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Name: Richard V. Underwood Date of Degree: August, 1962

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EXPERIMENTS WITH RADIATION FOR HIGH SCHOOL

Pages in Study: 51 Candidate for Degree of Master of Science

Major Field: Natural Science

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ADVISER'S APPROVAL James H. Zant

EXPERIMENTS WITH RADIATION
FOR HIGH SCHOOL

By

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Bachelor of Arts

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Stillwater, Oklahoma

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Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
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ADVISER'S APPROVAL ______________________

EXPERIMENTS WITH RADIATION

FOR HIGH SCHOOL

Report Approved:

Report Adviser

Technical Adviser

Dean of the Graduate School

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CHAPTER I

INTRODUCTION

Radiation, radioactive fallout, A-bombs, radioisotopes--today, these are common and familiar terms. But what do they mean to the high school pupil?

Since this is an atomic era and great strides are being made daily in understanding and controlling the atom, we probably should include such studies in the high school curricula.

Radioisotopes have offered science a new and unique tool for discovering and exploring many scientific problems. They can be used to measure the thickness of a given material, to take "X-ray" pictures of equipment or to trace the pathways of metabolism. This last enables us to know what happens to the food we eat, and understand how it becomes energy. Or, it may enable us to see how the plant takes CO_2 and H_2O and produces carbohydrates. Many problems such as these remain unsolved, but in time the fringe of knowledge will push into the half-light of dawn and another new day will unfold with new light on heretofore unguessed problems. It is high time then that we incorporate some of the new knowledge into the studies of the high school student.

This report will deal primarily with only the radioisotope phase of atomic energy and will include just enough theory to enable the student to use the material herein contained. This work is not intended to be a complete course or unit in itself, but it will contain necessary facts about radiation so that these experiments can be carried out by the high school student. It should be supplemented with theory from other sources.

The first part of the experiments will be of a general nature which may be used in biology, chemistry, or physics classes. The second part is intended primarily for use in biology classes and the last part is for work in chemistry classes.

CHAPTER II

GENERAL INFORMATION ABOUT RADIOACTIVITY

Radiation: What is it?

The term ionizing radiation is used to indicate the rays or particles ejected from an atom in an excited state. This radiation may be gamma rays from the nucleus, x-rays from the electrons, beta particles, alpha particles, neutrons, strange particles or neutrinos. In large enough doses, all of these produce visible damage to the body. In small amounts, handled properly, such radiation becomes a useful tool for science.

Alpha particles, denoted by α, being rather large, are stopped fairly easily and are probably least to be feared outside the body. If ingested or inhaled, they can cause much more severe damage, because all of the ionizing effect takes place within the subject.

Gamma (γ) rays and x-rays are most penetrating. The action and effects of each of these rays are the same. The difference in name merely indicates the point of origin. The gamma ray is from the nucleus and the x-ray is caused by a shift in electron position. Gamma rays will penetrate material which will easily shield against alpha and beta particles. For example, it takes 1.5 cm. of lead to slow a 3.0 Mev. gamma ray by a factor of 2 (1, p. 518), but a 3.0 Mev. alpha particle has a range of only about 1.7 cm. in air (1, p. 142). Beta particles have a range of 1.5 gm./cm.^{2} in aluminum (1, p. 174).

From this one can readily see that it would be much more simple to shield from alpha and beta particles than from the gamma or x-ray.

Effects of Gamma Ionizing Radiation on the Body (2, p. 6)

Dose rate in Roentgens	Effects
0-25	No observable effect
25-50	Blood change as manifested by count
50-100	10% exhibit symptoms of radiation sickness; full recovery within a few days
100-200	25% exhibit symptoms; probably no deaths; possibly disability
200-300	50% exhibit symptoms; 25% deaths
300-400	90% exhibit symptoms; 25% deaths; injury possible to all 90%
400-500	50% lethal
500-Over	Nearly all die within 30 days

As illustrated by the table, even small amounts of radiation have some effects on living tissue. One may easily see that it would be wise, even when using low levels of radiation, to form the habits necessary for handling larger amounts of the material. Care must be taken at all times.

Isotope Data Chart and Information on Availability

The high school science teacher can obtain specific amounts of radioisotopes under a general license for which no application is necessary. In other words, no special permit is required. Certain procedures for use must be followed, which include: (1) the radioactivity shall not be increased, (2) the material must not be handled in such manner to cause it to be applied to, ingested or inhaled by humans, (3) no person shall have on hand or use more than 10 such quantities of material (3, p. 2).

<u>List of Material and Amounts</u> (1, p. 521; 3, p. 5; 4, p. 8)

Isotope	Micro-curies	Sold as	Physical half life	Emission Spectrum Beta Particle Mev.	Gamma Ray Mev.
barium 140	1	———	2.6 min.	———	0.66
calcium 45	10	CaCl	163 days	0.25	———
carbon 14	50	Na_2CO_3	5568 yrs.	0.155	———
cobalt 60	1	$Co(NO_3)_2$	5.27 yrs.	———	1.1-1.3
copper 64	50	———	12.8 hrs.	0.58	1.34
fluorine 18	50	———	1.87 hrs.	0.64	———
hydrogen 3	250	H_2O	12.5 yrs.	0.02	———
iodine 131	10	NaI	8.08 days	0.6	0.8-.367
phosphorus 32	10	NaH_2PO_4	14.3 days	1.69	———
potassium 42	10	———	———	———	———
sodium 22*	10	NaCl in HCl	2.7 yrs.	0.55	1.28
sodium 24	10	———	15 hrs.	1.39	2.758
sulfur 35	50	Na_2SO_4	87.1 days	0.17	———

* Use this material with caution. This exchanges with the sodium of the body easily.

In addition to the above listed isotopes, many other labeled compounds and isotopes are available. See Appendix B for a list of sources. For a complete list of isotopes available under the general license, see bibliography reference 3.

Some Do's and Don'ts in Handling Radioisotopes

The primary principle of radiation protection is that unnecessary exposure to ionizing radiation should be avoided. If by accident some person were to swallow the amount of one sample of the radioisotope allowable under the general license, he would quite probably have no ill effects as a result of radiation. Every precaution must be taken to prevent such accidents, because, should a person by chance have a larger dose, the result would be quite damaging, and there is at present no known cure. Careless technique would contaminate the laboratory and raise the radiation received from the laboratory environment. Such radiation, called background count, would soon reach an extent that it would no longer be possible to measure the radioactivity in the desired material with any degree of accuracy. The following precautions are suggested (5, p. 1):

1. All work with unsealed radioisotopes should be done in trays. A special paper to absorb the material is also now available.

