Unit 2

Chapters 4 & 25

Chapter 4

Atomic Structure & the Periodic Table

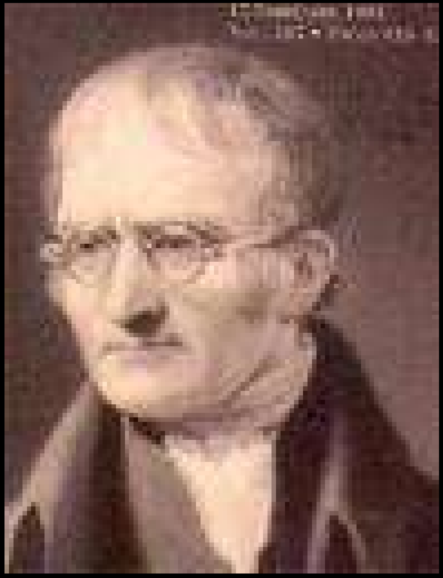
History of the Atom

Democritus *(around 460-370 B.C.)*

- a teacher from Greece during the 4th century BC
- first to suggest the existence of tiny particles making up matter
- named these particles "atoms"
  - did not explain chemical behavior
  - lacked experimental support

John Dalton(1766-1844)

- 2000 years after Democritus
- English school teacher
- Performed experiments to test and correct his atomic theory in 1803



Dalton's Atomic Theory

- All elements are composed of tiny, indivisible particles called atoms
- Atoms of same element are identical
- Atoms combine in whole number ratios
- Atoms of one element are never changed to atoms of a different element in a chemical reaction

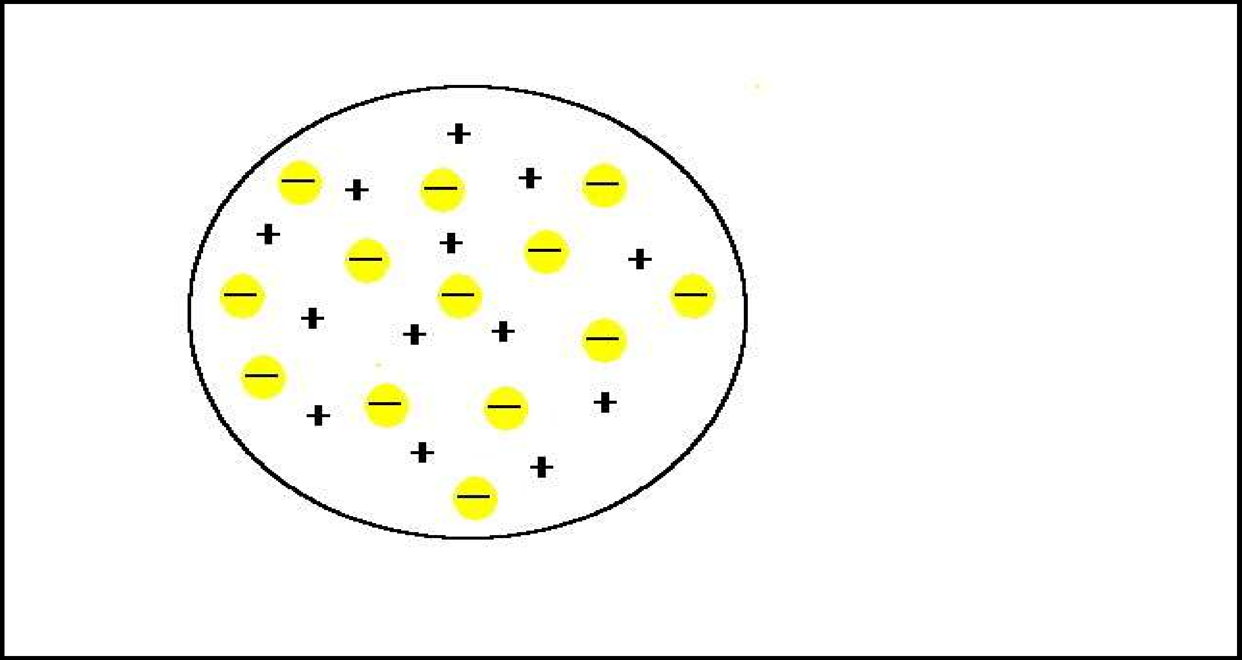
JJ Thomson (1856-1940)

