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Title of Study: TEACHING ATOMIC AND NUCLEAR PHYSICS IN HIGH SCHOOL

Pages in Study: Candidate for Degree of Masters of Science

Major Field: Natural Science

Scope of Study: The rapid advancements in Atomic and Nuclear Physics have left high school science teachers in need of teaching materials not usually presented in high school text books in this subject. Various topics concerning this field have been selected and simplified for use in a high school physics course. Such topics as; theories on the structure of the atom, fundamental particles, isotopes, natural radioactivity, nuclear fission and reactor physics have been presented in a readable form for high school students. Much of the report is devoted to demonstrations and experiments that can be performed in the class room.

Findings and Conclusions: Atomic and Nuclear Physics holds an almost unlimited amount of information available for high school physics teaching. Study in this field is an interesting one for high school classes and science clubs. Many college texts have material that can be adapted for high school classes and current magazines are carrying articles concerning experiments and demonstrations which can be used.

ADVISER'S APPROVAL James H. Zant

TEACHING ATOMIC AND NUCLEAR PHYSICS IN HIGH SCHOOL

By

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TEACHING ATOMIC AND NUCLEAR

PHYSICS IN HIGH SCHOOL

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INTRODUCTION

The purpose of this report is to collect and organize information, demonstrations and reference material in such a way as to give the author a better insight into the teaching of atomic and nuclear physics in a high school general physics course.

Various topics in this phase of physics have been selected and an attempt has been made to discuss briefly each topic in general terms and without mathematics except algebra and trigonometry. These topics include theories and facts on the structure of the atom, nuclear particles, isotopes, radio-activity, fission and reactors. Subtopics such as wave mechanics and the quantum theory have been touched upon lightly, but are too advanced for a thorough discussion in this report.

Information not usually found in the ordinary high school text has been included. A relatively up to date account of the newer teaching methods of this subject has been included in the chapter on demonstrations and experiments. A description of those experiments has been placed at the end of the report as chapter 6. They are related to the different topics discussed in the report. Also included is a bibliography of reference material, such as books and current articles.

This report grew from the idea that since the first atomic bomb blast in 1945, the words atom, fission, nuclear reactors, fallout, radiation and scores of others are continuously being used, not only by the scientist, but by almost every individual well informed on current news.

Yet, with all this emphasis on the "atomic age" our elementary and secondary schools have in many more instances than not failed to educate our young people properly in this field. There are several reasons for this; one being the tremendous rapidity of advances in this field the past few years. Another is the idea that it is a much too difficult subject for pre-college age students, but probably the basic reasons is the lack of knowledge and understanding of the subject on the part of teachers and administrators.

The fact is that the student hears the words "atomic age" so often, he may begin to feel acquainted with the atom. But many of these students will be disturbed, with further reading, to find that everything is not as clear and simple as it has been shown in some high school text or in the classroom. They find that the really up to date way of explaining the structure of the atom is in terms of "wave mechanics", "quantum theory" and other very complicated subjects, and with a small amount of investigation they find why these subjects have been left out of the discussion in their text books. It is useless to include something in a text that the student will not be able to understand.

On the other hand, the subject matter being taught on atomic structure will, in most cases, mislead the students into thinking they completely understand a subject about which even our greatest physicists are uncertain.

In a subject as difficult as this we should admit our inabilities to give a complete explanation, rather than give one which is clear and simple but partially incorrect. With this approach the student will not be so disturbed when in later studies he finds that what he learned earlier was simple but incomplete.

Much will have to be left for more advanced courses in this field of study because it is a highly mathematical subject. But with careful thought and preparation the high school teacher can bring to light much important information on atomic and nuclear physics. This has been attempted in this report.

CHAPTER II

THEORIES ON THE STRUCTURE OF THE ATOM

Dalton believed the atom to be the smallest particle of matter obtainable. He stated that the atom was the smallest particle into which matter could be broken by ordinary chemical means. This much of his theory still holds. Although the atom is the unit of chemical combinations, it also has constituents. If this were not true, how could a certain element, such as uranium, be radioactive? To be able to emit x-radiation, as Becquerel found, the atom must be complex.

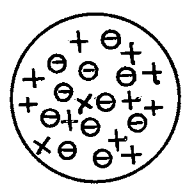

Figure 1

Along such lines of assumption J.J. Thompson proposed a model of the atom that was a sphere of positive electricity; more or less a billard type ball with negative charges embedded in the sphere as in figure one. This type of model answered well for many purposes but failed in others.

At this time, Rutherford and his co-workers were experimenting with scattering of alpha particles, which were positively charged particles emitted from radioactive material. They directed a beam of alpha particles onto a very thin foil of gold and measured the angular distribution of the scattered alpha particles by counting the scintillations on zinc sulfide screen connected to a microscope. When an alpha particle hits the zinc sulfide screen it produces a small flash of light which can be observed in the dark with a microscope. Rutherford set up an apparatus diagrammed in figure 2[1], in which he could rotate the screen in a circle about the foil to obtain the different angles of deflection.

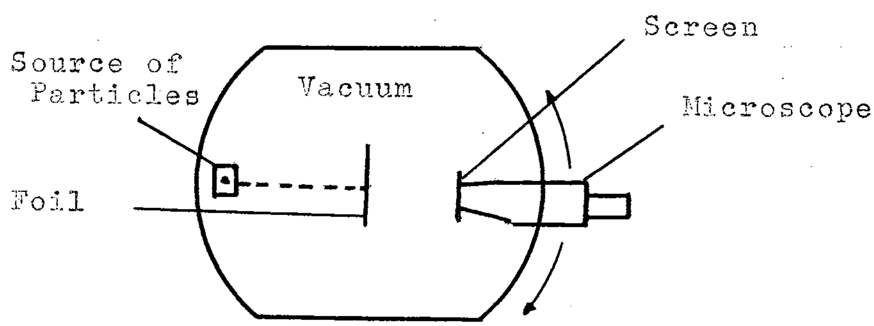

Figure 2

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[1]Ralph E. Lapp, Nuclear Radiation Physics, (New York, 1954) p. 27.

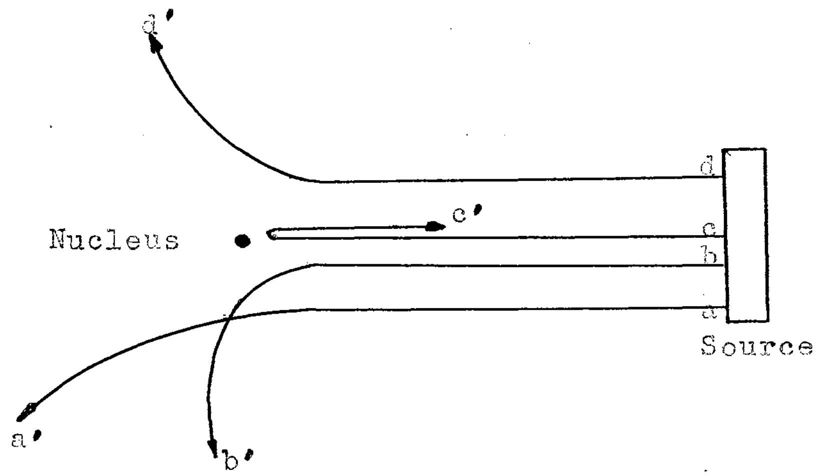

Figure 3

Most of the alpha particles were found to have a small angle of deflection such as aa' in figure 3, but others were found to have deviations such as bb' and cc' where cc' is a deflection of almost 180°.

To explain the different angles of scattering, Rutherford assumed there was an intense electric field within the atom and an alpha particle was scattered by a single atom. The angle of deflection, he assumed, depended upon how near the path of the alpha particle was to the nucleus of the atom.

To have such an intense field, that was strong enough to deviate the fast moving particles, Rutherford proposed to treat the entire positive charge as situated at a point, and the electrons were somewhere outside this point far enough to allow the alpha particles to move between the point nucleus and the electrons.

If the electrons were situated among the positive charges as Thompson assumed, there would be no electric field to deflect the alpha particles. Rutherford said the electrons were revolving about the nucleus with just the right velocity to create a centripetal force that would be in equilibrium with the electrical force the nucleus exerted on the electrons.

Such a point of view at once offered the picture of a tiny planetary system. The only difference between Rutherford's planetary model and astronomical conditions is that the attractive force of the atom is electrical, where as the attractive force of our solar system is Newton's force of mass attraction.

After much experimentation, Rutherford in 1911, summarized his atomic model as having a very small positively charged nucleus, (that of gold having a radius of less than 3.2×10^{-12}cm.), which contains almost all of the mass of the atom. Revolving about this point nucleus were the electrons, which were negatively charged.

A successful model of the atom would have to explain the phenomenon of spectral lines that every element emitted. The spectrum of an element, which might be a band or line spectrum, are images of a slit resulting from the emission of characteristic visible and ultraviolet radiations when the element has an electrical spark sent through it or is heated by some other method. If these radiations are dispersed by a prism or grating they consist of a number of sharp spectral lines, or of a continuous spectrum, which form the characteristic spectrum of the element. These different lines were a result of the radiations having different wave lengths and thus would be dispersed at different angles.