2. Rubber or plastic gloves should be worn in handling active solutions and contaminated substances. The use of tongs and forceps is recommended in handling these materials.[1]

3. Pipetting of radioactive material by mouth should not be done. Use a rubber bulb or slow vacuum via a suction flask trap.

4. When vaporizing solutions, the work should be carried out under a fume hood or near an exhaust fan. An open window which has the air flowing out will also suffice if the level of radiation is low.

---

[1] Author's note: A difference of opinion exists here, as one may be more clumsy with these devices. Extreme care should be used.

5. Eating, drinking, smoking and the use of cosmetics is not allowed where radioactive materials are being used.

6. All contaminated wastes should be placed in a labeled container for subsequent disposal.

7. All glassware used for radioactive solutions should be kept separate from uncontaminated glassware.

8. Radioactive materials should be plainly labeled and kept locked up when not in use.

9. A sign, indicating that radioactive materials are being used should be displayed during an exposed experiment.

10. Account for all radioactive materials received, used, disposed of or stored.

11. Hands should be washed after working with active solutions. Hands, clothing, and area should be monitored with a suitable radiation detector periodically.

12. A suitable carrier (nonlabeled molecule of the same configuration as that of the isotope) for the isotope involved should be available at all times in order that decontamination may be rapidly effected in the event of accident.

Decontamination and Disposal of Waste

Glassware may be placed in a large beaker of cleaning solution (35 mls. of saturated sodiumdichromate solution per liter of concentrated sulfuric acid) for 24 hours to remove any radioactive material. This should be done under a hood. The cleaning solution may be dumped down the drain with large quantities of water, and the glassware washed in the normal manner after rinsing it with water to remove the cleaning solution. When the half-life of the contaminating material is short, it is best to store the contaminated glassware ten half-lives. When active materials are heated to extreme dryness on glass, or when the glaze on porcelain has been broken, it is best to replace the equipment. Metal objects may be decontaminated with dilute nitric acid. Brass may be decontaminated with brass polish and plastics with ammonium citrate. Strong acids or alkalis are preferable for decontaminations where they can be used. The choice of which acid or alkali should be used will be based on which of these makes the radioactive material most soluble. A non-labeled solution of the same material is also very useful for decontamination procedures. Wooden objects, or those of porous nature will have to be burned or buried (7, p. 3).

Physical facilities must be decontaminated according to the nature of the material. Wood should be planed. Washing with carbon tetrachloride is sometimes successful in the case of paint, but removal and repainting is better. A special type of paint is now available, called stripping paint, which may easily be peeled off a surface, thus removing the radioactive material. Drains may be flushed with large amounts of water, scoured with rust remover and soaked with a solution of citric acid (1 lb. / gal. of water), then flushed with large amounts of water (7, p. 11).

Carbon 14 may be disposed of in sewers with large amounts of water. Sewage must not exceed 1 mC / 100 galloons. It may also be disposed of in garbage, not to exceed 1 uC / lb. of garbage. Carbon 14 may also be buried in small amounts such as would be used in the average high school laboratory. Phosphorus 32, iodine 131, and sulfur 35 may also be disposed of by flushing down the drain with plenty of water for 5 minutes. The waste from the drain must not exceed 1 millicurie/gallon. Insoluble materials can also be disposed of via sewage if it meets the above specifications (7, p. 11). In general, short half-lived material may be held for ten half lives and then buried under four feet of earth whenever the amount of radiation is small.

PART II

GENERAL EXPERIMENTS

EXPERIMENT I

ALPHA PARTICLE DEMONSTRATION (6)

Purpose:

To familiarize the student with the use of the cloud chamber as a laboratory tool and to demonstrate one of the radioactive particles.

Materials:

1 cloud chamber (may be obtained from the supplier listed in the appendix, or made following the instructions in Appendix A)

Absolute ethyl alcohol

Nylon stocking

Dry ice

Blotting paper

Alpha emission needle (as mentioned in Appendix A)

Procedure:

This experiment is designed for the use of laboratory-made equipment. Place blotter in bottom of dish. Wet blotting paper until it is dripping with alcohol. Cover dish and place the whole affair on block of dry ice. Observe that there are tracks before the radioactive source is put in; these are from cosmic radiation and alpha particles. Put in place the alpha needle as described in Appendix A. Alpha particles will be demonstrated by short vapor trails. If there are any beta particles present they will be demonstrated by longer and narrower zig-zag trails. Occasionally, pair production will be noted. Pictures can be taken of the trails for later use as demonstrations. To clear the cloud chamber, rub the glass portion with the nylon stocking.

Questions:

1. What causes the vapor trail?
2. Compare the range of alpha and beta particles.
3. What causes pair production?
4. What is an ion pair?
5. Why does the chamber clear when the glass is rubbed with nylon?
6. What uses can you think of for this device?

EXPERIMENT II

TYPES OF RADIATION

Purpose:

To show two of the various types of radiation.

Equipment:

Cloud chamber

Absolute ethanol

Dry ice

Strong Alnico bar magnet or a strong homemade D. C. electromagnet

Alpha needle

Procedure:

Set up the cloud chamber as in experiment I. Place magnet at various positions around and above the cloud chamber and observe the effect.

Questions:

1. Why do the vapor trails now curve in the presence of a magnetic field?

2. What application might be made of these facts?

3. Does the cloud chamber still have to be cleared with the nylon stocking as in the previous experiment? Why or why not?

4. Observe the length and size of each track. Read in an outside reference about the cathode ray tube and then determine the charge on the particles by their response to the magnetic field.

5. Attempt to take a flash picture of the results to show curvature of the particle. Could you get an indication of the particle size from the curvature and width of the track? If so, how?

Note:

Different sources of radiation may be used to show beta emission more clearly.

EXPERIMENT III

SHIELDING

Purpose:

To demonstrate the effects of shielding and to learn the use of the Geiger counter.