- English physicist
- Discovered the electron in 1897

Thomson's Experiment

- Cathode ray tube
  - Glowing beam formed between electrodes
  - Beam traveled from the cathode (-) to the anode (+)
  - Cathode rays attracted to metal plates that have a positive electrical charge and repelled by plates that carry a negative electrical charge
  - Knowing that opposite charges attract and like charges repel, he proposed that a cathode ray is a stream of tiny negatively charged particle
  - Production of cathode rays independent of kind of gas or type of metal used so concluded that electrons must be a part of all atoms of all elements
- By 1900, he had determined the mass of an electron to be about 1/2000 the mass of a hydrogen atom

Thomson's Model A.K.A. Plum Pudding Model



Millikan (1868-1953)

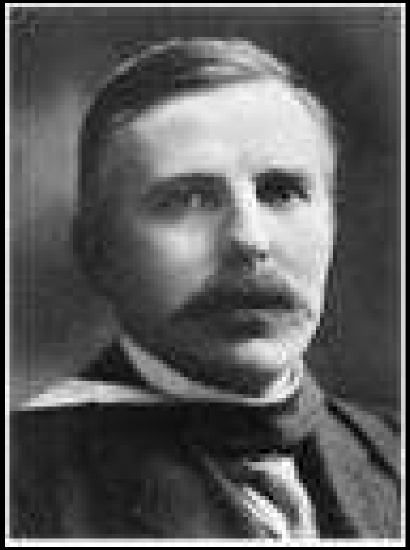
- American scientist
- Determined the ratio of the charge to the mass of an electron.
- Used these values to calculate an accurate value for the mass of an electron.
- Reported this mass in 1916 as 1/1840th the mass of a hydrogen atom.

Goldstein

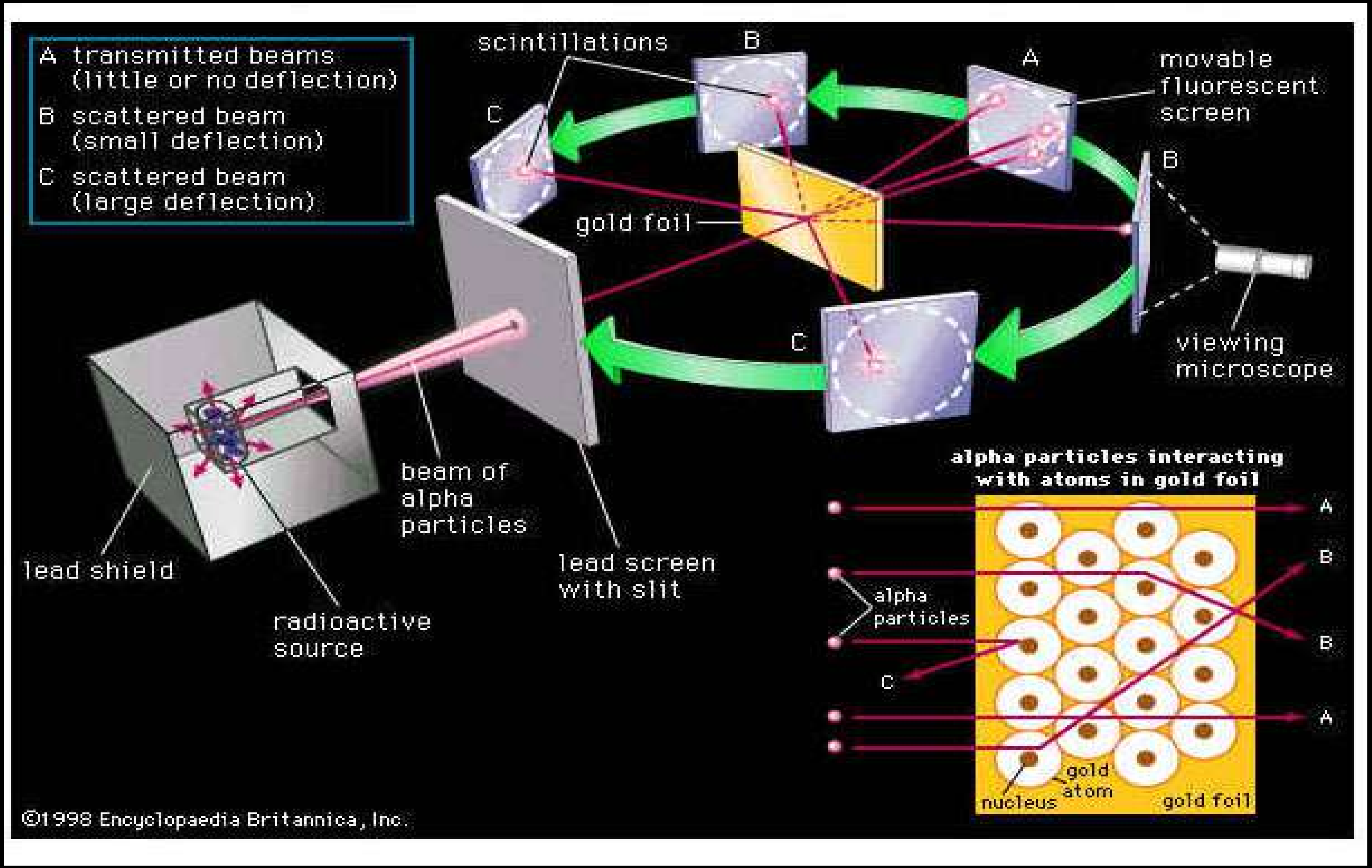
- Discovered the existence of the proton in 1886.
- Another ray coming from the CRT that was attracted to negative plates
- These particle have 1840 times the mass of an electron and one unit od positive charge

