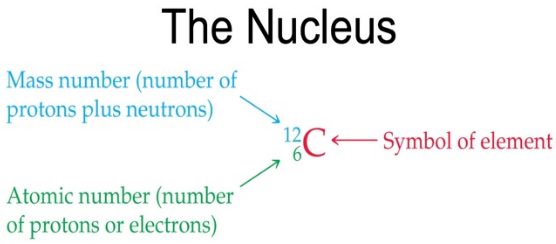
Chapter 21
Nuclear Chemistry

Review

Definitions

Chemical Energy is energy stored in the bonds of atoms and molecules.
Nuclear Energy is due to changes in the nucleus of atoms changing them into different atoms. Nuclear energy is enormous in comparison.



Nucleus is composed of the two **nucleons**, protons and neutrons.
The number of protons is the atomic number.
The number of protons and neutrons together is the mass number.

Isotopes: the same element have the different mass, due to different numbers of neutrons in those atoms.
Radioactivity: some nuclides of an elements are unstable, or radioactive, which can be called **radionuclides** (放射性核素).

Table 21.1 Properties of Alpha, Beta, and Gamma Radiation

	Type of Radiation		
Property	α	β	γ
Charge	2+	1−	0
Mass	6.64×10^{-24}g	9.11×10^{-28}g	0
Relative penetrating power	1	100	10,000
Nature of radiation	$^{4}_{2}$He nuclei	Electrons	High-energy photons

Types of Radioactive Decay:

1. **Alpha decay** is the loss of an α-particle.

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

2. **Beta decay** is the loss of a β-particle (a high-speed electron emitted by the nucleus): $^{0}_{-1}\beta$ or $^{0}_{-1}e$

$$^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e$$

3. **Gamma emission** is the loss of a γ-ray, which is high-energy radiation that almost always accompanies the loss of a nuclear particle: $^{0}_{0}\gamma$

4. **Positron Emission**: Some nuclei decay by emitting a **positron**, a particle that has the same mass as, but an opposite charge to, that of an electron: ${}^{11}_{6}C \longrightarrow {}^{11}_{5}B + {}^{0}_{1}e$

5. **Electron Capture (k-Capture):** An electron from the surrounding electron cloud is absorbed into the nucleus.

$${}^{81}_{37}Rb + {}^{0}_{-1}e \longrightarrow {}^{81}_{36}Kr$$

Table 21.3 Types of Radioactive Decay

Type	Nuclear Equation	Change in Atomic Number	Change in Mass Number
Alpha decay	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	−2	−4
Beta emission	${}^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}e$	+1	Unchanged
Positron emission	${}^{A}_{Z}X \longrightarrow {}_{Z-1}^{A}Y + {}^{0}_{+1}e$	−1	Unchanged
Electron capture*	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}_{Z-1}^{A}Y$	−1	Unchanged

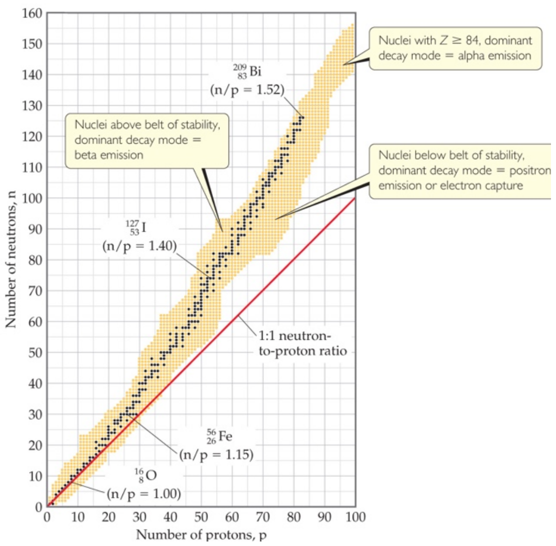
*The electron captured comes from the electron cloud surrounding the nucleus.

Table 21.2 Particles Found in Nuclear Reactions

Particle	Symbol
Neutron	${}^{1}_{0}n$ or n
Proton	${}^{1}_{1}H$ or p
Electron	${}^{0}_{-1}e$
Alpha particle	${}^{4}_{2}He$ or α
Beta particle	${}^{0}_{-1}e$ or β^-
Positron	${}^{0}_{+1}e$ or β^+

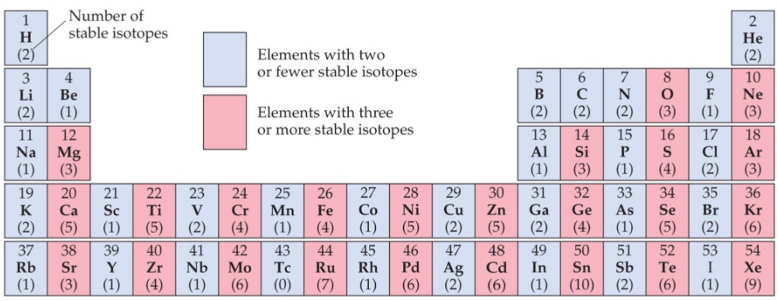
Nuclear stability:

1. Repulsions between the protons in the nucleus.
2. **Strong nuclear force** helps keep the nucleus together.
3. The ratio of neutrons to protons.



