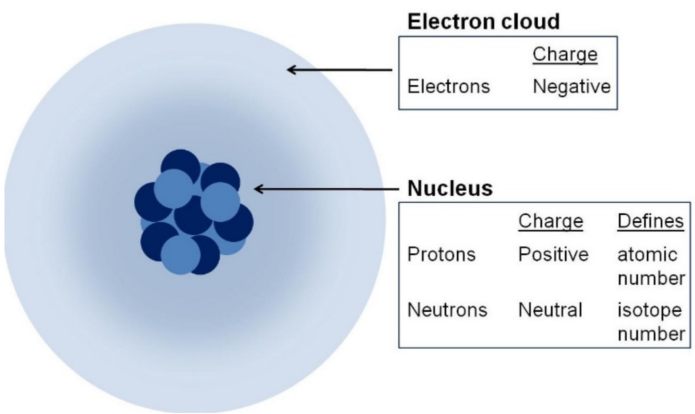
NUCLEAR CHEMISTRY

Learning Objectives:

I. Radioactivity



(Illustration by Leila Ross)

Radioactivity is a nuclear phenomenon. Protons and neutrons are attracted by strong nuclear force in the nucleus. In a neutral atom when neutron/proton ratio becomes unstable (usually n/p=1.) then the atomic nucleus spontaneously disintegrates to another new atomic nucleus and radiation is emitted. When the nuclei radiate, both atomic number and mass number change and the element is converted to a completely new element and energy is released as a form of radiation. The reaction takes place in the nucleus of the atom. For example, Uranium decays to Lead by spontaneous emission. This phenomenon is called radioactivity.

Usually, the symbol of an atom is expressed as:

$$^{A}_{Z}X$$

Z= atomic number

A= mass number

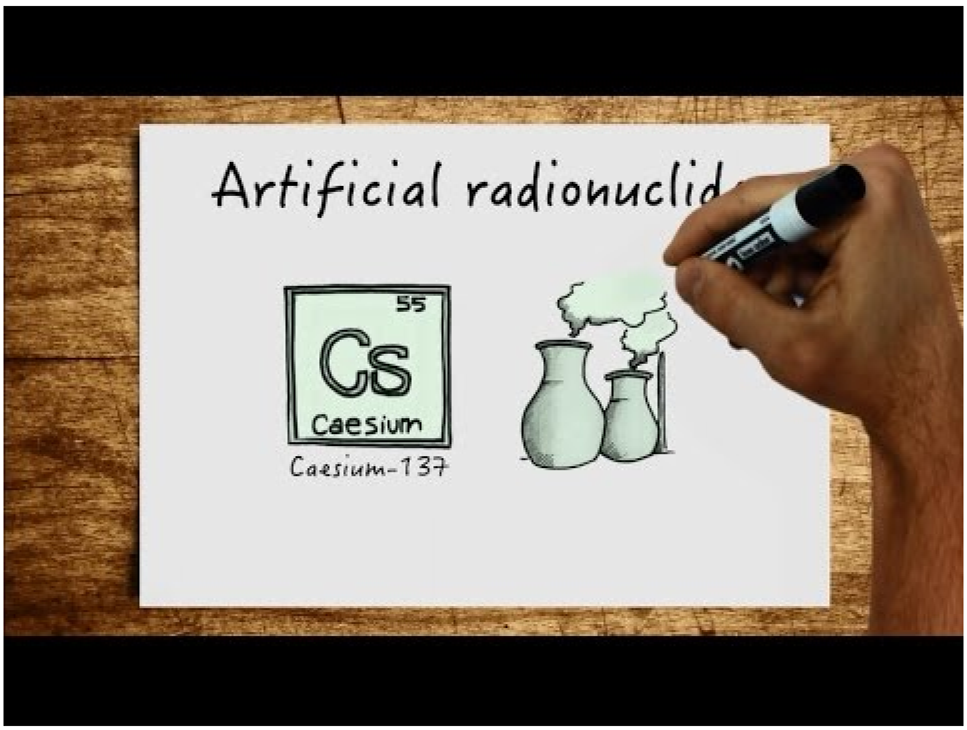
The process through which unstable nuclei become stable is called radioactive Decay. After the radioactive decay, the element becomes a new element (X') with new atomic and mass number.

The natural radiation that is always present in the environment, including radiation from the sun, stars and the earth itself. The typical average exposure in the U.S. from background radiation is about 310 millirems per year. Sometimes it is called background radiation. Humans cannot see, smell or feel the radiation, it can be only detected through instruments.

Materials that emit radiation are called **radioactive** materials. Radioactivity comes from the atomic nucleus composition i.e. ratio between neutron and proton in the nucleus and not from the electron cloud that surround nucleus. For example, $^{16}_{8}O$ is a stable isotope where the nucleus contains 8 protons and 8 neutrons. But $^{18}_{8}O$ is radioactive isotope due to unfavorable neutron/proton ratio. Some isotopes are radioactive, others are stable and do not emit any radiation. Most of the heavy elements after lead(Pb-206) have radioactive isotopes.

Watch the following video:

https://www.youtube.com/watch?v=dY10s71rv80



Chapter Objectives

II. History of Radioactivity

MARIE CURIE, HENRI BECQUEREL, WILHELM RÖNTGEN

The modern understanding of ionizing radiation got its start in 1895 with Wilhelm Röntgen. he discovered that, despite covering one in a screen to block light, there seemed to be rays penetrating through to react with a barium solution on a screen he'd placed nearby. he named them "X-Rays" temporarily as a designation of something unknown, and the name stuck.

This discovery was followed in 1896 by Henri Becquerel's discovery that Uranium(U) salts gave off similar rays naturally. Though originally thinking that the rays were given off by phosphorescent Uranium salts after prolonged exposure to the sun, he eventually abandoned this hypothesis.

Although it was Henri Becquerel that discovered the phenomenon, it was his doctoral student, Marie Curie, who named it: radioactivity. She would go on to do much more pioneering work with radioactive materials, including the discovery of additional radioactive elements: Thorium,(Th) Polonium(Po), and Radium(Ra). She was awarded the Nobel Prize twice, once alongside Henri Becquerel and her husband Pierre in Physics for their work with radioactivity, and again years later in Chemistry for her discovery of radium(Ra) and polonium(Po).

Watch the following video:

https://www.youtube.com/watch?v=azwesgfZ1b8

Chapter Objectives

III. Different types of Radiation

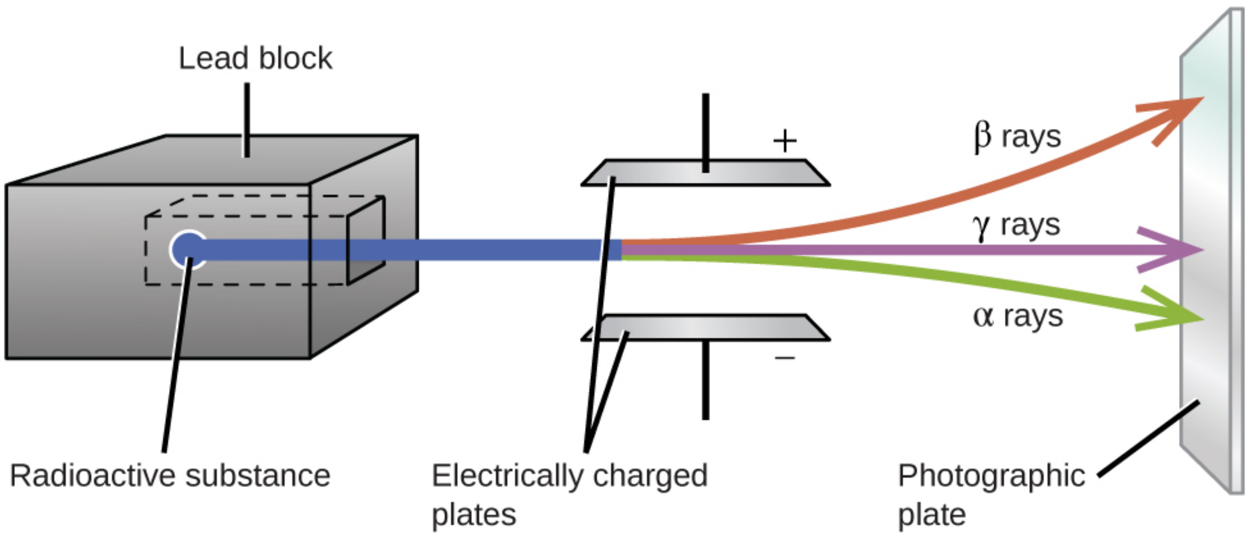
A radioactive nucleus can emit α (alpha) particle, β (beta) -particles, positron or γ (gamma) rays. An α particle is high energy nucleus that contains two protons and two neutrons, symbolized as $^{4}_{2}He$

A β particle is equivalent to high energy electron, can be symbolized as $^{0}_{-1}e$.

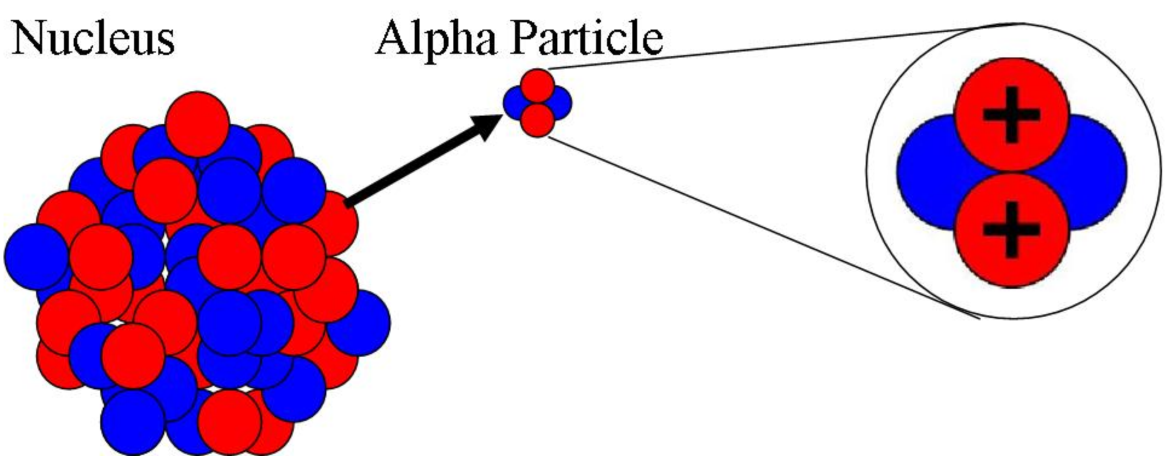
A positron is an antiparticle of a beta particle. A positron has +1 charge and negligible mass(β^{+}).

A gamma ray is high energy radiation with no mass and charge. Symbol of **γ ray is $^{0}_{0}\gamma$.**

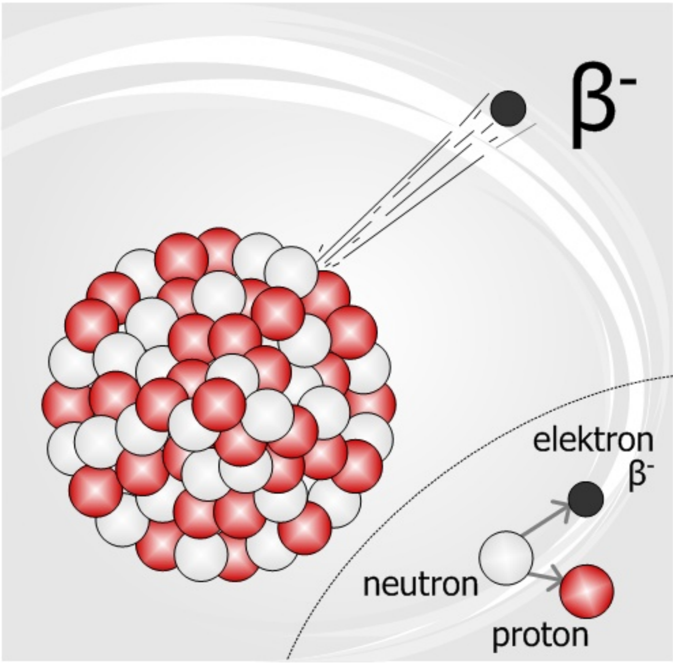
Below is the diagram where radioactive substances inside a lead block emit radiation and how they behave differently when electrical field is applied to the radiations.



