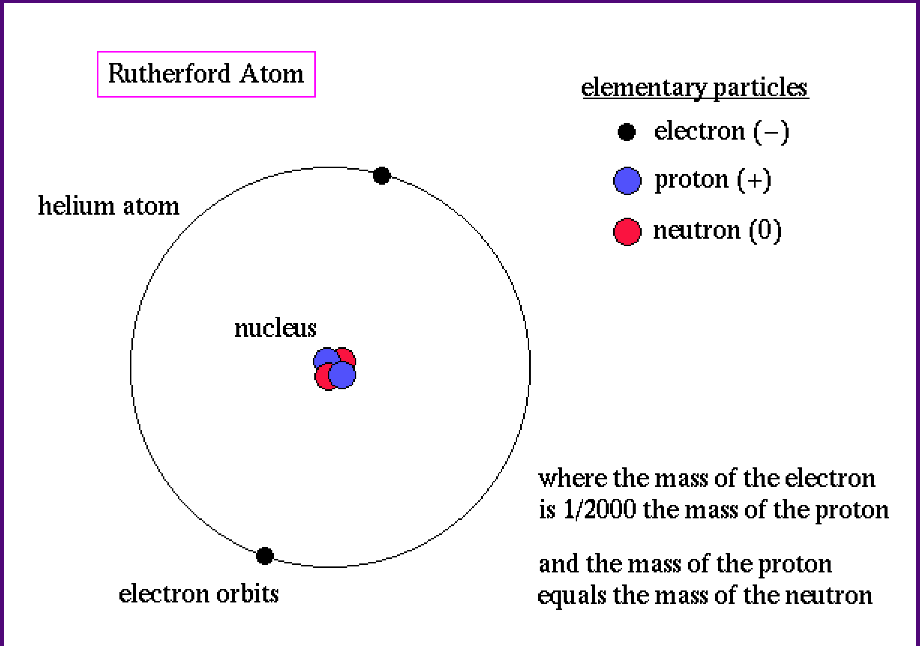
# Radiation Fundamentals



# Radiation Fundamentals

- **Definitions**
  - Atomic number (Z)-number of protons (number of positive charges) in a nucleus
  - Mass number-number of protons plus the number of neutrons
  - Nuclide-specified by atomic number, mass number, and charge
  - Isotope-different forms of a given element with same atomic number but differing numbers of neutrons.
    - $^{35}S$, $^{3}H$, $^{125}I$

# Radiation Fundamentals

- **Definitions**
  - Electromagnetic Radiation (Photon) – electomagnetic “particle or corpuscle” travels in waves at a velocity of 3E08 m/s in a vacuum. Each particle has zero mass, zero charge and an indefinitely long lifetime
  - Ionizing Electromagnetic radiation-photons possessing enough energy to completely free electrons from atoms thereby producing ions.
  - Non-ionizing radiation consists of photons not possessing sufficient energy to ionize atoms.  Examples include near ultraviolet rays, visible light, infrared light, microwaves and radiowaves.

# Radiation Fundamentals

- Definitions
  - Radioactivity-spontaneous process by which unstable atoms emit or radiate excess energy from their nuclei and thus change or decay to atoms of different element or to a lower energy state of the same element
  - Radionuclide-unstable atomic species which spontaneously decay and emit radiation
  - Radiation-high energy particles and electromagnetic rays emitted from atomic nuclei during radioactive disintegration

# Radiation Fundamentals

- Definitions
  - Radioactive decay-process by which an atom gives up energy and moves to a more stable state

