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Name: Roger Calvin Ewing   Date of Degree: August 5, 1961

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Title of Study: SELECTED EXPERIMENTS IN MODERN PHYSICS FOR HIGH SCHOOL

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Scope of Study: The purpose of this study is to present a number of experiments that illustrate the basic concepts necessary to the understanding of any study in modern physics. In the selection of experiments the guiding criteria has been to select those that would illustrate the fundamental concepts of modern physics and still fit into the traditional physics course. Materials used in the preparation of this report include basic texts in the study of modern physics and catalogs from the major scientific companies supplying schools with apparatus. Each of the experiments is divided into three sections. The first section discusses the experiment in general, the second section suggests an experimental procedure, and the third section suggests sources of apparatus for performing the experiment.

Findings and Conclusions: A survey of existing high school physics texts indicates that the field of modern physics is receiving attention, but at the present time no adequate criteria has been established for experimental presentation in this growing field. A survey of the existing cataloges that furnish schools with experimental apparatus also indicates that, while a limited quantity of apparatus is available in this field, much is to be desired. The cost of apparatus in this area is high, but in this atomic age it is necessary for the high school student to become acquainted as early as possible with the underlying concepts of modern physics.

ADVISER'S APPROVAL ______________________

SELECTED EXPERIMENTS IN MODERN
PHYSICS FOR HIGH SCHOOL

By

ROGER CALVIN EWING

Bachelor of Science

CENTRAL MICHIGAN UNIVERSITY

Mount Pleasant, Michigan

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SELECTED EXPERIMENTS IN MODERN

PHYSICS FOR HIGH SCHOOL

Report Approved:

James H. Zant

Report Adviser

Dean of the Graduate School

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Indebtedness is acknowledge to Drs. D. L. Rutledge and James H. Zant for their valuable guidance and assistence, and to the selection committee of the National Science Foundation who made it possible for me to make this study. Also credit is acknowledge to my wife, Nona Jean, for her constant encouragement in seeing this report brought to completion.

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CHAPTER I

INTRODUCTION

The purpose of this report is to present a number of experiments that illustrate the basic concepts necessary to the understanding of any study in modern physics. While the selection of experiments is always an arbitrary decision, it is felt that the ones that appear in this study are basic to the understanding of modern physics.

In the selection of experiments the guiding criteria has been to select those that would illustrate the fundamental concepts of modern physics and still fit into the traditional physics course. The traditional course in physics must of necessity be highly selective in its presentation of experimental phenomenon, as it is fully realized that time must be allotted for the study of mechanics, sound, heat, light, magnetism, electricity, as well as modern physics.

A survey of existing high school physics texts indicates that the field of modern physics is receiving attention, but at the present time no adequate criteria has been established for experimental presentation in this growing field. A survey of the existing cataloges that furnish schools with experimental apparatus also indicates that, while a limited quantity of apparatus is available in this field, much is to be desired. Therefore it is felt that this study fills an existing need.

Each of the experiments is divided into three sections. The first section discusses the experiment in general, the second section suggests an experimental procedure, and the third section suggests sources of apparatus for performing the experiment.

The first section, the discussion, attempts to give a basic understanding of the experiment to be performed, a brief history of the first investigation in this particular phenomenon, and in some cases a brief discussion of the experiment as first performed.

The second section of the experiment, the experimental procedure, suggests the method to be followed in performing the experiment. It should be noted that specific instructions are not given. The experiment is discussed in such a way that the procedure for performing it will be clear and can easily be duplicated. Where mathematics is required for the full understanding of the phenomenon the necessary equations are given and the development of the formulas are worked out or at least suggested. In all cases the formulas used will be understood after the student has covered the preceeding topics in the traditional physics course.

The third section of the experiment, experimental equipment, suggests sources of apparatus to be used. In some cases suggestions are given for making the equipment or perhaps for modifying existing equipment for a particular use. No attempt is made to suggest the use of cheap or homemade apparatus except where such apparatus would be adequate to obtain the desired results. In most cases sources of apparatus made especially for the experiment are included. This is done because it is felt that the cost of such equipment is negligible when compared to the over all benefit to the student.

It is also hoped that this report will serve as a guide to present teachers of physics who are thinking seriously of introducing experimental phenomena in this rapidly growing field.

CHAPTER II

SELECTED EXPERIMENTS

EXPERIMENT I

THE MILLIKEN OIL DROP EXPERIMENT

1. Discussion. The first experiments to determine the charge on the electron were performed by Townsend in 1897 and J. J. Thompson in 1898. The experiment as performed by them was to allow water vapor to condense on ions which in turn produced a cloud. They then measured the charge carried by this cloud. To determine the electronic charge it was necessary to assume that each droplet in the cloud had condensed on it one ion. The total charges carried by the droplets was considered to be the electronic charge.

The number of droplets in the cloud was determined by condensing and weighing the water. This weight was then divided by the average weight of a single droplet of water. The average weight of the droplets was determined by observing their average rate of fall and applying Stokes's law for falling particles. The total charge carried by the cloud divided by the number of water droplets in the cloud gives the charge per droplet, and according to the previous assumptions, the charge on the electron. The value obtained in this way was 3×10^{-10} esu of charge.

The above approach was later improved by H. A. Wilson in 1903 who devised the following procedure. The clouds were formed between the plates of a capacitor and the rate of fall of the cloud observed in the absence of any potential difference between the capacitor plates. Then the rate of fall of the cloud was observed with the capacitor charged to high potential. The calculations and results of the experiment were similar to those of Townsend and Thompson. Both the above procedures suffered from the fact that the weight of the water droplet was not constant during the observed time of fall and from the inability to determine definitely the number of ions on the individual droplet.

2. Experimental Procedure. The experiment as performed by Millikan utilized oil droplets since the higher surface tension greatly reduced the rate of evaporation and assured constant drop size throughout the experiment. Further, all measurements were made on single droplets. The apparatus to be used, see Figure 1, consists of a parallel plate condenser, a light source, a power supply, and a measuring microscope. The condenser is normally enclosed in a separate container to reduce the effects of air currents. Small drops of oil are sprayed into the box from an atomizer. One of these drops of oil eventually finds its