Since Rutherford's model had the electrons rotating about the nucleus they would always be accelerated toward the center as any rotating body would be. According to the electromagnetic theory, a charged body that is accelerated would continually radiate energy which would cause the electron to approach closer and closer to the nucleus. This continual radiation would result in a continous spectrum and not in the observed line spectrum. So although the Rutherford atom could explain many of the observed happenings it was insufficient for explaining spectral analysis.

Balmer in working with hydrogen had observed a series of these spectrum lines and found that he could predict their wave length λ, by using the equation

$$1/\lambda = R(1/2^2 - 1/n^2)$$

where R is the Rydberg constant equal to 109,680 and n is the integers 3, 4, 5, . . .

<u>Bohr's Theory on the Hrdrogen Atom</u>. A physicist named Bohr set out to devise a model of the hydrogen atom that would explain Balmer's series and other observed spectral phenomena of hydrogen.

He put the electrons in orbit as did Rutherford but differed from Rutherford's model with two very bold postulates. He first stated that the electron could revolve around the nucleus in certain specific orbits without radiating energy. The only allowable orbits, according to Bohr, are those in which the angular momentum of the electron <u>mvr</u> is equal to integral multiples of $h/2\pi$. The electron is restricted to these values of angular momentum and no other values are possible. This can be represented by the equation

$$mvr = \frac{nh}{2\pi} \quad \text{where } n = 1, 2, 3, 4, \ldots$$

Secondly he postulated that when the atom does emit or absorb energy it does so in whole units or quanta of energy of the amount <u>hf</u> where f is the frequency of the radiated waves and h is Planck's constant from the quantum theory.

In this theory, Planck visualized that when a material body sends out radiations it does so in whole units of energy called quanta. Therefore a quantum of energy was considered the atom of energy, where the word "atom" is thought of as the smallest unit, although all quanta do not have the same value.

Bohr said the product <u>hf</u> was the quantum of energy emitted when the electron jumps from one orbit to another of lower energy. This results in the equation

$$hf = E_1 - E_2$$

where E_1 is the energy in one orbit and E_2 the energy in the next larger orbit or lower energy orbit. The only time the atom emitted energy was during these hops from one orbit to the next.

With these postulates Bohr developed an equation which was identical to Balmer's for his series. This gave Bohr's theory much prestige and for many years it was considered a good model of the atom. In his explanation of the spectrum, he visualized that when an atom received energy when heated, the electron received part of this energy and would leave its present energy level and jump to the higher energy orbit corresponding to the amount of energy absorbed, which was always whole units of "hf". This idea seemed to be substantiated by experimental data.

With further research and developments however, refinements had to be made on Bohr's model. The idea of circular orbits were extended into elliptical orbits and then the orbits were gradually replaced with the idea of energy levels of the electron.

Wave Mechanics. The very important theory on "wave mechanics" was developed by de Broglie, in which he applied the dual characteristic of waves and particles that had been associated with light studies, to small particles such as electrons, protons and etc. He developed the idea that a particle such as an electron with a velocity v and mass m, would have a wave with velocity w and wave length λ associated with it given by the equations

$$w = c^2/v \text{ and } \lambda = \frac{h}{mv}$$

where c is the velocity of light. He assumed that the electron was enclosed in a wave group which had a velocity equal to that of the electron, but the individual waves were moving with a velocity faster than light. This theory began the very important study of wave mechanics.

Schrodinger imagined the electron as not existing at all as a granular object, but rather the electric charge being distributed about the nucleus in the form of an electric field or cloud. He thought of the density of the charge as being extinguished in almost all of the space surrounding the nucleus except in one small region. This region he called an energy packet, and had the idea this packet was what had been called the electron. Yet this theory also had its failings as its predecessors had. The important fact of de Broglie's and Shrodinger's theories is the association of the corpuscular and wave theories with particles of matter.

Heisenberg's Uncertainty Principle. The inability to find the position of the electron and its velocity at the same time brought about "Heisenberg's uncertainty principle," which is a theoretical principle and has not been experimentally shown as yet. Heisenberg succeeded in showing theoretically that one may choose either to determine the location of a flying electron, or to ascertain its speed with precision, but there can be no experiment that will fix location and velocity at once with maximum accuracy. He found the more accurate one was found, the less accurate the other could be calculated, but the product of the two inaccuracies is always constant.

Much of this chapter will seem vague to the high school student. This discussion was placed in this report for the purpose of showing the students that everything about the structure of the atom is not simple and clearly understood. The students should know some of the problems facing our physicists today and realize the necessity for able minded men in this field of study.

CHAPTER III

THE PARTICLES OF THE ATOM

Since Dalton's first hypothesis that the atom was the smallest particle of matter obtainable, great strides have been made in the exploration of this so called unit of matter. From much research comes the facts that the atom itself is made up of several particles. These are the electrons, protons, neutrons, positrons, neutrinos, photons and mesons. The last four are not considered actual components of the atom as the electron, proton and neutron are. As research continues more particles will be discovered, but for this report we will restrict ourselves to these.

Electron. In the previous chapter we were concerned with the location and movement of the electron and as stated previously no solution to this problem is known. But using the Bohr model of the atom we will think of the electron as a particle. This particle discovered by J.J. Thomson, has been found to have a charge of -4.803×10^{-10}esu. and a mass of 9.19×10^{-28}gm. or 0.00054862 atomic mass units. When ejected from a radioactive body they are termed, "beta rays", and will be discussed in the chapter on radioactivity.

Protons. Protons are the positively charged nuclei of the hydrogen atoms. Since the hydrogen atom is electrically neutral then the charge on the proton must equal that of the electron but with a positive sign. Therefore the proton's charge is 4.803×10^{-10}esu. The mass of the proton is 1.007582amu or in gram weight, 1.67248×10^{-24}gm. Protons were first observed by Goldstein in 1886 as positive rays in a discharge tube.

Neutrons. Neutrons are particles with a neutral electrical charge and whose weight is slightly greater than that of the proton. The atomic mass is 1.00896 and this is equivalent to 1.65477×10^{-24}grams. Due to lack of electrical charge the neutron was not discovered until 1932. With information from investigations of other men, Chadwick identified the neutron. Since neutrons lack charge they are not influenced by other atoms except at very close range, therefore, they penetrate thick layers of heavy elements with little loss of energy. This property also makes them useful for nuclear bullets.

Positron. In 1932, C.D. Anderson observed particles of the same mass and charge as the electron, being curved in the opposite direction to that of the electron in a strong magnetic field. They were first thought to be protons, but by further investigation Anderson announced they were positive electrons or "positrons". In nuclear reactions these particles are commonly emitted but their life span is short, lasting only in most cases, less than a microsecond.

Positrons do not form a part of ordinary matter.

There are two known processes which result in positrons. They are ejected from the nuclei of certain artificial radioactive materials, and they spring into existence, along with an electron in a process in which a gamma ray is annihilated. Charge is conserved in the process since the particles have charges of opposite sign.

Neutrino. Due to studies of energy distribution of the beta radiation and energy states within the nucleus of radioactive substances, physicists were faced with the problem of either relinquishing the principle of "conservation of energy" or postulating the existance of a non-detectable, yet energetic particle. They chose the latter and called it the "neutrino". Until recently there was no proof of the existence of this particle, but in 1953, its existence was established by its interaction with a proton.

The neutrino is assumed to have a mass much smaller than the electron and no electric charge. This accounts for its being extremely difficult to detect.

Photon. According to Planck's quantum theory, whenever radiation is emitted or absorbed by a body, it is done so in whole quanta, where a "quantum of energy" is given by

$$E = hf$$

with f being the frequency of radiation and h Planck's constant. Such a quantum of energy received the name "photon", which is a quantum of energy associated with light. Thus the photon is the product of Planck's constant and the frequency of radiation, and when ejected from a radioactive nucleus is refered to as gamma rays. Einstein was responsible for naming the photon in 1905, with his now famous photo-electric equation

$$hf = \frac{1}{2}mv^2 + p$$

in which p is the amount of energy it takes to release an electron from the surface of a metal and $\frac{1}{2}mv^2$ is the kinetic energy of the escaping electron. Since at impact the momentum as well as energy must be conserved, the photon must possess both energy and mass and, hence, momentum. Einstein later formulated this postulate as: "every quantity of energy of any form whatever, represents a mass which is equal to this same energy divided by c^2 with c being the velocity of light, and every quantity of energy in motion represents momentum."[1] This is represented by the equation

$$E = mc^2.$$

This equation resulted from his theory of relativity.

Mesons. The meson was discovered in 1936 as a component of cosmic radiation from outer space. A year before it was detected the meson was predicted theoretically. Our knowledge of the meson is much less clearcut than that of the other fundamental particles. Mesons can be either neutral, positive or negative and have variable masses. The light or ordinary meson, termed the "mu meson", has a mass

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[1]James M. Cork, Radioactivity and Nuclear Physics, (New York, 1950) p. 23.

of 215 times that of the electron. Another, the "pi meson", has a mass of 285 times that of the electron. Some evidence of another meson, the "tau meson", has been found and its mass may vary from 400 to 900 times that of the electron.