# Radiation Fundamentals

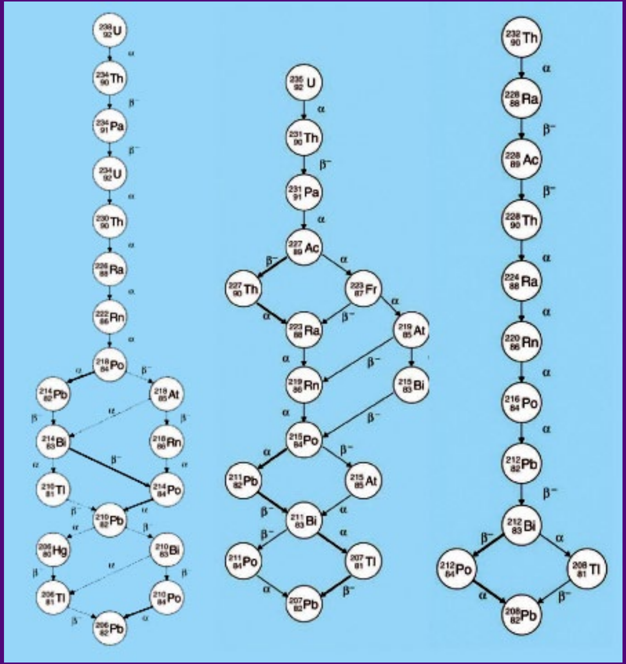
- Sources of Radiation
  - Solar radiation
  - Consumer products –smoke detectors, old luminous dial watches, TV's, building materials
  - Radioactive waste
  - Terrestrial radiation
    - Primordial radio nuclides - these are radio nuclides left over from when the earth was created. K-40, Rb - 87 .$^{226}Ra$ (Radium) with significant levels also from $^{238}U$, $^{232}Th$.
      - Found in igneous, sedimentary, sandstone and limestone
      - Fly ash from coal burning plants contains more radiation than that of nuclear or oil-fired plants.
  - Food and Drink-bananas, brazil nuts; etc

# Radiation Fundamentals

- Sources of Radiation (Cont'd)
  - Nuclear Power
  - Radon – Lower levels of houses and in Hot Springs
  - Each other
  - Cosmic Rays
    - At sea level – 30 mrem/yr
    - AT 10,000 ft – 140 mrem/yr
  - X-rays
  - Nuclear medicine

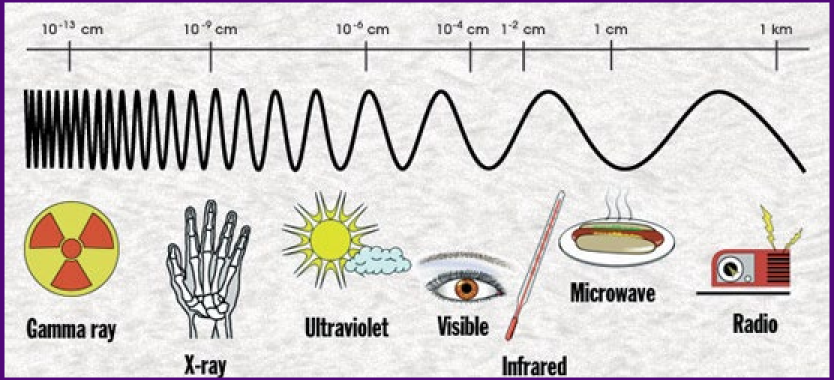
# Radiation Fundamentals

- Naturally Occurring Decay Chains
  - Uranium Decay Series
    - U238-Pb206
  - Actinium Decay Series
    - U235-Pb207
  - Thorium Decay Series
    - Thorium 232-Pb298



# Radiation Fundamentals

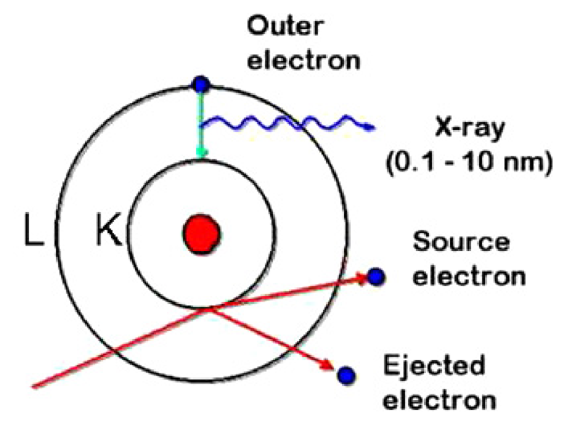
## Radiation Spectrum



# Radiation Fundamentals

## ❑ Ionizing radiation

- Radiation capable for producing ions when interacting with matter(enough energy to remove an electron from an atom.