Equipment:

Geiger counter V-700 survey meter from high school radiation kit provided by Office of Civil and Defense Mobilization

Various isotopes to emit alpha, beta, and gamma radiation (these could be an alpha ray tip similar to that used in the cloud chamber, phosphorus 32 and iodine 131)

Shielding materials such as sheet aluminum, paper, cardboard, plywood, polyethylene, sheet lead, and clay tile

Some sort of rack for holding the shielding between the radiation source and the G-M probe (See experiment V)

Instruction booklet for Geiger counter

Procedure:

Read the instruction booklet so that you know how to operate the Geiger counter properly. Then adjust the meter carefully to receive the background count. Note the counts per minute with and without the probe shield in place. Place the unshielded probe 1 inch from the alpha source. Note and record the reading. Turn the probe shield so that it covers the opening. What is the reading now when the probe is held 1 inch from the source? Open the shield and place a piece of paper between the probe and the source. Hold probe about 1 inch from the alpha source. Note counts per minute. Repeat this using the cardboard.

Close the probe shield and place the beta source (P^{32}) in the stand so that the probe will be about 4 inches from it. Cut a narrow (about 5 mm.) slot in one piece of aluminum and fit it about 2 inches from the beta source, so that it forms a sort of filter for the beta particles approaching the probe. Now open the shield on the probe to determine the counts per minute from this source. Place from 1 to 8 pieces of aluminum sheeting between the beta source and the probe and record counts per minute for each thickness. Use the other materials provided and check the amount of radiation which is coming through. Do the same with the gamma source.

Record your results in the table provided.

Shield type	Alpha cpm open	Alpha cpm closed	Beta cpm	Gamma cpm
Background				
Sample 1 in.				
6 in.				
Paper				
Cardboard				
Plywood				
Aluminum				
1 thickness				
2 "				
3 "				
4 "				
Lead				
1 thickness				
2 "				
3 "				
4 "				
Polyethylene				
1 "				
2 "				
3 "				
4 "				
Tile				

Questions:

1. Why do the alpha particles fail to excite the G-M tube?

2. Which material is most effective for beta radiation?

3. Which material is most effective as shielding against gamma radiation?

4. Which radiation would be most damaging to the body from external exposure?

5. What inference can be made as to size of the various particles?

6. Why was there a difference in beta readings when the probe shield was open or closed?

EXPERIMENT IV

CONTROL OF PARTICLES

Purpose:

To demonstrate that a magnetic field will not affect gamma radiation and to illustrate the basis upon which a beta spectophotometer operates.

Equipment:

Geiger counter

Lead pipe or lead slug with hole drilled in it

Beta source, P^{32}

Gamma source, I^{131}

Na^{22} which emits both beta and gamma

Strong horseshoe magnet or horseshoe-type electromagnet

1/32" lead foil

Each source should be diluted in 10 mls. of water.

Procedure:

Place sample of Na^{22} in cleaned bottle cap, and set lead pipe over it so that it acts as a "shot gun". Place the magnet so that one pole is on each side of the lead tube. Wrap the probe with the lead foil, but leave a very small (.5 cm.) slit open. Mount the G-M tube of the counter on a ringstand so that it is in a horizontal position about 15 cm. from the bench top with the slit side down. Keep the probe parallel to and about the same distance from the "shot gun" top and rotate it in a 90^{o} arc (in a horizontal plane) about the top of the lead tube. Record the various count rates. Repeat for the P^{32} and I^{131} using a closed shield on the G-M tube.

Record the approximate angles where the deflection is greatest.

Questions:

1. What is the difference between the angle of deflection of Na^{22} and P^{32}?

2. Why is there a difference here?

3. Was the gamma ray affected by the magnet? Why?

4. If an electromagnet is used, what differences were noted when the switch was opened or closed for each material?

5. Could you think of any application for the phenomena noted between the two beta emitters?

6. What further experiments would you like to try which would make use of this knowledge?

EXPERIMENT V

ABSORPTION OF BETA AND GAMMA RADIATION (8, p. 9-11)

Purpose:

To demonstrate the effects of shielding on various types of emission.

Materials:

6-10 squares of aluminum about 8 cm. square, each weighing about 1-1.5 gm.

Radioactive source (P^{32} or uranyl nitrate)

Stand to hold G-M probe and other materials (this should have two aluminum shelves, one with a hole cut in it to colimate the source)

Vial of KI(I^{131}) solution containing 20 mC.

Lead plate 1/32" thick

Meter stick

Geiger counter

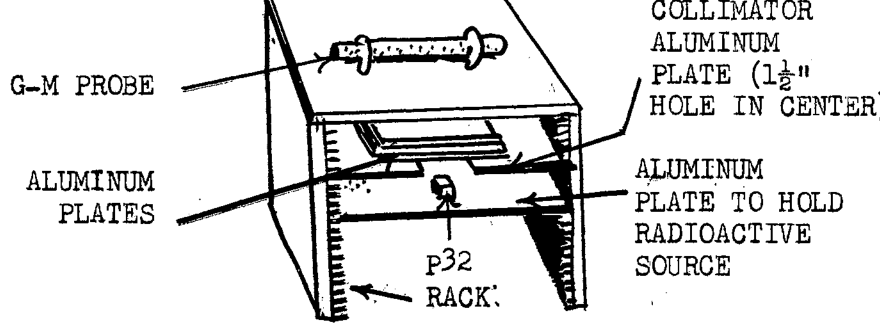

Figure 1

Procedure:

Place colimation plate 2 cm. below probe, and radioactive source shelf 4 cm. below probe. Open the sleeve on the probe. Determine the background count before the radioactive source is placed on the shelf. Count the source several times and average the result, then insert the aluminum plate over the hole and count several times and average the result. Repeat this procedure until 6 such plates have been used. Weigh the plates and divide the weight by the total area to determine the thickness of each plate in terms of gms./cm.^{2}. Plot the activity in cpm as the ordinate and total absorber thickness in gm./cm.^{2} as the abscissa on semi log paper. Determine half-thickness from the curve.

Repeat the steps followed before, only this time use the KI solution and lead plates. Be sure to close the window in the probe. Bring the KI solution just near enough to give a high cpm. Insert the lead plates as close to the probe as possible. This time, subtract the background reading each time before plotting the curve.

