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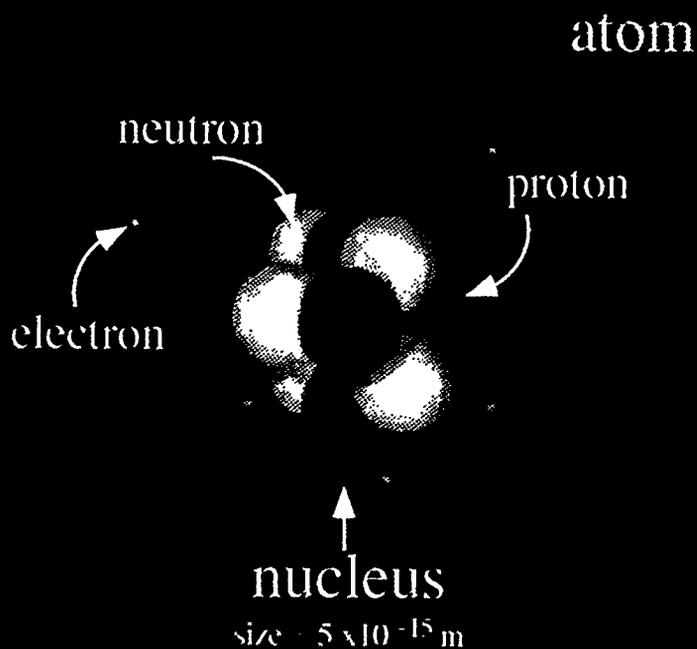
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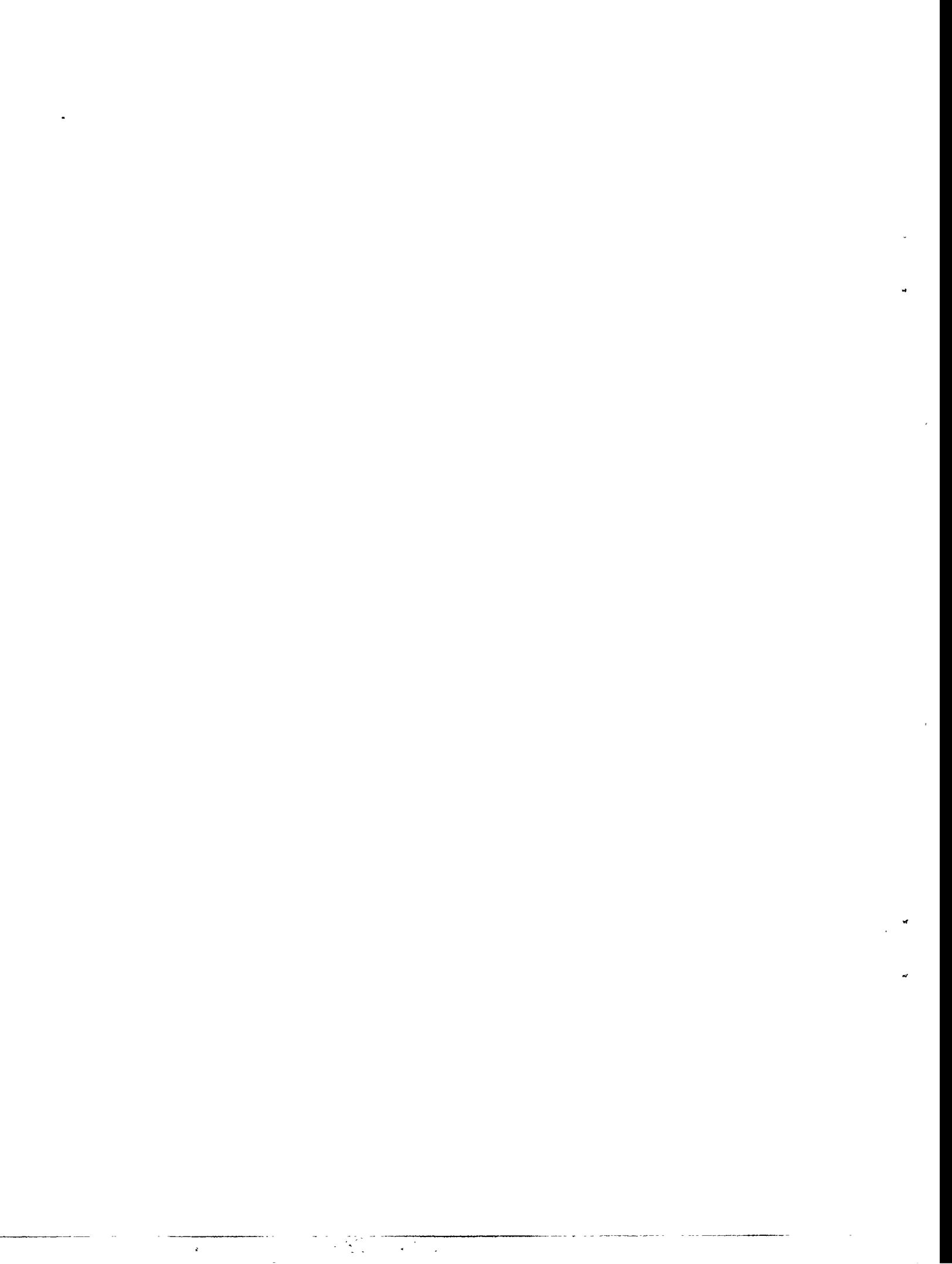
A, B, C's of NUCLEAR SCIENCE

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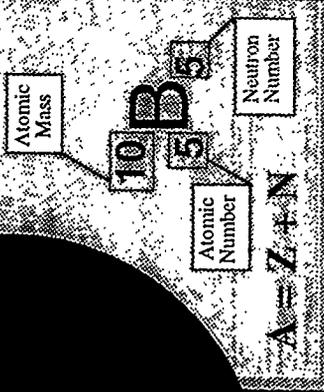
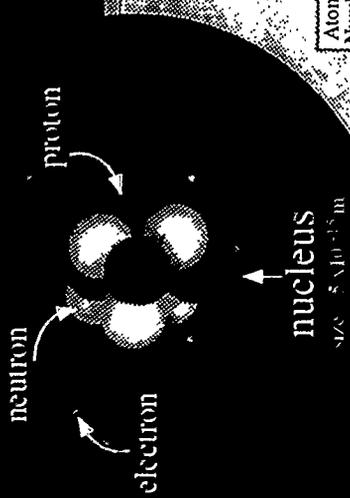


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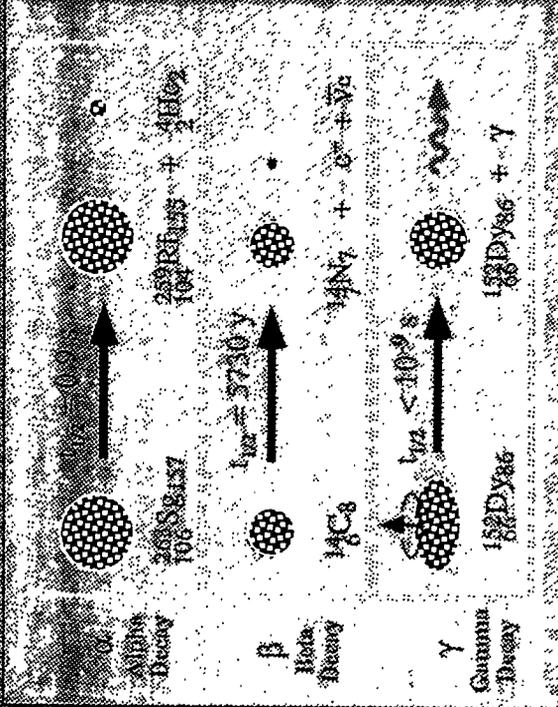
Nuclear Structure, Radioactivity, and Reactions