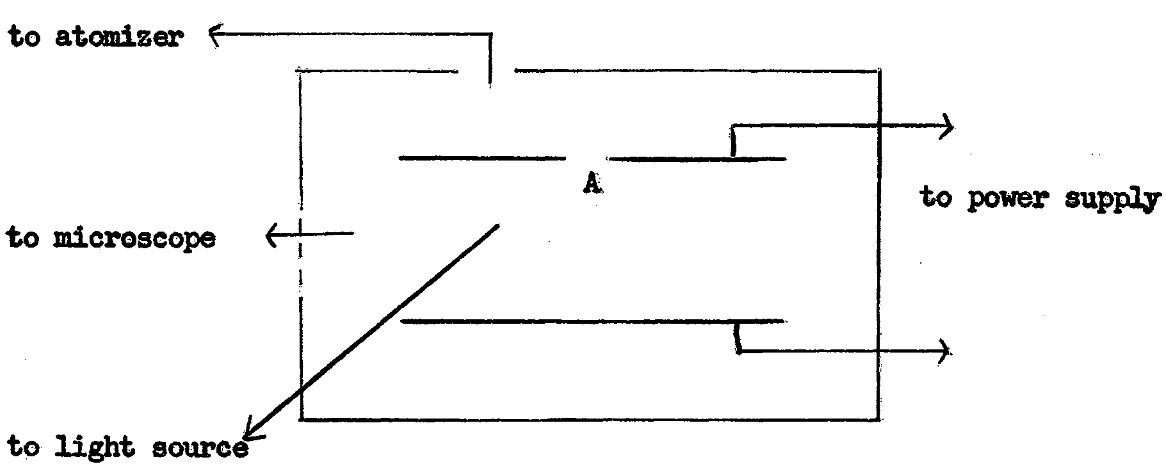

Figure 1

way through the pinhole in the top plate A and is then observed through a measuring microscope. Illumination is provided by a light source on one side. When the condenser is uncharged the forces acting on the drop are its weight

$$mg = (4/3)(\pi r^3 pg), \qquad (1)$$

the buoyant force of the air

$$m_o g = (4/3)(\pi r^3 p_o g), \qquad (2)$$

and a resisting force

$$F = Kv, \qquad (3)$$

due to the viscosity of the medium which by experiment is known to be proportional to the velocity of the drop. In the above equations m represents the mass of the oil drop, g is the acceleration due to gravity, r is the radius of the drop, p is the density of the oil drop, p_o is the density of the displaced air, and m_o is the mass of the displaced air. The proportionality constant K is given by Stokes's law as

$$K = 6\pi rn, \qquad (4)$$

where n is the viscosity of air. The velocity v of the drop is determined by observing its passage between the cross hairs of the measuring microscope. The equilibrium condition for the falling drop is then represented by the equation

$$(4/3)(\pi r^3 pg) - (4/3)(\pi r^3 p_o g) - 6\pi rnv = 0. \qquad (5)$$

If now the plates of the condenser are charged to a high potential difference the oil droplet may be caused to remain suspended in one position. The equilibrium condition is then represented by the equation

$$Eq + (4/3)(\pi r^3 p_o g) = (4/3)(\pi r^3 pg), \qquad (6)$$

where q is the charge on the droplet and E is the electrostatic field intensity between the plates of the condenser. It is now possible to eliminate r between the two equations and solve for the charge q. From many determinations it was found that q could always be represented by

$$q = ne, \qquad (7)$$

where n is an integer and e is the charge on the electron. The value of the charge from Millikan's work in 1917 is

$$e = 4.77 \times 10^{-10} \text{ esu} \qquad (8)$$

of charge. This same apparatus is capable of more precise determinations of e if a dynamic experiment is used in place of the static experiment suggested by equation (6). A description of the procedure and calculations will be found in most texts of modern physics. Particularly good descriptions are given by Semat (1958), and Hoag and Korff (1948).

3. Experimental Equipment. The equipment needed for this experiment consists of a condenser, light source, power supply, voltmeter, and a measuring microscope. In its most convenient form the apparatus is available from W. M. Welch Scientific Company (1959) or the Central Scientific Company (1958) at a cost of approximately $300.00. A considerable saving of money can sometimes be made by purchasing the components separately. For example, the condenser can be readily manufactured in any high school shop equiped to do metal work and any 30 to 50 watt light source shielded so as not to shine in the worker's eyes is adequate. More details on the dimensions and construction of the parallel plate condenser for this experiment may be found in a discussion by Hoag and Korff (1948). The voltmeter and power supply are available in kit form from several sources for approximately $30.00 and $50.00 respectively. See for example the catalogs of D. G. Heath Co. (1960), Allied Radio Corporation (1960), or Lafayette Radio Supply (1960). This leaves only the measuring microscope to purchase and adequate instruments of this

type are available at approximately $50.00.

EXPERIMENT II

DETERMINATION OF E/M

1. Discussion. J. J. Thomson in his studies dealing with electrical discharges in gases was the first to prove that cathode rays consist of electrified particles whose masses are some two thousand times lighter than the atom of hydrogen. These particles, known as electrons, are one of the fundamental constituents of all atoms.

Since electrons are fundamental components common to all atoms the determination of the electronic charge and mass is of extreme importance. These quantitities are fundamental to the study of atomic phenomenom and they appear in many formulas in atomic investigation. In 1897 Thomson was able to determine the charge of the electron to its mass, symbolized by e/m.

2. Experimental Procedure. Thomson determined e/m for electrons by allowing a narrow pencil of cathode rays to pass through electric and magnetic fields at right angles to each other. The arrangement to be used is shown in Figure 2. The cathode ray tube, as shown in Figure 2, contains a circular cathode C and a cylindrical anode A, containing a circular hole along the axis of the cylinder. Two parallel plates of length L, and separated a distance d, are placed behind the anode and the screen at the end of the tube is coated with zinc sulfide. A high potential source maintains a gas discharge between the cathode and anode. The circular hole in the anode acts as a collimator and allows electrons to proceed to the fluorescent screen S, with a uniform velocity v, where they produce a bright spot at O.

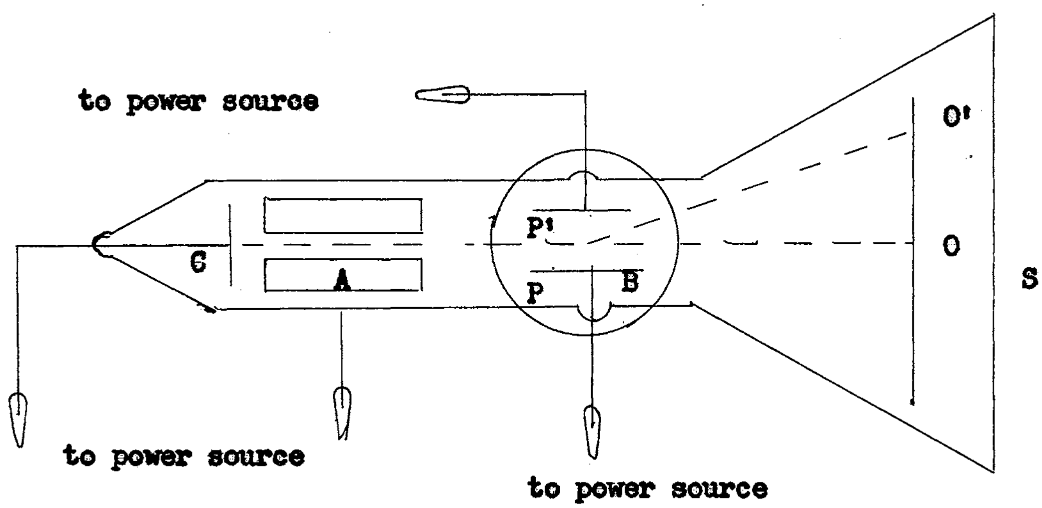

Figure 2

When a difference of potential V is maintained between the plates PP', the electrons will be deflected toward the positive plate by a force F, given by

$$F = (V/d)e = ma, \tag{9}$$

where e is the charge of the electron, m is its mass, and a is its acceleration. The path of the electrons will be parabolic between the plates since the electric field in this region is uniform. After passing through the plates the electrons will continue with uniform rectilinear motion until they strike the screen at O'.

