THE ELECTRONICS SCIENTIST

Homemade Electroscopes
Experimenting with a Geiger Counter

By Forrest M. Mims, III

More About Radiation Monitors

THE subject of nuclear radiation often generates concern about human safety. I was reminded of this recently while gathering information for this column. I had taken a portable Geiger counter into a department store to search for radioactive materials. In the sporting goods department, I found what I was looking for. When I pushed the Geiger counter into a display of a hundred or more Coleman lamp mantles, the counter emitted a chorus of loud chirps. The saleslady was thoroughly alarmed. As you may know (she didn't), lamp mantles contain radioactive thorium.

This month we'll explore the topic of low-level radioactivity. We'll also build from common household materials a couple of electroscopes, a type of early voltage and radiation detector.

Recently I've heard from two manufacturers of radiation monitoring instruments in response to my coverage of this topic for this magazine (see "Solid-State Developments," April 1983). First, Mr. Al Zirkes, Marketing Manager of the Dosimeter Corporation (P.O. Box 42377, Cincinnati, OH 45242), sent a thick package of information about his company's wide ranging line of radiation measuring instruments and related products.

Among its electronic monitors is the MiniRAD-D (Fig. 1), a pocket-sized monitor that displays (on a 4-digit liquid-crystal readout) radiation levels up to 2000 milliroentgens per hour (mR/hr). It includes an audible indication of the radiation level as well as a visual indication provided by flashing LEDs. The MiniRAD-D sells for $375.

Another member of Dosimeter Corporation's family of compact electronic radiation monitors is the MiniCON®II (Fig. 2). It displays radiation levels on a conventional moving-coil meter and includes an audible output. A useful advantage of the unit is its cable-connected, external Geiger tube. This greatly simplifies some measurements since the tube can be placed in locations where instruments with internal tubes will not fit. The MiniCON II sells for $450.

Dosimeter Corporation makes a complete line of electronic radiation monitors like the MiniRAD-D and the MiniCON II, but its best-known product is based upon an operating principle not included in my previous column. Noticing this omission, Mr. Zerkes wrote that I failed to describe ". . . the largest selling and lowest cost personnel radiation detection device, the Direct Reading Pencil Dosimeter, which outsells all of the instruments noted by a factor of at least 100."

I purposely omitted direct reading dosimeters from the previous article since they are not usually considered *electronic* devices. Other such devices include film badges, certain plastics, and phosphor screens.

In a very real sense, however, Dosimeter Corp.'s pocket dosimeters are indeed electronic devices. In fact, they are the modern version of one of the very first electronic instruments, the *electroscope.*

Since Dosimeter Corp.'s pencil dosimeters sell for as little as $95, they are certainly economical. However, since they require a charger that costs another $80 or more, they are not as economical as some competing devices.

For example, Mr. Dan Sythe of Solar Electronics International (156 Drakes Lane, Summertown, TN 38438), the second firm to respond to my earlier article, loaned me one of his company's Monitor 4 radiation detectors. This instrument, which I briefly described in the previous article, indicates alpha, beta and gamma radiation on a scaled moving-coil meter and with audible chirps—not bad for a device that sells for $150. In its nonaudio mode, the Monitor 4, indicates individual counts with a flashing LED. While it lacks the ruggedized construction of its more expensive counterparts, it is compact and has a low power consumption.

Later in this column I'll describe how I've used the Monitor 4 to measure the radioactivity of several objects found in or around most homes. Meanwhile, let's find out more about the operating principles of direct reading dosimeters.

Direct Reading Dosimeters. The direct reading dosimeter is a modern form of the venerable electroscope, one of the first devices capable of indicating the presence of static electricity. The electroscope is based upon the well-known principle that unlike charges attract while like charges repel.

Traditional electroscopes are made by folding a rectangular piece of gold leaf into two equal halves and hanging it from a conducting support in a glass bottle. The electroscope is "charged" by touching a positively or negatively charged object or electrode to a metal sphere attached to the conductor emerging from the bottle. This applies an equal charge to both leaves of gold foil. Since like charges repel, the leaves will then fly apart and defy gravity until their charge gradually leaks away into the surrounding air or is intentionally shorted to ground.

