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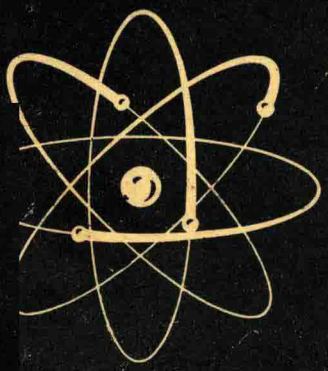
Laboratory Experiments in Radiation Biology



DIVISION OF NUCLEAR EDUCATION & TRAINING
UNITED STATES ATOMIC ENERGY COMMISSION

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UC–48

LABORATORY EXPERIMENTS

IN

RADIATION BIOLOGY

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Introduction

The purpose of this manual is to provide a set of experiments from which several may be selected for use in courses for advanced high school and beginning college students: experiments that may be used to demonstrate operation of fundamental principles without requiring extensive or costly specialized equipment. Most of the equipment required is that usually present in the biology, chemistry, and physics laboratories in a high school or small college, with the possible exception of the radiation detection equipment. Even the latter is present today in many high schools. An attempt has also been made to keep the experimental design and procedure sufficiently simple so that the student will not lose sight of the goal of the experiment or the principle to be demonstrated. Consequently, these experiments do not require a very advanced knowledge of special aspects of biology or very specialized techniques except in a few cases.

This laboratory manual is not an attempt at a comprehensive coverage of the subject of radiation biology for several reasons. For one, it is virtually impossible to write a manual that will entirely cover such a broad and diverse subject. In addition many aspects of the subject do not lend themselves at the present toward preparation of laboratory experiments that can be performed at the academic level for which this manual is intended. Either their requirements for special equipment, or advanced academic training are too great for the preparation of simple experiments.

Through the use of this manual the student can become familiar with several aspects of radiation biology. The first section of the manual discusses special techniques and the preparation of special equipment useful in performing experiments suggested in other parts of the manual. The experiments in the second section are intended to familiarize the student with the characteristics of radiation detection instruments, the interaction of radiations with matter, methods of measurement of radiation, and assay of radioactivity in various materials. The third and fourth sections are devoted respectively to radioactive tracer experiments and experiments on the biological effects of radiation. With only a few exceptions, this manual has very little discussion of theory. It is intended only as a guide to the performance of laboratory experiments. Many good reference books on the subject of radiation biology are currently available as sources of information for the theoretical background for these experiments. A list of some of the available references is included in Appendix I.

Some experiments presented in this manual do have special requirements. A few require specialized radiation detection equipment, such as a scintillation detector with an appropriate scaler. Others require a source of ionizing radiations capable of producing radiation effects. Access to service irradiations from such radiation sources (X-ray units, radioisotope teletherapy units, and occasionally nuclear reactors) can usually be obtained through the cooperation of the local radiologist, local hospital, nearby universities, or research installations. Frequently, the State Department of Health can furnish a list of such facilities. Another special requirement of some experiments is a particular knowledge of training in certain aspects of biology. For instance, it is recommended that a teacher who is entirely without previous experience in microbiology should not try to perform radiological experiments with bacteria unless he performs the experiment several times before attempting to use it in class.

At many schools it is difficult to obtain access to a source of ionizing radiations with which to produce the biological effects in the subject material. For this reason several experiments are included here which utilize

ultraviolet radiations. For that purpose germicidal or short wavelength ultraviolet lamps * are very effective in producing many of the biological effects similar to those caused by ionizing radiations. Because ultraviolet light is readily absorbed, i.e., penetrates poorly in biological material, it is necessary to use special techniques and special material. For this reason the experiments utilizing ultraviolet light to produce biological effects require the use of either thin layers of solutions or of suspensions of microorganisms or very thin or small organisms through which the ultraviolet light can penetrate.

* Commercial mercury vapor lamps with clear bulbs (or with removable filter) will emit short wavelength ultraviolet light. Extreme caution should be used in handling such lamps to prevent injury to the skin and eyes.

Contents

Radiological Safety

There are four major aspects in the safe use of radioactive isotopes in a high school or small college or university. These are:

1. Protection of Personnel.
2. Control of Contamination.
3. Disposal of Radioactive Waste.
4. Public Relations and Administration of the Radioactive Isotope Program.