atom
size 10^{-10} m

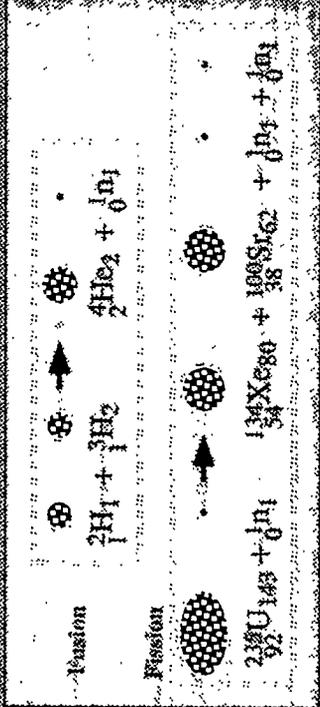


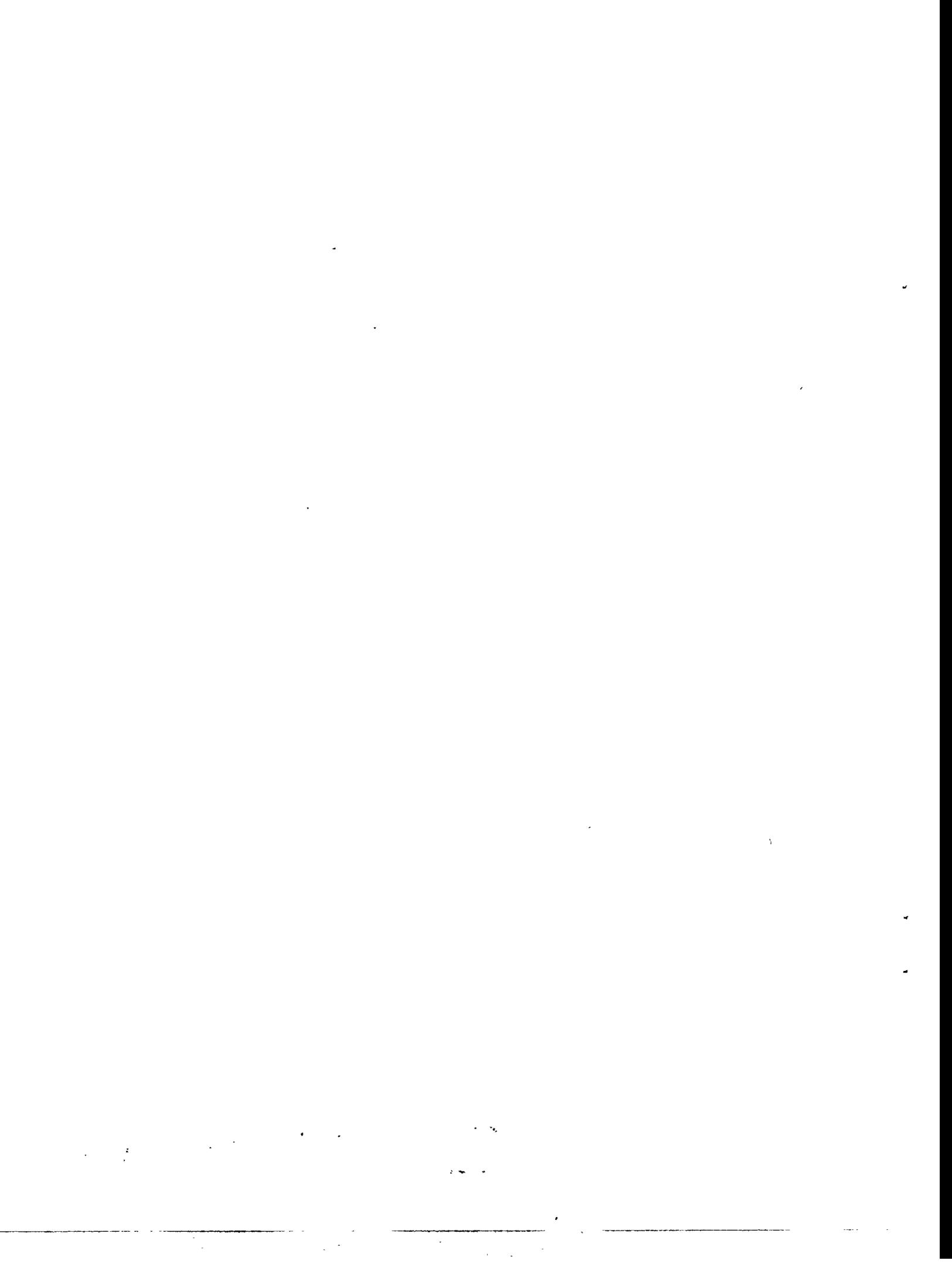
Particle	Mass MeV/c ²	Electric Charge	Spin
p proton	938	+1	1/2
n neutron	939	0	1/2
e ⁻ electron	0.511	-1	1/2
e ⁺ positron	0.511	+1	1/2
γ gamma	0	0	1
ν neutrino	0(?)	0	1/2
$\bar{\nu}$ antineutrino	0(?)	0	1/2

Radioactivity



Reactions





A, B, C's of Nuclear Science

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August 7, 1995

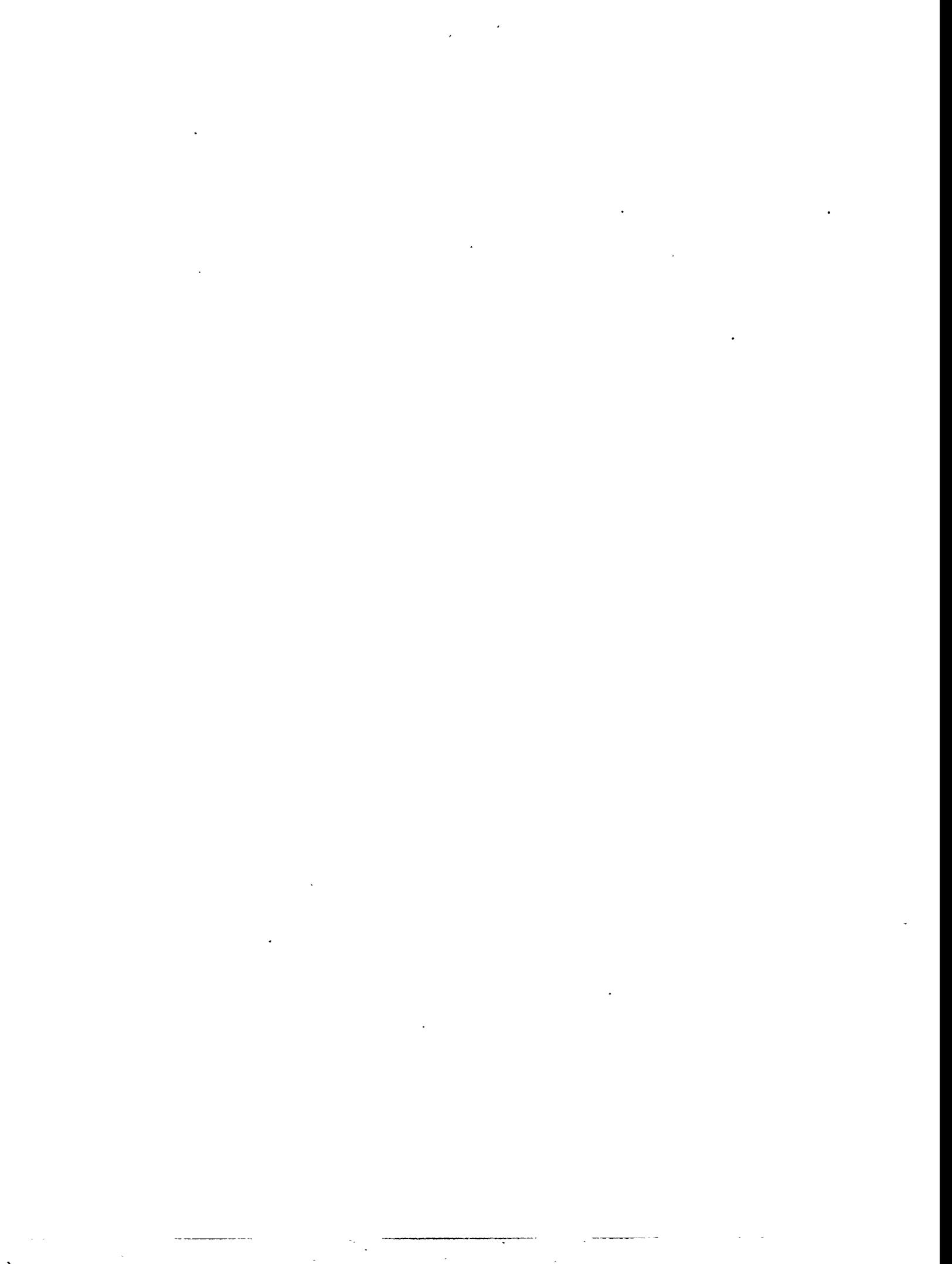
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A, B, C's of NUCLEAR SCIENCE

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ABC's of NUCLEAR SCIENCE

NUCLEAR STRUCTURE

An atom consists of an extremely small, positively charged nucleus surrounded by a cloud of negatively charged electrons. Although typically the nucleus is less than one thousandth the size of the atom, the nucleus contains more than 99.9% of the mass of the atom! Nuclei consist of positively charged protons and electrically neutral neutrons held together by the so-called strong or nuclear force. This force is much stronger than the familiar electrostatic force that binds the electrons to the nucleus, but its range is limited to distances on the order of a few $\times 10^{-15}$ meters.