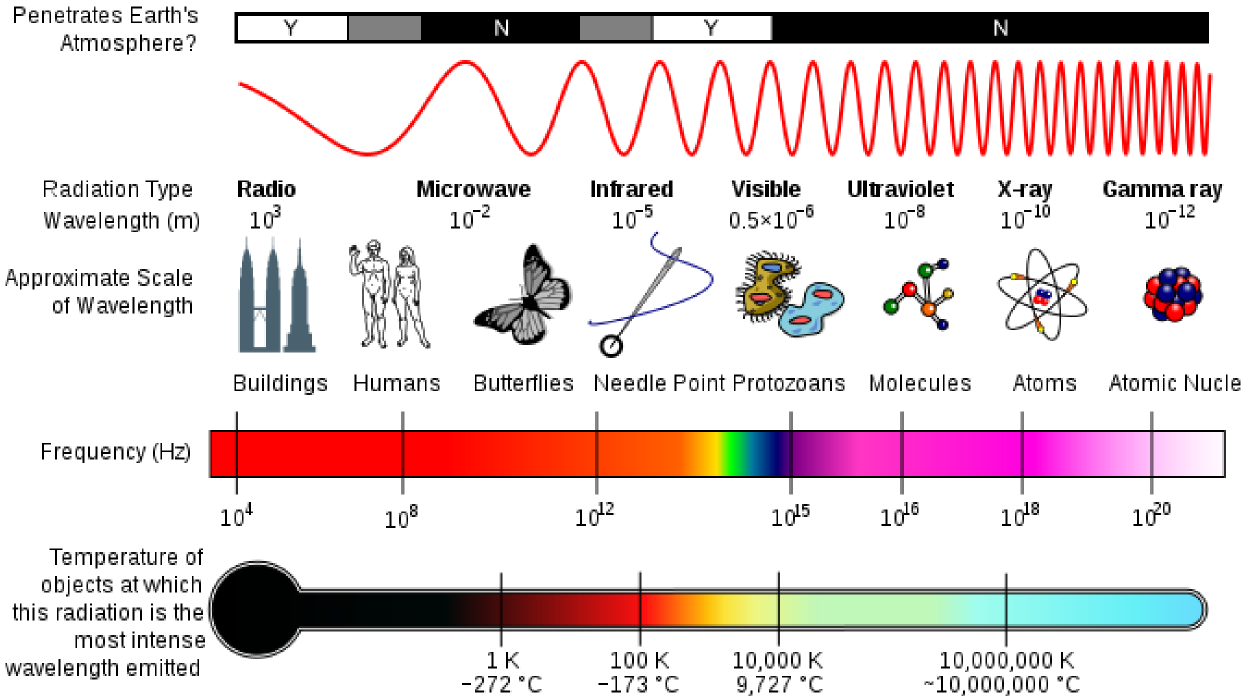
An alpha particle, because it's very heavy and has a very large charge, doesn't go very far at all. This means an alpha particle can't even get through a sheet of paper. An alpha particle outside your body won't even penetrate the surface of your skin. But, if you inhale or ingest material that emits alpha particles, sensitive tissue like the lungs can be exposed. This is why high levels of radon are considered a problem in your home. The ability to stop alpha particles so easily is useful in smoke detectors, because a little smoke in the chamber is enough to stop the alpha particle and trigger the alarm.



Beta particles go a little farther than alpha particles. You could use a relatively small amount of shielding to stop them. They can get into your body but can't go all the way through. To be useful in medical imaging, beta particles must be released by a material that is injected into the body. They can also be very useful in cancer therapy if you can put the radioactive material in a tumor. Positively charged but equivalent of mass of one electron are positron.

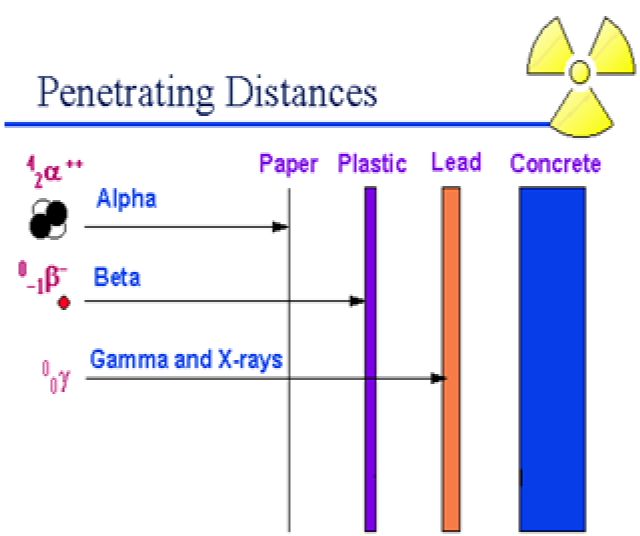


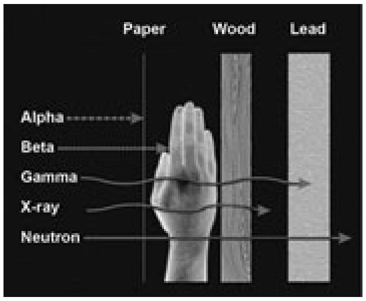
Gamma rays and x-rays can penetrate through the body. This is why they are useful in medicine—to show whether bones are broken or where there is tooth decay, or to locate a tumor. Shielding with dense materials like concrete and lead is used to avoid exposing sensitive internal organs or the people who may be working with this type of radiation. For example, the technician who does my dental x-rays puts a lead apron over me before taking the picture. That apron stops the x-rays from getting to the rest of my body. The technician stands behind the wall, which usually has some lead in it, to protect him or herself.



Radiation is all around us (called background radiation), but that is not a reason to be afraid. Different types of radiation behave differently, and some forms can be very useful.

The diagram below shows the penetrating power of different types of radiations.





Summary of all types of radiations:

Name	Symbol(s)	Representation	Description
Alpha particle	${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$		(High-energy) helium nuclei consisting of two protons and two neutrons
Beta particle	${}^{0}_{1}e$ or ${}^{0}_{-1}\beta$		(High-energy) electrons
Positron	${}^{0}_{+1}e$ or ${}^{0}_{+1}\beta$		Particles with the same mass as an electron but with 1 unit of positive charge
Proton	${}^{1}_{1}H$ or ${}^{1}_{1}p$		Nuclei of hydrogen atoms
Neutron	${}^{1}_{0}n$		Particles with a mass approximately equal to that of a proton but with no charge
Gamma ray	γ	 γ	Very high-energy electromagnetic radiation

Here is the summary of characteristics of all three types of radiation

Characteristic	Alpha Particles	Beta Particles	Gamma Rays
Symbols	α, ${}^{4}_{2}He$	β, ${}^{0}_{-1}e$	γ
Identity	Helium nucleus	electron	Electromagnetic radiation
Charge	2+	1-	None
Mass Number	4	0	0
Penetrating Power	Minimal (will not penetrate skin)	Short (will penetrate skin and some tissues slightly)	Deep (will penetrate tissues deeply)

Watch the following video:

https://www.youtube.com/watch?v=tYmMtSWPQEI

Questions:

1. Identify the type of radiation in following symbols of radiation (S):

a) $^{0}_{-1}S$

b) $^{4}_{2}S$

c) $^{0}_{+1}S$

2. Which nuclear emission has greatest mass and least penetrating power?

Ans: 1. a)

b) alpha

c) positron

2. Alpha

Chapter Objectives

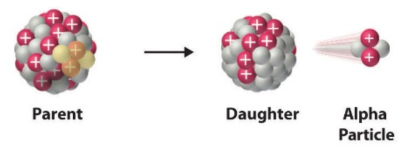
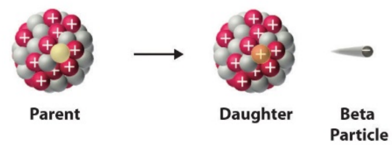
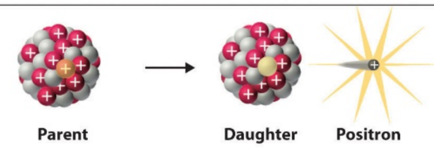
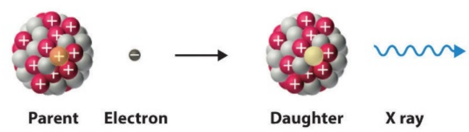
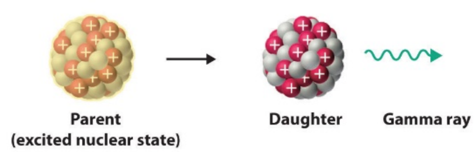
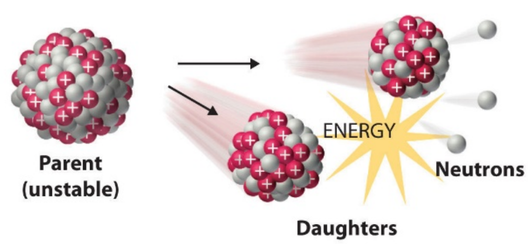
IV. Nuclear Reactions

Radioactive decay is the process by which the nucleus of an unstable atom loses energy by emitting radiation, including alpha particles, beta particles, gamma rays and positron emission or electron capture.

Most of the nuclides heavier than Lead (Pb) have been identified are radioactive. They spontaneously emit a particle, transforming themselves in the process into a different nuclide . In this section we discuss the two most common situations, the emission of an α particle (alpha decay) and the emission of an electron (beta decay).

Nuclear reaction is the conversion of one chemical element or an isotope into another chemical element. This process is also called nuclear transmutation. **In an equation for a nuclear reaction, the sum of the mass numbers (A) must be equal on both sides of the equation.** You can check the correctness of any of these nuclear reactions by noting that the total mass number is the same before and after the reaction; also the total atomic number is the same. Protons and neutrons are not created or destroyed; they are just shifted around. In gamma ray emission the nucleus doesn't change, only transforms from radioactive to stable nucleus. The original nucleus before emission is called **parent** nucleus and the newly formed nucleus after radiation is called **daughter** nucleus.

Here are six fundamentally different kinds of nuclear decay reactions, and each releases a different kind of particle or energy. The essential features of each reaction are shown in Figure below.

Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	
Beta decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}X' + {}^{0}_{-1}\beta$	
Positron emission	${}^{0}_{+1}\beta$	${}^{A}_{Z}X \longrightarrow {}_{Z-1}^{A}X' + {}^{0}_{+1}\beta$	
Electron capture	X rays	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}_{Z-1}^{A}X' + \text{X ray}$	
Gamma emission	${}^{0}_{0}\gamma$	${}^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$	
Spontaneous fission	Neutrons	${}^{A+B+C}_{Z+Y}X \longrightarrow {}^{A}_{Z}X' + {}^{B}_{Y}X' + C\,{}^{1}_{0}n$	

Common Modes of Nuclear Decay

Alpha Decay

Many nuclei with mass numbers greater than 200 undergo **alpha (α) decay**, which results in the emission of a helium-4 nucleus as an **alpha (α) particle**, ${}^{4}_{2}\alpha$

. The general reaction is as follows:

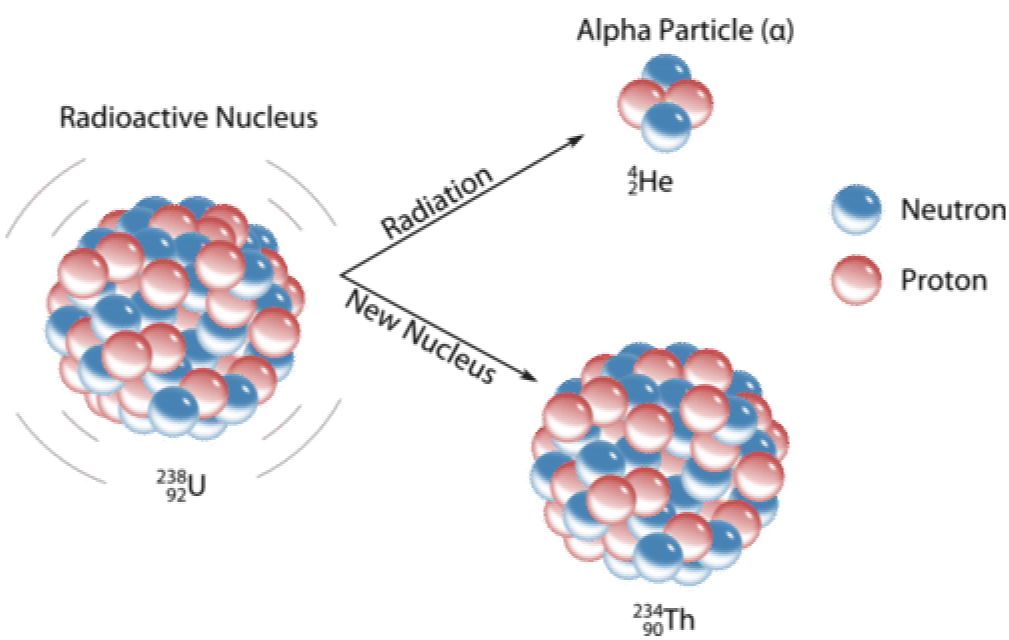
$^{A}{}_{Z}\mathrm{X(parent)} \rightarrow {}^{A-4}{}_{Z-2}\mathrm{X'(daughter)} + {}^{4}{}_{2}\alpha$ (alpha particle)

The daughter nuclide contains two fewer protons and four fewer neutrons than the parent. Thus α-particle emission produces a daughter nucleus with a mass number $A - 4$ and a nuclear charge $Z - 2$ compared to the parent nucleus. Radium-226, for example, undergoes alpha decay to form Radon-222:

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

Another example:

$$^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$$



Because nucleons are conserved in this and all other nuclear reactions, the sum of the mass numbers of the products, 222 + 4 = 226, equals the mass number of the parent. Similarly, the sum of the atomic numbers of the products, 86 + 2 = 88, equals the atomic number of the parent. Thus the nuclear equation is balanced.

Just as the total number of atoms is conserved in a chemical reaction, the total number of nucleons is conserved in a nuclear reaction.

Example: Write alpha decay of Cu-68

${}^{68}_{29}Cu \rightarrow {}^{4}_{2}He + {}^{64}_{27}Co$

Beta Decay

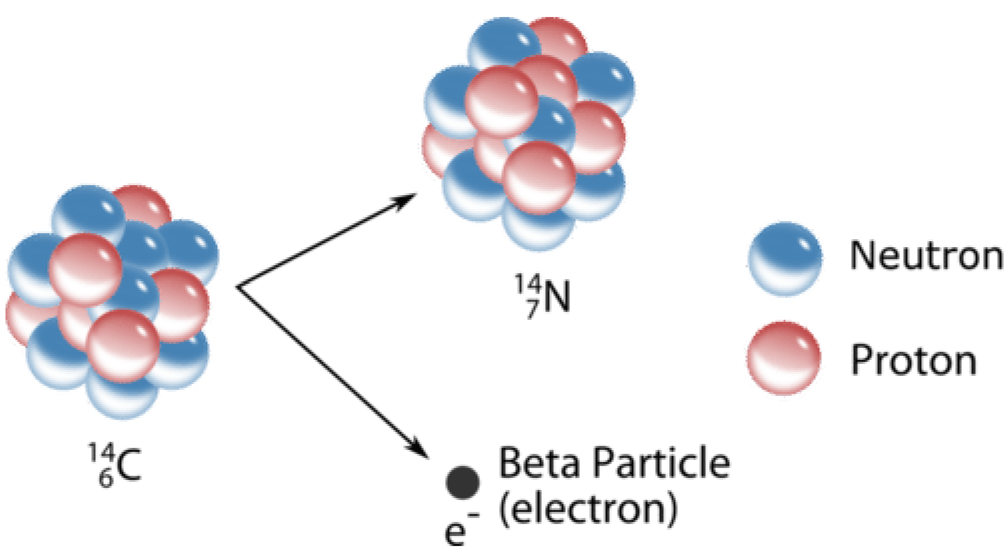
Nuclei that contain too many neutrons often undergo **beta (β) decay**, in which a neutron is converted to a proton and a high-energy electron that is ejected from the nucleus as a β particle:

The general reaction for beta decay is therefore

$${}^{A}_{Z}X(\text{parent}) \rightarrow {}^{A}_{Z+1}X'(\text{daughter}) + {}^{0}_{-1}\beta(\text{beta particle})$$

Although beta decay does not change the mass number of the nucleus, it does result in an increase of +1 in the atomic number because of the addition of a proton in the daughter nucleus. Thus beta decay decreases the neutron-to-proton ratio, moving the nucleus toward the band of stable nuclei. For example, carbon-14 undergoes beta decay to form nitrogen-14:

$${}^{14}_{6}\mathbf{C} \longrightarrow {}^{14}_{7}\mathbf{N} + {}^{0}_{-1}\beta$$



Once again, the number of nucleons is conserved, and the charges are balanced. The parent and the daughter nuclei have the same mass number, 14, and the sum of the atomic numbers of the products is 6, which is the same as the atomic number of the carbon-14 parent.

Example: Write Beta decay of P-18

$^{18}_{15}P \rightarrow {}^{0}_{-1}e + {}^{18}_{16}O$

Gamma Emission

Many nuclear decay reactions produce daughter nuclei that are in a nuclear excited state, which is similar to an atom in which an electron has been excited to a higher-energy orbital to give an electronic excited state. Just as an electron in an electronic excited state emits energy in the form of a photon when it returns to the ground state, a nucleus in an excited state releases energy in the form of a photon when it returns to the ground state. These high-energy photons are γ rays. **Gamma** (γ) **emission** can occur virtually instantaneously, as it does in the alpha decay of uranium-238 to thorium-234, where the asterisk denotes an excited state:

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th^{*}(\text{excitednuclearstate}) + {}^{4}_{2}\alpha - \longrightarrow {}^{234}_{90}Th + {}^{0}_{0}\gamma$$

If we disregard the decay event that created the excited nucleus, then

$$^{234}_{88}Th^{*} \longrightarrow {}^{234}_{88}Th + {}^{0}_{0}\gamma$$

or more generally,

$$^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

Gamma emission can also occur after a significant delay. For example, technetium-99*m* has a half-life of about 6 hours before emitting a γ ray to form technetium-99 (the *m* is for metastable). Because γ rays are energy, their emission does not affect either the mass number or the atomic number of the daughter nuclide. Gamma-ray emission is therefore the only kind of radiation that does not necessarily involve the conversion of one element to another, although it is almost always observed in conjunction with some other nuclear decay reaction. Here is an example.

$$^{125}_{53}I^{*} \longrightarrow {}^{125}_{53}I + \gamma$$

In general nuclear reaction of an element X can be represented in following way:

Alpha emission:

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Beta emission:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

Gamma emission:

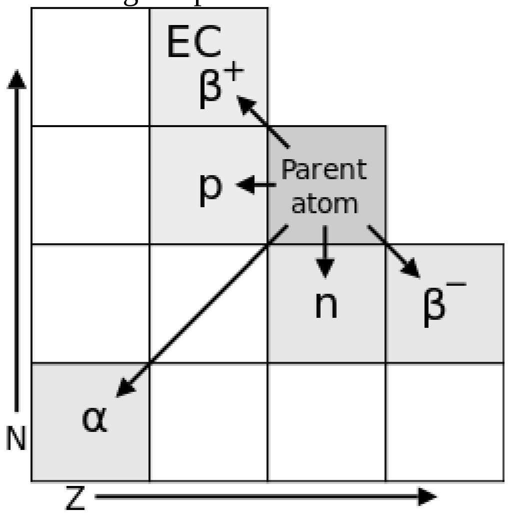
$$^{A}_{Z}X^{*} \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

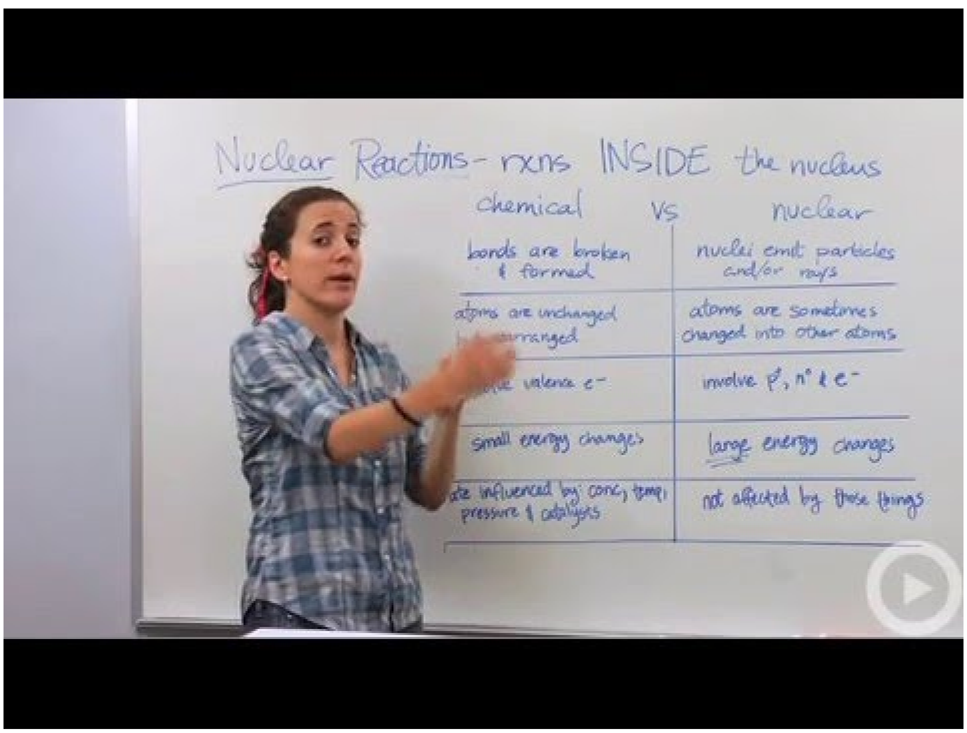
Positron emission: The symbol of positron is β^{+}. Carbon-11 isotope is a positron emitter.

$$^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{-1}e$$

In the above example, both sides of the equation have same mass numbers and atomic numbers 11 and 6 respectively.

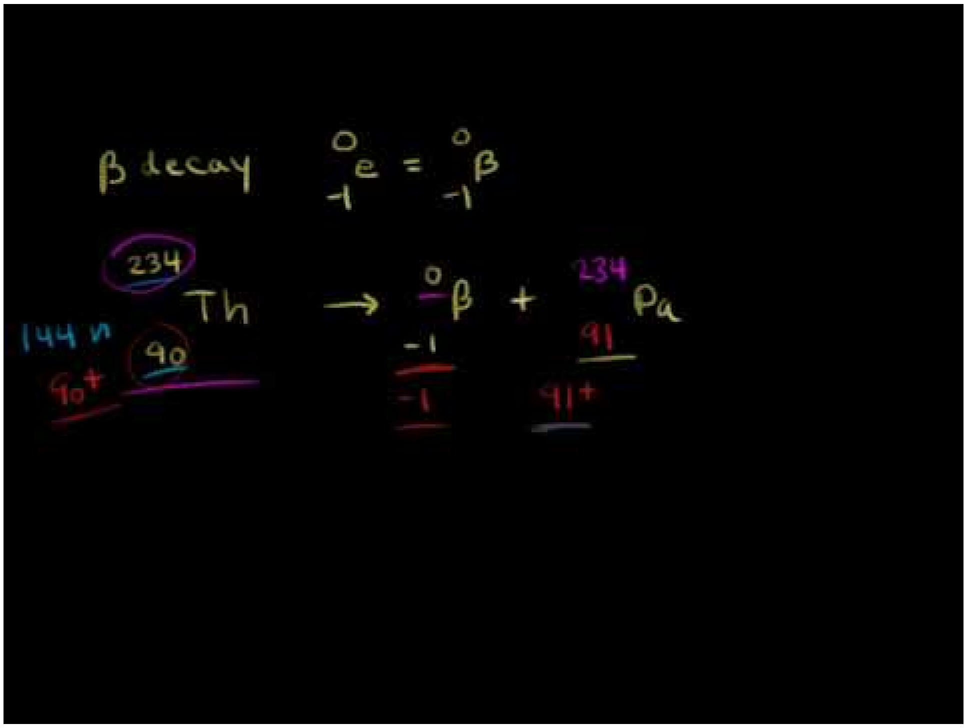
The change in proton and neutron number is shown below with the diagram:





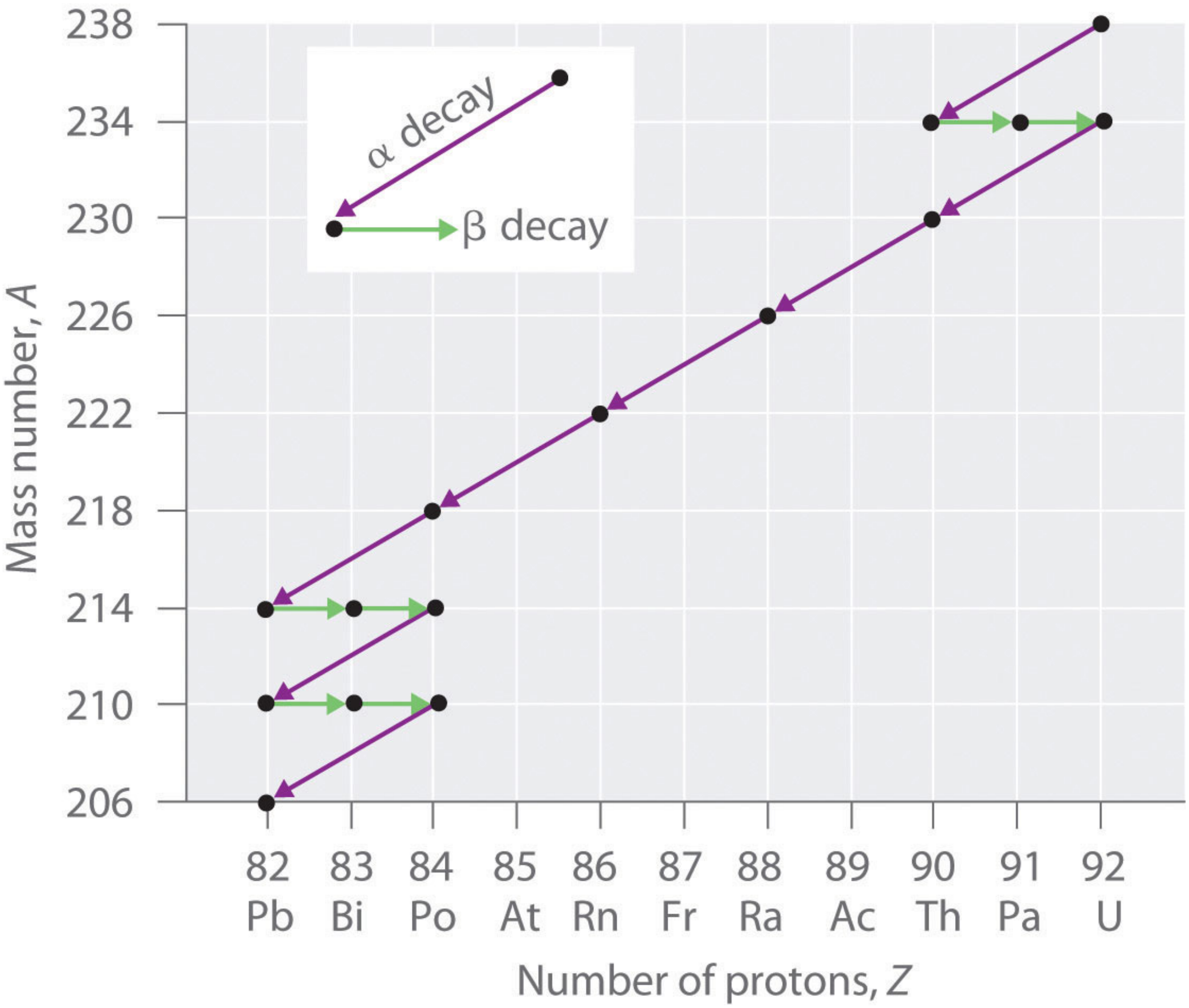
https://www.youtube.com/watch?v=EaFeix_IiN4

Here is another video on how to write nuclear equation:



https://www.youtube.com/watch?v=mzLOT6uOfO4

A radioactive atom can undergo series of apha and beta decay to finally reach to end product, a lead (PB) nucleus. Find below the decay of U-238



Nuclear reactions are not restricted to alpha, beta or gamma radiation. Sometimes a radioactive isotope is bombarded with a neutron or another radioisotopes to produce new radioisotopes. When one or more element is changed into two or elements it is called **radioactive transmutation.**

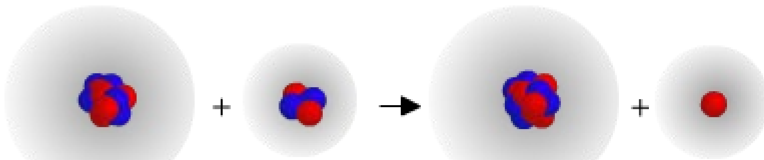
For example, in the reaction below, one nitrogen radioactive nucleus is bombarded by alpha particle to produce oxygen and hydrogen nuclei. Here also, the same rile i.e., total number of atomic number Z and total mass number A should be same on the both sides of the equation.

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

$$^{250}_{98}\mathrm{Cf} + ^{11}_{5}\mathrm{B} \longrightarrow ^{257}_{103}\mathrm{Lr} + 4^{1}_{0}\mathrm{n}$$

Find below an example of neutron bombardment:

$$^{232}_{90}\mathrm{Th} + ^{1}_{0}\mathrm{n} \longrightarrow ^{233}_{90}\mathrm{Th};$$



$${}_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{8}O^{17} + {}_{1}H^{1}$$

TRY THIS OUT!

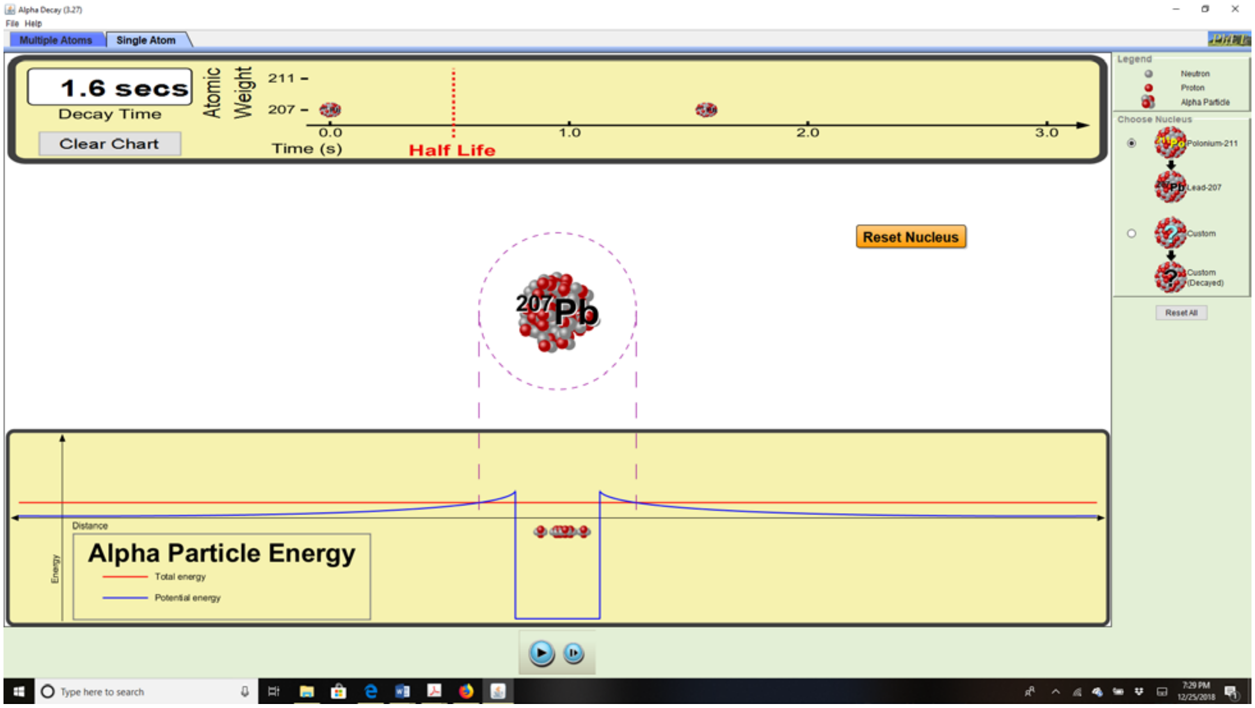
https://phet.colorado.edu/en/simulation/legacy/alpha-decay

Go to the simulation site below and click on the single atom.

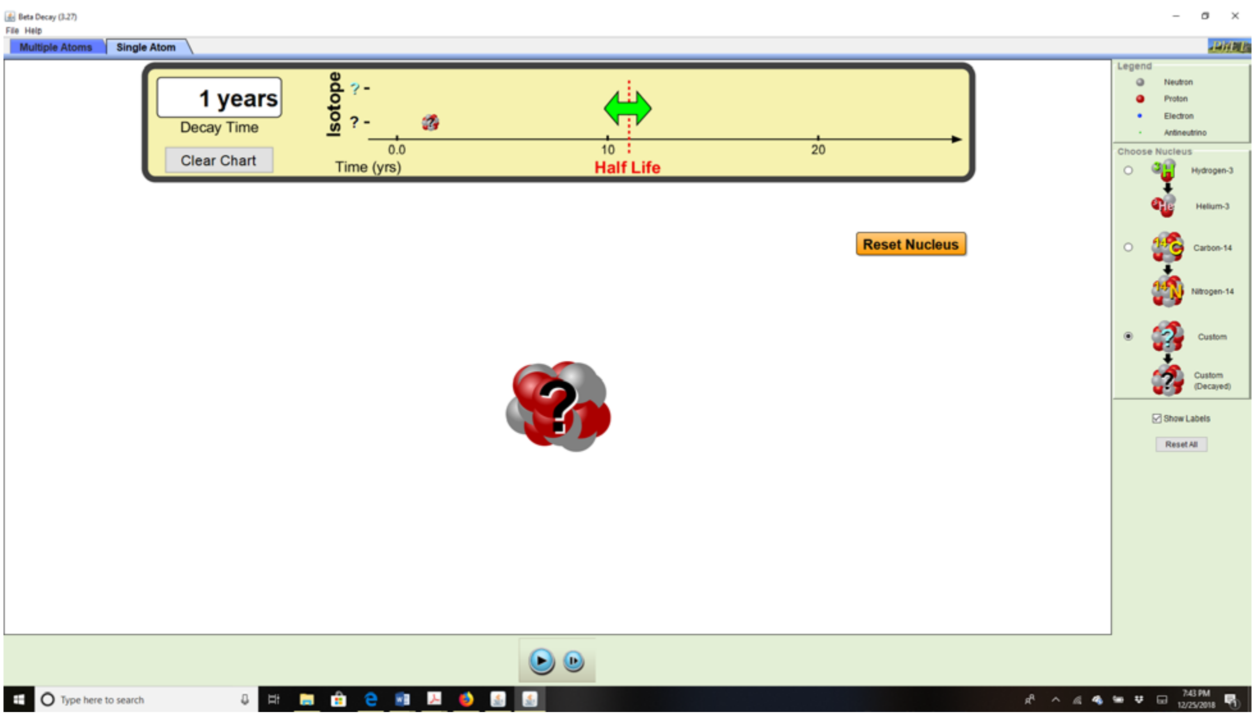
1) What is the symbol of parent nuclei(starting material)?
2) How many protons and neutrons does it have?
3) What is the daughter nucleus (product) of the reaction?
4) How many protons and neutrns does it have?
5) What is the symbol of the radiation?
6) Write the equation for nuclear reaction.
7) How long does it take to radiate?

Now Click on the custom nuclei

1) Can you identify the unknown element?
2) Write the equation for the decay reaction



https://phet.colorado.edu/en/simulation/legacy/beta-decay



Activity:
Go to the simulation site above and click on the single atom. Click on the 1st example.