These are all of equal importance, although in some respects the aspect last mentioned is the greatest source of problems.

The use of radioactive isotopes is regulated by the U.S. Atomic Energy Commission and, additionally, in some states by their respective health or atomic energy agencies. The prospective user of radioactive isotopes should obtain a copy of the Code of Federal Regulations, Title 10—Atomic Energy, Part 20—Standards for Protection Against Radiation, and Part 30—Licensing of By-product Material. These may be obtained free of charge from your regional U.S. Atomic Energy Commission Operations Office (see Appendix III for the addresses of the Operations Offices).

In addition, the prospective user of isotopes should contact the State Department of Health for a statement of regulations concerning the use of radioactive isotopes. In general, the quantities used for tracer studies may be obtained from distributors without any need for obtaining a specific By-product Materials License. The maximum quantities that may be obtained under the so-called "general license" are usually small in amount: Carbon-14, 50 μc; phosphorus-32, 10 μc; iodine-131, 10 μc; calcium-45, 10 μc; iron-59, 1 μc; cobalt-60, 1 μc; strontium-90, 0.1 μc. Under the general license a user may possess at one time up to 10 such scheduled quantities of material. For example, he may possess at one time 500 μc of carbon-14, but not as a single source, or 450 μc of carbon-14 (in 9 units) and 10 μc of phosphorus-32, since their total is equal to 10 scheduled quantities of general licensed material. The possession limits for most radioactive isotopes is found in Schedule B of Title 10, Code of Federal Regulations, Part 30 (10CFR30). Although these quantities of material may be purchased without need for a specific By-product Materials License, the user is not exempt from adhering to the regulations that are concerned with their use; hence the recommendation to obtain copies of these regulations.

In addition to the necessity of following state and federal regulations concerning the use of radioactive isotopes, the potential user must be sure that the administration of the school in which he teaches recognizes the usefulness of this teaching aid and is aware of the fact that the proposed user of radioactive isotopes can control any of the very small potential hazards that might arise through their use. This means that thorough planning is necessary to prevent accidents that might cause unfavorable public relations because of the unusual character of the material and because of the emotional prejudices of the public based on a lack of knowledge about radioactivity and radioactive materials. Although the general license quantities of radioactive material offer very little hazard through their use, the opportunity for their continued use is dependent upon convincing administrators and parents of the lack of hazard inherent in these small quantities, especially when handled properly. This means that a knowledge of basic principles of radiological safety and federal and state regulations is necessary.

No attempt has been made here either to summarize existing regulations or to cover all cogent points of radiological safety, but, instead, a list is given of some simple

rules relative to the handling of radioactive isotopes and for conduct in a laboratory in which they are used. The reasons behind these rules are readily recognized by persons with experience in the use of radioactive isotopes.

1. *Records.* A bound notebook may serve as a logbook in which you can keep an inventory of all the kinds and amounts of radioactive materials you possess, the date of receipt, the use made of them, the name of the user, and the method and date of their disposal.

2. *Monitoring.* The laboratory and equipment should be monitored to be certain of the absence of contaminations. This should be done periodically during and after each experiment and at regular intervals in addition. Written records of laboratory monitoring should be maintained. Clothing and hands of personnel should be checked after each experiment.

3. *Labeling.* A sign should be displayed in the working area, indicating that radioactive materials are being used. All radioactive materials must be labelled so that they may be recognized. Self-adhering labels with the proper legend and color are available commercially. Glassware and equipment that have been used, decontaminated, and found to be still contaminated should be labelled and segregated from general use. In fact it is common practice to segregate all such apparatus once it has been used with radioactive materials, whether it has been decontaminated or not.

4. *Controls.* Maintenance of control over radioactive material and equipment must be exercised. This is usually accomplished by keeping such materials under lock and key, when the responsible individual is not in the laboratory. Students should never be left without proper supervision in a laboratory with radioactive materials, not even radioactive waste solutions.

5. *Protective Equipment.* It is easier to prevent contamination caused by spills than to decontaminate laboratory furniture and equipment. Spills can be avoided by placing open containers into secondary containers, such as a beaker, or into a hole drilled in a flat block of wood which is not easily upset. Spills may be confined by working on a tray or large shallow pan lined with an absorbent material with a water-repellent backing. Disposable diapers, "diaper" paper, or newspapers backed with a layer of "oiled" paper may be used to prevent the spill from contaminating the working surface. Radioactive material is never handled directly. It is handled with forceps or tongs. Solutions are never pipetted by applying suction with the mouth. Mechanical pipetters are used. Where vaporization can occur, the operations should be performed in a fume hood.

