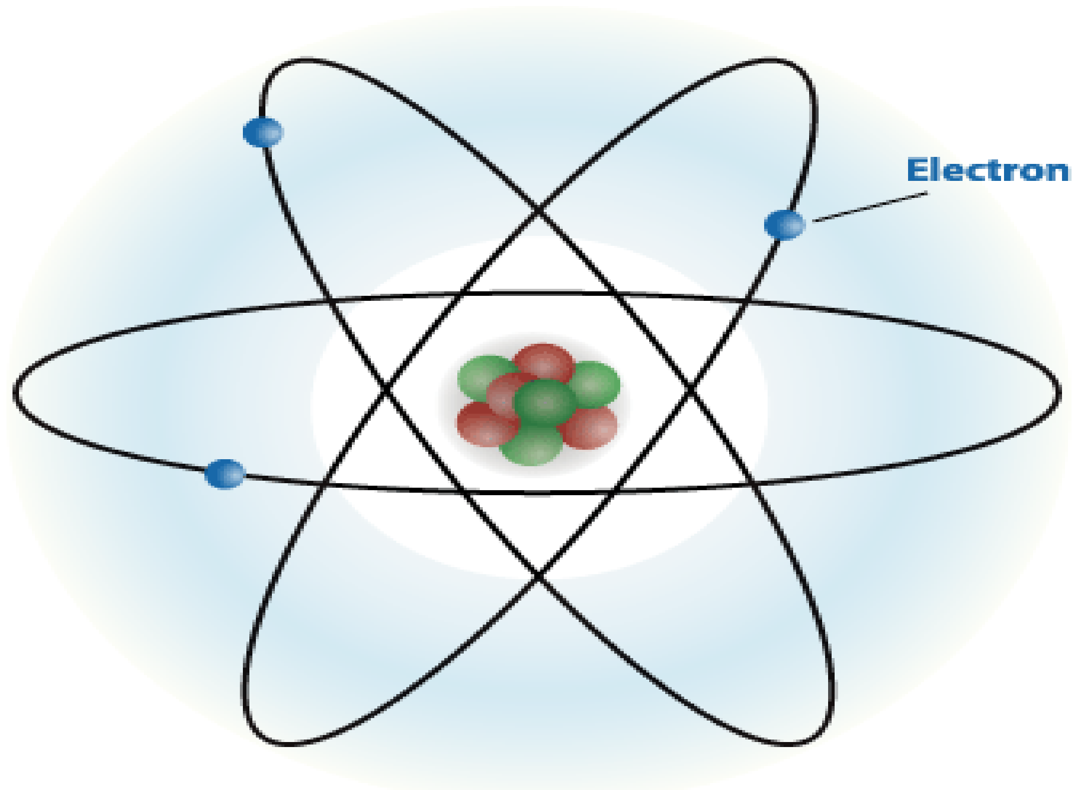
Radioactivity and Nuclear Chemistry:

In previous lectures told that the atom of one element does not change into another. Not so!

The Atom:



Atomic Symbols:

Atomic number(Z): # protons in the nucleus and equals the # electrons for a neutral atom.

Mass number(A): Total # protons and neutrons in the nucleus.

Denoted as:

$$^{A}_{Z}X$$

X represents the symbol for the element.

Isotopes:

Isotopes - Atoms with the same atomic number but different mass number.

Ex: The element chlorine

$^{35}_{17}Cl$ | $^{37}_{17}Cl$

$^{35}_{17}Cl$	$^{37}_{17}Cl$
17 protons	**17 protons**
18 neutrons	**20 neutrons**
17 electrons	**17 electrons**

Radioactivity:

Radioactive elements are unstable. Decay and emit fragments of themselves and energy to gain stability.

parent nuclide → daughter nuclide + particle

Types of Particles:

Alpha(α) particle: $^{4}_{2}\mathrm{He}$

Beta(β) particle: $^{0}_{-1}e$

Gamma(γ) particle: $^{0}_{0}\gamma$

Positron: $^{0}_{+1}e$

Alpha(α) Decay:

Atom emits an α particle and gets smaller.

