UNIT 9: ATOMIC PHYSICS

Black body:- is an ideal system that absorbs *all* radiation incident on it. It will radiate energy over the entire electromagnetic spectrum as shown in figure below. Any surface that absorbs all of the incident energy is the best emitting surface. *Such a surface reflects no radiant energy and hence would appear black in color.* A surface that is a good absorber of light is also a good emitter of light.

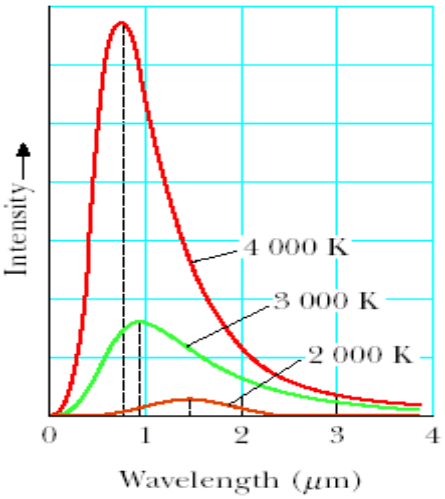
Black body radiation:- is a radiation emitted by a black body.

Experimental data for the distribution of energy in blackbody radiation at three temperatures are shown in figure below. The radiated energy varies with wavelength and temperature. As the temperature of the blackbody increases, the total amount of energy (area under the curve) it emits increases.

Also, with increasing temperature, the peak of the distribution shifts to shorter wavelengths. This shift obeys the following relationship, called **Wien's displacement law**,

$$\lambda_{max}\, T = 0.2898 \times 10^{-2}\ \text{m.K}$$

where λ_{max} is the wavelength at which the curve peaks and T is the absolute temperature of the object emitting the radiation.



Intensity of blackbody radiation versus wavelength at three different temperatures. Note that the total radiation emitted (the area under a curve) increases with increasing temperature.

The dual nature of light and matter

Dual nature of light

All electromagnetic waves, including light, have a dual nature.

Wave nature:- When traveling through space, they act like waves to give rise to interference and diffraction effects.

Particle nature:- When interact with atoms and molecules, the light (electromagnetic radiation) behaves as if it were composed of particles having energy E = hf and momentum $p = h/\lambda$.

Where $h = 6.63 \times 10^{-34}$ J.s **Planck's constant**

It acts like a stream of energy corpuscles called ***photons*** or ***light quanta***.

Dual nature of matter

In 1924, Louis de Broglie postulated that, **because photons have *wave* and *particle characteristics*, perhaps all forms of matter have both properties**. This was a highly revolutionary idea with no experimental confirmation at that time. Three years after de Broglie published his work, C. J. Davisson and L. H. Germer succeeded in measuring the wavelength of electrons. Their important discovery provided the first experimental confirmation of the *matter waves* proposed by de Broglie.

According to de Broglie, electrons, just like light, have a *dual particle–wave nature.*

From energy of a photon $E = h f = \dfrac{h c}{\lambda}$

Consequently, the momentum of a photon can be expressed as

$$P = \frac{E}{c} = \frac{hc}{c\lambda} = \frac{h}{\lambda}$$

From this equation, we see that the photon wavelength can be specified by its momentum, or $\lambda = h/P$. De Broglie suggested that *all* material particles with momentum *p* should have a characteristic wavelength $\lambda = h/p$.

Because the momentum of a particle of mass *m* and speed *v* is $mv = p$, the **de Broglie wavelength** of a particle is

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$ **de Broglie wavelength of a particle**

Further, de Broglie postulated that the frequencies of matter waves (waves associated with particles having nonzero rest energy) obey the Einstein relationship for photons, $E = hf$, so that