6. *Protective Clothing.* Protective clothing prevents contamination of the skin or personal clothing. Rubber gloves or plastic disposable gloves are used to cover the hands when working with radioactive material or potentially contaminated equipment; laboratory aprons or coats are used to cover personal clothing.

7. Nothing should be placed in the mouth in the laboratory. This includes food, beverages, cigarettes, fingernails, cosmetics, gum, etc.

8. Working areas should not be cluttered; unnecessary equipment should be removed from a working area in which it might become contaminated.

9. Experimental animals should have their cages labelled clearly.

10. Dry runs of experiments should be required before permitting radioactive isotopes to be used.

11. Radioactive waste should be collected and labelled. Arrangement for its disposal should be made personally by the person responsible for the radioactive isotopes. Quantities of soluble material that may be obtained under general license can generally be discharged into the sanitary sewer if they are diluted with large volumes of water. The method of disposal of solid wastes should conform with the state and federal regulations.

Sample Preparation

ASHING

For Geiger-Müller (G.M.) counting of beta particles, it is necessary to reduce the mass of the sample in order to detect a reasonable fraction of the beta particles emitted. If the liquid is evaporated from a sample so that self-absorption is reduced, the radioactivity of the dry residue may be counted with greater efficiency. In the case of tissue samples, the organic constituents may account for 30% of the mass of the tissue, while the minerals account for less than 1%. To achieve higher counting efficiency, it is necessary to eliminate the organic material. This is generally accomplished through either wet or dry ashing.

Dry ashing is generally performed in a muffle furnace at a temperature sufficiently high to burn up all the organic material but not sufficiently high to cause volatilization of the minerals. The ashing is performed in covered crucibles. The tissue is dried at low temperatures (about 105°C) to evaporate the water to prevent spattering and then is ashed about 600–650°C for as long as several hours. The mineral ash is removed from the cooled crucible by dissolving it with 5N HCl.

Wet ashing is generally preferred to dry ashing. It requires only simple equipment and does not require high temperatures. Small tissue samples (about 1 to 2 g) are placed in 10- to 15-ml test tubes and are just covered with concentrated nitric acid. The acid can be conveniently delivered from a polyethylene squeeze bottle.* The tubes are heated in a water bath at temperatures between 70 and 80°C. At higher temperatures the nitric acid boils off and the ashing proceeds at a much slower rate. Digestion of everything but some lipids or fats is usually complete in 10 to 30 min. The use of one part sulfuric acid to two parts nitric will yield more complete digestion of fats. Ashing should be carried on in a chemical fume hood to prevent dispersion of acid fumes and possibly radioactive material.

* Do not store concentrated nitric acid in polyethylene bottles.

PIPETTING

Radioactive solutions are never pipetted using a mouth-operated pipette. Macropipettes (1-ml pipettes or larger) are generally controlled with mechanical pipetters, which use controlled pressure upon a rubber bulb. Some are operated by control valves. Others use a screw or lever mechanism. For micropipettes (0.25 to 0.001 ml), a greased 1-ml syringe may be connected to the pipette by clear vinyl or Tygon tubing (⅛ in. inside diameter) and controlled with one hand.

To prevent small bottles of radioactive liquid from being spilled during pipetting, place them in a secondary container, such as a large beaker, or in a hole drilled in a flat block of wood. Such precautions prevent unnecessary contamination and also prevent loss of the radioactive material or sample during the manipulation of equipment around open vessels containing radioactive materials.

PREPARATION OF WORKING AREA AND PERSONNEL

Radioactive materials must be handled in a manner that will prevent their dispersion and the contamination of the laboratory. To protect the experimenter, protective clothing is worn: waterproof gloves (either rubber or plastic) and a laboratory apron or coat, depending on the nature of the work. Any unprotected clothing or surface of the body should be monitored during or after the experiment to assure that no contamination has occurred.