DATA SHEET

Plate no.	Total gms/cm^2	Activity	
		Observed	net
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Questions:

1. What is the half-thickness value of aluminum for beta particles?

2. What is the half-thickness of lead for gamma rays?

3. If greater accuracy were required, would the thickness of the window and/or shield in the probe need to be taken into account? If not, why?

4. Of what value is the knowledge of half-thickness?

5. Are there any other experiments that you would like to set up due to questions which have arisen during your work on this data? What are they?

EXPERIMENT VI

AUTORADIOGRAPHS

Purpose:

To show another useful device for measuring the presence of radioactivity or for showing where the radioactive material resides.

Theory:

An autoradiograph is a film which has been exposed, not by light, but by radiation. The subject itself exposes the film. This phenomena was first noted by Becquerel when he noticed that a photographic plate was fogged when a piece of uranium ore lay close by (9, p. 10). Each silver atom in the film which is struck by radiation is precipitated from the silver bromide in the photographic emulsion and becomes a free silver atom, and thereby leaves an image.

The best film to use is no-screen X-ray film. Regular high speed (tri-x) film can be used. If the latter is used it must be exposed from 20 to 50% longer. Exposure time must be determined experimentally. This exposure time depends upon the film, the energy of radiation and the distance the subject is from the film. An approach may be made to the subject by use of the following information: assume that 1 million counts are needed for regular tri-X film (6). Assume also, that the G-M counter is about 10% efficient in counting. Drill a 1 cm. square hole in a piece of thick lead and lay this over the source. Count the radiation coming through this hole in one minute and compute the length of time needed for proper exposure.

Materials:

No-screen X-ray film, or other film

Filter paper circles about $\frac{1}{2}$ cm. in diameter. These can be cut with a cork borer.

Solutions of various known radioactive sources, 1 microcurie/ml.

Saran wrap and cardboard

Procedure:

Soak the filter paper in the radioactive solution, then allow it to dry. Glue the filter paper to a cardboard and lay face down on the film that is still wrapped in paper and which has been further wrapped in saran wrap. Scotch tape the cardboard in position and allow it to be exposed as calculated above, or for about 12 hours if no-screen X-ray film is used. If tri-X film is used, an exposure time of about 60 hours may be needed (9, p. 21-22). Remove cardboard, saran wrap, and discs and dispose of these in the prescribed manner, then process the film.

Questions:

1. Could this process be used to compare the activities of various strengths or ages of radioisotopes? If so, write an experiment which you could use to do this.

2. What other applications of this process could you suggest?

3. What differences might be noted if the cardboard were placed face up instead of face down in this experiment?

EXPERIMENT VII

HALF-LIFE

Purpose:

To determine the half-life of radioactive isotopes from a series of activity measurements taken over a suitable period of time.

Materials: (8, p. 18)

A vial containing about 10 microcuries of I^{131} solution as potassium iodide (a P^{32} source may be substituted if desired)

Count rate meter

Rack upon which probe of meter and vial of radioisotope may be placed to keep the same geometrical proportions from day to day

A fairly long-lived reference source of radioactive material (a dial of an instrument or watch will be suitable)

Immediate surroundings need to be kept as constant as possible

Procedure: (8, p. 18)

Prepare a dry planchet, or use a vial of the radioactive solution. Place this near enough to the G-M tube that a large deflection will be noted. The beta shield should be in place on the probe. Observe and record counts per minute. Record time of day and date. Check the background count. Make a count on the long-lived source and record this result. Make similar observations at suitable intervals, such as each day for 1 to 2 weeks. Fill in the included chart and then, using semilog paper, plot the decrease in activity versus time in days. Activity should be on the ordinate axis. Compare your result with the published value for the half-life.

Radioactive Decay of I^{131}

Date	Time	Days	Observed cpm	Background	Standard cpm	Net cpm	k	Activity A

Theory:

There are errors made in counting due to the differences from day to day in the equipment used, or the source of energy with which it is powered. Therefore we use a standard of constant isotope for comparative purposes. Let us assume, for example, that the count on day one on the sample is 5,000 cpm; on day two it has fallen to 3,000 cpm. When we count the standard, we find that the count on day one was 50,000 cpm and on day two is 40,000 cpm. This indicates that something besides decay is affecting the cpm. We must then arrive at a corrected figure for this. First, subtract the background count from the observed cpm of the sample, and also from the standard. Then correct the result by the factor of 5/4ths. Assuming that the above figures have been corrected for background, we see that the standard has dropped by a factor of 5/4ths. When this is multiplied by the observed sample count for day two, we see that the activity should then be 3750 cpm, not 3,000 cpm as recorded. This 5/4ths factor is k on the chart.

Questions:

1. Why are half-life values important to us?
2. Why should the beta shield be in place in this experiment?
3. Why should we set up the apparatus to keep the geometry constant?

4. Is the k value of any significance in this experiment?

5. Give a suitable definition of half-life.

6. Assuming that a material of short half-life (less than 30 days) must decay to a point where there is but 10 microcuries per kilogram or less in order to be disposed of by conventional methods, how many half-lives would be a good rule of thumb to hold such material to insure that it would be practically harmless?

PART III

BIOLOGY EXPERIMENTS

EXPERIMENT VIII

TRANSLOCATION OF RADIOACTIVE PHOSPHORUS IN CELERY STALKS (8, p. 26)

Purpose:

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

Materials:

Fresh celery stalks containing many leaflets

10 mC Na_3PO_4 (P^{32})

Lead foil

Method:

Place 2 or 3 fresh, medium sized celery stalks with many leaflets in a jar containing 200 mls. of water and 10 mC of P^{32}. Determine radioactivity in 1, 5, 10, and 60 minute intervals by holding the G-M probe at a set distance from the leaves. You should shield the stalks and the liquid with lead foil. Allow to stand for 24 hours and again determine the radioactivity at the same distance from the leaves as before.

Prepare autoradiographs of a cross section of the stalk which has not been immersed in the liquid. You may also remove a leaflet each time the count is made and prepare autoradiographs of these. If you wish, you may leave the stalk for longer periods of time and check the autoradiographs of cross sections. Other plants, for example, tomatoes, may be used.