Stable or unstable?

1. **belt of stability**--it shows what nuclides would be stable.
2. Unstable: Nuclei above this belt have too many neutrons--decay by emitting beta particles. Nuclei below the belt have too many protons--become more stable by positron emission or electron capture.



3. **Magic numbers** of 2, 8, 20, 28, 50, or 82 protons or 2, 8, 20, 28, 50, 82, or 126 neutrons result in more stable nuclides.
4. Nuclei with an even number of protons and neutrons tend to be more stable than those with odd numbers.

Note: There are no stable nuclei with an atomic number greater than 83. Nuclei with such large atomic numbers tend to decay by alpha emission.

Nuclear transmutations can be induced by accelerating a particle to collide it with the nuclide.
Particle accelerators ("atom smashers") are enormous, having circular tracks with radii that are miles long.
Nuclear equations for nuclear transmutations:

1) $$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H \quad \text{or} \quad ^{14}_{7}N + \alpha \longrightarrow ^{17}_{8}O + p$$

2) Target nucleus　　Product nucleus

$$^{14}_{7}N\ (\alpha, p)\ ^{17}_{8}O$$

Bombarding particle　　Ejected particle

Radioactive decay is a first-order process.
Half-life is the time required for half of a radionuclide sample to decay.

$$\frac{0.693}{k} = t_{1/2}$$

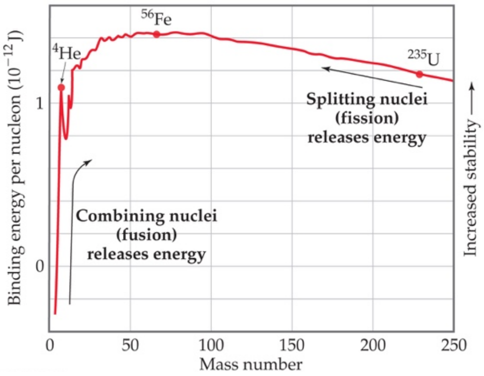
Measuring Radioactivity
Activity is the rate at which a sample decay.
Unit: Becquerel (Bq): one disintegration per second.
Curie (Ci): 3.7×10^{10} disintegrations per second, which is the rate of decay of 1 g of radium.

Instruments:
1. <u>Film badges</u> are used by people who work with radioactivity to measure their own exposure over time.
2. <u>Geiger counter</u> measures the amount of activity present in a radioactive sample.
3. Phosphors (scintillation counters): phosphors absorb radioactivity and emit light. <u>Scintillation counter</u> used to measure the amount of light emitted by a phosphor. It converts the light to an electronic response for measurement.

Radiotracers are radioisotopes used to study a chemical reaction.
Energy in nuclear reaction: $E = mc^2$.

The masses of nuclei are always less than those of the individual parts. This mass difference is called the **mass defect**.

The energy needed to separate a nucleus into its nucleons is called the **nuclear binding energy**.



Heavy nuclei gain stability and give off energy when they split into two smaller nuclei. This is **fission**.

Lighter nuclei emit great amounts of energy by being combined in **fusion**.

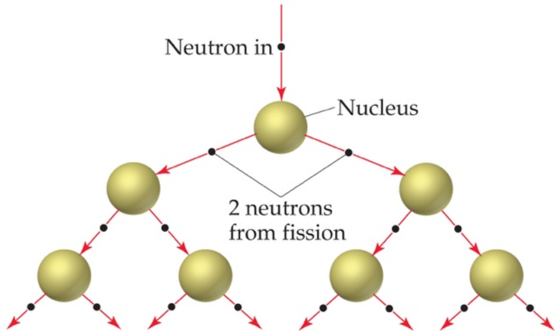
Nuclear Fission: Heavy nuclei can split in many ways.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{137}_{52}Te + ^{97}_{40}Zr + 2\,^{1}_{0}n$$

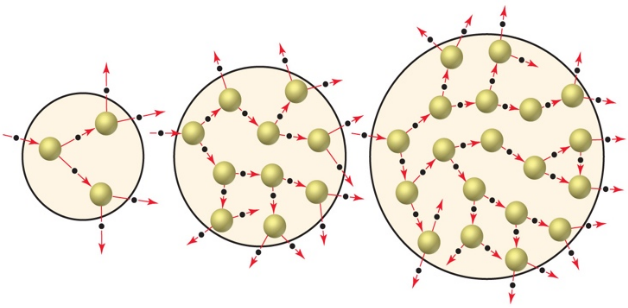
$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n$$

Nuclear chain reaction is a process continues that

1. Bombardment of the radioactive nuclide with a neutron starts the process.
2. Neutrons released in the transmutation strike other nuclei, causing their decay and the production of more neutrons.