All unnecessary items and equipment should be removed from the working area. The working surfaces should be impermeable

to aqueous solutions. This frequently may be accomplished by coating the working surface with wax. If you cannot wet a surface, it is difficult to contaminate it. Containment of possible spills is accomplished by working in a tray or large pan. Open containers are placed in secondary containers to prevent spill. The working surface of table or tray is covered with an absorbent material that has a water-repellent backing. Diaper paper, disposable diapers, water-repellent or "greased" or waxed paper covered with several layers of newspaper is a satisfactory means of preventing contamination of working surfaces and removing the spills which may occur.

DECONTAMINATION

Decontamination and contamination are closely related aspects of the same problem. It is far easier to prevent contamination than to decontaminate. Decontamination of a surface may be defined as the removal of radioactive materials present on surfaces in undesirable amounts that may be considered harmful to health and safety of personnel, or to the validity of experiments or products. Surfaces are easily contaminated when they have a tendency to hold radioactive materials that come into contact with them. Factors that increase the tendency to retain radioactive materials are porosity, roughness, wettability; specific chemical reactivity which allows chemical combination with the radioactive elements, and absorption of counter ions. Decontamination problems may be reduced by preparation of work surfaces, tools, and equipment to reduce or prevent contamination by decreasing the importance of any of the factors mentioned above.

Porous surfaces may be covered or sealed to protect against contamination. Rough surfaces also may be similarly protected. Surfaces that are easily wet by aqueous solutions may be made nonwettable by protecting or covering them with wax or silicones or by switching to nonwettable equipment constructed of polyethylene or other similar material.

For spills of dry materials, the application of paper with an adhesive surface (such as drafting tape) may be used to pick up the materials effectively. Sweeping usually will spread the contamination without effectively removing it. Decontamination with liquid cleaners usually consists of causing the contamination to be put into solution and to be retained in solution with as little destruction of surfaces as possible. Therefore the chemical characteristics and physical state of the contaminant should be known. Detergents and chelating agents are frequently used to keep the material in solution. Carrier (a dilute solution of the stable form of the radioactive element in the same chemical form) is sometimes added to aid in reducing adsorption to surfaces and to keep the material in solution. The proper acidity must be maintained. The volume of liquid and solid waste produced by the decontamination process should be kept as small as possible to reduce the problems of waste disposal. Decontamination of surfaces usually employs one of the reagents listed in Table 1, depending on which type of surface is to be cleaned. Destructive or abrasive procedures that destroy the integrity of the surface will cause the equipment to become easily contaminated with continued use. Decontamination of hands is generally accomplished with a mild nonabrasive soap (not a detergent) and the use of a soft brush, flexing the hand to stretch the skin and smooth out wrinkles. Should this method fail, detergents may be used cautiously, but chelating or sequestering agents should not be used since they increase absorption through the skin.

TABLE 1.—GENERAL REAGENTS FOR DECONTAMINATION

Reagent type	Typical representative	Where used	Remarks
Mineral acids	HCl, HNO_3, H_2SO_4	Metals, glass, plastics, paint	10% solutions, for dilute reagents. Destructive to surface. Usually most efficient reagents if materials can tolerate their use
Strong oxidizing solutions	Chromic acid cleaning solution	Glass, metals	Laboratory cleaning agent. Last-resort treatment. Often used for plutonium
Trisodium phosphate		Glass, paints, plastics	10% solution. Often used hot. Removes wax and is hard on paint
Fluoride	$(NH_4)_2SiF_6$	Glass, porcelain, and other silicone materials	0.1–1% solution
Complexing agents	Sodium citrate, versene, or EDTA*	All materials	1–10% solutions. Efficiency variable and pH-dependent. Often preferred choice for general use
Detergents	Household or commercial cleaning detergents	All materials	Efficiency variable. Choice sensitive to water properties as well as materials and contaminants used with scrubbing

* Ethylenediaminetetraacetic acid.