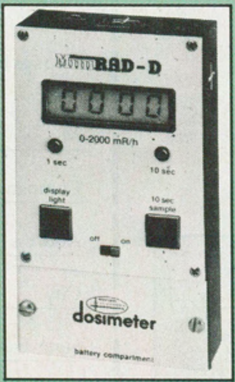

Fig. 1. Dosimeter's MiniRAD-D.

Fig. 2. MiniCON radiation monitor.

So how does the electroscope detect radiation? The charged leaves of the electroscope will gradually give up their charge by transferring electrons to or receiving electrons from the surrounding air. Unless it contains moisture, however, air is a poor conductor of electrons. Radioactive particles and rays have the ability to strip electrons from atoms that form air. These ionized atoms provide a conductive path for the charged leaves of an electroscope. Therefore, assuming no other leakage paths are present, the distance between the leaves of a charged electroscope is proportional to the cumulative radiation which has entered the space around the electroscope's leaves.

Figure 3 is a cutaway pictorial view of a typical pencil dosimeter made by Dosimeter Corporation. The device is prepared for use by first inserting the end containing the contact pin into the socket of a charger. The contact pin is mounted within a flexible metal bellows. When the dosimeter is pressed down into the charger's socket (Fig. 4), the opposite end of the contact pin makes contact with a metal member (the frame) inside the dosimeter. A charge of about 170 V is then transferred to the frame via the contact pin.

The charge is also applied simultaneously to a metal-plated quartz fiber suspended from and in electrical contact with a hinge on the frame. Since the frame and the fiber are given equal and like charges, the fiber swings away from the frame as illustrated in Fig. 3.

The sealed portion of the dosimeter that houses the quartz fiber and its frame is filled with dry air and is called an *ion chamber.* Radiation entering the chamber ionizes atoms of air, thereby providing a conductive path for some of the electrons on the fiber. As the charge on the fiber is gradually diminished by a radiation field, the quartz fiber moves toward the frame.

The position of the fiber can be viewed against a scale inside the dosimeter by peering through the instrument's eyelens while pointing the contact end toward a light source. Light enters the instrument through a glass collar around the contact pin.

A key component of the dosimeter is the contact-pin/bellows assembly. Since the bellows pulls the contact pin away from the frame when the instrument is pulled from the charging socket, the charged quartz fiber is electrically isolated from the outside world. Consequently, a dosimeter typically loses only about 0.25% of its charge per day.

The pencil dosimeter is a very important radiation monitoring device. Unlike most electronic monitors, it is truly pocket-sized. And although, it doesn't provide an indication of the *rate* of incoming radiation, it does give an accurate measure of *cumulative* exposure. Note too, that although it requires an external charger, one charger can be used to service dozens of instruments.

A Homemade Electroscope. Figure 5 shows a simple electroscope you can make from homemade materials. For best results use a heavy-gauge copper wire for the conducting support. Round off both ends of the wire with a small file and fine sanding paper. This eliminates sharp edges and burrs that would otherwise serve as discharge points for the charged leaves. Insert the support wire through a cork and form it as shown in the figure.

Some hobby and craft stores sell gold leaf which you can use to make a traditional electroscope. But I've used both standard and heavy-duty aluminum foil with good results. The standard gauge works best.

Prepare the foil by cutting it with sharp scissors to the size you plan to use. The finished size isn't critical so long as the leaves don't touch the sides of the bottle. Next, smooth the foil by placing it on a flat surface and stroking it a few times with a smooth pencil or your thumb. For best results, the foil should be as flat as possible. But this is not easy since it tends to curl when stroked.

After you smooth the foil, fold it in two equal sections over the edge of a piece of cardboard and hang the foil leaves over the support wired. Insert the cork with support wire and foil leaves into the jar as shown in Fig. 5. The leaves should be closely spaced and parallel to one another.

You can charge this homemade electroscope simply by touching the exposed end of the support wire with a comb you've stroked a few times through your hair. If both your hair and the comb are dry, the leaves will fly apart and remain extended for at least a

Fig. 4. Charging a dosimeter.

