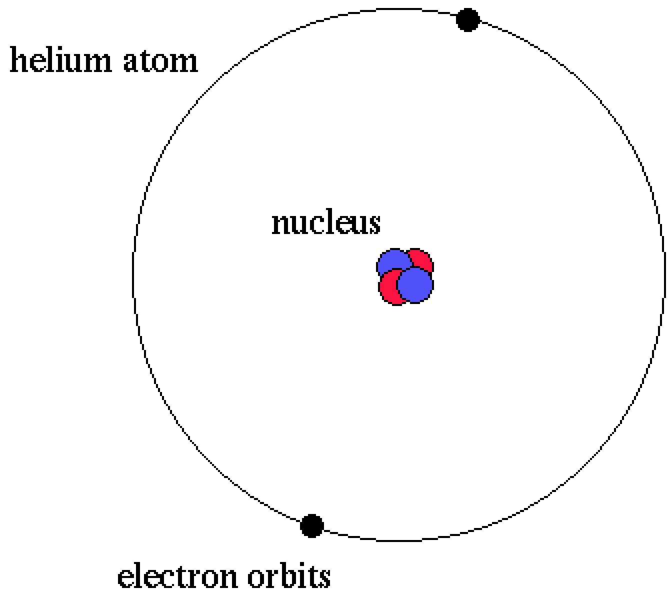
Radiation Fundamentals

Rutherford Atom



elementary particles

- electron (–)
- proton (+)
- neutron (0)

where the mass of the electron is 1/2000 the mass of the proton

and the mass of the proton equals the mass of the neutron

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.

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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

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Radiation Fundamentals

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

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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

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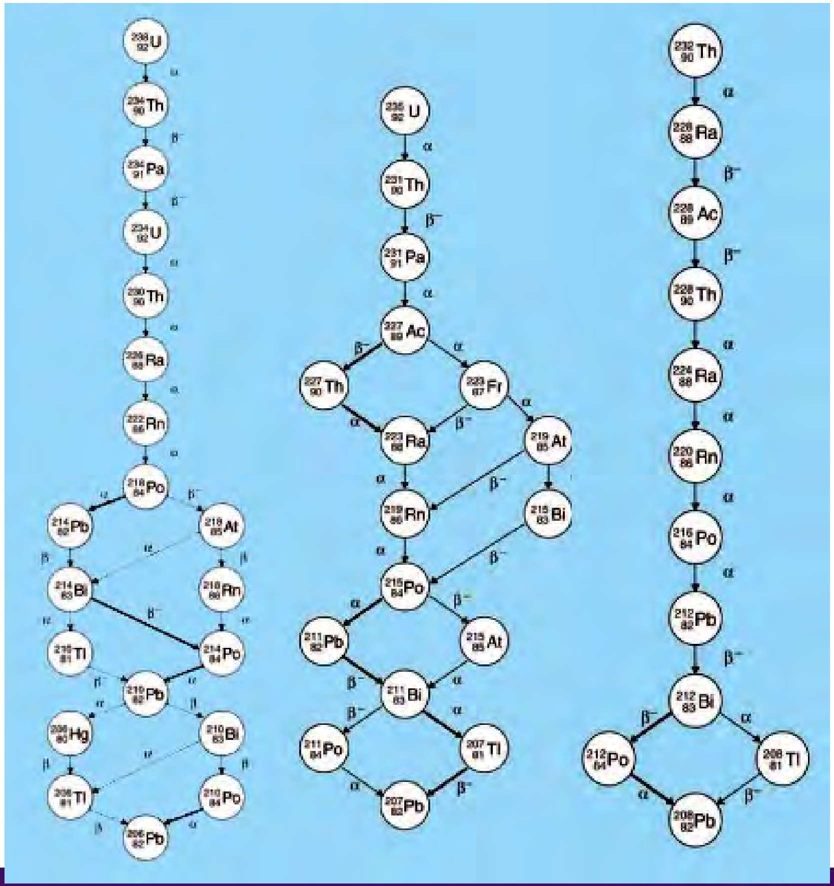
Radiation Fundamentals