If now a magnetic field H, produced by an electromagnet B at right angles to the electric field is established over the same distance L, such that its north pole faces the reader, the electrons will experience an additional force

$$F_1 = Hev, \tag{10}$$

where H is the strength of the magnetic field and v is the velocity of the electron. The direction of this force will be downward and opposite to that of the electric force when P' is positive.

The magnetic field is then adjusted until the electron strikes the screen at O. This indicates that the electric and magnetic fields are such that the forces they exert on the electron are equal and opposite. When this occurs

$$(V/d)e = Hev. \tag{11}$$

Now to obtain e/m it is necessary to ascertain the acceleration of the electron. This is done indirectly by measuring the amount of deflection, y, parallel to the electric field obtained by

$$y = \tfrac{1}{2}at^2, \tag{12}$$

and the time t during which the electron was accelerated is given by

$$t = L/v. \tag{13}$$

It is now possible by using equations (9) through (13) to obtain an expression for e/m which becomes

$$e/m = (2Vy)/(dH^2L^2). \tag{14}$$

It should be noted that the deflection y is proportional to the distance OO' on the screen S which is easily measured. A consistent set of units must be used for all quantities in the several equations. If e, V, and H are expressed in the em system and the remainder of the quantities are expressed in the cgs system then e/m will be expressed in emu of charge per gram. The present accepted value of e/m is 1.7589×10^7 emu/gram.

An excellent description of this experiment can be found in Semat (1959) on pages 43 through 47 and in Tolansky (1949) on pages 54 through 56.

3. Experimental Equipment. The apparatus to measure e/m can be obtained in complete form from W. M. Welch Scientific Co. (1961) for approximately $270.00. The Central Scientific Co. (1961) offers a different design of the apparatus for approximately $195.00. Leybold (1958) offers an apparatus similar to that available from Welch for approximately $200.00.

It should be noted that each of these is different in form from the original Thomson tube; the result is more flexability of operation and a better teaching instrument. Each is accompanied with a full set of instructions for the individual equipment and each can be used to demonstrate other phenomena such as the deflection of charged particles in a magnetic field or the principle of operation of the mass spectrograph.

For the worker with some free time to develop laboratory experiments and equipment there have been numerous articles in recent journals on the conversion of rather inexpensive cathode ray tubes so that they can be used in the measurement of e/m for electrons. See for example the article by Connell (1949) in the American Journal of Physics.

EXPERIMENT III

THE PHOTOELECTRIC EFFECT

1. Discussion. The term "photoelectric" as used here refers to the discharge of electrons from bodies when illuminated by light of suitable wavelength.

The discovery of photo-electricity is attributed to Hertz who in 1887 observed that when ultra-violet light falls on a spark gap the resistance to the flow of electricity across the gap is decreased. This discovery was accidental from the standpoint that it was unplanned. At the time of the discovery he was experimenting with electromagnetic waves that were produced by means of a spark gap and detected by an adjacent gap. To aid him in his observations he had enclosed his detecting apparatus in a black box and found that the passage of the spark across this gap would not occur until he had reduced the distance between the points.

Knowing that a spark emitted ultra-violet light he concluded that the light coming from the spark of the generator and falling on the terminals of the detector made passage of the spark easier.

A year later Hallwachs found that negatively charged metal loses its charge when ultra-violet light falls on it, but no observable effect is detected when ordinary light falls on the metal. He also noted that a positive charged metal underwent no change in the presence of ultra-violet light. He then concluded that ions must be emitted from bodies which lose charge when subjected to light of appropriate wavelength and also that these must be negatively charged ions. The discovery of the electron suggested the hypothesis that the photoelectric effect is due to the liberation of electrons from the illuminated material. This hypothesis was confirmed by Lenard who demonstrated that the photoelectric discharge is deflected in a magnetic field exactly as are cathode rays.

In 1900 Planck introduced the idea of quantum of energy, symbolized $h\underline{v}$, in order to explain the distribution of energy among the different wavelengths that emanate from a black body at different temperatures. His hypothesis states that radiation is emitted or absorbed by such a body in whole quanta, where a quantum of energy is given by

$$E = h\underline{v}. \qquad (15)$$

In 1905 Einstein made use of Planck's hypothesis to explain the photoelectric effect. According to Einstein the entire energy of a photon, $h\underline{v}$, is given up to an electron in metal and this electron leaves the metal with an amount of energy given by

$$K = \tfrac{1}{2}mv^2 = h\underline{v} - w, \qquad (16)$$

where m is the mass of the electron, v is its velocity, h is the Planck constant, $\underline{v}$ is the frequency of the incident light, and w is the work function of the metal.

2. <u>Experimental</u> <u>Procedure</u>. The apparatus to be used for measuring the Planck constant h and the work function of the metal w is shown in Figure 3.

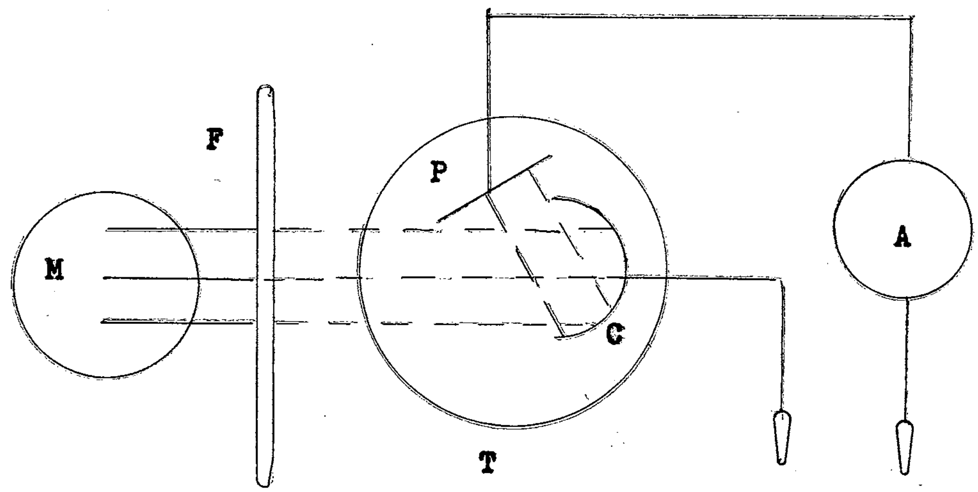

Figure 3

The mercury vapor lamp M emits a number of characteristic frequencies which are then absorbed, with the exception of one, by the selection filter F. This radiation of known intensity and frequency is allowed to fall on the cathode C of the photoelectric cell T which emits electrons that are drawn to the plate P as a result of the potential difference V between C and P. The milliammeter A between C and P measures the current which is proportional to the number of electrons that reach P.

