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Title of Study: THE USE OF SIMPLIFIED APPARATUS IN THE STUDY OF ATOMIC ENERGY

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Scope of Study: A study was made of the possible use of simple, inexpensive equipment in the study of atomic energy in junior and senior high schools. Apparatus and experiments were desired which could be used as instructional tools by the teacher or would be satisfactory for students to use in individual studies and projects. Devices were selected according to their teaching value, ease of construction, and historical significants.

Findings and Conclusions: Five devices, which can be used to detect and study atomic radiations, were selected and described. Several experiments were included to aid in the study of alpha, beta and gamma radiations. Two experiments designed to illustrate the use of radioactive isotopes in scientific research were presented. The materials of this report will be most useful to the teacher who does not have adequate commercial equipment, but it should be somewhat useful to all teachers, especially in the historical area of atomic studies. These devices and experiments should be well suited to student projects or for use in science clubs.

ADVISER'S APPROVAL James H. Zant

THE USE OF SIMPLIFIED APPARATUS IN THE STUDY OF ATOMIC ENERGY

By

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CHAPTER I

INTRODUCTION

The purpose of this report is to investigate the use of simple, inexpensive equipment in the study of atomic energy in junior and senior high school. Apparatus and experiments are desired which can be used as instructional tools by the teacher, or would be satisfactory for students to use in individual studies or projects. It was decided to avoid any division of material according to grade level or division in any other manner. The material will be used as a source to be drawn upon according to the need.

There is available an abundance of excellent commercial equipment for use in atomic studies, but sometimes in the case of the teacher and usually in the case of the student the cost of such material seriously limits their use. The need is for supplemental materials where a complete set of commerical apparatus is not available for the teacher, and for apparatus suitable and economical for student projects and studies.

In order to obtain descriptions of this type equipment and its use in atomic studies, letters were written to the Atomic Energy Commission, Government Printing Office, and other organizations. Textbooks, other books, and magazine articles pertaining to atomic energy were read and the material evaluated. Im some cases simplified apparatus was shown but in many cases the experimentation was conducted with commerical

Geiger or scintillation counters. In these cases an attempt was made to design and test simple devices which would serve the same purpose.

The report is divided into two sections. Chapter II will describe and give instructions for constructing four different types of devices to be used in detecting radiations. A discussion of the historical background and present day uses of the instruments is included to give the teacher and students a more complete knowledge of the early work in atomic energy as well as the current uses of these and related instruments.

Chapter III contains experiments which will help to study the characteristics of the radiations and also includes some experiments to show uses of the radiations in scientific study. The study is limited to the detection, study, and scientific uses of radiations from naturally radioactive materials.

The radioactive materials used in the experiments are now available in small amounts from most scientific supply houses. No license is required for these small quantities.

The books listed in the bibliography are recommended for instructions in the safe handling of radioactive materials. Although the handling of radioactive materials in any quantity involves some danger, the devices discussed in this report are largely designed to use small quantities of sealed sources and for the most part are as safe as the average laboratory experiment or project.

CHAPTER II

DETECTION DEVICES

This chapter will describe five simple detecting devices used in the study of atomic energy. A history of their development and uses will be given. The next chapter will contain experiments in which these devices are used.

Light-sensitive Film

History. In 1896, A. H. Becquerel was experimenting to find out whether pitchblende would emit X-rays after exposure to visible light. To test this possibility he wrapped a photographic plate in black paper to protect it from the light, placed a piece of pitchblende on the package, and set the combination in the sunlight for a few hours. Each time he developed the film he found it had been blackened by invisible rays which had penetrated the black paper. One day the weather was cloudy so he placed the device in the desk drawer to await fair weather. The cloudy spell lasted a few days and at the end of this time he developed the plate. He was greatly surprised to find that this plate was blackened without exposing the pitchblende to light. Repeated experiments proved that pitchblende emitted these radiations without exposure to light. By using photographic plates Becquerel had discovered radioactivity.

Materials. Almost any kind of light-sensitive film may be used to detect radioactive radiations. A fine grain or X-ray film will need less exposure time and give better impressions. No-screen X-ray film or dental X-ray film is especially effective. Special films, including those which will detect mesons and neutrons, are available from photographic supply companies.

Procedure. A repeat of Becquerel's experiment will effectively demonstrate the use of photographic film. Opaque paper is used to make an envelope in which the film is placed and sealed. The paper in which photographic film is wrapped is suitable for this purpose. Place a radioactive material on the envelope and leave for two days. The materials should be placed in a drawer or dark place to reduce the possibility of light getting through to the film. Develop the film and notice any darkening. This was caused by radioactive rays which penetrated the paper. A control may be placed in an envelope at a safe distance from any radioactive material to emphasize the effect. All work with the film must be done in complete darkness or with a faint red light. The materials and instructions for development of the film may be obtained from photographic studios.

Uses. The development of new emulsions for films and plates has produced a substantial increase in their use. Film is used for exposure badges for workers, to obtain information on the distribution of radioactive elements in plant and animal tissue, and recently has been used to study the energy and other properties of particles by their tracks in the film emulsion. Film is especially useful since it will record continuously for long periods of time, and it is rugged and lightweight. Drawbacks of film include the inability to place it effectively in a magnetic field and the time required for development after exposure.

Electroscope

History. After Becquerel had discovered that the rays from uranium were similar to X-rays in their ability to penetrate opaque materials and darken photographic plates, he wondered if they, like X-rays, could produce ionization of air. To determine this he used a gold-leaf electroscope. The electroscope was charged, and when he brought the uranium salt near to it, the electroscope discharged. He concluded that the rays from the uranium had the property of ionizing the air about them. In addition to the electroscope, the Geiger counter, ionization chamber, and the proportional counter are all based on the ability of atomic and nuclear particles to produce ionization when moving rapidly through air. Immediately after Becquerel's discovery, Marie Curie started a long and painstaking search for radioactive materials. The radioactive substances were tested by observing their affect on the rate of discharge of a charged electroscope. Using the electroscope as their guide, Marie and Pierre Curie were able to discover the elements polonium and radium.

