Radiation and Radioactivity

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Radiation Safety Program

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Updated Feb 2011

Views on Radiation Have Changed over Time

- In the first half of the 20th century the effects of radioactivity were often considered positive. Many consumer products contains radioisotopes.

In This Module…

- Structure of matter
- Radiation
- Ionizing and non-ionizing radiation
- Radioactive decay
- Common types of ionizing radiation
  - Alpha
  - Beta
  - Gamma
- Activity and half-life

Nomenclature

Atoms are often written with the notation:

$$^{A}_{Z}\text{Symbol}$$

Mass Number → A

Atomic Number → Z

Chemical symbol (H for Hydrogen, C for Carbon, Pb for Lead, etc.)

Another common notation is: **Symbol-A**

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Radioactivity

In an ***unstable*** atom, the ***nuclear forces*** are not strong enough to hold the nucleus of the atom together.

Unstable atoms want to become stable!

While becoming stable, ***unstable*** atoms emit ***radiation***. This process is known as ***radioactive decay***.

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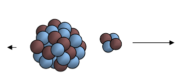
Radioisotopes

Atoms that are ***unstable*** are called ***radioactive***.

Radioactive atoms can emit various types of radiation with different amounts of ***energy***.



Radioactive atom, also known as:

radioisotope or ***radionuclide***

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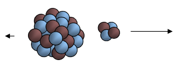
Sources of Radiation

Where does radiation come from?

Radioactive atoms



Man-made devices

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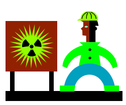
Radiation and Energy

- Radiation can be interpreted as a form of energy.



- Radiation will interact differently with matter depending upon how much energy it has.

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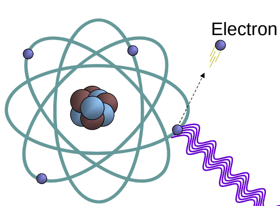
Interaction with Matter

When radiation strikes matter, it interacts with the atoms of the matter.

Radiation with enough energy can knock electrons out of orbit from the atoms it strikes.



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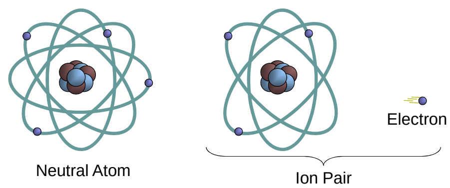
Ionizing Radiation

The process of creating ions is called ***ionization***.



Radiation which can cause ionization is known as ***ionizing radiation***.

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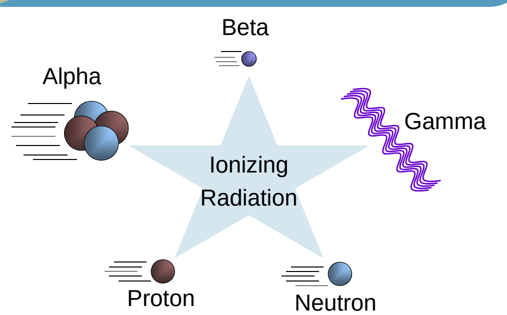
Types of Ionizing Radiation



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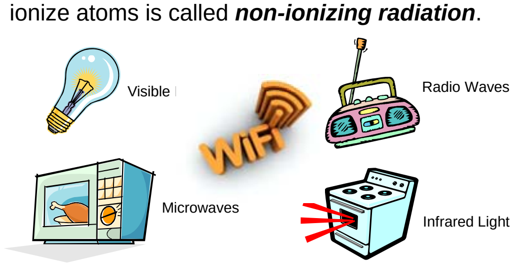
Non-Ionizing Radiation

Radiation which does not have enough energy to ionize atoms is called ***non-ionizing radiation***.



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Radioactive Decay

- The process of radioactive decay will continue until the resulting atom is stable
- Some decay series, such as that of uranium, are quite long
- While others, such as that of iodine, are short

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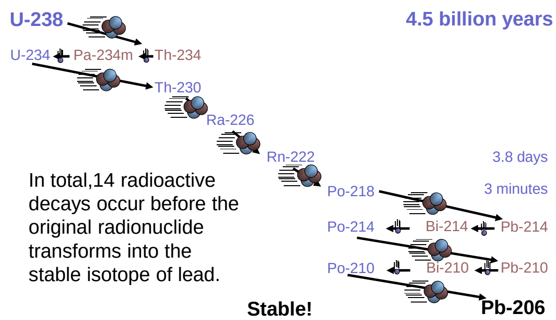
Uranium Decay Series



In total,14 radioactive decays occur before the original radionuclide transforms into the stable isotope of lead.