Ex:

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

NOTE: Atomic number and mass number must equal on both sides of arrow(→).

Z must go from 88 to 86(Rn).

Beta(β) Decay:

Results from conversion of neutron in nucleus converting into a proton and emitting an electron.

$$^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e}$$

Ex:

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

NOTE: Z must go from 6 to 7. Z = 7 is N.

Positron Emission:

Results from emission of an antiparticle of an electron. An antiparticle is a particle of the same mass but opposite charge.

Electron: ${}_{-1}^{0}e$ **Positron:** ${}_{+1}^{0}e$

Ex:

$$ {}_{6}^{11}\mathrm{C} \rightarrow {}_{5}^{11}\mathrm{B} + {}_{+1}^{0}\mathrm{e} $$

NOTE: Z must go from 6 to 5. Z = 5 is B.

Electron Capture:

Process in which a nucleus assimilates an electron from an inner orbital thus converting a proton into a neutron.

$$ {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{1}_{0}\mathrm{n} $$

Ex:

$$ {}^{55}_{26}\mathrm{Fe} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{55}_{25}\mathrm{Mn} $$

NOTE: Z must go from 26 to 25. Z = 25 is Mn.

Nuclear Stability and Predicting Radioactive Decay:

Two factors determine the stability of a nuclide.

1. The number of neutrons(N) and protons(Z) and their ratio(N/Z).

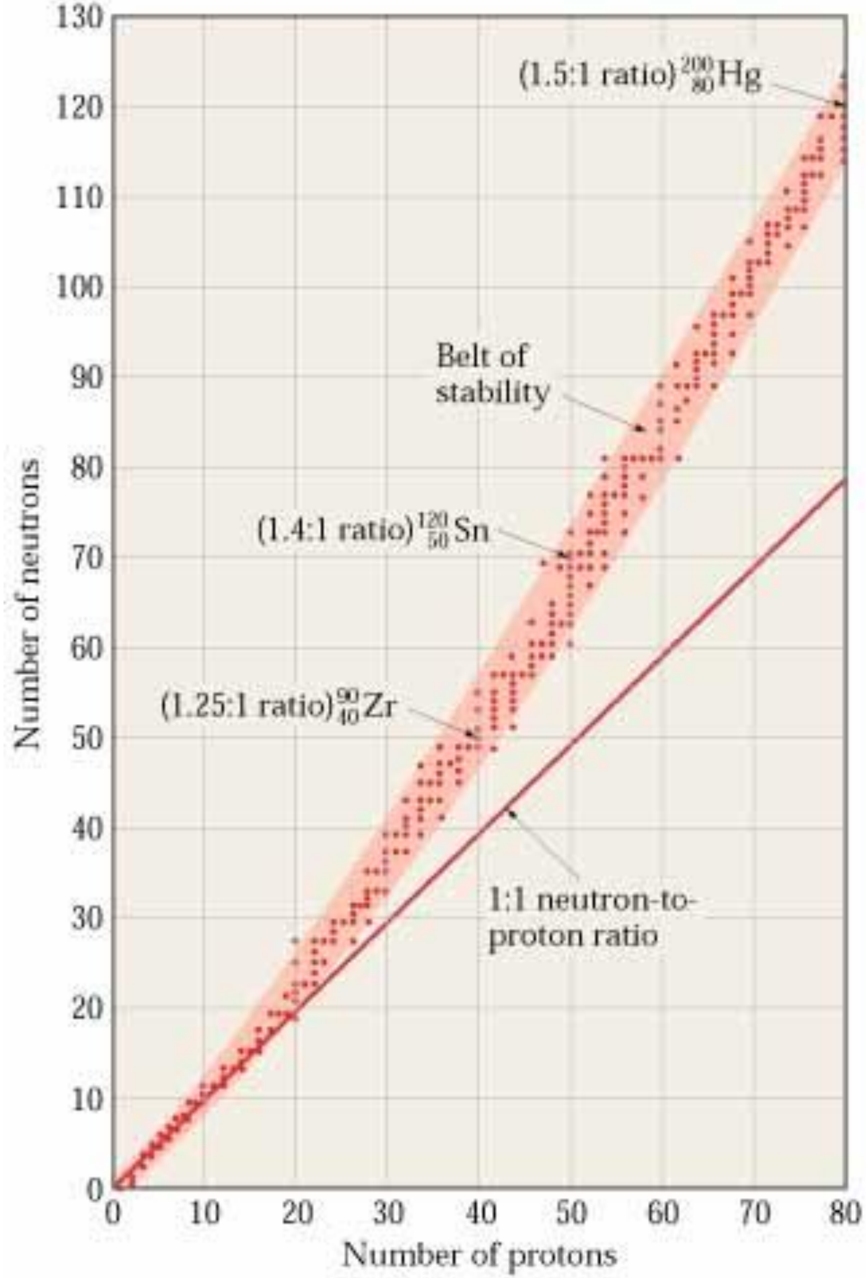
$$\frac{N}{Z} = \frac{(A - Z)}{Z}$$

2. Total mass of nuclide.

Plot of Neutrons vs. Protons:

N/Z ratio too high

β decay



N/Z ratio too low

positron emission or electron capture

Ex:

Predict if the following nuclei are stable or radioactive:

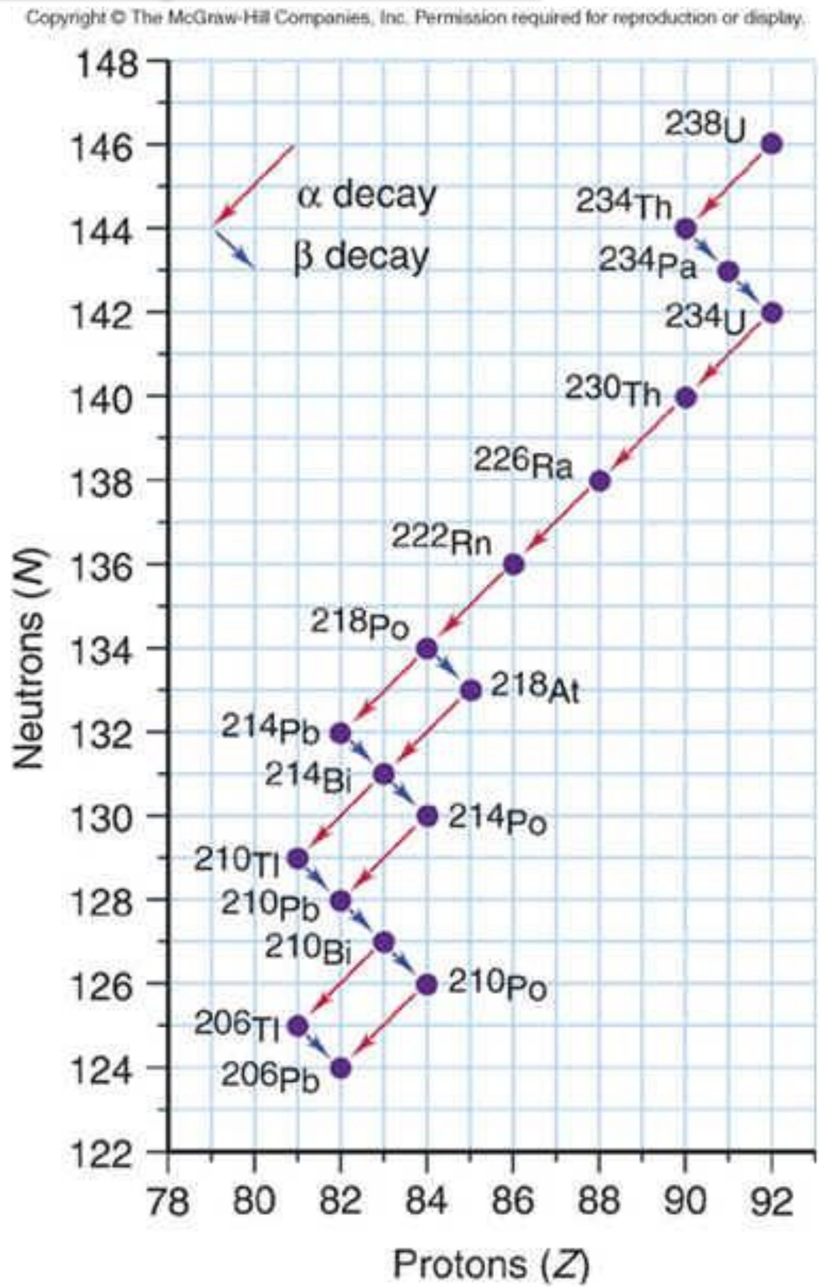
a) $^{18}_{10}\mathrm{Ne}$ **b)** $^{32}_{16}\mathrm{S}$