The number of protons in the nucleus, Z , is called the **atomic number**. This determines what chemical element the atom is. The number of neutrons in the nucleus is denoted by N . The **atomic mass** of the nucleus, A , is equal to $Z + N$. A given element can have many different **isotopes**, which differ from one another by the number of neutrons contained in their nuclei. In a neutral atom, the number of electrons orbiting the nucleus equals the number of protons in the nucleus. Since the electric charges of the proton and electron are $+1$ and -1 (in units of the proton charge) the net charge of the atom is zero. At present, there are 111 known elements which range from the lightest, hydrogen, to the recently discovered and yet to-be-named element 111. All of the elements heavier than uranium are man made. Among the elements are approximately 270 stable isotopes, and more than 2000 unstable or radioactive isotopes.

RADIOACTIVITY

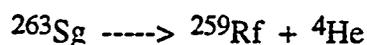
In 1896, Henri Becquerel was working with compounds containing the element uranium. To his surprise, he found that photographic plates covered to keep out light, became fogged, or partially exposed, when these uranium compounds were anywhere near the plates. This fogging suggested that some kind of ray had passed through the plate coverings. Several materials other than uranium were also found to emit these penetrating rays. Materials that emit this kind of radiation are said to be **radioactive** and to undergo radioactive decay.

In 1899, Ernest Rutherford discovered that uranium compounds produce three different kinds of radiation. He separated the radiations according to their penetrating ability and named them α (alpha), β (beta), and γ (gamma) radiation, after the first three letters of the Greek alphabet. The α radiation can be stopped by a sheet of paper. Rutherford later showed that an α particle is the nucleus of a He atom, ${}^4\text{He}$. Beta particles were later identified as high speed electrons. Six millimeters of aluminum are needed to stop most β particles. Several centimeters of lead are required to stop γ rays, which proved to be high energy photons. Alpha particles and γ rays are emitted with a specific energy that depends on the radioactive isotope. Beta particles, however, are emitted with a continuous range of energies from zero up to the maximum allowed for the particular isotope.

α Decay

The emission of an α particle, or ${}^4\text{He}$ nucleus, is a process called α decay. Since α particles contain protons and neutrons, they must come from the nucleus of an atom. The nucleus

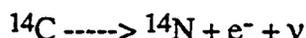
that results from α decay will have a mass and charge different from those of the original nucleus. A change in nuclear charge means that the element has been changed into a different element. Only through such radioactive decays or nuclear reactions can **transmutation**, the age-old dream of the alchemists, actually occur. The mass number, A , of an α particle is four, so the mass number, A , of the decaying nucleus is reduced by four. The atomic number, Z , of ${}^4\text{He}$ is two, and therefore the atomic number of the nucleus, the number of protons, is reduced by two. This can be written as an equation analogous to a chemical reaction. For example, for the decay of an isotope of the element seaborgium, ${}^{263}\text{Sg}$:



The atomic number of the nucleus changes from 106 to 104, giving rutherfordium, with an atomic mass of $263 - 4 = 259$. α decay typically occurs in heavy nuclei where the electrostatic repulsion between the protons in the nucleus is large. Energy is released in the process of α decay. Careful measurements show that the sum of the masses of the daughter nucleus and the α particle is a bit less than the mass of the parent isotope. Einstein's famous equation, $E = mc^2$, which says that mass is proportional to energy, explains this fact by saying that the mass that is lost in such a decay is converted into the kinetic energy carried away by the decay products.

β Decay

Beta particles are negatively-charged electrons emitted by the nucleus. Since the mass of an electron is a tiny fraction of an atomic mass unit, the mass of a nucleus that undergoes β decay is changed by only a tiny amount. The mass number is unchanged. The nucleus contains no electrons. Rather, β decay occurs when a neutron is changed to a proton within the nucleus. An unseen **neutrino**, ν , accompanies each β decay. The number of protons, and thus the atomic number, is increased by one. For example, the isotope ${}^{14}\text{C}$ is unstable and emits a β particle, becoming the stable isotope ${}^{14}\text{N}$:

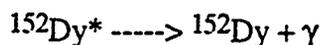


In a stable nucleus, the neutron does not decay. A free neutron, or one bound in a nucleus that has an excess of neutrons, can decay by emitting a β particle. Sharing the energy with the β particle is a neutrino. The neutrino has little or no mass and is uncharged, but like the photon, it carries momentum and energy. The source of the energy released in β decay is explained by the fact that the mass of the parent isotope is larger than the sum of the masses of the decay products. Mass is converted into energy just as Einstein predicted.

γ Decay

Gamma rays are a type of electromagnetic radiation that result from a redistribution of electric charge within a nucleus. A γ ray is a high energy **photon**. The only thing which distinguishes a γ ray from the visible photons emitted by a light bulb is its wavelength; the γ ray's wavelength is much shorter. For complex nuclei there are many different possible ways in which the neutrons and protons can be arranged within the nucleus. Gamma rays can be emitted when a nucleus undergoes a transition from one such configuration to another. For example, this can occur when the shape of the nucleus undergoes a change. Neither the mass number nor the atomic

number is changed when a nucleus emits a γ ray in γ decay. An equation for γ decay would look like:



Half-life:

The time required for half of the atoms in any given quantity of a radioactive isotope to decay is the **half-life** of that isotope. Each particular isotope has its own half-life. For example, the half-life of ^{238}U is 4.5 billion years. That is, in 4.5 billion years, half of the ^{238}U on Earth will have decayed into other elements. In another 4.5 billion years, half of the remaining ^{238}U will have decayed. One fourth of the original material will remain on earth after 9 billion years. The half-life of ^{14}C decay is 5730 years, thus it is useful for dating archaeological material. Nuclear half lives range from tiny fractions of a second to many, many times the age of the universe.

REACTIONS

If nuclei come close enough together, they can interact with one another through the strong nuclear force, and reactions between nuclei can occur. As in chemical reactions, nuclear reactions can either be exothermic (i.e. release energy) or endothermic (i.e. require energy input). Two major classes of nuclear reactions are of importance: **fusion** and **fission**.

Fusion

Fusion is a nuclear process in which two light nuclei combine to form a single heavier nucleus. An example of a fusion reaction important in thermonuclear weapons and in future nuclear reactors is the reaction between two different hydrogen isotopes to form an isotope of helium:



This reaction liberates an amount of energy more than a million times greater than one gets from a typical chemical reaction. Such a large amount of energy is released in fusion reactions because when two light nuclei fuse, the sum of the masses of the product nuclei is less than the sum of the masses of the initial fusing nuclei. Once again, Einstein's equation, $E = mc^2$, explains that the mass that is lost is converted into the energy carried away by the fusion products.

Even though fusion is an energetically favorable reaction for light nuclei, it does not occur under standard conditions here on Earth because of the large energy investment that is required. Because the reacting nuclei are both positively charged, there is a large electrostatic repulsion between them as they come together. Only when they are squeezed very close to one another do they feel the strong nuclear force, which can overcome the electrostatic repulsion and cause them to fuse.

Fusion reactions have been going on for billions of years in our universe. In fact, nuclear fusion reactions are responsible for the energy output of most stars, including our own Sun. Scientists on Earth have been able to produce fusion reactions for only about the last 60 years. At first, there were small scale studies in which only a few fusion reactions actually occurred. However, this led to the development of thermonuclear fusion weapons (hydrogen bombs).

Fusion is the process that takes place in stars like our Sun. Whenever we feel the warmth of the Sun and see by its light, we are observing the products of fusion. We know that all life on Earth exists because of the light generated by the sun produces food and warms our planet. Therefore, we can say that fusion is the basis for our life.

When a star is formed, it initially consists of hydrogen and helium created in the Big Bang, the process that created our universe. Hydrogen isotopes collide in a star and fuse forming a helium nucleus. Later, the helium nuclei collide and form heavier elements. Fusion is a nuclear reaction in which nuclei combine to form a heavier nucleus. It is the basic reaction which drives the sun. Lighter elements fuse and form heavier elements. These reactions continue until the nuclei reach iron (around mass 60) the nuclei with the most binding energy. When a nucleus reaches mass 60, no more fusion occurs in a star because it is energetically unfavorable to produce higher masses. Once a star has converted a large fraction of its core's mass to iron, it has almost reached the end of its life.

