# Module 1

An Introduction to Radiation

General Definition of Radiation

- Ionizing radiation, for example, X-rays, gamma-rays, α particles

- Ionizing radiation is capable of removing an electron from the atom with which it interacts (ionization).

- Non-ionizing radiation, for example, visible light, microwaves and radio waves.

- Non-ionizing radiation frees particles through interaction with the medium. For instance, microwaves interact with a medium to heat up the material.

Classification of Radiation
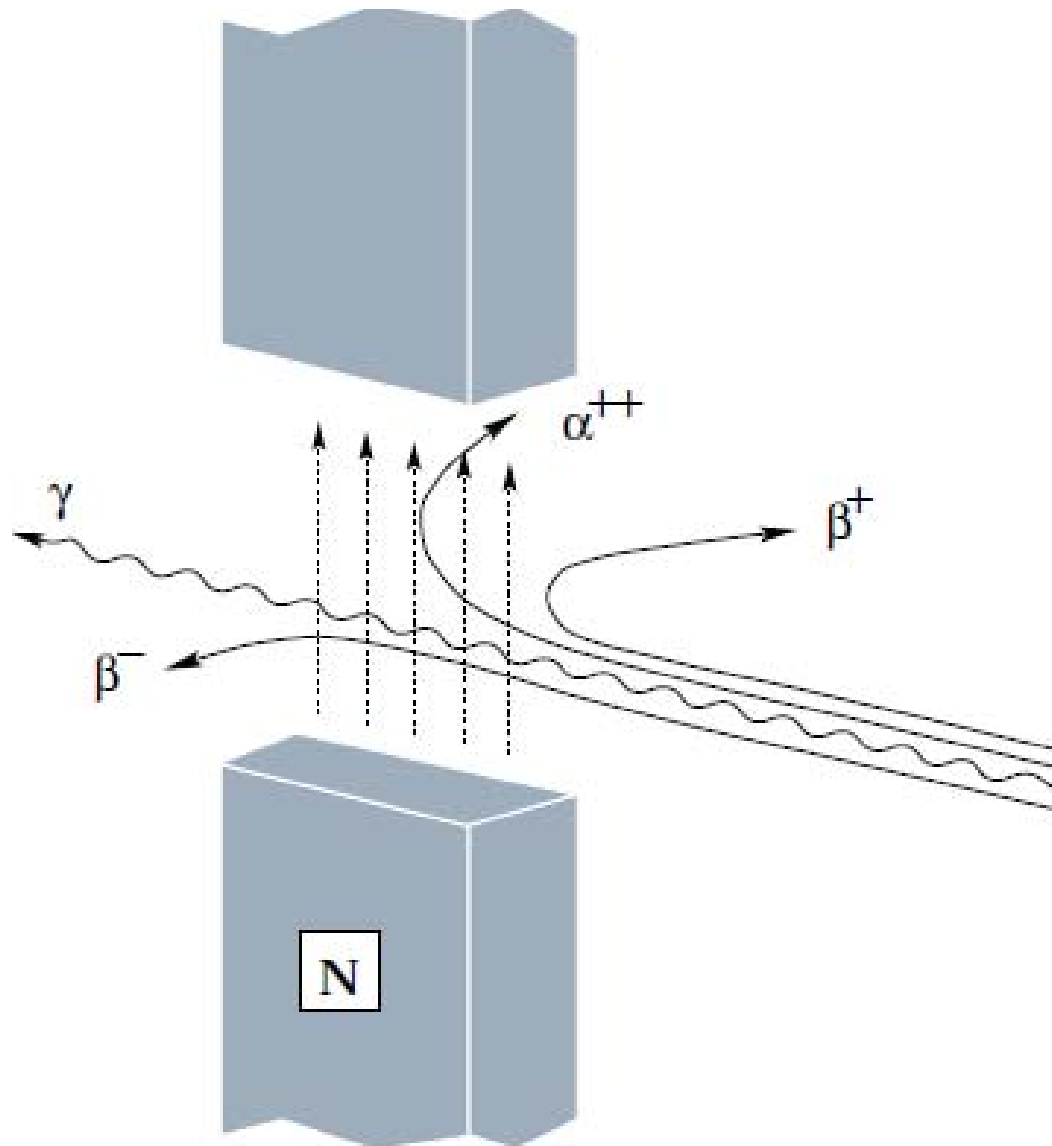
Electromagnetic Radiation

- Electromagnetic radiation is a special form of radiation. This radiation type is typified by the behavior of light.