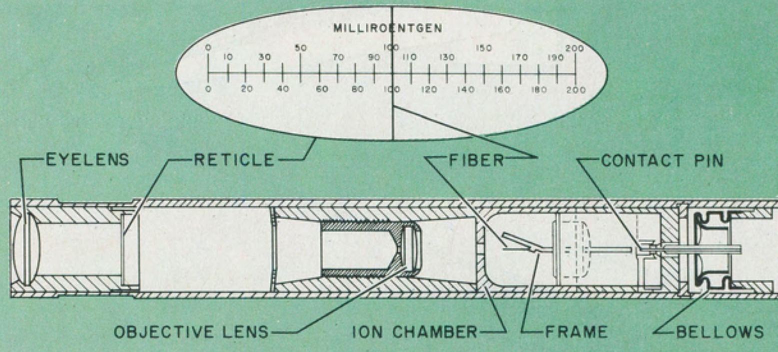

Fig. 3. Cutaway view of the pencil dosimeter.

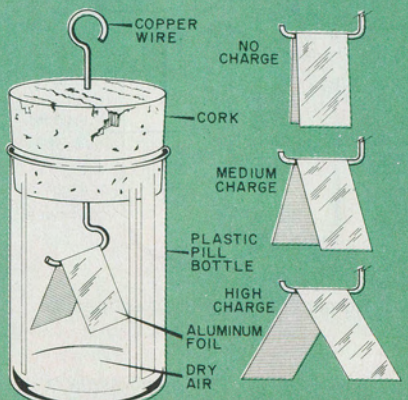

Fig. 5. A simple, do-it-yourself pill-bottle electroscope.

few seconds. On a very dry day, they will stay apart for quite some time.

If the leaves appear to stick to the sides of the bottle, use a larger container or smaller leaves. If the leaves fail to diverge when the electroscope is charged, make sure they have not become attached to one another at any slight nicks or frayed edges along the edge of the foil.

Failure of the leaves to diverge may indicate moist air in the electroscope's bottle (its ion chamber). Assuming everything else checks out, but the leaves still fail to repel one another, it may be necessary to replace the air in the bottle with dry air.

Several companies sell cans of pressurized, filtered, dry air for blowing dust from photographic film and mechanical devices. I've had good results using such air in my homemade electroscopes. Just remove the cork and leaves, squirt a dose of dry air into the bottle, and quickly replace the cork and leaves.

When you place a radioactive sample (see below) near the exposed electroscope wire, the leaves will begin to collapse at a much faster rate than normal. Move the sample away and the leaves will stop falling. This proves that a charged electroscope, even one made with household materials, can indeed detect ionizing radiation.

A Better Electroscope. Figure 6 shows another homemade electroscope with which I've experimented. It differs from the first in that it has but one moving leaf. The second leaf had been replaced by a rigid rectangle of two-sided copper-plated printed-circuit board.

The support member is a copper wire soldered to the back side of the pc board and bent around to the front side to form a support for the movable leaf. The leaf is a strip of smooth, flat aluminum foil. Shape the foil by wrapping one end of it around a wire with a diameter larger than that of the support wire. Then slip the resulting foil tube over the support wire to form a hinged leaf.

This electroscope can be installed in a plastic pill bottle much like the one in Fig. 5. I used, however, a small glass bottle of the type used to ship soft contact lenses. The bottle has a plastic cap into which you can easily insert the support wire. The cap provides a secure seal and is easily removed.

Note that this electroscope doesn't have a protruding wire contact. This greatly reduces the possible leakage paths and preserves the electroscope's charge for a longer time.

A Non-Electronic Electroscope Amplifier. You can amplify the motion of the leaves of an electroscope by reflecting a narrow beam of light from one of the leaves. If the reflected spot of light is directed toward a white card marked with an appropriate scale, you can easily measure movements of the leaf.

Figure 7 shows how you can use a helium-neon laser for this purpose. For best results, make sure the shiny side of the aluminum foil electroscope leaf faces *outward.*

If you place the white card a few feet away from the electroscope, the reflected spot of light may move 6" or more as the leaf falls from its fully charged, extended position. Since the foil surface is not perfectly flat, the reflected spot of light will be fairly large and blurred around the edges. Nevertheless, by arranging the electroscope, laser and card in suitable positions, you should have little difficulty detecting very tiny movements of the electroscope's leaf when a sample of radioactive material is placed near its external electrode.