Questions:

1. What causes translocation?

2. What questions does this study raise that you would like to investigate at some future time?

3. What membranes in the plant control translocation?

EXPERIMENT IX

BLOOD VOLUME STUDIES

Theory and purpose:

Ordinarily a dye is injected into the blood stream in a known concentration to determine the blood volume. The dye must be of such nature that it will not be rapidly absorbed by the system at the capillary, not excreted rapidly or readily metabolized, nor toxic to the body. Dyes which meet all these requirements are essentially non-existent. The dye, after dilution in the blood stream must then be measured. Determining dye content is not easily done.

If we find some radioactive chemical which will meet the above requirements, the dilution can easily be determined by measuring the radioactivity present and determining the dilution factor.

$$\text{Dilution factor (B)} = \text{mg. isotope added (A)} \; \frac{\text{Specific activity at } t = 0 \; (C^o)}{\text{Specific activity, final (C)}} - 1$$

$$B = A \frac{C^o}{C} - 1$$

Such a formula also takes into account the minute dilution caused by the addition of isotope solution.

This method has the added advantage that it is not interfered with by fatty substances in the liver, nor by hemolysis (10, p. 17). One method indicates that radiochromium Cr^{51} in the form of sodium chromate is added to a sample of the donor's blood. After about 1 hour the red cells are separated in a centrifuge and after washing in physiological saline (sterile technique must be used) are reinjected for dilution (11, p. 17).

Materials: (12, p. 19)

1 live rabbit

Na_2CrO_4 with radioactive Cr^{51}

Hypodermic syringe and needle

Geiger counter

Centrifuge and centrifuge tubes

Method: (13, p. 64)

Inject 1 ml. of Cr^{51} solution containing 10 mC into a vein of a rabbit. Five minutes after injection obtain 1 ml. of blood and determine the counts per minute per ml. and also the counts per minute of 1 ml. of the injected standard. Calculate as shown above. Weigh the animal.

Questions:

1. What is the volume of blood in your animal?

2. What percent of the total body weight is blood?

3. What possible use could be made of this knowledge?

4. Consider a drug which is effective at a precise level for treating animals. Two clients come to the veterinarian at the same time. One has a cow to be treated, the other a dog. Both need the same drug. What consideration needs to be taken into account to determine the dosage required for each?

EXPERIMENT X

FOLIAR VERSUS ROOT UPTAKE OF NUTRIENTS BY PLANTS (10, p. 7-10)

Purpose:

To determine whether plants will take in nutrients through the leaves, and if so, what the rate is compared to the usual uptake through the roots.

Materials:

Commercial liquid fertilizer such as Ortho-Gro (15-5-5)

Two 12" x 18" x 3" wooden flats

Enough expanded mica to fill the flats

Bean seeds (monocots or other plants could be used, too)

Radioactive phosphorus in the form of phosphoric acid (P^{32})

Plastic squeeze bottle fitted with plastic clothes sprinkler

Sheets of plastic bags to cover the flats

Method:

Keep in mind that in farming or gardening, fertilizer should be applied only once, and not more than twice because of the economics involved. We could do it many more times under laboratory conditions, but this would not have practical application.

Fill the flats with expanded mica. Plant the beans in 3 rows with individual seeds about 4 inches apart and about $\frac{1}{2}$ - 1 inch deep. Water well so that mica has taken up water but is not soggy. Cover flats with the plastic bag material to cut down evaporation. Keep the temperature at about 70° F. After the beans have come up, remove the polyethylene cover. Add the recommended amount of liquid fertilizer to which has been added 10 mC of P^{32} (Mix the fertilizer with the 10 mC of P^{32} so that you have enough for both flats). The liquid fertilizer is added to the soil in the case of one flat and this flat is labeled "control". Put the other half of your fertilizer in the squeeze bottle and fit with sprinkler. Sprinkle the beans with this mixture until it is all used. Label this flat "experimental". Be sure to water each flat daily.

At the end of 10, 15, and 20 day periods, remove one bean plant from each flat and wash exterior of bean under running water. Grind in mortar and pestle and extract with water. Filter and evaporate to dryness. Read counts per minute on each and compare. If any of the plants are allowed to grow to maturity, harvest some of the seed and check to see how much of the radioactivity can be located at this point and compare the two. Be sure to deduct background count each time.

DATA SHEET

Counts per minute

Flat	10 days	15 days	20 days	mature seed
Experimental				
Control				

Questions:

1. Which group of plants incorporated the greatest amount of phosphorus into its system?
2. What possible explanation could you give for this?
3. What application could be made of this knowledge?
4. What further research would you like to do along this line?
5. Write your proposals for variations to this experiment.

EXPERIMENT XI

DETERMINATION OF INTESTINAL ABSORPTION RATE (13, p. 83)

Purpose:

To show that after a mineral enters the stomach it is rapidly absorbed and distributed through the body.

Materials:

1 rat weighing 100 gms.

Stomach tube

10 mC of P^{32}

G-M counter

Rat holder

Procedure:

Give the rat 10 mC of P^{32} by stomach tube and place him in the holder with the tail tied in such a way that it remains under the G-M probe. Make counts every other minute for 30 minutes, then count every ten minutes for two hours. Record all data.

Questions:

1. What explanation do you have for these results?
2. What possible application could be made of the theory embodied here?
3. What other experiments would you like to do along this line?

EXPERIMENT XII

GENETIC CHANGE CAUSED BY RADIATION (14, p. 1-10)

Purpose:

To show that genetic change or mutation may be induced by ionizing radiation.

Materials:

Certified seeds, rye and mustard

X-ray machine (use at local hospital)

Seed flats

Soil

Fertilizer

Other garden implements and supplies are needed

P_2O_5

Desiccator

Method:

Sort by hand or sieve seeds to remove all odd sizes, shapes, broken pieces or small seeds. Place in desiccator over P_2O_5 for two weeks. Remove quickly and seal in saran wrap or plastic. Irradiate in one layer on a turn table (one from a store display unit will do) under 3 kiloroentgens (Kr) for rye and 70 Kr for mustard. Be sure you have from 50-100 of each seed. Keep an equal amount of each seed for a control. Store under the same dry conditions (sealed) for 2-6 weeks. Plunge seeds into deaerated (boiled 30 minutes, stoppered and allowed to cool) water for one hour.