Ex:2

Predict the mode of decay for the following nuclei:

a) $^{12}_{5}B$ **b)** $^{234}_{92}U$ **c)** $^{91}_{33}As$ **d)** $^{127}_{57}La$

Decay Series:



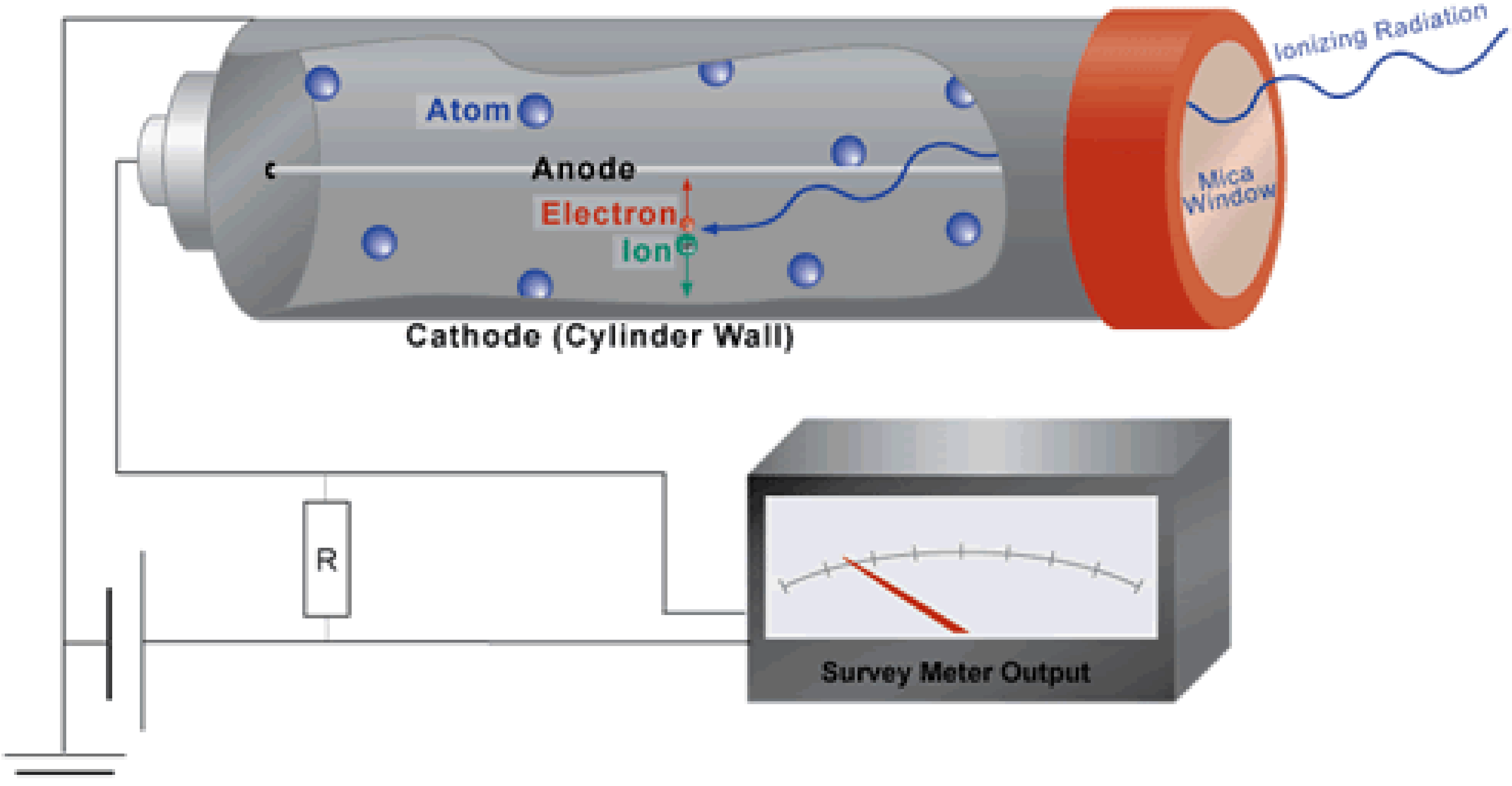
Decay series for uranium-238.