Materials. 2 pieces 7 inch No. 18 copper bell wire; a pint fruit jar; 2 strips of aluminum foil $1\frac{1}{2}$ inches by 3/8 inch; 8 penny nail; a block of wood to cover jar; and a penny.

Procedure. To make the electroscope, first bend an end of a 7-inch piece of uninsulated No. 18 copper bell wire around a nail to make a loop. Turn this loop at a right angle to the length of wire and solder it to a shiny penny. Place a second length of wire alongside the first without looping it and force both of them through a hole bored in the wooden block. Tape the two wires together just below the block and again one inch from the ends. Bend the last $\frac{1}{2}$ inch of the ends at right angles.

Arrange the length of the wires so that when the strips shown in the drawing are in place the finished apparatus will look like that shown. Cut two strips of light aluminum foil, each $1\frac{1}{2}$ inches long and 3/8 inches wide. Roll one end of each strip over an 8-penny nail to form a tight roll of three or four turns of the foil. Slide this roll off the nail and carefully slip it over the end of the bent wire. It should hang down and swing freely. Slip the second leaf on the other wire and adjust the wires so the two foil leaves do not quite touch. Place the block on the jar with the leaves inside the jar. This keeps the leaves from being affected by stray air currents.

To charge the electroscope, rub a comb briskly on something made of wool and touch the penny with the comb. The leaves should spread apart since an excess of electrons collect in the leaves and being like charged they repell each other. Hold a watch with a radium dial or other radioactive source near the penny but do not touch it. Time how long it takes the leaves to lose the charge. Charge the electroscope again but this time do not bring the watch near the electroscope and check the time required for the electroscope to lose its charge. When the radioactive material was brought near to the electroscope it ionized the air in the vicinity of the electroscope. This ionization allowed the excess electrons to leak away and the leaves collapsed.

The electroscope may be refined by taping a scale on the jar on a level with the leaves so the rate of leakage can be more accurately recorded. Making one leaf stationary also aids in making readings. Accurate quantitative results require microscopic examination of the changes in the leaves.

Uses. The electroscope is mainly useful in detecting alpha particles.

Alpha particles produce a greater amount of ionization than the other types of radiation. Minute electroscope type devices are used as gauges to determine the amount of radiation to which atomic energy workers have been exposed. Specially developed electroscopes are still being used in research but other devices have largely replaced them.

DIAGRAM FOR AN

ELECTROSCOPE

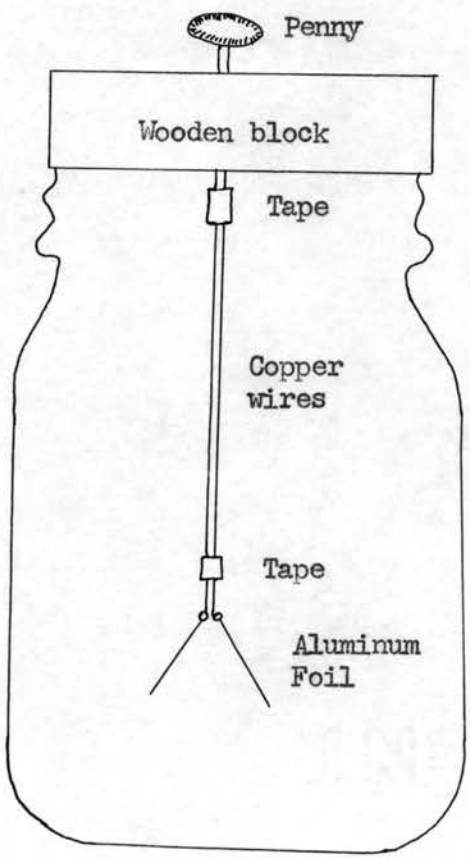

Figure I

Wilson Cloud Chamber

History. Charles T.R. Wilson of Cambridge University in England noted that vapor condenses on tiny bits of dust to form raindrops. He wondered if it would condense on anything as small as a subatomic particle. By producing an atmosphere saturated with water vapor in the chamber he found that the paths of particles from radioactive materials were marked with droplets of water. The particles had ionized the air and these ions had served as nuclei on which the water could condense. Wilson developed the Wilson cloud chamber in 1912 and for his accomplishment he shared the Nobel prize for physics in 1927.

Materials. Alpha ray source; 250-ml "soft-glass" Ehrlenmeyer flask; two 1/8-inch pipe nipples; 2½-inches long; two #6 one-hole stoppers; hose clamp; 10-inch length of pressure hose; hydrometer bulb; two 45-volt B batteries; 1½-inch brass machine screw; two burette clamps; wire; ringstand; Sealstik or DeKhotinsky cement.

Procedure. 1. Put two holes diametrically opposite each other in the flask as near the base as practicable. To do this, attach the rubber bulb and stopper to the flask. Heat a point on the flask in a bunsen flame. When the glass is molten, squeeze the bulb sharply. This will produce a hole which can be enlarged further by heating. One hole should be large enough to hold a wire, and the other, the screw containing the radioactive source.