Sow a recorded number of each variety and treatment (50 or more seeds) in flats of soil, or peat and sand, or exploded mica ½ inch deep. Water daily with dilute fertilizer, but don't make soil soggy. Keep lights on 24 hours near flats to keep a constant temperature of near 70° F. Count the number which die before they grow significantly. If a mutation study is carried out, let seeds grow to maturity and follow the steps noted after the questions.

Questions:

1. What significant changes, if any, did you note between control and treated seeds, as to number germinating, growth in 6 days and number reaching maturity and any other changes you may have noted. If no differences were noted, explain why this might be.

2. What differences do you note in the above factors between the two varieties of seed?

3. What questions does this experiment raise?

4. What other experiments could you suggest which would give more precise information on the questions which are raised by this experiment?

5. What is the difference between X-rays and those produced by a gamma emitter?

Mutation Study:

A study of mutation takes more time and space than the average high school usually has available. If it is available, then the following steps could be taken. Only a few mutations will be desirable. These are worth looking for in this work, as desirable mutations give us improved varieties of plants. Many of the mutations are of a recessive nature and won't show up readily. Some are also undesirable.

1. Take steps to assure self-pollination (bag if necessary).

2. Harvest the seeds from each plant. Keep these labeled in

individual packages.

3. Include a few seeds from each plant in your work for the next growing season. Store these normally.

4. Plant as before and allow self-pollination only (these are R_2 seeds).

5. Keep careful notes and records concerning date of planting and harvest, and variations which could indicate a mutation. Such items as leaf shape, flower and plant color, height of plant, yield, and maturity date should all be noted.

6. Harvest seeds from suspected mutants and plant again. Note results. These are the R_3 seeds.

PART IV

CHEMISTRY EXPERIMENTS

EXPERIMENT XIII

PROPERTIES OF ISOTOPES OF THE SAME ELEMENT (8, p. 21)

Purpose:

To show that different isotopes of the same element possess the same chemical properties.

Materials:

KI and radioactive KI (I^{131})

Separatory funnel

Coke bottle caps (cleaned of cork and paint)

Carbon tetrachloride

Chlorine water

Bromine water

Dilute NaOH

Geiger counter

Procedure:

Dilute the KI^{131} (1 mC) about 50 times, and add a few drops of dilute NaOH. Then add a tiny crystal of normal KI. Measure the activity of the solution with the geiger counter. Pour one third of the solution into a separatory funnel and add 2-3 drops of bromine and chlorine water and 10-15 mls. of CCl_4. Note that the lower layer shows the characteristic iodine color. Allow the lower layer to run into a beaker and check it for activity.

Questions:

1. Has the radioactive iodine acted like normal iodine, i.e., has it accompanied the normal iodine into the separated layer? You may wish to repeat the experiment with only normal iodine present to see how it acts.

2. What is the only difference between the two iodine sources?

3. What use do you think you could make of this knowledge?

4. Can you name elements whose isotopes may respond differently (isotopic effect)? Why do they respond differently?

Precautions:

Don't pipette radioactive material orally. Use a squeeze bulb. Keep the solution slightly basic at all times!

Note:

For further experiments on chemical comparison, see page 22 of Schenberg (8)

EXPERIMENT XIV

DIFFUSION RATES

Purpose:

To show the diffusion rate of various chemicals in water.

Materials:

Barium chloride (Ba^{140}) and sodium sulfate (Na^{22})

Non-radioactive forms of the same chemicals

Two 2 foot lengths of $\frac{1}{2}$ cm. bore glass tubing with corks to fit

Two 100 ml. beakers

Geiger counter

Ring stand and clamps

Procedure:

Prepare a saturated solution of each chemical. Add a small amount of radioactive material to each respective solution. Fill the 2 foot tubing with distilled water by a pipette-like procedure and stopper the upper end with the cork. Lower into the saturated solution and clamp in place. Measure radioactivity at various marked points on the column at varying intervals of time. Plot time against net counts per minute at each point to show a curve of the various diffusion rates.

Questions:

1. Does the diffusion take place at a constant rate until equilibrium is reached?

2. Do the two solutions diffuse at the same rates? Why or why not?

3. What causes diffusion?

EXPERIMENT XV

MOLECULAR EXCHANGE (13, p. 54)

Theory and Purpose:

Non-ionized molecules have atoms in motion. Such atoms exchange with atoms of the same specie. When atom exchange ratio is measured, we find that not all atoms are in motion. Atoms from insoluble compounds can appear in soluble ions if a soluble ion is present which contains the same specie.

Atoms in molecules are not bound as firmly as we like to think; although ions aren't formed by many compounds they will exchange places with a similar atom of the same specie.

$$Ca^{45} \longrightarrow Ca^{40} \quad \text{or} \quad H \longrightarrow H^3$$

$$Ch_3CH_2OH + H^3 \longrightarrow CH_3CHH^3OH + OH$$

This is called molecular exchange and probably does not represent energy transfer. This phenomenon is probably not related to ionization but the position of the atoms in the molecule make some compounds more active for molecular exchange. This is a very important phenomena to be remembered, as a radioisotope can enter or leave a tissue chemical structure by either molecular exchange or metabolism.

Materials and equipment:

P^{32} and S^{35} Cysteine (The expense of the latter may be prohibitive to most high schools and therefore that part of the experiment may be left out.)

Methionine, cystine and cysteine

Chick bones

Procedure:

Weigh one gram cystine and dissolve in hot but not boiling water. Decant dissolved portion and add 5 N HCl to remainder to put it into solution. Add 1 mC of S^{35} Cysteine to each amino acid solution and let stand 1 hour. Precipitate with KOH solution, wash, dry, and determine S^{35} content with the Geiger counter.

Take a fresh chick bone or bone slice and place in a solution of P^{32}. Let it stand for 2 days, then remove and wash and let stand in distilled water. Check the P^{32} content of the bone.

Take a 1 gm. sample of insoluble magnesium phosphate and add 5 mls. of a P^{32} solution. Shake 10 minutes, wash and determine the P^{32} in the precipitate.

Questions:

1. Why do you get radioisotopes in the precipitated amino acid?
2. Why is radioisotope found in the $MgPO_4$?
3. How and why did P^{32} become part of the bone?
4. Is this information of any value for future experiments? How?

