It's better to have a half-life than no life!

Radioactive Decay

Alpha, Beta, and Gamma Decay

What does it mean to be radioactive?

- Some atoms have nuclei that are unstable.
- These atoms spontaneously “decompose” to form different nuclei and produce/release one or more particles or photons.

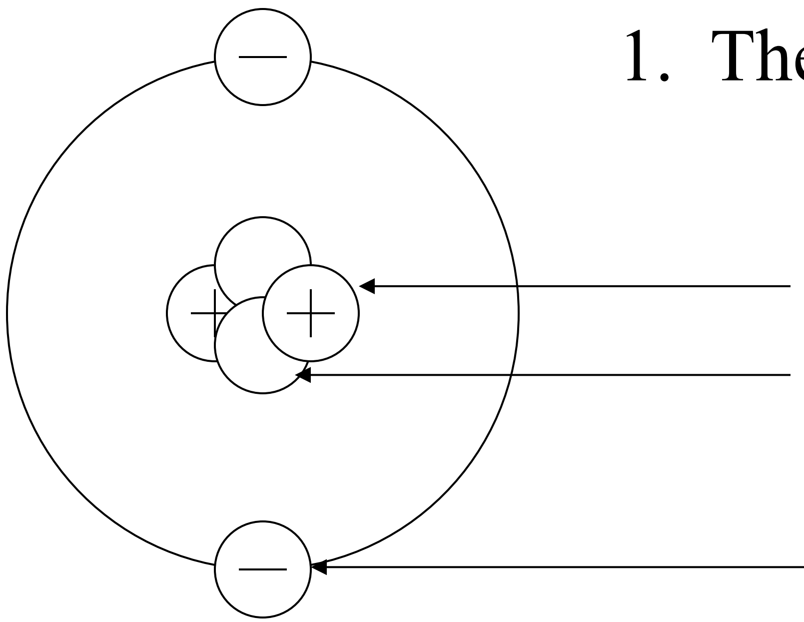
Radioactive

- Atoms that are radioactive have a neutron/ proton ratio much greater than 1
- Radioactivity can be detected by a Geiger counter

The Atom

The atom consists of two parts:

1. The nucleus which contains:



protons
neutrons

2. Orbiting electrons.

The Atom

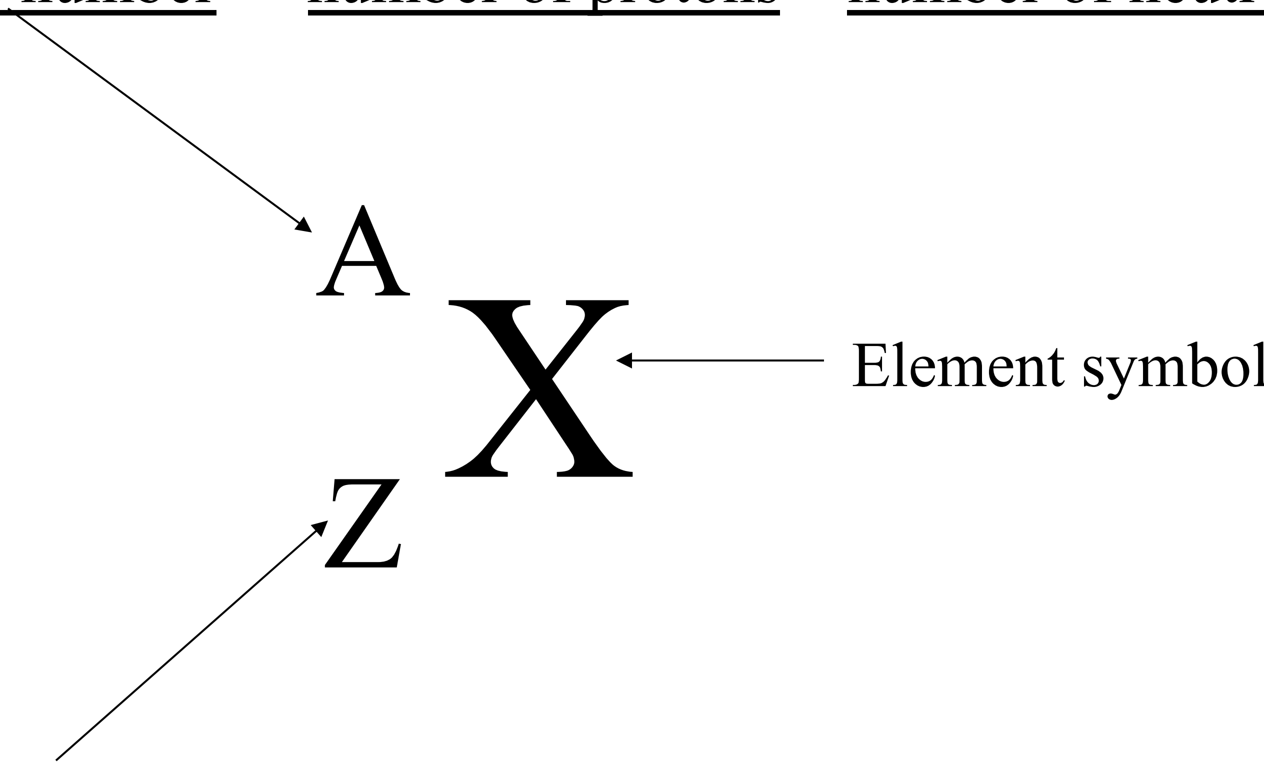
All matter is made up of elements (e.g. carbon, hydrogen, etc.).

The smallest part of an element is called an atom.

Atoms of different elements contain different numbers of protons.

The mass of an atom is almost entirely due to the number of protons and neutrons.

Mass number = number of protons + number of neutrons



Atomic number = number of protons

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

A = number of protons + number of neutrons

Z = number of protons

A – Z = number of neutrons

Number of neutrons = Mass Number – Atomic Number

There are many types of uranium:

$^{235}_{92}U$

A	
Z	
Number of protons	
Number of neutrons	

$^{238}_{92}U$

A	
Z	
Number of protons	
Number of neutrons	

There are many forms or "isotopes" of uranium:

$$^{235}_{92}U \qquad ^{238}_{92}U$$

A	235
Z	92
Number of protons	92
Number of neutrons	143

A	238
Z	92
Number of protons	92
Number of neutrons	146

Isotopes of any particular element contain the same number of protons, but different numbers of neutrons.

Most of the isotopes which occur naturally are stable.

A few naturally occurring isotopes and all of the man-made isotopes are unstable.

Unstable isotopes ***can become stable*** by releasing different types of particles.

This process is called radioactive decay and the elements which undergo this process are called radioisotopes/radionuclides.

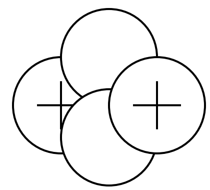
Radioactive Decay

Radioactive decay results in the emission of either:

- an alpha particle (α),
- a beta particle (β),
- or a gamma ray(γ).

Alpha Decay

An alpha particle is identical to a helium nucleus.



It contains two protons and two neutrons.

About Alpha Particles

- Most alpha emitters occur naturally in the environment.
- Alpha particles don't get very far in the environment when released.
- Alpha particles pick up electrons and turn into helium gas.
- Cannot penetrate most matter.
- Can be dangerous if inhaled or ingested (radon gas in igneous rock, soil or well water).