- It has properties like both a wave and a particle.

- The wave-like behavior is best shown in diffraction where light interferes with itself.

- The particle-like properties of light are clearly shown when the photoelectric effect is studied.

- In the photoelectric effect, photons of a given frequency impinge on a metal, emitting monoenergetic electrons regardless of the intensity of the light.

- Thus, the photon acts a particle with one photon knocking out one electron. :

Electromagnetic Formulas
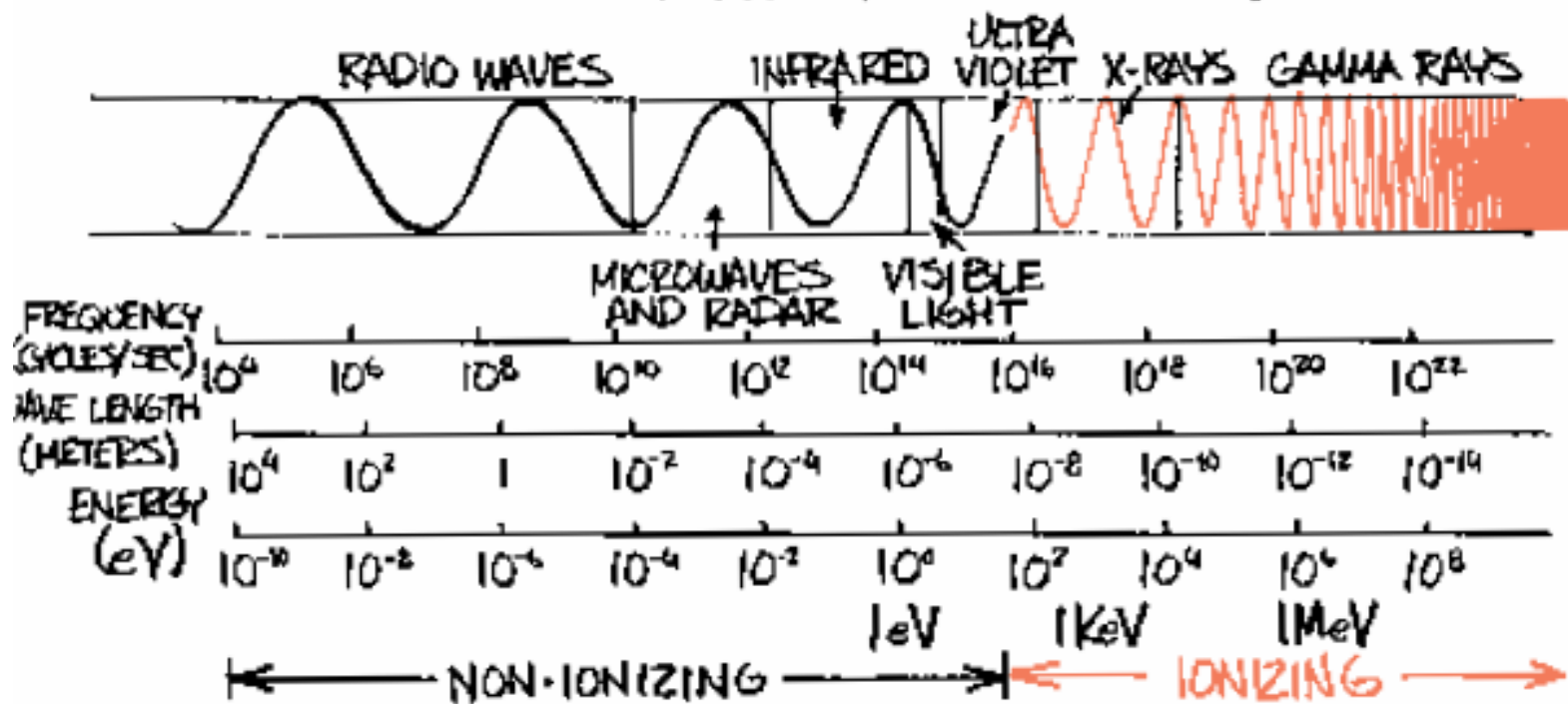
- E= $h\nu$

- $C = \lambda\nu$

Radioactive Decay

- alpha decay—the emission of a helium nucleus.

- beta decay (both β^- and β^+)—the emission of an electron and an antineutrino or the emission of an anti-electron (positron) and a neutrino, respectively.

- electron capture—the capture of an orbital electron by the nucleus with the emission of a neutrino.

Gamma and X-ray Emission

- Electromagnetic radiation is often emitted following radioactive decay.
- You will recall that electromagnetic radiation is named according to its origin, in the transitions of the orbital electrons of the atom for X-rays, and in transition within the nucleus for gamma-rays.
- Gamma-rays are commonly emitted during the deexcitation of the daughter nucleus following any of the nuclear decay modes.
- The nuclear decays can often interact with the atomic electrons.
- When this occurs, X-rays will result. The interaction of photons with matter is discussed in the next lesson.

ELECTROMAGNETIC SPECTRUM

RADIO WAVES INFRARED ULTRA VIOLET X-RAYS GAMMA RAYS