Preparation of a Card Mount

For many experiments it is of value to mount the radioactive sample between as thin a support and cover as possible to reduce the amount of scattering and absorption. This preparation may be accomplished simply and with little cost by making a card mount. This consists of a piece of stiff paper, such as poster board, and two layers of thin plastic such as cellophane, polystyrene, Saran-Wrap or Mylar. The card is cut to fit snugly into a G.M. tube mount that has positions for a shelf beneath the tube. A hole between 1 and 2 in. in diameter is cut in the center of the card so that the hole is directly beneath the thin end-window of the G.M. tube. The area of a large sheet of the plastic (about 12 × 12 in.) should be measured in square centimeters, and the sheet should carefully be folded and weighed. The density thickness * is obtained by dividing the weight in milligrams by the area in square centimeters. For Saran-Wrap the density thickness is usually between 1.5 and 2.0 mg/cm². One sheet of this plastic is cemented over the hole in the card (see Fig. 1a). To the upper surface of the plastic apply a drop of 1% protein or a drop of egg white with a medicine dropper so that the area of the drop is about ¼ in. in diameter. Withdraw the drop of liquid and allow the spot to dry. † The protein from the solution allows the surface to be wet easily. Now apply about 0.1 μc of the radioactive isotope to the dried spot on the plastic sheet. The radioactive solution will wet only the area touched by the protein solution or egg white. Allow the radioactive sample to dry and seal a second layer of plastic over this spot. ‡ Use a minimum of cement since the excess will be drawn off by capillary action toward the radioactive spot in the center (see Fig. 1b). Label the sample properly.

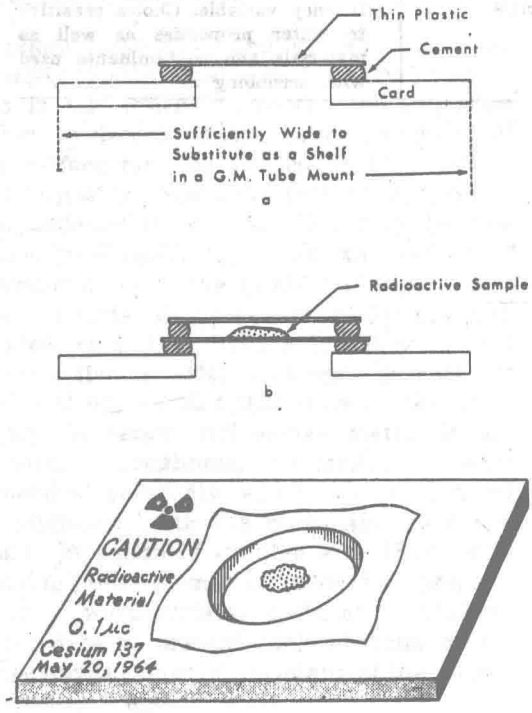


FIGURE 1.

* For the significance of the term density thickness, see Preparation of Calibrated Absorbers.

† A heat lamp may be used to accelerate the drying of solutions.

‡ The card mount may also be sealed with a drop of very dilute collodion solution or by careful use of a can of spray plastic (of the type used to set women's hair). With the latter, care must be used to completely seal the sample and to prevent dispersal of the sample by the jet of spray.

Preparation of Calibrated Absorbers

Commercial sets of calibrated absorbers usually cost about $100 per set. A good set of absorbers may be prepared for less than one dollar. The accuracy of the calibration depends only upon the amount of care taken during their preparation and the quality of the balance used in making the weight determinations.

Calibrated absorbers used for beta-particle absorption measurements may be made out of any low atomic number material. If the thickness is determined in density-thickness units (mg/cm^2), the amount of absorption of beta particles is dependent only upon the density thickness and is independent of atomic number (for low atomic number materials).

Aluminum foil is one good material from which thin absorbers can be made. Prepare several cards (such as those used for card mounts) with 2-in.-diameter holes in them. A sandwich of these cards should fit snugly into the G.M. tube mount. Smooth aluminum foil should be unrolled on a clean flat surface. Cut off a large but conveniently sized rectangular piece and measure its surface area in square centimeters. Carefully fold this piece without making sharp folds in it so that it can be unfolded without wrinkles. Weigh the piece, if possible, to the nearest milligram. Divide the weight in milligrams by the total surface area in square centimeters. This will give you the average thickness in milligrams per square centimeter or density-thickness units. Unfold it and carefully smooth out the wrinkles. Cut pieces large enough to cover the holes in the cards. Cement them in place over the holes (see Fig. 2). One card should have no aluminum over the hole. One should have one sheet of aluminum covering the hole. Others should have two, four, and even larger numbers of sheets of aluminum covering the hole. Thicker sheets of aluminum may be calibrated in the same manner to provide thicker absorbers. Write on the corner of the card the total thickness of aluminum which covers the hole. It is important that the sheets of aluminum be very flat and in close contact with each other when they are cemented over the holes. Larger thicknesses of metal can frequently be obtained from hobby shops. Aluminum, plastic, and copper are materials most easily obtained for this use.

