

Nuclear Chemistry

Nuclear chemistry is the study of atomic nuclei. Nuclei is plural for nucleus. Remember, a nucleus is the center of an atom consisting of protons and neutrons. Nuclear equations represent the atomic # and atomic mass of nuclei. You will know if you are looking at a nuclear equation if the masses are shown. Showing the atomic # is optional since an element's atomic symbol can only have one atomic number.

Ex: ${}^{14}_6\text{C}$ represents carbon with a mass of 14 and can be called **carbon-14**.

Remember, **isotopes** are atoms of the same element that have different atomic mass. Atoms of the same element must have the same # of protons. If they have a different # of neutrons they will have a different mass. Isotopes of elements represented by their # of protons and mass are called **nuclides**. Most elements exist as stable nuclides and are not radioactive. Elements that are always radioactive are said to have **no stable isotopes**. Elements with atomic # 84 and above only exist as unstable isotopes and are always radioactive. Some other elements are also always radioactive, their mass on the periodic table is in parenthesis (mass).

Ex: ${}^{(209)}_{84}\text{Po}$ and ${}^{(98)}_{43}\text{Tc}$

Radioactivity is the spontaneous breakdown of unstable atomic nuclei. The forces of nature drive systems towards greater stability. The **ratio of protons to neutrons** in a nucleus determines whether a nucleus is stable. An unstable nuclei can become more stable by giving off a part of itself to attain a more stable proton to neutron ratio.

Radioactivity results in the release of radiation (see Table O for types of radioactive emanations). If a nuclei changes its # of protons (atomic number) as a result of radioactivity it is said to have **transmuted**. Transmutation refers to the process of one element changing into another. When this occurs by itself it is called **natural transmutation or radioactive decay**.

Ex: ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^4_2\text{He}$

In the above example, the unstable isotope radium-226 becomes more stable by emitting (giving off) an alpha particle. This results in a natural transmutation. Radium-226 naturally transmutes into Radon-222.

Natural transmutation will have only 1 item to the left of the arrow.

Artificial Transmutation occurs when a high energy particle bombards (collides with) a nucleus resulting in the formation of one or more new elements.

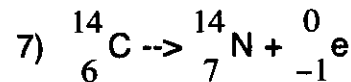
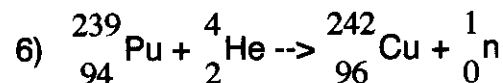
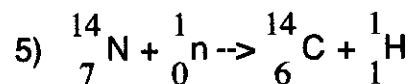
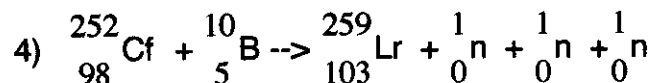
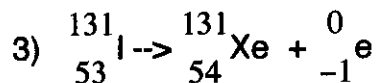
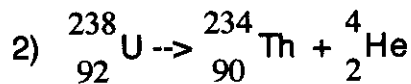
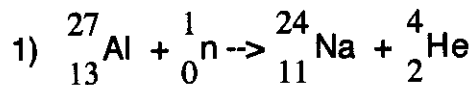
Artificial transmutation will have 2 items to the left of the arrow.

In the example below, an alpha particle bombards a Nitrogen-14 nucleus resulting in a transmutation. A different element, Oxygen-17 and a proton are produced.

Ex: ${}^{14}_7\text{N} + {}^4_2\text{He} \rightarrow {}^{17}_8\text{O} + {}^1_1\text{H}$

Note Packet # 8

Identify the following nuclear reactions as natural transmutation or artificial transmutation.

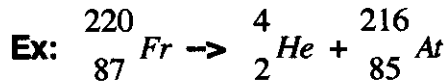
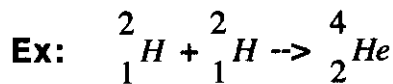


Detecting Radiation: Radiation can be detected with:

1. Photographic film
2. Phosphorescent material
3. Devices that detect ionized gases such as a geiger counter.

Biological Effects of radiation: Exposure to radiation is measured in **rems**. Radiation can cause harm to living organisms. The negative effects are usually the result of the ionizing effect of radiation.

Balancing Nuclear Equations: A balanced nuclear equation must have equal amounts of mass on both the left and right side of the arrow and equal amounts of atomic # on both the left and right side of the arrow. Use the atomic # to identify the unknown element or particle.