The fusion chain cannot continue and so its fuel is reduced.

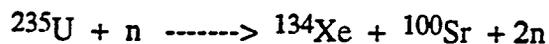
Some stars keep shrinking until they become a cooling ember made up of iron. However, if a star is sufficiently massive, a tremendous violent brilliant explosion can happen. A star will suddenly expand and produce in a very short time, more energy than our Sun will produce in its lifetime. When this happens, we say that a star has become a supernova.

While a star is in the supernova phase, many important reactions occur. The nuclei are accelerated to much higher velocities than can occur in a fusing star. With the added energy caused by their speed, nuclei can fuse and produce elements higher in mass than iron. The extra energy in the explosion is necessary to overcome the energy barrier of a higher mass element. Elements such as lead, gold, and silver found on earth were once the debris of a supernova explosion. The element iron that we find all through the earth and in its center is directly derived from both supernovae and dead stars.

More peaceful uses of fusion are being researched today with the hope that soon we will be able to control fusion reactions to generate clean, inexpensive power.

Fission

Fission is a nuclear process in which a heavy nucleus splits into two smaller nuclei. An example of a fission reaction that was used in the first atomic bomb and is still used in nuclear reactors is:



The products shown in the above equation are only one set of many possible product nuclei. Fission reactions can produce any combination of lighter nuclei so long as the number of protons and neutrons in the products sum up to the those in the initial fissioning nucleus. As with fusion, a great amount of energy can be released in fission because for heavy nuclei, the summed masses of the lighter product nuclei is less than the mass of the fissioning nucleus.

Fission occurs because of the electrostatic repulsion created by the large number of positively charged protons contained in a heavy nucleus. Two smaller nuclei have less internal electrostatic repulsion than one larger nucleus. So, once the larger nucleus can overcome the strong nuclear force which holds it together, it can fission. Fission can be seen as a "tug-of-war" between the strong attractive nuclear force and the repulsive electrostatic force. In fission reactions, electrostatic repulsion wins.

Fission is a process that has been occurring in the universe for billions of years. As mentioned above, we have not only used fission to produce energy for nuclear bombs, but we also use fission peacefully everyday to produce energy in nuclear power plants. Interestingly, although the first man-made nuclear reactor was produced only about 50 years ago, the Earth operated a natural fission reactor in a uranium deposit in West Africa about 2 billion years ago!

Cosmic Rays

High energy electrons, protons, and complex nuclei can be produced in a number of astronomical environments. Such particles travel throughout the universe and are called cosmic rays. Some of these particles reach our Earth. As these objects hit our atmosphere, other particles called pions and muons are produced. These particles then slow down or crash into other atoms in the atmosphere. Since the atmosphere slows down these particles, the higher we travel the more cosmic radiation we see. When you visit the mountains or take an airplane ride, you will encounter more cosmic radiation than if you stayed at sea level.

Most cosmic radiation is very energetic. It can easily pass through an inch of lead. Since cosmic radiation can cause genetic changes, some scientists believe that this radiation has been important in driving the evolution of life on our planet. While cosmic radiation can cause some damage to individuals, it also has played an important role in creating humans. It is naturally produced and will always be around. Our earth's atmosphere and magnetic field do a good job shielding us from harmful effects. However, if we were to leave the earth and travel to some planet, we could be subjected to very high levels of radiation. Future space travelers will have to find some way to minimize exposure to cosmic rays.

Exercise:

Turn on the Geiger counter. Use the most sensitive scale. Make sure no radioactive material is nearby. What do you hear? Every few seconds, you will hear some beeps from the counter. Some of these counts are caused by cosmic rays. Surround the counter by some concrete or iron. Do the counts go away? Take the Geiger counter to a mountain such as Mount Diablo or Mount Tamalpais. Can you measure an increase in rate? It might be necessary to make measurements for 5 to 10 minutes to achieve sufficient statistical accuracy.



RADIATION SAFETY

The radioactive sources are very low level isotopes referred to "license free" sources. This does not mean, however, that these materials represent no hazard to students. The Nucleus, P.O. Box R, Oak Ridge, Tennessee, 37830, has provided the following guidelines for use of low-level radioactive materials in classroom environments:

1. Eating, drinking, and application of cosmetics in the laboratory are not permitted.
2. Pipetting by mouth is never permitted. Use suction devices such as pipette fillers.
3. Gloves and lab coats should be worn when working with all liquid radioisotopes.
4. Before leaving the lab, wash your hands thoroughly then check for possible contamination with a survey instrument.
5. Report ALL spills, wounds, or other emergencies to your teacher.
6. All radioactive liquids wastes are to be poured into the liquid waste container, NEVER a sink.
7. Maintain good housekeeping at all times in the lab.
8. Store radioactive materials only in designated storage area. Do not remove sources from the lab.

EXPERIMENT # 1 *The Inverse Squares*

INTRODUCTION:

While using photographic film and sources similar to radium and uranium, Henri Becquerel discovered radiation in 1896. The following experiment will use a completely safe beta (β) particle of radiation (Strontium -90).

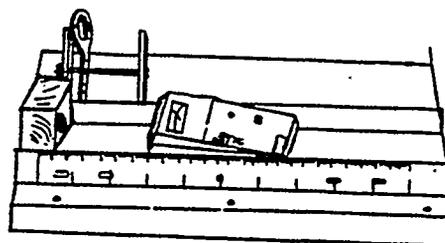
We have learned that radiation travels in all directions in straight lines from the center of the source like rays from the sun. As the radiation moves farther from the source, It becomes less intense. With this information, we also know that the inverse square law applies accurately only when the distance from the source is several times greater than the diameter of the detector. In this experiment the distances are 8, 16, 24, and 32 cm from the source. Data point one equals equal eight centimeters equals, data point 2 equals sixteen centimeters and so on.

OBJECTIVE:

To explore and calculate (if any) the relationship of distance from radioactive sources and the intensity of beta radiation.

MATERIALS:

Geiger counter
rail tracker
Sr-90 (Beta source)
stop watch/beeper
counting paper or counter
graph paper



RAIL TRACKER

PROCEDURE:

BETA RADIATION

1. Place beta radiation source into hole on wooden block of rail tracker.
2. Set digital Geiger counter to one minute intervals and turn on power. Allow the instrument to warm up for a few minutes.
3. Record the background activity.
4. Place the beta radiation source into the hole on wooden block of rail tracker.
5. Place the counter on the slider, 8 cm from the beta source. Record the distance in Table 1.
6. Record counts per minute in Table 1.1. for each trial and calculate the average .
7. Move Geiger counter and slider to 16 cm from source. Repeat step 6.
8. Move Geiger counter to 24 cm and repeat step 6.
9. Move Geiger counter to 32 cm and again repeat step 6.
10. Calculate the uncertainty as the square root of the average*. Record the calculation in column 8 of Table 1.1.
The plus or minus of this number will indicate the standard error of the experiment.

DATA:

Table 1.1: BETA RAYS - DISTANCE (cm)
 Background _____ cpm Sr-90 time = 60 sec

Distance (cm)	Data Points	r ²	T r 1	i a 2	l s 3	Average (cpm)	uncertainty +sq rt average	(1/r ²)** avg ct of 1st data pt
8	1	1						
16	2	4						
24	3	9						
32	4	16						

1. Graph the activity readings (cpm) vs. distance.
2. Graph the activity readings (cpm) vs. $1/r^2$.

QUESTIONS:

1. Why was the background activity recorded for this experiment?
2. What is the source of the background activity?
3. Would the background activity be the same taken at sea level as taken on top of a mountain? EXPLAIN?
4. What happens to the intensity of beta activity when the distance between the Geiger counter and source is four times as great as the initial distance?
Three times as great?
5. According to the inverse square law, when the distance is doubled from 8 to 16 cm the reading should decrease to 1/4 its initial reading. Do your data calculations agree with the inverse square? Explain why or why not.
6. Explain how distance and radioactive materials are potential hazards to you?
7. Interpolate the number of counts for the beta source at a distance of 12 cm.

