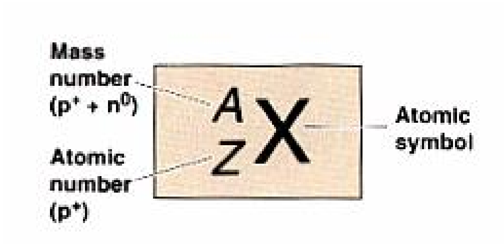
ATOMIC STRUCTURE

- An atom is composed of a positive nucleus surrounded by negatively charged electrons. The nucleus is composed of ***protons*** and ***neutrons***. The protons and neutrons in a nucleus are referred to as ***nucleons***.

- The general designation for an atom is shown below:

  - The atomic number (Z) represents the number of protons in the nucleus.
  - The mass number (A) represents the number of protons and neutrons in the nucleus.
  - The number of neutrons in the nucleus can be determined by A – Z.



- Atoms of the same element that have different number of neutrons are called ***isotopes***. Therefore, isotopes of an element have the same atomic number but different mass numbers. Each isotope of an element is referred to as a ***nuclide***.

- Nuclides that exhibit radioactivity are called ***radionuclides***.

<u>Examples:</u>

1. Determine the number of protons and neutrons in an atom of $^{207}_{82}Pb$.

   Protons = Z =

   Neutrons = A – Z =

2. Which of the following nuclides are isotopes?

   $^{85}_{34}X$ $\quad$ $^{85}_{35}Y$ $\quad$ $^{87}_{34}Z$ $\quad$ $^{88}_{36}R$

RADIOACTIVITY

- The discovery of radioactivity can be attributed to several scientists. Wilhelm Roentgen discovered X-rays in 1895 and shortly after that Henri Becquerel observed radioactive behavior while experimenting with salts of uranium. However, the term radioactivity was first coined by Marie Curie in 1898.

- ***Radioactivity*** is the spontaneous emission of particles and/or rays from the nucleus of an atom. Nuclides are said to be either ***stable*** (non-radioactive) or ***unstable*** (radioactive).

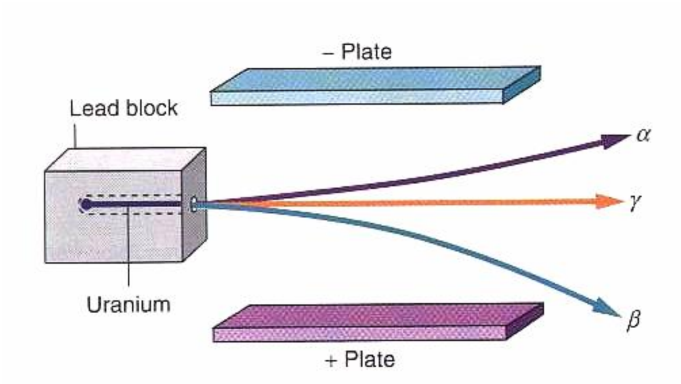
- All elements having an ***atomic number greater than 83*** (bismuth) have ***unstable nuclei***, which undergo ***spontaneous decay*** (disintegration), and are therefore ***radioactive***.

- These elements can undergo one of three different kinds of decay called ***α (alpha)***, ***β (beta)*** and ***γ (gamma)***. When decaying, the original nucleus (A) changes into another nucleus (B) and gives off radiation (b) according to the general equation shown below:

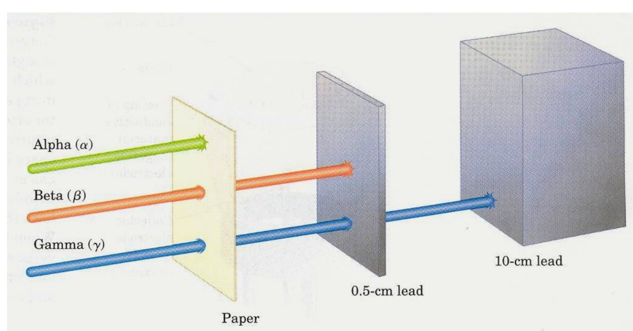
$$\mathbf{A} \longrightarrow \mathbf{B} + \mathbf{b}$$

Parent ⟶ daughter + radiation

- The three different kinds of radiations can be distinguished by their ***interactions with an electric field***.
- ***α-Radiations*** carry a ***positive*** charge and are attracted to the negative plate.
- ***β-radiations*** carry a ***negative*** charge and are attracted to the positive plate.
- ***γ-radiations*** carry ***no charge*** and are attracted to neither plate.