## ❑ Sources

- X-rays
- Radioactive material produce alpha, beta, and gamma radiation
- Cosmic Rays from the Sun
- Gamma Ray Bursts

# Radiation Fundamentals

- 4 Main Types of Ionizing Radiation

  - Alpha Particles ($\alpha$)-nuclei of helium-4 atoms of 2 neutrons + 2 protons. Most massive and carry highest charge of 4 forms. Emitted by nuclides heavier than lead when neutron to proton ratio is too low. Examples are radon 222 and radium 226

  - Beta particles ($\beta^-$ and $\beta^{+)}$ – free electrons that have been kicked out of their orbit or emitted from a nucleus. Examples are tritium and C-14

# Radiation Fundamentals

- 4 Main Types of Ionizing Radiation (cont'd)

  - Gamma (γ)- Gamma rays are high energy photons that accompany fission and often occur with a charged particle. Examples are I-125 and 131, Co-57 and Cs-137

  - X-rays- high energy photons emitted when electrons fill vacated orbitals. Can be produced by fission or by deceleration of charged subatomic particles such as in an x-ray machine.

    - Bremsstrahlung-When high-speed charged particles rapidly accelerate (or decelerate) Bremsstrahlung X-rays are emitted.

# Radiation Fundamentals

- Methods of Interaction.
  - Neutron
    - Emitted from disintegrating nuclei and known as slow or fast electrons.
      - Fast electrons
        - Elastic scattering with heavy nucleus (neutron bounces off)
        - Elastic scattering with light nucleus (neutron transfers energy to light nucleus)
        - Inelastic scattering (neutron momentarily absorbed and released at reduced energy level)
      - Slow electrons (known also as ‘thermal’ neutrons)
        - Radiation capture (slow neutron momentarily absorbed by nucleus and gamma radiation emitted
        - Particle ejection (slow neutron enters target nucleus forming a compound nucleus excited to high enough energy level to eject a new particle while the incident neutron remains in the nucleus
        - Fission( nucleus that absorbs the incident neutron, splits into 2 similarly sized parts, releasing several neutrons and electromagnetic radiation including heat)

# Radiation Fundamentals

- Methods of Interaction.
  - Neutron
    - Produced in nuclear reactors and on a smaller scale in bombardment devices like the Troxler density gauge. (Am/Be and Cs-137)
    - Have no electrical charge therefore they do not experience Coulomb repulsion or attraction like charged particles.

# Measuring Radiation

## Units for Measuring Radiation

- Decay Rate
  - Becquerel: 1 atom decaying per second, one dps, the SI unit for radioactivity.
  - Curie: $3.7 \times 10^{10}$ dps, originally defined as the activity of 1 g $^{226}Ra$.
- Specific Activity
  - Specific activity is the decay rate per unit mass of a specific isotope and measured in units of Ci/g or Bq/g with appropriate modifiers for order of magnitude.

# Measuring Radiation

Millicurie and Microcurie are units of activity that describe the rate of radioactive decay as a function of time.

| | | | |
|---|---|---|---|
| 1 curie | Ci | = | $2.22 \times 10^{12}$ dpm |
| 1 millicurie | mCi | = | $2.22 \times 10^{9}$ dpm |
| 1 microcurie | µCi | = | $2.22 \times 10^{6}$ dpm |

dpm = disintegration per minute

# Measuring Radiation

- Half life
  - Time required for one-half of the radioactive atoms in a sample to decay or disintegrate.
  - Half-life can be measured in seconds, hours, days and years.
  - It is used to tell how long radioactive material must be stored before it can be discarded as normal waste.
    - Disposal cannot occur until 10 times the half-life has passed.

# Measuring Radiation

- Common Half Lives
  - Tritium ($^{3}H$) – 12.3 years
  - Carbon ($^{14}C$) – 5,730 years
  - Phosphorous ($^{32}P$) – 14.3 days
  - Phosphorous ($^{33}P$) – 25.4 days
  - Sulfur ($^{35}S$) – 87.4 days
  - Iodine ($^{125}I$) – 60.14 days
  - Uranium ($^{238}U$) - 4.47E9 years

# Measuring Radiation

- Decay Law
  - Rate at which quantity of radioactive material decays directly proportional to number of radioactive atoms present.
    - Expressed by the equation – $dN/dt = \lambda N$ (Equation 1)
    - $dN/dt$ = the disintegration rate of radioactive atoms.
    - $\lambda$ = decay constant
    - N is number of radioactive atoms present at time t
  - Further integration of this equation yields:
    - $N = N_0 e^{-\lambda t}$ (Equation 2)
    - Where $N_0e$ is the initial number of radioactive atoms present and e is the base of the natural logarithms