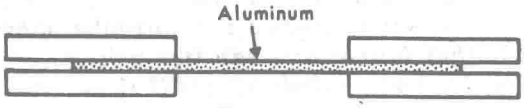


FIGURE 2.

Preparation of a Split Source

A split source is useful for making resolving time * measurements to test the characteristics of G.M. tubes. The source generally consists of a planchet † divided equally into two parts, each of which has a moderately long-lived beta emitter of medium to high energy. Both halves of the source should have relatively equal activities each of which should yield at least 3000 to 4000 counts/min so that counts of at least 30,000 to 40,000 may be obtained in a reasonable amount of time. Count rates of about 5000 per minute are more advantageous. With a resolving time of 200 μsec, the loss at 3000 counts/min caused by coincidence will amount to 1% or more, and the standard deviation ‡ for the difference is about 1%. For sources that yield 10,000 counts/min and a total count of 100,000, the loss through coincidence is about 3.3%, and the standard deviation is about 0.2%.

If the sources are to be used under a G.M. tube that has a tube mount with a shelf for holding 1-in.-diameter sources, it is convenient to use 1-in.-diameter planchets that are cut in half. Either plastic or metal planchets may be used. If flat metal planchets are used, one corner may be bent up to use as a handle, by which the planchet may be manipulated with forceps. After cutting the planchet in half, clean it and apply the radioactive solution to each half. When the radioactive spot is dry, coat the spot with very dilute model airplane "dope," diluted lacquer or collodion, or use spray lacquer such as women use to hold their hair in place. This will seal the radioactive material to the planchet and decrease the possibility of spreading contaminations. Blank split planchets are prepared also. These blanks are necessary to maintain constant scattering conditions during the counting of the separate halves of the split source.

* For the meaning of resolving time, see the section entitled Resolving Time.

† A small shallow cup or circular flat plate used to contain radioactive samples is a planchet.

‡ For the meaning of standard deviation, see the section entitled Counting Statistics.

Electroscope

The purpose of this experiment is twofold: (1) to become familiar with the operating characteristics of the electroscope or ion-chamber type radiation detection instruments and (2) to use the electroscope in measuring the activity of a radium D & E source (or radiolead-210 – bismuth-210).

Materials Required

1. A Landsverk model L–75D electroscope.
2. A stop watch or timer.
3. Several radioactive reference sources (preferably calibrated).

Procedure

The Landsverk L–75D analysis unit is a simple, easy to operate, versatile, and durable instrument. There are three controls on the top of the unit: (1) the small black button operates the self-contained light source; (2) the red button serves to charge the electrometer; and (3) the large knob is used to adjust the amount of charge on the fiber (which is indicated on a 0 to 100 scale). To use the instrument, depress both the light button and the red charging button while adjusting the voltage to the desired scale setting with the zero control (adjustment) knob. When the electroscope has been adjusted to zero and the charging button is released, the fiber image will move down scale about 5 to 10% of the length of the reticle (or scale) before it stops. This is an electrostatic induction effect. If the fiber is to be set near the zero mark, the fiber image must be moved past the zero mark before the charger button is released. Actually it is a waste of time to try to start a reading from the zero mark of the scale. The scale is so linear that readings may be started from any point. Only if extreme accuracy is sought, need the readings be made on approximately the same region of the reticle (or scale). The former procedure has the desirable result that two or more measurements can often be made consecutively without recharging the instrument. This feature can save much time when very low activities are to be measured because it is not necessary to wait for the electroscope to return to its former low background drift after it is recharged.

Note.—Refer to the instruction manual of the Landsverk electroscope for more detailed discussion and operating instructions.

Measurements are made by performing the following operations:

1. While holding the light switch down, press the charging button to charge the electroscope.

2. With the charging button depressed, turn the knob to adjust the charging voltage to bring the fiber near zero.

3. With a stop watch or timer, determine the rate of drift of the fiber in divisions per minute across the reticle. This is the background rate of drift. It is best to record the position of the fiber and start the stop watch. When the fiber reaches a convenient scale division after some time, the stop watch is stopped and the fiber position is recorded. Record the time. Calculate the rate of movement of the fiber in scale units per minute.