- The three different kinds of radiation have different energies and penetration abilities.
- ***α-Rays*** have low energy and can be blocked by a thin sheet of paper.
- ***β-Rays*** have moderate energy and can be blocked by a thin sheet of metal.
- ***γ-Rays*** have high energy and can only be blocked by a thick sheet of lead.



ALPHA & BETA DECAYS

- ***Alpha decay*** occurs when a nucleus changes into another nucleus and gives off an ***α-particle***, which is a ***helium nucleus*** $\left({}^{4}_{2}\text{He}\right)$.

$$ {}^{232}_{90}\text{Th} \longrightarrow {}^{228}_{88}\text{Ra} + {}^{4}_{2}\text{He} $$

- Note that the ***sum*** of the ***atomic numbers*** and the ***mass numbers*** on the ***left*** and the ***right*** side of the equation are ***equal***.

- Loss of alpha particle from the nucleus results in loss of 4 in mass number (A) and loss of 2 in atomic number (Z).

- ***Beta decay*** occurs when a nucleus changes into another nucleus and gives off a ***ß-particle***, which is an ***electron*** $\left({}^{0}_{-1}\text{e}\right)$.

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

- In ***beta decay***, a ***neutron*** is transformed into a ***proton*** and an ***electron***. The proton remains in the nucleus, while the ***electron is emitted as a beta particle***.

$$ {}^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} $$

- Loss of beta particle from then nucleus results in no change in the mass number (A) and increase of 1 in the atomic number (Z).

<u>Examples:</u>

1. ${}^{238}_{92}\text{U}$ undergoes alpha decay. Write the equation for the process.

$$ {}^{238}_{92}\text{U} \longrightarrow {}^{??}_{??}\text{X} + {}^{4}_{2}\text{He} $$

2. Write the equation for the α-decay of radium isotope ${}^{226}_{88}\text{Ra}$.

$$ {}^{226}_{88}\text{Ra} \longrightarrow {}^{??}_{??}\text{X} + {}^{4}_{2}\text{He} $$

GAMMA & POSITRON DECAYS

- ***Gamma decay*** occurs when a nucleus gives off ***γ-rays*** , and becomes a less energetic form of the same nucleus.

$$^{204}_{82}Pb^{*} \longrightarrow \, ^{204}_{82}Pb + \gamma$$

- Loss of gamma from the nucleus results in no change in mass number (A) or atomic number (Z).

- Certain nuclear processes can also lead to a fourth form of radiation, called a ***positron*** $\left(^{0}_{+1}e\right)$

$$^{17}_{9}F \longrightarrow \, ^{17}_{8}O + \, ^{0}_{+1}e$$

<u>Examples:</u>

1. Complete the following equations for nuclear decays:

$$^{46}_{21}Sc^{*} \longrightarrow \, ^{46}_{21}Sc +$$

$$^{47}_{21}Sc \longrightarrow \qquad\qquad + \, ^{0}_{-1}e$$

2. What nuclide forms when ^{214}Pb successively emits two beta particles, then one alpha particle from its nucleus. Write successive equations showing these changes.

$$^{214}_{82}Pb \xrightarrow{\beta} \qquad\qquad + \, ^{0}_{-1}e \xrightarrow{\beta} \qquad\qquad + \, ^{0}_{-1}e \xrightarrow{\alpha} \qquad\qquad + \, ^{4}_{2}He$$

TRANSMUTATION OF ELEMENTS

- The transformation of one element into another by natural or artificial means is called ***transmutation***.

- Transmutation occurs naturally in radioactive decay, but transmutation by artificial methods was not achieved until 1919 when Ernest Rutherford succeeded in transforming a nitrogen nuclide into an oxygen nuclide by bombardment with alpha particles.

$$ {}^{14}_{7}N + \underbrace{{}^{4}_{2}He}_{\text{alpha particle}} \longrightarrow {}^{17}_{8}O + {}^{1}_{1}H $$

- Rutherford's experiments opened the door to development of many transmutations by bombardment with various particles. Large instruments called accelerators were developed to accelerate these particles for penetration into the nucleus. Some examples of these transmutations are shown below:

$$ {}^{40}_{18}Ar + {}^{1}_{1}H \longrightarrow {}^{40}_{19}K + {}^{1}_{0}n $$

$$ {}^{209}_{83}Bi + {}^{2}_{1}H \longrightarrow {}^{210}_{84}Po + {}^{1}_{0}n $$

$$ {}^{238}_{92}U + {}^{12}_{6}C \longrightarrow {}^{244}_{98}Cf + 6\,{}^{1}_{0}n $$