Ernest Rutherford (1871-1937)

- University of Manchester, England
- Decided to test the theory of atomic structure
- Designed gold-foil experiment in 1911



Gold Foil Experiment



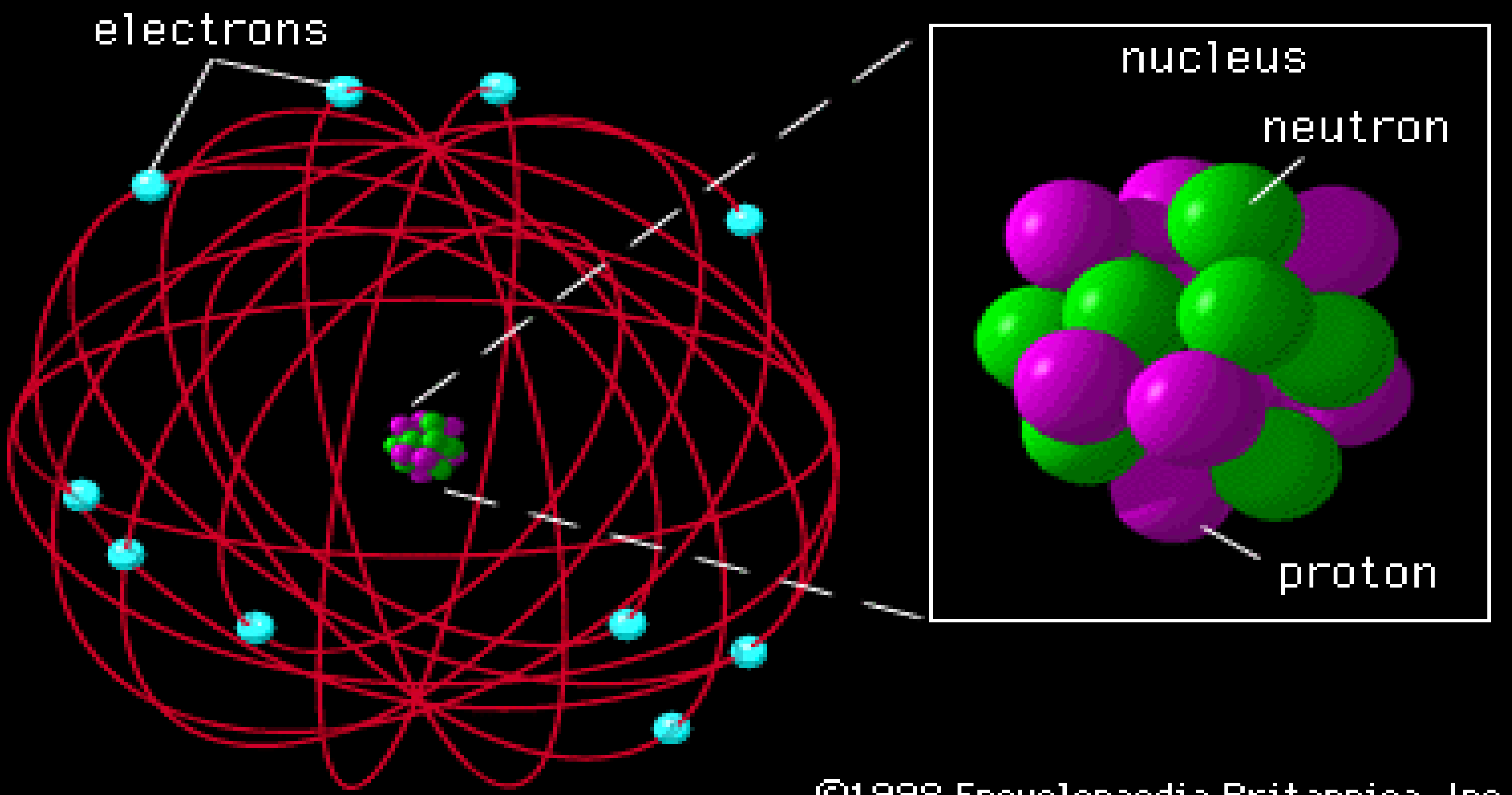
How gold foil worked.

