Chemistry 132 NT

You can't escape death and taxes. But, at least, death doesn't get worse.

Will Rogers

1

Chem 132 NT

Nuclear Chemistry

Module 3

Energy and Nuclear Reactions

- **Mass-Energy Calculations**
- **Nuclear Fission and Nuclear Fusion**

The core of a nuclear reactor used in research.

2

Review

- Using the notation for a bombardment reaction
- Calculating the decay constant from the activity
- Relating the decay constant, half-life, and activity
- Determining the fraction of nuclei remaining after a specified time

3

Mass-Energy Calculations

- When nuclei decay, they form products of lower energy.
  - The **change of energy** is related to the **change in mass**, according to the mass-energy equivalence relation derived by Albert Einstein in 1905.
  - Energy and mass are equivalent and related by the equation

$$E = mc^2$$

Here c is the speed of light, 3.00×10^8 m/s.

4

Mass-Energy Calculations

- When nuclei decay, they form products of lower energy.
  - If a system **loses energy**, it must also **lose mass**.
  - Though mass loss in chemical reactions is small (10^{-12} kg), the mass changes in **nuclear reactions** are approximately a **million times larger.**

5

Mass-Energy Calculations

- When nuclei decay, they form products of lower energy.
  - Consider the alpha decay of uranium-238 to thorium-234.

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

238.05078 234.04359 4.00260

  - We have written the atomic mass (in amu) beneath each nuclide symbol.

6

Mass-Energy Calculations

- When nuclei decay, they form products of lower energy.
  - The change in mass for this reaction, in molar amounts is

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

238.05078 234.04359 4.00260

$$\Delta m = (234.04359 + 4.00260 - 238.05078) = -0.00459 g$$

7

Mass-Energy Calculations

- When nuclei decay, they form products of lower energy.
  - The change in mass for this reaction, in molar amounts is

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He \quad \Delta m = -0.00459\ g$$

238.05078 234.04359 4.00260

  - The energy change for 1 mol of uranium-238 is

$$\Delta E = \Delta mc^2 = (-4.59 \times 10^{-6}\ kg) \times (3.00 \times 10^8\ m/s)^2$$

$$\Delta E = -4.13 \times 10^{11}\ J = -4.13 \times 10^8\ kJ$$

8

Mass-Energy Calculations

- The equivalence of mass and energy explains the fact that **the mass of an atom is <u>always</u> less than the sum of the masses of its constituent particles.**
  - When nucleons come together to form a stable nucleus, energy is released.
  - According to Einstein's equation, there must be a **corresponding decrease in mass**.

9

Mass-Energy Calculations

- The **binding energy** of a nucleus is the energy needed to break a nucleus into its individual protons and neutrons.
  - Thus the binding energy of the helium-4 nucleus is the energy change for the reaction

$$^{4}_{2}\mathrm{He} \rightarrow 2^{1}_{1}\mathrm{p} + 2^{1}_{0}\mathrm{n} \qquad \Delta m = 0.03040 \text{ amu}$$

4.00260 2(1.00728) 2(1.008665)

  - Both binding energy and the corresponding mass defect are reflections of the stability of the nucleus.

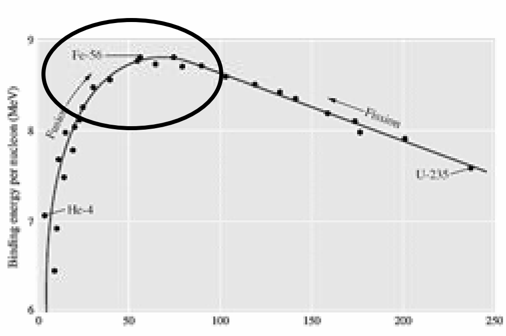
10

Mass-Energy Calculations

- The **binding energy** of a nucleus is the energy needed to break a nucleus into its individual protons and neutrons.
  - The figure on the next slide shows the values of **binding energy per nucleon** plotted against the mass number for various nuclides.
  - Note that nuclides **near mass number 50** have the largest binding energies per nucleon.

11

Plot of binding energy per nucleon versus mass number.



12

Mass-Energy Calculations

- The **binding energy** of a nucleus is the energy needed to break a nucleus into its individual protons and neutrons.
  - For this reason, **heavy nuclei might be expected to split** to give lighter nuclei, while **light nuclei might be expected to combine** to form heavier nuclei.