Radiation Sources. By now you may be wondering where to obtain a radioactive source to check out a homemade electroscope. One possibility is to purchase a source from a manufacturer or distributor of radiation monitors. For instance, Dosimeter Corporation sells a source containing 5-microcuries or cesium 137 for $35.

You can obtain other sources for considerably less, though. The cheapest is probably a thorium impregnated lamp mantle made by Coleman, Aladdin and Gaz. These mantles contain thorium-232, an isotope that can be bred into uranium-233, the fissionable isotope used in nuclear reactors and weapons. Thorium-232 emits alpha particles, and decays through a series of ten *radio-daughters* (subsequent elements), the first being a beta emitter, radium-228.

Another reasonably low-priced radioactive source is the polonium-210 used in Staticmaster dust removers, a product of Nuclear Products Company (Box 5178, El Monte, CA 91734). The Staticmaster is a soft brush equipped with a replaceable cartridge containing a strip of metal coated with polonium-

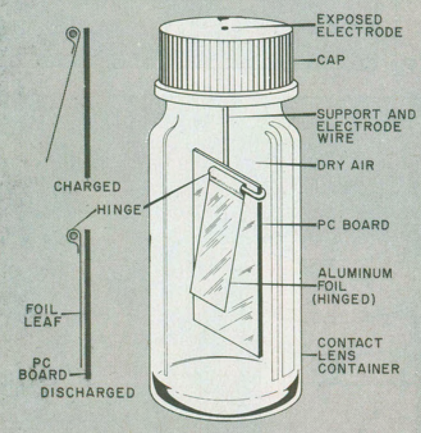

Fig. 6. Homemade miniature electroscope.

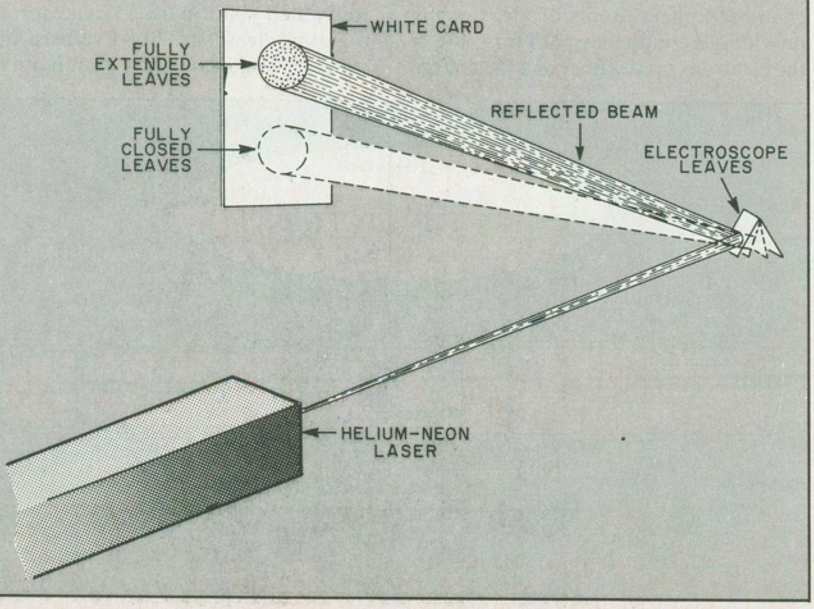

Fig. 7. Amplifying the movements of an electroscope's leaves with a laser.

210 permanently encapsulated in tiny ceramic beads. The polonium-210 emits a potent spray of alpha particles that ionizes the air near the brush. This provides a conductive path for the static charge that attracts dust particles to glass lenses, phonograph records, and photographic film.

STATICMASTER brushes (they come in two sizes) and replacement cartridges are available from some audio equipment and camera stores. If you just want a radioactive source, buy only a replacement cartridge. Be sure to comply with the safety precautions supplied with the cartridge!

Experimenting with a Geiger Counter. Solar Electronics International's Monitor 4 is a compact Geiger counter that indicates radiation levels by means of a moving-coil meter, flashing LED, and an audible chirp generator. The instrument incorporates CMOS circuitry and consumes only about 3 mW in a low radiation field. This provides a life of up to 2000 hours for the 9-V battery that powers the instrument, so long as the radiation level doesn't exceed a nominal background.