- Directed a narrow beam of alpha particles at a very thin sheet of gold foil
- Particles should have passed easily through with only slight deflection due to the positive charge thought to be spread out in the gold atoms
- Most particles passed straight through, some bounced off the foil at very large angles and some even bounced straight back

Results of Gold Foil

- Based on these results, he concluded that most of the atom is empty space, with a large positive charge in the center
- He named this center the nucleus.
- *The atom is mostly empty space.*

Rutherford's Model



James Chadwick (1891-1974)

- English physicist
- Confirmed existence of the neutron in 1932
  - No Charge and approximately the same mass as a proton.

Chart with All information on Particles in an Atom

Particle	Symbol	Relative Charge	Relative Mass	Actual Mass (g)
Electron	e	-1	1/1840	9.11×10^{-28}
Proton	p	1	1	1.67×10^{-24}
Neutron	n	0	1	1.67×10^{-24}

Atomic Structure

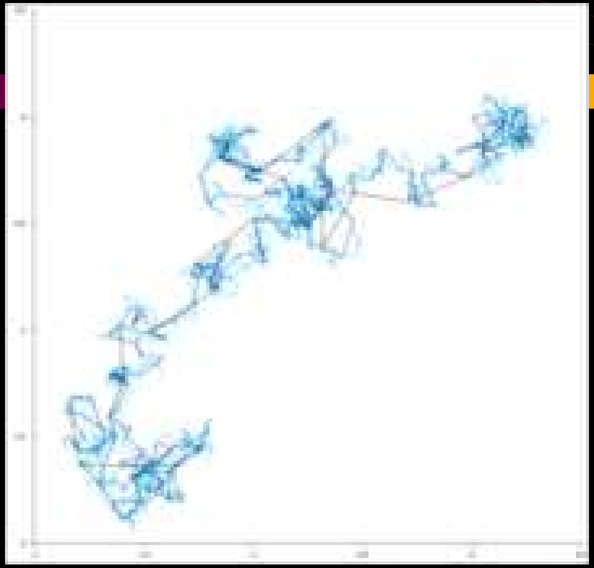
Atomic Mass Units

- The atomic mass units (amu's) are defined as:
  - A unit of mass equal to one-twelfth the mass of carbon-12.
    - The relative mass of a proton is 1 amu, of a neutron is 1 amu, and of an electron is 1/1840 amu.
    - If an atom were the size of a large football stadium, the nucleus would be about the size of a marble in its center.
- A reference atom was identified as Carbon-12

Fill in the blank

- The ______________ is defined as *the smallest particle of an element that retains the chemical properties of that element*. All atoms consist of two regions, the nucleus and the electron cloud. The nucleus contains at least one positively charged _______________ and usually has one or more electrically neutral ______________. The electron cloud takes up the majority of the size of the atom and contains one or more negatively charged ______________.

Subatomic Particles



- What are they?
  - Protons
  - Neutrons
  - Electrons
- Oppositely charged particles attract each other while like charged particles repel each other.

Atomic Number

- Mass Number
  Atomic Number **Z**
- Atomic Number **(Z) -** *the number of protons in the nucleus of each atom of that element.*
- All atoms are neutral
- The same numbers of electrons in an atom as there are protons.
- The identity of an atom is determined by the number of protons, not by the number of electrons or neutrons.
- The number of electrons and the number of neutrons can each vary and the atom will still be of the same element.
- If the number of protons changes, then the atom becomes an atom of a different element.