Alpha Decay

- **Equations are balanced by making sure the sum of the atomic numbers and mass numbers on both sides of the equation are equal.**

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

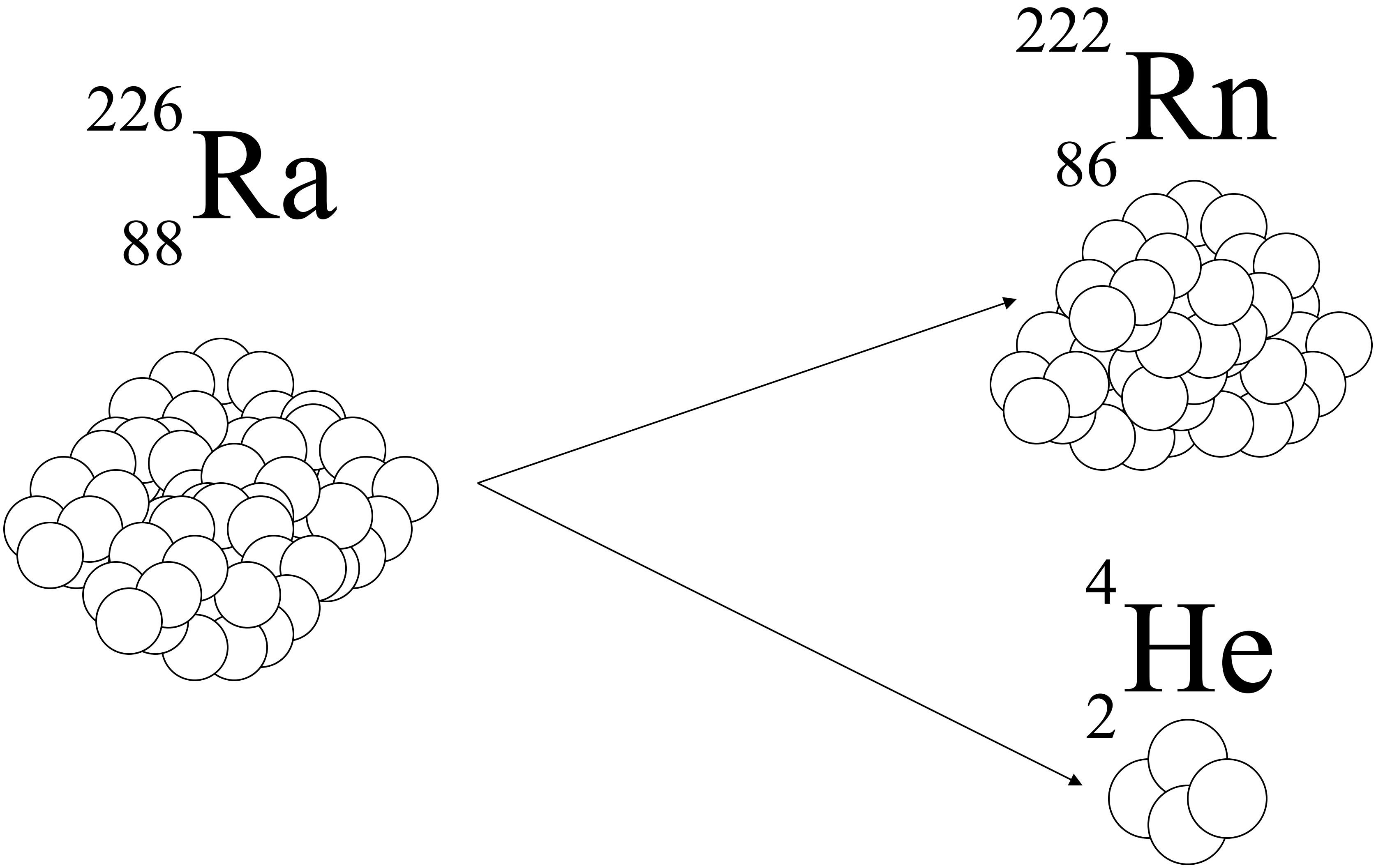
unstable atom

"more" stable atom

alpha particle

Example of Alpha Decay

(Radium-226 to Radon, Half-life: 1,601 years)



Alpha Decay

(Radium-226 to Radon)

