination, and to carry on rescue operations in fields of high radiation, protecting themselves and others from undue exposure, and helping all people to keep their radiation exposure to a minimum. In the public schools, teachers can make a great contribution by presenting the fundamentals of nuclear science in an interesting, realistic, and accurate manner.

At the time this publication is being prepared, we are on the threshold of developing power for peacetime purposes from nuclear reactions. To insure that this important resource makes its greatest possible contribution to mankind will call for wise decisions on the part of many people as well as for a group of highly trained and dedicated nuclear scientists.

For reasons such as these, teachers, especially science teachers, are being encouraged to extend and enrich the treatment of nuclear science in their high school general science, biology, physics, and chemistry classes. Furthermore, the low cost of small quantities of radioactive materials, the availability of instruments, and the simplicity of procedures to exploit the potentialities of tracer isotopes combine to produce an interesting challenge to science teachers.

Following are basic rules for handling radioactive materials:

1. Use only those quantities of radioactive materials for which no licensing or special regulations are required.
2. Be sure you know what nuclear reaction is producing the radiation with which you are working.
3. Know exactly what quantity of unstable nuclei for which you are responsible.
4. Acquaint yourself with the characteristics of the radiation emitted by whatever unstable nuclei with which you will be working.
5. Before obtaining the necessary radioactive materials, be sure all of your exercises are sufficiently well planned to allow you to use the short-lived materials before they undergo extensive decay.
6. From the moment your radioactive materials arrive, be sure your storage facilities are such that you will know precisely where each bit of it is until you are through working with it and it has been flushed down the drain or otherwise disposed of.

Plant Absorption

Teachers can well begin their work with radioactive materials by investigating the absorption of these materials by plants. The illustrative exercise presented here attempted to shed light on the question of whether growing plants would absorb fission product fallout from the soil.

To represent the fission product fallout, 6 isotopes were selected which are available in 10 microcurie quantities. Two milliliters of 1 microcurie per milliliter solutions of each of the isotopes were placed in containers. Eight milliliters of water were added to each.

After the solutions of radioactive materials had been prepared, the following weeds, growing vigorously at the time, were selected: one with a blossom (dandelion), one with seed pods (wild mustard), one with a bulb (wild onion), and one (clover) which absorbs strontium 90 and eventually deposits it in dairy products. The plants were washed clean with minimum injury to the roots and dead materials were stripped away. Then the plants were placed in the radioactive solutions.

At the end of 64 hours, parts of a leaf or of whole leaves were selected from each of the plants in each of the 6 preparations. These were spread out on 35-millimeter cards and wrapped with transparent plastic. (*Note: Rubber gloves should be worn at all times when you handle any material suspected of containing radioactive isotopes.*) These small sample cards were to be used to test for the presence of absorbed radioactive materials without having to remove the whole plants from the solutions. The use of 35-millimeter size test cards, after the materials were exposed to X-ray films (if autoradiographs were obtained) made it possible later to frame the films with 2" x 2" binders and use them in a classroom projector.

At the end of 120 hours, the complete plant preparations were removed from the solutions, washed in running water to free them of adhering radioactive materials, laid out on 5" x 7" cards, wrapped with transparent plastic, and put in lightproof wrappings with 5" x 7" sheets of X-ray film. The accompanying photographs (figs. 23, 24, and 25) show the results from five of the isotope solutions. No absorption of chromium 51 is observable and there is reason to question the calibration of the original quantity of this material.

Although autoradiography provides an interesting way to study the absorption of radioactive materials by plants, it does not lend itself to accurate quantitative studies. Consider, for example, photograph A in figure 25. One might attempt to interpret quantitatively the deposit of radioactive material in the various plant tissues or organs. The greater exposure of the overturned tip of the dandelion leaf shows clearly how significant the distance is between the plant tissue and the photographic film. To make quantitative investigations, procedures would have to be developed to insure that each tissue or organ was the same distance from the film.

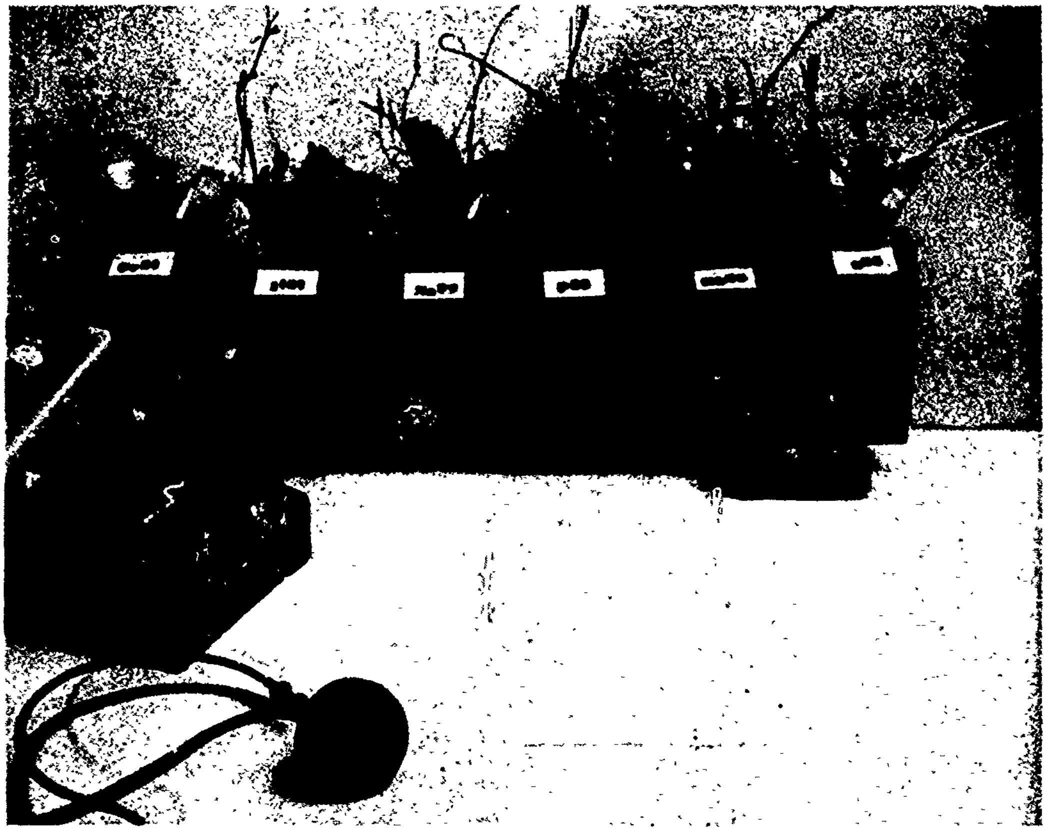


FIGURE 23.—This arrangement of the plant materials should be securely fastened to a shelf to avoid spills.