8) What is the symbol of parent nuclei(starting material)?
9) How many protons and neutrons does it have?
10) What is the daughter nucleus (product) of the reaction?
11) How many protons and neutrns does it have?
12) What is the symbol of the radiation?
13) Write the equation for nuclear reaction.
14) How long does it take to radiate?

Now Click on the custom nuclei

3) Can you identify the unknown element?
4) Write the equation for the decay reaction

Questions:

1. Given the reaction: ${}^{60}_{28}Co \rightarrow {}^{60}_{29}Ni + {}^{0}_{-1}e$, is an example of beta emission

a) True
b) False

2. Write a nuclear equation of for the decay of Iridium-192 with beta and alpha emission.

Ans: 1. a) True

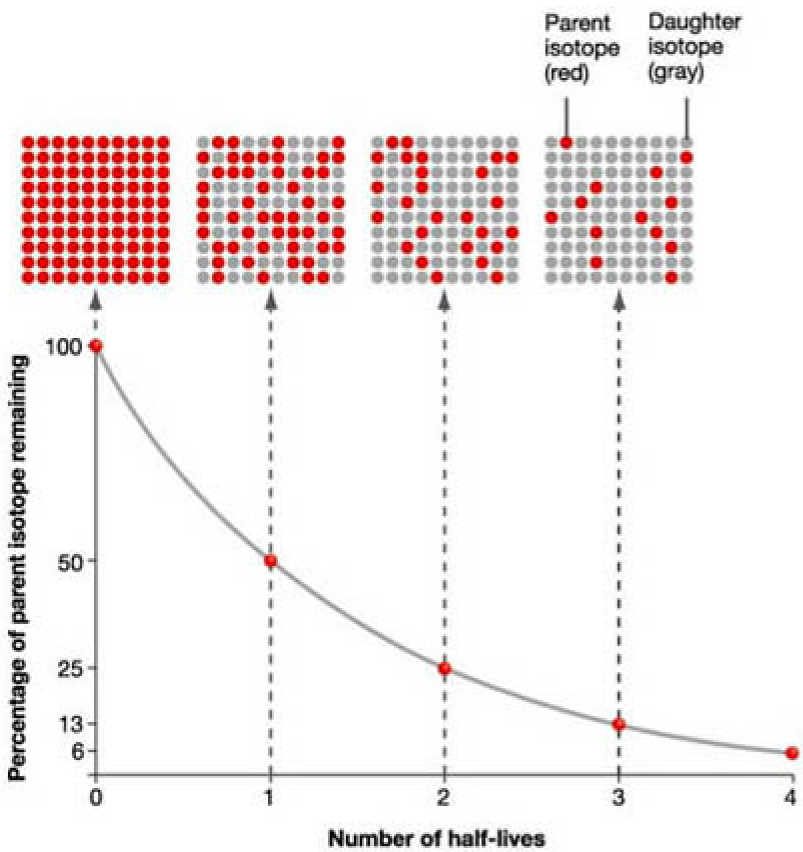
2. ${}^{192}_{77}Ir \rightarrow {}^{192}_{78}Pt + {}^{0}_{-1}e$ (beta decay)
${}^{192}_{77}Ir \rightarrow {}^{188}_{75}Pt + {}^{4}_{2}He$ (alpha decay)

Chapter Objectives

V. Half life

Radioactive atoms are unstable. They become stable through decays. The **half-life** is the time it takes for one half of a radioactive sample to decay. Knowing the half-life and amount of radioactive substance, one can calculate how much sample remains after a period of time. The half -life of an isotope is a physical property. The value can be from fractions of a second to billions of years. Half -life values are constant. There is no way to speed up or slow down this natural process. The diagram below shows the exponential plot of percentage of radioactive isotopes versus remaining vs. number of half-lives. If a radioactive nucleus starts with 100 g or 100 molecules (100%) amount, after each half-life the amount gets decreased to half.

100% $\xrightarrow[\text{1st half life}]{}$ 50% $\xrightarrow[\text{2nd half life}]{}$ 25% $\xrightarrow[\text{3rd Half life}]{}$ 12.5%



Theoretically, a radioactive substance should emit radiation for infinite period of time. As evident from the figure above. In reality, radiation decays to 0.01% after ten half lives.

Here is the table of common radioisotopes and their half-lives.

Table of Selected Half-lives					
Element	**Mass Number**	**Half-Life**	**Element**	**Mass Number**	**Half-Life**
Uranium	238	4.5 billion years	Californium	251	800years
Neptunium	240	1 hour	Nobelium	254	3seconds
Plutonium	243	5 hours	Carbon	14	5730years
Americium	246	25 minutes	Carbon	16	0.74seconds

The half life of a radioisotope is independent of temperature and pressure and only characteristic properties of that isotope. It only gives us information about how slow or how fast c chemical reaction occurs. Radioactive isotopes with shorter half lives are preferred in medical field due to less harmful side effects.

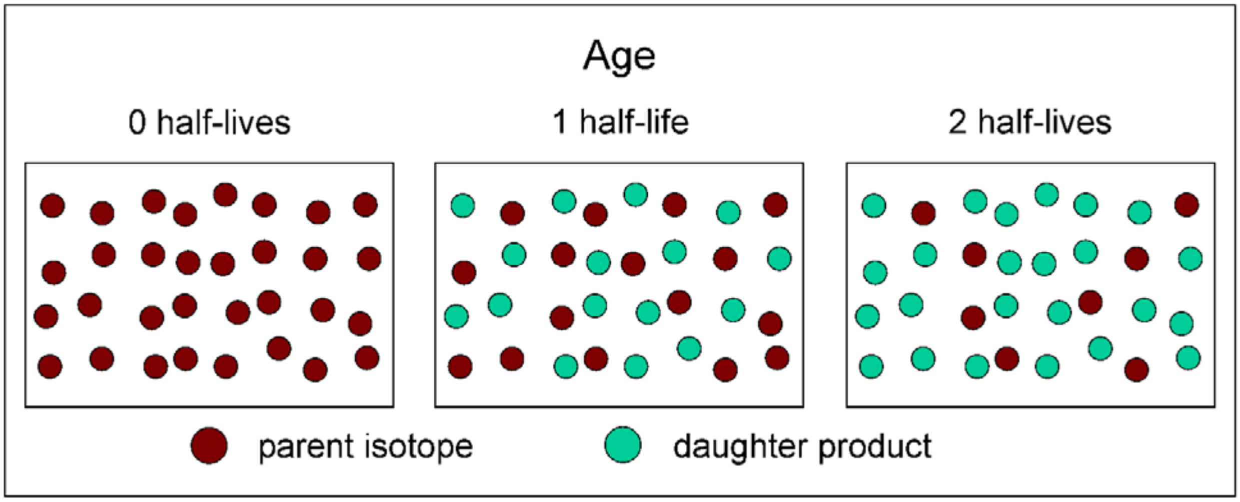
We can determine the amount of a radioactive isotope remaining after a given number half-lives by using the following expression:

amount remaining=initial amount×(1/2)^n

where *n* is the number of half-lives. This expression works even if the number of half-lives is not a whole number.

Number of half-lives elapsed	Fraction remaining	Percentage remaining
0	$^1/_1$	100
1	$^1/_2$	50
2	$^1/_4$	25
3	$^1/_8$	12.5
4	$^1/_{16}$	6.25
5	$^1/_{32}$	3.125
6	$^1/_{64}$	1.563
7	$^1/_{128}$	0.781
...	...	...
n	2^{-n}	$100/(2^n)$

Here is another diagram on parent/daughter amount after one and two half lives are spent.



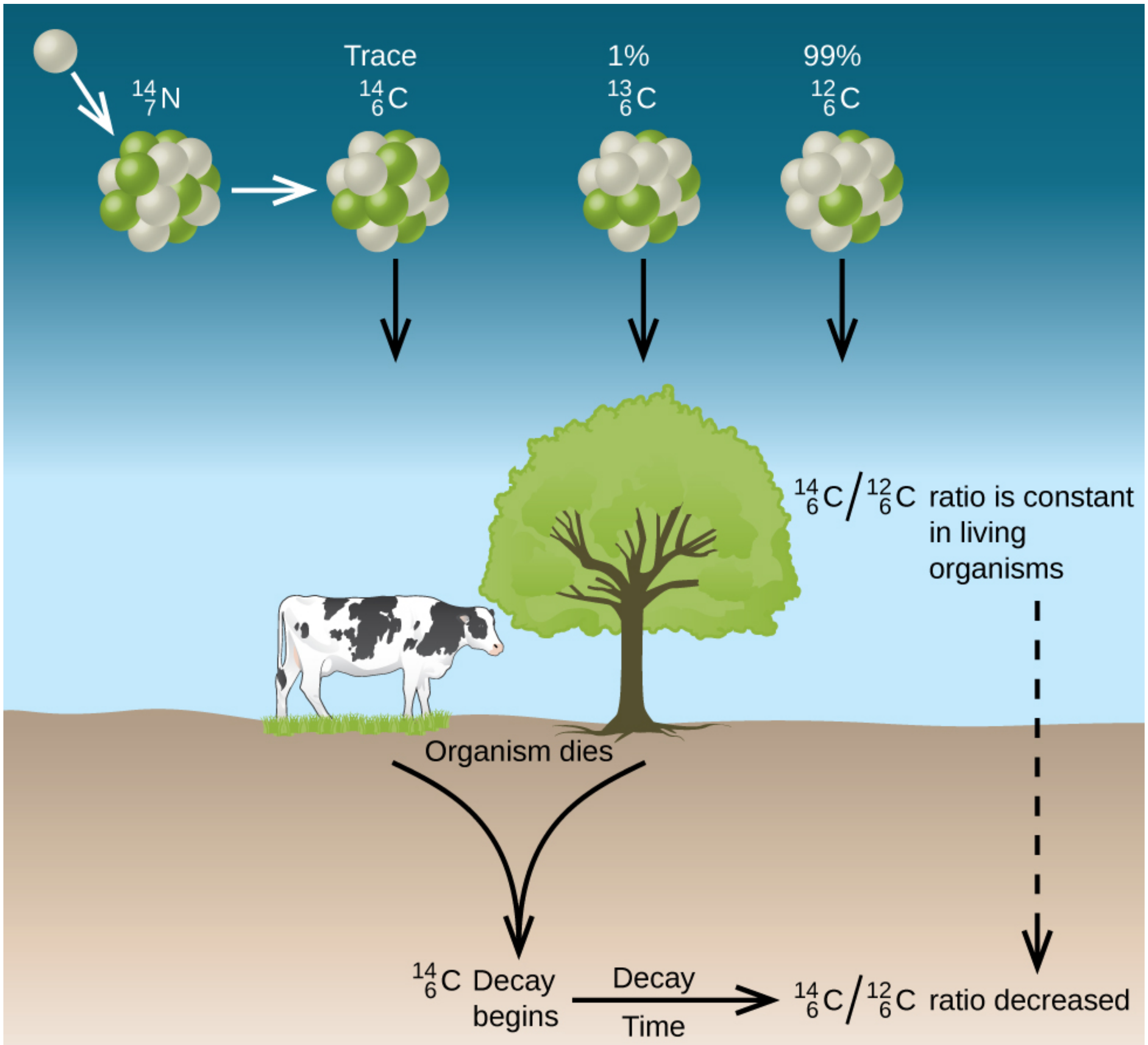
Application of half life: Radioactive dating:

Radiocarbon dating (also referred to as carbon **dating** or carbon-14 **dating**) is a method for determining the age of an object containing organic material by using the properties of **radiocarbon**, a radioactive isotope of carbon. The method was developed in the late 1940s by Willard Libby, who received the Nobel Prize in Chemistry for his work in 1960.