GOING FURTHER:

1. Evaluate how background activities may influence your data?

*formula for uncertainty of the square root average

$$\text{Uncertainty} = \pm \sqrt{\text{average}}$$

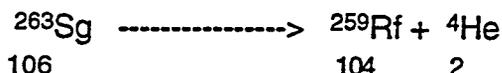
EXPERIMENT # 2

ALPHA PLEASE LEAVE HOME

INTRODUCTION:

An alpha (α) particle is a nucleus of a helium -4 atom. It has two protons and two neutrons with an atomic mass of 4. The new nucleus that results from alpha decay will have a mass and charge different from those of the parent nucleus. A nucleus which undergoes alpha decay transforms into a new element. This process is called transmutation.

EXAMPLE



The atomic number changes from 106 to 104. Measurements show that the sum of the masses of the daughter nucleus and the alpha particle is less than the mass of the parent isotope. Recalling Einstein formula $E=mc^2$, this loss of mass is converted into energy. This form of energy is a positively charged particle moving at high speed. It is easily stopped by paper or your hand.

In this experiment the distances are: 0.5, 1.0, 1.5, 2.0 cm. Data point one equals 0.5 cm. Thus data point two equals 1.0 cm and so on.

OBJECTIVE:

The purpose of this experiment is to find the range of alpha particles and determine if the inverse square law applies.

MATERIALS:

Geiger counter
rail track
Po-210
Stop watch/beeper
counting paper or hand counter
graph paper

PROCEDURE:

1. Set the digital Geiger counter to one minute intervals and turn on power. Allow a minute for instrument to warm up.
2. Record the background activity.
3. Place alpha radiation source into the hole in wooden block of rail tracker.
4. Place the instrument on the slider 0.5 cm from source.
5. Record the counts per minutes in Table 2.1. Do this for three trials. Record the cpm in Table 2.1 for each trial and calculate the average.
6. Move Geiger counter to 1.0 cm and repeat step 5.
7. Move Geiger counter to 1.5 cm and again repeat step 5.
8. Move Geiger counter to 2.0 cm and repeat step 5.
9. Calculate the uncertainty of the square root of the average*. Record the calculation in column 8 of Table 2.1
The plus or minus of this number will indicate the standard error of the experiment.

DATA:**Table 2.1: ALPHA RADIATION - DISTANCE**

Background _____ cpm

Po-210 time = 60 seconds

Distance (cm)	Data Points	r^2	T r 1	i a 2	I s 3	Average (cpm)	uncertainty +sq rt average	$(1/r^2)^{**}$ avg ct of 1st data pt
0.5	1	1						
1.0	2	4						
1.5	3	9						
2.0	4	16						

1. Graph the activity readings (cpm) vs. distance.
2. Graph the activity readings (cpm) vs. $1/r^2$.

QUESTIONS:

1. At what distance did the alpha radiation count equal that of the background count?
2. What is the charge of the alpha particle? How do you know this.
3. List several reason why the alpha particle does not travel more than several centimeters.

GOING FURTHER:

1. What is the mass of an alpha particle compared to an electron?
2. Using "Chart of Nuclides," what identify the daughter isotopes and the particles emitted from each?

A, B, C's OF NUCLEAR SCIENCE

EXPERIMENT # 3 STOP THAT GAMMA

INTRODUCTION:

This activity is very similar to the experiments #1 and #2 and may give better results.

Gamma rays are high energy electromagnetic radiation emitted as a result of transition of a **high energy level of the nucleus** to a lower level. These of high energy particles from the nucleus are also called photons. Gamma radiation has a higher penetration power than alpha and beta radiation.

Because of fluctuations of the meter, it is difficult to obtain an extremely accurate count of radiation with the scales set to x1. One must count the audible beats.

The source of gamma radiation for the experiment is Cobalt -60 (Co-60.) In this experiment, the distances are 8, 16, and 24 cm from the source. Eight centimeters equal one data point, sixteen centimeters equals 2 data points and so on..



OBJECTIVE:

The purpose of this experiment is to find the range of gamma rays and determine if the inverse square applies.

MATERIALS:

Geiger meter
rail track
gamma source (Co-60)
stop watch/beeper
counting paper or hand counter
graph paper

PROCEDURE:

1. Place gamma source into hole in wooden block of rail tracker.
2. Set the digital Geiger counter to one minute intervals and turn on power. If you have an analog Geiger counter it may be necessary to count the audible beeps.
3. Record the background activity.
4. Place the instrument on slider, 8 cm from the gamma source.
5. Record the counts per minutes in Table 3.1 for three trials. Record the cpm in Table 1 for each trial and calculate the average.
6. Move Geiger counter and slider to 16 cm from source. Repeat step 5.
7. Move Geiger counter and slider to 24 cm from source. Repeat step 5.
8. Calculate the uncertainty of the square root of the average. Record the calculation. *This will be used to indicate the standard error of data in the experiment.*

DATA:

Table 3.1: GAMMA RAYS - DISTANCE (cm)

DATA:

Table 3.1: GAMMA RAYS - DISTANCE (cm)
Background _____ cpm Co-60 time = 60

DATA POINTS	Distance (cm)	r ²	T r 1	i a 2	I s 3	Average (cpm)	uncertainty* + -sq rt average	1/r ² **
1	8	1						
2	16	4						
3	24	9						

1. Graph the activity readings (cpm) vs. distance.
2. Graph the activity readings (cpm) vs. $1/r^2$.

QUESTIONS:

1. In what ways are light waves and gamma radiation related.
2. Where does the energy of the photons originate.
3. How are photons and X ray alike? Different?
4. What happens to the intensity of gamma radiation when the distance between 8 cm and 24 cm.

GOING FUTHER:

1. What is the speed of gamma rays?
2. Make a graph combining the data of $1/r^2$ vs cpm for experiments 1, 2, and 3.



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EXPERIMENT #4

Penetrating Power

INDRODUCTION:

There is a great difference in the penetrating powers for alpha, beta, and gamma rays. Of the three types of radiation, alpha particles are the easiest to stop. A sheet of paper is all that is needed for the absorption of alpha rays. However, it may take a material with a greater thickness and density to stop beta particles. Gamma rays have the most penetrating powers of all three radiation sources.

OBJECTIVE:

The purpose of this experiment is to demonstrate the interactions of alpha, beta, and gamma radiation with matter.

MATERIALS:

radiation sources:

gamma source Co-60,

alpha source Po-210

beta source Sr-90

Geiger counter

rail tracker

absorber set

PROCEDURE:

Part A

1. Set Geiger meter to x1 scale and turn on. Allow a few minutes for the instrument to warm up. Record the background activity.
2. Place the alpha source (Po-210) inside the hole in the wooden block or rail tracker.
3. Arrange the polyethylene samples according to thickness with the least thickness in inches. Place the polyethylene in the special material holder on rail track. Rotate the arm to cover the radiation source. (*see drawing*) Move the Geiger counter and slider next to the sample.
4. Take three trial reading of radiation intensity for each thickness of polyethylene and record in Table 4.1. The time required for each trials is 10 seconds. Because of fluctuations with the meter better results are obtain when counting beats.
5. Plot a graph for this activity: thickness vs number of counts.

Part B

1. Replace the alpha source with the beta source (Sr-90).
2. Check Geiger counter for x1 setting.
3. Arrange the plastic and lead samples according to thickness

- with the least thickness first. Place the first sample in the material holder and rotate arm to cover source. Move the Geiger counter and slider next to the sample.
4. Take three trials reading or radiation intensity for each thickness of all samples and record in Table 4.2. The time for counting numbers of beats is 10 seconds. Again count the audible beats.
 5. Plot a graph for this activity.

PART C

1. Replace the beta source with the gamma source (Co-60).
2. Check x1 scale position for Geiger counter.
3. Arrange the lead samples according to thickness with the least thickness first. Place the first lead sample in the material holder and rotate arm to cover source. Move the Geiger counter and slider next to the sample.
4. Take three trials reading of radiation intensity for each thickness of all lead samples and record in Table 4.3. The time for counting numbers of beats is 10 seconds. Again count the audible beats.
5. Plot a graph for this activity.