The pi meson is a short lived particle, decaying in about 10^{-8} seconds to a mu meson and probably a neutral meson. The mu meson's average life is about 10^{-6} seconds and its decay products are not known. It is believed that pi mesons play an important part in the mechanism of nuclear forces.

As can readily be seen Dalton's unit of matter is not as simple as once thought. Perhaps further research and experimentation will yield even more complicated structures. These so called fundamental particles may be found to contain other components just as the atom is.

Isotopes. Since the atom is composed of three of the fundamental particles its weight and mass must be from the weight of these particles. Another term, the "atomic number", is obtained from these particles. Also since an atom is electrically neutral then the number of protons and electrons are equal. The number of electrons or protons of an atom is called its atomic number, which varies between 1 for hydrogen and 92 found in uranium, for the naturally occuring atoms. The electron is so light compared to the neutron and proton that the electron does not enter into the mass of the atom with any significance. This is also true for the other fundamental particles. Thus the total number of neutrons and protons make up the atomic mass which varies between 1 for hydrogen and 328 for uranium of the naturally occuring elements. This can be represented by $_1H^1$ and $_{92}U^{238}$. with the subscript being the atomic number and the superscript being the mass number.

Every piece of matter in the earth and, as far as we know, in other parts of the universe is made up of one or more of the simple substances called elements, and the smallest portion of an element which can exist is an atom. Each element exists in a number of varieties called "isotopes ", having the same atomic number but different mass numbers. To be neutral the atom must always have the same number of protons, therefore isotopes are elements having the same number of electrons and protons but varying numbers of neutrons. The 102 elements have, in all, more than 1,200 isotopes, of which about 300 are found in nature and 900 to 1100 have been made artificially.

It was found that the nucleus of an atom is lighter than the sum of the weights of its components. To give an example, the mass of the helium nucleus which is $_2He^4$ is found to be slightly less than the weight of two separate neutrons and protons added together. This difference in mass is called the "mass defect", and when calculated in energy is known as the "binding energy" of the nucleus.

CHAPTER IV

NATURAL RADIOACTIVITY

Radioactivity is the property possessed by many elements, in which a spontaneous degeneration of the nucleus takes place. This degeneration is the result of the emission of three types of radiation, two of which are particles and the third being energy in the form of electromagnetic waves. The reason for this emission is instability of the radioactive atoms. That is, they are freak atoms, but are able to correct themselves by getting rid of particles or energy within their nuclei.

Some of the properties of these radiations have been observed by placing a small amount of the radioactive material at the bottom of a slit in a lead block and subjecting the radiations to a strong magnetic field.

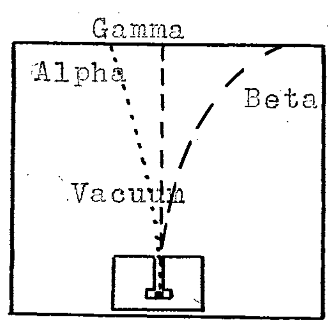

Figure 4

Radiations. In figure 4, a diagram of such an apparatus is shown, with the magnetic field perpendicular to the plane of the paper and directed inward. A photographic plate is placed some distance from the opening in the block and left for a time after the whole apparatus evacuated. Then if the plate is developed, three distinct spots are observed, one being directly in front of the opening, one slightly to the left and the third considerably displaced to the right. If the experiment is repeated, but with the field directed outward the distance between the spots that are deviated are switched with the one on the left being farther from the central image and the right one closer, with the central image being unchanged. Knowledge of the action of charged particles moving in a magnetic field tells us that two of the radiations are charged oppositely, one being positively charged and the other negatively. The third being uneffected tells us it is electrically neutral. The distances the two charged particles were deviated give a clue to their masses and charges.

These radiations have received the names alpha, beta and gamma rays, with the alpha particle having the positive charge and beta the negative charge. This leaves the gamma ray as the neutral radiation.

Experiments have shown the alpha particle as having twice the charge of the electron and the same mass as that of the helium nucleus. This latter property is verified by the fact that if alpa particles are captured in an evacuated glass container and an electric spark is sent through them they will emit spectral lines coinciding with those of helium.

The beta particles were found to have the same mass and charge as the electron, therefore they are thought of as high speed electrons with velocities approaching that of light. Since the nucleus does not contain electrons, by the theories on the structure of the atom, one thought is that they are not present until emitted and they are born from the transition of a neutron to a proton.

As stated before, gamma rays are not particles, but are thought of as energy in the form of electromagnetic waves or photons emitted by an excited nucleus which permits this nucleus to go to its lowest energy state from a higher one. To illustrate this, a radioactive nucleus may emit an alpha or beta particle but if it is not at its

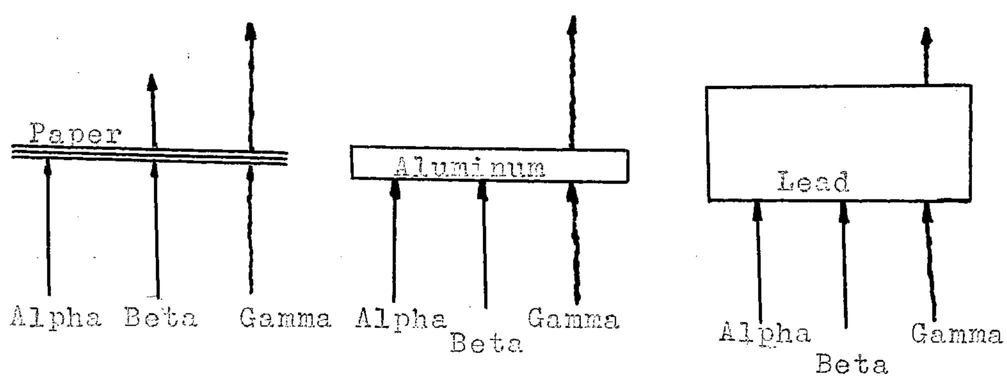

Figure 5

lowest energy level then photons can be emitted until this ground energy or lowest energy is reached.

Penetrating power of radiations. The penetrating power of the three different radiations varies considerably. As shown in figure 5, alpha radiation is usually absorbed by a few sheets of paper where as beta and gamma rays penetrate without much absorption. While beta particles are absorbed by a few millimeters of aluminum, gamma rays may penetrate a thickness of several centimeters. Even a few centimeters of lead will not completely absorb the gamma radiation but will absorb a large portion of it as the figure shows. This difference in penetrating power has many applications in industry, one being the checking of thicknesses and for deformations in materials.

Nuclear Reaction Equations. As stated previously, when a nucleus emits radiations it degenerates or more commonly "decays" into another nucleus that is more stable. The nucleus that emits the radiation is called the "parent" and the decay product is the "daughter". Thus when a parent element such as radium of mass 226 and atomic number 88 emits an alpha particle the product is radon with mass 222 and atomic number 86, with radium being the parent and radon the daughter. This decay is represented by nuclear reaction equations similar to chemical equations. The above reaction or decay would be represented by

$$_{88}Ra^{226} \longrightarrow {}_{86}Rn^{222} + {}_{2}He^{4}$$

with the superscripts representing the mass numbers and subscripts the atomic numbers. The alpha particle is represented by $_2He^4$ since it has the same mass as helium and a positive charge of 2 which is the atomic number. The emission of a beta particle is represented as

$$_{89}Ac^{227} \longrightarrow {}_{90}Th^{227} + {}_{-1}e^0.$$

Here an isotope of actinium emits a beta particle, represented by $_{-1}e^0$ where the mass is 0 and charge is a negative 1, to produce an isotope of thorium. Study of the equations shows that the mass number before decay is equal to the sum of the mass numbers of the products after decay. The same is true for the atomic numbers or subscripts.

Half-life. Early in the history of radioactivity it was discovered that the activity of radioisotopes diminished with time at a rate characteristic for each isotope. The time required for an isotope to lose one-half of its activity is called its "half-life", and this half-life is a unique property of that radioisotope. It cannot be changed by pressure, temperature, chemical states or any physical environment the isotope might be subjected to.

The unit of measure of radioactivity was named after the discoverer of the activity, Madame Curie. One "Curie" is an activity of 3.7×10^{10} disintegrations per second, usually represented by 3.7×10^{10} d/s. Since this is a high measure, the millicurie and microcurie were developed with the magnitude of .001 curie and 10^{-6} curie respectively.

Half-life periods vary greatly. The table below gives an idea of the wide range of half-life periods in a few radioisotopes.