The minimum mass that must be present for a chain reaction to be sustained is called the **critical mass**. If more than critical mass is present (**supercritical mass**), an explosion will occur.

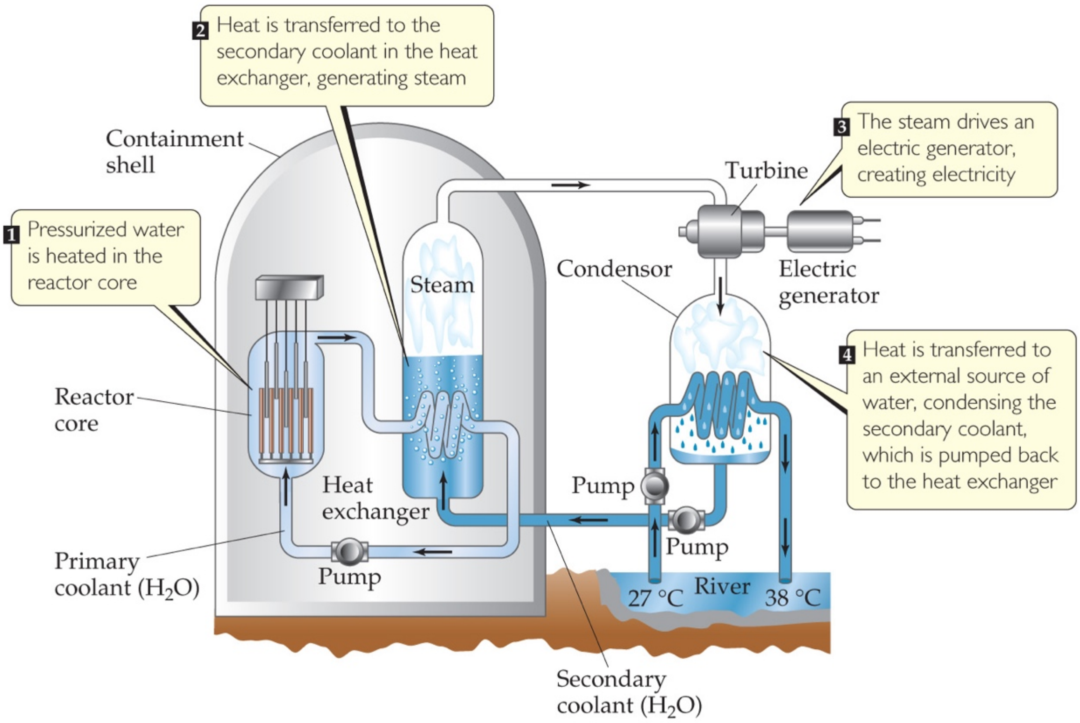


Subcritical mass
Rate of neutron loss > rate of neutron creation by fission

Critical mass
Rate of neutron loss = rate of neutron creation by fission

Supercritical mass
Rate of neutron loss < rate of neutron creation by fission

Nuclear Reactor



Reactors must be stopped periodically to replace or reprocess the nuclear fuel. The original intent was that **nuclear waste** would then be transported to reprocessing or storage sites.

Nuclear Fusion-small atoms are combined, much energy is released.
Extremely high temperatures and pressures are needed to cause nuclei to fuse, which was achieved using an atomic bomb to initiate fusion in a hydrogen bomb.

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

Ionizing radiation is more harmful to living systems than nonionizing radiation (such as radiofrequency electromagnetic radiation).
Ionizing radiation---Most living tissue is ~70% water, ionizing radiation is that which causes water to ionize, which creates unstable, very reactive OH radicals, then damage cells.

$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH$$

Low-level, long-term **exposure** can cause health issues. Damage to the growth-regulation mechanism of cells results in cancer.

Radiation dose:
Gray (Gy): absorption of 1 J of energy per kg of tissue.
Rad (for radiation absorbed dose): absorption of 0.01 J of energy per kg of tissue (100 rad = 1 Gy).
Note: Not all forms of radiation harm tissue equally. A **relative biological**

effectiveness (RBE) is used to show how much biological effect there is. The effective dose is called the **rem**.

Table 21.9 Effects of Short-Term Exposures to Radiation

Dose (rem)	Effect
0–25	No detectable clinical effects
25–50	Slight, temporary decrease in white blood cell counts
100–200	Nausea; marked decrease in white blood cell counts
500	Death of half the exposed population within 30 days

Radon-222 is a decay product of uranium-238, which is found in rock formations and soil. Most of the decay products of uranium remain in the soil, but radon is a gas.