DATA:Table 4.1 PENETRATION POWER:

Alpha Rays - Polyethylene

thickness (inches)	Background count		Po-210		average
	scale	t 1	r i a counts/10s 2	l s 3	
0.0040					
0.0080					
0.020					
0.030					
0.062					
0.125					
0.250					

**DATA:Table 4.2 PENETRATION POWER:
Beta- Poly and Lead**

thickness (inches)	scale	Background count			average
		t 1	r i a counts/10s 2	l s 3	
polyethylene					
0.0040					
0.0080					
0.020					
0.030					
0.062					
0.125					
0.250					
lead					
0.032					
0.062					
0.125					
0.250					

**DATA:Table 4.3 PENETRATION POWER:
Gamma Rays - Lead**

thickness (inches)	Background count	Co-60			average
	scale	t 1	r i a counts/10s 2	i s 3	
0.032					
0.062					
0.125					
0.250					

QUESTIONS:

1. Why allow time for the Geiger counter to warm up?
2. Is it necessary to take background readings every day? Explain.
3. What type of results would you expect if same alpha sample was doubled in quantity.
4. Is polyethylene an effective shield for beta radiation? Lead? Explain.
5. What results would you observe if you used aluminum for shielding beta rays.
6. From your graph, what thickness of lead is needed to absorb Sr -90 beta rays? For Co -60 gamma rays?
7. What materials other than lead are effective for shielding gamma radiation?
8. What amount of lead is needed to reduce gamma radiation to one-half of a previous intensity count?
9. What general statements can you make about the thickness of the absorbing material on the count rates.

GOING FURTHER:

1. If the density of air is 1.3 mg/cc. How long would a column of air be needed for absorbing beta rays in the source Sr-90.
2. How long would a column of air needed to be to reduce the intensity of Co-60 gamma ray by a factor of 10? Explain.
3. Make a chart comparing alpha, beta, and gamma radiation, including such information on charge, mass, penetration, speed and energy.



EXPERIMENT #5 RADIOGRAPHY

INTRODUCTION:

Radiography is the production on an image on photographic film created from a radiation source. The principle is the same as taking a photograph with a camera, but radiation is substituted for light. An image is produced by ionizing radiation on the undeveloped film. When film is processed, it can show the location and intensity of the source used and the shape of objects placed between the source and film.

OBJECTIVE:

To investigate the intensity of beta particle on photographic film.

MATERIALS:

Polaroid film type 57
Polaroid Land Film Holder #500
Beta source (Sr - 90)
Tape

PROCEDURE:

1. Place film with lens side up on a flat surface.
2. Uncoil a paper clip and place it in the center of the film.
3. Next, place the beta source over the clip, so that the quarter inch window is directly over the object. Carefully, tape the objects to the film.
4. Allow the film to absorb the radiation over night.
5. Remove the objects from the film.
6. Turn select lever on film holder to load and load film.
7. Next, turn select lever on film holder to process and remove film.
8. Allow 60 seconds for the development of film before removing picture.
9. Repeat the same procedures, but move the source 1 cm from clip and film.
10. For a control, repeat steps 1-8 without paper clip.

DATA:

Draw your observations.

QUESTIONS:

1. Why is it necessary to have a control?
2. Compare the paper clip images with the control image.
3. Why was there a difference in intensity?
4. Would gamma radiation produce an image of the paper clip?
Explain.

GOING FURTHER:

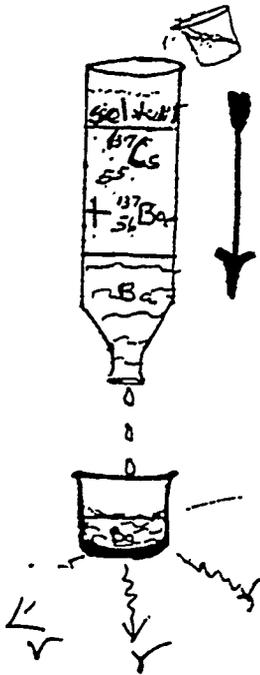
1. Try different types of objects, such as plastic comb, rubber band, or string.
2. Determine the maximum distances and length of exposure time need to produce images of above objectives.

A, B, C's OF NUCLEAR SCIENCE EXPERIMENT #6 HALF-LIFE

INTRODUCTION:

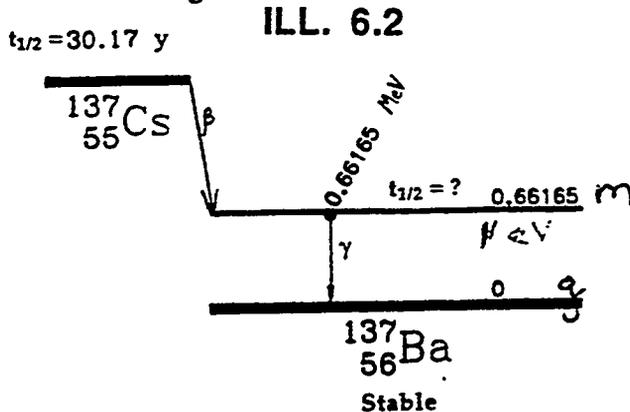
ILL. 6.1

ISOGENERATOR



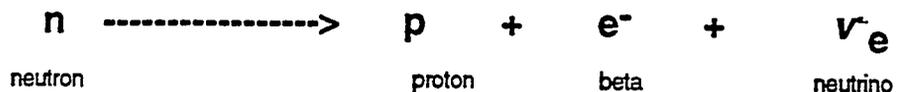
Cesium -137 is a radioactive element with a half -life of 30 years. Its decay results in the formation of Ba -137 with a very short half-life. Both elements have the same atomic mass but Cesium has an atomic number of 55 and Barium has an atomic number of 56. Because they are different elements, they have different chemical properties and can be separated by chemical processes.

This experiment uses a glass column isogenerator (see illustration 6-1) and a **9.0 pH specific** chemical solution called EDTA. The EDTA at 9.0 pH will react chemically with the radioactive daughter element Ba-137 and not the parent element. The Cesium stays in the isogenerator and the radioactive Barium is allowed to flow down the tube. If the pH of EDTA is greater than 9.0, the possibility of Cs bleeding though is greater. And if the pH of EDTA is allowed to fall below 9.0, the Ba will come out of the isogenerator slower.



The chemical decay of Cs -137 is a two step process. (see illustration 6.2) First , a neutron inside the ^{137}Cs nucleus undergoes beta decay which converts the neutron into a proton and a beta particle (electron) and a neutrino are emitted. The ^{137}Ba nucleus produced by this process is left in an excited state, 662 keV above the ground state. When this level decays, a 662 keV gamma ray is emitted. (See illustration 6.3) It is at this state that you will determine the half -life of $^{137}\text{Ba}^m$. (Note: The "m" state stands for meta stable:). Finally, $^{137}\text{Ba}^m$ becomes stable with a mass of 137, with 56 protons and 81 neutrons.

ILL. 6.3



OBJECTIVE:

To determine the half-life of Barium -137.

MATERIALS:

isogenerator (generator) column	
9 microcuries of Cs-137	
Ring stand	0.1M EDTA
Buret clamp - round jaws	pH indicator
Vial w/screw cap	
Zip lock plastic bag	
Geiger meter	
Stop watch	
Counter	

Procedure:

Part A (*It is suggested that the teacher prepare steps 1 -3 before class*).

1. The first step of preparation is to remove the large cap above the reservoir. This may be difficult, due to the vacuum created in the column itself. This should be done by holding the column secure in one hand and using the thumb to push in an upward motion. Do this slowly to keep the liquid inside the column. Once this has been done, place the column in the buret clamp and mounted on the ring stand.
2. With gloves on and a vial under the column, remove the small cap at the bottom of the column. Catch the liquid and determine with the Geiger meter that there is no contamination present. At this point replace the small cap with the stopcock provided. Make sure the stopcock is in the off position. Fill the column with 3 mL of 0.1 m EDTA (pH 9.0). Allow the column to sit for approximately one hour. This moves the Cesium down the column, allowing better results on your first "Milking of the Cow."
3. This procedure is very pH specific and could influence the results of your experiments. It is suggested that the pH of EDTA solution be checked often. Also the solution should be replaced every six months.

PART B

(The following procedure is to be followed once the column has been prepped for the elution procedure. It is important that gloves , goggles and a lab apron be worn throughout this procedure)

1. Remove the top cap from the column. Write down the mL value for the level of EDTA by reading it from the top of the column.
2. Prepare your glass vial to catch the eluant. Place this directly under the column, adjusting the height of the column to be no more than two inches above the container. For more safety protection, place the vial in a zip lock bag and seal it.