Atomic Mass

- Mass Number - *total number of protons and neutrons in the nucleus of an atom*.
- Almost the entire mass of an element is due to mass of the protons and neutrons.
- Chemists have arbitrarily assigned a value of 1 **atomic mass unit (amu)** to represent the mass of a proton or neutron.
- Because these particles occur in the nucleus, they are called **nucleons**.

Shorthand and Hyphenated Notation

- $^{4}_{2}He$
  - 4 is the mass number
  - 2 is the atomic number
- $^{14}_{7}N$
  - 14 is the mass number
  - 7 is the atomic number

- Helium-4
- Nitrogen-14

Isotopes

- *Atoms that have the same number of protons but different numbers of neutrons*
- Isotopes of an element have different numbers of neutrons and have different mass numbers.
- Isotopes are chemically alike because they have identical numbers of protons and electrons, which are responsible for chemical behavior.
- Most elements occur naturally as mixtures of isotopes.

Example Calculations

- The element strontium has three isotopes, strontium-86, strontium-88, and strontium-90. Given that strontium has an atomic number of 38, how many neutrons are in each of these isotopes?
- Strontium-86 — Neutrons 48
- Strontium-88 — Neutrons ?
- Strontium-90 — Neutrons ?

Average Atomic Mass

- An element's **average atomic mass** *is the weighted average of the atomic masses of the naturally occurring isotopes of that element.*
- The **relative abundance** or **percent abundance** of an element's isotope is its *frequency of occurrence in nature.*

Example Calculations

- Naturally occurring copper consists of 69.17% copper-63, which has an atomic mass of 62.93 amu, and 30.83% copper-65, which has an atomic mass of 64.93 amu. The average atomic mass of copper can be calculated by multiplying the atomic mass of each isotope by its relative abundance (expressed in decimal form) and adding the results.
- Avg. atomic mass = $\{\frac{\%}{100} \times \text{mass of isotope}\} + \{\frac{\%}{100} \times \text{mass of isotope}\} + \{\text{etc.}\}$

Chapter 25

Nuclear Chemistry

Radioactivity

- Radioactivity
  - The property by which an atomic nucleus gives off alpha, beta or gamma radiation.
- Radioisotopes
  - An isotope that has an unstable nucleus and undergoes radioactive decay
- Radiation
  - The penetrating rays emitted by radioactive source.

History of Radioactivity

Henri Becquerel

- Becquerel

  At that time, French physicist Henri Becquerel (1852–1908) was studying minerals that emit light after being exposed to sunlight, a phenomenon called phosphorescence.

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The Discovery of Radioactivity

Becquerel accidentally discovered that phosphorescent uranium salts—even when not exposed to light—produced spontaneous emissions that darkened photographic plates.

Marie Curie (1867-1934) Pierre Curie (1859-1906)

Took Becquerel's mineral sample (called pitchblende) and isolated the components emitting the rays.

They concluded that the darkening of the photographic plates was due to rays emitted specifically from the uranium atoms present in the mineral sample.

Marie Curie named the process by which materials, uranium and thorium, give off such rays radioactivity; the rays and particles emitted by a radioactive source are called radiation.

- Also discovered the radioactive elements polonium and radium.

Radioactive Decay

As you may recall, isotopes are atoms of the same element that have different numbers of neutrons.

- Isotopes of atoms with unstable nuclei are called **radioisotopes.**
- An unstable atom emits radiation and changes into a “new” stable atom.
- This contradicts Dalton’s Atomic Theory.

Types of Radiation

- Alpha radiation
  - helium nuclei that have been emitted from a radioactive source
- Beta radiation
  - fast-moving electrons formed by the decomposition of neutron in an atom.
- Gamma radiation
  - High-energy electromagnetic radiation given off by a radioisotope