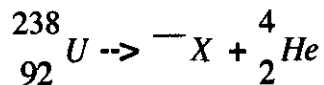


Notice the sum of the masses on both sides of the arrow are =.
The sum of the atomic number on both sides of the arrow are =.

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Balancing nuclear equations can be used to identify an unknown isotope.

Ex: Identify the unknown isotope in the following equation.



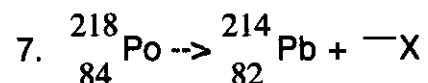
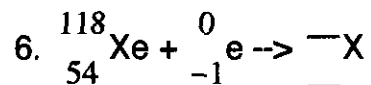
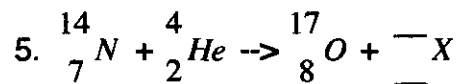
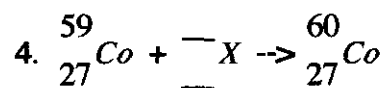
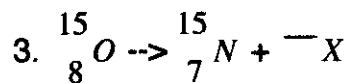
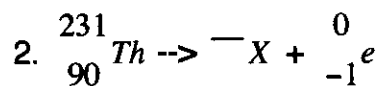
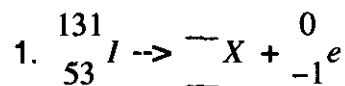
To solve: The sum of the mass on both sides of the arrow must be equal $238 - 4 = 234$.
The sum of the atomic # on both sides of the arrow must be equal $92 - 2 = 90$.



the element Thorium. The unknown isotope is ${}_{90}^{234}\text{Th}$ called Thorium-234.

Practice Balancing Nuclear Equations:

Balance the nuclear equation and determine the unknown isotope or Table O particle for the following. State the name of each nuclide or Table O particle.



Note Packet # 8

Properties of Table O Emissions

Name	Symbol	Charge	Mass	Penetrating Ability	Ionizing Ability
Alpha	${}^4_2\text{He}$	+2	4 amu	low	high
Beta	${}^0_{-1}e$	-1	0	medium	medium
Gamma	${}^0_0\gamma$	0	0	high	low
Neutron	1_0n	0	1	low	none
Proton	1_1H	+1	1	low	low
Positron	${}^0_{+1}e$	+1	0	destroyed when it contacts matter containing electrons	

Remember! When using Table O, the bottom number is the charge of the object.

Ex: What is the charge of a positron? answer +1

What is the charge of a neutron? answer 0

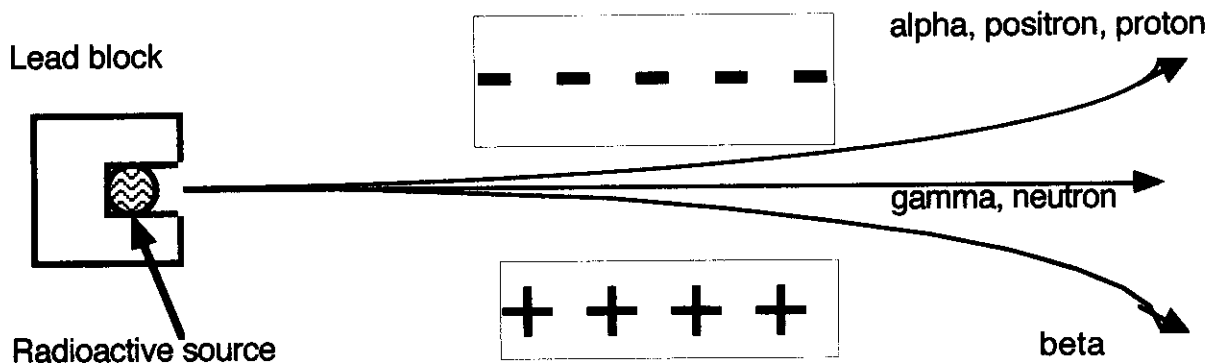
Ionizing ability describes the ability of the emission to create ions when it interacts with matter. The greater the charge of the emission the greater the ionizing ability. Alpha has the greatest charge, therefore, the greatest ionizing ability. This is important because radiation damage to living things is the result of the formation of ions.