This experiment is concerned with obtaining the maximum velocity of emitted electrons for two different frequencies of light.

When light of known frequency $\underline{v_1}$ falls on the cathode C it will cause the milliammeter A to register a flow of current if the plate P is positive with respect to the cathode C. If the intensity of the light is kept constant it will be found that, as long as the plate P is positive, the milliammeter reading is constant. As P is made negative with respect to C the current through A will decrease and when P is made sufficiently negative no current is seen to flow through A. At this point

$$V_{o-1}e = \frac{1}{2}mv^2_{max} = K_{1(max)} \qquad (17)$$

where V_{o-1} is the potential difference that just stops the flow of electrons between P and C, e is the electronic charge, and K_1 is the maximum kinetic energy of the emitted electron. Using a different intensity of light it will be found that V_{o-1} has the same value. It is therefore assumed that the kinetic energy of the electrons leaving the cathode C do not exceed a maximum value given by equation (17).

Following the same procedure for a frequency $\underline{v}_2$ there results

$$V_{o-2}e = \frac{1}{2}mv^2 = K_2. \qquad (18)$$

It is now possible using equations (16), (17), and (18) to solve for the Planck constant h and the work function w of the metal obtaining

$$h = (K_1 - K_2)/(\underline{v}_1 - \underline{v}_2) \qquad (19)$$

and

$$w = (K_2\underline{v}_1 - K_1\underline{v}_2)/(\underline{v}_2 - \underline{v}_1). \qquad (20)$$

Blackwood, Osgood, and Ruark (1959) give an excellent description of the photoelectric effect on pages 71 through 90. Oldenberg (1954) discusses the above experiment on pages 79 through 92.

3. Experimental Equipment. The equipment necessary to perform this experiment consists of a mercury vapor lamp, selection filters, a photoelectric cell, a microampere meter, and a suitable power source. The mercury vapor lamp assembly can be obtained from the Central Scientific Co. (1961) for approximately $120.00. This consists of a suitable support, filter holder, and condensing lens system. Suitable selection

filters for this experiment can be obtained from Leybold (1958) for approximately \$7.00 each. Photoelectric cells vary in price from \$10.00 to \$50.00 and can be obtained from any of the companies that supply schools with scientific apparatus. The power supply suggested in Experiment I will be satisfactory as a power source. It is also possible to use batteries as a power source.

EXPERIMENT IV

EXCITATION AND IONIZATION OF ATOMS BY ELECTRONS

1. Discussion. Free atoms are usually in their lowest energy states or normal states. If the atoms are to emit radiation it is necessary that they be raised to some higher energy level or state. If in the process of being raised to a higher state electrons are gained or lost the atom is said to be ionized. On the other hand if no electrons are gained or lost the atom is said to be in an excited state. The spectral lines observed from the radiated light of atoms is due to the rise or fall of electrons in going from the one state to the other. If the atom does not change its state, no spectral lines are observed. On the other hand if the lines are intense this is an indication that many atoms are changing their energy states. The stronger or brighter lines are due to the greater frequency of transition from one state to the other.

The frequency of the emitted radiation for hydrogen an "hydrogen like" ions can be calculated from the following formula

$$\bar{v} = Z^2R(1/n_f^2 - 1/n_i^2) \qquad (21)$$

where $\bar{v}$ is the wave number, Z is the atomic number, R is the Rydberg constant, and n_f and n_i are the final and initial energy states of the atom. For an explanation of the development of (21) see pages 205 through 215 in Semat (1958).

A convenient way to excite atoms is by the bombardment of the atoms with electrons. The bombarding electron must have kinetic energy at least as great as the energy required to raise the atom from one energy state to the next. This type of experiment was first successfully carried out by Franck and Hertz in 1914. In 1922 Foote, Meggers, and Mohler made a detailed study of this phenomena using sodium and potassium vapor.

2. <u>Experimental</u> <u>Procedure</u>. For this experiment it is necessary to have an evacuated tube containing a small quantity of sodium vapor. This tube contains a filament F, a grid G, and a plate P, connected as shown in Figure 4.

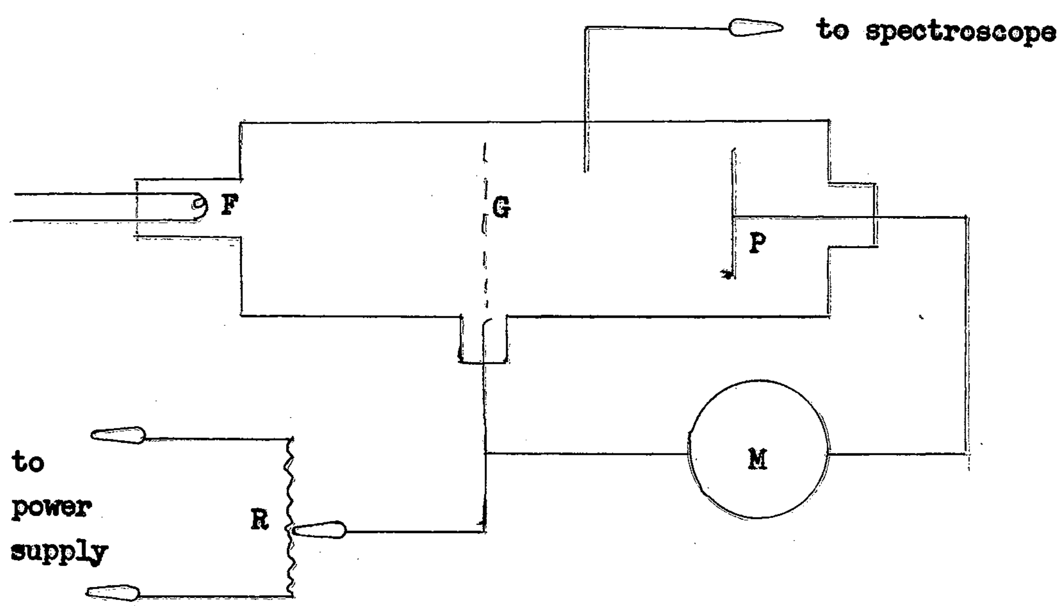

Figure 4

Electrons leave the heated filament F and are accelerated toward the grid G by a difference of potential E. It is to be noted that the plate P and grid G are at the same potential. Therefore the velocity of the emitted electrons between G and P is uniform. The kinetic energy of the electrons of charge e and mass m traveling with uniform velocity v is given by

