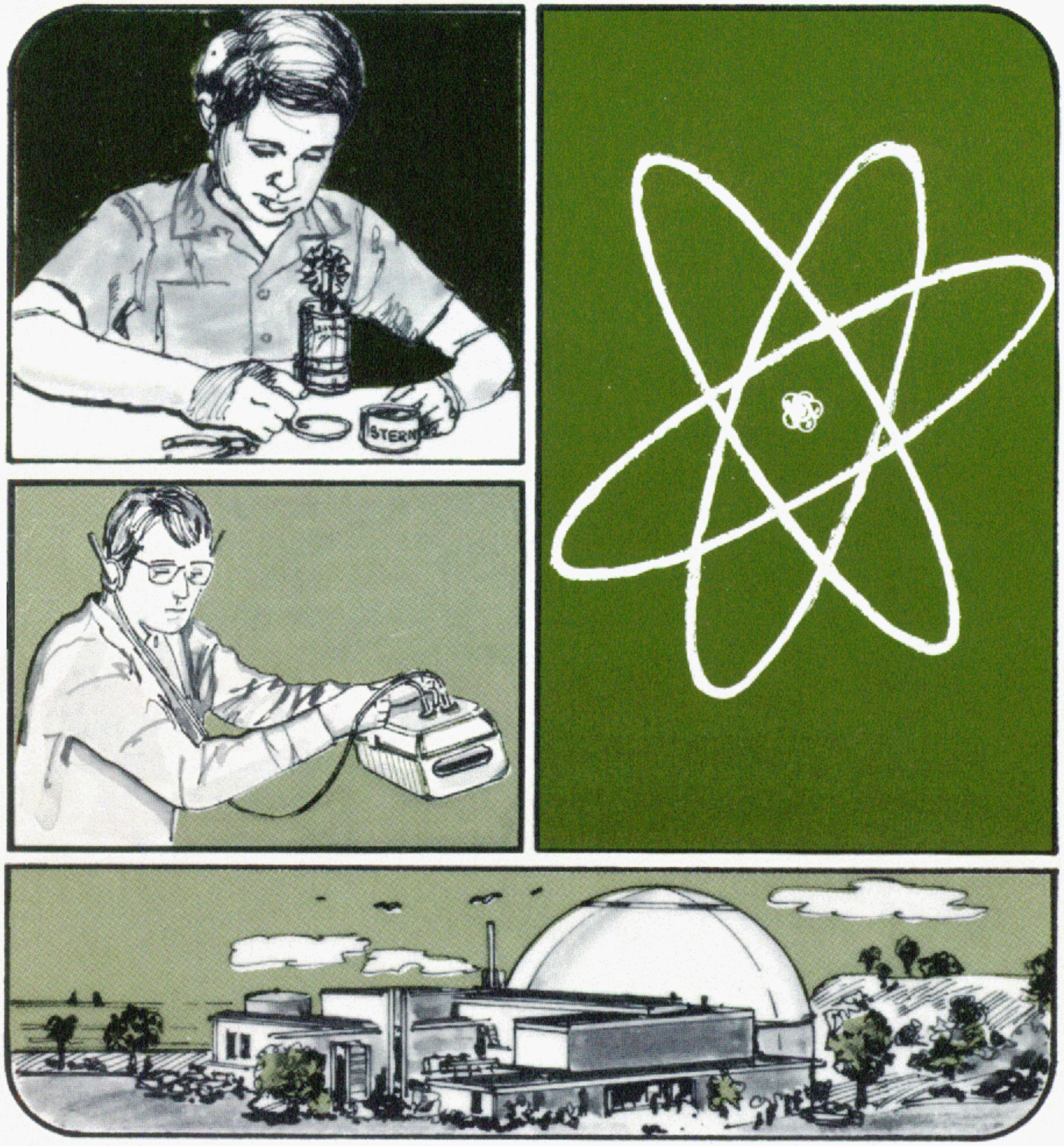
Nuclear Experiments You Can Do



...from Edison

We are grateful to Exxon Nuclear Company. Inc.
for their providing funds for the initial publication of this booklet.

NOTE

The experiments herein require an alpha ray source and a gamma ray source. Suitable sources not exceeding the low radioactivity limits set by the U.S. Nuclear Regulatory Commission are available to the public.

By far the least expensive "license free" or "exempt quantity" sources that could be found are made by The Nucleus Inc., Box R, Oak Ridge, Tennessee 37830. They provide an alpha ray source, containing polonium-210, designated as S-2. They also provide a gamma ray source, containing cesium-137, designated as S-6. Mail order cost is $5 apiece.

Each is a solid source housed within a one-inch diameter by l/4-inch thick plastic disc with identifying label. S-6 is completely sealed. But since sealing would block alpha rays, S-2 is uncovered. Therefore the user is cautioned not to disturb the polonium-210 coating recessed within the disc.

These solid sources are regarded by the supplier as safe. But as with chemicals and tools, radioactive materials should be respected and used with care. A brochure on proper handling techniques and safety precautions comes with the sources.

Shortly after this booklet was first published, we were informed of an even less expensive low-level source of alpha, beta, and gamma radiation. It is the silk gas mantle used for ordinary camping lanterns.

Readily available in stores selling camping equipment, gas mantles cost around 60¢ for a bag of two. We recommend they be left in their sealed plastic bag.

We were also told that coal, slate, and granite are possible low-level radioactive sources.

Nuclear Experiments You Can Do ...from Edison

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1982, Second Printing
1982, Third Printing
1986, Fourth Printing

INTO THE SECOND CENTURY OF LIGHT

A PUBLICATION OF THE
THOMAS ALVA EDISON FOUNDATION
21000 WEST TEN MILE ROAD
SOUTHFIELD, MICHIGAN 48075

ADVANCING SCIENCE, TECHNOLOGY AND ENGINEERING EDUCATION

THE PROMISE AND POTENTIAL OF NUCLEAR ENERGY

Nature provides many examples of the amazing properties and energy of the atom. The sun, being a nuclear reactor, is one example. Radioactivity is another.

Most of the nuclear power produced in the world today comes from the controlled splitting (fission) of radioactive uranium in reactors that transform uranium's nuclear energy into heat. Heat, in turn, creates steam for turbines to generate electricity, to propel ships, to drive industrial processes.

As a fuel, uranium has a distinct advantage over coal, oil, and gas. The latter three, as you know, are in limited supply. On the other hand, when uranium can be used in advanced nuclear fission reactors such as breeders, the known reserve of uranium would provide the world with energy for centuries to come. It represents a heat source that, properly controlled, is safe and does not significantly affect our environment.

This booklet contains some of the basic facts about nuclear energy, along with experiments related to these facts. An understanding of nuclear energy is essential if future citizens are to deal intelligently with questions on energy options . . . questions we face as a nation and as a world community.

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A GIGANTIC AND ILLIMITABLE FORCE

Many decades ago, Thomas Alva Edison wrote these words in his diary:

> *I am much interested in atomic energy, but so far as I can see, we have not yet reached the point where this exhaustless force can be harnessed and utilized. . . . The energy could be turned into electricity. . . . The force residing in such a power is gigantic and illimitable.*

Unfortunately, Edison didn't live long enough to see his words come true. He died 11 years before Enrico Fermi succeeded in producing the first controlled nuclear chain reaction in 1942. But Edison was right. The forces residing in atomic, or nuclear, energy *are* gigantic, and these forces can be turned into electricity.

In 1975, for example, 54 power plants across the United States were using nuclear energy to generate electricity. They supply almost one tenth of all the electricity consumed by the country. In the years ahead, we can look forward to even greater development of nuclear power.

This booklet is an introduction to nuclear energy. The eight experiments presented in the text will help you understand a few of the basic facts about the tremendous energy locked inside atoms. Before you begin to experiment though, you should know a bit more about atoms:

What's an Atom?