Penetrating ability describes how well an emission can penetrate matter. The more mass an emission has the less matter it can penetrate. For example, alpha has the greatest mass, therefore, it has the least penetrating ability. Gamma has no mass, therefore, it has the greatest penetrating ability. Remember gamma is similar to X-rays. X-rays penetrate material easily.

Note Packet # 8

Deflections of Table O Emanations

The particles from Table O are attracted or deflected to charges based on the concept that opposite charges attract. Positive particles are attracted to negative charges. Negative particles are attracted to positive charges. Neutral particles are unaffected by charges. The following diagram illustrates the paths of Table O particles as they pass through an electric field.



The charges of Table O particles can be determined by examining the bottom number. For elements the bottom number is the number of protons which is the nuclear charge. For Table O items the bottom number is the charge.

An **accelerator** is a device that speeds up (increases the kinetic energy of) subatomic particles using electric and or magnetic fields. An accelerator can only accelerate charged particles. It should be noted that neutrons and gamma can not be accelerated.

Table N is used to determine the decay mode for many radioisotopes.

Look at Table N

Exs: The decay mode of gold-198 is beta.

The decay mode of francium-220 is alpha.

The decay mode of neon-19 is positron.

What is the decay mode of the following?

1. Carbon-14
2. Strontium-90
3. Iodine-131
4. Radium-226

Note Packet # 8

Nuclear Energy: The quantity of energy released in a nuclear reaction is millions of times greater than the energy released in a normal chemical reaction. During a nuclear reaction a tiny amount of mass is converted to energy. Even a tiny amount of mass produces an enormous amount of energy. Einstein's famous equation describes this process.

$$E = mc^2$$

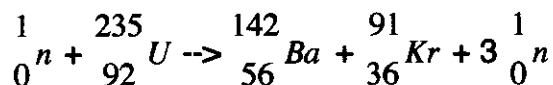
E = energy released

m = mass converted to energy

c = speed of light (3×10^8 m/s)

Nuclear Fission is the splitting of large nuclei to produce smaller nuclei while releasing lots of energy. The energy produced is a result of a small amount of matter being converted to energy. Nuclear fission is used in nuclear reactors and atomic bombs. The fuels for fission are usually isotopes of **uranium** or **plutonium**. Fission is initiated (started) by a neutron. A neutron strikes a large nucleus and temporarily joins it, making it unstable. The nucleus then splits into 2 smaller nuclei. At the same time it releases additional neutrons.

The most common fission equation seen on the regents is :