FIGURE 24.—Enlarged test film from sodium 22 preparation. The film was exposed to the test card for 11 hours, developed 5 minutes, and fixed for 10 minutes.

The basic procedure outlined in this exercise lends itself to additional investigations. One might use duplicate or triplicate plant preparations and restore one set of the plants to pure water to see whether the absorbed radioactive materials are thrown off by the usual physiological processes. Selecting plants with variegated leaf patterns might lead to interesting results. Additional ideas are presented in chapter V of this publication.

Animal Absorption

Although many teachers tend to avoid experimentation with the higher animals, effective techniques have been developed which allow teachers and their students to explore the absorption of radioactive materials by the simpler animals.

Several teachers have reported attempts to observe the absorption of phosphorus 32 by fish. The usual procedure is to dilute 10 microcuries of phosphorus 32 with something less than a liter of water. Small fish, usually goldfish, are left in the solution from 1 to 10 days. When the fish are removed from the solution, the soft tissues are removed (using rubber gloves) and the skeleton is prepared for autoradiography. Suggested exposure times for the prepared skeleton on no-screen X-ray film range from 24 through 120 hours. Teachers who have encountered discouraging results with this procedure have obtained better results in some cases, however, when the phosphorus 32 was taken up by food plants or injected into earthworms or other small animals and fed to the fish. The thickness of the skeleton materials, coupled with the high energy of the beta particles from phosphorus 32, precludes getting a sharply defined autoradiograph from this procedure.

Bill Whitehurst of Peoria, Ill., reports the following procedure for studying the absorption of phosphorus 32 in the frog:

Inject one microcurie of the phosphorus 32 into the bodies of three earthworms. Small injections along the bodies will bring best results. Force feed the worms to the frog carefully (rubber gloves). Place the frog in 300 milliliters of water in a container of such size that the bottom will be covered to about a depth of one-half inch.

The rate at which the radioactive material is excreted by the frog may be estimated by taking one milliliter samples of the water from the container at convenient intervals, evaporating this water on small aluminum foil disks (planchets), and then placing the aluminum disks near a Geiger counter tube.

After approximately 24 hours, the animal should be killed and 0.025 gram samples of blood and other body fluids collected. Similar weight samples of all the other organs should be prepared.

The body fluids can be transferred immediately to aluminum foil planchets, dried, and counted with the Geiger counter. A few drops of alcohol should be added to the tissue or organ samples which are then ground to a paste with a mortar and pestle, washed onto planchets, dried, and counted as promptly as possible.

The remaining parts of the frog can be sliced with a razor blade to make autoradiographs as in the previous plant absorption exercises. If the bones are sandpapered down to thin strips before placing them on the X-ray film, the autoradiograph will be a more accurate silhouette.

The data obtained from this exercise should be studied to determine when the excretion rate began to rise abruptly, which organs contain the greatest concentration of phosphorus 32, and so on.

In another investigation, the author attempted to determine whether or not aquatic animals differ in their absorption of fission fallout materials from their water environment:

A wish to use autoradiography and to project the autoradiographs for classroom study purposes led to collection of specimens of minnows, crayfish, and

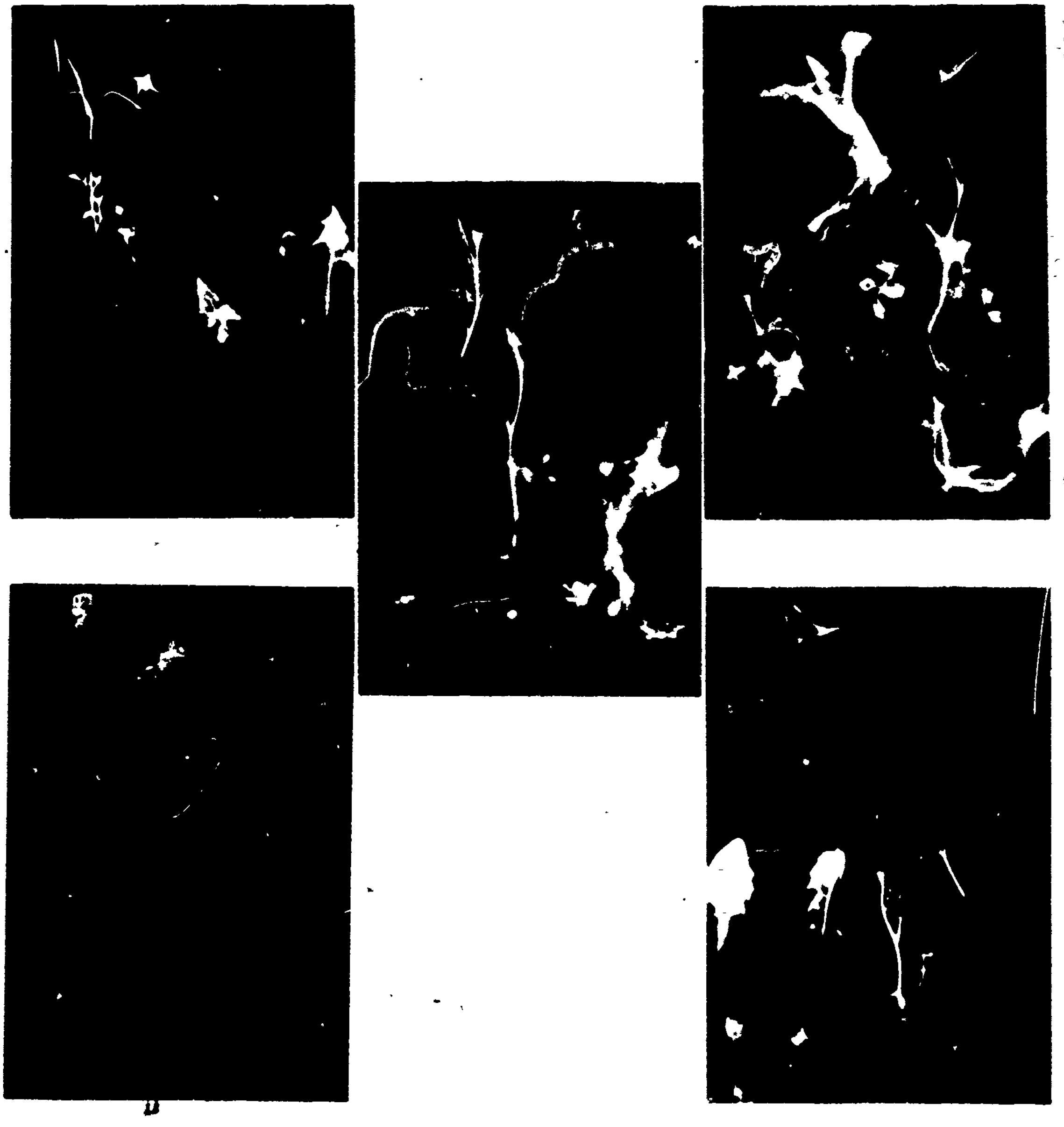


FIGURE 25.—Contact prints from X-ray film exposed, for varying numbers of hours, to plants left for 120 hours in different preparations. A.—10-hour exposure to plants left in 10 milliliters of water containing 2 milliliters of 1 microcurie per milliliter iodine-131, 20 days old. B.—6-hour exposure, rubidium 86. C.—6-hour exposure, phosphorus 32. D.—15-hour exposure, sulfur 35. E.—10-hour exposure, sodium 22.

salamanders approximately 35 millimeters in length from a small stream. Specimens of each of the three species were placed in approximately 20 milliliters of water containing 2 milliliters of 1 microcurie per milliliter solutions of isotopes such as iodine 131, sodium 22, phosphorus 32, and sulfur 35.