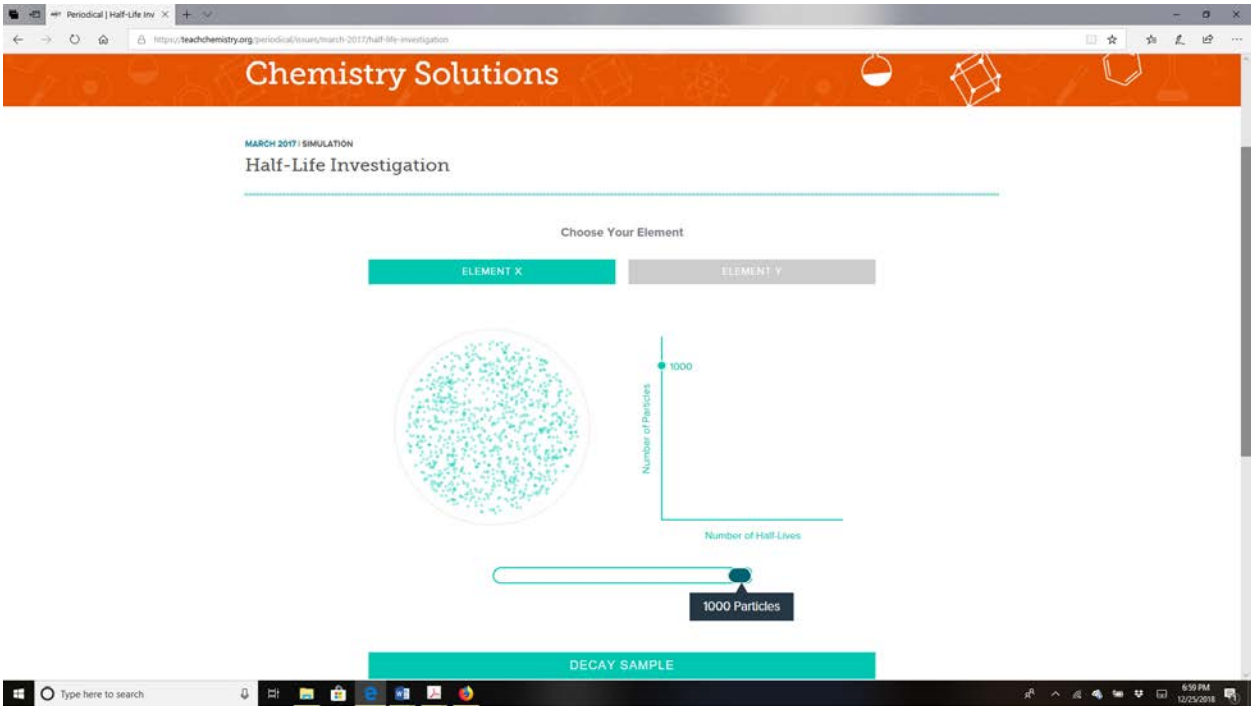
Radiocarbon, or carbon 14, is an isotope of the element carbon that is unstable and weakly radioactive. The stable isotopes are carbon 12 and carbon 13.

Carbon 14 is continually being formed in the upper atmosphere by the effect of cosmic ray neutrons on nitrogen 14 atoms. It is rapidly oxidized in air to form carbon dioxide and enters the global carbon cycle.

Plants and animals assimilate **carbon 14** from carbon dioxide throughout their lifetimes. When they die, they stop exchanging carbon with the biosphere and their carbon 14 content then starts to decrease at a rate determined by the law of radioactive decay.



Try this out
https://teachchemistry.org/periodical/issues/march-2017/half-life-investigation

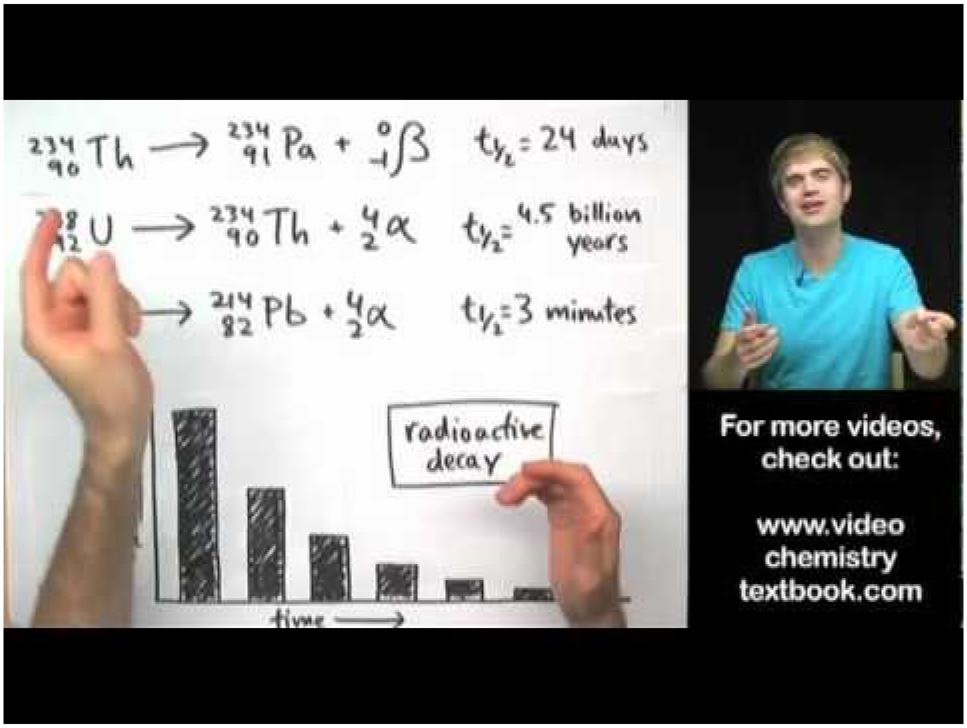


Activity:

Go to the above simulation and click on the Element X. Then click on "Decay Sample".
Notice the graph of half life.
What is the half life of element X?

<u>Watch this out!</u>

https://www.youtube.com/watch?v=opjJ-3Tkfyg



Questions:

1. If the half life of Iodine-131 is 8.0days, how much of a 100. mg sample of Iodine-131 remains after 40 days?

Ans: 3.13mg

Chapter Objectives

VI. Units of Radioactivity

We already know that radioactivity is not detectable by our senses. We cannot hear it, feel it or smell it. Then how do we know it is there? Alpha, beta, gamma, positron all have a property, we can use to detect them: when these rays interact with matter, they usually knock electrons out of the electron cloud surrounding an atom and creates positively charged ions from the neutral atom. That is why, we sometimes call them ionizing radiation.

Ionizing radiation is characterized by two physical measurements 1) intensity, which the number of particles of photons emerging per unit time and 2) the energy of each particle or photon emitted.

Intensity:
Instrument such as Geiger Muller counter and the proportional counter contain a gas such as helium or argon. When radiation ionizes this gas, the instrument registers this fact by indicating that an electric field is passing between two electrodes.

Radiation in a sample is measured by the number of disintegration per second. most often using the curie(Ci)=$3.7*10^{10}$ disintegration per second. This is radiation of very high intensity.
Becquerel is another unit: 1 Bq= 1 disintegration. Bequerel is SI unit of radiation.
We can also define millicurie and microcurie.
1 mCi= 3.7*10 dps and 1 μCi= 3.7 *10^4 dps

The intensity of any radiation decreases with the square of the distance from the source. If the distance from the radiation source doubles, radiation decreases by a factor of four.

Energy:
Roentgen: measure of energy delivered by a radiation source. 1 roentgen= $2.58*10^{-4}$ C of ions per kilogram.

The exposure of a substance to radioactivity is measured with the Rad (radiation absorbed dose) or the rem (radiation equivalent for man). Sievert is the SI unit. **1 Sv= 100 rem.**

Both natural and human made sources of low level radiation exist such as 1) radon seepage in buildings, 2) rocks and soils 3) minerals in our body 4) cosmic radiation, 5) medical X-rays, 6) nuclear medicine.

Watch the following video:

https://www.youtube.com/watch?v=0gpDezTFYO4

Chapter Objectives

VII. Common Radioisotopes Used in Medicine

Medical imaging is the most widely used aspect of nuclear medicines. The goal of medical imaging is to create a picture of a target tissue. To create an useful image we require 1) a radioactive materials, 2) A method of detecting radiation and 3) a computer to process the intensity

Radioisotopes are highly used in medical field due to their power of radiation. Here are some common radioisotopes that are used to treat diseases.

Radioisotope	Treatment
I-131	thyroid disease
Tc-99m	gastrointestinal bleed
Th-201	coronary artery

Co-60	Chemotherapy
C-11, O-15, N-13, F-13	positron emission tomography
Ir-192, I-125	internal medicine

Not only nuclear radiations are used to save people's lives, nuclear reactions occurring at nuclear reactor help survive our lives.

Another important type of medical image is positron emission tomography (PET). This method is based on the fact that certain isotopes emit positron. Positron have very short lives, it collides with an electron producing gamma rays.

More to read: magnetic Resonance Imaging & how radiation damages tissues

MRI image of human brain

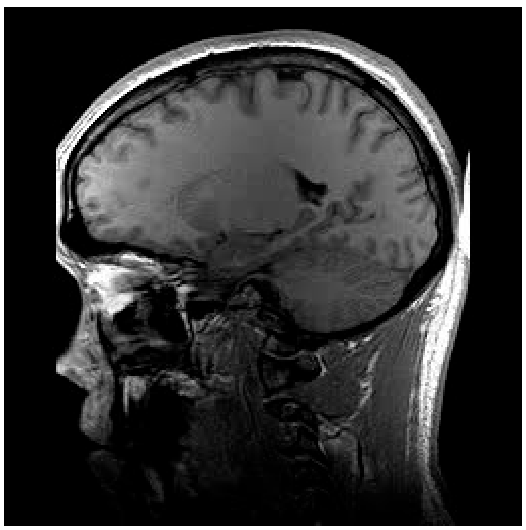
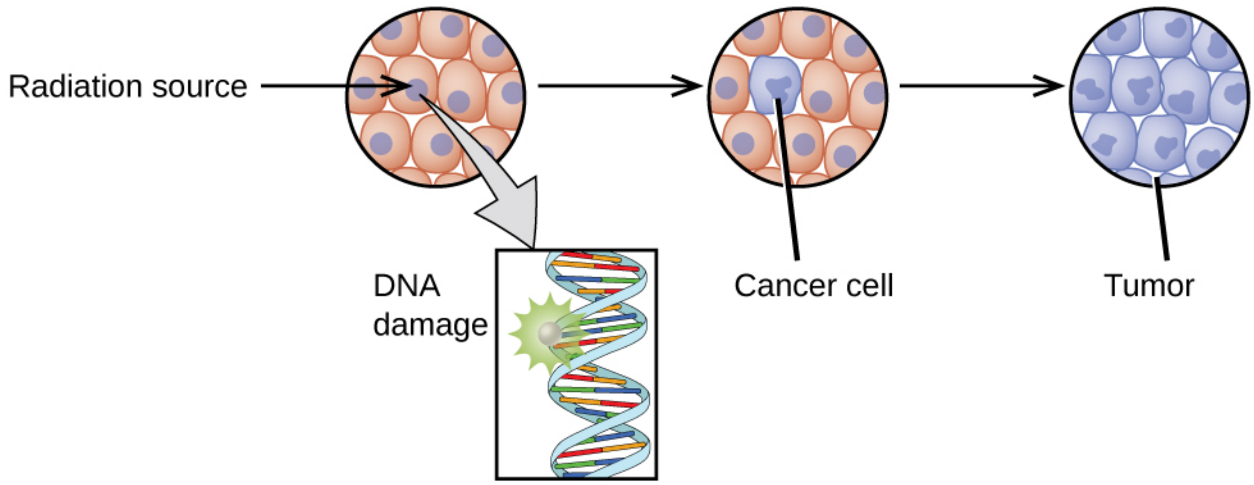


Image of damaged tissue using radiation source



Watch the following video:

https://www.youtube.com/watch?v=C31X6KaZ0RE

<u>Following information has been obtained from Government of US Nuclear Research Center and recommended for reading.</u>

How does a nuclear reactor generate electricity?

Let's begin at the end and see how it all fits together.

We begin by looking at an electric motor. A motor consists primarily of two major components: a *stator*, which stands still, and a *rotor,* which rotates within the stator. When electricity is applied to the motor, electromagnets within the stator and the rotor push and pull on each other in a way that causes the rotor to rotate. The magnets in the stator pull magnets in the rotor toward them, and then, as the rotor magnets pass by reverse themselves and push the rotor magnets away. The parts are arranged so the pulling and pushing are all in the same direction, so the rotor spins inside the stator. The electrical energy applied to the motor results in mechanical energy in the rotor.