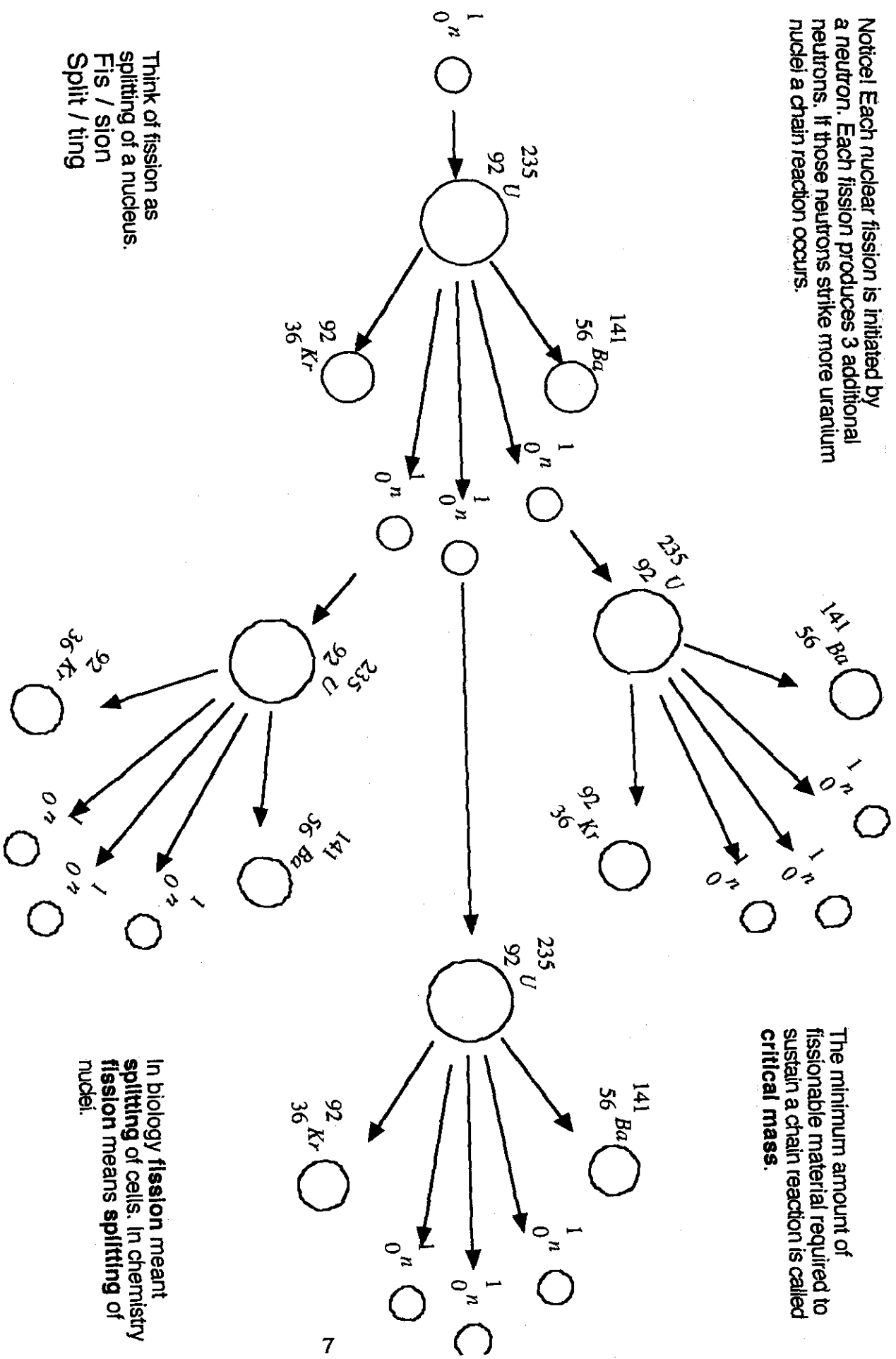


This fission equation shows how a uranium nucleus is struck by a neutron. The neutron temporarily joins the nucleus making it unstable. The uranium nucleus splits and forms a barium-142 nucleus and a krypton-91 nucleus. This splitting is accompanied by the release of 3 additional neutrons. If the released neutrons strike other uranium nuclei, a **chain reaction** will occur. A controlled chain reaction is what occurs in a nuclear reactor. An uncontrolled chain reaction results in an atomic explosion (atomic bomb). In order for the released neutrons to strike more large nuclei there must be a minimum amount of mass available. This minimum amount of mass is called **critical mass**. Without the critical mass a chain reaction can not occur.

The following page shows a diagram of a fission chain reaction.

Nuclear Fission Diagram

Notice! Each nuclear fission is initiated by a neutron. Each fission produces 3 additional neutrons. If those neutrons strike more uranium nuclei a chain reaction occurs.



The minimum amount of fissionable material required to sustain a chain reaction is called **critical mass**.

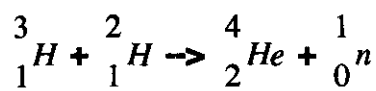
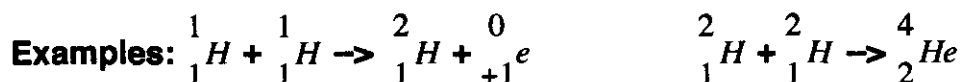
Think of fission as splitting of a nucleus.
Fis / sion
Split / ting

In biology **fission** meant splitting of cells. In chemistry **fission** means splitting of nuclei.

Note Packet # 8

Nuclear Fusion: Nuclear fusion releases the most energy of any reaction at all. Nuclear fusion joins light (small) nuclei to form a larger nucleus. The fuels for fusion are usually the isotopes of hydrogen; ${}^1_1\text{H}$ proton; ${}^2_1\text{H}$ deuteron; or ${}^3_1\text{H}$ triton.

Fusion is the nuclear reaction that powers the sun and the stars. Our sun is a giant fusion reactor, converting hydrogen into helium. Obviously, the sun releases a lot of energy.



