Name:

Nuclear Physics

I. Representation of an atom or nuclide:

Radium-228 OR $${}^{228}_{88}\mathrm{Ra}$$

name of element followed by atomic mass
(which is the # of protons + neutrons)

228 *(atomic mass)*
Ra *(symbol)*
88 *(atomic number which is the # of protons as well as the # of electrons)*

II. Mass Defect and Nuclear Stability

A. Let's look at helium-4:

2 protons (2 X 1.007276amu) = 2.014552amu
2 neutrons (2 X 1.008665amu) = 2.017330amu
2 electrons (2 X 0.0005486amu) = 0.001097amu
total combined mass: 4.032979amu

The actual mass of the atom is measured to be 4.00260amu! That is 0.03038amu less then the sum of all of its particles, it is also called the **mass defect.**

B. The mass defect is caused by the conversion of mass (m) to energy (E) when the nucleus was originally formed.

C. Using Einstein's equation $E=mc^2$, we can actually calculate the energy that was formed when the nucleus was formed! This is called the **nuclear binding energy.** (It can also be thought of as the amount of energy required to break apart the nucleus; therefore, the nuclear binding energy is also a measure of the **stability** of a nucleus.)

III. Nuclear Reactions – Chemical reactions involve the breaking and forming of bonds between different atoms. In a **nuclear reaction** the situation is different – in a nuclear reaction changes occur involving the number of protons, neutrons, or electrons in a single atom.

Proton is symbolized ${}^{1}_{1}p$ Electron : ${}^{0}_{-1}e$ OR ${}^{0}_{-1}\beta$ Neutron: ${}^{1}_{0}n$

In **nuclear equations** the total of the atomic number and the total of the mass number must be equal on both sides of the equation. Example:

$${}^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$$

Mass Number: 9+4 = 13 12+1 = 13
Atomic Number: 4+2 = 6 6+0 = 6

Practice: Complete the following nuclear equations:

1. $${}^{218}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + \underline{\hspace{3cm}}$$

2. $${}^{253}_{99}\mathrm{Es} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{256}_{101}\mathrm{Md} + \underline{\hspace{4cm}}$$

3. $${}^{142}_{61}\mathrm{Pm} + \underline{\hspace{3cm}} \rightarrow {}^{142}_{60}\mathrm{Nd}$$

4. $${}^{212}_{84}\text{Po} \rightarrow {}^{4}_{2}\text{He} + \underline{\hspace{4cm}}$$

IV. Radioactive Decay is the spontaneous disintegration of a nucleus into a slightly lighter nucleus, accompanied by emission of particles, electromagnetic radiation, or both.

Types of Radioactive Decay

A. Alpha Emission – an alpha particle (α) is 2 protons and 2 neutrons (or a helium atom) bound together and is emitted from the nucleus during some kinds of radioactive decay.

$${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$$

Clothes will shield you form alpha particles.

B. Beta Emission – a beta particle (β) is an electron emitted from the nucleus when a neutron is converted to a proton.

$${}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\beta$$

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

Metal foil will shield you from beta particles.

C. Positron Emission – a positron is a particle that is emitted from the nucleus when a proton is converted into a neutron.

$${}^{1}_{1}\text{p} \rightarrow {}^{1}_{0}\text{n} + {}^{0}_{1}\beta$$

$${}^{38}_{19}\text{K} \rightarrow {}^{38}_{18}\text{Ar} + {}^{0}_{1}\beta$$

D. Gamma Emission – gamma rays (γ) are high-energy electromagnetic waves emitted from a nucleus as it changes from an excited state to a ground energy state. Very similar to light, but is much more dangerous. Gamma emission usually occurs immediately following other types of decay.
Lead or concrete will protect you from gamma rays.

Practice: Complete the following nuclear reactions and state the type of radioactive decay:

1. $${}^{206}_{82}\text{Pb} \rightarrow {}^{202}_{80}\text{Cm} + \underline{\hspace{4cm}}$$

2. $${}^{234}_{90}\text{Th} \rightarrow \underline{\qquad\qquad} + {}^{0}_{-1}\beta$$

3. $${}^{40}_{20}\text{Ca} \rightarrow {}^{40}_{19}\text{K} + \underline{\qquad\qquad}$$

4. Write an equation to represent the decay of thorium-230 by alpha emission.

E. Effects of Nuclear Radiation: The effects of radiation depend on the amount and exposure. Massive doses can be deadly. DNA molecules are sensitive to alpha, beta, positron, gamma, and x-rays.