All matter is made up of atoms . . . different kinds of atoms joined in different combinations. The page you are reading is made up of zillions of atoms. So are you. And so is everything else around you. An atom is an exceedingly tiny thing: 200 million atoms lying side by side would span a distance of only one inch.

As late as the 19th century, many leading scientists of the day thought that atoms were indivisible blobs of matter, sort of like tiny solid balls. Now we know that atoms are far more complex. We also know that under the right conditions certain atoms can be split into smaller atoms.

An easy way to picture an atom is to think of it as a miniature solar system. In the center (somewhat like our sun) is a relatively large structure called the nucleus. Whirling around the nucleus (somewhat like the planets) are tiny particles called electrons. Each electron carries a negative electric charge.

Atoms of one material differ from atoms of another material because of the make-up of their nuclei and the number of electrons they have.

The nucleus of most atoms consists of two kinds of particles: protons and neutrons. Both the proton and neutron have about the same size and weight. However the proton carries a positive electric charge, while the neutron has no charge at all.

Note that we said the nucleus of *most* atoms contains both protons and neutrons. The exception is the hydrogen atom, the simplest atom of all. Its nucleus contains but a single proton.

The number of electrons orbiting an atom's nucleus is equal to the number of protons in the nucleus. Each electron carries a negative charge, and each proton carries a positive charge. Thus the charges balance. This makes the atom electrically neutral, which is another way of saying that the total negative charge equals the total positive charge.

Radioactivity

Interestingly, the neutron and proton were not discovered until well into the 20th century. But right around the turn of this century, scientists observed that certain atoms undergo mysterious transformations. For example, atoms of radium (a rare metallic element) turn into atoms of radon (a rare gaseous element).

Equally as surprising, the radium atom emits a tiny particle, called an alpha particle, when the change takes place. This alpha particle consists of two neutrons and two protons. It is identical to the nucleus of a helium atom. A stream of alpha particles is called an alpha ray.

We now know that this transformation is an example of radioactive decay, a process whereby one atom breaks apart to form one or more smaller atoms.

Radium atoms decay into radon atoms and alpha particles spontaneously. In other words, every so often an atom in a chunk of radium metal will decide, on its own, to break apart. There are many other atoms that will break apart spontaneously. Scientists call these substances naturally radioactive.

When an atom breaks apart, the decay process also gives off energy. In certain circumstances, it is possible to capture this energy in the form of heat, then use the heat to generate electricity. This is the principle of operation of all the nuclear-powered electricity generating plants that are at work today.

Atomic Cousins

There's one more nuclear term we want to define here: isotope. A bit earlier we said that different atoms have different nuclei and different numbers of electrons. An atom of oxygen, for example, has eight protons and eight neutrons in its nucleus and eight electrons whirling around the nucleus. Broadly speaking, it is the number of protons and electrons that determine the character of an atom and, consequently, the character of the chemical element that the atoms form.

Sometimes, a specific chemical element will contain atoms of slightly differing form. The numbers of protons and electrons will be the same, but the number of neutrons will not. These slightly different atoms are called isotopes. There are, for example, isotopes of oxygen that contain seven and nine neutrons, instead of eight.

Isotopes play an important role in nuclear energy. Specifically, an isotope of uranium called U-235 was the first material used to create a nuclear chain reaction.

If you have followed what we've said so far, you are ready to learn more about nuclear energy by performing the experiments that follow. Good luck.

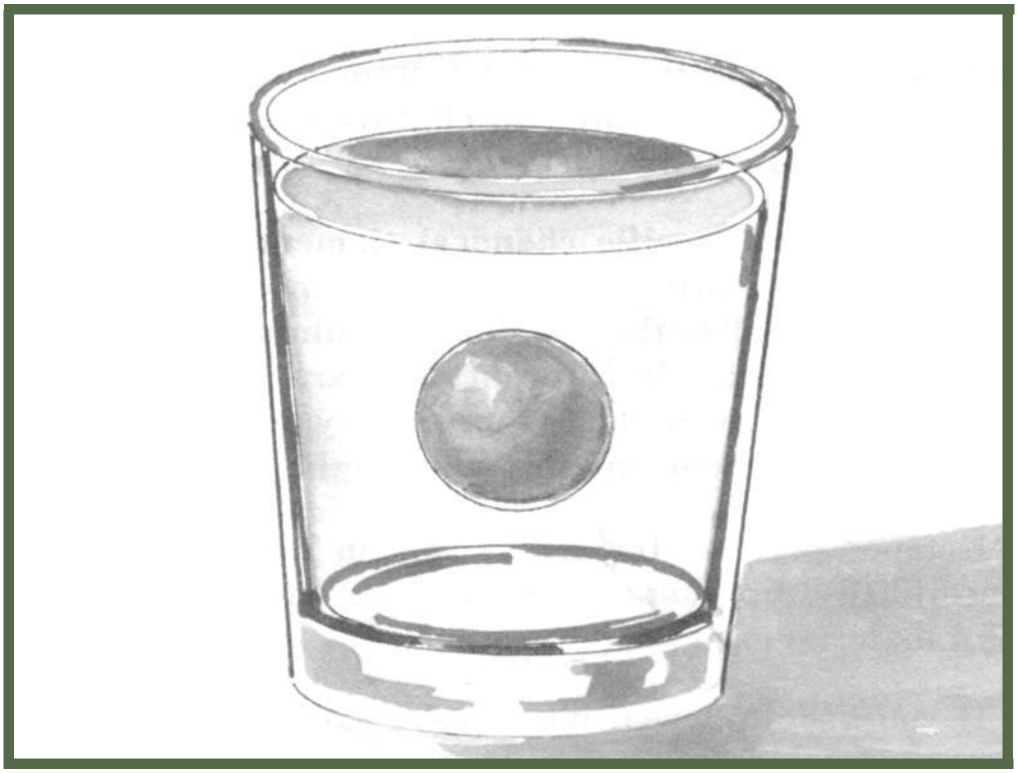
EXPERIMENT 1

An Oil-Drop Model of a Splitting Atom

THINGS YOU NEED: A small water glass. Five or six ounces of rubbing alcohol. An ounce or so of cooking oil. Some water. A teaspoon and a butter knife. A paper towel.

Many scientists have suggested that a splitting atom behaves somewhat like a drop of liquid when it breaks up into droplets. This experiment demonstrates the point.

Fill the water glass about half full with rubbing alcohol, then add enough water to fill the glass two-thirds full. Stir the alcohol-water mixture with the teaspoon.



Next, wipe the teaspoon dry and fill it with cooking oil.

Now comes the tricky part: Carefully bring the spoon close to the surface of the alcohol-water mixture in the glass, then gently tip the spoon over. If you've done the job right, a single blob of oil will slide into the glass.

If the blob of oil is floating on the surface, carefully add a bit more alcohol to the mixture (use your teaspoon): if the blob has sunk to the bottom of the glass, spoon in some more water. The idea is to change the blob of oil into an oil drop that hovers somewhere in the middle of the glass, as shown in the drawing.

Note how perfectly spherical the drop is. The forces that hold the oil drop together are analogous to the forces that hold an atom together.

Now take the butter knife and carefully prod the drop apart. At first, the drop will bulge. Then, it will tear apart into two perfectly round oil drops. The oil-drop "atom" will have split into two smaller "atoms." Note that the drop wouldn't split until it was critically deformed by the knife. Atoms behave in much the same way: They resist splitting until some action critically deforms them.

EXPERIMENT 2

A Domino Model of a Chain Reaction

THINGS YOU NEED: A set of dominos.

Back in the beginning we talked about atoms that decay spontaneously into smaller atoms. Inside a nuclear power plant, though, atoms are *made* to split. And this splitting occurs more or less on schedule, rather than by accident.