Fusion is not used in nuclear reactors on Earth. The reacting particles for fusion are nuclei. Nuclei have + charges. Like charges repel each other. To initiate (start) a fusion reaction nuclei must be brought very close together. Very high temperatures must be attained to bring the nuclei close enough together to initiate a fusion reaction. The temperature required to start nuclear fusion is approximately 40 000 000 K. Such high temperatures are required to provide the kinetic energy required to overcome the repulsive forces between the + reacting nuclear particles. There is presently no container that can contain material at such a high temperature.

Note Packet # 8

Half-life: A radioactive isotope is known as a radioisotope. Radioisotopes decay (change) at specific rates. The rate of decay is measured by **half-life**. Half-life is the amount of time required for 1/2 of a radioisotope to decay (transmute) into another element. Half-life is a very reliable method to date (determine the age of) an object. External factors such as temperature, pressure, moisture, gravity, or time itself do not affect half-life rate. **Nothing changes half-life rate!!!!!!** It remains constant.

Carbon-14 is used to date items that were once alive.

Uranium-238 and **Potassium-40** have very long half-lives and are used to date rocks and meteorites since they are extremely old.

To solve half-life problems it is necessary to set up a half-life table. This will take some practice. Do not attempt to answer half-life questions without setting up a table. Failure to do so may result to injury to your chemistry grade.

To set up a half-life table you will need a starting point. Think of the common chemistry term **at #**, even though half-life doesn't involve atomic #.

a is for the starting amount of radioisotope

t is for time

is for # of half-lives

The top row always gets filled out the same way. 1 0 0

We start with **1** full amount at time **0** and **0** 1/2 lives.

The amount column starts at 1 and each successive column is cut in half: 1, 1/2, 1/4, 1/8, etc.

The 1/2 life column is simply counted 0-4 (or as many as we need).

The column all the way to the left is for a specific amount of material if it is given in the question. Ex: 200 g of original sample.

	Amount of original sample	Time	# of 1/2 lives
	1	time of 0 half-lives 0	0
	1/2	time of 1 half-lives	1
	1/4	time of 2 half-lives	2
	1/8	time of 3 half-lives	3
	1/16	time of 4 half-lives	4

This part of the table is always the same.

Where do you find the length of time of the half-life?

It will either be given to you in the question or you will have to look it up in **Table N**.

Pay attention to the different time units in table N. There are many different ones.

Ex: What is the 1/2 life of Iodine -131? Use table N. Answer 8.07 d

Note Packet # 8

Try this example: What is the $1/2$ life of ^{19}Ne ?

Example:

The following questions can be answered by completing a half-life table for Neon-19. Use Table N to determine the half-life of Neon-19.

	Amount of original sample	Time	# of half-lives
150g	1	0	0
75g	$1/2$	17.2s	1
37.5g	$1/4$	34.4s	2
18.75g	$1/8$	51.6s	3
9.375g	$1/16$	68.8s	4

1. What is the half-life of neon-19? **17.2 s**
2. How many half-lives are required for $1/8$ of an original sample of ^{19}Ne to remain unchanged? **3 half lives**
3. How long will it take for $1/16$ of the original sample to remain? **68.8 s**
4. What fraction of the original sample will remain after 34.4 s? **$1/4$**
5. If the original sample of ^{19}Ne had a mass of 150 g how much would remain after 51.6 s? **18.75g**
6. If the original sample of ^{19}Ne had a mass of 150 g how much would remain after 4 half-lives? **9.375g**
7. What happens to the half-life of ^{19}Ne as time increases? **Nothing!** It remains constant.

Note Packet # 8

Now you try one!

Set up a table!

Don't just guess!

1. How many half-lives are required for 1/16 of an original sample of ^{85}Kr to remain unchanged?
2. What is the half-life of ^{85}Kr ?
3. How long will it take for 1/8 of the original sample to remain?
4. What fraction of the original sample will remain after 32.28y?
5. If the original sample of ^{85}Kr had a mass of 300g how much would remain after 43.04y?
6. If the original sample of ^{85}Kr had a mass of 300g how much would remain after 2 half-lives?
7. What happens to half-life as time increases?