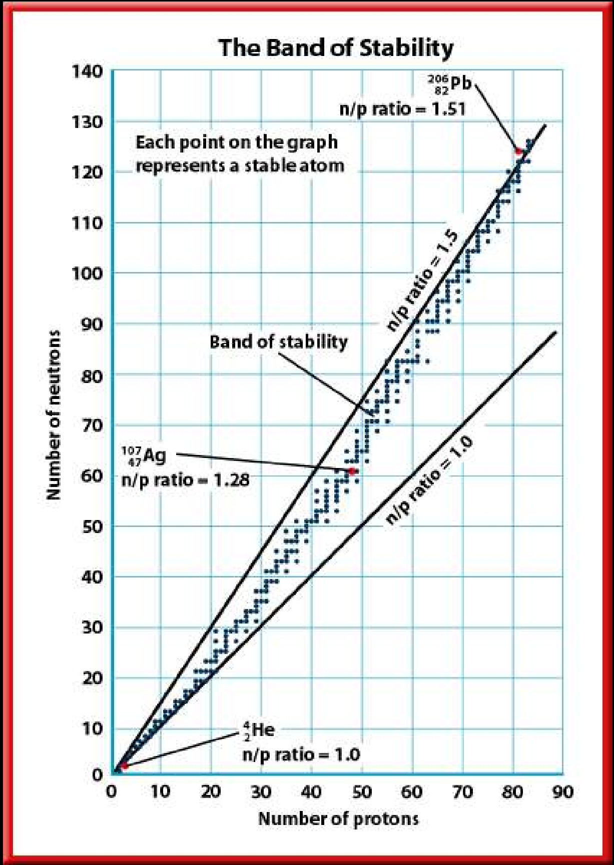
Types of Radiation

Type	Symbol	Charge	Penetrating Power	Shielding
Alpha	á, $^{4}_{2}He$	+2	Low (0.05mm body tissue)	Paper or clothing
Beta	â, $^{0}_{-1}e$	-1	Moderate (4 mm body tissue)	Metal foil
Gamma	ã	0	Very High (Penetrates body easily)	Lead, concrete

Nuclear Reactions

Why are elements radioactive?

- Band of stability
  - The location of stable nuclei on a neutron vs. proton plot.
- Depends on the neutron-proton ratio.
- Elements 1-20: A stable element exists the if proton number is equal to neutron number
- Element 20-82: Neutron number must be greater then proton number to be neutral.
- Elements above 82: All radioactive. 83 protons and above have too much repulsion.



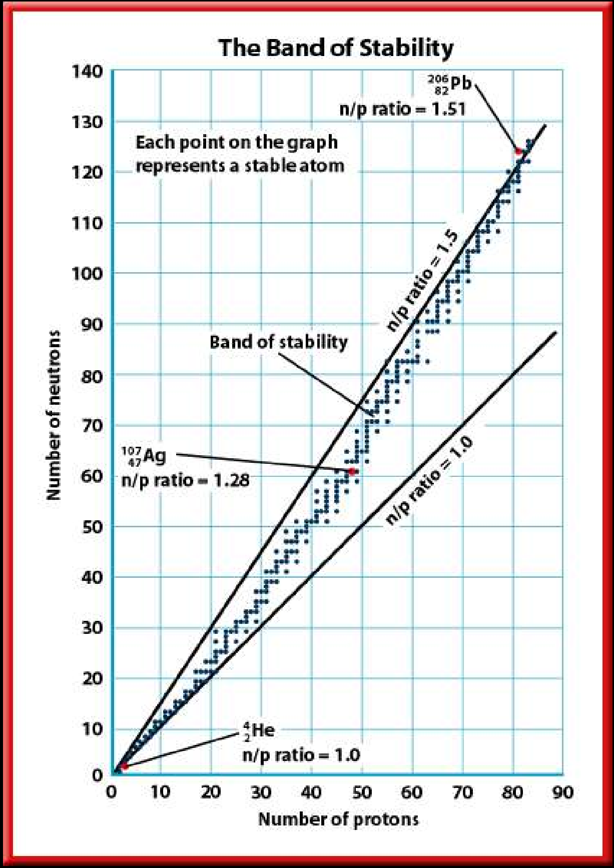
Why are elements radioactive?

- Example:

What is more stable Lithium 6 or Lithium 7?

Elements 1-20 want equal amounts of protons and neutrons.