2. Cement the alpha ray tip, procurable from scientific supply houses, to the end of the screw.

3. Using the sealing cement, which can be handled like sealing wax, seal the wire lead and the screw into their respective holes, as shown

DIAGRAM FOR WILSON

CLOUD CHAMBER[1]

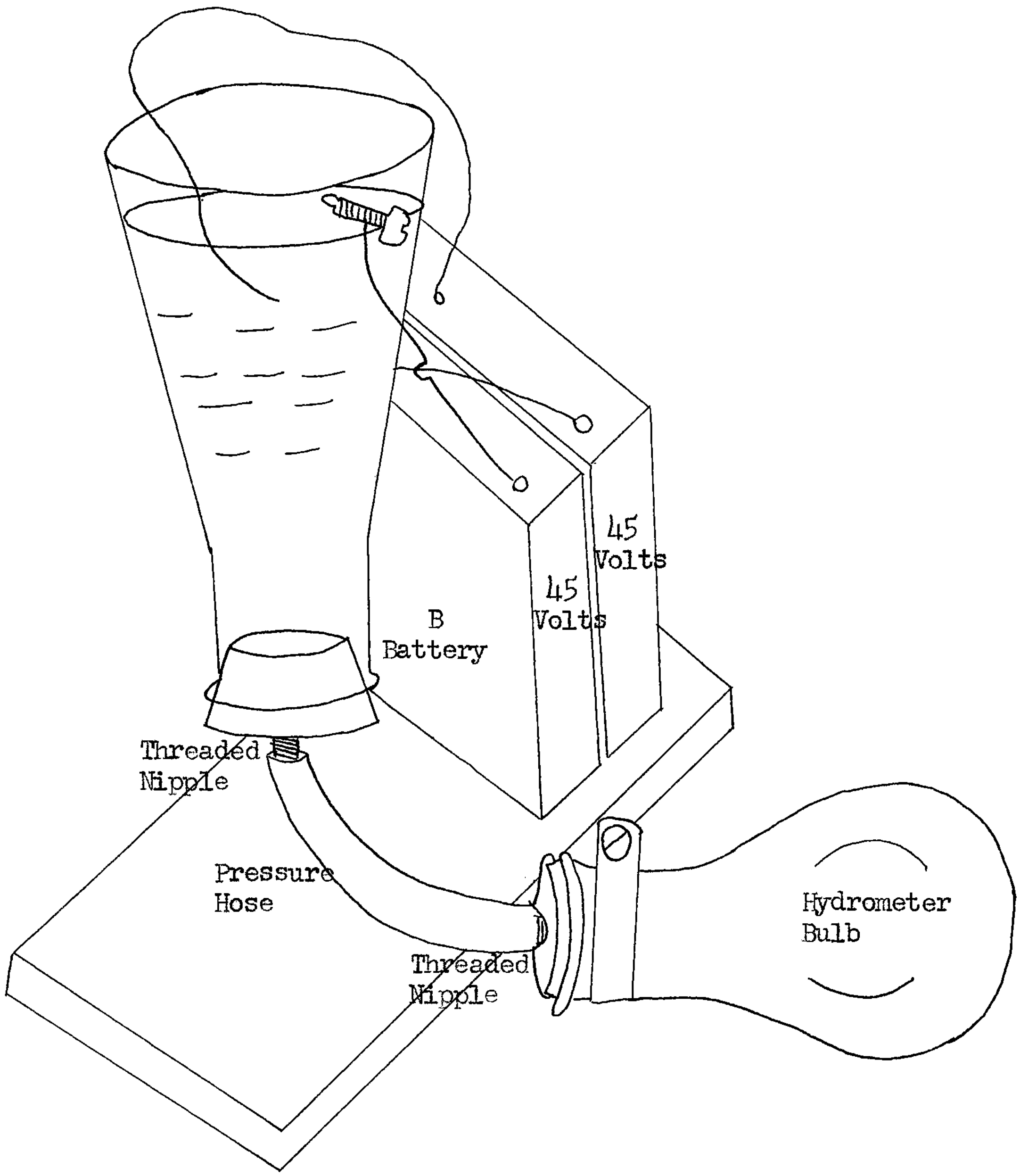

Figure 2

[1]Samuel Schenberg, et al, Laboratory Experiments with Radioisotopes for High School Science Demonstrations, (Washington, 1958), pp. 16-17.

in Figure 2. Allow about 3/4 of an inch of the screw to protrude into the flask.

4. Fill the flask with about 230 ml of water to which has been added 1 ml of alcohol and some dye, such as nigrosine. A pinch of salt will increase the conductivity of the water. Insert the stopper and bulb assembly and invert. When the bulb is filled with water, the level in the flask should be about 2 cm from the top.

5. Mount the flask on a ringstand by using a clamp on the neck of the flask and another below the stopper. This prevents the stopper from being expelled on compression.

6. Attach the 90-volt battery as shown in the diagram.

7. To operate, compress the bulb so that the level of the liquid rises, wait five or ten seconds, then release the bulb suddenly. Look for short momentary vapor tracks of alpha particles emanating from the alpha tip. A small light source which casts a beam above and parallel to the surface of the liquid will greatly increase the visibility of the tracks.

Discussion. When air is compressed the temperature of the air rises. If the gas is allowed to cool to room temperature and then the air is suddenly decompressed, the temperature drops and precipitation occurs if there are nuclei of condensation present. Ions in air are excellent nuclei on which condensation forms. At the moment of decompression, droplets of condensation appear around the ions produced as the alpha particles ionize atoms of air along their paths. These vapor trails or tracks are clearly visible immediately after decompression. They will be seen to radiate from the alpha ray tip and will indicate the path of the radiation. In the cloud chamber, ions are swept out of the air by means of the 90-volt battery. When the tracks disappear the experiment may be repeated. Different types of tracks can be produced by changing the source of the radioactive particles in order to get beta rays.

Uses. Photographs taken in cloud-chamber studies show clearly how various atoms break up, and how fast their particles lose energy. They also show what combinations take place when particles collide.

Spinthariscope or Simple Scintillation Counters

History. In 1903, W. Crookes in England, and J. Elster and H. Geitel in Germany, independently reported that the luminescence produced by alpha particles on zinc sulfide was not a uniform glow but consisted of thousands of individual flashes which could be seen with a microscope. Crookes developed a small device he called a "spinthariscope" for making these scintillations visible. It consisted of a tube with a zinc sulfide screen at one end, with a speck of radioactive salt one millimeter from it, and a lens in the other end.