Note Packet # 8

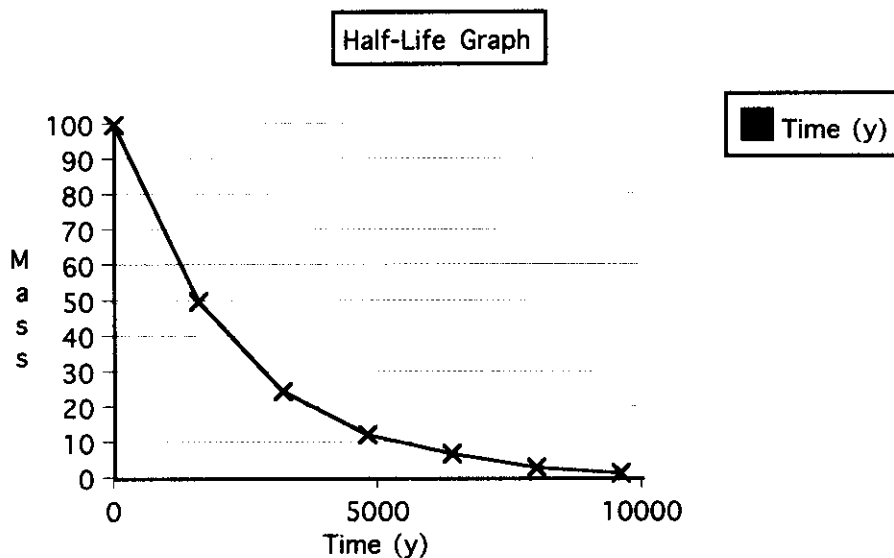
Half-life Graphs: Half-life graphs plot mass vs. time. All half-life graphs have the same general appearance. The mass declines rapidly at first and decreases at a slower rate as time increases.

Ex: Create a half-life graph for mass vs. time for 6 half-lives using 100g of ^{226}Ra .

To solve: Look at Table N to determine the half-life of ^{226}Ra .

The half-life of ^{226}Ra is 1600 y.

Time (y)	Mass (g)	Half-life rate does not change! For ^{226}Ra it will always be 1600 y.
0	100	
1600	50	
3200	25	
4800	12.5	
6400	6.75	
8000	3.375	
9600	1.688	



Important information:

If a radioisotope has a short half-life it will decay (change) rapidly

If a radioisotope has a long half-life it will decay (change) very slowly.

Common question: Which radioisotope will decay the least during a 10 year period?

Iodine-131 Radium-226 Phosphorous-32 Cesium-137

To solve:

You must know that the radioisotope with the longest half-life will decay the least during any time period. Look at table N and compare half-lives. Answer: radium-226

Note Packet # 8

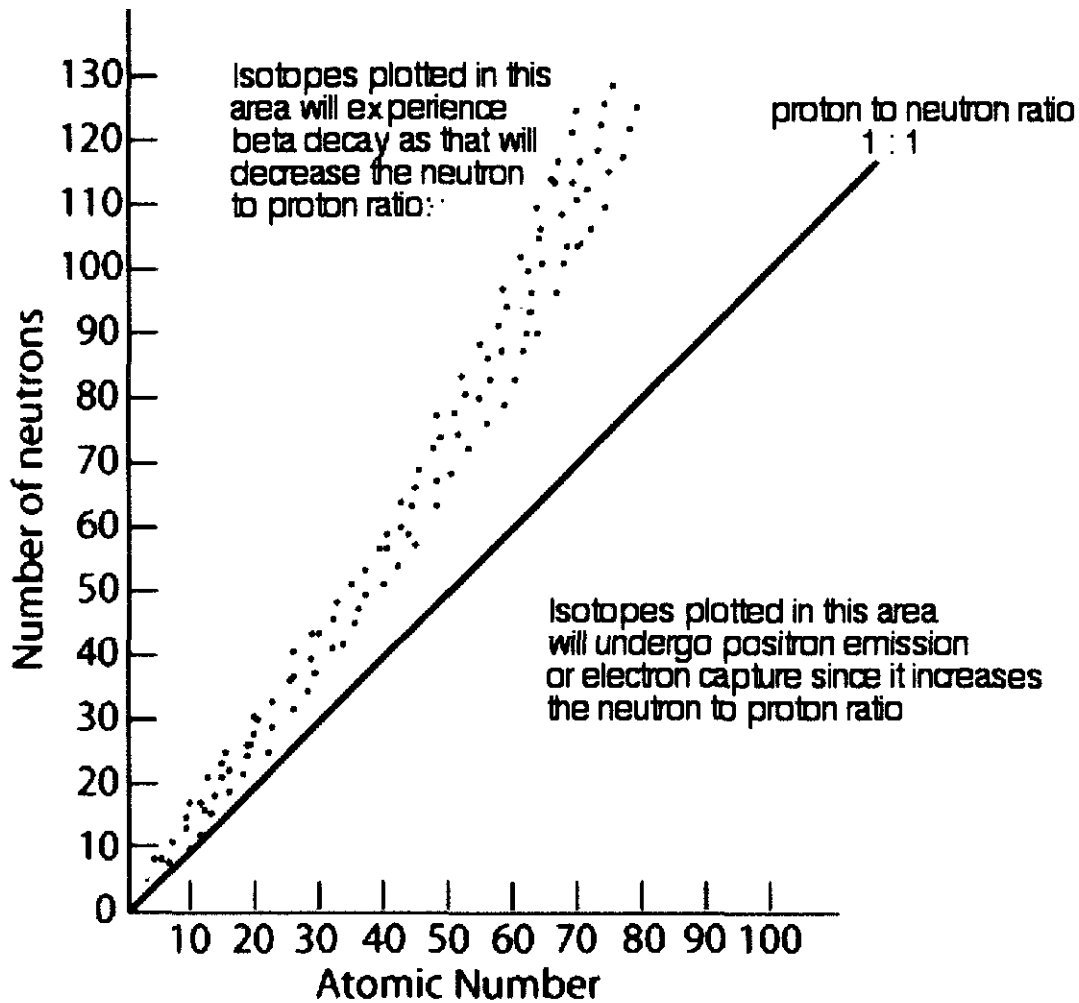
Band of Stability: Different radioisotopes will emit different particles to become more stable.