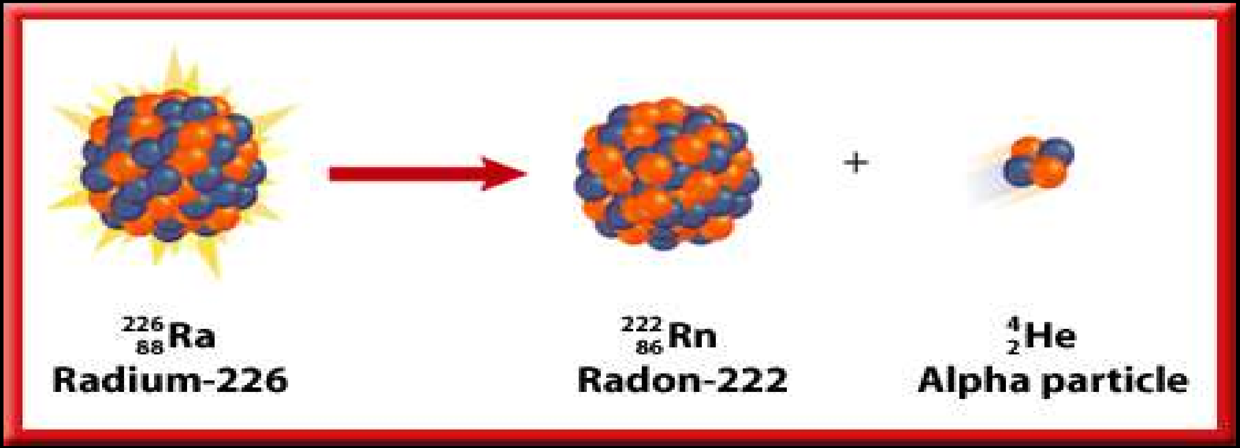
Lithium 7 has 4 neutrons to 3 protons. Lithium 6 has 3 protons and 3 neutrons (mass no.=6 and atomic number =3) therefore it is the most stable.



Alpha Decay

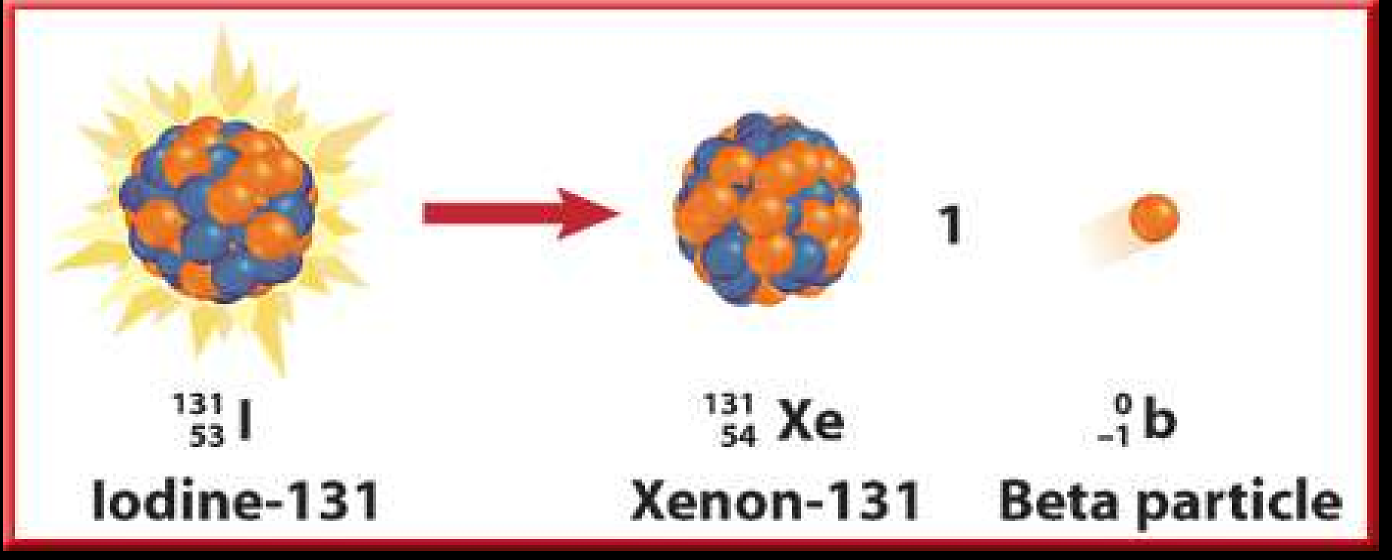
- Limited to very large nuclei.

  Radium-226, an atom whose nucleus contains 88 protons and 138 neutrons, undergoes alpha decay by emitting an alpha particle.



Beta Decay

An example of the beta decay process is the decay of iodine-131 into xenon-131 by beta-particle emission.



Gamma Decay

The emission of gamma rays does not change the atomic number or mass number of a nucleus.

Gamma rays almost always accompany alpha and beta radiation, as they account for most of the energy loss that occurs as a nucleus decays.

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He + 2^{0}_{0}\gamma$$

Example of Balancing a Nuclear Equation

Write a balanced nuclear equation for the alpha decay of thorium-230.

You are given that a thorium atom undergoes alpha decay and forms an unknown product.