The Monitor 4 uses a Geiger tube having a mica end-window to permit the detection of alpha particles. The tube also detects beta particles and gamma and x-radiation.

I've used the Monitor 4 to detect radiation from several sources. For example, a Coleman lamp mantle lying on a flat surface produces a reading of 0.1 to 0.2 mR/hr when the Geiger tube's port is placed directly over the mantle. Rolling the mantle into a tight bundle and placing it next to the port gave a reading of 0.4 to 0.5 mR/hr.

When I placed a sheet of paper between the mantle and Geiger tube, the radiation level was only slightly lowered. Since alpha particles are stopped by paper, the bulk of the radiation appears to be beta particles emitted by the radium-228 byproduct of the thorium in the mantle.

I've also used the Monitor 4 to detect the alpha emission from the polonium-210 microbeads in a Staticmaster IC200 static eliminating brush. When the Geiger tube port is placed directly against the grid over the polonium-210 microbeads, the radiation level exceeds the Monitor 4's maximum detection level of 50 mR/hr. Alpha particles are blocked by only a few centimeters of air. When the grid over the polonium-210 is placed exactly 1-cm from the Geiger tube port, the radiation level is 10 mR/hr. At 2-cm, the level is too low to measure.

Since polonium-210 decays with time, Staticmaster cartridges are stamped with an expiration date. Therefore, the measurements you obtain may differ from those I obtained.

You can use the Monitor 4 and similar monitors to detect very low levels of radiation if you first determine the natural background count. The background count can range from several to more than a hundred counts per minute, although the typical figure is between 10 and 25 counts per minute.

The background count is caused by cosmic rays, the natural radioactivity present in soil, and perhaps the building materials of your home or office. The background count can vary with atmospheric conditions. For instance, a tightly sealed home can collect a higher than usual accumulation of radioactive radon gas emitted by construction materials such as brick and tile.

After you measure the background count, you can proceed to check suspected low-level radiation sources. For instance, on a day when the background was 16 counts per minute (averaged over 5 minutes), the center of the screen of a color television set I use as a computer monitor gave a count of 28 per minute. While this figure is nearly double the background rate, it's still low.

Other radioactive sources around my home, checked on a day when the background averaged 11 counts per minute, include a glazed brick used as a step for a storage building (40 counts/minute) and a ceramic tile entryway (16 counts/minute). An ionization-type smoke detector with an internal radiation source produced no detectable radiation above the background count.

Other household radiation sources include older pieces of earthenware glazed with orange or red pigment containing uranium oxide. And though they are no longer manufactured due to their hazardous properties, watches and clocks with hands and numbers coated with radium impregnated luminescent paint are still around.

Mr. Milo Voss, Manager of Safety, Health and Plant Protection at the Ames Laboratory of the U.S. Department of Energy, is one of many health physicists who have studied low-level background radiation. In a recent telephone conversation, Mr. Voss recounted how aerial surveys have spotted higher than usual radiation levels over some cemeteries and golf courses. Apparently the radiation sources are the granite headstones in the cemeteries and the phosphate fertilizer spread over the greens of the golf courses. Mr. Voss also observed that pilots and passengers of high flying aircraft are exposed to higher than usual levels of radiation.

Summing Up. The subject of nuclear fission always generates considerable controversy, particularly when so-called minimum acceptable exposure levels are discussed. Some health physicists believe no level of exposure can be incurred without some risk to the population. Others feel this view is far too extreme, particularly in light of the naturally occurring background radiation to which we are all subjected.

Milo Voss, for instance, has studied thorium in some detail and concluded in a 1979 report that the material is relatively safe unless it is inhaled or ingested. On the other hand, Walter Wagner, a Veterans Administration health physicist, has filed a $300 million class action lawsuit against the Coleman Company and other manufacturers of lantern mantles. Mr. Wagner is convinced that the thorium in the mantles constitutes a public health hazard.

Despite their divergent views regarding exposure levels, both sides agree that, for better or worse, naturally occurring radioactive sources abound. They are found in granite, bricks, grains, soils, and even in our bodies. The ceramic housing of a DIP integrated circuit can be slightly radioactive!

Another area of agreement is that radiation, no matter its source, is very difficult to accurately measure—much more difficult than measuring light. ◇