Chemistry 132 NT

If you're courting a pretty girl, an hour can seem like a second. If you sit on a red hot cinder, a second can seem like an hour. That's relativity.

Albert Einstein

1

Chem 132 NT

Nuclear Chemistry

Module 2

Radioactivity and Nuclear Bombardment Reactions

- **Nuclear Bombardment Reactions**
- **Radiation and Matter: Detection and Biological Effects**
- **Rate of Radioactive Decay**
- **Applications of Radioactive Isotopes**

The core of a nuclear reactor used in research.

2

Review

- Writing a nuclear equation
- Deducing a product or reactant in a nuclear equation
- Predicting the relative stability of nuclides
- Predicting the type of radioactive decay

3

Nuclear Bombardment Reactions

- In 1919, **Ernest Rutherford** discovered that it is possible to change the nucleus of one element into the nucleus of another element.
  - **Transmutation** is the change of one element to another by bombarding the nucleus of the element with nuclear particles or nuclei.

4

Nuclear Bombardment Reactions

- In 1919, **Ernest Rutherford** discovered that it is possible to change the nucleus of one element into the nucleus of another element.
  - Rutherford used a radioactive alpha source to bombard nitrogen nuclei.

$$^{14}_{7}\mathbf{N} + ^{4}_{2}\mathbf{He} \rightarrow ^{17}_{8}\mathbf{O} + ^{1}_{1}\mathbf{H}$$

  - He discovered that protons are ejected in the process.

5

Nuclear Bombardment Reactions

- The British physicist **James Chadwick** suggested in 1932 that the radiation from beryllium consists of **neutral particles**, each with a mass approximately that of a proton.
  - Chadwick's suggestion led to the **discovery of the neutron**.

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

6

Nuclear Bombardment Reactions

- Nuclear bombardment reactions are often referred to by an **abbreviated notation**.
  - For example, the reaction

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

is abbreviated

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

7

A Problem To Consider

- Write the abbreviated notation for the following bombardment reaction.

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

  - The notation is:

$$^{9}_{4}Be(\alpha,n)^{12}_{6}C$$

8

A Problem To Consider

- Write the nuclear equation for the bombardment reaction denoted $^{27}_{13}Al(p,d)^{26}_{13}Al$.
  - The nuclear equation is:

$$^{27}_{13}Al + ^{1}_{1}p \rightarrow ^{26}_{13}Al + ^{2}_{1}H$$

9

Nuclear Bombardment Reactions

- Bombardment of heavy nuclei **require accelerated particles** for successful transmutation reactions.
  - A **particle accelerator** is a device used to accelerate electrons, protons, and alpha particles and other ions to very high speeds.
  - It is customary to measure the kinetic energy of these particles in units of **electron volts**.

$$1\,\text{eV} = 1.602 \times 10^{-19}\ \text{J}$$

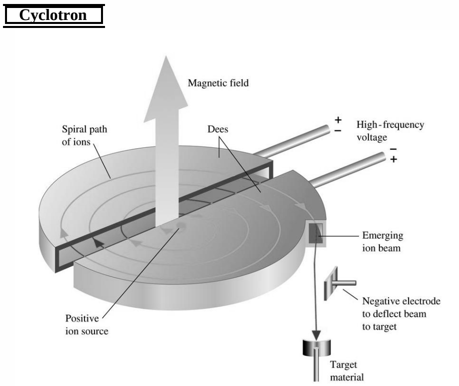
10

Nuclear Bombardment Reactions

- Bombardment of heavy nuclei **require accelerated particles** for successful transmutation reactions.
  - The figure on the next slide shows a diagram of a **cyclotron**, a type of particle accelerator consisting of two hollow, semicircular metal electrodes in which charged particles are accelerated in stages.

11

Cyclotron



12

Transuranium Elements

- The **transuranium elements** are elements with atomic number greater than that of uranium (Z=92), the naturally occurring element of greatest Z.
  - The first transuranium element was produced at the University of California at Berkley in 1940 by **E. M. McMillan and P. H. Abelson**.
  - They produced an isotope of element 93, which they named **neptunium**.

13

Transuranium Elements

- The **transuranium elements** are elements with atomic number greater than that of uranium (Z=92), the naturally occurring element of greatest Z.
  - Recent work has yielded other elements including the heaviest to date, 118.

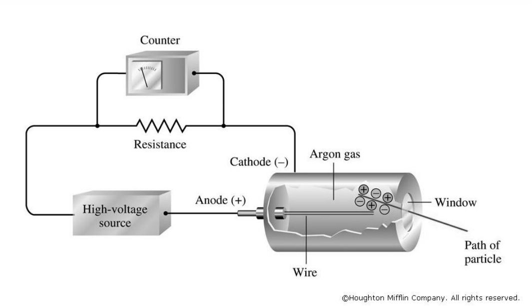
14

Radiations and Matter: Detection

- Two types of devices, **ionization counters** and **scintillation counters**, are used to count particles emitted from radioactive nuclei.
  - A **Geiger counter** (figure on next slide), a kind of ionization counter used to count particles emitted by radioactive nuclei, consists of a metal tube filled with gas, such as argon.

15

Geiger Counter



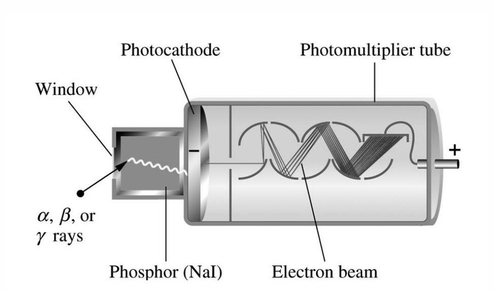
16

Radiations and Matter: Detection

- Two types of devices, **ionization counters** and **scintillation counters**, are used to count particles emitted from radioactive nuclei.
  - A **scintillation counter** (figure on next slide) is a device that detects nuclear radiation from flashes of light generated in a material by the radiation.