MICROWAVES AND RADAR VISIBLE LIGHT

FREQUENCY (CYCLES/SEC)	10^4	10^6	10^8	10^{10}	10^{12}	10^{14}	10^{16}	10^{18}	10^{20}	10^{22}
WAVE LENGTH (METERS)	10^4	10^2	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}	10^{-14}
ENERGY (eV)	10^{-10}	10^{-8}	10^{-6}	10^{-4}	10^{-2}	10^0	10^2	10^4	10^6	10^8

1eV 1KeV 1MeV

◄—————— NON·IONIZING ——————► ◄— IONIZING —►

Energy from Mass

- $E = mC^2$ where E is the energy, m is the mass and C is the speed of light.

- The energy available for a decay is always the maximum possible energy that can be deposited per decay.

- For the alpha decay of ^{255}U to ^{231}Th, the mass difference is 0.00499 amu.

Positron Decay

- A special point with β⁺ or positron decay is that it happens when an electron and its anti-particle, a positron, are created in the region of the nucleus.

- The electron is absorbed by the nucleus and the positron is emitted. Thus, for a nucleus to decay by this mode, the nucleus must have twice the rest mass of an electron available (i.e., 1.022 MeV).

- The positron is the anti-particle to the electron and will eventually annihilate with an electron in the material, yielding two photons of 0.511 MeV energy emitted back-to-back.

- This is known as annihilation radiation.

- (Positron emitters are becoming increasingly important to medical imaging, as the two photons emitted by annihilation of the positron can be used to precisely determine the position of the positron at the time of annihilation in positron emission tomography or PET. PET scans are currently used for imaging the heart and brain in real time.)