For periods of ranging up to 80 hours, none of the minnows absorbed observable amounts of any of the isotopes from the solution. The crayfish and salamanders, on the other hand, showed absorption ranging up to 1,000 counts per minute on the civil defense-type Geiger counter with the probe held approximately one-half inch from the specimens.

The test animals were removed from the isotope solutions, washed clean under running hot water, embedded in paraffin blocks, frozen, and sectioned with a razor blade. Although the results from this procedure were, in general, discouraging, the shortcomings appeared to be more in connection with the efficiency of the technique than in the theory underlying its design.

At some sacrifice of detail, autoradiographs of the crayfish were prepared by simply pressing the specimen as flat as possible on cardboard, wrapping the preparation with transparent plastic, and placing the preparation in contact with no-screen X-ray film. An accompanying photograph (fig. 26) illustrates one such result.

FIGURE 26.—A small crayfish left for 118 hours in 20 milliliters of water containing 2 milliliters of 1 microcurie per milliliter sodium 22 was removed, washed clean, pressed flat, and left in contact with no-screen X-ray film for 10½ hours.

The improvement of simple animal absorption exercises remains a challenge to teachers. Many of the phenomena of animal life might be clarified effectively by use of tracer isotopes. It would be interesting, for example, to study not only the absorption of various elements by animals but also the transportation of the elements within the organs of the animals and their eventual excretion. Tracing the deposition of materials during spectacular bodily changes holds special interest. Insect metamorphosis, egg formation, pregnancy, and regeneration or other tissue-repair processes might lend themselves to isotope investigation.

Uranium, Thorium, or Radium Compounds

In 1896 Becquerel observed that crystals of uranium salt emit radiation capable of penetrating opaque materials, affecting photographic film, and discharging electroscopes. Many exercises have been developed since then to shed additional light on this phenomenon.

In connection with her project to be reported to the Kansas Junior Academy of Science, Sandra Hodgson of the Manhattan, Kans., High School, developed the following procedures:

Uranium nitrate was chosen as the starting material for the preparation of the active sources. To obtain a higher degree of purity, reagent grade material was recrystallized. The crystalline form was dissolved in reagent grade nitric acid, and the volume of solution was reduced to near dryness with a heat lamp. Six hundred milliliters of distilled water were added and the solution heated. Fifty milliliters of ammonium hydroxide were added slowly over a period of 20 to 30 minutes with continued stirring. The hot solution was filtered through a double layer of ashless filter paper and the precipitate was allowed to dry overnight. The filter papers containing the precipitate were transferred to a platinum crucible, dried under a heat lamp, and ignited to the black oxide, U_3O_8, by means of a Meeker burner.

Miss Hodgson hoped to prepare uniform distributions of the precipitated uranium oxide on filter paper disks. She ran into considerable trouble in doing this. Brushing the material onto the filter paper and bonding with a spray of acrylic resin produced neither a uniform layer nor complete bonding. Improved results were obtained, however, by mixing equal volumes of molten paraffin and acetone, adding the powdered oxide, and applying the mixture to filter paper. Repeated heatings of the filter paper tended to obtain a uniform distribution. Using these filter paper sources, Miss Hodgson was able to obtain sharply defined silhouettes by sandwiching opaque materials between the filter paper preparation and no-screen X-ray film. Her exposure times ranged between 3 and 24 hours.

"The clock that took its own picture" has become a satisfying exercise for many teachers. The detail of the autoradiograph can be improved if the dial is removed from the clock or watch and separated from the X-ray film by nothing thicker than transparent plastic. Exposure times are difficult to estimate because of the wide variation in activity of luminous paints used on dials. Results seem to range from a few hundred counts per minute to more than 5,000 per minute when checked with the civil defense-type Geiger counter with the probe at a distance of approximately one-quarter inch from the dial.

By mounting the dial on a card and placing the preparation over the film opening of a small box camera, loading the camera with ordinary film, and starting exposures with 2 hours and doubling the exposure time for each frame to be rolled in contact with the dial, a wide range of exposure times can be readily investigated. Again, by using a dial less than 35 millimeters in diameter, the resultant films can be framed and used for projection purposes.

Autoradiographs can be used very effectively to show the distribution of radioactive materials in ore specimens. If the distribution of the radioactive material follows a crystalline pattern and the ore sample is ground flat on one surface, results are improved. An accompanying photograph illustrates the results (fig. 27).

FIGURE 27.—A contact print from a 5" x 7" sheet of no-screen X-ray film in contact with a polished ore specimen (uraninite, gummite, uranophane, and crysolite). Exposure 4 hours.

Although Kenneth Vinten of the Canal Zone knew that a Geiger counter gives a good indication of whether or not an ore sample contains uranium, he needed a method to identify uranium when he didn't have a Geiger counter. He suggests the following procedure:

Step 1. Grind the ore sample thoroughly.

Step 2. Gently boil for 15 minutes a 5-to-10 gram sample in enough 1-to-1 sulfuric acid to prevent spattering.

Step 3. Place the residue and the acid solution under an ultra-violet light. A yellow or greenish-yellow fluorescence in either strongly suggests that the ore sample contains uranium.

In this analytical test it is assumed that the uranium in the ore sample is converted into sulfate salts and that only these salts will give the yellow or greenish-yellow fluorescence.

Don Harrod, chemistry instructor in Michigan's Benton Harbor High School, reports a high level of interest among his chemistry students in a laboratory exercise involving the separation of uranium from its daughter products. His procedure involves the following steps:

1. Prepare a saturated solution of ammonium nitrate in distilled water.
2. To 20 milliliters of this solution, add 5 grams of uranyl nitrate.
3. Transfer 5 milliliters to a small petri dish and the other 15 milliliters to a separatory funnel.
4. Add 75 milliliters of ethyl acetate to the separatory funnel and shake it for one minute.
5. Draw off the lower aqueous thorium and protactinium layer and transfer 5 milliliters each of the aqueous and ethyl acetate solutions to two petri dishes.
6. Measure the beta activity by holding the Geiger counter tube equal distances from each of the three samples.