Uranium-238 undergoes a series of decays until stability.

Detection of Radioactive Decay:

Measure the effect radioactive decay has on surrounding atoms.

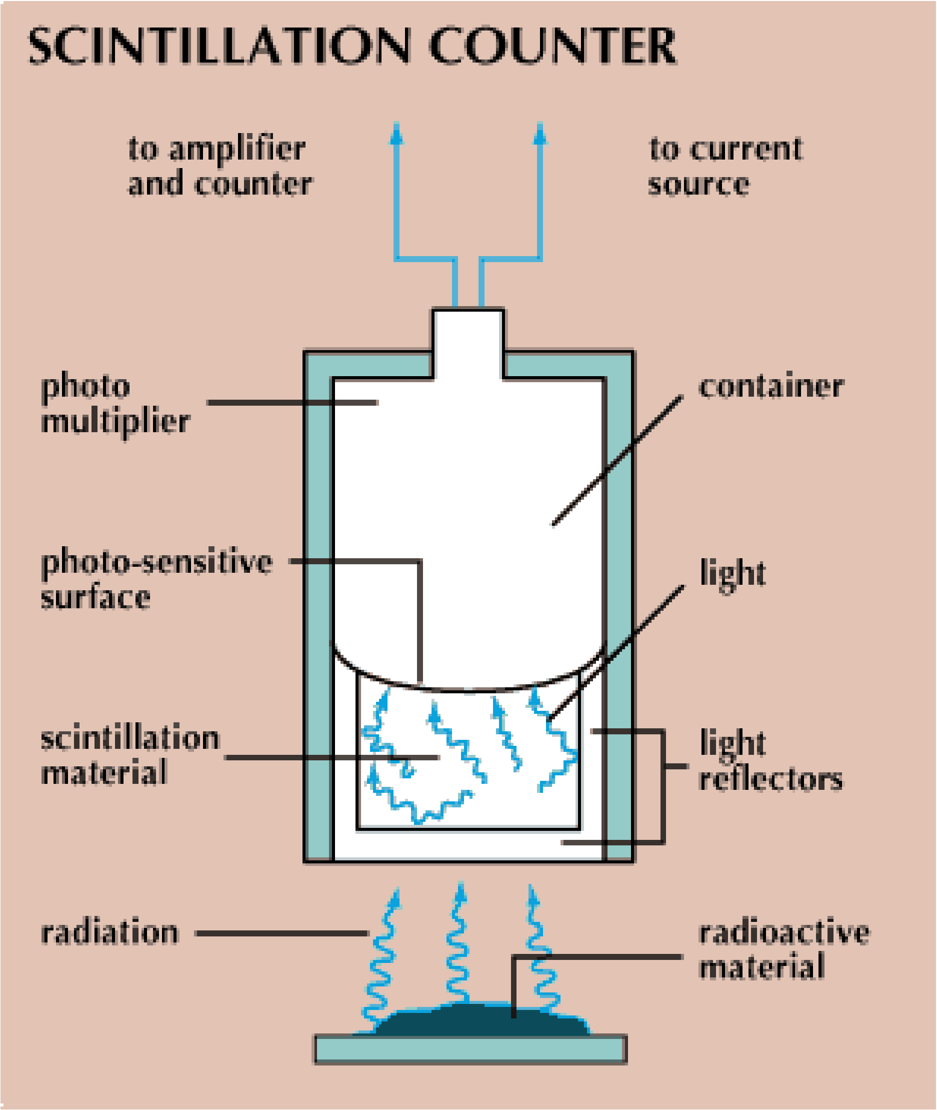
Ionization Counters(Geiger-Müller):