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APPENDIX A

CLOUD CHAMBER CONSTRUCTION (7)

Materials:

One round clear plastic refrigerator dish

One $\frac{1}{2}$ petri dish to fit refrigerator dish

One piece of heavy blotter paper

India ink

Thumb tack

Alpha emitter (use material from radium dial)

Clear nail polish

Nylon stocking

Method:

Cut out the blotting paper to fit the bottom of the refrigerator dish. Punch the thumb tack through the center of the blotting paper. Paint the point with clear nail polish and then dip in the powdered alpha emitter which has been scraped from the luminous dial of a watch or airplane instrument panel. Allow this to dry. Paint the blotting paper with India ink. Insert in the bottom of the refrigerator dish so that the thumb tack is point up. Wet the blotting paper with absolute alcohol so that it is dripping wet. Cover the refrigerator dish with the petri dish. Set the whole arrangement on top of a piece of dry ice. See Experiment I for how to operate.

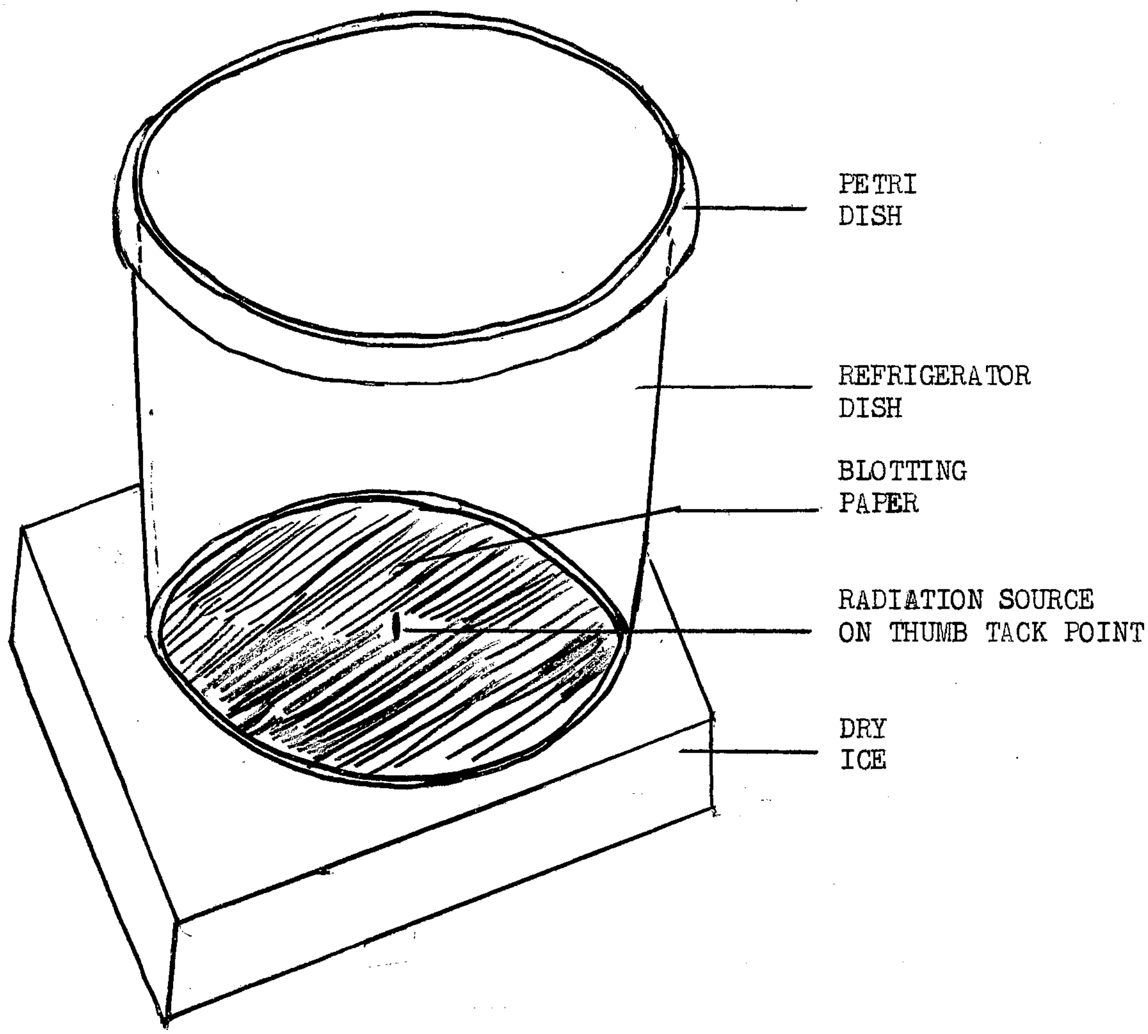

Figure 2. Homemade Cloud Chamber

APPENDIX B

SOURCES OF MATERIALS

The companies listed below are some which have had material for distribution upon request:

Atomics international
21600 Vanowen Street
Canoga Park, California

Babcock & Wilcox Company
Atomic Energy Division
161 East 42nd Street
New York 17, N. Y.

Consolidated Edison Company
Public Information
4 Irving Place
New York 3, N. Y.

Dow Chemical Company
Midland, Michigan

Esso Research and Engineering Co.
Public Relations Division
P. O. Box 45
Linden, N. J.

General Dynamics Corporation
Educational Branch
445 Park Ave.
New York 22, N. Y.

General Electric Company
Educational Section
Syracuse, N. Y.

General Mills
Mechanical Division
Nuclear Equipment Department
1620 Central Avenue
Minneapolis 13, Minn.

Phillips Chemical Company
Educational Section
Idaho Falls, Idaho

Union Carbide Nuclear Company
Oak Ridge, Tennessee

Information agencies:

Atomic Energy Commission
Educational Services Branch
Washington 25, D. C.

Chamber of Commerce of the
United States
1615 H Street, N. W.
Washington 25, D. C.

Government Printing Office
Washington 25, D. C.

National Academy of Sciences
National Research Council
Washington, D. C.

National Committee for the Development of Scientists and Engineers, Washington, D. C.

Science Service
Washington, D. C.

United Nations
Department of Public Information
Chief, Education Section
New York, N. Y.

U. S. Atomic Energy Commission
Technical Information Services
P. O. Box 62
Oak Ridge, Tenn.

Suppliers of Application exempt quantities of Radioisotopes:

Abbot Laboratories
Oak Ridge Division
Oak Ridge, Tenn.