Rutherfords Alpha = He^{2+}

Spectral Tube

Radon

B

Mecury
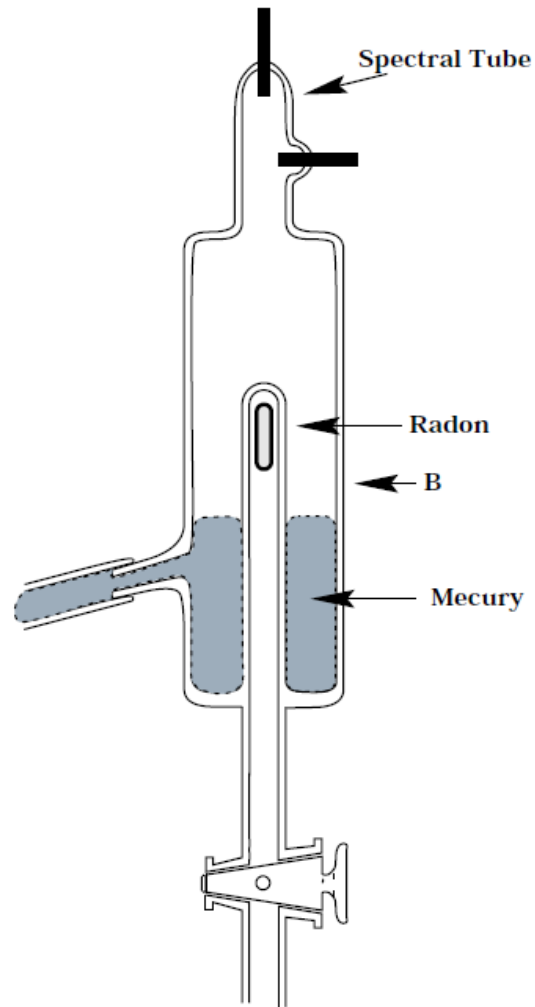
Cosmic Rays
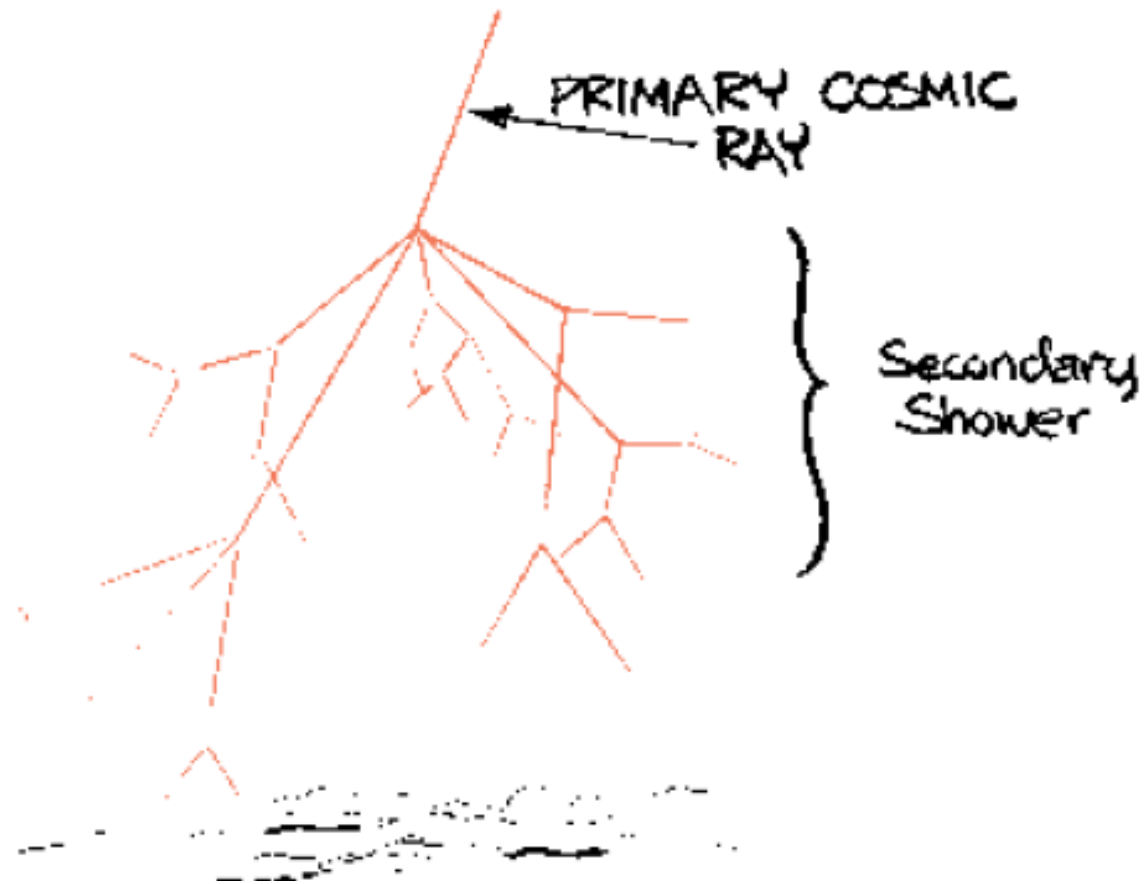
The Concept of Half-life