Reference: https://www.nde-ed.org/EducationResources/CommunityCollege/RadiationSafety/radiation_safety_equipment/SurveyMeters.htm

Scintillation Counters:

Solid



Liquid

Reference: http://kids.britannica.com/comptons/art-53895/Scintillation-materials-emit-light-flashes-when-radiation-is-absorbed

Kinetics of Radioactive Decay:

$$\text{Decay Rate} = \frac{-\Delta N}{\Delta t}$$

ΔN: change in number of nuclei.

Δt: change in time(t_{FINAL} - $t_{INITIAL}$).

SI Unit of Radioactive Decay:

Unit of Radioactivity:

becquerel(Bq)

1 Bq = 1 disintegration per second(d/s).

curie(Ci)

$$1\ Ci = 3.70 \times 10^{10}\ d/s$$

For convenience use

$$mCi = 1 \times 10^{-3}\ Ci$$

$$\mu Ci = 1 \times 10^{-6}\ Ci$$

Activity:

Radioactivity also expressed as Activity(A).

Activity or Decay Rate α N

or

$$A = kN$$

$$A = \frac{-\Delta N}{\Delta t} = kN$$

Radioactive decay or Activity a first-order process.

Radioactive Integrated Rate Law:

$$\text{In}\frac{N_t}{N_o} = \text{In}\frac{A_t}{A_o} = -kt$$

N_o = number of nuclei of a sample at t = 0 s.

N_t = number of nuclei remaining at time t.

A_o = activity of a sample at t = 0 s.

A_t = activity of sample at time t.

k = rate constant.

t = time.

Half-Life:

Radioactivity often expressed in half-life($t_{1/2}$). The time it takes for half the nuclei present in a sample to decay to daughter nuclei.

For First Order Reactions,

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

Ex:

If a sample of Sr-90 has an activity of 1.2×10^{12} d/s, what is the activity and the fraction of nuclei that have decayed after 59 years(yr). $t_{1/2}$ = 29 yr for Sr-90.

Radiocarbon Dating:

A process which uses measuring the amount of radioactive isotopes to age an object.

Radiocarbon dating measures the amount of C-14 and C-12 to age a carbon based object.

Cosmic rays initiate a series of nuclear reactions in the atmosphere. Generates C-14.

$$^{14}_{7}\mathrm{N} + ^{1}_{0}\mathrm{n} \rightarrow ^{14}_{6}\mathrm{C} + ^{1}_{1}\mathrm{p}$$

Radiocarbon Dating cont...:

Through the generation and natural decay of C-14, the concentration of C-14 in atmosphere remains constant. Eventually C-14 in atmosphere taken into plants and animals.

When an organism dies it no longer takes in C-14 and the amount decreases with decay.

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

Ex:

A sample of bone has a specific activity of 5.22 d/min·g of carbon. If a living organism has a specific activity of 15.3 d/min·g, how old are the bones?

Uses of Radioactivity:

1. Atomic Bomb and Nuclear Power

When U-238 exposed to neutrons.

$$^{238}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{140}_{56}\text{Ba} + {}^{93}_{36}\text{Kr} + 3\,{}^{1}_{0}\text{n} + \text{Energy}$$

U-235 undergoes a chain reaction.

2. Fusion

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

Birth of matter is stars.

3. Medicine Diagnosis