Table I

At. No.	Element	Mass	Half-life	
90	Thorium	232	1.39×10^{10}	years
19	Potassium	40	18.3×10^{8}	"
88	Radium	226	1620	"
6	Carbon	14	5580	"
1	Hydrogen	3	12.5	"
86	Radon	222	3.82	days
85	Astatine	218	2	seconds
84	Thorium C'	212	3×10^{-7}	seconds

Almost all of the naturally radioactive elements lie in a range of atomic numbers from 81 to 92. Careful study of these elements has shown that they can be grouped into three series known as the thorium, uranium-radium and actinium series. The transuranic elements fall into another series called the neptunium series.

The mass numbers of every isotope in the thorium series are either identical or whole multiples of 4. Thus it is called the 4 n series. As an example the mass numbers of a few elements are: Th, 232, Th X,224, Th C,212, and Th C",208 all divisible by 4. Likewise the uranium-radium series is called the (4n ≁ 2) series, actinium the (4n ≁ 3) series. All of the series have some common properties. They all possess a single long lived isotope, a single gaseous isotope, and the end product of all three are stable isotopes of lead.

Transmutations. Alchemist for centuries had tried to produce gold from other metals but had come to the conclusion that it was impossible to produce one element from another. However, with the discovery of radioactive transformations, this theory was proven wrong. The first artificial transmutation was produced by Rutherford in 1919, when he bombarded nitrogen with alpha particles. Some of the nitrogen was converted to oxygen given by the equation

$${}_7N^{14} + {}_2He^4 \longrightarrow {}_8O^{17} + {}_1H^1$$

where ${}_1H^1$ represents a proton.

It was 1934 before a radioactive isotope was produced. This was by the Joliots', when they bombarded an isotope of aluminum with alpha particles and produced an unstable phosphorus isotope and a neutron. This reaction is represented by the equation

$${}_{13}Al^{27} + {}_2He^4 \longrightarrow {}_{15}P^{30} + {}_0n^1.$$

The phosphorus then decays, by emitting a positron, to a stable isotope of silicon represented by

$${}_{15}P^{30} \longrightarrow {}_{14}Si^{30} + {}_1e^0.$$

Since that time over 1000 such species of radioisotopes have been produced. Many of which have become very useful in medicine, agriculture and industry.

There are several types of nuclear reactions. Bombardments of elements by photons, deuterons which are neutron-proton systems, neutrons, protons, alpha particles, beta particles, and gamma rays, produce many various reactions. Even for a single target nucleus and a single bombarding particle, several different reactions may take place. When an isotope of copper, ${}_{29}Cu^{63}$, is bombarded with deuterons, the following reactions[1] may take place:

$$
\begin{aligned}
{}_{29}Cu^{63} + {}_{1}H^{2} &\rightarrow {}_{30}Zn^{64} + {}_{0}n^{1} \\
&\rightarrow {}_{30}Zn^{63} + 2\,{}_{0}n^{1} \\
&\rightarrow {}_{29}Cu^{64} + {}_{1}H^{1} \\
&\rightarrow {}_{29}Cu^{63} + {}_{1}H^{2} \\
&\rightarrow {}_{29}Cu^{62} + {}_{1}H^{3} \\
&\rightarrow {}_{28}Ni^{61} + {}_{2}He^{4}
\end{aligned}
$$

with the first and third reactions occuring most frequently.

The equipment necessary for producing high energy particles for different nuclear reactions are tremendous. Engineers and physicists are continuously searching for particle accelerators for bombarding purposes. Those now in use include the Van de Graaff generator, betatron, cyclotron, synchrocyclotron, proton cyclotron, betatron synchroton, cosmotron and linear accelerators.

Because the individual reactions taking place cannot be observed directly, due to the very minute size of the particles and radiations envolved, means of observation have been devised, utilizing the effects these particles have upon gases. The Wilson cloud chamber is one of the most widely used of these instruments. Although the types

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[1] Lapp, p. 285.

used in research are very complex instruments, the principle of the chamber is very simple. In the chapter on demonstrations and experiments, directions are given for constructing a simple, useable cloud chamber, along with the explanation of the principles envolved in this apparatus.

CHAPTER V

NUCLEAR FISSION AND REACTOR PHYSICS

<u>Fission</u>. Shortly after the discovery of the neutron it was found by Fermi, that mass and therefore, energy could be released by splitting up heavy elements to form components whose mass number lies in the middle of the mass number scale. This process is called fission.

The process of splitting a nucleus was explained as being similar to a spherical drop of liquid that was excited by application of energy. This drop would start oscillating and become an ellipsoid and if the energy was great enough the drop would form a dumbell shape and then pull apart.

The energy necessary to split the nucleus would come from the absorption of a neutron or gamma radiation. Fission could be brought about by fast or slow neutrons, but only a very few elements could be split with the latter. In 1939, Bohr and Wheeler in their paper, "The Mechanisms of Nuclear Fission", traced the fission of uranium by slow neutrons to U^{235} rather than the heavier isotope U^{238}.

It was found that the slow neutron would cause the U^{235} nucleus to split into two parts called fragments or fission products. This splitting of one unstable nucleus into two stable nuclei resulted in the releasing of energy, which came from rearranging the nucleons into stable nuclei. An example of the release of energy can be shown with this reaction equation,

$${}_0n^1 + {}_{92}U^{235} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q,$$

where Q represents the amount of energy released.

If the masses of the products are computed to the nearest ten thousands of an atomic mass unit a loss of .2154amu is found. This amount of mass converted to energy is found to be 200 Mev. This much energy is millions of times the amount acquired if combustion took place. This then, is a process in which mass is converted to energy as Einsteins equation, $E = mc^2$ tells us is possible.

Besides the two large fragments and energy released, it was found that from one to three neutrons were also emitted. This gave physicists an insight into what is now termed "nuclear chain reactions". To produce a continuous series of nuclear reactions the fission neutrons would have to be conserved so that out of every 2 or 3 emitted one would produce another fission.

<u>Nuclear</u> <u>Reactors</u>. There are two basic types of chain reactions, controlled and uncontrolled. The controlled chain reactions take place in nuclear reactors. Nuclear reactors are systems in which non-fissionable and fissionable materials are so arranged that the reactions can be controlled. An example of the uncontrolled reaction would be the atomic bomb, which will be discussed later.

The essential problem in attaining a nuclear chain reaction is one of neutron economy; that is to conserve as many neutrons as possible for further reactions. This, theoretically seems simple but under actual conditions it may not be. Such factors as capture of neutrons by impurities and escape from the surface of the material by neutrons all present limiting factors in the conservation of neutrons.

A chain reaction can do one of three things. It can progress at a steady rate, it can speed up, or it can die down. Which it does, depends upon the number of neutrons emitted from the fission material, and the number that is conserved for other fissions. As stated before, if one neutron out of the 2 or 3 emitted, is conserved for another fission then a steady rate is maintained, but if less than one is available the chain reaction would cease. A conservation of more than one neutron per fission would produce a multiplication of the reactions. This multiplication factor is very important in the construction of reactors. It is defined as the ratio of the production of neutrons, P_n, to the sum of the rates of absorption, A, and leakage, L, written

$$k = \frac{Pn}{A + L}.$$

When k = 1 a steady rate is maintained, and if k is less or greater than 1 then the reaction is decreased or increased respectively.

Because of the many fissions taking place within the reactor, it is a source of energy, neutrons and radioisotopes. Various types of reactors are built depending on which of these products are wanted. In the fission of one Kilogram of material with mass number of 235, 23 x 10^6 Kw-hr. of energy can be produced. Neutrons with wide energy ranges are present and isotopes that are produced consist of Pu^{239} from U^{238}, C^{14} from N^{14} and U^{233} from Th^{232} and many others.

Reactors can be placed in three general categories, depending upon the speed of neutrons involved. They are (1) thermal reactors, using low energy neutrons, (2) resonance reactors with intermediate speed neutrons, and (3) fast reactors with very high speed neutrons. Only thermal reactors will be discussed, for this type is much more applicable and common than the others.

Two basic types of thermal reactors are homogeneous and heterogeneous. The former consists of a mixture of the fissionable material and a liquid substance known as a "moderator", which is a material placed in the reactor to slow down the high speed neutrons produced in the fissions, to a slow enough velocity for utilization in the thermal reactor. A common type of homogeneous reactor consists of a solution of uranyl nitrate in water, with the uranium enriched with the lighter isotope by as much as 1 part of U^{235} to 6 parts of U^{238}, as compared to natural uranium where the ratio is 1 to 140.[1]

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[1]Henry Semant, Introduction to Atomic and Nuclear Physics, (New York, 1954) p. 446.

Most reactors, especially the large ones, are of the heterogeneous type in which the fissionable material is placed in containers scattered throughout the moderator. In many cases these containers are spaced in a lattice work in graphite, which serves as the moderator. This type of reactor is a large structure with many layers of the moderator and fissionable material and is called a nuclear pile. Heavy water, which is very effective in slowing down the fast neutrons, is being used as the moderator in some reactors, with the fuel immersed in the water.