The study of radioactivity by scintillations was used by Ernest Rutherford in 1908. He found that he could count the flashes of light produced by the alpha particles on the fluorescent screen. This was one of the two devices he used to prove that alpha particles were ionized helium atoms. Prior to 1930 the visual counting of scintillations was virtually the only method used for both quantitative and qualitative studies of individual alpha particles.

Discussion of Scintillators. To meet the requirements of a scintillator, the material must be able to convert the kinetic energy of the particle into a fleeting pulse of light. There are scintillators of both organic and inorganic origin. The organic phosphors have a short pulse time, which allows them to record more impulses, but do not produce as much light and are less effective than the organic materials when used with more energetic radiations such as gamma rays. The inorganic, unlike the organic, do not scintillate when pure but must have a small amount of activator present. Since the various radiations from radioactive materials behave differently and require different scintillators, they are discussed separately.

Alpha particles passing through the material produce fast electrons in the material, which in turn cause light pulses. Alpha particle detection by scintillation is carried out largely with zinc sulfide, using a trace of silver as activator. The larger crystals of zinc sulfide are difficult to obtain but small crystals are satisfactory with alpha particles since they have such a short range.

The excitation which produces fluorescence in the presence of beta rays is caused directly by the fast moving electron. Among the organic phosphors particularly suitable for use with beta emission, anthracene crystals give the highest light yield. A zinc sulfide phosphor and other materials can also be used.

Gamma rays produce scintillations indirectly. This production involves Compton scattering, photoelectric capture and ion-pair production, and is greatly dependent upon the energy of the radiation. The process of producing light pulses by gamma rays requires a greater mass of phosphor material and crystals of up to 2 inches thick are frequently used. Crystals of sodium iodide activated with about 1 per cent of thallium are the most commonly used phosphor for gamma ray detection.

Liquid and gaseous scintillators are now being employed with good results. Some scintillating materials are molded into transparent plastics which can be made or cut into the desired shape.

Materials. Hand lens; a round carboard mailing tube into which the lens will just fit; a round cardboard tube slightly larger than the first one; fluorescent zinc sulfide powder; piece of cork; straight pin; gamma ray source; a wooden plug 1/4 inch thick which will just fit into the larger tube; glue; low gloss black paint; and some thumbtacks.

Procedure. A scintillation counter similar to the spinthariscope invented by Crookes may be constructed as shown in Figure 3. Paint the inside to the tubes with the low gloss black paint. Determine the focal length of the lens by looking through the lens at an object and moving the lens up or down until you have a sharp image. The focal length is approximately the distance from the lens to the object. Mount the lens in the small tube and cut a strip of cardboard 1/4 inch wide and just long enough to go around the inside of the tube. Glue this in place $\frac{1}{2}$ inch from the end of the small tube. Allow to dry and place the lens in against the strip. Cut another strip just wide enough to fill out the tube and glue it in to hold the lens in place. Coat the surface of the wooden block with glue and sprinkle heavily with fluorescent zinc sulfide powder. Glue a small piece of cork in one end of the large tube just far enough from the end to allow the wooden block to be inserted. Glue an alpha particle source to the head of a pin and stick the pin into the cork to such a depth that the source will be in the center of the tube about one millimeter from where the edge of the wooden block will be when it is inserted. Place the block in the tube with the coated surface to the inside and fasten in place with thumbtacks inserted through the tubing. Slide the tubes together to complete the counter.

To view the scintillations, go into a dark room and let your eyes dark adapt for 5 to 10 minutes. Look into the counter through the lens and watch for faint flashes from the screen. The distance from the lens to the screen may need to be adjusted by sliding the tubes together or apart slightly. Each flash represents an alpha particle striking the screen, with some of its energy being changed to light. The alpha particles are derived from the atomic decay of an atom in the radioactive source. Other materials may be checked for alpha particle emission by putting samples into the counter in place of the alpha particle source.

Similar light pulses may be seen by observing the hands or numerals of a watch which has a fluorescent dial. In this case the alpha source is embedded in the fluorescent substance. The pulses may be made visible by observing the watch with a hand lens in a dark room.

Uses. Although the method of counting light pulses by eye is no longer used, the scintillation detector, when used with electronic counters, is now rapidly finding widespread use. The development and use of the photomultiplier tube to replace the eye of the observer in recording the light pulses has made it an instrument of sensitivity and precision. The scintillation counter takes many forms and shapes and is used where fast accurate counting is needed. Recently the scintillation counter was used to detect the antiproton where it was necessary to count the particles transversing a distance of 40 feet in 51 billionths of a second.

DIAGRAM FOR SCINTILLATION COUNTER

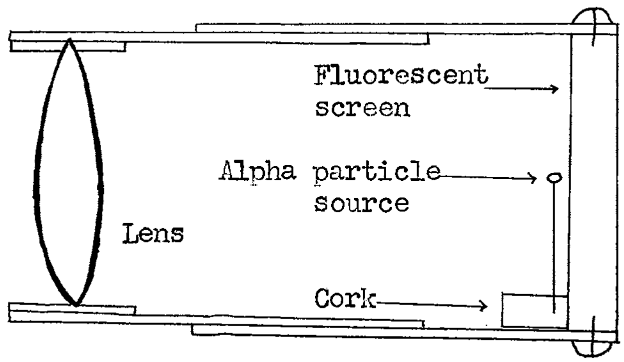

Figure 3

Continuous Cloud Chamber[2]

History. The idea of a continuously sensitive cloud chamber was proposed by A. Langsdorf in the United States in 1939. The device he constructed, called a diffusion cloud chamber, was somewhat complicated and it was not until about twelve years later that simpler forms were designed and operated successfully.