# Measuring Radiation

- Decay Law
  - Since activity (A) is proportional to N, the equations is expressed as
    - $A = A_0 e^{-\lambda t}$
  - T can be mathmatically shown the half life ($T_{1/2}$) of a particular radionuclide is related to the decay constant $\lambda$ as follows
    - $\lambda = 0.693/T_{1/2}$
  - Therefore substituting this value into equation 3 gets

$$A = A_0 e^{-(0.693/T1/2)t}$$

# Measuring Radiation

## Radioactive Decay Equation

Use this equation to determine the activity of radioactive material at any given time.

$$A(t) = [A_0]\,[e^{(-\lambda t/T)}]$$

| | |
|---|---|
| $A(t)$ | = number of radioactive atoms at a given time |
| $A_0$ | = number of radioactive atoms at time zero (originally) |
| $e$ | = base of natural log |
| $\lambda$ | = a constant (0.693) |
| $t$ | = number of days of decay |
| $T$ | = half-life (in days) of the radioactive material of interest |

# Half-life Problems

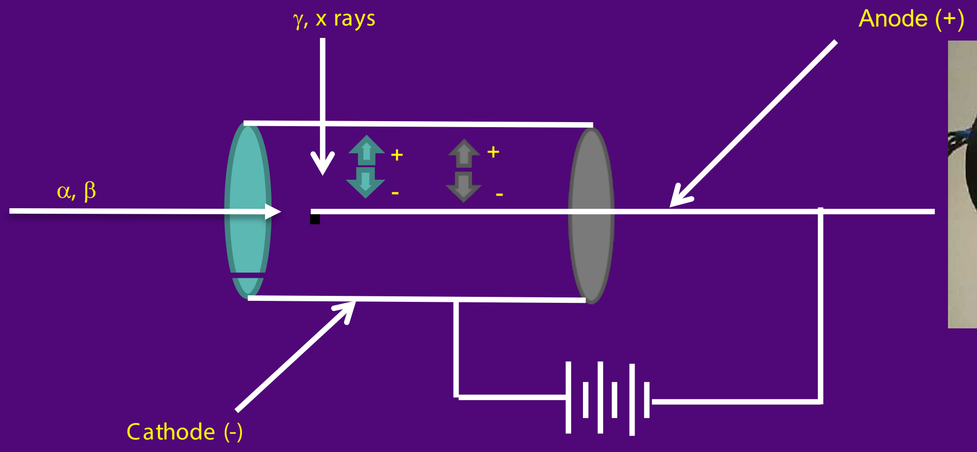
- Practice Problem
  - What is the half-life of a 100.0 g sample of nitrogen-16 that decays to 12.5 grams in 21.6 seconds?
  - 100/12.5=3
  - 21.6 x 3 = 64.8 seconds

# Half-life Problems

- Practice Problem:
  - A researcher obtains 250 mCi of Phosphorous-32 ($T_{1/2}$ = 14.3 days). What is the activity in 60 days.
    - $A_0 = 250$ mCi
    - $\lambda = 0.693/14.3$ days $= 0.048 d^{-1}$
    - $A = A_0 e^{-\lambda t}$
    - $250e^{-(0.048)(60)} = 14.03$ mCi

# Measuring Radiation

- Gas filled – Ion pairs formed by radiation collected by charged electrodes.




# Measuring Radiation

- Gas filled
  - 3 types –
    - Ionization detects $\gamma$ rays
    - Proportional detects $\alpha$ and $\beta$ particles
    - Geiger-Mueller detects $\gamma$ rays and $\beta$ particles
  - Geiger-Mueller most widely used
    - Versatile
    - Dependable
    - Particularly sensitive to medium to high energy beta particles
    - Detect relative large sources of medium to high energy gamma or x-rays
    - Not very good at detecting low energy betas

# Measuring Radiation

- Check a survey meter before using it to make sure it is appropriate to use.
  - Check the battery.
  - Check the calibration date.
    - State regulations require instruments that are used for measuring exposure rate and contamination to be calibrated every 12 months.
  - Check the capability of the meter using a radioactive source to ensure that the meter is working properly.

# Measuring Radiation

- Scintillation detectors
  - Electron de-excitation produces light
  - Collected and turned into electrical current
  - 2 types
    - Solid scintillation detector
      - Common well counter employs 2” x 2” crystal of sodium Iodide within lead shielded wall.
      - Sample vial lowered into hollowed chamber for counting
      - Thin crystal NaI detectors useful for detecting emissions of I-125.