Radiation Exposure (Personal Radiation Dose Test) - Measured in **rem's** (it is a quantity of radiation that causes change to human tissue).

Detecting Radiation (page 714): **Film badges, Geigir-Muller counters, and scintillation** are three common devices used to detect and measure nuclear radiation. International standards allow up to 5rem's a year exposure for those who work with and around radioactive material.

Applications of Nuclear Radiation: Radioactive Dating, Radioactive Tracers (both medical and agricultural uses), Radiation Therapy (chemotherapy)

V. Half-life – is the time required for half the atoms of a radioactive nuclide to decay. Each radioactive nuclide has its own half-life. Example: Cargon-14 has a half-life of 5715-5730 years. Page 708

Example Problem: Phosphorus-32 has a half-life of 14.3 days. How many mg of phosphorus-32 remain after 57.2 days if you start with 4mg of the isotope?

Amount of Phosphorus-32	Time Elapsed
4mg	0 days have past
2mg	14.3 days have past
1mg	28.6 days have past
0.5mg	42.9 days have past
0.25mg	57.2 days have past

Another way to work problems:

# of half-lives = time elapsed X ratio for half-life

$$\#\text{ of half-lives} = 57.2\text{ days} \times \frac{1\text{ half-life}}{14.3\text{ days}} = 4\text{ half-lives}$$

So now we know the answer will be:

$$4\text{mg} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} = 0.25\text{mg}$$

Practice:

1. The half-life of polonium-210 is 138.4 days. How many mg of polonium-210 remain after 415.2 days if you start with 2mg of the isotope?

2. The half-life of radon-222 is 3.824 days. After what time will ¼ of a given amount of radon-222 remain?

VI. Nuclear Fission and Fusion

A. Nuclear Fission – the splitting of a nucleus into smaller fragments (the splitting is caused by bombarding the nucleus with neutrons). This process releases enormous amounts of energy. (page 717)
A nuclear chain reaction is a reaction in which the material that starts the reaction (neutron) is also one of the products and can be used to start another reaction.

1. **Nuclear Reactors** use controlled – fission chain reactions to produce energy or radioactive nuclides.
2. **Nuclear Power Plants** use heat from nuclear reactors to produce electrical energy. They have 5 main components: page 718
    - **a. shielding** – radiation absorbing material that is used to decrease exposure to radiation.
    - **b. fuel** – uranium is most often used
    - **c. control rods** – neutron absorbing rods that help control the reaction by limiting the number of free neutrons
    - **d. moderator** – water (sometimes carbon) is used to slow down the fast neutrons produced by fission
    - **e. coolant** – water acts as a coolant and transports heat between the reaction and the steam turbines to produce electric current

Nuclear Power Plants produce a great deal of energy, the current problems with nuclear power plants include environmental requirements, safety of operation, plant construction costs, and storage and disposal of spent fuel and radioactive waste.

3. **Atomic Bomb** – fission reaction

B. Nuclear Fusion – light mass nuclei combine to form a heavier, more stable nucleus. Nuclear fusion releases even more energy per gram of fuel then nuclear fission!!

1. **Sun/Stars** – four hydrogen nuclei combine at extremely high temperatures and pressures to form a helium nucleus – this is a fusion reaction.
2. **Hydrogen Bomb** - uncontrolled fusion reactions of hydrogen are the source of energy for the hydrogen bomb. Hydrogen bombs generate a great deal more of energy then an atomic bomb.
3. **Fusion as a Source of Energy**: because fusion reactions generate a great deal more energy and their products are less harmful then fission reactions. Research is being done to try to use fusion instead of fission, there are a few problems: temperature of 10^8 Kelvin is required and no known material can withstand the temperature.

C. Nuclear Waste (produced from fission and fusion reactions)

1. **Types of Nuclear Waste** - spent fuel rods, dismantled nuclear power plants, military, radioisotopes used in many hospitals
2. **Containment** – on-site storage and off-site disposal (Remember that every radioactive substance has a half-life, some only a few months, others hundreds of thousands of years.)
    - **a. On-Site Storage** – most common nuclear waste is spent fuel rods from nuclear power plants
      -water pools
      -dry casks (concrete or steel)
    - **b. Off-Site Disposal** – disposal of nuclear waste is done with the intention of never retrieving the materials.
      -77 disposal sites around the United States
      -new site near Las Vegas, Nevada Yucca Mountain