But that same machine can be used in reverse: If some outside force causes the rotor to spin, the interaction of the magnets causes electricity to be produced: the "motor" is now a "generator," producing electrical energy as a result of the mechanical energy applied to its rotor. That's the most common way to make large quantities of electricity.

So how do you make the rotor spin? That's where the nuclear reactor comes in, although still indirectly. Recall that a nuclear reactor generates heat. The fuel rods get hot because of the nuclear reaction. That heat is used to boil water, and the steam from that boiling water is used to spin the rotor. As we have seen, when the rotor spins, electricity comes out of the stator.
When water boils, the steam that is produced occupies much more physical space than the water that produced it.

So if you pump water through some sort of a heat source — like a nuclear reactor, or a coal-fired boiler — that is hot enough to boil the water, the exiting steam will be travelling much faster than the water going in. That steam runs through a machine called a turbine, which acts something like a highly-sophisticated windmill. The physical structure is vastly different from a windmill, and a large turbine can be far more powerful than any windmill that has ever been made, but the effect is somewhat the same: the steam, or wind, causes part of the machine to spin, and that spinning part can be connected to a generator to produce electricity.

The steam leaving the turbine is collected in a device called a condenser — essentially a metal box the size of a house, with thousands of pipes running through it. Cool water flows through the pipes, and the steam from the turbine is cooled and condenses back into water. Then the water is pumped back through the heater and the cycle continues.

Now, back to the nuclear reactor . . . We have seen how the reactor generates heat, and we have seen how heat is used to generate steam and how the steam then powers the turbine, which spins the generator that produces electricity. The final piece in the puzzle is how the heat from the nuclear reaction generates the steam.

The fuel rods are suspended in a water bath contained in a large metal container somewhat like a gigantic pressure cooker. A typical "reactor vessel" might be 15 feet in diameter and 20 feet high, and some are much larger than that. In some types of reactors, the water is allowed to boil, and the heat generated in the fuel rods is carried away in steam. These are called "boiling water reactors" (or "BWR"). In others, the water is held at a very high pressure — on the order of 2000 pounds per square inch. (By the way, that is more than 60 times the pressure in the tires of a typical car.) In that situation, the water cannot expand and cannot boil.

The water in that type of reactor carries the heat away while remaining liquid, and that heat is then transferred to another water system where the boiling occurs. This transfer takes place in a device aptly named a "steam generator." These are called "pressurized water reactors" (or "PWR"). A small PWR might have two steam generators. A large one might have four. Some have three. The steam from all of the steam generators is typically combined into a single "main steam line" that carries the steam to the turbine, so the reactor and all of the steam generators act together as a single steam source.

The water from the condenser is pumped directly into the reactor vessel for a BWR, or into the steam generators for a PWR.

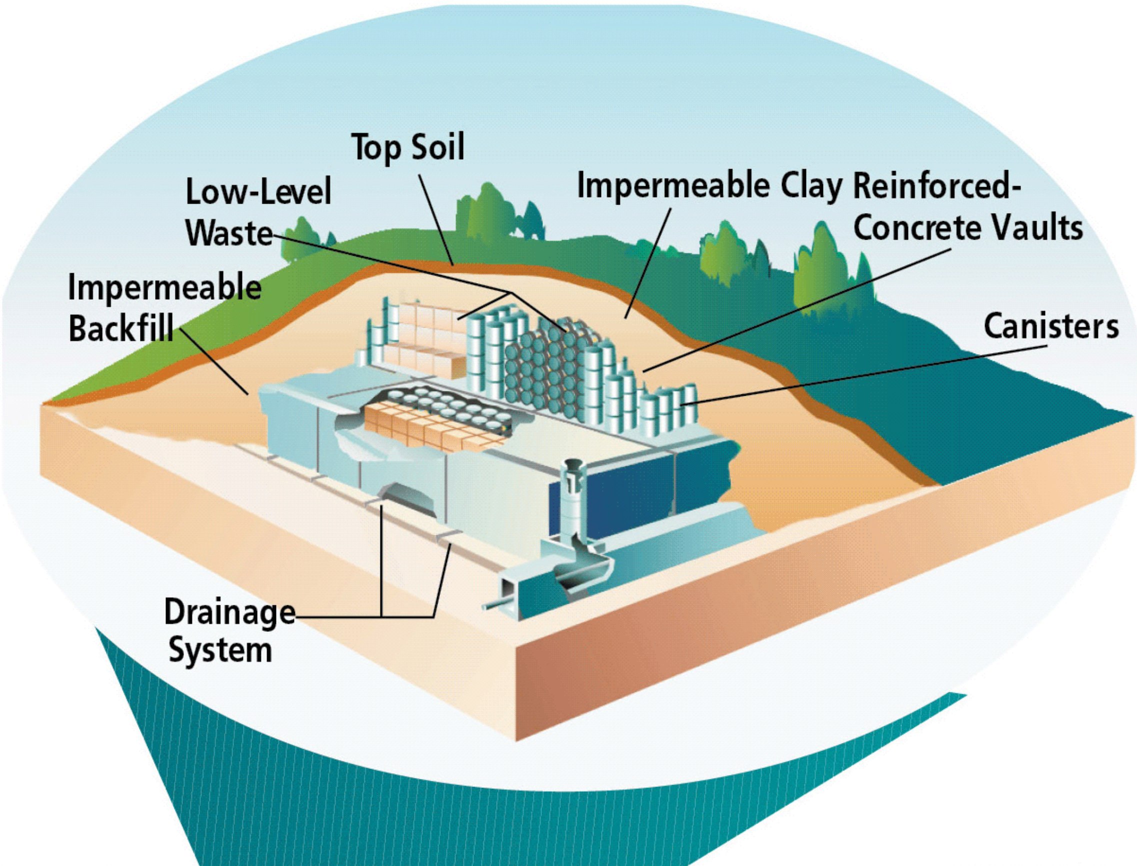
So there you have it: the nuclear reaction heats the fuel, the fuel heats the water to make steam, the steam spins the turbine, the turbine turns the generator, and the generator makes electricity.

Low-Level Waste

Low-Level Waste Disposal

Low-level waste includes items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. This waste typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipments and tools, luminous dials, medical tubes, swabs, injection needles, syringes, and laboratory animal carcasses and tissues. The radioactivity can range from just above background levels found in nature to very highly radioactive in certain cases such as parts from inside the reactor vessel in a nuclear power plant. Low-level waste is typically stored on-site by licensees, either until it has decayed away and can be disposed of as ordinary trash, or until amounts are large enough for shipment to a low-level waste disposal site in containers approved by the Department of Transportation.

Low-Level Waste Disposal

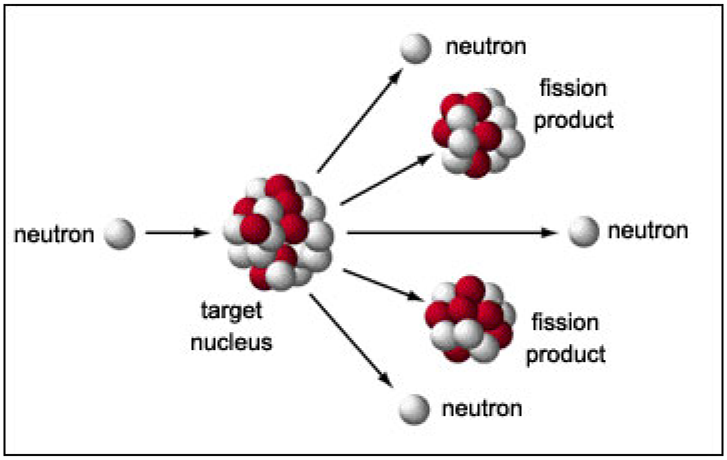


This LLW disposal site accepts waste from States participating in a regional disposal agreement.

[Chapter Objectives]

VIII. Nuclear Fission and Fusion

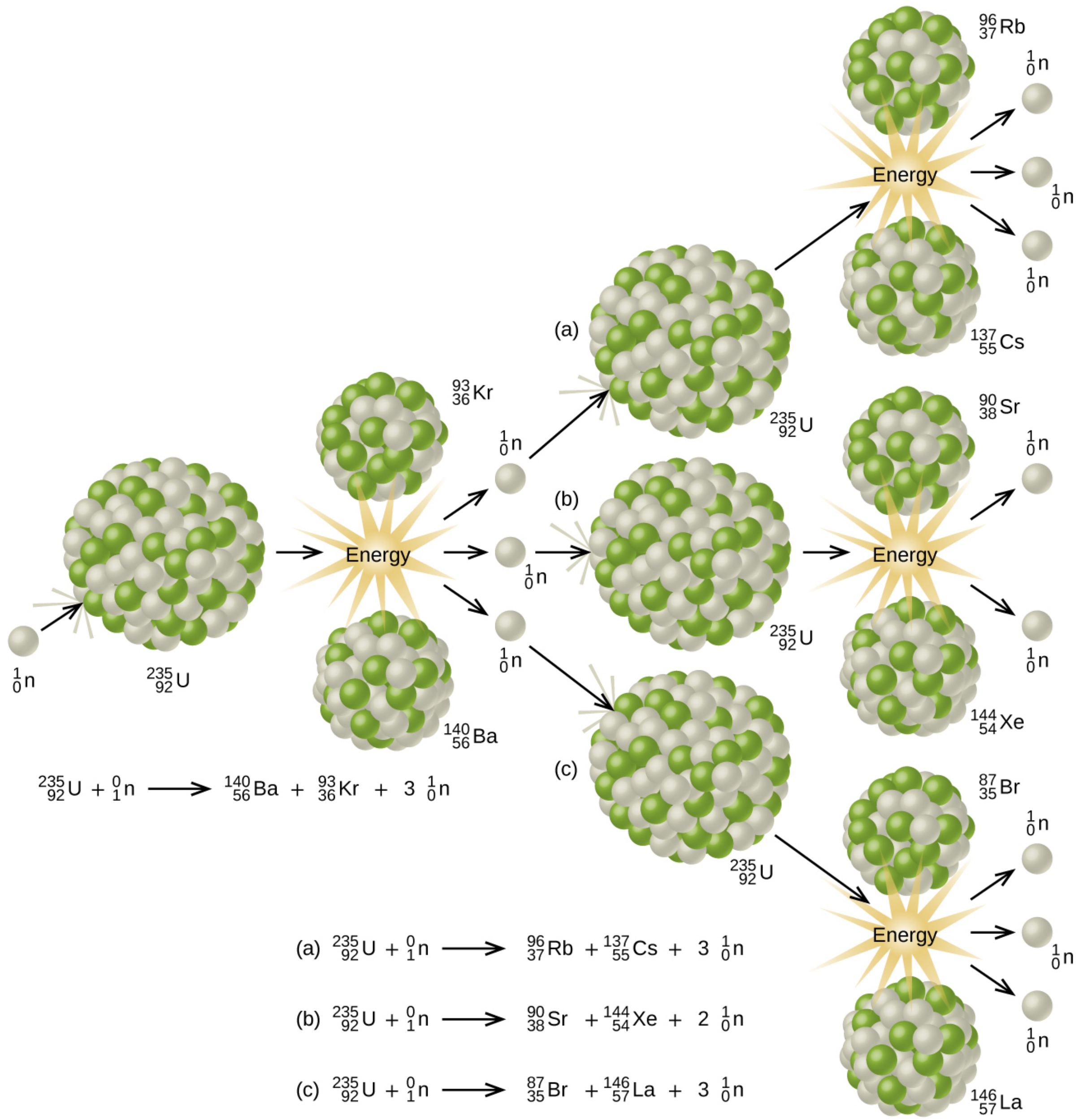
Nuclear fission is the splitting apart of a heavy nucleus into lighter nuclei and neutrons. When a heavy nucleus of Uranium-235 is bombarded with a neutron, it splits into smaller elements and few other neutrons. Those neutrons again collide with other nuclei and the **chain reaction** continues.



Nuclear Fission reaction diagram

The main important part of this kind of nuclear reaction is the generation of HUGE amount of energy which is called **atomic energy**. The fission energy generated from nuclear plants have application in producing electricity and in many other fields.

Nuclear Fission reaction diagram



Nuclear fusion is another type of nuclear reaction and is described as joining together of two light nuclei to form larger nucleus.
Both nuclear fission and fusion release good deal of energy. Nuclear fission is used in nuclear power plants to generate electricity. Nuclear fusion occurs in stars.