# Measuring Radiation

- Scintillation detectors
  - 2 types
    - Liquid Scintillation Counter
      - Detects presence of low energy β and α particles
        - Sample and phosphor combined in solvent within the counting vial
        - Vial lowered into well between 2 photomultiplier tubes to be counted
        - Essential tool for counting H-3 and C-14.

# Measuring Radiation

- Scintillation detectors
  - Sample mixed with an organic liquid (cocktail)
  - Produces light (scintillates) when exposed to radiation.
  - Advantages of LSC:
    - Good for low energy $\beta$ emitters that are difficult to count by other methods
    - Very efficient ~100%
    - Count more than 1 nuclide at a time
    - Good for liquid samples.

# Measuring Radiation

- Scintillation Detectors
  - Disadvantages of LSC:
    - Relatively high background (4-20 cpm)
    - Liquid samples required and some samples are difficult to liquefy.
    - Counting volume is small.
    - Not as efficient as surface barrier detectors for alpha emitters.
    - Mixed waste disposal problems

# Measuring Radiation

- Counting Efficiencies
  - Active radiation detection system never see 100 % of disintegrations in radioactive sample
  - Due to factors in counting system and radionuclides in sample
    - Ratio of count rate (cpm) to disintegration rate (dpm) expressed as percent is the efficiency of counting system.
      - Cpm/dpm x 100% = efficiency
      - Efficiencies of counting system from various nuclides determined through calibration of system with standards of these same radionuclides

# Measuring Radiation

- Counting Efficiencies
  - Due to every counting system registers certain number of counts from environmental radiation and electronic noise in the counter, the more correct formula is:
    - $^{cpm}\text{sample} - {}^{cpm}\text{background} / {}^{dpm}\text{sample} \times 100\% = \text{efficiency}$

# Measuring Radiation

- **Efficiency Problem:**
  - A sample of 14C labeled compound is counted in a liquid scintillation counter. The sample count rate is 1500 cpm and the background is 35 cpm. If the counter is 80% efficient for 14C, what is the activity of the sample:
  - $= (1500-35/0.80)$ dpm = 1831 dpm
  - $= 1831$ dpm/$2.22 \times 10^{6}$ dpm = $8.2 \times 10^{-4}$ µCi

# Measuring Radiation

- Semiconductors/solid state
  - Electrons trapped in impurities and collected; analogous to gas filled detectors
    - Germanium for detecting $\gamma$ rays
    - Silicon diode for detecting $\alpha$ and $\beta$ particles.

# Measuring Radiation

- Performing a meter survey
  - Areas that should be frequently surveyed include:
    - Waste storage areas
    - Source vial storage areas
    - Frequently used areas and equipment
    - Floor beneath work and storage areas
      - Perform surveys after using radioactive material or before leaving an area that is posted for radioactive usage.
    - Recommended exposure rates
      - Frequently occupied areas: less than 2 mrems/hour at 30 cm
      - Storage areas: less than 5 mrems/hour at 30 cm

# Measuring Radiation

- Performing a Meter Survey
  - Pass the probe over the area to be surveyed moving the probe at about 2 cm/second.
  - Try to constantly maintain a distance of 1cm from the object or area.
  - Take care not to contaminate the probe while surveying.

# Measuring Radiation

- Wipe Test
  - Wipe tests are used to test removable contamination from any radioactive material.
  - Best survey method for detecting low-energy beta emitters. Only way to detect contamination from H-3.
  - To compete a wipe survey:

1. 1. Cut filter paper or paper towels into 1.5″ x 1.5″ strips.
2. 2. Wearing disposable gloves, rub the paper over the
3. test area.

# Measuring Radiation

- Wipe Test & Action Levels
  - For most accurate results, a liquid scintillation detector should be used.
  - The contamination level is equal to the difference of the count rate of the actual wipe and the control sample.
  - You need to decontaminate if:
    - Radioiodine levels are greater than 200 dpm/100 $cm^2$.
    - Other radionuclide levels are greater than 2,000 dpm/100 $cm^2$.

dpm = disintegrations per minute

To convert measurements to “ dpm” divide the liquid scintillation counter or gamma counter results (given in “ cpm”) by the counter’s efficiency (refer to instrument’s manual).

# Measuring Radiation

- Survey Records
  - Be sure to document contamination and exposure rate surveys so that you can prove the survey was done.
  - Keep survey records in an easily accessible form for the Radiation Safety Officer or IDPH to examine.
    - UNI Environmental Health and Safety provides blank survey forms. Call 273-3445.