Examples:

Complete each of the following transmutations:

1. $ {}^{23}_{11}Na + {}^{1}_{1}H \longrightarrow $ ______ $+ {}^{1}_{0}n$

2. $ {}^{16}_{8}O + {}^{1}_{0}n \longrightarrow $ ______ $+ {}^{4}_{2}He$

RADIONUCLIDES

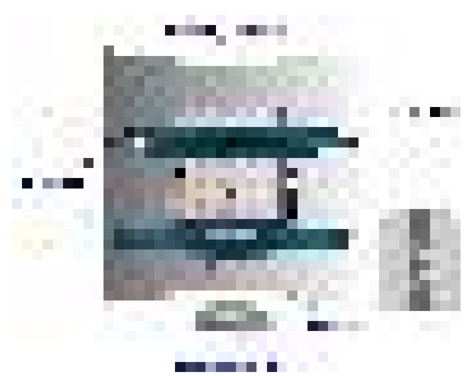
- A ***nuclide*** will be ***radioactive*** if it meets any of the following criteria:

  1. Its ***atomic number*** is greater than ***83***.
  2. It has ***fewer n than p*** in the nucleus (except $^{1}_{1}H$, $^{3}_{2}He$)
  3. It has ***odd number of neutrons*** and odd number of ***protons*** (except for $^{2}_{1}H$, $^{6}_{3}Li$, $^{10}_{5}B$, $^{14}_{7}N$)

Examples:
Which is the radionuclide in each of the following pairs?

1. $^{208}_{82}Pb$ and $^{222}_{86}Rn$ $\longrightarrow$
2. $^{19}_{10}Ne$ and $^{20}_{10}Ne$ $\longrightarrow$
3. $^{63}_{29}Cu$ and $^{64}_{29}Cu$ $\longrightarrow$

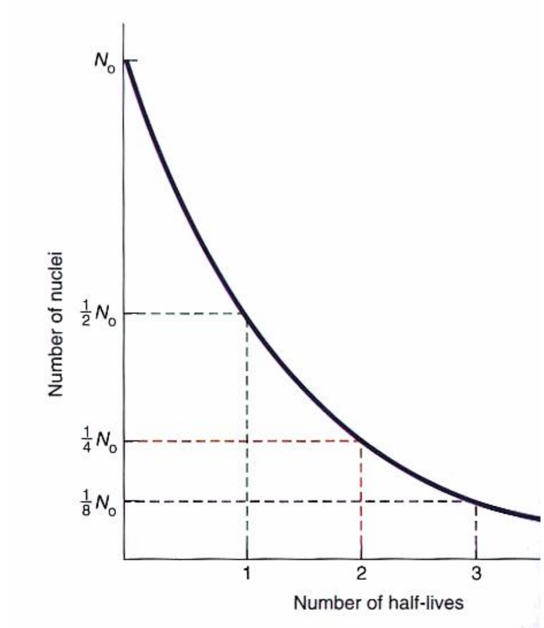
- One example of a practical use for radionuclides is their use in smoke detectors.
- In these detectors, the radioculide decays to form α-particles.
- The α-particles ionize (charge) the air particles and keep a current running through the circuit.
- When smoke particles interfere with the ions, current is reduced in the circuit, and an alarm goes off.



HALF-LIFE

- The ***time*** it takes for ***half*** of any ***radionuclide to decay*** is called ***half-life***. Some nuclides have half-lives of only seconds, while others have half-life of years.

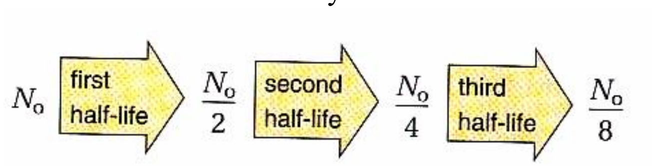
- The rate of decay of any radionuclide follows the graph to the right, with ***each half-life*** reducing the amount of radionuclide to ***half of the previous amount***.



<u>Examples:</u>

1. Iodine-131 has a half-life of 8 days. What mass of a 40 g sample of iodine-131 will remain after 24 days.

$$24 \text{ days} \times \frac{1 \text{ half-life}}{8 \text{ days}} = 3 \text{ half-lives}$$



$$\text{sample remaining after 3 half-lives} = \frac{40 \text{ g}}{8} = 5 \text{ g}$$

2. How long would it take for a sample of C-14 to decay from 20.0 g to 0.625 g? (½-life of C-14=5730 y)

½ Life	0	1	2	3	4	5	6	7
g	20.0							

$$\cancel{\text{half-lives}} \times \frac{5730 \text{ y}}{1\ \cancel{\text{half-life}}} =$$

NUCLEAR REACTIONS

- Similar to transmutation, nuclear reactions occur when two or more smaller nuclei combine to form a larger one.