17

Scintillation Counter



18

Radiations and Matter: Detection

- The **activity of a radioactive source** is the number of nuclear disintegrations per unit time occurring in a radioactive material.
  - A **Curie (Ci)** is a unit of activity equal to 3.700 x 10^{10} disintegrations per second (dps).
  - A sample of technetium having an activity of 1.0 x 10^{-2} Ci is decaying at a rate of

$$(1.0 \times 10^{-2}) \times (3.700 \times 10^{10}) = 3.7 \times 10^{8} \text{ nuclei per second}$$

19

Biological Effects and Radiation Dosage

- To monitor the effect of nuclear radiations on biological tissue, it is necessary to have a **measure of radiation dosage**.
  - The **rad** (from radiation absorbed dose) is the dosage of radiation that deposits 1 x 10^{-2} J of energy per kilogram of tissue.
  - However, the biological effect of radiation not only on the energy deposited but also on the **type of radiation**.

20

Biological Effects and Radiation Dosage

- To monitor the effect of nuclear radiations on biological tissue, it is necessary to have a **measure of radiation dosage**.

  - The **rem** is a unit of radiation dosage used to relate various kinds of radiation in terms of biological destruction.
  - It equals the rad times a factor for the type of radiation, called the **relative biological effectiveness (RBE).**

$$\text{rems} = \text{rads} \times \text{RBE}$$

21

Biological Effects and Radiation Dosage

- To monitor the effect of nuclear radiations on biological tissue, it is necessary to have a **measure of radiation dosage**.
  - Beta and gamma radiations have an RBE of about 1, where neutron radiation has an RBE about 5 and alpha radiation an RBE of about 10.
  - A single dose of about 500 rems is fatal to most people.

22

Rate of Radioactive Decay

- The **rate of radioactive decay**, that is the number of disintegrations per unit time, is proportional to the number of radioactive nuclei in the sample.
  - You can express this rate mathematically as

$$\text{Rate} = kN_t$$

where N_t is the number of radioactive nuclei at time t, and **k** is the **radioactive decay constant**.

23

Rate of Radioactive Decay

- The **rate of radioactive decay**, that is the number of disintegrations per unit time, is proportional to the number of radioactive nuclei in the sample.
  - All radioactive decay follows **first order kinetics** as outlined in our Kinetics chapter.
  - Therefore, the **half-life** of a radioactive sample is related only to the radioactive decay constant.

24

Rate of Radioactive Decay

- The **half-life, $t_{½}$**, of a radioactive nucleus is the time required for one-half of the nuclei in a sample to decay.
  - The first-order relationship between $t_{½}$ and the decay constant **k** is

$$t_{½} = \frac{0.693}{k}$$

25

A Problem To Consider

- The decay constant for the beta decay of technetium-99 is 1.0 x 10^{-13} s^{-1}. What is the half-life of this isotope in years?
  - Substitute the value of k into our half-life equation.

$$t_{½} = \frac{0.693}{1.0 \times 10^{-13} s^{-1}} = 6.9 \times 10^{12}\ s$$

26

A Problem To Consider

- The decay constant for the beta decay of technetium-99 is 1.0 x 10^{-13} s^{-1}. What is the half-life of this isotope in years?
  - Then convert from seconds to years.

$$6.9 \times 10^{12}\ s \times \frac{1\ min}{60\ sec} \times \frac{1\ h}{60\ min} \times \frac{1 d}{24\ h} \times \frac{1\ y}{365\ d} = 2.2 \times 10^{5}\ y$$

27

Rate of Radioactive Decay

- Once you know the decay constant, you can calculate the **fraction of radioactive nuclei remaining** after a given period of time.
  - The first-order time-concentration equation is

$$\ln\frac{N_t}{N_o} = -kt$$

28

A Problem To Consider

- Phosphorus-32 has a half-life of 14.3 days. What fraction of a sample of phosphorus-32 would remain after 5.5 days?
  - If we substitute $k = 0.693/t_{½}$ we get

$$\ln\frac{N_t}{N_o} = \frac{-0.693\,t}{t_{½}}$$

29

A Problem To Consider

- Phosphorus-32 has a half-life of 14.3 days. What fraction of a sample of phosphorus-32 would remain after 5.5 days?
  - Substituting t = 5.5 d and $t_{½}$ = 14.3 d, you obtain

$$\ln\frac{N_t}{N_o} = \frac{-0.693\,(5.5\text{d})}{(14.3\text{ d})} = -0.267$$

30

A Problem To Consider

- Phosphorus-32 has a half-life of 14.3 days. What fraction of a sample of phosphorus-32 would remain after 5.5 days?
  - Hence,

$$\text{Fraction nuclei remaining} = \frac{N_t}{N_o} = e^{-0.267} = 0.77$$

31

Applications of Radioactive Isotopes

- A **radioactive tracer** is a very small amount of radioactive isotope added to a chemical, biological, or physical system to study the system.
  - A series of experiments using tracers was carried out in the 1950's by **Melvin Calvin** at the University of California at Berkley, to **discover the mechanism of photosynthesis in plants**.

32

Applications of Radioactive Isotopes

- Another example of radioactive tracers is **isotopic dilution**, a technique to determine the quantity of a substance in a mixture.
  - Human **blood volumes** are determined using the technique of isotopic dilution.

33

Applications of Radioactive Isotopes

- **Neutron activation analysis** is an analysis of elements in a sample based on the conversion of stable isotopes to radioactive isotopes by bombarding a sample with neutrons.
  - Human hair samples are identified by neutron activation analysis.

Operational Skills

- 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

Time for a few review questions