- Half-life is defined as the time it takes a given activity of a specific nuclide to decay to half its initial value.

- The half-life was found to be independent of the temperature, pressure, and phase of matter by scientists such as Rutherford and the Curies in the first three decades of this century.

- In review, an exact expression for determining the activities at times between half-lives is where N is the number of a nuclide at time, t, N_0 is the number of the nuclide present at a given initial time, and $T_{1/2}$ is the half-life of the given nuclide. The activity A from a nuclide is directly proportional to the amount present where 8 is the mean life (also known as the decay constant).

$$N = N_0 \exp\left(-\frac{ln2}{T_{\frac{1}{2}}}t\right)$$

$$A = \frac{dN}{dt} = -\frac{ln(2)}{T_{\frac{1}{2}}}N = -\lambda N$$

Bohr Atom

- You may recall that the Bohr's atom was a simplified model of the atom with the electrons in quantized orbits around the nucleus.

- The orbital electrons could change orbits by absorbing or emitting a quanta of light.

De Broglie Wavelength

- A quick review of the wave-like properties of particles will be useful in understanding the interaction of radiation with matter. In 1924, de Broglie postulated that a particle must have a wavelength of:

$$\lambda = \frac{h}{mV}; \quad v = \frac{E}{h}$$

- where V is the velocity of the particle, m is the mass of the particle, h is Plank's constant, < is the frequency of the particle's wave packet, and E is the kinetic energy of the particle. The wave-like properties were confirmed by Davisson and Germer in electron diffraction from a nickel crystal.

Compton Wavelength

- A useful concept for a particle's wavelengths is the Compton wavelength:

$$\lambda = h/mC$$

- The Compton wavelength represents the smallest size that a particle can have (the size it would have when traveling near the speed of light). For example, a 10 eV electron would have a de Broglie wavelength of 3.878 x 10^8 cm, while the minimum wavelength an electron can have is 2.42621 x 10^{-10} cm.

- While the minimum wavelength of the electron is small, the size of the nucleus ranges from 1.2 - 8x10^{-13} cm.

- The wave function of an electron is much larger than the nucleus at any energy. The positrons needed for β^+ are created at the time of decay by the creation of a positron and an electron from a photon near the nucleus. The electron is absorbed by the nucleus.

- The electrons for electron capture are from the small amount of an electron's wave function found at the nucleus from the innermost electrons with wave functions at the origin (e.g., 1s, 2s, 3s 4s, . . .).

- Note: the interaction is largest when the two wave functions involved in the interaction have roughly the same wavelength.

Units Review

- There are two basic sets of units used in the scientific literature, the MKS and the CGS system.

- The CGS system is composed of the units of **centimeter** for length, **grams** for mass and **seconds** for time.

- The MKS system has **meters** for length, **kilograms** for mass and **seconds** for time.

- The MKS units use **coulombs** for charge while the CGS units use **electrostatic units** (esu).

Decay Rate Units

- The **curie** is 3.7 x 10^{10} disintegrations per second. *A curie is roughly the rate of decay rate of decay per gram of radium (1 curie per gram).*

- The SI unit for measuring the amount of a radioactive decays, is a **becquerel** (Bq) one decay/second.