- The general form of a nuclear reaction is:

$$a \;+\; A \;\rightarrow\; B \;+\; b$$

- In all nuclear reactions, the sum of atomic numbers and mass numbers on both side of the equation must be equal. For example:

$$^{56}_{26}Fe + ^{209}_{83}Bi \longrightarrow ^{266}_{109}Mt + ^{1}_{0}n$$

$$^{2}_{1}H + ^{98}_{42}Mo \longrightarrow ^{99}_{43}Tc + ^{1}_{0}n$$

- Large amount of energy is released in nuclear reactions and as a result a significant amount of mass is converted to energy. Einstein's equation, $E = mc^2$, can be used to calculate the amount of energy released in a nuclear reaction.

Example:

1. Calculate the mass loss and the amount of energy released in the nuclear reaction shown below:

$$\underset{7.016\text{ g}}{^{7}_{3}Li} \quad + \quad \underset{1.008\text{ g}}{^{1}_{1}H} \longrightarrow \underset{4.003\text{ g}}{^{4}_{2}He} \quad + \quad \underset{4.003\text{ g}}{^{4}_{2}He} \quad + \quad \text{energy}$$

Mass of reactant =

Mass of products =

Mass Loss =

Energy released $E = mc^2 =$

MASS DEFECT

- The mass of the nucleus is actually less than the sum of the masses of the protons and neutrons that make up the nucleus.
- This difference in mass is called the ***mass defect***. The energy equivalent to this mass is called the ***nuclear binding energy***, and is the energy required to break the nucleus into protons and neutrons.

Example:

1. Calculate the mass defect and the nuclear binding energy for an α-particle (helium nucleus) from the following data:

   Mass of proton = 1.0073 g/mol

   Mass of neutron = 1.0087 g/mol

   Mass of electron = 0.00055 g/mol

   Step 1: Calculate the mass of an α-particle:

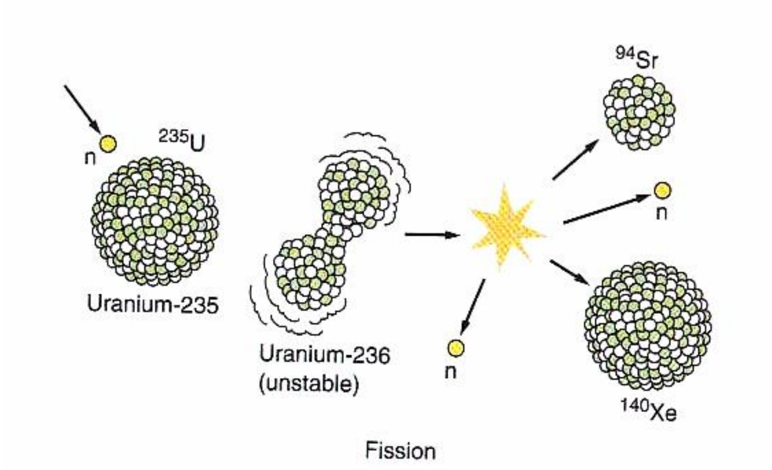
   Step 2: Calculate the mass of individual particles in α-particle:

   Step 3: Calculate the mass loss:

   Step 4: Calculate the binding energy:

NUCLEAR FISSION & FUSION

- ***Fission*** is the process by which a ***large nucleus is "split"*** into two smaller nuclei, with a ***large amount of energy released***.



$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{236}_{92}U \text{ (unstable)}$$
$$^{236}_{92}U \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

- A ***nuclear bomb*** is an example of an ***uncontrolled fission***, while a ***nuclear reactor*** is an example of a ***controlled fission***.

- ***Fusion*** is the process by which ***smaller nuclei combine*** to ***form larger ones***, with the ***release of energy***. Fusion reactions require temperatures of millions of degrees in order to initiate.

- The ***sun*** uses ***fusion*** to produce a ***helium nucleus from 4 hydrogen nuclei***, giving off ***2 positrons*** and energy.

$$4\,^{1}_{1}H \longrightarrow ^{4}_{2}He + 2\,^{0}_{+1}e + \text{energy}$$