Thorium-230 is the initial reactant, while the alpha particle is one of the products of the reaction. The reaction is summarized below.

$$^{230}_{90}\text{Th} \rightarrow\ ^{X}_{Y}\underline{Z\ \ } + {}^{4}_{2}\text{He}$$

How to figure this out?

- Must solve for X, Y and look up Z
- Solving for X:
  - $230 = X + 4$
  - $X = 226$
- Solving for Y:
  - $90 = Y + 2$
  - $Y = 88$
- Look up 88 (Atomic number) on the periodic table and you have Z, the element.

Answer

- $^{226}_{88}$ Ra
- Or Radium-226

Question 1

- What element is formed when polonium-214 radioisotope undergoes alpha decay? Give the atomic number and mass number of the element.

Answer

$$^{210}_{82}\mathrm{Pb}$$

Question 2

- What element is formed when iron-60 undergoes beta decay? Give the atomic number and mass number of the element.

Answer

$$^{60}_{27}\mathrm{Co}$$

- It may surprise you to learn that of all the known isotopes, only about 17% are stable and don’t decay spontaneously

Half-life

- The time it takes for ½ of the unstable atoms to become stable.
- A list of common half-lives are provided on page 847.
- Equation for solving ½ life problems
    - $A = A_0 \times (½)^{t/T}$
        - A_0 is the initial amount of radioactive material.
        - t is the time interval.
        - T is the ½ life of the substance.
        - A is the final amount of radioactive material remaining.

Half-life Example Problem

- Iron-59 is used in medicine to diagnose blood circulation disorders.
- The half-life of iron-59 is 44.5 days.
- How much of a 2.000-mg sample will remain after 133.5 days?

Knowns & Unknowns

- Knowns
  - Half Life = 44.5 Days = T
  - Sample Size = 2.000 mg = A_0
  - Duration of time 133.5 days = t
- Unknown amount of sample after 133.5 Days = A
- Equation:
  - $A = A_0 \times (½)^{t/T}$

The Work & Answer

- A = 2.000 mg (1/2)^(133.5/44.5)
- A = 2.000 mg (1/2)^3
- A = 2.000 mg x 0.125
- A = 0.2500 mg

Transmutation Reactions

- The conversion of an atom of one element into an atom of another element by the emission of radiation.
- High energy particles combine with the nucleus of an atom.
- Elements above atomic no. 92 are formed through this process.
- Transuranium Elements
  - An element in the periodic table with an atomic number that is greater 92

Nuclear Fusion

- The combining of atomic nuclei is called nuclear fusion.
- Occurs within the Sun, where hydrogen atoms fuse to form helium atoms.
- Release very large amounts of energy but require extremely high temperatures, also called thermonuclear reactions.

Nuclear Fission

- Heavy atoms (mass number > 60) tend to break into smaller atoms, thereby increasing their stability.
- The splitting of a nucleus into fragments is called nuclear fission.
- Nuclear fission releases a large amount of energy.
- One fission reaction can lead to more fission reactions, a process called a chain reaction.
- A chain reaction can occur only if the starting material has enough mass to sustain a chain reaction; this amount is called critical mass.

Nuclear Reactors

- Nuclear power plants use the process of nuclear fission to produce heat in nuclear reactors.
- The heat is used to generate steam, which is then used to drive turbines that produce electricity.
- Cadmium and boron are used to keep the fission process under control.

Nuclear Reactors

- Neutron Absorption
  - A process used in a nuclear reactor to slow the chain reaction by decreasing the number of moving neutrons; this is done with control rods made of a material such as cadmium.
- Neutron Moderation
  - A process used in a nuclear reactor to slow the neutrons so they can be captured by the reactor fuel to continue the chain reaction.

Radiation Detectors

- Geiger counter
  - use ionizing radiation, which produces an electric current in the counter, to rate the strength of the radiation on a scale.

- Film badge
  - A small radiation detector worn by work near radiation sources.
- Scintillation Counter –
  - A device that uses a specifically coated surface called a phosphor to detect radiation.

Uses of Radiation

- With proper safety procedures, radiation can be useful in industry, in scientific experiments, and in medical procedures.
  - Smoke alarms
  - Medicine
    - A radiotracer is a radioisotope that emits non-ionizing radiation and is used to signal the presence of an element or of a specific substance.

      Radiotracers are used to detect diseases and to analyze complex chemical reactions.
    - X-rays
  - Food