Some nuclear reactors, besides producing useful power and energy also produces another fissionable material that can be used as fuel in the reactor. These are called "breeder" reactors. One example is the use of natural uranium to produce plutonium, P^{239}, which is fissionable by both slow and fast neutrons. Another reactor using ordinary water as the moderator is called a "swimming pool reactor". In this, the fuel is lowered into the water, the same as in the heavy water reactor.

In all types of the heterogeneous reactors the fuel must be canned or placed in metal containers to prevent the "coolant" from being severely contaminated. The coolant is a gas or liquid circulated through the reactor to keep the pile from becoming too hot from the tremendous amounts of heat liberated from the fissions. This coolant is then run through a "heat exchanger" where heat is removed and can be used by steam turbines to produce power for driving other machinery.

The power level of a reactor, which is the rate at which energy is being produced, is proportional to the number of fissions taking place per unit of time and this in turn is proportional to the number of neutrons in the reactor. Therefore by controlling the number of neutrons the power level of the reactor is controlled. This is done by inserting into the reactor, through slots, steel rods containing cadmium and boron, which absorb many of the neutrons. These controlling rods adjust the rate of fission by being pulled out or pushed in. To start a pile reaction, the controlling rods are gradually pulled out until the level wanted is reached.

For protection of workers from radiations large shielding devices are necessary in the construction of nuclear reactors. These consist of very thick concrete walls, thick layers of lead, iron, wood and steel.

Fuels for the reactors are varied, but the following are a few of the different fuels used in reactors now in operation; Th^{232}, U^{233}, U^{235}, U^{238}, and Pu^{239}. From these fuels come many waste products that are very dangerously radioactive. This has created a grave problem for physicists to determine what can be done with them. Some are used in industry, medicine, and agriculture, but many others are useless and must be placed in a region where they will not endanger human life.

<u>Uncontrolled</u> <u>Nuclear</u> <u>Chain</u> <u>Reactions</u>. As mentioned

before, the atomic bomb is an example of uncontrolled nuclear chain reactions. Since so much energy is released per fission of U^{235}, if enough fissions could be produced in a very short time, a powerful explosion would result. The energy released by the complete fission of one kilogram of U^{235} would be equivalent to that produced by about 18,700 tons of TNT. If properly arranged the fission of one kilogram of the uranium can take place in 0.4 microseconds. This amount of energy released in such a short time would be a tremendous explosion.

In order to initiate such a chain reaction the uniting of two "subcritical masses" into one "overcritical mass" in a very short time must be accomplished. The critical mass of a fissionable material is that size in which the number of neutrons lost from the surface is equal to those

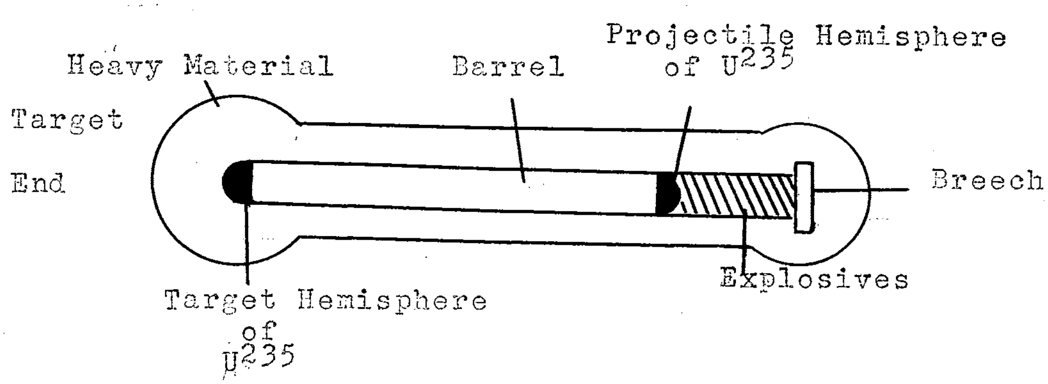

Figure 6

produced. Therefore a subcritical mass is one in which the number lost is more than number produced which would not result in a continued reaction. In an overcritical mass the number produced would exceed the number lost, therefore a multiplication of the chain reaction would occur.

Besides assembling the components into an overcritical mass, the mass must be kept at an overcritical state long enough for the reaction to proceed with efficiency before the tremendous temperatures and pressure created by the fissions blow the fissionable material into a subcritical state.

One way to assemble such an apparatus is shown diagramatically in figure 6, showing two hemispheres of U^{235} placed at separate ends of the gun barrel with the target and being embedded in a large mass of heavy material. The other mass of U^{235} is the projectile which can be hurled at the target by ordinary explosives that could be exploded with the breech. The projectile would then weld itself onto the target and form an overcritical mass. Cosmic radiation or other neutron sources could initiate the fission reaction. The inertia of the momentum of the projectile would be sufficient to allow the chain reaction to proceed with enough efficiency to produce the explosion before the overcritical mass was separated.

<u>Nuclear</u> <u>Fusion</u>. Another type of nuclear reaction is the process of fusion, in which light nuclei unite to form a heavier nucleus and during this process energy is released. This is the basis for the hydrogen bomb which is classified

as a thermonuclear weapon, so named because of the need of tremendous temperatures to set off the fusion process. A reaction similar to the one which takes place in the hydrogen bomb detonation could be represented as:

$$H^2 \neq H^3 \longrightarrow He^3 \neq 2n^1 \neq 10.6 \text{ Mev.}$$

With 10.6 Mev of energy released per fusion one can readily see the reason for the devastating power of thermonuclear reactions.

Not only destruction results from nuclear fusion, but our very existence depends upon nuclear fusion. The fundamental source of the universe's energy, the sun, utilizes this process. It had long been a question of just how the sun could liberate the great amounts of energy that it does and yet retain its high temperature. Nuclear fusion seemed to be the answer. The process by which this fusion can take place is made possible by the high temperature inside the sun, estimated to be 14 to 20 million degrees centigrade.[1]

Radioactivity Dangers. Although much has been and more will be accomplished from nuclear reactions, it is a dangerous process. During these nuclear reactions radioactive isotopes are continually being created. They are responsible for the radiation of the particles that are dangerous to living organisms near the isotopes. With the detonation of nuclear bomb great clouds of the radioisotopes are thrust

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[1]Frank M. Durbin, Introduction to Physics (New Jersey, 1955), pp. 713.

miles into the air and left free to drift toward and settle over populated areas. One of the most dreaded of these "fallout particles" is the strontium 90 isotope, which like calcium, is utilized by plants for food. It collects in the leaves of the plants and waits to be eaten by an animal. This animal in turn may be eaten by humans and thus the radioactive strontium finds itself within the human tissues where it can do much destruction by emitting the fast moving radiations that destroy the cells of the tissues.

Unfortunately the symptoms of over exposure to radioactivity are slow in revealing themselves, thus a lethal dose can be obtained before a person even knows he has been in contact with it. Some of the more noticeable effects of over exposure include, loss of hair, destruction and death of bones, decrease in number of white blood cells, sterility, altered heredity offsprings, cancer and cataracts on the eye.

Although the dangers are great, there have been surprisingly few accidents envolving these isotopes. This is primarily due to the work of radiation health organizations and safety precautions.

The amount of radiation that a person can safely be exposed to is 0.3 roentgens per week. We are continually exposed to small amounts of background radiation from cosmic rays and the relatively small amounts of radioisotopes in the surroundings.

A useful piece of equipment used in checking the amount of radiation present is the Geiger-Mueller counter commonly called the Geiger counter. This instrument will be discussed in the following chapter and instructions on how to build a simple one for classroom use will be given.

Time will not permit a discussion of the applications of nuclear physics, but included in the bibliography are references on this topic.

CHAPTER VI

DEMONSTRATION AND EXPERIMENTS

Nuclear and Atomic Physics, along with any other scientific subject, can be taught much more effectively by visual means, rather than by verbal means only. Nothing can replace experiences as teaching methods. Included within this chapter are a number of experiments and demonstrations that can be carried out in the high school physics class. They vary in difficulty, but all are at a level that any average physics class can do if the needed equipment is available.

The only expensive equipment needed is the Geiger-Muller count rate meter often called the Geiger counter. There are instructions on how to build a simple and inexpensive one, but one is needed in many cases to record counts which the homemade one will not do.

For this chapter the author relied heavily on a booklet, put out by the Atomic Energy Commission, entitled, "Laboratory Experiments with Radioisotopes", edited by Samuel Schenberg. It can be obtained from "Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

The following were taken from this booklet: Intermittent Cloud Chamber, Half Life, Effect of Magnetic Field upon

Beta and Gamma Radiation, Inverse Square Law, Absorption of Gamma Radiation, and Absorption of Beta Radiation.

This chapter is far from exhausting the number of experiments and demonstrations available to the teacher, but it is a group of the more important ones in the author's opinion.

<u>Demonstration of the Stability of Thomson's Model of the Atom</u>. Thomson, in the development of his atom model felt that his structure gave a stable atom. The basis for this can be shown by the following demonstration.

<u>Materials</u>. Circular battery or crystallizing jar with 30 turns of no. 18-20 wire; 6 volt storage battery; 6-ohm rheostat; small corks; steel sewing needles and a bar magnet.