In this exercise the two alpha-emitting uranium isotopes are separated from their beta-emitting daughters. The uranyl nitrate is extracted into ethyl acetate while the thorium and the protactinium nitrates remain in the water.

Fission Product and Other Environmental Radiation

Applications of nuclear energy in the design of military weapons has brought with it the problem of fission products being projected into the upper atmosphere and later falling and accumulating in the soil. Teachers should feel called upon to shed some light on this problem of radioactive fallout because it may have far-reaching biological implications.

Clarification of the basic reaction in the fission of uranium-235 atoms and the subsequent production of their fission products can best be obtained by visualizing the reaction. Techniques for doing this have been covered in chapter I. The accompanying photograph represents an additional idea (fig. 28).

William Crumrine, instructor in the Marshall, Mich., High School, has modified a typical chemistry demonstration to suggest how fission

T. L. Handy High School, Bay City, Mich.

FIGURE 28.—Uranium 235 fission model. Before release of neutron to which student points, a uranium 235 nucleus occupied the same position.

fallout takes place. Following is his description of the demonstration:

In this demonstration we use a common simple combination chemical reaction (zinc and sulfur to yield zinc sulfide) to simulate an atomic explosion and the resulting white powdered zinc sulfide to simulate radioactive fallout. By using a map or chart (a regular aeronautical chart is ideal) directions and distances to large cities can be determined.

Letter the names of the cities to be used on small pieces of white cardboard, fold in half so that they will stand, then place these name cards on the sheets of black paper. On a very large table or the floor, place these cards at the determined positions. A small electric fan can be used to simulate the prevailing wind for the particular geographical area.

Place a ringstand on the city to be bombed, attach a ring, add a wire gauze, and a pile of well-mixed material containing 5 grams of zinc dust and 2 grams of powdered sulfur. If more fallout material is desired add 2 grams of finely powdered calcium hydroxide. Adjust the ringstand to the proper height and place a lighted Bunsen burner under the mixture. (CAUTION: *Everyone should stand back at least 10 feet as the reaction takes 20 to 30 seconds to take place and is rather violent.*)

Teachers or their students in several parts of the country have built collectors which allow them to observe and measure the quantity of fission products falling from the atmosphere. Quoting from an exercise suggested by James M. Wallace of Jackson, Mich.:

To build a collector all you need is an 8" x 10" sheet of metal, cloth, petroleum jelly, cellophane or its equivalent, no-screen X-ray film, and developing chemicals. Wrap the sheet of metal with a cloth and cover it with petroleum jelly. Place it on top of your school or other appropriate location and leave it for 1 or 2 weeks. Bring it down, wrap it with cellophane, and take it to a darkroom. In the darkroom, place the film, emulsion side down, over the plate and cover with a book to hold the film close to the plate. After 24 to 40 hours, remove the film and develop.

The satisfaction obtained from this procedure may be heightened by putting a lead silhouette on a portion of the collecting plate. By shielding the film from the effects of any radioactive material on the plate, you will have additional evidence that the film was exposed by the fallout material.

Plotting Radiation Fields

Teachers may want to take part in training actual monitors for measuring radiation fields in time of nuclear warfare. The intensities of the radioactive sources required to simulate a radiation field suggest that this exercise would not be suitable for high school age students. It would be interesting, however, to see whether

FIGURE 29.—Michigan teachers participate in a problem that involves plotting a simulated fallout radiation field.

FIGURE 29.—Continued.

FIGURE 29.—Continued.

a simulated fallout radiation field could be prepared using a 10-foot-square sheet of cardboard to which had been attached small paper disks soaked in 1 microcurie per milliliter solutions of cobalt 60, sodium 22, or some other gamma-ray emitting isotope. The procedure would be similar to that suggested in the following laboratory exercise guide sheet:

Guide Sheet for Laboratory Exercise

What you can learn from this exercise:

How to read a Geiger counter accurately.

How to translate a survey instrument's readings into a picture of radiation sources and intensities in an area.

We presume you already know:

The difference between the 1X, 10X, and 100X ranges on the counter.

That the general geometry and/or peculiar shielding effects while the counter is being read may affect its readings.

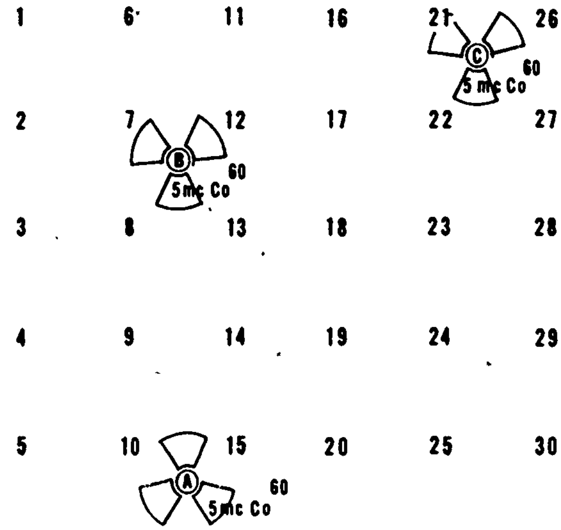
How isobars are drawn to show areas of equal atmospheric pressure on weather maps.

How contour lines show elevations on topographic maps.

That the intensity of radiation received at any point from a source depends directly upon the intensity of the source, *but,*

If one of two equal point sources is twice as far away, the radiation received from the more distant one is only a fourth as great.

A Practice Radiation Area



In the practice radiation field above, the numbers show the stations at which readings are to be taken and the letters show radiation sources.

Here's the general idea:

It's a well-known fact that a uranium prospector can't take readings over each square foot of the country in which he hopes to find pay dirt. His problem is to get a clear picture of where ore bodies are without covering the whole country. Similarly, if nuclear war should be waged, then after a bomb burst or after the population has been exposed to radioactive fallout, only scattered estimates could be obtained of radiation hazards. Ways must be devised to estimate intensities throughout the whole affected area.

By taking scattered readings over the area and then connecting all areas showing equal radiation intensities, two things are accomplished. First, it becomes possible to estimate how strong the radiation is where no reading could be taken and, second, it becomes easier to spot the places from where the radiation seems to be coming.

In this exercise a part of the school ground has been converted into a practice radiation field. Cobalt 60 sources have been "planted" to provide the radiation. Thirty spots have been marked where readings are to be taken. Your "map" of the area will then show the isointensity lines based on your readings.