The isotope of uranium called U-235 is ideally suited for such action. U-235 atoms are easily split by bombarding them with neutrons. In effect, the neutrons act like bullets that trigger the splitting of the uranium atoms.

When a neutron strikes a U-235 atom, several things happen:

1. The atom breaks apart into the smaller atoms of barium and krypton.
2. A substantial amount of energy is released.
3. Two or more neutrons are hurled away by the splitting atom.

Item 1 is not too important, because we aren't really concerned with the by-products of the split uranium atom.

Item 2 is very important. This energy will be converted into electricity (we'll see how in a later experiment).

Item 3 is absolutely vital. For these emitted neutrons make it possible to produce a steady stream of nuclear energy. Why? When one U-235 atom splits, the neutrons it releases cause other U-235 atoms to split. The additional neutrons released trigger still other U-235 atoms. And on and on it goes. This kind of process is called a chain reaction.

Imagine a chunk of U-235 in which a chain reaction has begun. If the reaction takes place quickly enough, an enormous amount of energy is released.

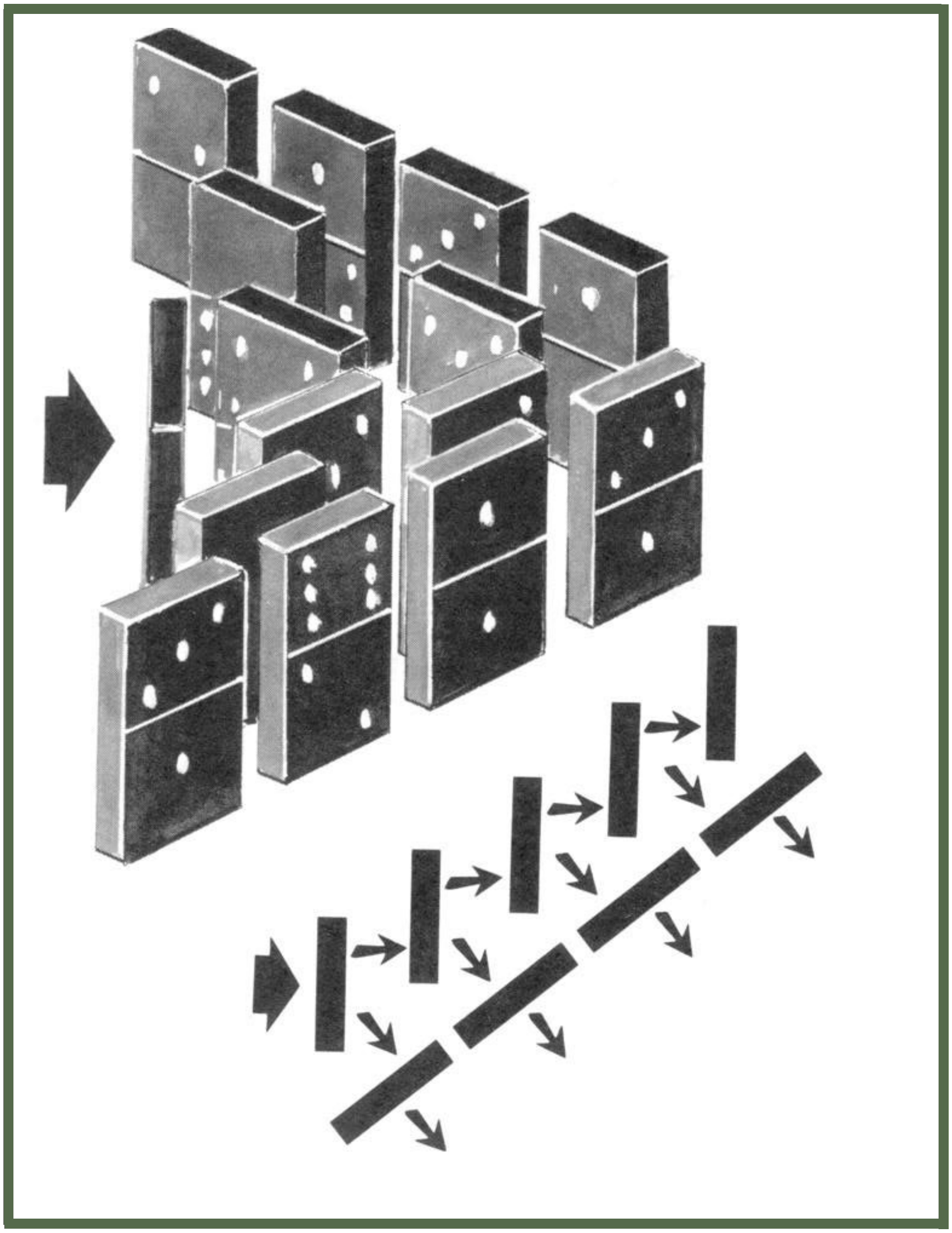
You can demonstrate this type of rapid-fire chain reaction by setting up your dominos as shown in the first domino drawing. When you tip the leading domino over, as if shooting a neutron bullet into uranium, it tips two other dominos over (releases two new neutrons). In turn, the two falling dominos tip over four more. And the uncontrolled chain reaction goes to completion.

But in a nuclear power plant, a runaway chain reaction — that is, an "atomic bomb" explosion — is impossible. Nuclear power plants control the reaction. Here's how it's done:

The heart of a nuclear power plant is a nuclear reactor. Without getting bogged down in details, a reactor contains bundles of nuclear fuel (U-235) separated by materials that absorb neutrons. Thus when a U-235 atom splits, all but one of the neutrons are absorbed before they can reach other U-235 atoms. The single remaining neutron is available to split another U-235 atom.

The result is a steady release of energy over a long period of time . . . a chain reaction that lasts years instead of a fraction of a second.

You can model this slow-moving kind of chain reaction by setting up your dominos as shown in the second domino drawing. This type of chain reaction "wastes" some of the neutrons produced. Some dominos fall without hitting other dominos.



EXPERIMENT 3

Observing Radioactivity with an Electroscope

THINGS YOU NEED: A source of alpha rays (see inside front cover). Two water glasses (one about an inch taller than the other). An old 12-inch phonograph record. A piece of wool cloth. A four-inch length of 1/4-inch diameter wood dowel. A six-inch length of clean stiff wire. Aluminium foil. Foil from a chewing gum wrapper.

This experiment is similar to a late-19th-century method of observing the effects of radioactivity. It's based on the fact that alpha particles can discharge an object that's been charged with static electricity. The principle isn't hard to understand.

When alpha particles strike atoms in the air, they "peel" electrons away from the atoms, leaving positively charged ions. These ions (and the negatively charged electrons) are then available to discharge the static electricity on any nearby object.

In this experiment, a simple electroscope indicates the presence of static electricity on the surface of a phonograph record. Make the electroscope as follows:

1. Twist one end of the wire around the center of the dowel. Leave a length of wire about three inches long protruding.
2. Bend a small L-shaped hook in the end of the wire.
3. Wrap and crumple some aluminum foil around the middle of the dowel. The ball of foil you make should be about 3/4 inches in diameter; the foil must make good contact with the wire.

4. Soak the chewing gum wrapper in warm water to remove the paper liner. Cut a small strip about two inches long and 3/8 inches wide.

5. Fold the strip in half, then place it over the hook.

6. Carefully insert the entire assembly into the smaller glass; the strip should hang freely in the center.

Next, put the taller glass about four inches away from the electroscope. Rub one surface of the record with the wool cloth for several seconds to charge it with static electricity. Then place the record, charged side down, on the taller glass. The rim of the record must hang over the foil ball on the electroscope.

As soon as you bring the charged record into position, you will see the two foil leaves of the electroscope spring apart. They are reacting to the record's static electric charge.