Atomic Research Laboratory
10717 Venice Boulevard
Los Angeles 34, Calif.

Isotopes Specialties Co., Inc.
170 West Providencia St.
Burbank, California

Nuclear-Chicago Corporation
353 East Howard Ave.
Des Plaines, Ill.

Nuclear Consultants, Inc.
33-61 Crescent Street
Long Island City 6, N. Y.

Oak Ridge National Laboratory
Radioisotope Sales Dept.
P. O. Box P
Oak Ridge, Tenn.

Suppliers of equipment:

Radiation Diffusion Cloud Chamber $9.75 with samples

Scientific Company
1231-41 N. Honore St.
Chicago 22, Ill.

APPENDIX C

FREE STUDENT MATERIAL

1. "Isotopes", Oak Ridge National Laboratory, Oak Ridge, Tenn.

2. "The World Within the Atom", A Westinghouse Little Science Series Booklet. School Service, Westinghouse Electric Corp., P. O. Box 2278, Pittsburgh 30, Penn.

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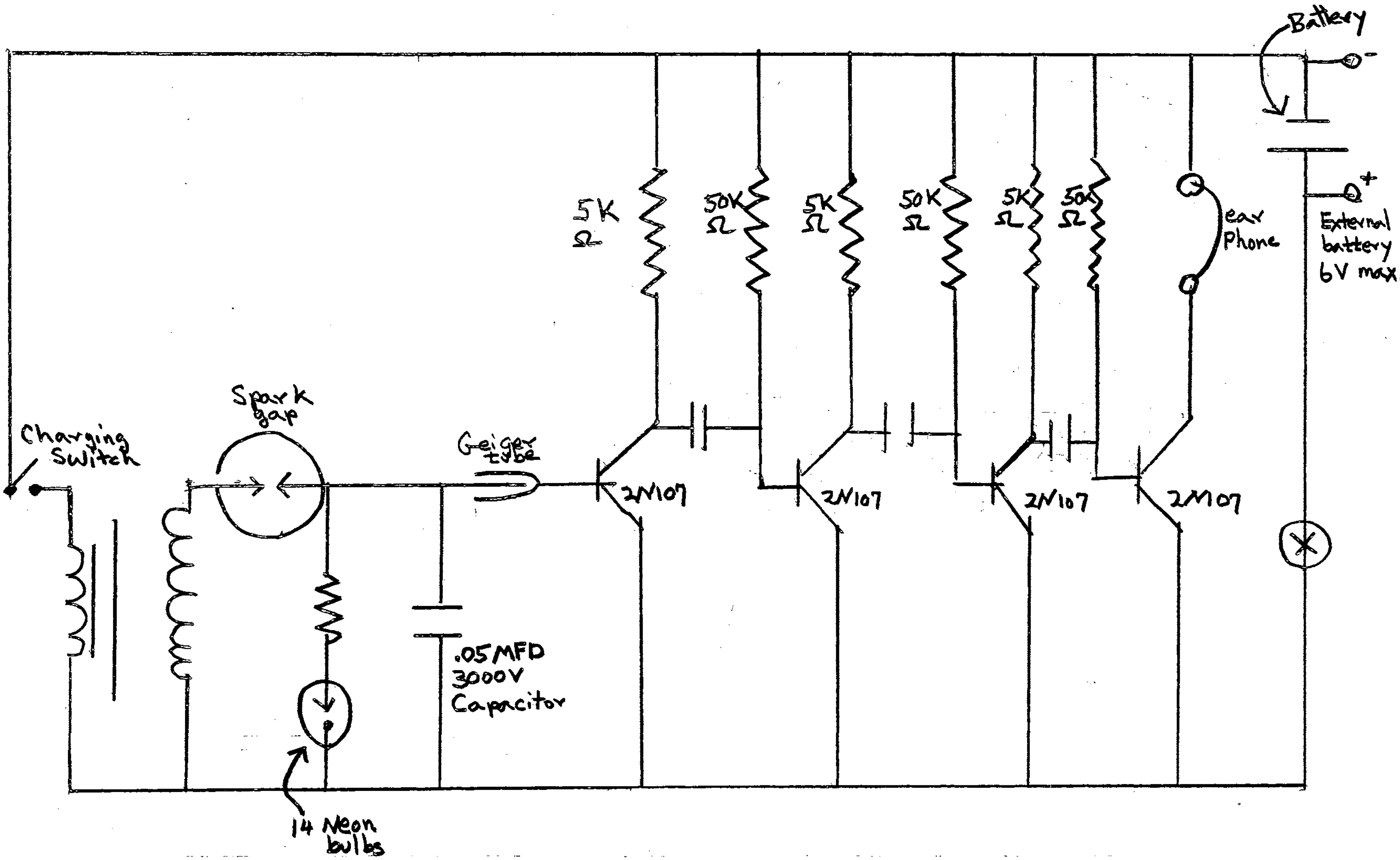

Figure 3. Wiring diagram for Transistor, Dry Cell Operated Geiger Counter.

APPENDIX E

GLOSSARY

Curie (C): That quantity of radioactive isotope which undergoes 3.7×10^{10} disintegrations per second. A millicurie (mC) is 1/1000 part of a curie. A microcurie (uC) is 1/1,000,000 of a curie (7, p. 16).

Isotope: Nuclides which have identical numbers of protons, but different numbers of neutrons (1, p. 47).

Relative Biological Effect (R. B. E.): Specific ionization which damages tissues. Measurable with living organisms, but not with instrument (1, p. 503). Accepted values for R. B. E. are: gamma = 1; beta = 1; alpha = 20; fast neutrons = 20; thermal neutrons = 1.

Roentgen (r): The roentgen is that quantity of X or gamma radiation such that the corpuscular emission per 0.001293 gram of air, dry, at 0^{o} C. and 760 mm. of mercury, produces in air, ions carrying one electrostatic unit or quantity of electricity of either sign (7, p. 16).

Roentgen Equivalent Man (rem): That dose of any radiation which produces a biological effect equal to that produced by one roentgen of high voltage X-radiation (7, p. 16).

Roentgen Equivalent Physical (rep): That dose of ionizing radiation which produces energy absorption of 83 ergs per cubic centimeter of tissue (7, p. 16).

VITA

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Professional Organizations: National Science Teachers Association, National Association of Biology Teachers.