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

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

<u>Alpha Decay</u>

(Radon-222 to Polonium, Half-life: 3.8 days)

$$^{222}_{86}\mathrm{Rn} \longrightarrow {}^{A}_{Z}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$$

$$^{222}_{86}\mathrm{Rn} \longrightarrow {}^{218}_{84}\mathrm{Po} + {}^{4}_{2}\mathrm{He}$$

Alpha Decay

(Uranium-234 to Thorium-230, Half-life: 246,000 years)

$$^{A}_{Z}X \longrightarrow \; ^{230}_{90}Th + \; ^{4}_{2}He$$

$$^{234}_{92}U \longrightarrow \; ^{230}_{90}Th + \; ^{4}_{2}He$$

Alpha Decay

Thorium-230 to Radon-226, Half-Life: 75,380 years)

$$^{230}_{90}\mathrm{Th} \longrightarrow {}^{A}_{Z}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$$

$$^{230}_{90}\mathrm{Th} \longrightarrow {}^{226}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He}$$

Alpha Decay

Polonium-218 to Lead-214, Half-Life: 3.05 minutes)

$$^{A}_{Z}X \longrightarrow \, ^{214}_{82}Pb + \, ^{4}_{2}He$$

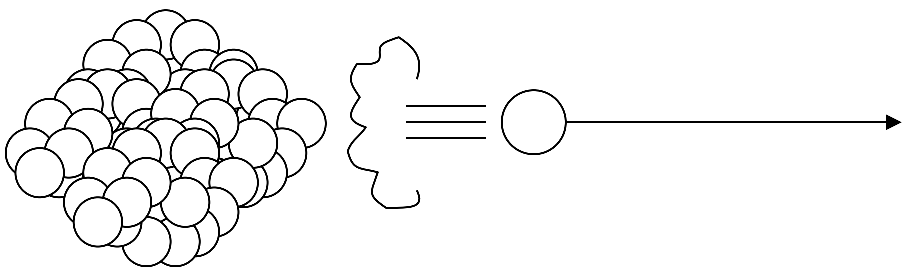
$$^{218}_{84}Po \longrightarrow \, ^{214}_{82}Pb + \, ^{4}_{2}He$$

Human Use of Alpha Particle Emitters:

- Radium-226 may be used to treat cancer, by inserting tiny amounts of radium into the tumorous mass.
- Polonium-210 serves as a static eliminator in paper mills and other industries.
- Some smoke detectors use the alpha emissions from Americium-241 to help create an electrical current.

Beta Decay

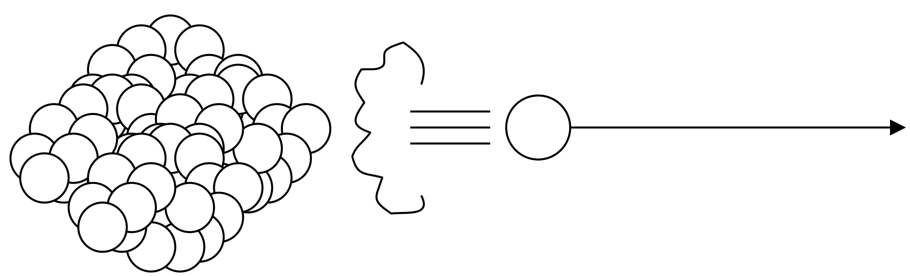
A beta particle is a fast moving electron which is emitted from the nucleus of an atom undergoing radioactive decay.



Beta decay occurs when a neutron changes into a proton (+) and an electron (-).