Now bring the alpha radiation source close to the electroscope ball under the record, with the source opening pointing at the ball. As the alpha particles discharge the static electricity (by producing ions in the surrounding air), the foil leaves will drop to their original position.

If you rotate the large glass slightly, you will shift a still-charged part of the record's surface over the electroscope. The leaves will fly apart again.

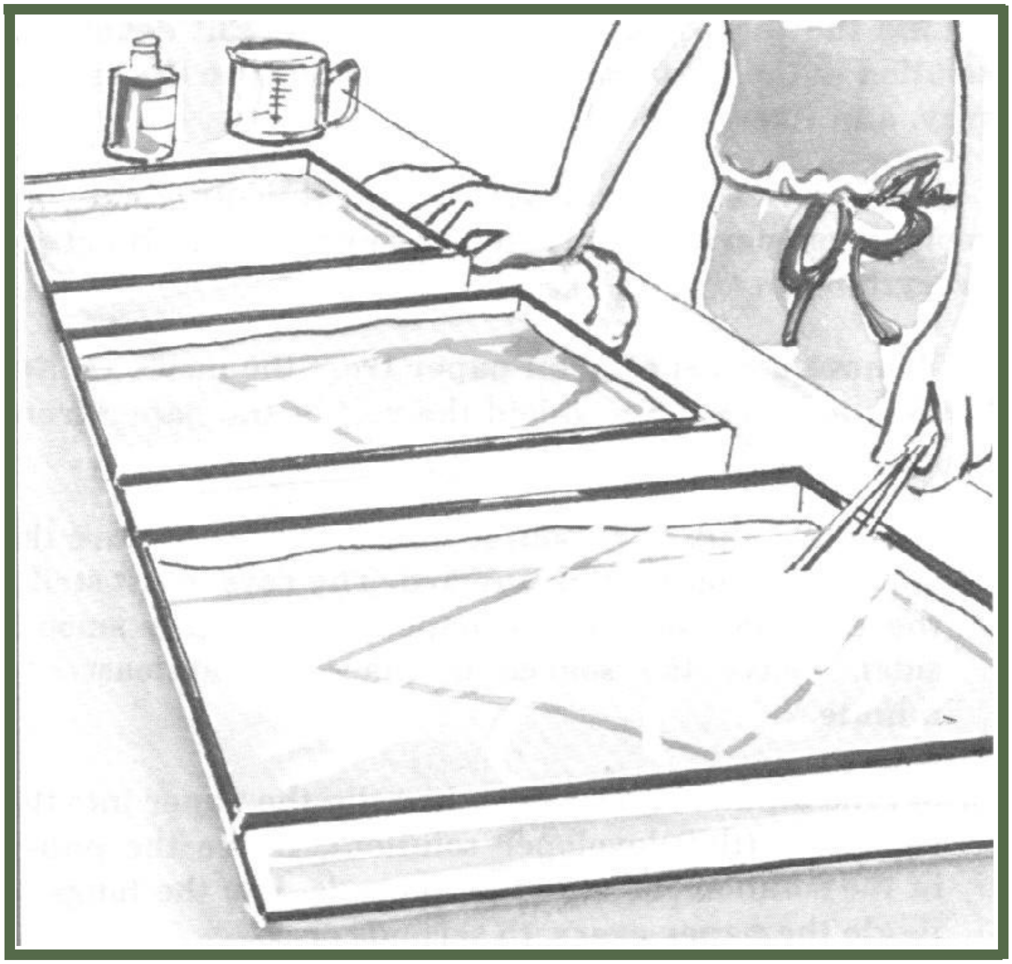
Repeat the experiment several times, holding the alpha source at different distances each time. You will observe that the farther away the source is from the record, the longer it takes to discharge the static electricity over the foil ball.

NOTE: Before dismantling your equipment, read Experiment 7.

EXPERIMENT 4

Observing Radioactivity by Radiography

THINGS YOU NEED: Alpha ray source from Experiment 3. Photographic print paper and a "one shot" kit containing developer, stop-bath, and fixer (both paper and kit are available at photo supply shops). A 16-ounce measuring cup. Three small plastic trays. A photographic "safelight" (optional). A dark room to work in (a bathroom is ideal). Plastic tongs.



This is an optional experiment on radiography, which is the art of taking a picture with radiation other than light . . . X-rays, for example. In this case we'll use alpha rays. Here, photographic print paper exposed to alpha rays will, when developed, show the radiation as. . . well, you'll see.

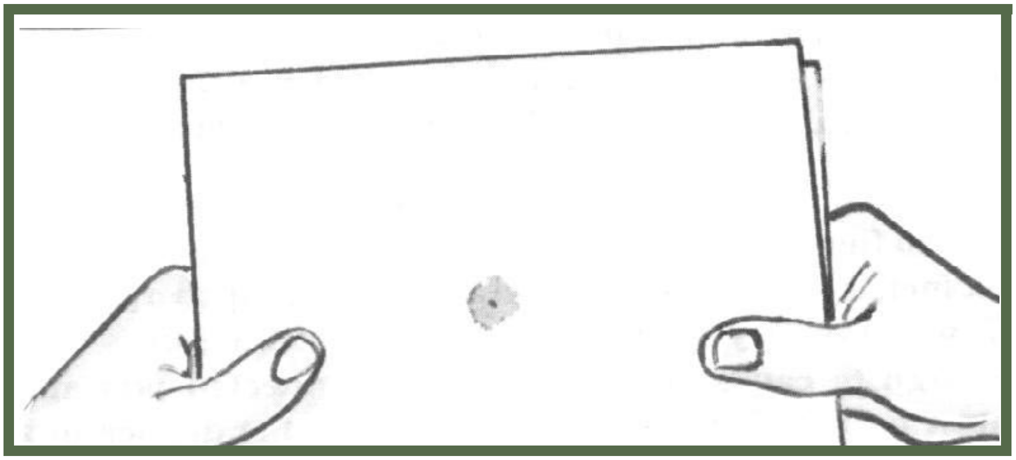
If you do not have access to photographic lab equipment and decide to buy the materials needed, start by mixing the three chemical powders supplied in the kit. Follow directions, but don't worry too much about water temperature; the quality of the developed print won't matter. Wash your hands if you get any powder or solution on them; some people are sensitive to the chemicals and can develop minor skin rashes if exposed to them.

Line the three plastic trays in a row. Put developer solution in the first tray, stop-bath solution in the second tray, and fixer in the third tray.

If you have a safelight, you can use it to illuminate the room as you perform the rest of the experiment. If not, do everything in *total darkness:*

1. Remove a sheet of print paper from the package. Reseal the package to shield the rest of the paper from light.
2. Place the alpha ray source on the paper; be sure the opening is pointing downward. The rays must strike the emulsion side of the paper (the creamy smooth side). Leave the source in place for at least one minute.
3. Set the alpha source aside, then slip the paper into the first tray (the developer solution). Leave the paper in the solution for about 90 seconds. Use the tongs to jiggle the paper every 15 seconds or so.
4. Pick up the piece of paper with your tongs, and transfer it to the second tray (the stop-bath solution). Leave the paper in that tray for 20 seconds.
5. Now with your tongs, transfer the paper to the third tray (the fixer solution). Leave it in the solution for at least five minutes. You can turn on the room lights after the paper has been in the third tray for 30 seconds.
6. Rinse the completed print under cold running water for at least five minutes.

If you've followed these instructions carefully, the print will show a darkened circular area corresponding to the opening in the alpha source. The longer the source was left in contact with the paper, the darker the area will be.



NOTE: Before disposing of the photographic solutions, read Experiment 7. The solutions are good for at least 12 print runs. But before each run, be sure to rinse all traces of fixer solution off the tongs.