3. Turn the stopcock to the "on " position. Allow about 20 drops of the eluant to flow into the container: No more that 3 mL is need. Turn the stopcock off immediately after the correct amount of eluant has flowed through.
4. Turn on the Geiger count and record the background radiation.
5. Set the Geiger counter with scale to x10, and place next to the sample. Recorded readings in table 6.1 every 30 seconds for the next 5 minutes.
6. Change scale setting to x1 and repeat step 4.
7. Fill the column again with EDTA eluant up to at least the 5 mL mark. If the cow is to be milked again, it is necessary to wait an ample amount of time to ensure the daughter has been allowed to grow in and the recovery is good. (a good guideline is 15-30 Minutes.)
8. If the column is not to be used within a week's time period, it is necessary to bleed all of the EDTA out and place deionized water back in the column for long term storage. The cap should also be place on the column as securely as possible. Remember this is an ionization exchange column, and it a must never be allowed to go dry. For long term storage, it is best to store in distilled water and as air tight as possible.

DATA:

**Table 6.1 HALF-LIFE OF Ba -137
First Milking**

1st Trial time (s)	CPM scale x10	2nd Trial time (s)	CPM scale x1
30 s			
60 s			
90 s			
120 s			
150 s			
180 s			
210 s			
240 s			
270 s			
300 s			

1. Make a graph of the cpm vs. time.
2. Draw the best fit curve.
3. Compute your uncertainty square root average.

Questions:

1. What is the half-life of Cesium -137?
2. What is the half-life of $^{137}\text{Ba}^m$?
3. What type of decay is Cesium undergoing?
4. Why is this a two step operation to produce a stable Barium -137?
5. List the most important safety steps taken to prevent radiation.
6. Compute your percent error by comparing the value you obtained by the graph and by the calculation with the accepted value of the half-life of $^{137}\text{Ba}^m$.

A, B, C's OF NUCLEAR SCIENCE

EXPERIMENT # 7 *Magnetic Deflection of Beta Rays*

INTRODUCTION:

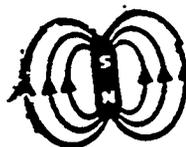
The placing of magnetic field across the path of beta radiation causes a change in the direction of the rays so that they bend. The strength of the magnets and the energy of the beta particles will determine the degree of deflection of the beta particles from the source.

OBJECTIVE:

To deflect the path of beta radiation by means of magnetism.

Materials:

Geiger counter
rail tracker
two cow magnets
magnet holders
beta source (Sr-90)

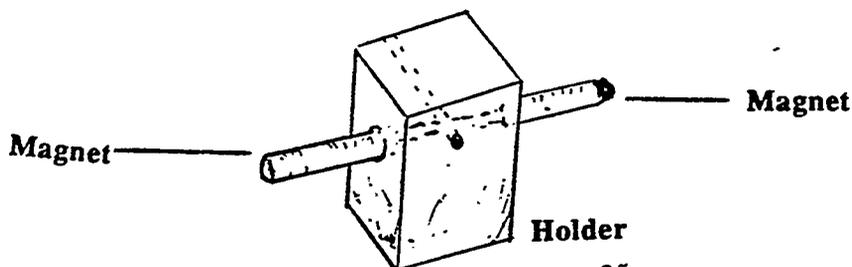


magnetic fields

PROCEDURE:

1. Turn on the Geiger counter with scale set to x1 and take a background measurement.
2. Place the beta source (Sr-90) into the wooden block.
3. Set the aluminum magnet holder so that the quarter inch hold is in line with the path of beta particles. *See figure 7.1.*
4. Place the Geiger counter 8 cm from the source. In front on the window of the Geiger counter place a second shield of aluminum with a quarter inch opening in from of its window.
5. Take a reading with the source and magnet holder in place but without any magnets.
6. Place one cow magnet into the magnet holder so that a magnetic field crosses the path of the beta particles.
7. Record the counts per minute for three trial in table 7.1.
8. Next, place unlike poles of the two cow magnets into the opening of the magnet holder and repeat step 7.

Figure 7.1 Magnets and Holder



DATA:

Table 7.1 Magnet Deflection of Beta Rays

Background count _____ Sr-90 Time = 60 seconds

# of magnets	T R I A L S			AVE (cpm)	Uncertainty + - sq rt average
	T 1 counts	R 2 per	I 3 minute		
none					
1					
2					

1. Graph the above data and indicate the error of uncertainty.

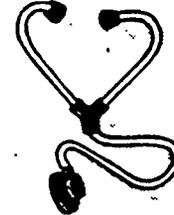
QUESTIONS:

1. Does the addition of one magnet have any effect on the beta particles? Explain.
2. Does the amount of bending of beta particles increase or decrease when two magnets are used in the experiment? Explain.
3. What results would you expect if gamma particles were used? If alpha particles were used?

GOING FURTHER:

1. How are magnets have used in a cyclotron?
2. Carefully remove the Geiger counter, and with your hands rotate it until you determine the maximum deflection of beta particles.
3. Repeat the above experiment, using gamma rays.

A, B, C's OF NUCLEAR SCIENCE
EXPERIMENT #8 *Radiation Makes House Calls*



INTRODUCTION:

Radioactivity is found in the home. The news media has reported on the problem of Radon, Rn, build-up in our homes. However, the news reports failed to mention that Rn is a naturally occurring nuclear decay product. It is a daughter element of uranium and thorium.

All around us natural deposits of Uranium, ^{235}U (0.7% abundance) and ^{238}U (99.3% abundance) and Thorium, ^{232}Th are decaying and producing many progeny. We ourselves are radioactive. Our intake of food will sometimes have traces radioactive elements. Potassium -40 is found in many foods such as bananas, salt substitute and many other foods.



OBJECTIVE:

To demonstrate to the student that some house-hold items are radioactive.

MATERIALS:

Geiger counter
Glass crystal
Lantern mantle
Pottery glaze
Smoke detector
Watch

PROCEDURE:

1. Turn on Geiger counter with scale set to x1 and take a background count.
2. Place the different materials in front of the Geiger counter.
3. Record the reading in table 8.1.
4. Applying usage from the "Chart Of The Nuclides," recorded data in table 8.1, and table 8.2, fill in the questions marks found in table 8.2 for the crystal glass.

DATA:**Table 8.1: RADIATION IN HOME**

Background _____ cpm Scale = x1 time = 60 seconds

MATERIALS	COUNTS PER MINUTE
LANTERN MANTLE	
POTTERY GLAZE	
SMOKE DETECTOR	
WATCH	
GLASS CRYSTAL	

Table 8.2: RADIATION DECAY

Radioactive Source:	Isotopes	Radiation(s)	Gamma Ray Energy	Notes
Lantern mantle	^{232}Th	alpha rays & beta & gamma rays	0.240 MeV	natural
Pottery Glazed	^{235}U , ^{238}U	alpha rays & beta & gamma rays	0.063 MeV	natural
Smoke Detector	^{241}Am	alpha rays & beta & gamma rays	0.059 MeV	man-made
Painted Watch	^{226}Ra	alpha rays & beta & gamma rays	0.0510 MeV	natural
Glass Crystal	?Pb	?	? MeV	?

QUESTIONS:

- Which of the house-hold materials had the greatest radiation intensity? The least radiation intensity?
- What radioactive element is present in a Coleman Mantle? in a smoke detector? In a painted watch?
- What unit is used to describe the magnitude of radioactive decay energies?
- An isotope of the element calcium has a half-life of 12 years, how long will it take for 1/4 of the calcium to *decay*?
a. 4 year b. 8 years c. 12 years d. 16 years e. 24 years

A, B, C's OF NUCLEAR SCIENCE
EXPERIMENT #9 **It's In The Clouds**

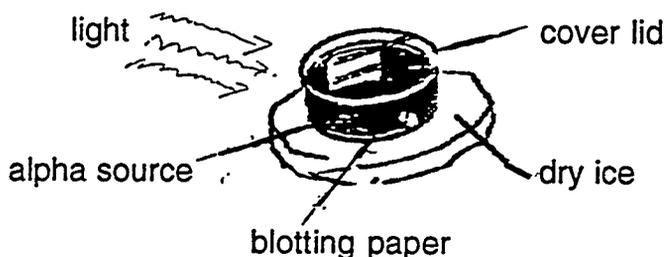
INTRODUCTION:

Would like to observe the effects of nuclear radiation? The cloud chamber is excellent for studying the rate of alpha decay and the range of an alpha particle. Alcohol vapors are held up by high pressure by dry ice. When a harmless radioactive alpha source is inserted in the chamber, the tracks from the alpha particles can be observed.

OBJECTIVE:

To create condensation trails which are evidence of the passage of alpha particles.