4. Place the radioactive sample to be analyzed inside, below, or to the side of the ionization chamber, depending on the type of measurement to be made. Repeat steps 1, 2, and 3 to establish the rate of drift of the fiber for the radioactive sample plus the background rate of drift.

5. Subtract the background rate of drift from the total rate to get the net rate of drift from the activity alone. Repeat the above procedure for a standard source of known activity.

Using a simple ratio the activity in microcuries can now be calculated as follows:*

$$A_u = \frac{\text{divisions per minute with source of unknown activity} \times A_s}{\text{divisions per minute with calibrated source}}$$

where A_u is activity of the unkown source and A_s is activity of the calibrated source.

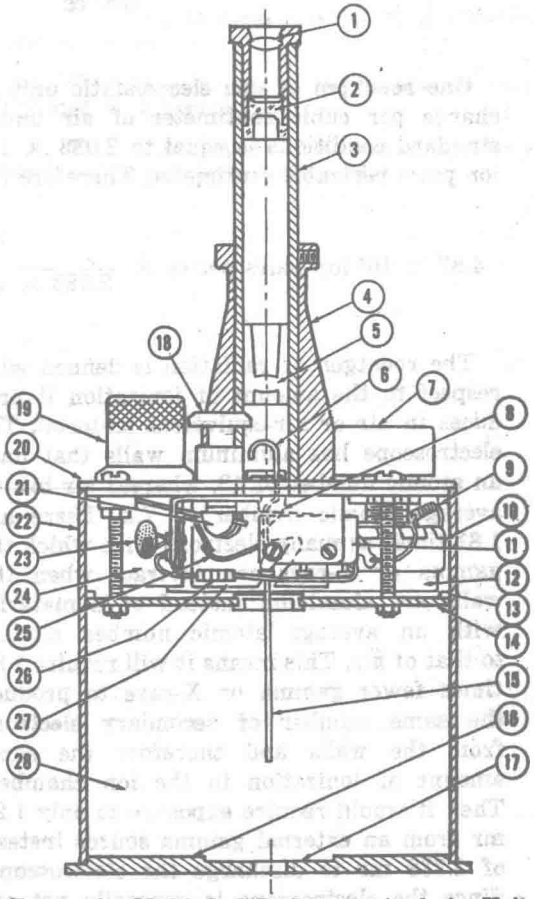
Questions

1. What causes the electroscope to lose charge when a radioactive source is inside? What causes background drift?
2. How sensitive would you expect the electroscope to be in the presence of gamma radiation? Try a cobalt-60 source in the instrument and estimate the relative efficiency for measuring beta and gamma radiations. Try the cobalt-60 source either below or outside on the side of the instrument. You can fasten it in place with cellophane tape.

* For the technique of calibrating an uncalibrated source, see the section entitled Calibration of a Radioactive Source.

Electroscope and Inverse Square Law

The purpose of this experiment is to become familiar with the operation and characteristics of the Landsverk electroscope. Read sections A and B of the Landsverk manual and observe the diagram (Fig. 3). The electroscope works in principle like a condenser or capacitor with air as the dielectric. When a charging potential is applied to it, it acquires a charge, the amount of which is dependent on its capacitance. The air between the electrodes serves as an insulator. When the air is irradiated, the ions produced in the air are attracted to the charged electrodes and neutralize a small amount of charge. The reduction in charge causes a measurable decrease in the potential difference between the electrodes. In practice the decrease in charge on an electroscope is measured by the decreased deflection of a quartz fiber attached to the positive electrode; see item 6 in Fig. 3.



1. Eyepiece.
2. Reticle.
3. Microscope barrel.
4. Microscope mounting turret.
5. Objective lens.
6. Quartz fiber electrometer.
7. Zero control knob.
8. Insulator prism.
9. Resistor.
10. Zero control potentiometer.
11. Micro switch.
12. Transistor power supply.
13. Lockring.
14. Separator plate.
15. Collecting electrode.
16. Base plate.
17. Recess for planchet holder.
18. Charging button.
19. Battery holder cap.
20. Top plate.
21. Charging button plunger.
22. Window.
23. Capacitor.
24. Battery holder bottom.
25. Electrode contact.
26. Resistor.
27. Shield electrode.
28. Ion chamber.