Beta Decay

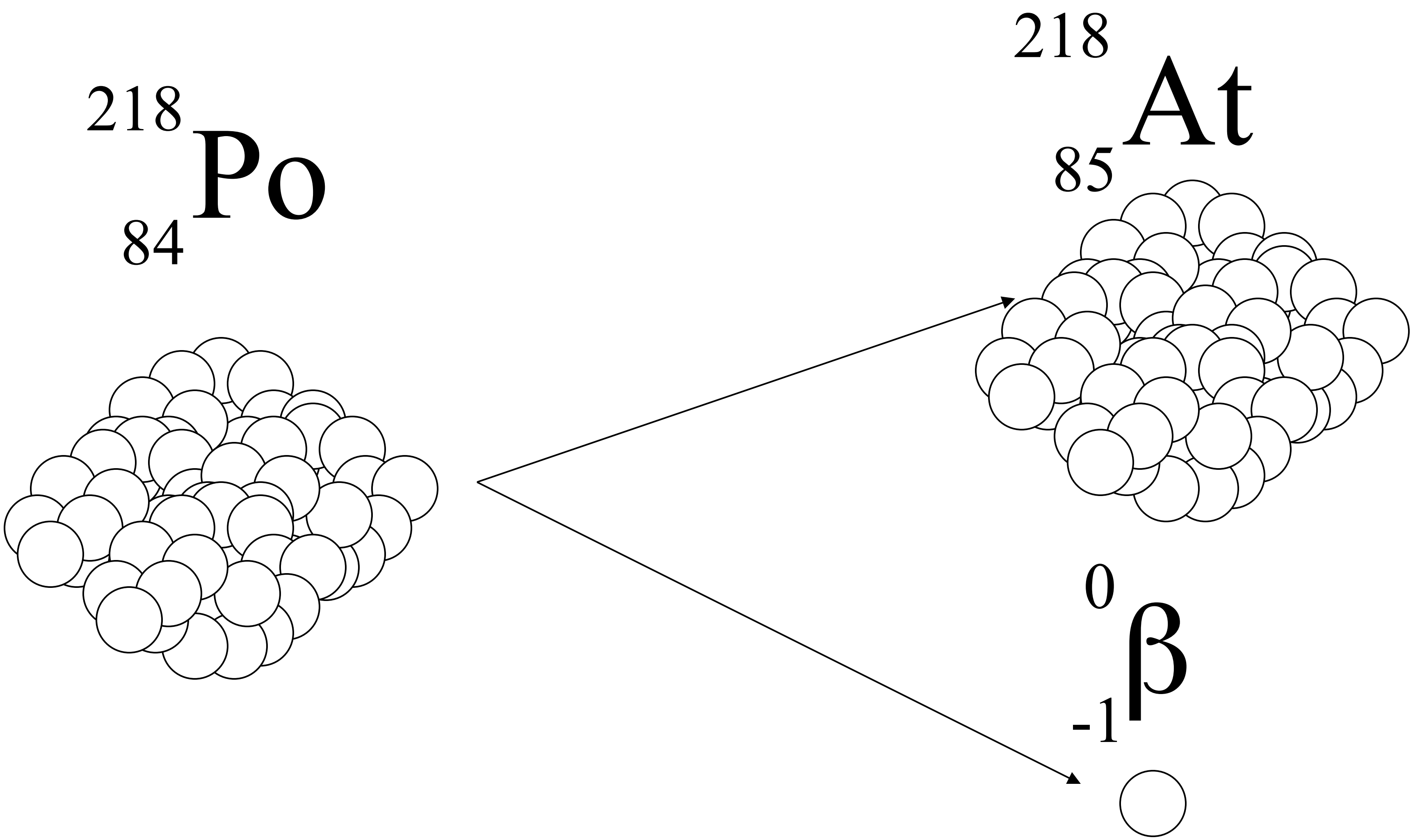
As a result of beta decay, the nucleus has <u>one less neutron</u>, but <u>one extra proton</u>.



The atomic number, Z, increases by 1 and the mass number, A, stays the same.

Beta Decay

(Polonium-218 to Astatine, Half-Life: 3.1 Minutes)



About Beta Particles

- Identical to electrons.
- Beta particles travel several feet in open air and are easily stopped by solid materials.
- There are both natural and man-made beta emitting radionuclides.
- Potassium-40 and carbon-14 are weak beta emitters that are found naturally in our bodies.
- Beta radiation can cause both acute and chronic health effects.