Curie Definition
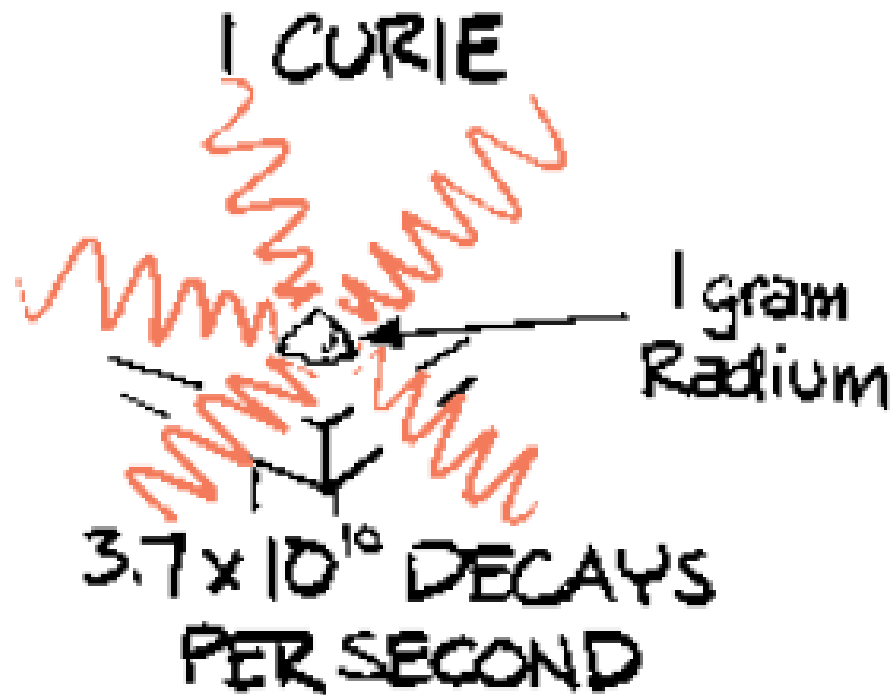
Units of Dose

- Absorbed dose is the energy absorbed per unit mass of tissue in the body.

- The concept of dose was developed where a **rad** is defined as 100 erg/g in the CGS system or a **gray**, defined as 1 J/kg in the MKS system.

- From the definition, it is easy to see that 1 gray = 100 rad. One centigray (cG) is exactly equal to one rad.

Units of Exposure

- H = Q*N*D
- Q = quality factor
- N is the dose distribution factor
- The units of H are in **rem** if the dose is in **rad**, and in **sieverts** (Sv) if dose is in gray.

Quality Factor/RBE

- The quality factor Q is often taken to be the equivalent of the relative biological effectiveness (RBE).

- RBE is defined by:

- RBE = D_R/D_X where D_R is the standard radiation (usually gamma-rays or x-rays) and D_X is dose needed from the radiation X to achieve the same biological result.

Dose Specification

- Two types of dose may be calculated—whole body dose and organ dose. Whole body dose is calculated by the following equation:

- Whole Body Dose = Energy Absorbed/ Mass of Body

- Organ dose is calculated by the following equation:
- Organ Dose = Energy Absorbed/ Mass of Organ

- This organ dose is important when describing exposure to ingested radionuclide and when exposure is in a non-uniform radiation field.

Kerma

- The concept of kerma is extremely important in determining the damage done to materials from tissues to semiconductors.

- Kerma is defined as the sum of all of the kinetic energy of all primary and secondary charged particles in a defined volume element of a given material.

- The charged particle equilibrium is the condition where the number of charges entering a volume is equal to and the same sign as those leaving the volume.

- When this condition is met, kerma is equal to the dose.

Linear Energy Transfer

- Linear energy transfer (LET) is a measure of the energy loss along the length of a particle's trajectory.

- The LET depends on both the type of particle and its energy.

- A high value for LET means more energy deposited in a given particle.

- Particles with high LET often also have high RBE and quality factors.