EXPERIMENT 5

Observing Radioactivity with a Cloud Chamber

THINGS YOU NEED: A piece of dry ice (see paragraph four below). A large glass jar with lid; the jar should be about five inches high and about four inches wide (an old peanut butter jar would be fine). A piece of thick blotting paper. Glue. A piece of black velvet cloth. An old towel. Some rubbing alcohol. A powerful flashlight or high-intensity desk lamp. Alpha ray source from Experiment 3.

A cloud chamber is a device that allows scientists to see the trails made by nuclear particles. It was invented in 1912 by Charles T.R. Wilson, a pioneer atomic physicist.

Wilson discovered that water vapor can condense on ions just as it does on bits of dust to form raindrops. Now since nuclear particles, such as alpha rays, produce ions as they streak through water vapor, the vapor that condenses on these ions shows up as fine whitish trails.

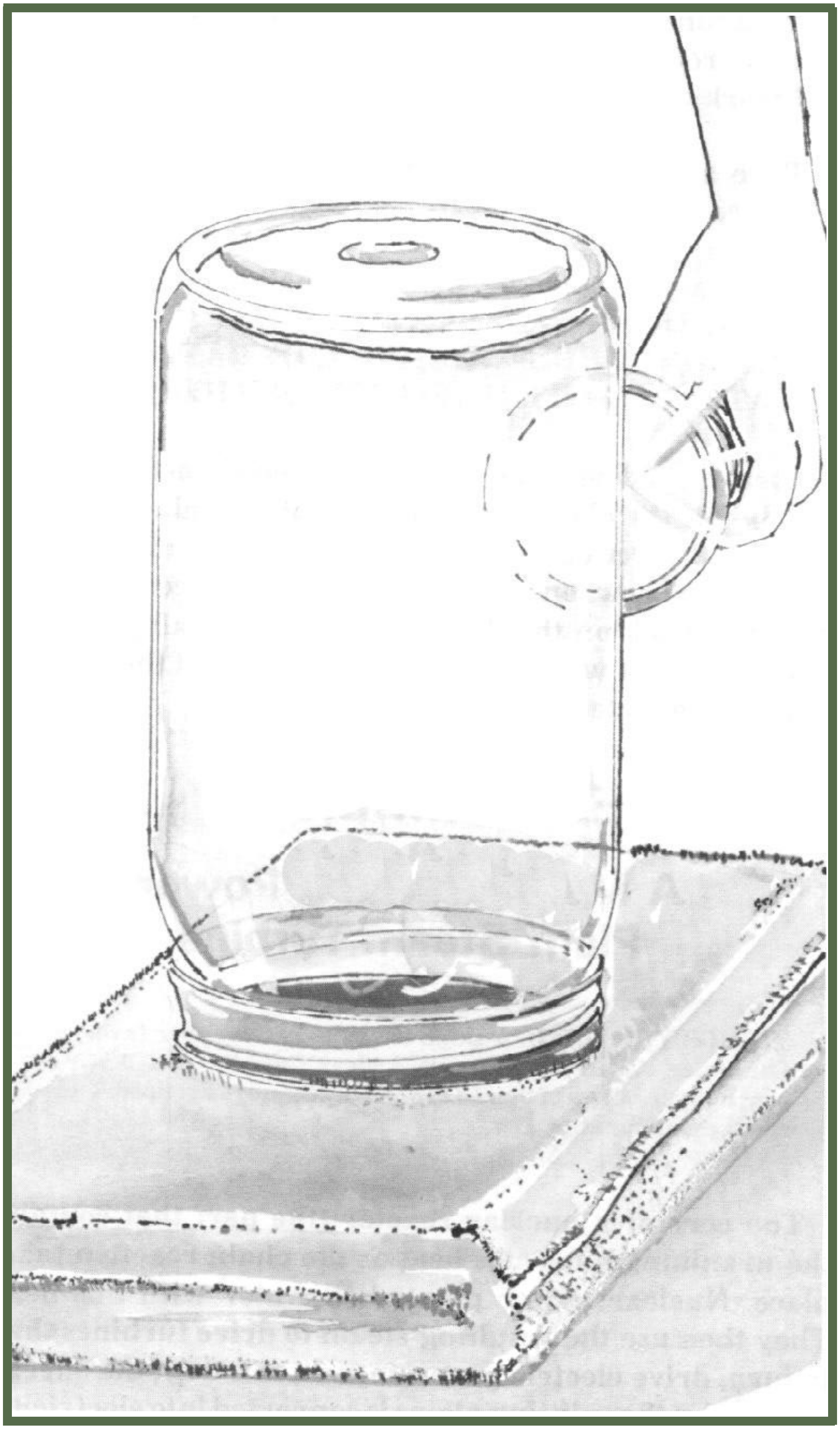
The cloud chamber in this experiment is a modification of Wilson's original design. It is called a diffusion-type chamber, and it uses alcohol vapor instead of water vapor.

Look up Dry Ice in your Yellow Pages telephone directory to find a dealer in your area. You need a piece about six inches by six inches by two inches (roughly two pounds in weight). Dry ice is frozen carbon dioxide. It is cold enough to cause severe burns to unprotected skin and must be handled very carefully. Wrap the dry ice in a towel; never touch the exposed ice. For safety's sake, it is a good idea to wear leather gloves when you handle the block.

Make the cloud chamber as follows:

1. Cut a circle of black velvet cloth to fit inside the metal jar lid. Cement it in place with a few dabs of glue.
2. Cut a circle of blotting paper to fit inside the bottom of the jar. Cement it in place with a few dabs of glue.
3. After the glue has dried fully, drip some rubbing alcohol onto the blotting paper. Keep dripping until the blotting paper is completely saturated, but does not show an excess of alcohol on its surface.
4. Screw the lid on the jar. Then place the jar, lid side down, on top of the wrapped block of dry ice.
5. Darken the room completely, then position the flashlight as shown in the drawing.
6. Wait patiently and keep looking at the path of the light beam.

After several minutes (it takes the chamber several minutes to form its cloud) you will see occasional white tracks near the metal lid. These are produced by the passage of cosmic rays (radiation from outer space) through the cloud chamber.



The alpha source used in earlier experiments is not an ideal source for use inside a cloud chamber. However, it will work (usually) if you modify it as follows:

1. Tape a piece of aluminum over the opening on the source.

2. Using a pin or needle, pierce a small hole through the tape and foil. BE VERY CAREFUL NOT TO LET THE PIN OR NEEDLE TOUCH THE RADIOACTIVE MATERIAL AT THE BOTTOM OF THE OPENING.

Open the cloud chamber (it'll be cold, so take care). Resaturate the blotting paper with rubbing alcohol Place the alpha source on the black velvet so that the hole points inwards. Screw on the glass bottom, place the cloud chamber back on the dry ice, and wait. If all goes well, you will see fat white tracks characteristic of the passage of alpha particles.