Materials. Some rubbing alcohol; black velvet; a strip of felt or weather stripping; airplane glue; and a straight-sided jar. A jar such as those used for peanut butter or certain cosmetics will do as long as it is the one-pound size or larger and is clear on the sides and bottom. The lid must have a rubber washer or cardboard filler.

Procedure. With model airplane glue or similar cement, stick a piece of weatherstriping or heavy felt a little less than one inch in

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[2]Nelson Beeler and Franklyn Branley, Experiments with Atomics (New York, 1954), pp. 63-65.

width around the inside wall at the bottom of the jar. Cut a strip of black velvet 1 inch wide and glue this on the inside wall of the jar at the top. Cut a circular piece of black velvet just large enough to fit inside the metal cover and glue this in place.

Pour enough rubbing alcohol into the jar to saturate the felt around the edge and to cover the entire bottom well. Then put the cover on as tightly as you can. Make a stand for the chamber by filling a pound coffee can about halfway with a false bottom made with cardboard. Put about an inch of crushed dry ice on top of the cardboard. Be very careful when handling the dry ice. It is so intensely cold that it can give you a severe frost bite.

Put the chamber on the dry ice with the metal top down. Hold your hand on the glass bottom of the jar, which is at the top now, and warm the chamber slightly. You are now ready to make observations. Put the beam of a strong flashlight or a slide projector directly on the chamber at one side. Watch closely from above and when the warm vapor condenses, which may take about five minutes, you will see a continous rain of fine droplets which first appear about one inch below the top. After five or ten minutes, the amount of this rain or fog decreases, and as conditions in the chamber become right you will see about an inch above the bottom cobweblike threads suddenly appearing and disappearing at various angles. These are vapor trails that are made by the appearance of droplets along the path of cosmic rays which pass through the chamber.

If you hold radioactive materials near the jar you will be able to see their cloud tracks also. The atomic particles pass through the chamber producing ions. Alpha particles will need to be placed inside the jar to produce tracks. The alcohol and water in the jar then condenses on these ions to produce vapor trails.

Holding your hand on the jar makes the top of the chamber a warm zone, and the dry ice in the can makes a cold zone. Somewhere between these two extremes the air is saturated with vapor and it is in this region where the tracks form.

Uses. The continuous cloud chamber has an advantage over the Wilson cloud chamber in being continually ready to record an event. The main drawback of the continuous cloud chamber is that, at best, the sensitive region is no more than three inches deep. Nevertheless, it has found many uses, especially in the study of high energy particles obtained in the laboratory.

CHAPTER III

EXPERIMENTS

This chapter lists several experiments which may be conducted using the instruments described in Chapter II.

The experiments are largely designed to help the student develop a better understanding of atomic radiations. These are confined to the natural radiations from radioactive substances. The properties include the ability of the various radiations to penetrate materials, the effect of a magnetic field upon the path of the radiation, and a study of the radiation energies.

Some of the experiments will aid the students in the general study of radioactivity. These experiments include a study of the half life of a radioactive substance and the reduction in radiations at increasing distance from the source.

The use of radioactive isotopes in scientific research has increased rapidly during recent years. The experiments describing the use of radioactive phosphorus to study the uptake and deposition of phosphorus in fish and celery were included to give the students some insight into how these materials are used as an aid in scientific studies.

The experiments are not designed to be used in any definite sequence but are independently constructed so that any number or order may be used according to the need.

EXPERIMENT I

SEPARATING RADIOACTIVE MATERIAL FROM ORE

Purpose. To remove a considerable amount of the inert material from uranium ore and to make a radioactive pellet.

Materials. Radioactive ore; no-screen X-ray film, a lightproof box; materials to crush ore; materials to develop film; and some clear plastic cement.

Procedure. 1. Crush the piece of uranium ore into particles approximately the size of large grains of sand and spread them out on the bottom of the box.

2. In the dark cut a piece of film the size of the box and place it over the crushed ore. Mark the film and box to retain orientation of the two.

3. After 24 hours remove the film and develop it.

4. Return the developed film to the box and note dark areas. Remove the grains in the areas where the film was darkened and throw away the remainder.

5. Crush the material that is left into slightly finer particles and spread them out on the bottom of the box. Cover the material with another piece of film being sure to mark it and the box.

6. Develop this film and remove the materials in the areas where the film was darkened. This process may be repeated again to further concentrate the material or it may be used in its present concentration.

7. To make a radioactive pellet, mix the material into about an equal amount of clear plastic cement and allow to dry. Be careful to allow some of the material to be exposed at the surface if you want

an alpha particle emitter because a heavy coating of glue will stop most of the alpha particles. The material may also be inclosed in a medicine capsule but this will also reduce alpha particle radiation. The use of the pellet form or medicine capsule is recommended to reduce the danger of inhaling or absorbing the radioactive materials. These will make ideal radioactive sources for further experimentation.

EXPERIMENT II

THE ENERGY OF ALPHA PARTICLES

Purpose. To use a Wilson cloud chamber to study the energies of alpha particles.

Materials. Wilson cloud chamber; 2 or 3 sources of alpha particles; a centimeter ruler; and a light source.

Procedure. 1. Set up the Wilson cloud chamber with one of the alpha sources in position.

2. Place a small light source so it will cast a beam above and parallel to the surface of the liquid.

3. Compress the bulb so that the level of the liquid rises, wait five or ten seconds, then release the bulb suddenly. Look for short momentary vapor tracks of alpha particles emanating from the alpha tip.

4. Observe the tracks for a few minutes, checking to see if some are longer than others. Try to observe groups that are of about the same length. Record the name of the element contained in the alpha source and approximate length of the tracks. Record only the average length of groups of tracks as individual tracks will vary. Be sure to record two or more group lengths if they are observed.

5. Replace the original alpha particle source with a different one and repeat the experiment. When you have recorded the data for all available sources, check a handbook and record the actual energies of alpha particles emitted from the elements you have used.