<u>Method</u>. Arrange the rheostat, battery and jar as in the figure below. Fill the jar about 3/4 full of water and connect the circuit. Then with the needles stuck through the center of the corks so they will float upright, stroke

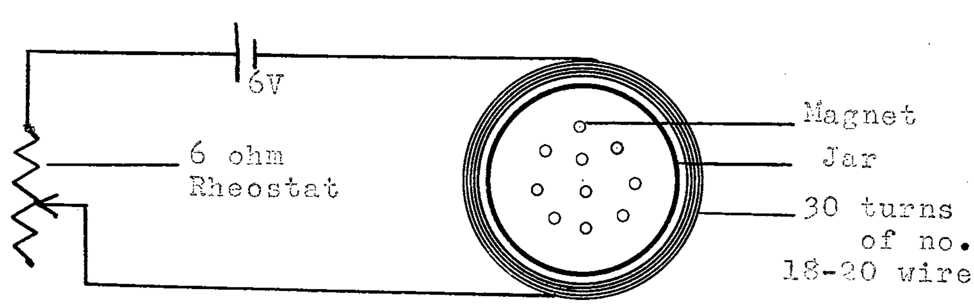

Figure 7

the needles with the magnet and place in the water one at a time.

Observe and record by drawings the position of each floating magnet.

Discussion. The results show the stability of the small magnets within a circular magnetic field. It also shows the stability of the 2 and 8 particles in orbits around the center.

The circular magnetic field is stronger in the center of the field; thus pulling the magnets as near to the center as possible. With addition of more magnets repulsion forces them into the various orders and arrangements.

An interesting effect is noticed when the field is strengthened and weakened.

A HOME MADE GEIGER COUNTER

The simple homemade Geiger Counter diagrammed on the next page brings the possibility of individual laboratory work with radioactive materials within the scope of the science classroom. The counter circuit is actually much simpler than the usual radio circuit. It is made with standard and easily obtainable radio parts and can be built on a breadboard in a short time. It operates on 115 volt A.C. line. Its circuit uses a voltage doubler which provides just over 300 volts. Be sure to get a 300 volt Geiger tube. Two suppliers of these tubes are: Electronic Products Inc., III E. 3rd St., Mount Vernon, N.Y., and Victoreen Instrument Company, 3800 Perkins Avenue, Cleveland, Ohio.

PARTS LIST TO GEIGER COUNTER

1-pair headphones

1-STANCOR Transformer Type Ps8415 or equivalent (T_1)

1-6AL5 Vacuum Tube (V_1)

1-7 pin miniature tube socket

1-1 to 6 megohm resistor, 1/2 watt (R_1)

1-0.0002 mfd, 400 volt capacitor (C_3)

2-0.1 mfd - 150 volt capacitors (C_1 and C_2)

1-300 volt Geiger Tube (Electronic Products Inc., type 30-G or Victoreen Instrument Co. Type 1B86)

CIRCUIT DIAGRAM FOR

HOMEMADE GEIGER COUNTER[1]

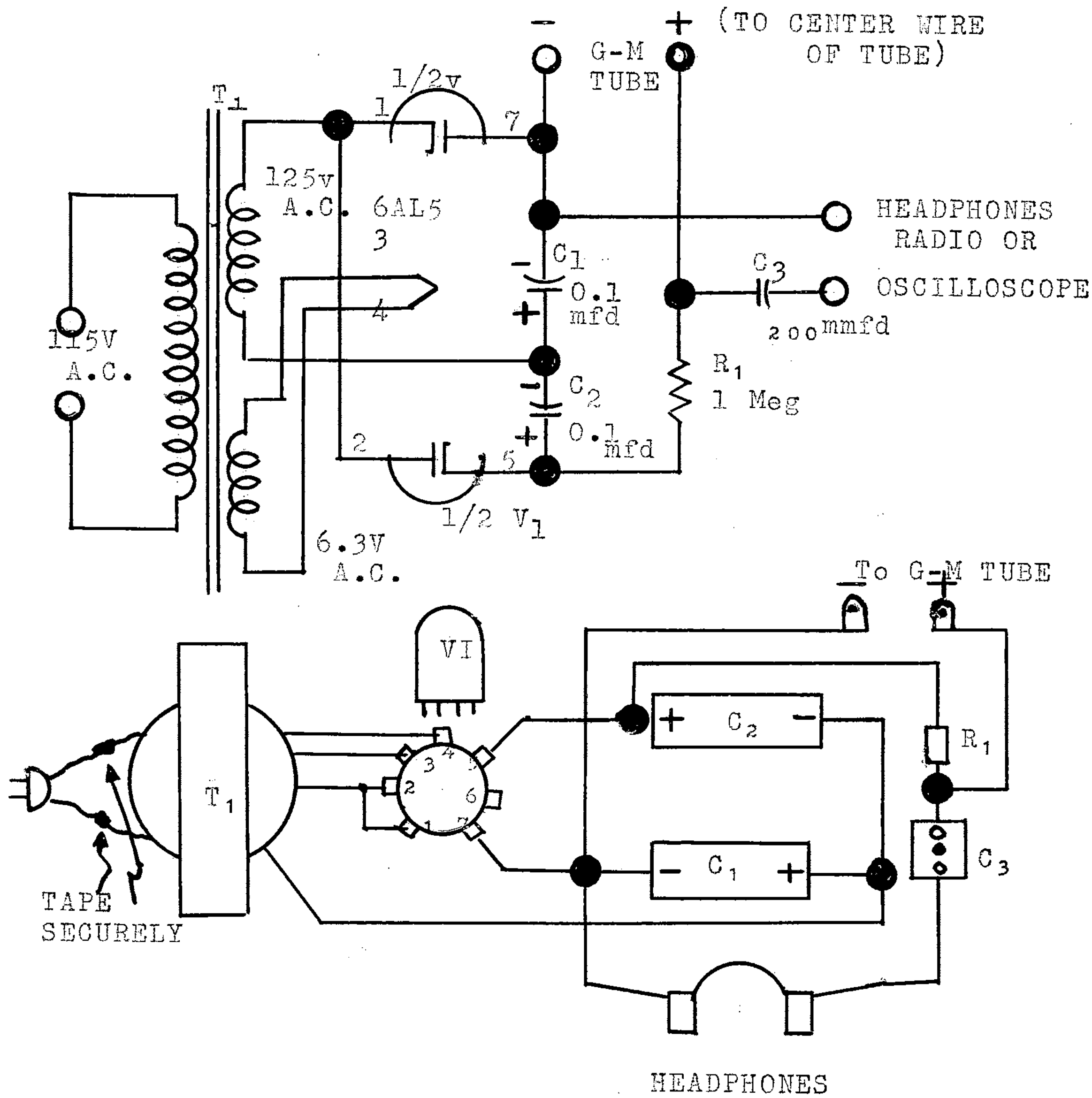

Figure 8

[1]Government Printing Office, Washington, D.C.

Intermittent Cloud Chamber

Purpose. To set up a simple cloud chamber in which ionization tracks may be observed.

Materials. Alpha ray tip; 250-ml "soft-glass" Ehrlenmeyer flask; two 1/8-inch pipe nipples, $2\frac{1}{2}$-inches long; two #6 one-hole stoppers; hose clamp; 10-inch length of pressure hose; hydrometer bulb two 45-volt B batteries; $1\frac{1}{2}$-inch brass machine screw; two burette clamps; wire; ringstand; Sealstik or Dekhotinsky cement.

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

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

3. Using the sealing cement, which can be handled like sealing wax, seal the wire lead and the screw into their respective holes, as shown in the Figure 9. Allow about 3/4 of an inch of the screw to protrude into the flask.

4. Fill the flask with about 230 ml of water to which

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

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

6. Attach the 90 volt-sweeping field as shown in the diagram.

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

<u>Discussion</u>. When air saturated with water vapor is compressed it evolves heat. If the heat is allowed to escape and then the air is suddenly decompressed, the temperature drops and precipitation occurs if there are nuclei of condensation present. Ions in air are excellent nuclei on which condensation forms. At the moment of decompression, droplets of condensation appear only around ions produced as the alpha particles ionize atoms of air along their paths. These vapor trails or tracks are clearly visible immediately after decompression. They will be seen to radiate from the alpha

ray tip and will indicate the path of the radiation. In the cloud chamber, ions are swept out of the air by means of the 90-volt battery. When the tracks disappear the experiment may be repeated.