Bohr Atom
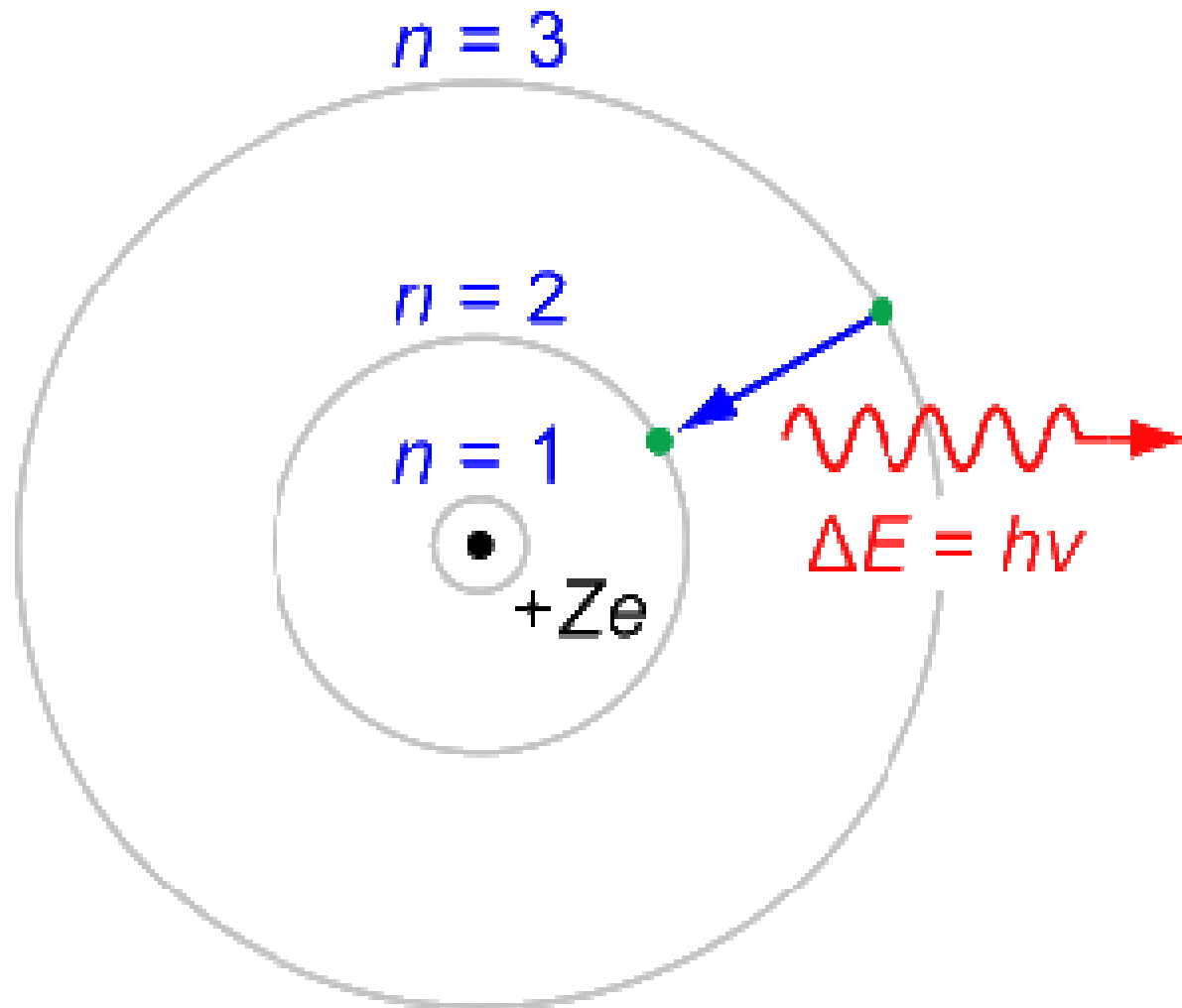
Bohr Atom

- Centripetal Force equals electrostatic attraction. $m_e v^2/r = ke^2/r^2$

- Solving for Energy gives $E = -ke^2/2r$

- Quantum Rule on angular momentum $m_e vr = n\hbar$

- *Energy Level given by $E = -(ke^2)^2 m_e/2\hbar^2 n^2$*

- *Binding Energy $E = -13.6eV/n^2$*