$$\frac{1}{2}mv^2 = Ee. \qquad (22)$$

When the potential difference between F and G is approximately 2.1 volts a yellow light is observed between G and P. No radiation is observed prior to this potential difference assuming that the potential is constantly being increased. It is to be observed that the potential difference is regulated by the rheostat R. If this light is examined with a spectrograph it is found to consist of the sodium resonance lines only. It is known that the resonance lines are produced when an atom is raised from its normal state to next higher energy state and then returns to its normal state emitting characteristic lines. It is concluded from this that the atoms are in an excited state as a result of the bombardment of electrons and return to the normal state causing the emission of the yellow light. This means that the energy of the electron must be at least equal to the quantum of energy corresponding to the sodium D lines. The wavelength of this line is computed from

$$Ee = hc/\lambda \qquad (23)$$

where h is the Planck constant, c is the velocity of light, and is the emitted wavelength. Calculations give 5898 A^{o} for the wavelength which agrees favorable with the wavelength of the sodium D line. For an explanation and development of formulas (22) and (23) see Semat (1958).

If the potential difference is increased to approximately 4 volts the color of the light emitted changes, indicating that additional spectral lines are being produced. Other lines will appear at a potential difference of 4.4 volts and 4.6 volts. When the potential difference is increased to 5.4 volts ionization takes place. This is indicated by the large increase of current as indicated by the galvanometer M.

The occurrence of the entire optical spectrum of sodium is explained by the fact that the energy of the bombarding electrons is such as to remove electrons from the sodium atom and these electrons in turn may return to any level thus causing the emission of the complete spectrum. It is well to point out here that selection rules have been established for the transitions of electrons from one state to the other and those forbidden by the rules have little chance of occuring.

3. Experimental Equipment. A particularly satisfactory gas filled helium tube for this experiment is available from Ealing Corporation (1959) at $80.00. A similar apparatus utilizing a mercury filled tube is available from Leybold (1958) at $70.00. Each tube will require as additional equipment a variable power supply which may be batteries and rheostat or a power supply unit such as recommended in Experiment I; a good high resistance voltmeter such as utilized in Experiment I; a current sensitive galvanometer capable of measuring very low currents. With the Leybold tube an RCA vacuum tube microammeter at a price of $100.00 has been found to work well. A less sensitive and therefore less expensive meter should work with the Ealing apparatus.

Light intensities radiated from the Leybold tube are probably too low to observe but one should be able to observe the appearance of spectral lines with the Ealing tube. Some type of spectroscope or spectrometer would of course be necessary.

EXPERIMENT V

RANGE OF ALPHA PARTICLES

1. Discussion. The alpha particle is one of the radiations given off by radioactive atoms. The different types of radiation can be distinguished by their penetrating power and also by their different responses in the presence of electric and magnetic fields. Rutherford and Royds were the first to prove conclusively that the alpha particle was a doubly ionized helium atom. Geiger in an attempt to detect a single alpha particle developed the well known Geiger counter which is an extremely sensitive instrument for determining the amount of radioactive radiation given off by some atoms.

The determination of e/m for the alpha particle was an important step in elucidating its nature. The principle of the method used by Rutherford and Robinson is identical to the method discussed in Experiment II. For this type of experiment a source of homogeneous alpha particles is necessary. An interesting method for obtaining this homogeneous source is discussed by Tolansky (1949) on page 232. This method consists of exposing a wire for some time to radon. This results in an active deposit of Ra A, Ra B, and Ra C on the wire. The decay periods of these are such that after a short time alpha particles are emitted from the wire by Ra C only. This then constitutes the homogeneous alpha source.

2. Experimental Procedure. In this section two methods will be discussed for determining the range of alpha particles. This in no way is meant to imply that these are the only ways.

a. Method 1. The first method for measuring the range of the alpha particle uses a Wilson cloud chamber containing a gas such as hydrogen, nitrogen, or air. The apparatus, see Figure 5, consists essentially of a cylinder C, containing a suitable gas saturated with water vapor, a movable piston P, a viewing window W, and an alpha source A. A light source is also provided at one side to give ample illumination. When the piston is rapidly lowered the decreased air pressure in the cylinder results in supersaturation of the water vapor. Any ions present in the cylinder will cause condensation of the water on them in the form of small droplets. These droplets are then easily seen through the window at the top of the cylinder.

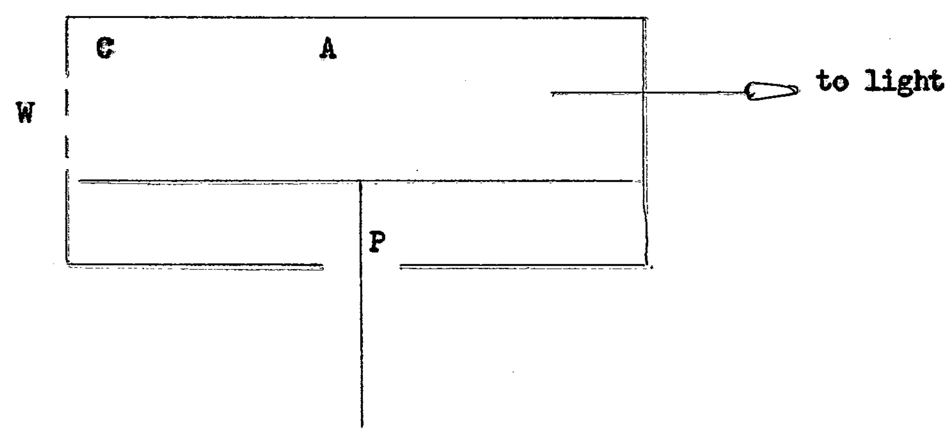

Figure 5

When a source of alpha particles is introduced at A their movement through the cylinder will cause ionization of the gas. These ions in turn, when the cylinder is rapidly lowered, will have small droplets of water condence on them and the passage of the alpha particles through the cylinder is then seen as a collection of droplets of water called tracks. These tracks in general are straight lines and their lengths determine the energy of the alpha particle indirectly by showing its range which is easily measurable.

b. Method 2. The second method for determining the range of alpha particles in a gas is to measure the ionization produced in the gas at different distances from the source of the alpha particles. This method, see Figure 6, is due to W. H. Bragg. A narrow beam of alpha particles is formed by allowing the radiation from a suitable source L to emerge from a small aperture in a lead box. Two metallic grids G and G',