DIAGRAM FOR INTERMITTANT
CLOUD CHAMBER

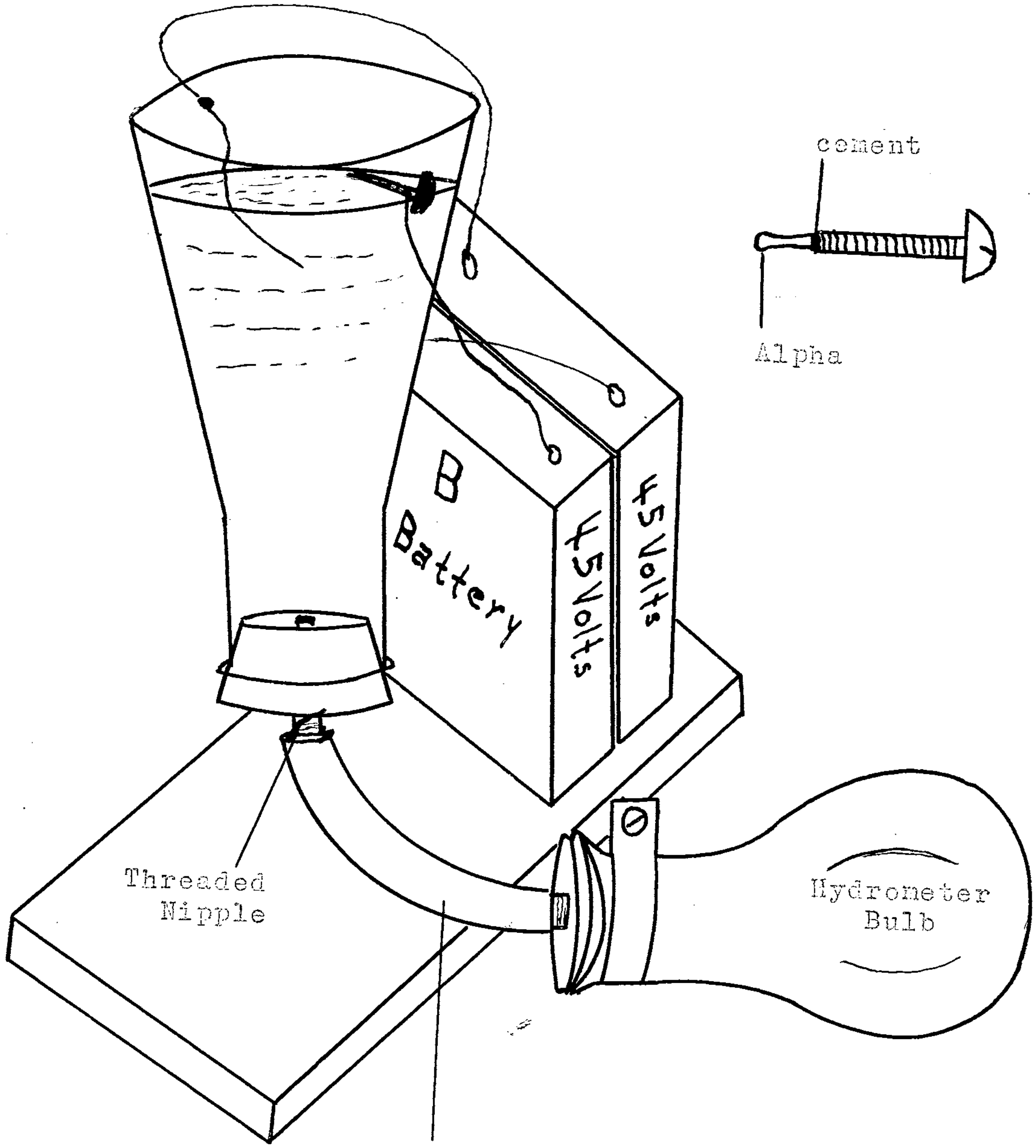

Figure 9

Half Life

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

Materials. A vial of about 10 microcuries of I^{131} (as potassium iodide) solution; count-rate meter; a rack or holder upon which the vial and the G-M tube may be placed for repeated tests so that the relative geometry between the two and the immediate surroundings may be kept as constant as possible.

Method. 1. Switch on the meter and allow it to warm up. Adjust it to the operating voltage of the tube.

2. Place the vial of I^{131}, containing about 10 microcurie activity, near enough to the tube to give a large deflection on the count meter. Since I^{131} is a gamma source, the beta shield on the G-M tube should be closed.

3. Observe and record the counts per minute. Also record the day and time of this observation.

4. Make similar observations at suitable intervals, such as each day over a period of a week, or, better, over a period of a few weeks. Use a similar table as shown below.

Table II RADIOACTIVE DECAY OF I^{131}

Date	Time	Days	Observed c/m	Background	Net cpm	Activity A
4-27	9:30pm	.0	650	25	625	1.0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
5.5	4:00am	7.27	360	20	340	.47
.	.	.	.	.	.	.

5. Draw a graph, plotting A (net counts per minute) as ordinate against time t in (days) as abscissa on semilog paper. Draw the most reasonable straight line through the plotted points, and determine the half life directly from the graph. Compare this with the published value (8.08 Days) for I^{131}.

Effect of a Magnetic Field Upon Beta and Gamma Radiation

Purpose. To demonstrate that beta particles from a radioactive source are deflected by a magnetic field, that the angle of deflection in the same field depends upon the energy of the beta particles, and that gamma radiation is unaffected by a magnetic field.

Materials. Count rate meter; 1/32-inch lead foil; strong Alnico magnet; 10 microcuries each of P^{32}(a beta source), Tl^{204}(a beta source), I^{131}(a gamma source) in 2 ml of water; three 100 ml beakers or wide-mouth bottles.

Method. 1. Place each radioactive solution in a separate beaker and wrap with a sheet of lead foil. Adjust the shield on the Geiger probe so that there is an 0.5-cm slit exposing the Geiger tube. Wrap lead foil around each end of the probe so that the slit is near the middle of the Geiger tube and is reduced to 2.5 cm in length or slightly less than the distance between the magnetic poles. With some convenient support, mount the Geiger tube in a horizontal position about 15 cm from the bench top, with the slip facing downward. Cover the beaker containing the P^{32} with lead foil having an opening the same size as the slit on the probe. Place the beaker directly beneath the probe with the two slits parallel.

2. Record the counting rate.

3. Position the Alnico magnet so that the magnetic field is perpendicular to the path of the beta radiation

and parallel to the two slits.

4. Record the counting rate.

5. Keep the probe parallel to and at the same distance from the slit on the beaker and move it slowly through a 90^{o} arc on each side of the magnetic poles. Rotate the probe as it is moved so that its opening faces the radiation front.

6. Record the approximate angle of deflection where the count rate is greatest.

7. Remove the magnet and record the counting rate.

8. Reverse the magnetic poles and again note the angle of deflection where the count rate is greatest.

9. Repeat the experiment using Tl^{204}.

10. Close the shield on the Geiger tube and repeat the experiment using I^{131}.

Results. The addition of a magnetic field in the path of beta radiation causes a change in the direction of the rays so that they follow an arc-shaped path. The experiment shows that beta particles are deflected by a force acting perpendicularly to the magnetic field. The direction of deflection depends on the direction of the magnetic field; has no effect on the gamma rays from I^{131}.

Discussion. The direction in which the rays from P^{32} are deflected relative to the absolute direction of the magnetic field, establishes the fact that they consist of negatively charged particles. Beta rays are, in reality, highspeed electrons. The gamma radiation from I^{131} is unaffected by the magnetic field because it is electromagnetic radiation and has no charge.

If a strong Alnico magnet is used, the beta particles may be deflected 90° or more. This exemplifies the means used in a cyclotron to keep charged particles in a circular path. Two cylindrical Alnico V magnets, 1.5 x 18 cm, with opposite poles facing each other, about 1.5 cm apart, will produce an angular deflection of the beta rays from P^{32} in the vicinity of 20°. The use of an electromagnet in this experiment would provide the advantages of enabling the demonstrator to control the magnetic field by means of a switch.

To demonstrate that the angle of deflection also varies with the energy of the beta emitter, the experiment should be repeated using the Tl^{204}, a thallium isotope which emits low-energy beta particles. The energy of a beta particle refers to its kinetic energy or velocity. The deflection of the thallium beta will be at a greater angle (a smaller radius of curvature) than that observed with the radiation from P^{32}, indicating that the radiation from Tl^{204} has a lower kinetic energy.

Before counting the solution containing the Tl^{204} should be evaporated to dryness to give a higher counting rate. Evaporation should be carried out without boiling, preferably under a heat lamp. A light spray of clear lacquer or plastic over the dry residue will prevent subsequent loss of the radioactive material either by accidental spillage or curious fingers. A solution of collodion is a cheap effective coating for a dried sample mount.

This experiment illustrates the principle of the beta-ray spectrometer where a magnetic field separates betas of different energies.

Inverse Square Law

Purpose. To show that the intensity of gamma radiation varies inversely with the square of the distance from the source.

Materials. Geiger counter; gamma-source button; stand for holding probe, with a movable shelf on which the gamma source is placed; ruler or markings denoting distances in centimeters on the stand.

Method. 1. Close the shield on the probe, which is attached to the stand in a horizontal position.