Be alert to the following:

Remember that your body will get the same radiation as that being picked up by your Geiger counter. These radiation intensities are, of course, harmless. Use this opportunity to learn how to get around in a radiation field and still keep your "dose" as low as possible.

Take readings under .45 mr/hr on the 1X scale and readings between 0.45 and 4.5 on the 10X scale.

Take some practice readings at your first station to see whether there are things you can do or avoid doing to be sure that you get the same result another person would get at the same spot.

To reduce shielding effects or other sources of error, take readings while you are facing north, east, south, and west. After correcting each reading for special instrument error, use the average reading at each station.

This is what to expect:

Here is an example from a similar exercise. At station 9, let's say, the Geiger counter would pick up radiation from the three sources planted at A, B, and C. We can assume that the Co^{60} sources are fresh. The intensity of the radiation received at station 9 from each of the sources follows the formula:

$$mr/hr = \frac{1.59 \times mc \text{ of } Co^{60}}{D^2}$$

mr/hr = milliroentgens per hour
mc = number of millicuries of Co^{60}
D = distance in yards from source
1.59 = number of milliroentgens per hour received from 1 millicurie of Co^{60} at a distance of one yard

Thus at station 9, the radiation rate becomes:

$$mr/hr = \frac{1.59 \times 20mc \text{ of } Co^{60}}{3yd \times 3yd}$$

$$mr/hr = \frac{1.59 \times 20}{9}$$

Intensity at station 9 from "A" = 3.53mr/hr

Similarly, from source B — $mr/hr = \frac{1.59 \times 5mc \text{ of } Co^{60}}{3yd \times 3yd}$

$= .88mr/hr$

Since source C is the same as B, we can use what we know about A to estimate how much source C will produce at station 9. Since station 9 is three times farther away, we know that the radiation received will be one-ninth as great. For this we use the inverse square law:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

$$\frac{8.8mr/hr}{I_2} = \frac{9yd \times 9yd}{3yd \times 3yd}$$

$$I_2 = 0.1mr/hr$$

From all this we can now expect the Geiger counter to read at station 9 the total of these three separate rates:

Total radiation received at station 9 = 3.53mr/hr
+0.88mr/hr
+0.1mr/hr
=4.51mr/hr

A second example will not only add to your understanding but, we hope, also teach a safety lesson. Suppose a student becomes tired between Stations 21 and 22 and sits down. To get out of the way of the other students he chooses a spot that puts him only 0.6 inch from source C. How hot a spot is he on? Again we know that:

$$mr/hr = \frac{1.59 \times 5mc \text{ of } Co^{60}}{6/36 \times 6/36}$$

$$= 28,620$$

At this rate he will have to sit there only a few minutes to pick up about as much radiation as is ordinarily used in a chest X-ray.

Procedure:

1. Record your readings at each of the 30 stations on the data sheet below. It makes no difference where you begin. Remember to apply your calibration curve before averaging your 4 readings at each station.
2. Now enter the corrected average reading at each station on the practice chart or "map" below.
3. Sketch a line enclosing all stations that show readings above 20mr/hr and similarly for stations between 15 and 20mr/hr; 10 and 15mr/hr; 5 and 10mr/hr; 2.5 and 5mr/hr; and 0.1 and 2.5 mr/hr.

Questions:

1. Assuming that the sources of radiation in this practice exercise were actually "hot spots" following a radioactive fallout, at which stations would civil defense rescue workers be exposed to dose rates greater than 10mr/hr?
2. Would the accumulation of radiation from several ore bodies in the same general area be likely to throw a prospector off the track by giving higher readings than those that would be received directly over one of the bodies? Why?

Data Sheet

Station Range	North	East	South	West	Readings Corrected	Readings Average
1	____	____	____	____	____	____
2	____	____	____	____	____	____
etc.						

Practice Chart

1	6	11	16	21	26
2	7	12	17	22	27
3	8	13	18	23	etc.

Fallout Products

Interesting science projects can be planned to investigate whether or not plants and animals store up fission fallout materials. Atomic bomb tests have scattered enormous numbers of different kinds of radioactive atoms throughout the world. At least two of these fission products have such long half-lives that they will continue to move into and through food chains and nutrition cycles for many years.

Each kind of plant or animal tends to select for storage certain elements. Organisms differ in the degree of concentration of any one element. For example, if smart weed and wild rye are grown together, the smart weed may pick up from the soil twice as much of some kinds of radioactive wastes as of other kinds. Algae and spirogyra may absorb 6 to 8 times as much of some elements as do euglena and volvox. Black crappies will concentrate nearly twice as much strontium phosphate in their skeletons as blue gills. Science projects to explore this problem would require students to collect and extract the mineral content from large quantities of plant or animal material. Unless the mineral content can be concentrated into relatively small volume, the counts, because of the absorption of fallout, would scarcely reach levels adequate to register on the usual type of Geiger counter.

Miscellaneous Demonstrations and Exercises

Just as tracer isotopes have been effective in helping solve research and industrial problems, so do they hold promise of helping teachers improve their laboratory demonstrations and exercises. Ingenious teachers everywhere are finding that Geiger counters and photographic films add a new method whereby abstract and complex phenomena can be more effectively presented or explored.

Representative of exercises developed by a group of science teachers in Connecticut is one to show the speed of diffusion of sodium ions in water. Eight milliliters of water were placed in a small graduated cylinder. With the greatest possible care, a milliliter of 1 microcurie per milliliter solution of sodium 22 was added to the bottom of the cylinder. Readings were begun immediately with the Geiger counter held against the side of the cylinder at the lower and upper levels of the liquid.

The addition of radioactive isotopes to electrolytic solutions makes it possible to observe the mechanisms of the plating process more easily and thereby to understand them better. Using radioactive isotopes clarifies the action of ionic exchangers.

Several exercises, described in other literature, employ bacteria which are cultured in nutrient media containing phosphorus 32, sodium 22, or carbon 14. Colonies of the bacteria may yield very satisfying autoradiographs.

Teachers can rather easily simulate applications of radioactive materials to industrial problems. Fluid-flow indicators, level indicators, and compactness gages are good examples. Less than 0.25 milliliter of one microcurie per milliliter solution of cobalt 60 in a sealed capsule is adequate to provide the gamma radiation source needed in such demonstrations. To clarify the principles applied in the design of a depth gage, fasten the cobalt 60 capsule to the side of a tall graduate. Cut a hole the size of the capsule in a 2-inch band of lead and wrap it around the graduate. Take a Geiger counter reading across from the capsule. Now gradually fill the graduate and observe the effect on the Geiger counter reading.