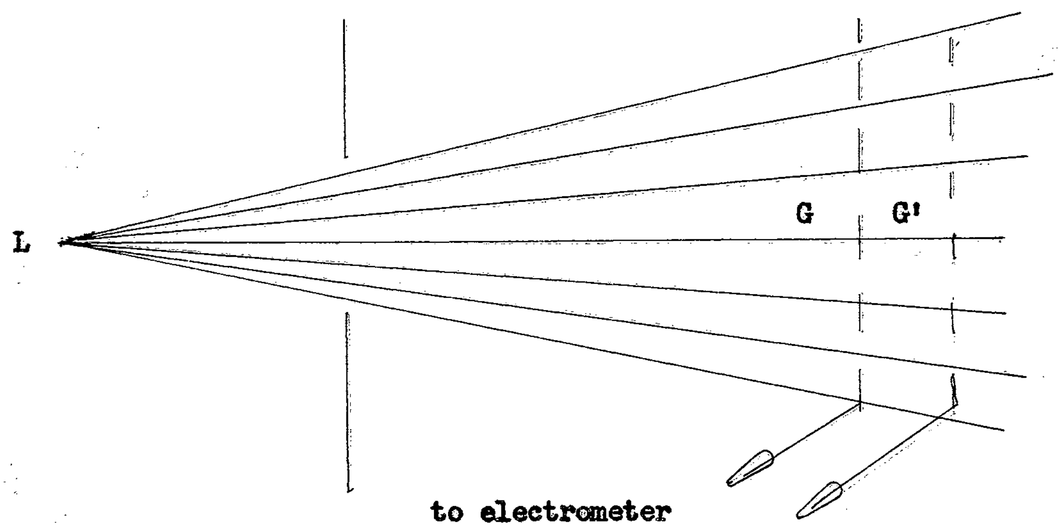

Figure 6

parallel and close to each other form an ionization chamber. The current between these grids, measured by an electrometer, is proportional to the intensity of the ionization produced between them by the alpha particles. The source is so adjusted that it can be moved toward or away from the grids and by this means the amount of ionization produced at every point of the alpha particle path can be measured. It is also possible to keep the source fixed and vary the gas pressure within the ionization chamber.

A graph, see Figure 7, shows the range R of the alpha particle versus the amount of ionization I as measured by the electrometer.

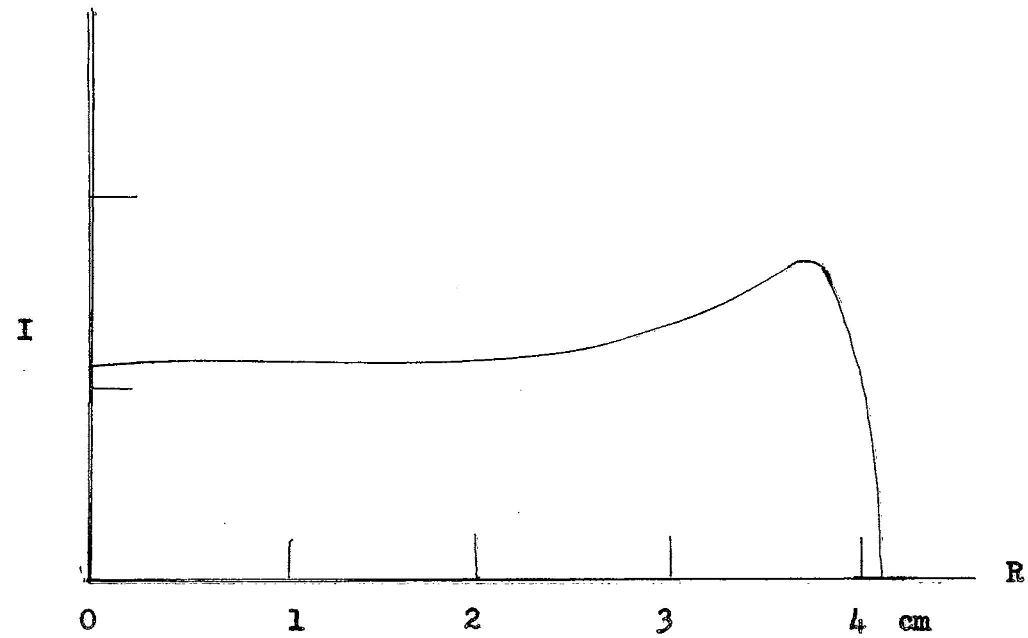

Figure 7

It is to be noted that for the greater part of the range the ionization current is almost constant, while the latter part of the range increases and comes to a peak. This peak at the end of the range is due to an increase in the efficiency of the ionization of the gas by the slower moving alpha particles.

Descriptions of these experiments, as well as others, can be found in Semat (1958) on pages 312 through 319, in Tolansky (1949) on pages 231 through 253, and in Richtmyer, Kennard, and Lauritsen (1955) on pages 433 through 449.

3. Experimental Equipment. Method 1 requires the use of a cloud chamber which can be obtained from The Welch Scientific Company (1961) in a range of prices from $18.25. The cloud chamber comes complete with radioactive source included. This piece of apparatus can also be

used to observe beta particle tracks as well as the alpha tracks.

Method 2 requires the use of some form of electroscope such as the Wolf Electroscope made by Leybold (1958) for approximately $80.00.

Probably the most efficient form of apparatus to use is some type of alpha particle detector such as a scintillation counter and scalar. While this apparatus is quite expensive it is extremely flexible and can be adapted to many other types of experiments in the physics laboratory such as measuring the half life of a radioactive substance and the inverse square law for gamma radiation. Satisfactory systems of this type are available at prices ranging upwards from $400.00. See for example the 1961 Central Scientific Company catalog.

EXPERIMENT VI

ENERGY DISTRIBUTION OF BETA PARTICLES

1. Discussion. The beta rays given off by some radioactive substances was soon found to consist of rapidly moving electrons. The Curies were the first to show that some radioactive substances give off negative particles more penetrating than the alpha particle. Becquerel in 1899 found that these particular rays were easily deflected in a magnetic field. This deflection indicated that these beta rays were charged particles. In Becquerel's experiment the beta rays were allowed to emerge from a slit and after being deflected by a magnetic field to fall on a photographic plate. It was observed that a broad band on the plate had been blackened by the rays rather than a narrow band which would be the case if the beta particles all had the same energy. This was an indication that the energy of the particles was variable. Those with less energy traveling the shorter path while those with greater energy

traveled the longer path. This is a point of great interest. It is to be noted that alpha particles are emitted with constant energy as indicated by their range and discussed in Experiment V.

The nature of the charge carried by the beta particle was demonstrated in a very simple way. The beta ray particles were allowed to fall on a lead plate connected to an electroscope. The particles were absorbed by the plate and gave up their charge which was shown to be negative. Becquerel made approximate e/m measurements for the beta particle and shortly thereafter Kaufmann made exact measurements using a similar process to that described in Experiment II. It was thus definitely confirmed that the beta ray was really an electron.

The continuous beta ray spectrum, so called because of the variable velocities of the emitted electrons, is opposed to the idea of sharply defined energy levels. It is known that the energy levels of the nuclei are sharply defined. How then is it possible for the beta particles to have this variable energy? This dilemma was tentatively solved by Pauli in 1931 who postulated that with every beta emission there was also another particle that was emitted at the same time with such energy that the total emission of the two particles was constant as regards their energy. This particle, the neutrino, has recently been detected. See for example pages 318 and 319 in Blackwood, Osgood, and Ruark (1959) in which the detection of the neutrino is discussed.