6. Compare the number of different alpha particle energies listed with those you have recorded for the various elements. Make a graph of the data with the ranges on one axis and the cube of the velocities on

the other axis. When the figures have been plotted the resulting graph should produce a straight line. A check might be made of any that deviate too far from the line.

7. The energies of alpha particles may also be computed by using the electroscope to determine the range of the alpha particles in air and applying the formula: $E = 2.12\ R^{2/3}$, where E is in million electron volts and R is in centimeters.

EXPERIMENT III

THE RANGE OF ALPHA RADIATION IN AIR

Purpose. To determine the range of alpha particles in air.

Materials. Alpha particle source; electroscope; centimeter ruler; ring stand with supporting material for alpha particle source; and a stop watch.

Procedure. 1. Establish the amount of change in the electroscope reading which will be used as a standard amount of discharge for the experiment. The scale can be marked "S" and "F" for the starting and finishing points.

2. Keeping all radioactive materials at a distance, charge the electroscope and record the time required for it to discharge from "S" to "F" due to natural leak. Make three readings and record the average. On very damp days the natural leak may discharge the electroscope so rapidly that it will be difficult to carry on the experiment.

3. Mount the alpha source on the ring stand in such a manner that it is at the same height as the knob on the electroscope. Place the source at a distance of one centimeter from the knob of the electroscope.

4. Charge the electroscope and record the time required for the electroscope to discharge the standard amount. Subtract this answer from the time required for discharge due to natural leak. The result is the difference in discharge rate due to the presence of the alpha source. Make two more readings to check the data.

5. Move the alpha source to a distance of two centimeters from the knob of the electroscope and make readings and record data.

6. Continue to move the alpha source away from the electroscope

until the time for discharge no longer changes.

7. When moving the alpha source does not affect the discharge time, the distance is beyond the range of alpha particles in air.

8. Make a graph by plotting the distances on one axis and the time required for discharge on the other axis. A study of the curve should indicate the range of the alpha particles. There may be more than one abrupt change in the curve if more than one energy is represented in the alpha particles.

9. Check your results with a handbook or other source.

EXPERIMENT IV

PENETRATION BY ALPHA PARTICLES

Purpose. To check the ability of alpha particles to penetrate materials.

Materials. Alpha particle source; no-screen X-ray film; two lightproof envelopes, about two inches square, a lightproof box into which the envelopes will fit, and some aluminum foil.

Procedure. 1. In the dark cut three pieces of film which will fit into the envelopes. Notch or otherwise mark the films so they can be distinguished when you have completed the experiment.

2. Place one piece of film into an envelope and put it on the bottom inside the box. Cover the envelope with a sheet of aluminum foil.

3. Place a piece of film in the other envelope and put it on top of the foil. Place the other piece of film on top of the second envelope and the alpha source on top of the last piece of film. The source should be approximately in the middle of the film.

4. Place the lid on the box and let it stand for 24 hours. Remove the films in the dark and develop them.

5. The dark areas on the films were produced by the alpha particles. Some of the film was not darkened because the alpha particles could not penetrate that far through the material.

6. Estimate the penetrating ability of alpha particles in light of your experiment.

7. A cloud chamber could also be used to check the ability of the alpha particles to penetrate materials.

EXPERIMENT V

THE INVERSE SQUARE LAW AND TOTAL RADIATION

Purpose. To show that the intensity of radiation varies inversely with the square of the distance from the source and to measure the total radiation from the source.

Materials. A quart fruit jar; 2 extra jar lid flats; a small gas or air valve with a threaded end and nut; glue; luminescent zinc sulfide powder; an alpha particle source; a strip of cork the length of the jar; a pin; some cardboard; materials to drill a hole in the lid; hand lens; metric ruler; vacuum pump; and a stop watch.

Procedure. 1. Cut a piece of cardboard the same size as the bottom of the inside of the jar. Cut an area of one square centimeter out of the center of the cardboard. Glue the cardboard onto the bottom of the jar.

2. Paint the bottom of the jar that is exposed through the cardboard with glue. Sprinkle the glue with luminescent zinc sulfide powder.

3. Glue the piece of cork along the side of the jar extending it from top to bottom.

4. The gas valve will be placed in the lid so the jar can be evacuated. Place the extra flats in the lid for reinforcement and drill a hole through the lids just large enough to admit the threaded end of the valve. Put the threaded end of the valve through the lid from the top and tighten the nut on the inside.

5. Glue the alpha source to the head of the pin. Stick the pin into the cork so the alpha source is one centimeter from the screen and

in the center of the screen. Put the lid on the jar and evacuate as much air as possible from the jar.

6. Take the hand lens, jar, and stop watch into a dark room and let your eyes adjust to the dark for about five minutes. View the screen from the bottom to see if you can count the scintillations. If the scintillations are to rapid to count use a weaker source.

7. Count the number of scintillations for three different three minute periods and record the numbers.

8. Move the source to a distance of two centimeters, count the scintillations and record. Do the same for 3, 4, and 5 centimeters.

9. Use the data and draw a graph, plotting counts per minute as ordinate against distance in centimeters as abscissa.

10. Draw another graph, plotting counts per minute as ordinate against the square of the distance in centimeters as abscissa. The two graphs and the data should illustrate the inverse square law.

11. Using the data you have obtained an estimate can be made of the total number of alpha particles being emitted by the source. The particles are emitted approximately equal in all directions. Since the particles move out in all directions, they may be considered to be moving as an expanding sphere. At a distance r the area of this sphere would be $A = 4\pi r^2$. The distance r is the distances the source was from the screen. By substituting one of the distances into the equation, the area which would be receiving radiation at that rate will be obtained. The number of particles for one square centimeter was counted so now if this is multiplied times the total area, the answer will be a good estimate of the total radiation from the source. As an example suppose the count was 15 scintillations at a distance of 2 centimeters.