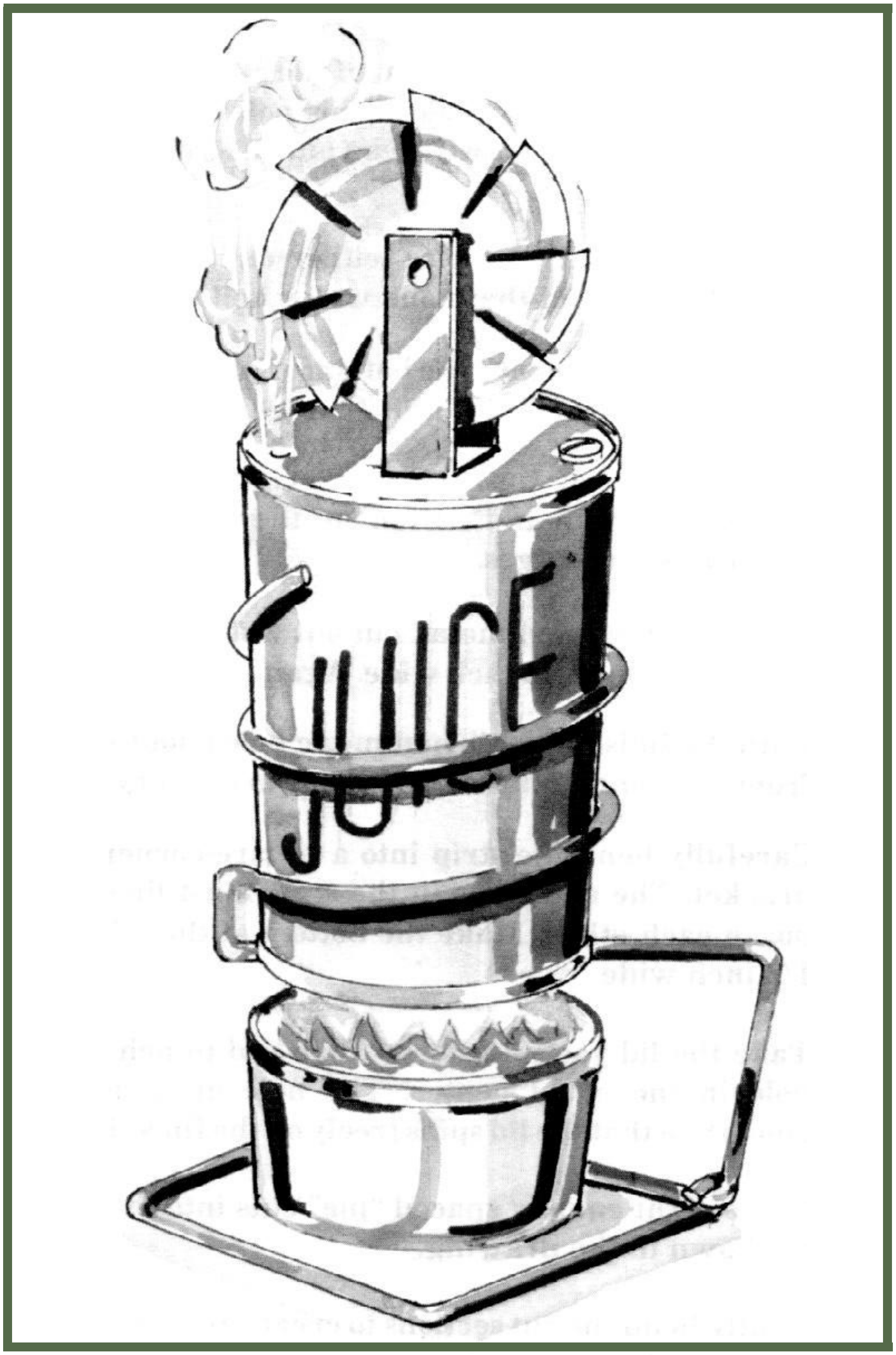
EXPERIMENT 6

A Model Nuclear Power Plant Steam Turbine

THINGS YOU NEED: A small unopened can of your favorite fruit juice. An empty soup can. A clean finishing nail. A wire coat hanger. A can of Sterno canned heat. An eye dropper. Two small sheet metal screws.

The core of a nuclear reactor (the part that contains the uranium) generates heat as the chain reaction takes place. Nuclear power plants boil water with this heat. They then use the resulting steam to drive turbines that, in turn, drive electric generators. In this way, the energy emitted by the splitting atoms is converted into electricity.

This simple model will show you how a steam turbine operates. Here's how to build it:



1. Use the nail to punch two small holes in the top of the fruit juice can. The holes should be on opposite sides of the top, about l/4 inch from the edge.
2. Pour all of the fruit juice out of the can (maybe you'd like to take a juice break at this point). Remove the paper label, then rinse the can out with water as best you are able.
3. Plug one of the two holes (either one) with a sheet metal screw. And that's our water boiler.
4. Now carefully remove the bottom of the soup can with a can opener, and set it aside.
5. Using a pair of tinsnips, cautiously cut along the length of the can and flatten out the metal. Look out for those sharp edges.
6. From the flattened metal, cut out a strip about 4-l/2 inches long and l/2 inch wide. Again, work with care.
7. With the finishing nail, hammer a hole about l/4 inch from each end of the strip and one in the very center.
8. Carefully bend the strip into a square-cornered "U" bracket. The end holes in the strip must line up opposite each other. Make the bottom of the "U" about l/2 inch wide.
9. Take the lid you set aside earlier and punch a small hole in the exact center. The hole must be large enough so that the lid spins freely on the finishing nail.
10. Make eight equally spaced "pie" cuts into the can lid as shown in the drawing.
11. Gently bend the cut sections to create an eight-bladed turbine wheel.

12. Using the finishing nail as an axle, assemble the fan inside the “U” bracket.

13. Locate the bracket on the can so that when steam shoots from the opening, it will hit the flat part of the blades. Now mount the bracket on the can with the other sheet metal screw. To keep the turbine wheel centered, wrap some tape on the axle on both sides of the wheel.

14. Fashion a simple support stand out of the coat hanger, as illustrated. The stand must support the juice can about four inches over the open Sterno can.

15. Use the eye dropper to fill the can about l/3 full with water.

16. Light the Sterno and place it under the boiler. In a few minutes, the water will boil and steam will spin the turbine.

EXPERIMENT 7

Demonstrate How Radioactivity Can Be Shielded

THINGS YOU NEED: Equipment from Experiments 3 and 4 (see also the last paragraph in this section). Small pieces of different materials such as paper, aluminum foil plastic, and wood.

Certain radioactive emissions can be dangerous. Thus, nuclear power plants have extensive shielding to protect employees and people living in nearby communities. This shielding is so effective that you can spend your whole life living next to a nuclear power plant and receive only about the same total dose of radiation as if you had taken a chest X-ray.

This experiment demonstrates the radioactivity shielding properties of various materials. But before starting it, you should know a little more about the three kinds of radiation given off by a radioactive substance: alpha rays, beta rays, and gamma rays.

As we said earlier, alpha rays are made up of alpha particles, and each alpha particle is identical, in all respects, to the nucleus of a helium atom. Because of its relatively large size (compared with other forms of radiation) an alpha particle is easily blocked by many common materials.

Similarly, beta rays are made up of beta particles. A beta particle is actually an electron. It is much smaller than an alpha particle and, therefore, has greater penetrating power. Denser materials are needed to stop beta particles.

But of the three, gamma rays have the greatest penetrating power; so they require the densest shielding materials. Curiously, gamma rays are *not* made up of particles. There is no such thing as a gamma particle. Gamma rays consist of individual packets of energy called photons.

Now to work. The two experiments you performed earlier, Experiments 3 and 4, are easily modified to demonstrate how alpha rays can be shielded. All you need do is cover the opening on your alpha source with different materials before you perform the experiments. If a particular material blocks alpha rays, the static electricity around the electroscope (Experiment 3) will not be discharged, and the photographic paper (Experiment 4) will show nothing.

Test as many different materials as you can find; keep a log that records whether or not each specific material blocks alpha rays. Try to include a thin sheet of mica in your tests. Perhaps your chemistry or science teacher may be able to lend you a piece. You will find that this material allows alpha rays to pass through.

Testing materials for their ability to stop gamma rays is not as simple as the alpha ray experiment. For this you need a gamma source and a Geiger counter, which detects radioactivity. If, as suggested in Experiment 8, your class has built a Geiger counter and has a gamma source, you can investigate a much wider range of materials. Some possibilities include concrete, steel, water, and lead.

EXPERIMENT 8

Build a Geiger Counter (A Class Project)

THINGS YOUR CLASS WILL NEED: Geiger counter components (see parts list and circuit diagram). Gamma ray source.*

Chances are you've heard of a Geiger counter before. This versatile instrument is one of the most useful pieces of equipment ever developed for detecting the presence of radioactive emissions.