Beta Decay

(Thorium-234 to Protactinium, Half-Life: 24 days)

$$^{234}_{90}Th \longrightarrow \, ^{A}_{Z}Y + \, ^{0}_{-1}\beta$$

$$^{234}_{90}Th \longrightarrow \, ^{234}_{91}Pa + \, ^{0}_{-1}\beta$$

Beta Decay

(Thallium-210 to Lead-210, Half-Life: 1.3 minutes)

$$^{A}_{Z}X \longrightarrow {}^{210}_{82}Pb + {}^{0}_{-1}\beta$$

$$^{210}_{81}Tl \longrightarrow {}^{210}_{82}Pb + {}^{0}_{-1}\beta$$

Beta Decay

(Bismuth-210 to Pollonium, Half-Life: 5.012 days)

$$^{210}_{83}\mathrm{Bi} \longrightarrow ^{A}_{Z}\mathrm{Y} + ^{0}_{-1}\beta$$

$$^{210}_{83}\mathrm{Bi} \longrightarrow ^{210}_{84}\mathrm{Po} + ^{0}_{-1}\beta$$

Beta Decay

$${}^{A}_{Z}X \longrightarrow {}^{214}_{83}Bi + {}^{0}_{-1}\beta$$

$${}^{214}_{82}Pb \longrightarrow {}^{214}_{83}Bi + {}^{0}_{-1}\beta$$

Human Use of Beta Particle Emitters

- Iodine-131 is used to treat thyroid disorders, such as cancer and graves disease (a type of hyperthyroidism)
- Phosphorus-32 is used in molecular biology and genetics research.
- Strontium-90 is used as a radioactive tracer in medical and agricultural studies.
- Tritium is used for life science and drug metabolism studies to ensure the safety of potential new drugs. It is also used for luminous aircraft and commercial exit signs, for luminous dials, gauges and wrist watches.
- Carbon-14 is a very reliable tool in dating of organic matter up to 30,000 years old.
- Beta emitters are also used in a variety of industrial instruments, such as industrial thickness gauges, using their weak penetrating power to measure very thin materials.

Gamma Decay

Gamma rays are not charged particles like α and β particles. They are ***released with these particles***.

Gamma rays are electromagnetic radiation with high frequency. They have 10,000 times more energy than visible light.

When atoms decay by emitting α or β particles to form a new atom, the nuclei of the new atom formed may still have too much energy to be completely stable.

This excess energy is emitted as gamma rays (gamma ray photons have energies of $\sim 1 \times 10^{-12}$ J).

- Gamma photons have no mass and no electrical charge--they are pure electromagnetic energy.
- Because of their high energy, gamma photons travel at the speed of light and can cover hundreds to thousands of meters in air before spending their energy.
- They can pass through many kinds of materials, *including human tissue*. Very dense materials, such as lead, are commonly used as shielding to slow or stop gamma photons.

Important Points

- The penetrating power of gamma photons has many applications.

- Gamma rays penetrate many materials, but they do not make the materials radioactive.

Uses for Gamma Rays:

Cobalt-60:

- sterilize medical equipment in hospitals
- pasteurize certain foods and spices
- treat cancer
- gauge the thickness of metal in steel mills.

Cesium-137:

- cancer treatment
- measure and control the flow of liquids in industrial processes
- investigate subterranean strata in oil wells
- measure soil density at construction sites
- ensure the proper fill level for packages of food, drugs and other products.

Human Exposure to Radiation

- Most people's primary source of gamma exposure is naturally occurring radionuclides (soil, water, processed meats, and high potassiuim foods like bananas)
- Nuclear Medicine/Medical Imaging (lung, bone, thyroid scans)
- Mining waste, weapons testing, accidents, etc.