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Iodine Decay

- Iodine-131 decays to xenon-131 which is a stable nuclide

$$^{131}_{53}\mathrm{I} \rightarrow ^{131}_{54}\mathrm{Xe(stable)} + ^{0}_{-1}\mathrm{e}$$

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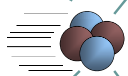
Alpha Radiation

Nucleus of a helium atom (^{4}He)

Composed of two protons and two neutrons



Carries two units of positive charge (+2)

Emitted from the nuclei of radioactive atoms

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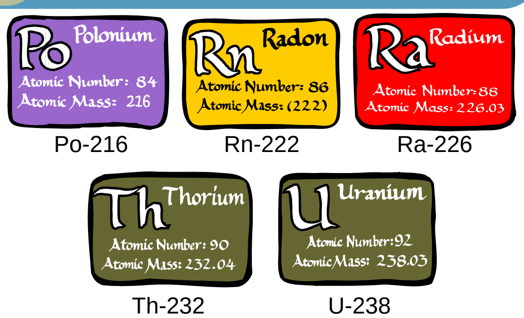
Typical Alpha Emitters



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Alpha Radiation

- Alpha particles are very heavy
  - Approximately 7,000 times as heavier than an electron.
- Alpha radiation is highly energetic.
  - Alpha particle energies range between approximately 4 and 9 MeV.
- Because of its size, the alpha particle does not travel far in matter:
  - Approximately **7 cm of air**
  - Stopped by a **piece of paper**
  - Will not penetrate the **dead outer layer of your skin**

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Alpha Decay

- Alpha decay results in the creation of a new atom which may also be radioactive.
- For example, Rn-222 emits an alpha particle during radioactive decay and becomes Po-218

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

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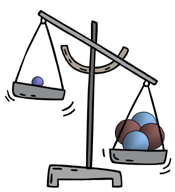
Beta Radiation



- Beta particles are *electrons*.
- They are emitted from the nucleus of a radioactive atom.
- Beta particles are very light.
  - Their mass is approximately 7,000 times smaller than the alpha particle and 2,000 times smaller than proton or neutron.

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Beta Radiation

- Beta particles can carry either a positive or a negative electric charge
- Therefore, there are two kinds of beta radiation:
  - Positive beta (positron)
  - Negative beta (electron)

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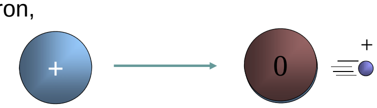
Beta Radiation

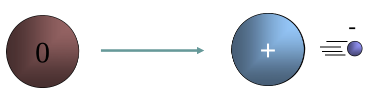
- Positrons carry one unit of positive electric charge
- Apart from the charge, other aspects of positrons are the same as those of an electron
- Electrons occur freely in nature
- Positrons have only a transitory existence

Beta Radiation

Beta particles are emitted from the nucleus of a radioactive atom when a proton transforms into a neutron,



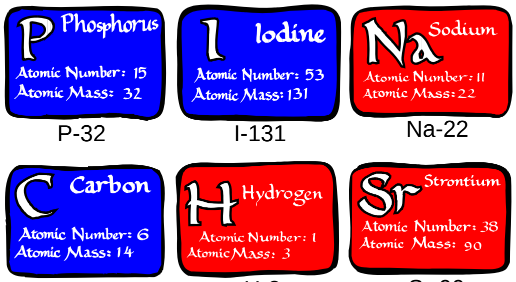
or when a neutron transforms into a proton.



Beta Radiation Penetration

- Maximum energy values for beta particles vary from 18 keV for ^{3}H to 4.81 MeV for ^{38}Cl
- Beta particles are less ionizing than alpha particles and can travel farther in matter:
  - Approximately 200 cm in air
  - They can penetrate the skin
  - Approximately 0.2 cm in tissue
- A thin layer of plastic is an effective shield.

Typical Beta Emitters



P-32 | I-131 | Na-22

C-14 | H-3 | Sr-90

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Examples of Beta Decay

Phosphorus-32

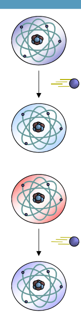
Beta particle (electron)

Sulfur-32

Sodium-22

Beta particle (positron)

Neon-22



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Beta Radiation

- When beta particles pass through matter, x-rays can be produced.
  - This is called ***bremsstrahlung***, meaning “braking radiation”
- The higher the atomic number, the more bremsstrahlung will be produced.

X-ray machine

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Negative Beta Decay

- Like alpha decay, negative beta decay also results in the creation of a new atom which may itself be radioactive.
- For example, iodine undergoes beta decay and transforms into xenon

$$^{131}_{53}\text{I} \rightarrow {}^{131}_{54}\text{Xe(stable)} + {}^{0}_{-1}\text{e}$$

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Positive Beta Decay

- Another example of beta decay is positron decay, which also results in the creation of a new atom.
- Basis of PET

$$^{18}_{9}F \rightarrow {}^{18}_{8}O + {}^{0}_{1}e$$

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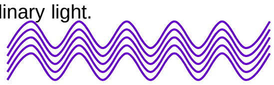
Gamma Radiation

- Gamma radiation is not made up of physical particles like alpha or beta radiation.
- Gamma radiation is made up of ***photons*** just like ordinary light.
- The energy of gamma radiation is **much greater** than that of ordinary light.



  - Photons are packets of energy with no mass.