For the compactness gage, follow a similar procedure but use iodine 131 and place it near the bottom of the graduate. Fill the graduate with easily compressible materials such as cotton, sponge rubber, or shredded leaves. Take counter readings, with the material in the graduate pressed into various fractions or

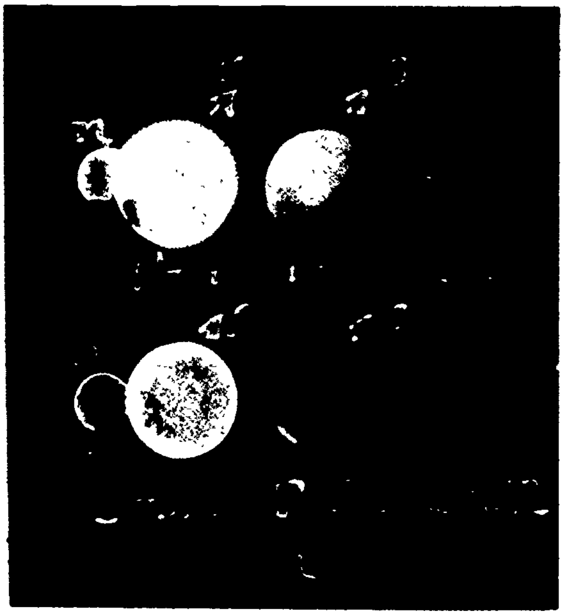


FIGURE 30.—Autoradiograph to clarify the electron printing process. Ink was a 10-microcurie per milliliter solution of sulfur 35. Paper disks (upper row) were soaked in 1-microcurie per milliliter solution of phosphorus 32 to show the diffuse effect of a high-energy beta. Circles (lower row) contained a 1-microcurie per milliliter solution of sulfur 35 to show the sharp images produced by a low-energy beta.

multiples of its original volume by removing or adding appropriate quantities.

For the fluid-flow indicator, arrange a long stretch of hose between a water source and discharge sink. Insert the cobalt 60 capsule in the hose next to the water source. Note that a Geiger counter reveals the capsule's location as it passes through the hose.

The electron printing process is an interesting demonstration. Microcurie quantities of long-lived isotopes are added to the ink which is used to produce a master copy. The master copy is then pressed against photographic printing paper. The radiation from the ink registers on the photographic paper which, after development, is an exact reproduction of the master copy. One microcurie per milliliter solutions of sulfur 35 and phosphorus 32 can be used as "inks." The diffuse effect produced by the high energy beta particles from phosphorus 32 can be compared with the sharply defined images from the low energy betas from sulfur 35. Eight to 10 hours of exposure are adequate if no-screen X-ray film is used. Several months' exposure may be required if photographic printing paper is used. By that time the activity of the phosphorus 32 will have decayed to such an extent as to complicate the procedure.

Chapter V

Ideas for Research and Development

Just a few generations ago science teachers, who, in preparation for any original research, wanted to document themselves on their subject, had to read only a few books. They could build most of the equipment necessary for their experiments. Today's science teachers and their students find that extensive reading backgrounds and elaborate equipment are often said to be essential to original research. The history of science shows that the satisfaction a teacher gains from investigating his own hypotheses and those of his students stimulates a powerful enthusiasm in both teacher and students.

The use of radioactive isotopes as tracers is a relatively recent development in science. Elaborate equipment and procedures are not required. Tracers therefore provide an effective method by which teachers and students may test original hypotheses. After a teacher has acquired a working knowledge of radioactive isotopes and their characteristics, one investigation tends to lead to subsequent investigations at a greater rate than time permits completing.

A certain investigation revealed that an additional layer of aluminum foil or cellulose tape produced enough additional shielding effect to cause a shadow on photographic film. It was further noted that low, medium, and high energy beta particles penetrate identifiably different numbers of layers of aluminum foil. Recognizing the similarity to the shielding effect of photographic emulsions, the investigator thought that color film, with its 3-layered emulsion, might produce the equivalent of a color autoradiograph if the test material contained 3 different isotopes with 3 different beta energies.

It was a simple matter to adapt a previous experiment to test the color autoradiograph hypothesis. (The "jumbo" pack of 9 isotopes distributed by one supplier includes calcium 45, sulfur 35, and phosphorus 32. These 3 isotopes yield medium, low, and high energy beta particles.) Individual paper disks were soaked in 1 microcurie per milliliter solutions of the 3 isotopes. These paper disks were glued to a 35-millimeter test card. After this test card had been wrapped with transparent film, it was mounted over the film opening of a 35-millimeter camera. The camera, in turn, was loaded with color film and the various frames were advanced at increasing exposure times. When the film was processed, several of the frames showed only the slightest evidence of success, but it was enough to capture the investigator's enthusiasm. He was led to reexamine the design of his experiment and now awaits an opportunity to test further hypotheses.

Perhaps the questions following this paragraph will lead teachers to make investigations whereby they can experience the satisfaction of formulating their own hypotheses, designing experiments to test them, collecting data and then carrying on from a first-trial investigation to a more fruitful one. If a careful time schedule is arranged and the radioactive material budgeted accordingly, as many as 20 investigations can be carried out with the quantities of radioactive materials included in a single "jumbo" pack. Photographic film is the only really essential equipment, but a Geiger counter adds immensely to the investigator's results and considerably to his peace of mind. (Remember the ground rules for handling nuclear radiations, especially No. 2, p. 31.)

Do germinating seeds take up mineral salts from soil water? How soon after they become moist does the absorption process, if any, occur? How are radioactive materials distributed throughout the tissues of a plant seedling?

Is osmosis a one-way action? Does the rate at which osmosis occurs depend upon the temperature?

In the reaction between barium chloride and sodium chromate, what is the insoluble product?

How completely can iodine be separated from iodine water by shaking with carbon tetrachloride? Ammonium chloride from sodium chloride by fractional crystallization?

Do barium chloride and sodium sulfate diffuse at equal rates through water?

Are plants which absorb the most water from the soil the first to show symptoms of salt "sickness"? If plants which have absorbed radioactive material are transferred to distilled water, will they throw off the absorbed radioactive material?

Are simple animals more likely to avoid a path through a radioactive area than one through a nonradioactive area? Does this imply that those organisms which evolved at a time when the earth's background radiation was higher can detect nuclear radiation and avoid it?

Can isotopes be used to label different plant tissues? If a plant is taken from a solution containing radioactive material, will newly formed tissues be free of radioactive deposits?

Can isotopes be used to check whether or not a plant graft has been successful?

Can isotopes be used to "count" micro-organisms?

Is it possible to cause a spider to deposit radioactive material in its web? Can an autoradiograph of the web be made?

Do albino plants differ from normal plants' absorption of isotopes? How does light affect the absorption of soil minerals?

Can isotopes be used to tag seeds gathered from experimental plants grown with control plants?

Can isotopes be used to compare the water-holding capacity of soils? The erosion rate?

Do aquatic plant and animal forms absorb minerals directly from the water or only through their food?