- **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

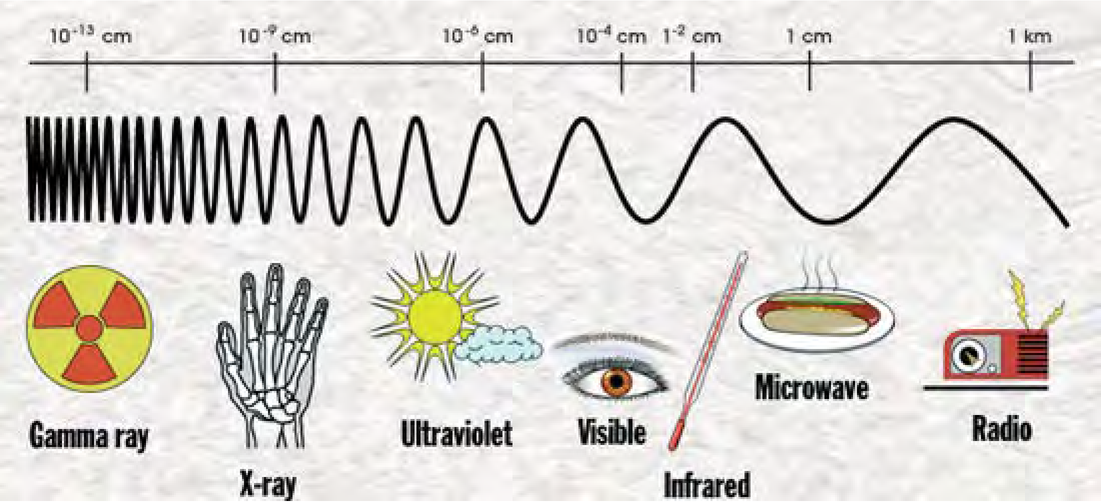
Radiation Fundamentals

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



Radiation Fundamentals

Radiation Spectrum



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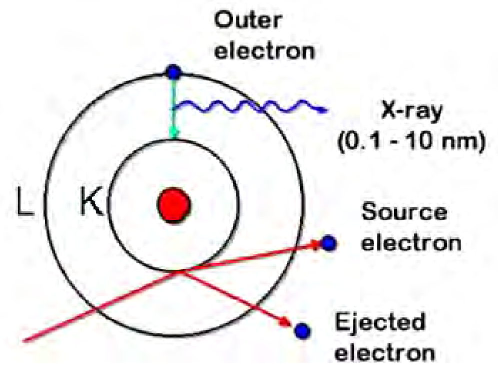
Radiation Fundamentals

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

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Radiation Fundamentals

- **4 Main Types of Ionizing Radiation**
  - Alpha Particles (α)-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 (β^- and β^+) – 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: 3.7×10^{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	=	2.22×10^{12}
1 millicurie	mCi	=	2.22×10^{9}
1 microcurie	μCi	=	2.22×10^{6}

dpm = disintegrations 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.
    - λ = decay constant
    - N is number of radioactive atoms present at time t
  - Further integration of this equation yields:
    - $N=N_0e^{-\lambda t}$ (Equation 2)
    - Where N_0e is the initial number of radioactive atoms present and e is the base of the natural logarithms

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Measuring Radiation

- Decay Law
  - Since activity (A) is proportional to N, the equations is expressed as
    - $A=A_0e^{-\lambda t}$
  - T can be mathmatically shown the half life ($T_{1/2}$) of a particular radionuclide is related to the decay constant λ as follows
    - $\lambda=0.693/T_{1/2}$
  - Therefore substituting this value into equation 3 gets $A=A_0e^{-(0.693/T1/2)t}$

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 (originatlly)
- e = base of natural log
- λ = 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**

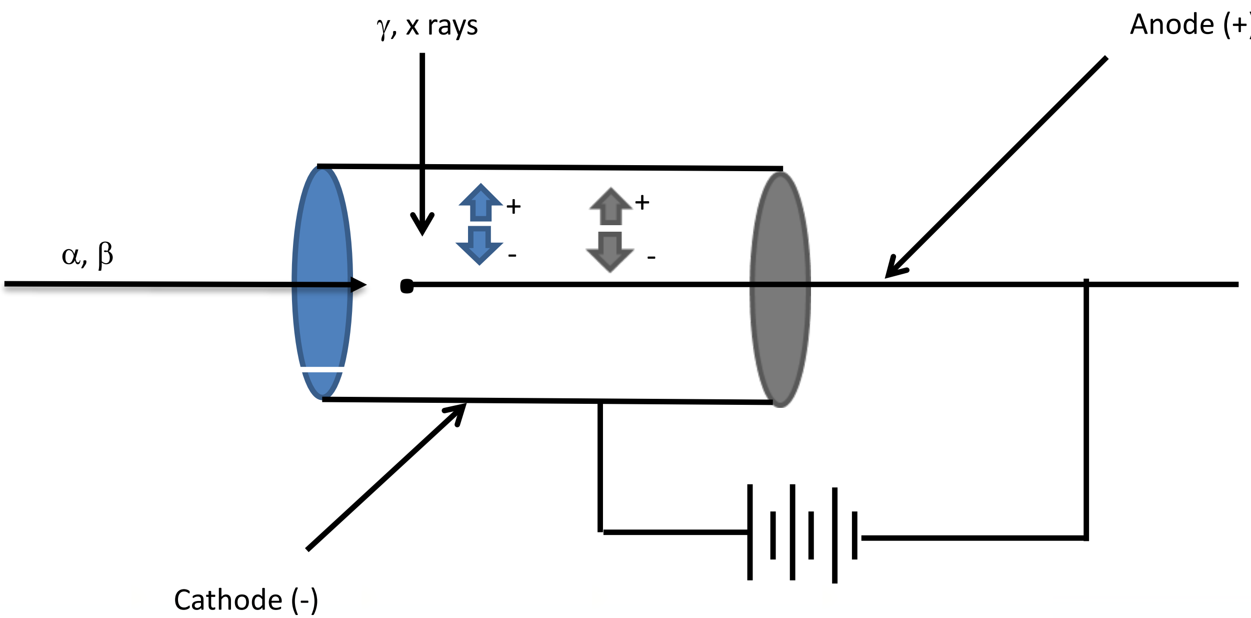
Half life problems

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
  - $\lambda = 0.693/14.3 \text{ days} = 0.048 d^{-1}$
  - $A = A_0 e^{-\lambda t}$
  - $250 e^{-(0.048)(60)} = 14.03$ mCi

Measuring radiation

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



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Measuring radiation

- Gas filled
  - 3 types –
    - Ionization detects γ rays
    - Proportional detects α and β particles
    - Geiger-Mueller detects γ rays and β 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.

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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 β emitters that are difficult to count by other methods
    - Very efficient ~100%
    - Count more than 1 nuclide at a time
    - Good for liquid samples.
      - .

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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

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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 x 10^6 dpm = 8.2 x 10^{-4} μCi

Measuring radiation

- **Semiconductors/solid state**
  - Electrons trapped in impurities and collected; analogous to gas filled detectors
    - Germanium for detecting γ rays
    - Silicon diode for detecting α and β 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 1 cm 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. Cut filter paper or paper towels into 1.5" x 1.5" strips.
    2. Wearing disposable gloves, rub the paper over the 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 conter 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.