FIGURE 3.—Model L-75D Isotope Analysis Unit. *(Used with the permission of the Landsverk Electrometer Co., Glendale, Calif.)*

If the electroscope is fully charged at 145 volts and at 93 volts it is discharged full scale, then the decrease in potential is 52 volts. The capacitance of the electroscope is about 3 $\mu\mu$F. The charge Q on the electroscope is equal to the product of the capacitance C and the voltage V: $Q = CV$

The decrease in charge (ΔQ) is equal to C multiplied by the decrease in voltage (ΔV):

$$\Delta Q = C \times \Delta V \qquad C = 3\ \mu\mu F = 3 \times 10^{-12}\ \text{farad}$$

$$\Delta Q = 3 \times 10^{-12}\ \text{farad} \times 52\ \text{volts} = 156 \times 10^{-12}\ \text{coulomb}$$

$$= 156 \times 10^{-12}\ \text{coulomb} \times \frac{1\ \text{electron charge}}{1.602 \times 10^{-19}\ \text{coulomb}} = 97.4 \times 10^{7}\ \text{electron charges}$$

The volume of the ionization chamber of the electroscope is 200 cc. To produce a full-scale deflection of the fiber of the electroscope, 97.4×10^7 electron charges must be collected from the air volume. That amount of charge per air volume is:

$$\frac{97.4 \times 10^7 \text{ electron charges}}{200 \text{ cc}} = 4.87 \times 10^6 \frac{\text{ion pairs}}{\text{cc}}$$

One roentgen of one electrostatic unit of charge per cubic centimeter of air under standard conditions is equal to 2.083×10^9 ion pairs per cubic centimeter. Therefore the 4.87×10^6 ion pairs that must be produced in the ion chamber for a full-scale deflection would require that the ion chamber be exposed to a dose of radiation equal to

$$4.87 \times 10^6 \text{ ion pairs per cc} \times \frac{1 \text{ r}}{2.083 \times 10^9 \text{ ion pairs per cc}} = 2.338 \times 10^{-3} \text{ r} = 2.338 \text{ mr}$$

The roentgen of radiation is defined with respect to the amount of ionization it produces in air or air-equivalent material. The electroscope has aluminum walls that have an atomic number of 13, whereas air has an average atomic number of 7.2. There are 1.81 times as many electrons with which the gamma or X-rays can interact when the walls are aluminum instead of a material with an average atomic number similar to that of air. This means it will require 1.81 times fewer gamma or X-rays to produce the same number of secondary electrons from the walls and therefore the same amount of ionization in the ion chamber. Then it would require exposure to only 1.29 mr from an external gamma source instead of 2.338 mr to discharge the electroscope. Since the electroscope is generally not operated at standard gas conditions (0°C and at a pressure of 76 cm Hg), corrections must be made for temperature and pressure. Increased temperature and reduced pressure results in fewer gas molecules in the ion chamber, which results in less sensitivity to the penetrating radiations. Operation at 76 mm Hg and 72°F (22.2°C) would cause the required dose for full-scale deflection to be equal to 1.39 mr.

One milligram of radium would produce a dose rate of 84 mr/hr at 10 cm or 1.4 mr/min. Exposure of the electroscope for less than 1 min would produce a full-scale deflection of the fiber. At distance of 100 cm, the dose rate would be 0.84 mr/hr or 0.014 mr/min. Thus at 100 cm an exposure would produce a deflection of about one-hundredth of full scale or one scale unit per minute. Therefore accurately measurable deflections could be obtained in 10 to 20 min for distances somewhat greater than 100 cm.

Materials Required

1. A meter stick.
2. A 1-mg radium source or a radioactive source with an equivalent gamma-ray intensity.
3. A Landsverk electroscope.
4. A timer or stop watch.

Procedure

Calculate the dose rates at distances between 10 and 200 cm for a 1-mg radium source (or other source with an equivalent gamma intensity). How long can you work within 18 in. or 45 cm from the source without exceeding a dose of 10 mr? Place an indicator mark or plastic container on which the source may be located. Measure off distances from that point *before putting the radioactive source in place* and mark them with a wax pencil or crayon on the bench or use cellophane tape to hold down paper markers indicating the distance. Place the source at the indicated location. Read the position of the fiber. Place the charged electroscope with its center directly over a dis-