Do pollen grains which have absorbed a radioactive isotope transfer radioactivity to a plant embryo?

Can an isotope be used to mark the exact instant a plant or animal tissue dies?

Can isotopes be used to check the rates at which fluids move through plant tissues under different conditions?

Can a long-lived isotope be deposited on recording tape for "playback" purposes, using a Geiger counter fitted with an audioamplifier?

Is the conductivity of an electrolyte influenced in any way when the electrolyte is made up from a salt containing a radioactive isotope?

Do ice crystals forming in water "capture" dissolved salts?

Do some ions participate solely as "spectators" in a chemical reaction?

Can a curve that shows the decay rate of a mixture of two isotopes be analysed to determine the half-lives of the two component isotopes? (The table on p. 20 should allow the student to calculate the curve to be expected from the decay of a mixture containing equal original quantities of iodine 131 and phosphorus 32, for example.)

Can the positive and negative beta particles emitted by zinc 65 be separated in a magnetic field so as to cause separate spots to appear on X-ray film?

Can the effects of toxic materials in weed or insect killers be determined by using isotopes?

Are there identifiable differences in body cells or tissues of irradiated plants and animals?

Can wooden blocks impregnated with iodine 131 be used as controls or to provide additional data when demonstrating the coefficient of friction?

Chapter VI

Social and Economic Implications

Recently, nuclear science has been a factor in social, economic, political, and, in some cases, moral controversies. To present these issues truthfully and without bias is a challenge to all teachers.

High school students want to know whether it is right or wrong to share scientific knowledge with other nations, whether energy sources should be publicly or privately controlled, and whether one nation is justified in contaminating the air above another nation with fallout from nuclear weapon tests.

Examining the social implications of nuclear science calls for techniques by which the teacher can examine critically the events and circumstances under discussion without becoming too closely identified with any one point of view.

Sister Joseph Ann at St. Mary's Cathedral High School in Saginaw, Mich., found panel discussion an effective technique for discussing peacetime uses of radioisotopes, in fields such as medicine, industry, and agriculture.

Don Lindquist, science instructor in the Pontiac, Mich., High School, resorted to a role-playing technique when his students brought up a question that was producing controversy within the community. He set the scene as follows:

> Our scene opens in a middle western city, population about 25,000. This city has three manufacturing concerns, all heavy users of electrical power. The manufacturers have arranged for the community to become a site for a nuclear reactor, and the newspaper has just released the news. Almost everyone is talking about it.

Six roles were played by members of the class. An executive in one of the manufacturing concerns was assumed to be in favor of the reactor. His wife, a clubwoman who, although she confessed that she knew little about reactors, was up to date on gossip. Their daughter, a high school junior, had a limited science background and no opinion on reactors, but had a reasonably open mind. The fourth role was that of a businessman with a knowledge of nuclear energy limited to what he had read in the paper and a fear of contamination from the plant. His wife was deathly afraid of radiation and knew positively that reactors can and very probably would blow up. The sixth role was that of a high school student who had just finished a course in nuclear energy.

Taking his cue from some of the more recent radio and television programs, Fred Moore, instructor in the Owosso, Mich., High School, dramatized interviews with famous scientists. His scripts contained expressions such as:

> Approaching now is the ever-popular teacher, English-American preacher, and member of the Royal Society—John Dalton, . . . And now we have an Englishman, Mr. Electron himself, . . . Dr. Aston, what evidence led you to the discovery of isotopes?

The story of nuclear science has been told many times and many ways. Therefore this publication limits any material of this nature to a chronology of events and observations leading up to our present knowledge about nuclear science (see last section). The chronology may serve as a teaching aid to bring the subject into perspective, to identify elements of it which, if inadequately understood, become stumbling blocks to further understanding, and to show the cumulative progress of the science.

The chronology should lend itself to student assignments such as:

1. Trace the sequence of events which led to the identification and description of the electron.
2. Identify examples of scientists making observations earlier in their work and later used to invent or design something.
3. Prepare a graph or chart showing the rate at which advances in knowledge of nuclear science have progressed and spot basic developments that may have activated sudden spurts forward.

Chapter VII

Protection From Radioactive Fallout: An Instructional Unit

Many science teachers add special meaning to their treatment of nuclear science by presenting a separate unit on protection from radioactive fallout. A sample unit prepared by Jack E. Jines, Santa Fe High School, Whittier, Calif., follows:

Radioactive fallout, sometimes called residual radiation, is a hazard which follows any thermonuclear explosion. Although not more than 15 percent of the fatalities following the A-bomb at Hiroshima were caused by radiation, the problem is increased in H-bomb detonation. The actual danger from fallout depends upon many variables: size and nature of the bomb, height, and meteorological conditions, local topography, and others. Fatalities and sickness from radioactive fallout can be reduced materially if people exercise proper precautions.

Science classes are in a strategic position to teach facts about radioactive fallout. These should include:

1. Nature of radioactive fallout.
2. Effects of it.
3. Methods of protection from it.
4. Methods of decontamination.

This unit is divided into two parts. Part I lists some *typical* facts which students should be expected to derive from a study of radioactive fallout. Part II describes some *demonstrations* to help students to learn and understand these facts.

In the secondary schools of California 45 to 60 percent of the students taking a particular science course do so to meet the science requirement for graduation. Facts about radioactive fallout may well be presented in any science course composed primarily of students who are taking it for this reason. The specific content will vary with the ability and grade level of the students.

Part I—Typical Facts To Be Derived From a Study of Radioactive Fallout

A. *Nature of radioactive fallout*

1. Hazards from radioactive fallout are much greater from ground bursts than from air bursts. Ground bursts from H-bombs produce more fallout than ground bursts from A-bombs. Fallout from the 1954 Pacific tests showered Japanese fishermen 72 miles away.
2. For given areas, fallout patterns vary, since the pattern depends on meteorological conditions as well as the size of the bomb, its design, height, local topography, and other factors. Hazardous conditions may exist in areas more or less than 200 miles from the detonation.
3. Fallout particles may be visible but the radiation from the particles can be detected only with the aid of special devices or instruments.
4. Danger from radioactive fallout is substantially reduced by taking cover. A shelter under 3 feet of earth with properly designed entrance will cut the radiation to about one five-thousandths of that outside; the basement of a house will cut the rate to about one-tenth of that outside.
5. Radiation levels will decrease through the natural decay of the fallout radioactivity.

B. *Effects of radioactive fallout*

1. Biologists do not agree completely on the physiological effects of radiation.
2. The following beliefs, however, are generally accepted:
   a. All radiation is injurious to tissue, but there are commonly accepted safety limits to guide us both in peacetime and after an atomic explosion.[1]
   b. Radiation dosage is cumulative; that is, total exposure must be computed in terms of exposure over a period of hours, days, and years.
   c. Certain tissues are more radiosensitive than others. Radiation damage occurs when the growth and generation of self-replenishing tissues are inhibited in combination with death of cells:
      (1) Bone marrow is especially affected and lack of platelets, a factor in blood coagulation, frequently results from radiation injury.
      (2) Genetic effects, though statistical in nature and remote in time, result from radiation exposure.