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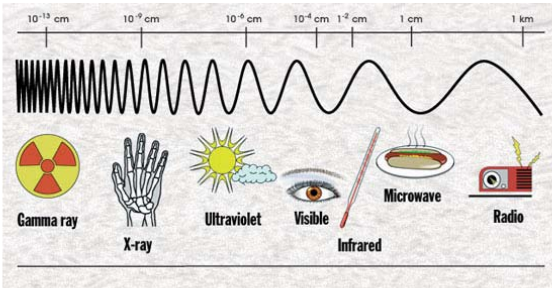
Electromagnetic Spectrum



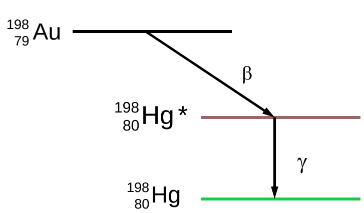
Courtesy NASA/JPL-Caltech

Gamma Emission

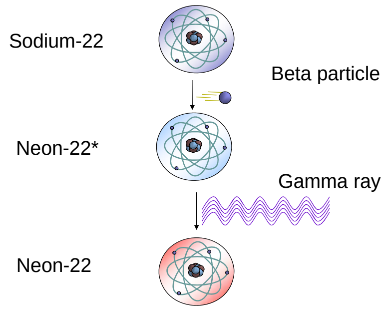
- Gamma rays are emitted from the nuclei of radioactive atoms.
  - Unlike x-rays which are produced through electron interactions.
- The emission of a gamma ray is always preceded by either a beta decay or an alpha decay.

Gamma Decay

- Au-198 decays by beta emission to an excited state of Hg-198

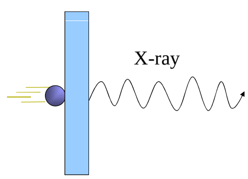


Example of Gamma Decay



X-Rays

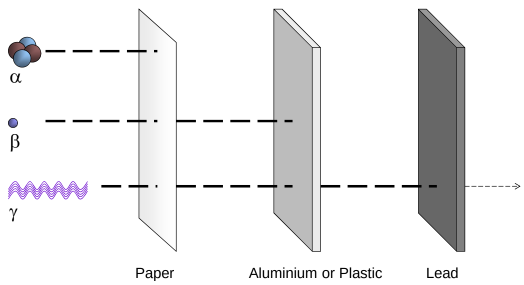
X-rays are emitted when high speed electrons are slowed down or change direction as a result of interactions with atoms in a target material.



Gamma Rays and X-Rays

- Both gamma rays and x-rays are ionising radiation.
- Gamma rays and x-rays do not have a range.
  - They can theoretically travel forever.
- However, as gamma rays and x-rays pass through matter, their ***intensity*** is reduced.

Penetrating Power



Activity

- The rate of radioactive decay is referred to as the ***activity***.
  - The number of decays per unit of time.
- The SI unit of activity is the ***becquerel*** (Bq).
  - One becquerel is one decay per second.
- The historic unit for activity is the ***curie*** (Ci).

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

Activity

- Activity of 1 mg of U-238 is **10 Bq**
- Activity of 1 mg of Am-241 is **$1\text{x}10^8$ Bq**
- The drastic difference in activity between uranium-238 and americium-241 is related to a unique property of all radionuclides called the ***half-life***

Half-Life

- The ***half-life*** of a radionuclide is the time required for it to lose 50% of its activity by radioactive decay.
- Each radionuclide has its own unique half-life, regardless of the quantity or form:
  - Solid
  - Liquid
  - Gas
  - Element or compound

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Half Life

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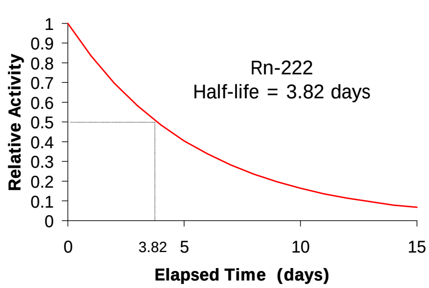
Half-Life



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Half-Life

- The half-life of a radioisotope is an **unalterable** property of the radioisotope.
- Half-lives range from microseconds to billions of years.
  - Uranium-238 4.5×10^9 years
  - Cesium-137 30.07 years
  - Radon-222 3.8 days
  - Polonium-212 3.04×10^{-7} seconds

Half-Life Example

- Assume we have 1000 Bq of P-32.
- P-32 has a half-life of 14.3 days.

# of half-lives elapsed	Activity remaining
One half-life (14.3 days)	
Two half-lives (28.6 days)	
Three half-lives (42.9 days)	

Half-Life

- A good rule of thumb to remember is that after 7 half-lives the activity decreases to about 1% of the original value.
- After 10 half-lives the activity reduces to about 0.1% of the original value.

Half-Life

- Activity and half-life are related mathematically by the following equation:

$$\frac{A}{A_0} = \frac{1}{2^n} \qquad A = A_0 \frac{1}{2^n}$$

  - A is the activity remaining after n half-lives
  - A_0 is the original activity present

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