A Geiger counter is a relatively simple device. Its heart is the Geiger tube, a chamber filled with a mixture of special gases and equipped with a pair of internal electrodes that must be charged at high voltage.

Normally, the gas inside a charged Geiger tube does not conduct electricity. However, if a radioactive emission strikes the tube, the gas is momentarily ionized, and it becomes a conductor for a split second. Thus, a pulse of electric current flows through the tube, from electrode to electrode. The electrical circuit of the Geiger counter is designed so that a click is produced by the headphones each time a pulse of current flows through the tube. Each click you hear means that a radioactive emission has struck the Geiger tube.

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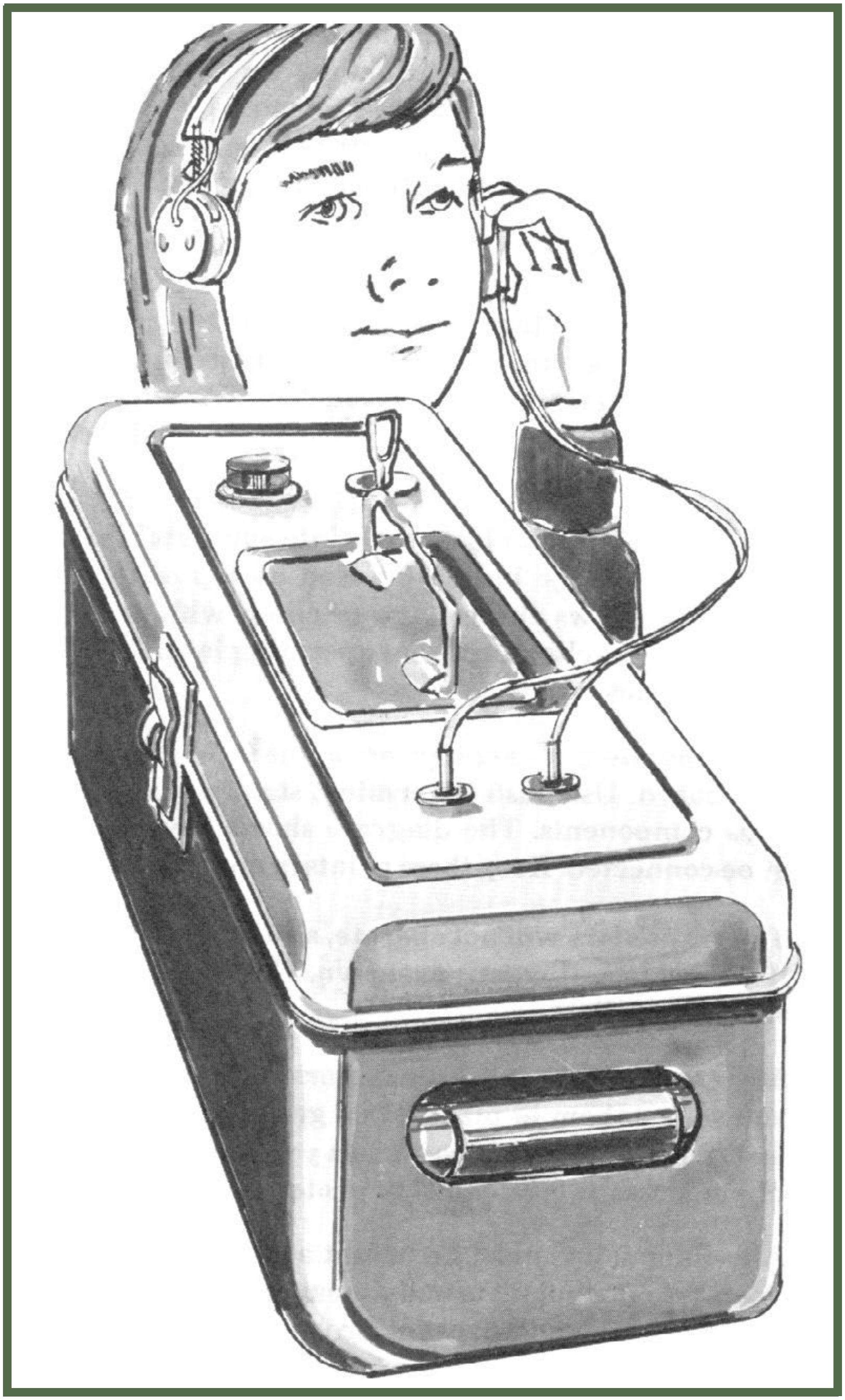
*Your school may have a gamma ray source or a chunk of radioactive ore. If not, try to find an old luminous-dial watch or clock. These timepieces, unlike newer models, have a small amount of radioactive material, radium, mixed in with the dial phosphors. If all else fails, a low level gamma ray source intended for educational use is available by mail order (see inside front cover).



Some Geiger tubes will respond to alpha, beta, and gamma radiation. However, the tube we used has a thin metal envelope that cannot be penetrated by alpha particles. Thus, this instrument detects only beta and gamma rays, along with cosmic rays from outer space.

The Geiger tube needs about 900 volts to work. And believe it or not, our little unit can generate that voltage from the six-volt battery. But don't let that high voltage frighten you. The unit is completely safe because it has a very low current output. Nevertheless, don't touch the Geiger tube or the capacitors. You *can* get a mild shock if you go looking for trouble.

How does the unit build six volts into 900 volts? In steps. Tapping the charge button (located on top of the unit) many times allows the voltage to climb with each tap. Eventually the voltage reaches operating level. We'll say more about this later.

Build the Geiger counter on a piece of perforated chassis board. Use push-in terminal strips to support the various components. The diagram shows how the parts must be connected. Keep these points in mind as you work:

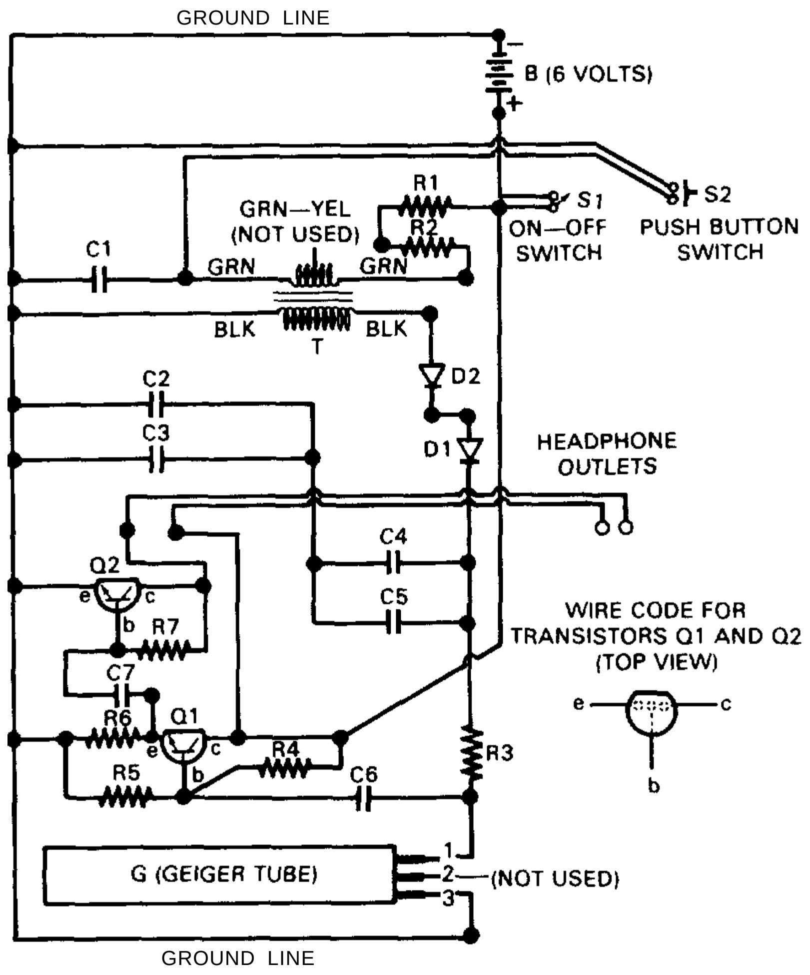
1. The transistors will not operate, and may be damaged, if not connected exactly as shown. This is also true of the silicon rectifiers.