The area receiving radiation at this rate would be $A = 4 \times 3.14 \times 2 \times 2$ or $A = 50.24$ square centimeters. If one square centimeter was receiving 15 alpha particles at a distance of 2 centimeters, then 50.24 square centimeters would receive 15×50.24 or a total of 754 scintillations per minute. Using the other distances and numbers of scintillations a good estimate of the total radiations per minute of the alpha source should be possible.

DIAGRAM FOR INVERSE SQUARE LAW APPARATUS

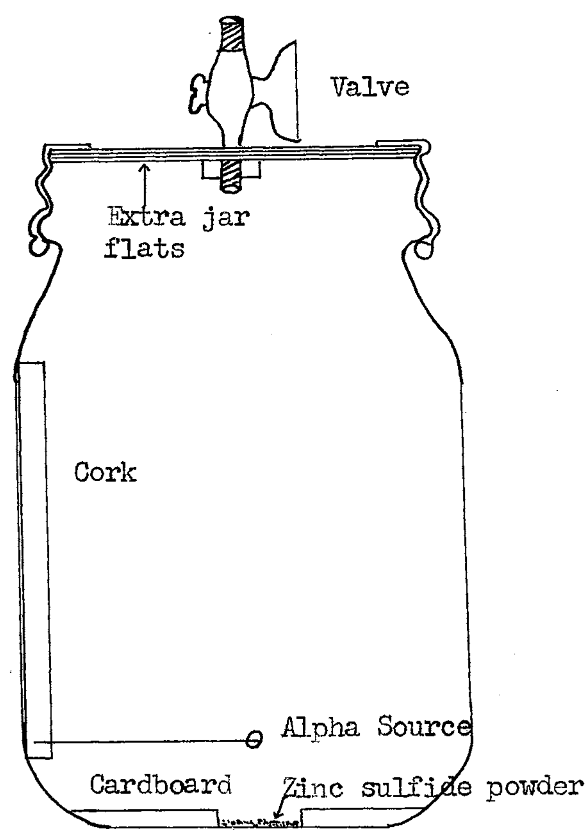

Figure 4

EXPERIMENT VI

PENETRATION OF BETA RADIATION

Purpose. To check the penetrating ability of beta particles.

Materials. Beta radiation source; no-screen X-ray film; 3 lightproof envelopes about 2 inches square; a lightproof box into which the envelopes will fit; aluminum foil; and an aluminum plate about 2 inches square and one millimeter thick.

Procedure. 1. In the dark cut three pieces of film which will fit into the envelopes. Notch or otherwise mark the films so they can be distinguished when you have completed the experiment.

2. Place one piece of film into an envelope and put it on the inside of the box next to the bottom. Cover the envelope with the aluminum plate.

3. Insert another sheet of film into another envelope and place it on top of the aluminum plate. Cover this envelope with a sheet of aluminum foil.

4. Put a sheet of film into the last envelope and place it on top of the aluminum foil. Place the beta radiation on top of the last envelope about in the center.

5. Remove and develop the film. The dark areas on the film were produced by beta radiation which penetrated to the film. If some of the film was not darkened, the beta radiation did not penetrate that far. Estimate the penetrating ability of beta radiation.

6. The penetrating ability of beta radiation could also be checked using a cloud chamber.

EXPERIMENT VII

EFFECTS OF A MAGNETIC FIELD UPON BETA RADIATION

Purpose. To check the effect of a magnetic field upon the path of beta particles.

Materials: No-screen X-ray film; a beta radiation source; strong Alnico magnet; small diameter 3 inch test tube; pint fruit jar; light-proof box slightly larger than the jar and at least three inches taller; 3 pounds of lead wool which may be obtained from plumbing companies; cardboard; glue; and some thumbtacks.

Procedure. 1. Put enough of the lead wool into the fruit jar so the end of the three inch test tube will just come to the top of the fruit jar when placed on the lead. Hold the test tube in a vertical position in the center of the jar and pack lead wool around it until the jar is full. Put the beta radiation source in the bottom of the test tube and this will provide a well for producing a beam of beta radiations. Another method would be to drill a hole slightly larger than the test tube in a block of lead and insert the test tube.

2. Fix the box so the top can be removed and glue a layer of cardboard on the inside of the lid. Put the jar into the box and make it solid so the jar cannot move about in the box.

3. In the dark cut a piece of X-ray film the size of the inside of the lid. Fasten it to the inside of the lid with two thumbtacks placed in opposite corners. Mark the film to retain its orientation on the lid. Place the lid on the box and allow to stand for 24 hours.

4. Develop the film and note the dark area.

5. Position the magnet to aline the magnetic field perpendicular

to the path of the beta radiation and close to it. Fasten a new sheet of film to the lid and allow to stand for 24 hours.

6. Develop the film and note the dark area.

7. Compare the dark area on this film to the one made without the magnet. The addition of a magnetic field perpendicular to the path of beta particles causes a change in direction since the beta radiation is composed of charged particles.

8. Increasing the magnetic field will increase the deflection. The amount of deflection will also depend upon the energy of the individual particles. Since the energies will vary considerably, the dark area on the film will be somewhat elongated. There may be some portions which are denser than other parts. These dense areas indicate a concentration of beta particles with similar energies.

EXPERIMENT VIII

PENETRATING ABILITY OF GAMMA RAYS

Purpose. To check the ability of gamma rays to penetrate materials.

Materials. Gamma ray source; no-screen X-ray film; 3 lightproof envelopes about 2 inches square; a lightproof box into which the envelopes will fit; aluminum foil; an alumuminum plate about 2 inches square and about one millimeter thick; and a lead plate about 2 inches square and one or two millimeters thick.

Procedure. 1. In the dark cut three pieces of film which will fit into the envelopes. Notch or otherwise mark the films so they can be distinguished when you have completed the experiment.