You may have to interpret a graph that represents which isotopes are unstable and which particles they emit to become more stable.

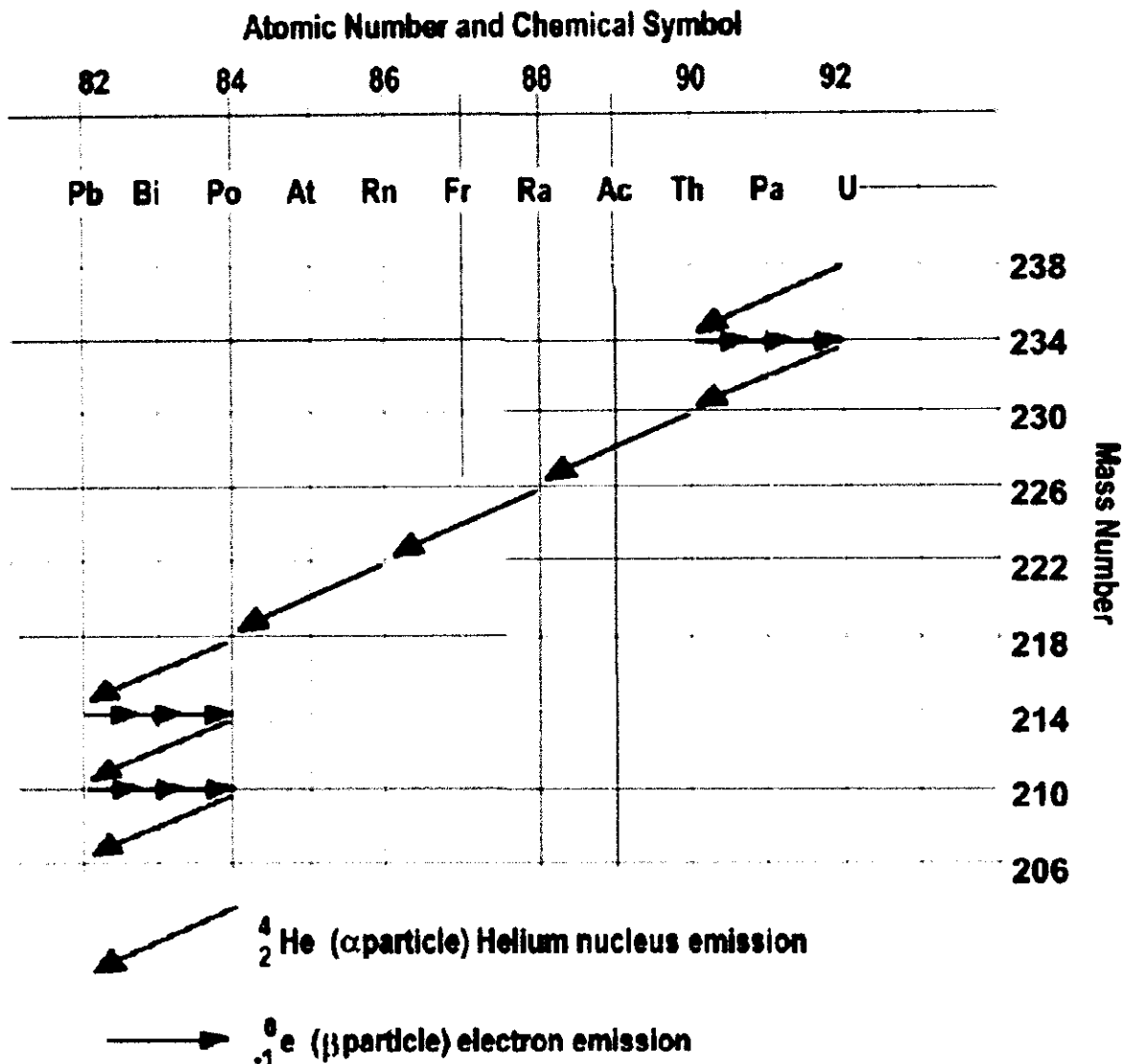
The plotted points are stable nuclei. If the protons vs. neutrons of an unstable nuclide are plotted on this table the point will lie outside of the band of stability. You can use logic and simple arithmetic to determine the particle emitted to reach the band..