2. Place the gamma source on the shelf 4 cm below the probe.

3. Turn on the G-M counter and, after making the necessary adjustments, determine the counts per minute.

4. Lower the shelf with the gamma source to the 5-cm mark and determine the counts per minute.

5. Repeat step 4, lowering the shelf 1 cm at a time, Stop the experiment when the shelf stands at 17 cm.

6. Record distance and corresponding counts per minute.

7. Using d= 4 cm calculate $1/d^2$ for 4cm, 8 cm, 12cm, and 16cm, where 8 cm = 2d, 12cm = 3d and etc.

8. Calculate theoretical activity and compare with experiment results and plot activity vs. distance.

Results. Below is a sample of recorded data and calulations.

Sample Data and Recordings

Distance (cm)	Activity (c/m)	Distance (cm)	Activity (c/M)
4	32,000	11	4,000
5	20,000	12	3,500
6	10,500	13	3,000
7	8,000	14	2,500
8	7,000	15	2,250
9	6,000	16	2,000
10	4,500	17	1,800

Discussion. The inverse square law states that the intensity of radiation expressed in counts per minute is inversely proportional to the square of the distance from the radioactive source or $A \propto 1/d^2$. The following table shows how closely the actual measurements follow the law.

d (cm)	$1/d^2$	Theoretical activity (c/m)	Measured activity (c/m)
4 (d) - - - - - - - -	1	32,000	32,000
8 (2d) - - - - - - -	1/4	8,000	7,000
12 (3d) - - - - - - -	1/9	3,555	3,500
16 (4d) - - - - - - -	1/16	2,000	2,000

Absorption of Beta Radiation

Purpose. To demonstrate the manner in which aluminum and other materials absorb beta particles emitted by a radioactive isotope.

Materials. G-M tube and counter; a radioactive source such as P^{32} or uranyl nitrate; six to ten aluminum squares about 7.5 cm on a side, each weighing about 1 to 1.5 g; stand to hold probe, radioactive source, and aluminum squares (the stand should be equipped with two aluminum shelves 6 by 6 inches, one of which has a hole ½ inch in diameter in the center to act as a collimator); small watch glass.

Method. 1. Arrange apparatus as shown in figure 10.

2. Turn on the Geiger counter and determine the background count in counts per minute before inserting the radioactive source.

3. Place the collimator aluminum plate 2 cm below the probe.

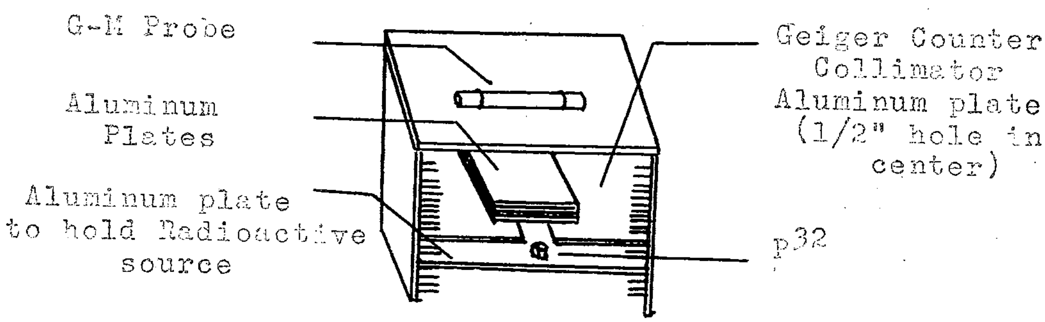

Figure 10

4. Place the radioactive source of an aluminum shelf 4 cm from the probe (with sleeve removed and directly under the hole in the collimator aluminum plate.

5. Take readings and record the average activity in counts per minute.

6. Insert aluminum plate one over the hole on the collimator aluminum plate and determine the average activity in counts per minute.

7. In succession, repeating the process in step 6 for each, add plates 2, 3, 4, 5, 6, and 7 to plate one.

8. Weigh the plates used and divide by the total area to obtain the thickness of each plate in terms of grams per square centimeter.

9. Plot the activity in counts per minute as ordinate, against the total absorber thickness in g/cm^2 as abscissa, on semilog paper. Determine the half-thickness directly from the curve.

10. Repeat using cardboard absorbers. Compare the half-thickness obtained with that for aluminum.

Discussion. Where greater accuracy is desired, it is necessary to take into account, and to add to the thicknesses of the aluminum plates, the thickness of the window in the probe, which is 30 mg/cm^2, and the thickness of the air, which is determined by multiplying the distance, in cm, of the air from the top plate to the probe by 1.3 mg/cc.

Absorption of Gamma Radiation

Purpose. To demonstrate absorption of gamma rays by lead plates.

Materials. A vial of I^{131} (as Potassium iodide) solution containing about 20 microcuries; count rate meter; lead plates, about one thirty-second of an inch thick and about 10 cm square; meterstick; suitable rack or other means for supporting the vial, the G-M tube, and the lead plates in proper relation to each other.

Method. 1. Measure the weight in grams and the area in square cm of each lead plate to determine the thickness in grams per square cm.

2. Switch on the count rate meter and allow it to warm up. Adjust it to the operating voltage of the G-M tube.

3. Cover the tube window with the metal sleeve. Observe and record the background in counts per minute.

4. Bring the vial of I^{131} near enough to the tube to give a count-per minute reading high on the scale. Record this reading.

5. Then observe and record the reading as each lead plate is placed between the radiation source and the G-M tube. The lead plates should be placed as near the G-M tube as possible.

6. Plot the activity corrected for background (i.e. the recorded readings minus the background reading) on semilog paper against the absorber thickness in gm/cm^2.

Determine the half thickness directly from the curve. Compare with published value.

A Demonstration Illustrating the Principle of the CYCLOTRON.

Purpose. To demonstrate how particles are effected by a magnetic field which is the principle of the cycloton.

Materials. Demonstration electromagnet; steel BB shot; ultraviolet fluorescing paint; ultraviolet light source; 19 inch glass tube with diameter of 4 mm.

Method. The magnetic field is supplied by the electromagnet mounted in a horizontal position. The core of the magnet was pulled out so as to extend about four inches. Then a glass is bent and mounted as in figure 11.

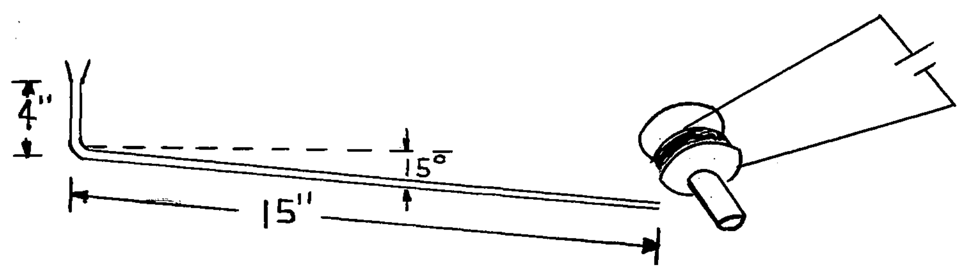

Figure 11

Steel BB shot are substituted for the atomic particles. Ultraviolet fluorescing paint is placed on the extended pole and on the BB shot. A source of ultraviolet light is shown upon the demonstration in order to illuminate the pole of the magnet. The use of the fluorescing paint and the light makes the demonstration unique in that an illusion of an atomic world is created.

In operation, the steel shot are dropped down the tube in rapid succession. Ordinarily, the steel shot would emerge from the tube and simply fall to the table. However in the presence of the electric field above the bubing causes the shot to take a nearly circular path about the core of the magnet.

The effect is enhanced by a totally darkened room in which nothing is seen but the light from the fluorescing core of the magnet and the moving fluorescing particles.

Differently sized particles, each size with a different color paint, can be used to show similar effects on particles of different masses.

The proper positioning of the glass tube is critical to the operation of the demonstration and can be determined only by experimentation.

CHAPTER VII

CONCLUSION

This report has only begun to cover the possibilities for Atomic and Nuclear studies in a high school physics course. Much material has been left untouched in this report due to lack of time.

A high school physics teacher is faced with the dilemma of having too much material to cover in too little time. The teacher must be careful to select those topics of classical physics that is necessary and yet have time for the newer advances, such as this report suggests. Different teachers and classes must spend more time on certain topics than others; therefore the individual teacher will have to carefully decide upon the time to be allotted for this phase of physics in the high school classes.

In particular instances where little or no time can be allotted for this study as a class, this field holds unlimited opportunities for projects for the brighter students. The experiments can be done by the students under close supervision of the teacher and then perhaps a report to the class will not only help the student in accomplishing the project but should create more interest among the other students.

Another possibility for this study is in science clubs.

A tremendous amount of science is learned before and after class hours. Interested students can carry out many of the demonstrations and experiments that are listed in this report.

For schools seeking another semester of advanced science this type of study could very easily be expanded for this purpose. The topics covered could be broadened and many more demonstrations and experiments could be included.

The author feels, because of the gigantic effect upon our future that Atomic and Nuclear Physics will have, the high schools must begin to educate the citizens and future leaders in this phase of science; not just to produce scientists, but to give the lawyers, doctors, housewives, factory- workers, salesmen, grocerymen and others some knowledge of this growing science that will mold their future.

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