2. <u>Experimental</u> <u>Procedure</u>. The experiment suggested here to determine the energy of the emitted beta particles is similar to that first performed by Becquerel using the apparatus shown in Figure 8 (Se mat, 1958). The beta source C is shielded from the Geiger counter G by a lead block. The beta rays must pass through the two shielding slits

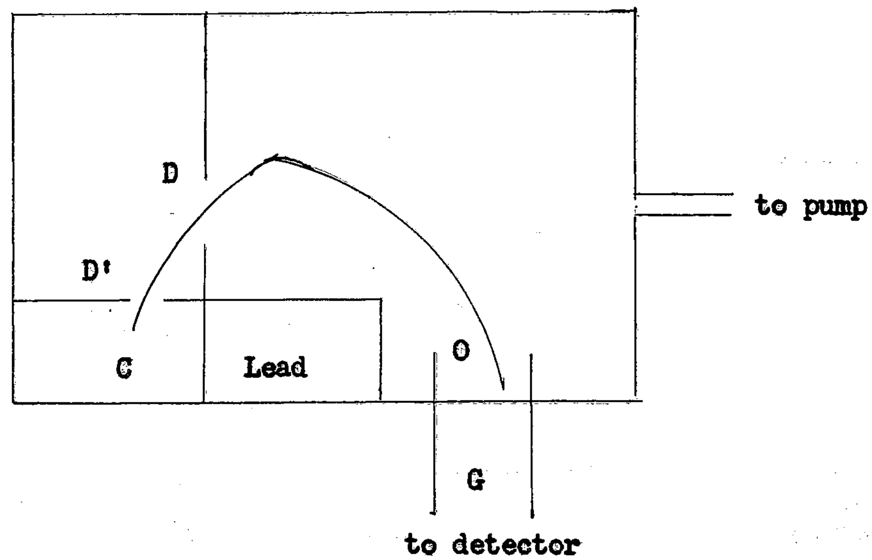

Figure 8

D and D' before being detected. A magnetic field perpendicular to the paper causes the beta particles to bend and some will enter the counter at O. The number of beta particles entering O is then determined by the Geiger counter G. The magnetic field intensity H is then varied and the number of beta particles entering O is redetermined. This process is continued until no beta particles enter O. With the data thus obtained it is possible to determine the energy of the particles.

The path of the beta particles in the magnetic field is given by

$$R = mv/eH, \tag{24}$$

where R is the radius of the path, m is the mass of the electron, v is the velocity of the electron, H is the strength of the magnetic field, and e is the charge of the electron. All quantities except v and R are known and since R is easily measured the velocity v can be easily calculated.

If a photographic film is used as the detecting agency in place of the Geiger counter it will not be necessary to vary the magnetic field intensity. By observing the blackness of the film and using formula (24) it is possible to determine the energy of the beta particles as a function of their velocity.

3. Experimental Equipment. This experiment on the determination of the energy distribution of beta particles is somewhat more exacting than that for alpha particles. The piece of apparatus suggested by Figure 8 is not available as a standard piece of equipment. It is possible, however, to build this piece of apparatus in the school shop. It would of course be necessary to consider the strength of the magnet available before commencing construction of this apparatus in order that the dimensions of the chamber would be adequate. The magnet is a standard item and so is the vacuum pump needed. If a film is used as the detecting agency it would be necessary to have some form of densitometer to determine the degree of blackness of the film. Suitable densitometers can be obtained for this purpose from any photo supply store in the neighborhood of #30.00. A suitable Geiger counter as the detecting agency is available from the Central Scientific Company (1961) for approximately $50.00.

EXPERIMENT VII

INVERSE SQUARE LAW FOR GAMMA RADIATION

1. Discussion. The gamma ray is the third type of radiation given off by some radioactive substances. Gamma rays were discovered some time after the existence of alpha and beta rays had been established. The outstanding property of gamma rays is their extreme penetrating power and their lack of response in electric or magnetic fields. The fact that gamma rays have an extreme penetrating property suggested that they were of the same nature as X-rays and this has subsequently been confirmed.

Gamma rays are now known to be very short electromagnetic waves.

Since the gamma ray can be very injurious, due to its high penetration, experiments with this source are very limited in a high school class. The experiment suggested, however, does not use a gamma source of any potential danger.

2. Experimental Procedure. For this experiment it is necessary to have a suitable gamma source, measuring stick, and detecting device. A convenient detecting instrument is the Geiger counter which indicates quite readily the amount of radiation given off by radioactive substances.

The purpose of this experiment is to show that the intensity of radiation is proportional to the square of the distance from the source. This is readily determined by measuring the intensity of radiation at different distances from the gamma source as determined by the Geiger counter. The data thus obtained is plotted on a graph, the intensity of radiation versus the square of the distance from the source. This should result in a straight line showing that

$$I = kS^2 \qquad (25)$$

where I is the intensity of the gamma rays, S is the distance from the gamma source, and k is the proportionality constant.

3. Experimental Equipment. An electroscope, such as the Wolf Electroscope suggested in Experiment V, would be satisfactory as the detecting agency for determining the intensity of the gamma radiation. A Geiger counter, such as suggested in Experiment VI, would also be satisfactory as the detecting agency as would be the scintillation counter and scalar. A suitable gamma source can be obtained from The Welch Scientific Company (1961) for approximately $2.00.

EXPERIMENT VIII

MEASUREMENT OF HALF LIFE OF RADIOACTIVE MATERIAL

1. Discussion. For every radioactive element the rate of emission of alpha, beta, or gamma particles is directly proportional to the mass of the substance originally present. This would indicate that the atoms do not effect each other in promoting the emission of particles. This constant emission of particles results in the decay of the original substance. By measuring the gradual decrease in the particles emitted it is possible to determine the rate of decay of the radioactive substance.

By half life is meant the time that it takes a radioactive substance to lose one half of its mass through emission of alpha, beta, or gamma particles. Repeated experiments with radioactive materials show that the rate of decay for any particular substance is constant. The half life of radioactive elements may be as short as 3×10^{-7} seconds in the case of Thorium C' and as long as 4×10^{12} years in the case of Rhenium. The decay of radioactive substances may be represented by

$$N = N_o e^{-kt} \qquad (26)$$

where N_o indicates the number of atoms present when the time t is zero, e is the base of natural logarithms, k is a constant for the particular radioactive substance and N is the number of atoms present after a time t. To determine the half life of any radioactive substance it is only necessary to know the decay constant k. In equation (26) if N is set equal to $N_o/2$ and t is set equal to T then

$$T = 0.693/k, \qquad (27)$$

where T represents the half life of the radioactive substance whose decay constant is k. It is to be noted that it is impossible to determine when any one particular atom will decay as radioactive decay follows the laws of chance. Also to be noted is the fact that N_0 does not enter into equation (27) for the half life. Therefore T does not depend upon the quantity of the original substance present. Also the measurement of T is not affected by the efficiency of the counting device used to measure the radiations occuring since the device measures a small but fixed percentage of all disintegrations.