The emission of a beta particle ${}_{-1}^0e$ results in the atomic number increasing by 1.

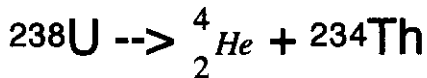
The emission of a positron ${}_{+1}^0e$ results in the atomic number decreasing by 1



Uranium Decay Series



Some unstable isotopes such as uranium-238 become more stable through a series of natural transmutations. Starting with uranium-238 you can follow every step along the way to predict the decay mode and product.



Use the next page to complete all the transmutations until ${}^{206}\text{Pb}$ is formed.

Note Packet # 8

Note Packet # 8

Uses of Radioisotopes include dating of ancient objects, radiotracing, medical treatments, and food preservation.

Dating is the process of determining the age of ancient objects using half-life calculations. See the section on half-life.

Radiotracing uses radioisotopes to trace (follow) normal chemical processes. Radioactive elements (radioisotopes) behave chemically the exact same way as their nonradioactive version. This allows them to be incorporated into normal chemical reactions and followed (traced). They can be followed using a variety of radiation detection techniques.

Carbon-14 is used to trace many organic or biochemical reactions. Radioisotopes can be located by their radioactivity and are used to diagnose diseases such as cancer. Radiotracers ingested by humans must have short half-lives and be easily eliminated by the body. **Technetium-99** is used to locate brain tumors. **Iodine-131** is used to diagnose thyroid problems.

Medical Treatments use radioisotopes to kill cancer cells with measured doses of radiation. Cancer cells are more susceptible to radiation than normal healthy cells. The idea is to kill the cancer cells while leaving the healthy cells alone. **Radium** and **cobalt-60** are used in cancer therapy.

Food Preservation Radiation is used to kill many unwanted organisms that contaminate food. Insects, fungus, mold, and bacteria can be killed with radiation. The radiation passes through the food and leaves nothing behind. When pesticides are used for the same purpose unwanted pesticide residue remains behind and can cause negative health effects.

Nuclear Energy Producing energy from nuclear material is an appealing concept. Nuclear fission can produce enormous amounts of low cost energy. Nuclear energy does not rely on fossil fuels. A properly operating nuclear power plant does not produce smoke or greenhouse gases. However, there are some drawbacks to using nuclear energy. These include transporting, storing, and securing both nuclear fuels and waste. Also if the nuclear power plant malfunctions there can be a radiation leak or explosion.

Note Packet # 8

Nuclear Debate Nuclear energy is often the topic of heated debate. Mankind benefits from and is haunted by nuclear technology. There are many pros and cons to the debate. Make a list of each.

Pros

Cons