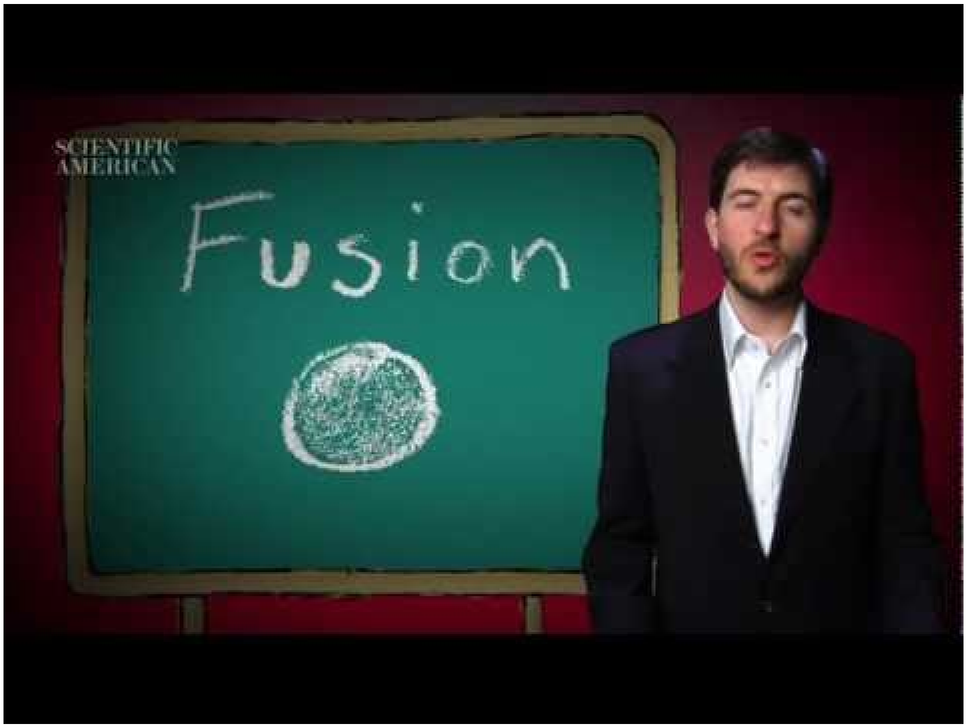
All the trans-uranium elements (elements with atomic numbers greater than 92) are artificially prepared by a fusion process in which the heavy nuclei is bombarded with lighter atom.

Nuclear Fusion Reaction

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + 2^{1}_{0}n$$

When deuterium and Tritium nuclei are converted into Helium nucleus extra mass is released as energy.

Watch this out!



https://www.youtube.com/watch?v=3rn339v_Q-w

The following information taken from AACT

Here is the Lise Mietner Video on Vimeo about Nuclear Fission and Fusion reaction

https://vimeo.com/120411660

This video tells the story of Lise Meitner, a pioneering female scientist in the field of nuclear chemistry, who was denied a Nobel Prize but has an Element named in her honor.

Lise Meitner Video Questions

Instructions
While watching the *Founder of Chemistry Video* about Lise Meitner, answer the following questions:

1. Lise Meitner helped discover the process of nuclear fission. What are the *two* nuclear developments made possible by her discovery?

2. Why did Meitner attend private school throughout her life?

3. What scientific development was Max Planck responsible for?

4. What element did Meitner and Hahn discover together?

5. Meitner and other scientists experimented with Uranium by bombarding the element with neutrons. What were the scientists hoping to discover?

6. The process of fission supports a famous equation, and scientist. What is the equation, and who is the scientist?

7. Is energy absorbed or released during an exothermic reaction?

8. What atomic number is Meitnerium, the element named after Meitner?

Chapter Objectives

PRACTICE QUESTIONS: Chapter 3

1. Which isotope of oxygen is most likely to be a β emitter?

a. ^{15}O b. ^{16}O

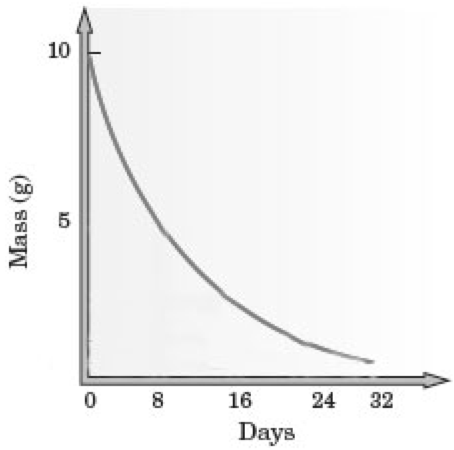
c. ^{17}O d. ^{19}O

2. Which isotope of oxygen is most likely to be a positron emitter?

a. ^{15}O b. ^{16}O

c. ^{17}O d. ^{19}O

Examine the following graph for a particular isotope.



3. A change in which of the following conditions would change the value of the half-life?

   a. amount of sample

   b. temperature

   c. pressure

   d. using a different isotope

   e. None of the affect the half-life.

4. Approximately what percentage of an individual's average annual exposure to radiation is associated with naturally occurring radiation?

   a. 20%   b. 40%

   c. 60%   d. 80%

5. Which of the following forms of radiation consists of hydrogen nuclei?

   a. α b. β

   c. γ d. none of these

6. Which of the following elements is not likely to be produced by nuclear fission?

   a. Ba   b. H

   c. Kr   d. Sr

7. The ionizing ability of radiation is measured by which of the following?

   a. becquerel   b. curie

   c. roentgen   d. all of these

8. Krypton-85 has a half-life of 10 years. Approximately what percentage of Kr-85 produced from nuclear testing in 1956 still remains radioactive today?

   a. 25%   b. 12%

   c. 6%   d. 3%

9. Chromium-51 decays by electron capture. What isotope is formed when ^{51}Cr decays in this way?

a. ^{50}Cr b. ^{52}Cr

c. ^{51}Mn d. ^{51}V

10. What percentage of a radioactive sample remains after 5 half-lives?

a. 6.25% b. 3.13%

c. 1.56% d. 0.781%

11. A radiation detector which is located 2.0 meters from a radiation source indicates a radiation intensity of 100. mCi (millicuries). What would the radiation intensity be if the detector was 1.0 meter from the source?

a. 25 mCi b. 50.mCi

c. 2.0×10^2 mCi d. 4.0×10^2 mCi

12. What is the atomic number of the element produced when an element with atomic number Z emits a positron?

a. Z — 2 b. Z — 1

c. Z + 1 d. Z + 2

13. Polonium-210 is an α emitter. What isotope is formed when ^{210}Po emits an α particle?

a. ^{210}At b. ^{206}Pb

c. ^{206}Rn d. ^{208}Xe

14. Which material is most commonly used to shield ourselves from radioactive materials?

a. glass b. iron

c. lead d. paper

15. Which of the following forms of radiation is identical to the nucleus of a helium atom?

a. α b. β

c. γ d. positron

16. Nuclear wastes are stored both at the sites of power plants and at special facilities maintained by the Department of Energy. What is the approximate amount of waste stored on site at power plants?

a. 500 metric tons b. 5000 metric tons

c. 50,000 metric tons d. 500,000 metric tons

17. Which of the following radioactive processes does not result in transmutation?

a. α emission b. β emission

c. γ emission d. all of the above

18. Which of the following scientists discovered X-rays?

a. H. Becquerel b. M. Curie
c. A. Einstein d. W. Roentgen

19. The federal government has developed a plan to store nuclear wastes at an underground site in which state?

a. Arizona b. Montana
c. Nevada d. Wyoming

20. Which of the following is most resistant to damage by exposure to radiation?

a. bacteria b. human tissue
c. viruses d. They are all equally resistant to damage.

21. Which of the following statements is true?

a. In heavy atoms there are generally many more protons than neutrons.
b. In heavy atoms there are generally many more neutrons than protons.
c. In heavy atoms the number of protons and neutrons are nearly equal.
d. Most heavy atoms do not exist in a number of isotopic forms.

22. Which of the following affects the half-life of a radioactive sample?

a. the age of sample b. the size of the sample
c. the temperature of the sample d. none of these

23. Barium-122 has a half-life of 2 minutes. If 10.0 g of Ba-122 are produced in a nuclear reactor how much Ba-122 will remain 10 minutes after production ceases?

a. 2.50 g b. 1.25 g
c. 0.625 g d. 0.313 g

24. Which of the following is the speed of light?

a. 3.0×10^8 cm/sec b. 3.0×10^8 m/sec
c. 3.0×10^8 mi/sec d. 3.0×10^8 mi/hour

25. Which of the following scientists discovered radioactivity?

a. H. Becquerel b. M. Curie
c. A. Einstein d. E. Rutherford

26. Approximately what percentage of the electricity produced in the United States comes from nuclear energy?

a. 5% b. 15%
c. 35% d. 55%

27. Which of the following is the name of the free radical formed after radiation knocks an electron out of a water molecule?

a. hydronium b. hydroxide

c. hydroxium d. hydroxyl

28. Which isotope of phosphorous is most likely to be a positron emitter?

a. ^{29}P b. ^{30}P

c. ^{31}P d. ^{32}P

29. Which of the following is a measure of effect of radiation on biological material?

a. curie b. gray

c. rad d. sievert

30. Which of the following statements is true?

a. In light atoms there are generally many more protons than neutrons.

b. In light atoms there are generally many more neutrons than protons.

c. In light atoms the number of protons and neutrons are nearly equal.

d. Most naturally occurring isotopes of light atoms are radioactive.

31. Transmutation is caused by which of the following radioactive processes?

a. α emission b. γ emission

c. both a and b d. neither a nor b

32. Mercury-197 is a γ emitter. What isotope is formed when ^{197}Hg emits γ radiation?

a. ^{197}Au b. ^{197}Hg

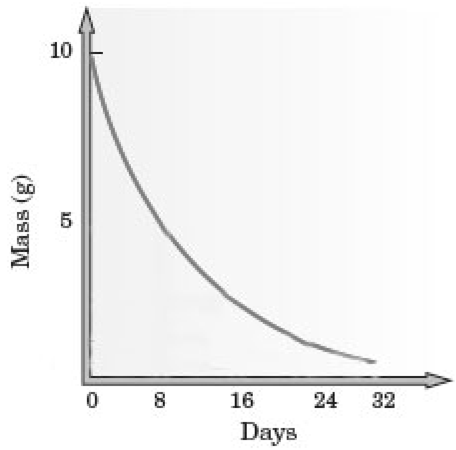
c. ^{197}Tl d. ^{197}Pb

33. Which of the following is typically the largest source of radiation exposure for humans?

a. artificial radiation sources b. atmospheric radon

c. cosmic rays d. terrestrial radiation

Examine the following graph for a particular isotope.



34. A change in which of the following conditions would change the shape of this curve?
    a. amount of sample
    b. temperature
    c. pressure
    d. None of the affect the shape of the curve.

35. Which of the following radioisotopes can be used to monitor thyroid function?
    a. C-14 b. H-3
    c. I-131 d. P-32

36. Which of the following forms of radiation involves the heaviest particles?
    a. α b. β
    c. γ d. positron

37. Approximately how many stable isotopes have been identified?
    a. 92 b. 118
    c. 264 d. more than 300

38. Which of the following gives the correct order for the energies of portions of the electromagnetic spectrum?
    a. radio > infrared > ultraviolet b. radio > ultraviolet > infrared
    c. ultraviolet > infrared > radio d. ultraviolet > radio > infrared

39. Which of the following is the correct relationship between the rad and the gray?
    a. 1 Gy = 100 rad b. 1 Gy = 1000 rad
    c. 1 Gy = 0.01 rad d. 1 Gy = 0.001 rad

40. Which of the following types of radiation can be stopped by ordinary clothing?
    a. α b. β

c. γ d. all of them

Answer Key

1. d

2. a

3. d

4. d

5. d

6. b

7. c

8. d

9. d

10. b

11. d

12. b

13. b

14. c

15. a

16. c

17. c

18. d

19. c

20. c

21. b

22. d

23. d

24. b

25. a

26. b

27. d

28. a

29. d

30. c

31. a

32. b

33. b

34. d

35. c

36. a

37. c

38. c

39. a

40. a