2. Place one piece of film into an envelope and put it inside the box on the bottom. Cover the envelope with the lead plate.

3. Insert a sheet of film in another envelope and place it on top of the lead plate. Cover this envelope with the aluminum plate.

4. Place the last sheet of film in the envelope and lay it on the aluminum plate. Put the gamma ray source on the top envelope about in the middle.

5. Return the lid to the box and allow to stand for 24 hours. Remove and develop the films.

6. The dark areas on the film were caused by gamma ray penetrations to the film. A decrease in darkening indicates a decrease in gamma ray intensity.

7. Compare the penetrating ability of gamma rays to that of alpha and beta particles.

EXPERIMENT IX

HALF LIFE

Purpose. To determine the half life of a radioactive isotope.

Materials. No-screen X-ray film; a vial of about one microcurie of I^{131} in solution; and a lightproof envelope.

Procedure. 1. In the dark insert a piece of X-ray film into the lightproof envelope. Lay the envelope in a spot where it will not be disturbed and place the vial of I^{131} on top of the envelope.

2. Allow the materials to remain in this position for 24 hours. Remove the film and develop it. The dark area was caused by the activity of the I^{131}.

3. Follow the same procedure each day for 16 days using the same sample of iodine and keeping the exposure time the same. Be certain to mark each film so you will know which day it was exposed.

4. Arrange the developed films in order from 1 through 16. Make an estimate of the film which is only one half as dark as number one. One less than the day you select gives the half life of I^{131}. Check your answer by finding the film that is one half as dark as number 2. Two less than the number you select will also give the half life.

5. A more accurate estimate can be obtained by using a standard light source and a light meter. Check the amount of light passing through the first film. The film which will allow twice this much light to pass through has received one half the exposure, and represents the half life of I^{131}.

EXPERIMENT X

TRANSLOCATION OF RADIOACTIVE PHOSPHORUS IN CELERY STALKS[1]

Purpose. To show the translocation of P^{32} in a celery stalk.

Materials. Fresh celery stalks containing many leaflets; about 10 microcuries of P^{32}; quart jar; no-screen X-ray film; and a lightproof box about the size of a cigar box.

Procedure. 1. Place 2 or 3 medium sized celery stalks in a jar containing 200 ml of water and 10 microcuries of P^{32}. Allow to stand for 24 hours.

2. Place some film in the lightproof box. Slice 2 or 3 cross sections of the stalks from the parts of the stalks which were above the water level. Put the slices on top of the film in one end of the box.

3. Take some of the small leaflets and lay them on the film in the other end of the box. Place a block of wood or something on them so they will lie flat.

4. Close the box and allow to stand for 24 hours. Develop the film and notice the dark areas. The film may be printed on regular high-contrast paper if desired and the radiations will then appear as bright spots on the dark background.

5. The radiations should appear strong in the veins of the leaflets and in the vascular system of the stalks. If these are not noted repeat the experiment allowing the celery to stand in the solution for 2 or 3 days and the results will be much more striking.

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[1] Schenberg, p. 26.

EXPERIMENT XI

REMOVAL OF RADIOACTIVE PHOSPHORUS FROM WATER BY GOLDFISH[2]

Purpose. To show that a fish will remove radioactive phosphorus (P^{32}) from the water and concentrate it in various parts of its body, especially in the skeletal system.

Materials. Goldfish, 2 to 3 inches long; a jar containing 600 ml of tap water; radioactive phosphorus; Elodea or other fresh-water plant; X-ray film; and dissecting materials.

Procedure. 1. Place the goldfish in a jar containing 600 ml of tap water, 10 microcuries of radioactive phosphorus, and some Elodea or other suitable fresh-water oxygenating plant.

2. Keep the fish in this solution 3 to 5 days.

3. Remove the fish and wash it in running water for several minutes in order to wash away surface solutions.

4. Etherize the fish and then place it in a histological solution for 12 to 24 hours in order to fix and harden the tissues (80% alcohol is an example of such a fixative).

5. Prepare the skeleton of the fish.

6. Allow the skeleton to dry in order to avoid direct injury to the film.

7. Place the skeleton on covered film (covered with standard black lightproof paper).

8. Use a board or whatever necessary to hold the skeleton flat

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[2]Ibid., p. 30.

against the film.

9. Keep in this position to expose the film to the skeleton for 2 to 4 days.

10. Develop the film and print with glossy high-contrast paper. The brightness of the skeletal parts indicates the deposition of the radioactive phosphorus.

CHAPTER IV

CONCLUSION

This report was written to investigate the use of simple, inexpensive apparatus in the study of atomic energy. It is felt that the construction and use of the materials described would greatly aid in the student's understanding of atomic energy. A study of the simple apparatus will provide the necessary basic knowledge for an understanding of more complicated equipment.

In the field of atomic energy, where so much of the substance of study is invisible, it is very difficult to develop an understanding without equipment which will aid in the visualization of the subject. Most science teachers will have commercial equipment available, but if such equipment is limited, some of these simple devices should be valuable aids. The material should be especially helpful for student projects or science clubs.

The material contained in this report could be used as a basis for more advanced student projects and studies. The cloud chambers are providing a great deal of knowledge to science. The addition of a camera to record tracks in the chamber would greatly increase its value. The student could study the different types of tracks and watch for collisions and decay of particles. Photographs of activity in the cloud chamber could be used to study the energies and other properties of the particles or rays.

Various types of film are available which would provide more advanced study. Energies of particles, collisions, and work with neutrons are some of the things that are being done using film. The development and understanding of this type film is rather difficult but would offer a challenge for some of the more alert students.

In recent years it has grown increasingly clear that the basic elements of all science depend upon atomic structure and behavior. It is clear that we need to make a special effort to help students develop a basic knowledge of atoms and their constituents. Helping them to build and operate their own devices for atomic studies is a logical method for developing this knowledge.

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