2. Try not to overheat the transistors and rectifiers when you solder them in place. It's a good idea to grip each lead with long-nose pliers when you start to solder (the pliers act as a "heat sink" to protect the parts).

3. All solder joints must be bright and shiny. Gray, dull, grainy solder joints usually mean poor electrical connections and could prevent proper operation.

4. The Geiger tube is so delicate you could deform it

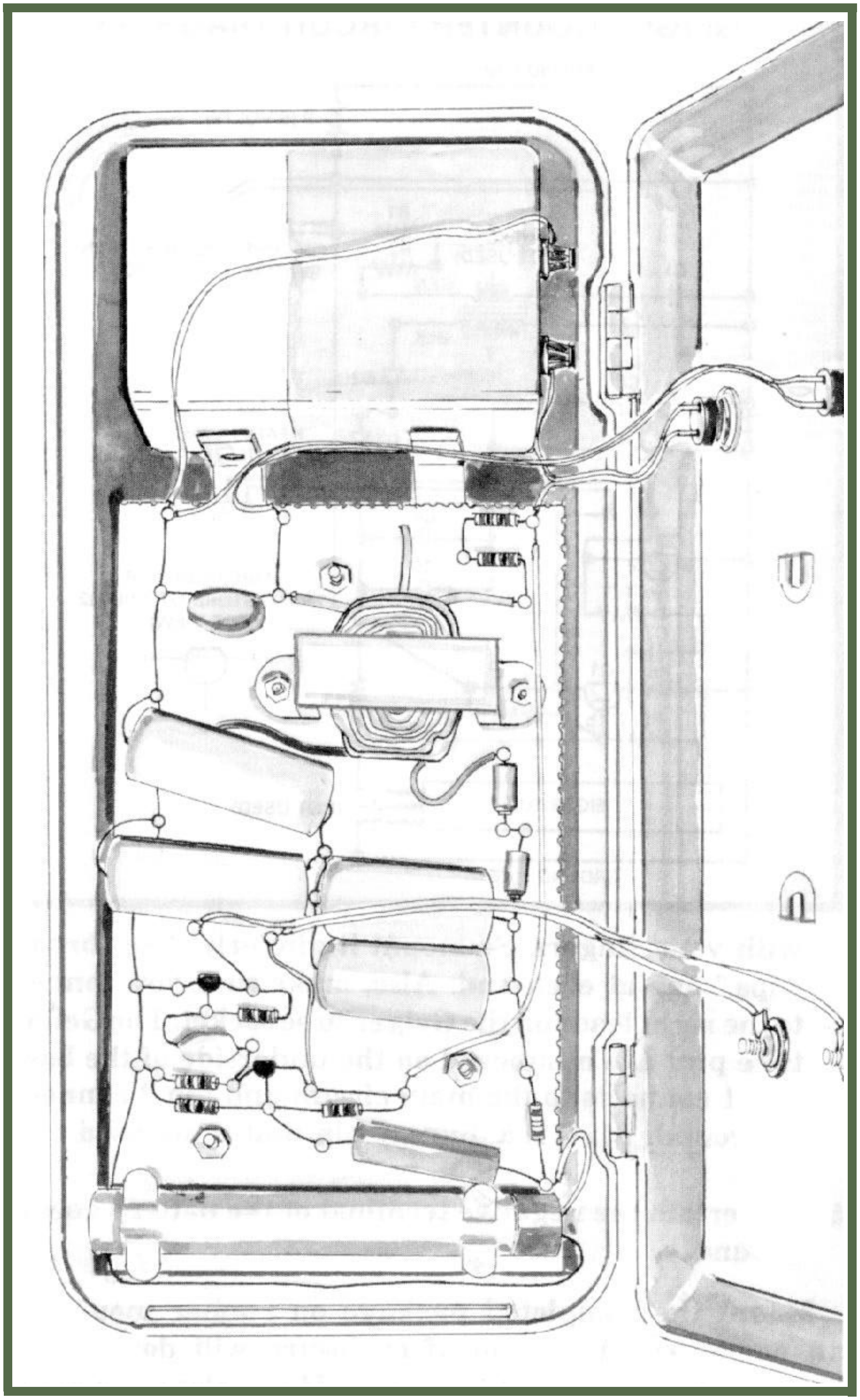
GEIGER COUNTER CIRCUIT DIAGRAM



with your fingers. So mount it gingerly. Use "broom clips," one at each end. Also, make sure you connect to the right leads on the Geiger tube socket. The Geiger tube pins are numbered on the underside of the base. Pin 1 connects to the main circuit and pin 3 connects to ground. Pin 2 is a dummy pin that is not used.

5. Be certain the negative terminal of the battery goes to ground.

Mount the completed package on rubber mounts in an enclosure. Any kind of enclosure will do; we just happened to pick a metal tool box. If you also use a metal



box, don't let any of the exposed wiring touch the metal walls.

Before you install the assembly, cut a large rectangular hole in the wall next to where the Geiger tube will be. The hole will serve as a radiation window. Incidentally, both switches and the headphone pin jacks must be mounted on top of the enclosure.

Procedure for Charging Geiger Counter

1. Needless to say, turn on the power switch (S1).
2. Put on the headphones.
3. Tap the charge switch (S2) firmly in a rapid-fire manner about 60 times, or until you hear random clicking. This is normal background noise caused by cosmic rays.
4. After the unit is charged up, tap the switch occasionally to keep it charged. You'll be able to tell how often this has to be done when you start using the counter. It may range from several seconds to a minute or so.

Assuming you have a gamma source, note that when you bring the source near the Geiger counter, or vice versa, the clicking will increase dramatically.

If you were fortunate enough to locate more than one source, the counter will indicate their relative strengths by the clicking intensity.

With the Geiger counter and gamma ray source, you can now do the last part of Experiment 7 (on gamma ray shielding materials).

Geiger Counter Parts List

Rl, R2 — l.0-ohm, l/2-watt carbon resister

R3 — 1,500,000-ohm, l/2-watt carbon resistor

R4, R5, R7 — 560,000-ohm, l/2-watt carbon resistor

R6 — 2700-ohm, l/2-watt carbon resistor

Cl — 0.0033-mfd, 600-volt tubular capacitor

C2, C3, C4, C5 — 0.47-mfd, 600-volt tubular capacitor

C6 — 0.006-mfd, 1600-volt tubular capacitor

C7 — 0.047-mfd, 250-volt (or higher) tubular capacitor

T — 6.3-volt AC, 1.0 ampere filament transformer

S1 — SPST toggle switch

S2 — SPST normally open push-button switch

Dl, D2 — Silicon rectifier, 1000-volt PIV rating, l-ampere (or higher) rated current capacity, low reverse current (20 microamperes or lower)

Ql, Q2 — NPN silicon transistor (2N3402 or equivalent)

Headphones — 2000-ohm high sensitivity headphones

B — 6-volt battery with screw terminals

G — Geiger tube (A tube and bakelite socket are available for about $20 from The Nucleus Inc., Box R, Oak Ridge, Tennessee 37830. Ask for tube-socket unit SG-2)

Perforated chassis board

Push-in terminals

Hookup wire

Suitable enclosure

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