13

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - For example, one of the possible mechanisms for the decay of californium-252 is

$$^{252}_{98}\text{Cf} \text{ ® } ^{142}_{56}\text{Ba} + ^{106}_{42}\text{Mo} + 4^{1}_{0}\text{n}$$

14

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - In some cases a nucleus can be induced to undergo fission by bombardment with neutrons.

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \rightarrow ^{142}_{54}\text{Xe} + ^{90}_{38}\text{Sr} + 4^{1}_{0}\text{n}$$

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \rightarrow ^{139}_{546}\text{Ba} + ^{94}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \rightarrow ^{144}_{55}\text{Cs} + ^{90}_{37}\text{Rb} + 2^{1}_{0}\text{n}$$

15

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - When uranium-235 undergoes fission, **more neutrons are released** creating the possibility of a chain reaction.
  - A **chain reaction** is a self-sustaining series of nuclear fissions caused by the absorption of neutrons released from previous nuclear fissions.

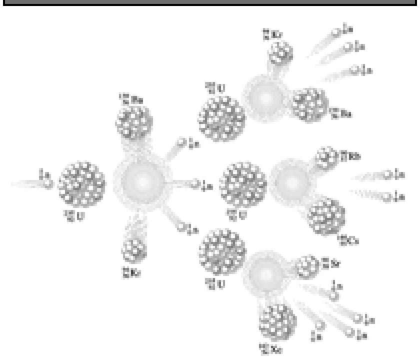
16

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - The next slide shows how such a chain reaction occurs.
  - To sustain a nuclear chain reaction you must achieve a **critical mass**, which is the smallest mass of fissionable material required for a chain reaction.

17

Representation of a chain reaction of nuclear fission.



18

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - A **supercritical mass** of fissionable material decays so rapidly as to cause a **nuclear explosion**.

19

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - A **nuclear fission reactor** is a device that permits a controlled chain reaction of nuclear fissions.

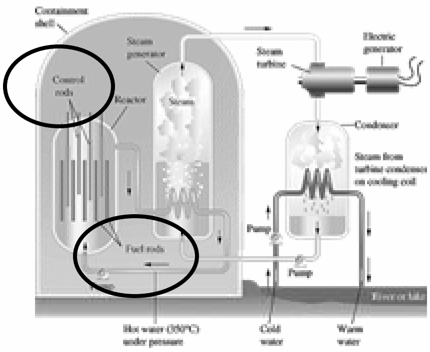
20

Nuclear Fission and Nuclear Fusion

- **Nuclear fission** is a nuclear reaction in which a heavy nucleus splits into lighter nuclei and energy is released.
  - The **fuel rods** are the cylinders that contain fissionable material.
  - **Control rods** are cylinders composed of substances that absorb neutrons and can therefore slow the chain reaction.

21

Light-water nuclear reactor.



Nuclear Fission and Nuclear Fusion

- **Nuclear fusion** is a nuclear reaction in which a light nuclei combine to give a more stable heavy nucleus plus possibly several neutrons, and energy is released.
  - An example of nuclear fusion is

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

Nuclear Fission and Nuclear Fusion

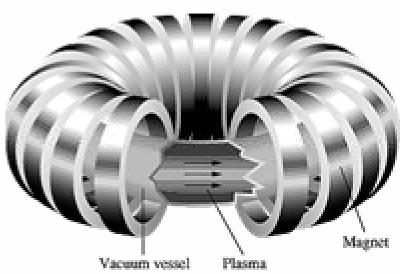
- **Nuclear fusion** is a nuclear reaction in which a light nuclei combine to give a more stable heavy nucleus plus possibly several neutrons, and energy is released.
  - Such fusion reactions have been observed in the laboratory using particle accelerators.
  - **Sustainable fusion** reactions require temperatures of about **100 million ^{o}C**.

Nuclear Fission and Nuclear Fusion

- **Nuclear fusion** is a nuclear reaction in which a light nuclei combine to give a more stable heavy nucleus plus possibly several neutrons, and energy is released.
  - At these elevated temperature, a **plasma** results, that is, an electrically neutral gas of ions and electrons.
  - A **magnetic fusion reactor** uses a magnetic field to hold the plasma.

25

Plasma confinement in a tokamakreactor.



26

Operational Skills

- Calculating the energy change for a nuclear reaction

27

Key Equations

$$\text{Rate} = kN_t$$

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

$$\ln\frac{N_t}{N_o} = -kt \quad \text{or} \quad \log\frac{N_t}{N_o} = \frac{-kt}{2.303}$$

$$DE = (Dm)c^2$$

Time for a few review questions

28

29