[1] Brues, Austin M. Modes of Radiation Injury, *Chemistry*, 29:1:21-30, September 1955. Washington 6: Science Service, 1955.

C. *Protection from radioactive fallout*

1. Best protection is distance from the source.
2. Three feet of earth over a shelter, such as a basement, with windows shielded reduces rate to one five-thousandths of that outside.
3. Emergency cover, such as the basement of the house or unexposed hallways, affords some measure of protection.
4. Any type of cover is better than no cover at all. In an extreme emergency material such as canvas, clothing, and newspapers, can be used to lower exposure rate until better protective cover is available. However, such thin material provides virtually no protection from gamma radiation.
5. Since radiation may continue for hours, days, or even longer, *it is not safe* to leave shelter until civil defense radiological monitors certify the area as safe.
6. Remember that only through the use of special detection devices can one know the intensity of radioactivity, although the fallout particles may be visible.

D. *Procedures for and effects of decontamination*

1. Decontamination means getting rid of matter giving off dangerous radioactivity.
2. Decontamination is a mechanical process. Radioactivity *cannot* be destroyed or neutralized by chemical agents. Boiling, heating, or electrical treatment have no effect. Principal means of decontamination are washing and burying.
3. The procedure for decontamination will vary with the nature of the surface contaminated and the extent of contamination. For example, in some cases hosing down a contaminated surface will be adequate; in others steam or sand blasting may be required, or it may be necessary to remove the substance and bury it deep in the earth.
4. Time will reduce contamination. Natural decay of radioactive materials greatly reduces the hazards of radioactivity.
5. Civil defense radiological monitors will measure the extent of contamination and post areas unsafe to enter.

Part II—Demonstrations To Teach Facts About Radioactive Fallout

To be up-to-date, high school science departments should possess at least one Geiger counter and a cloud chamber. Although commercial models usually give best results, students can build these instruments. The following demonstrations require the use of these radiation detection devices.

A. *Demonstrating nature of radioactivity*

1. To demonstrate the invisible nature of radioactivity, let the students observe two rocks, one containing uranium ore (approximately $3 from standard scientific supply houses) and the other no radioactive material. Place each rock on separate pieces of fast photographic film (use dental X-ray film) in a darkened container such as a desk drawer. After 24 hours remove the film (being careful not to expose to light) and develop it. Let students compare the negatives. What has caused the image on the film under the uranium ore?
2. In a darkened room set up a cloud chamber saturated with methyl alcohol and cooled on a cake of dry ice. The cloud chamber may be either purchased or student-built.[1] Let the students observe the "tracks" formed by the cosmic rays and other radioactivity always present in the atmosphere. Here is an excellent time to point out that small amounts of radioactivity are not harmful. Now let the students observe the increase in the number of "tracks" or "condensations" within the chamber when radioactive ore or other radioactive sources are brought near it. This demonstration shows the invisible nature of radioactivity as well as the ionization power of the rays since the condensations within the chamber result from the formation of ions as the rays shoot through the gases of the chamber.
3. Nature of radioactivity may easily be demonstrated by using a Geiger counter. (Take readings at a given time daily for comparative study. This would be especially interesting during periods of atomic testing at the Nevada Proving Grounds.) The radioactivity of such articles as luminous paints and watch dials can be shown. With a sensitive Geiger counter, demonstrate more technical aspects of the nature of radioactivity. Some examples are: (a) effect of distance away from source (varies inversely as the square of the distance); (b) effect of decay or half-life (using a source such as phosphorus 32, radioactivity can be measured at definite time intervals). Now plot a graph, using intensity against time, which will show that intensity drops sharply at first and then tapers off more slowly.[3]

B. *Effects of fallout.*[4] (No demonstrations.)

C. *Protection against fallout.*

Radiation that emanates from fallout has differing penetrating powers. Alpha has a very short range, and gamma the greatest penetrating power. Using radio-

[1] For details of construction, see *Laboratory Experiments with Radioisotopes for High School Science*, p. 15-16. Washington: U. S. Government Printing Office, 1953. 30 cents. A chamber with instructions and radioactive sources may be purchased from the Atomic Laboratories, Inc., P. O. Box 343, Berkeley, Calif.

[3] A radioactivity demonstrator, "Classmaster," produced by the Nuclear Instrument and Chemical Corporation, Chicago, Ill., is useful for many different demonstrations. The particular Geiger counter used in class should, in any event, include the beta window and metal shield for alpha particles, and give readings in counts/minutes. Small vials containing solutions of 10 microcuries of radioactive isotopes such as P^{32} and I^{131} may be obtained from commercial laboratories. Ten microcuries are relatively inexpensive and are safe for classroom use.

[4] *Laboratory Experiments with Radioisotopes for High School Science*, ibid.

active sources such as I^{131} for gamma radiation, or P^{32} for beta radiation, it is possible to study relative effects of various types of shielding. The great energy imparted by A-bombs and H-bombs cannot (and should not) be duplicated in high school laboratories, but the results obtained by using the sources named above will illustrate effects of shielding.

To study relative effects of shielding the following procedure is suggested:

Materials:

1. G–M tube and counter.
2. Radioactive source such as P^{32}, I^{131}, or uranium ore.
3. Shielding such as newspapers, a wooden box, concrete blocks, assorted pieces of metal, and some soil.

Method:

1. With the Geiger counter record the background rate.
2. Mount the G–M probe in a fixed position so that equal distance can be maintained from the source and shielding throughout the tests.
3. Mount the radioactive source in a fixed position and measure the counts/minutes with *no shielding.*
4. Next check the effects of shielding, using some of the following:

   Newspapers—single sheet.

   Newspapers—multiple sheets.

   Aluminum or other metal squares of uniform thickness and density.

   Wooden box (can simulate hallway of a frame house).

   Wooden box—surrounded by concrete blocks (simulated basement, etc.).

   Wooden box—surrounded by concrete box, covered with soil (simulated basement shelter).

It should not be assumed that radiation could be reduced as effectively from a thermonuclear bomb as that from the small sources used in this demonstration. However, the basic principles of shielding can be illustrated and gamma radiation can be shown to have much greater penetrating power than either alpha or beta radiation.

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Most of the entries concern new ways to teach the nuclear science story and are divided into 5 groups. The first 3 groups list readings for elementary grades, high school, and college, with the high school predominating. The fourth group gives a list of basic texts and the fifth, a list of readings on various phases of radioactivity.

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