Figure 9.1
The Cloud Chamber



MATERIALS:

Chamber with cover
radiation source
2 blotting paper viewers
Strong light source (300 W to 500 W)
dry ice
denatured ethyl alcohol

PROCEDURE:

1. Soak the blotting paper with alcohol.
2. Place the blotting paper in the chamber and cover.
3. Place the chamber on dry ice. (See figure 9.1)
4. Insert the radioactive source through the hole in the side of the chamber.
5. Focus the strong light through the chamber.
6. Observe vapor trails against the black bottom of the chamber.
7. Replace the radioactive source in test tube when experiment is done.

DATA:

1. Draw and label your observations.

QUESTIONS:

1. Why are alpha particles easy to view with the chamber?
2. Why is dry ice needed?
3. Why is alcohol needed?

Glossary of Nuclear Terms

absorber

Any material that stops ionizing radiation. Lead, concrete, and steel attenuate gamma rays. A thin sheet of paper or metal will stop or absorb alpha particles and most beta particles.

alpha particle (alpha radiation, alpha ray)

A positively charged particle (a Helium-4 nucleus) made up of two neutrons and two protons. It is the least penetrating of the three common forms of radiation, being stopped by a sheet of paper. It is not dangerous to living things unless the alpha-emitting substance is inhaled or ingested or comes in contact with the lens of the eye.

atom

A particle of matter indivisible by chemical means. It is the fundamental building block of elements.

atomic number

The number assigned to each element on the basis of the number of protons found in the element's nucleus.

atomic weight (atomic mass)

Approximately the sum of the numbers of protons and neutrons found in the nucleus of an atom.

background radiation

The radiation of man's natural environment originating primarily from the naturally radioactive elements of the earth and from the cosmic rays. The term may also mean radiation extraneous to an experiment.

beta particle (beta radiation, beta ray)

An electron, of either positive charge (β^+) or negative charge (β^-), which has been emitted by an atomic nucleus or neutron in the process of a transformation. Beta particles are more penetrating than alpha particles but less than gamma rays or x rays.

contamination

Radioactive material deposited or dispersed in materials or places where it is not wanted.

cow

A radioisotope generator system.

curie (Ci)

The basic unit used to describe the intensity of radioactivity in a sample of material. One curie equals 37 billion disintegrations per second, or approximately the radioactivity of 1 gram of radium.

daughter

A nuclide formed by the radioactive decay of a different (parent) nuclide.

decay (radioactive)

The change of one radioactive nuclide into a different nuclide by the spontaneous emission of alpha, beta, or gamma rays or by electron capture. The end product is a less energetic, more stable nucleus. Each decay process has a definite half-life.

decontamination

The removal of radioactive contaminants as by cleaning and washing with chemicals.

density

That property of a substance which is expressed by the ratio of its mass to its volume.

dose

A general term denoting the quantity of radiation or energy absorbed in a specific mass.

electromagnetic radiation

Radiation consisting of electric and magnetic waves that travel at the speed of light. Examples: light, radio waves, gamma rays, x rays.

electron

An elementary particle with a unit electrical charge and a mass $1/1837$ that of the proton. Electrons surround the atom's positively charged nucleus and determine the atom's chemical properties.

electron capture

A radioactive decay process in which an orbital electron is captured by and merges with the nucleus. The mass number is unchanged, but the atomic number is decreased by one.

eluant

Washing solution — (The solution that is introduced into the cow).

eluate

The washings obtained by elution (the solution that comes out of the cow).

elute

To separate by washing (to milk).

excited state

The state of an atom or nucleus when it possesses more than its normal energy. The excess energy is usually released eventually as a gamma ray.

fission

The splitting of a heavy nucleus into two roughly equal parts (which are nuclei of light-

er elements), accompanied by the release of a relatively large amount of energy in the form of kinetic energy of the two parts and in the form of emission of neutrons and gamma rays.

fission products

Nuclei formed by the fission of heavy elements. They are of medium atomic weight, and almost all are radioactive. Examples: strontium-90; cesium-137.

gamma ray

A highly penetrating type of nuclear radiation similar to x radiation, except that it comes from within the nucleus of an atom and, in general, has a shorter wavelength.

Geiger counter

A Geiger-Muller detector and measuring instrument. It contains a gas-filled tube which discharges electrically when ionizing radiation passes through it and a device that records the events.

generator

A cow — a system containing a parent-daughter set of radioisotopes in which the parent decays through a daughter to a stable isotope. The daughter is a different element from that of the parent and, hence, can be separated from the parent by elution (milking).

half-life

The time in which half the atoms of a particular radioactive nuclide disintegrate. The half-life is a characteristic property of each radioactive isotope.

health physics

That science devoted to recognition, evaluation, and control of all health hazards from ionizing radiation.

induced radioactivity

Radioactivity that is created by bombarding a substance with neutrons in a reactor or with charged particles produced by particle accelerators.

ion

An atomic particle that is electrically charged, either negative or positive.

ionizing radiation

Radiation that is capable of producing ions either directly or indirectly.

irradiate

To expose to some form of radiation.

isomer

One of several nuclides with the same num-

bers of neutrons and protons in the nucleus, but capable of existing for a measurable time in different nuclear energy states.

isomeric transition

A mode of radioactive decay where a nucleus goes from a higher to a lower energy state. The mass number and atomic number are unchanged.

isotope

Isotopes of a given element have the same atomic number (same number of protons in their nuclei) but different atomic weights (different numbers of neutrons in their nuclei). Uranium-238 and uranium-235 are isotopes of uranium.

K-Capture

The capture by an atom's nucleus of an orbital electron from the first or K-shell surrounding the nucleus.

keV

One thousand electron volts.

MeV

One million electron volts.

microcurie (μCi)

One millionth of a curie (3.7×10^4 disintegrations per second).

milk

To elute a cow.

MINIGENERATOR

A trademark of Union Carbide Corporation that is used to identify radioisotope generator systems for educational uses.

neutrino

An electrically neutral particle with a negligible mass. It is produced in many nuclear reactions such as in beta decay.

neutron

One of the basic particles which make up an atom. A neutron and a proton have about the same weight, but the neutron has no electrical charge.

nuclear reactor

A device in which a fission chain reaction can be initiated, maintained and controlled. Its essential components are fissionable fuel, moderator, shielding, control rods, and coolant.

nucleon

A constituent of the nucleus; that is, a proton or a neutron.

nucleonics

The science, technology, and application of nuclear energy.

nucleus

The core of the atom, where most of its mass and all of its positive charge is concentrated. Except for hydrogen, it consists of protons and neutrons.

nuclide

Any species of atom that exists for a measurable length of time. A nuclide can be distinguished by its atomic weight, atomic number, and energy state.

parent

A radionuclide that decays to another nuclide which may be either radioactive or stable.

photon

A quantity of electromagnetic energy. Photons have momentum but no mass or electrical charge.

proton

One of the basic particles which make up an atom. The proton is found in the nucleus and has a positive electrical charge equivalent to the negative charge of an electron and a mass similar to that of a neutron: a hydrogen nucleus.

rad

Radiation Absorbed Dose. The basic unit of absorbed dose of ionizing radiation. One rad is equal to the absorption of 100 ergs of radiation energy per gram of matter.

radioactive dating

A technique for estimating the age of an object by measuring the amounts of various radioisotopes in it.

radioactive waste

Materials which are radioactive and for which there is no further use.

radioactivity

The spontaneous decay or disintegration of an unstable atomic nucleus accompanied by the emission of radiation.

radioisotope

A radioactive isotope. A common term for a radionuclide.

radionuclide

A radioactive nuclide. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

rate meter

An electronic instrument that indicates, on a meter, the number of radiation induced pulses per minute from radiation detectors such as a Geiger-Müller tube

scaler

An electronic instrument for counting radiation-induced pulses from radiation detectors such as a Geiger-Müller tube.

scintillation counter

An instrument that detects and measures gamma radiation by counting the light flashes (scintillations) induced by the radiation.

secular equilibrium

A state of parent-daughter equilibrium which is achieved when the half-life of the parent is much longer than the half-life of the daughter. In this case if the two are not separated, the daughter will eventually be decaying at the same rate at which it is being produced. At this point both parent and daughter will decay at the same rate until the parent is essentially exhausted.

shielding

A protective barrier, usually a dense material, which reduces the passage of radiation from radioactive materials to the surroundings.

source

A radioactive material that produces radiation for experimental or industrial use.

spill

The accidental release of radioactive materials.

stable

Nonradioactive.

tracer

A small amount of radioactive isotope introduced into a system in order to follow the behavior of some component of that system.

transmutation

The transformation of one element into another by a nuclear reaction.