3. Experimental Procedure. A standard experiment in radioactive decay is the measurement of thorium emanation. In this experiment the quantity of the radioactive element is measured by its activity. This is done by allowing the thorium radiation to enter the condenser of an ionization chamber and then charging the condenser every 15 seconds to its initial potential difference and measuring the rate of discharge by observing the leaf of an electroscope.

The data thus obtained is plotted on a graph, see Figure 9, in which the time is plotted versus the natural log of the activity. The natural log of the activity is used for two reasons. First of all this results in a straight line graph rather than a curve, second, it is possible to cover a much wider range than could be represented by a linear scale.

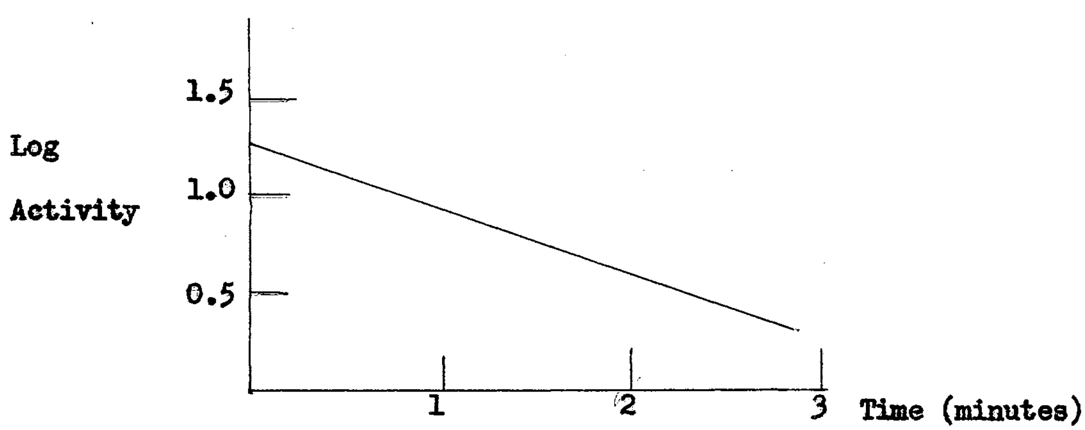

Figure 9

It is to be noted that the decay constant k represents the reciprocal of the time during which the activity N decreases to the fraction 1/e of its initial value.

A discussion of the above experiment and development of formulas (26) and (27) can be found in Oldenberg (1954) on pages 276 through 279.

3. Experimental Equipment. The W. M. Welch Company (1961) offers an emanation electroscope for $60.00 that contains the necessary radioactive source for performing this experiment. With this piece of equipment it is possible to determine the half life of thoron to within two seconds. This apparatus may be stored with out disassembly and is nonhazardous.

The Wolf electroscope, mentioned in Experiment V, would also be satisfactory. It would also be possible to monitor the decrease in activity with a scintillation counter and scalar as mentioned in Experiment V.

CHAPTER III

CONCLUSIONS

The experiments that appear in this study are not only basic to the understanding of modern physics, but have been chosen with the awareness that safety must be the prime consideration in the high school class. It should be noted that experiments dealing with X-rays and other phases of modern physics that could well be hazardous to the beginning student in this field of study have not been chosen. This in no way implies that such experiments are not vital, but it is felt that they might well be put off for the college years.

Although the high school physics course must cover a great deal of material it is possible to devote time to experimental atomic physics. It should be possible for the high school physics class to understand and duplicate the experiments discussed in this study.

There is no question that the cost of experimental apparatus in this field is expensive when compared to apparatus used for many of the traditional experiments in high school physics. However in this atomic age it is necessary for the student to become acquainted as early as possible with the basic concepts in this ever expanding field. Whether the physics student goes on to college to further his knowledge in this area should not be considered a criteria for the acquisition of equipment. In this modern era all students should have a basic knowledge of modern physics and the high school class should provide this opportunity for those interested. With a little thought and planning it should be possible, over a period of a few years, to obtain all of the apparatus mentioned in this report.

It should also be noted that the apparatus used in this field can also be adapted to laboratory work in biology and chemistry. For example in the field of biology absorption of radioactive substances by plants can be measured with the Geiger counter. In the field of chemistry atomic phenomena is also studied and these experiments would be appropriate there.

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SELECTED SOURCES FOR EXPERIMENTAL APPARATUS

Allied Radio Corporation. Electronic Equipment. 100 North Western Avenue, Chicago 80, Illinois.

Central Scientific Company. Laboratory Apparatus. 1700 Irving Park Road, Chicago 13, Illinois.

Concord Radio Corporation. LaFayette Electronic Parts. 901 West Jackson Blvd., Chicago, Illinois.

E. Leybold's Nachfolger. Leybold Physics Apparatus for Teaching Purposes. Koln, Germany, and J. Klinger. Scientific Apparatus. 160th Street, Jamaica 32, New York.

Heath Company. Electronic Equipment. 305 Territorial Road, Benton Harbor, Michigan.

The Ealing Corporation. Ealing Scientific Instruments. 33 University Road, Cambridge 38, Massachusetts.

W. M. Welch Scientific Company. Welch Laboratory Apparatus. 1515 Sedgwick Street, Chicago 10, Illinois.

VITA

ROGER CALVIN EWING

Candidate for the Degree of

Master of Science

Report: SELECTED EXPERIMENTS IN MODERN PHYSICS FOR HIGH SCHOOL

Major Field: Natural Science

Biographical:

Personal data: Born at Ludington, Michigan, December 26, 1922, the son of Roger William and Edith Agnes Ewing.

Education: Attended grade school in Ludington, Michigan; graduated from Ludington High School, Ludington, Michigan in 1942; attended the University of Nebraska, Lincoln, Nebraska, for three terms in 1943 and 1944; graduated from Muskegon Community College, Muskegon, Michigan in 1948; received the Bachelor of Science Degree from Central Michigan University, Mount Pleasant, Michigan, with a major in Mathematics in June 1950; attended Michigan State University, East Lansing, Michigan, for a 12 week summer session in 1959; attended Western Reserve University, Cleveland, Ohio, for an 11 week summer session in 1960; completed requirements for the Master of Science degree at the Oklahoma State University, Stillwater, Oklahoma, in August, 1961.

Professional Experience: Science teacher at Custer High School, Custer, Michigan, for school year 1950-51. Physics and Mathematics teacher at Utley High School, Flint, Michigan, from 1951 to 1953. Science and Mathematics teacher at Ludington Junior and Senior High School, Ludington, Michigan, from 1953 to 1960.