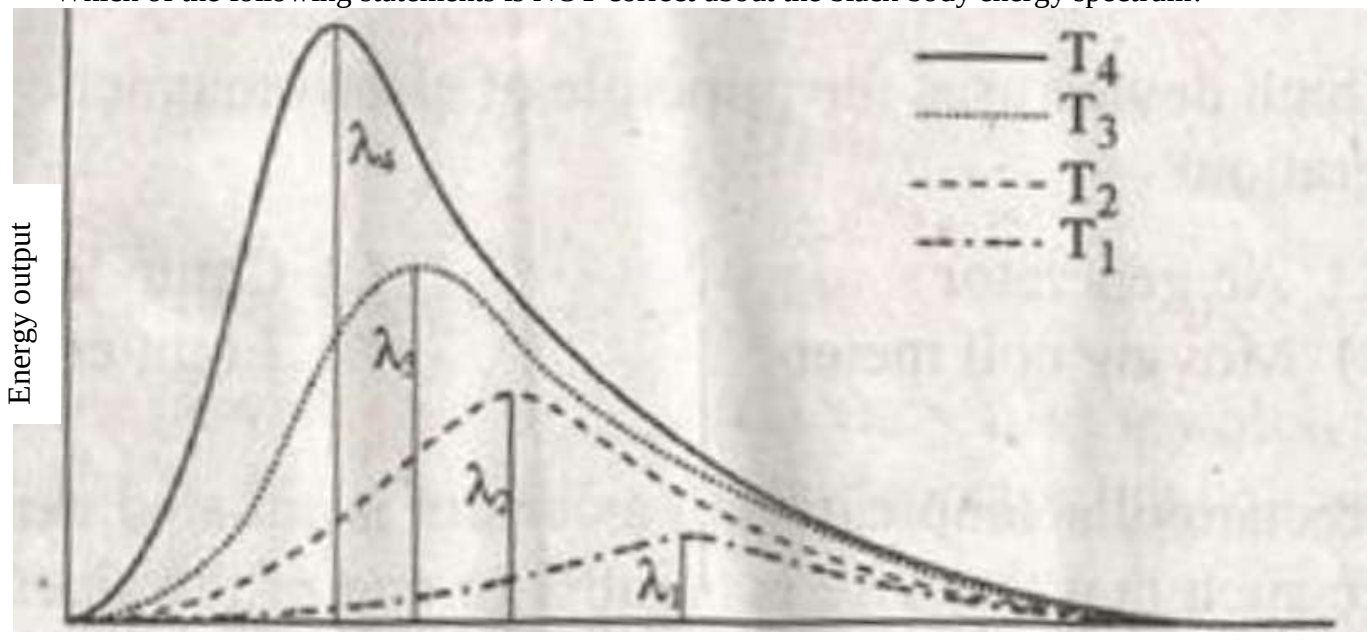
$$f = \frac{E}{h}$$

Example

1. Compare the de Broglie wavelength for an electron ($m_e = 9.11 \times 10^{-31}$ kg) moving at a speed of 10^7 m/s with that of a baseball of mass 0.145 kg pitched at 45.0 m/s.
   Ans. $\lambda_e = 7.28 \times 10^{-11}$ m , $\lambda_b = 1.02 \times 10^{-34}$ m
2. Find the de Broglie wavelength of a proton ($m_p = 1.67 \times 10^{27}$ kg) moving with a speed of 10^7 m/s.
   Ans. $\lambda_p = 3.97 \times 10^{-14}$ m
3. An electron is accelerated from rest through a p.d V. Show that its de Broglie wavelength is given by:

$$\lambda = \frac{h}{\sqrt{2m_e eV}}$$

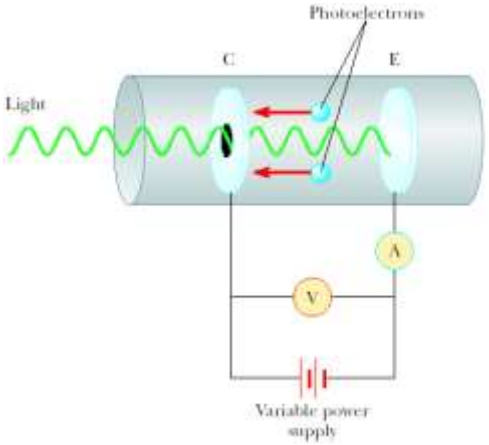
   Where $e = 1.6 \times 10^{-19}$ C charge carried by an electron
   m_e is mass of electron
4. An electron falls from rest through a potential difference of 100 V. What is its de Broglie wavelength?
   Ans. $\lambda = 0.123$ *nm*
5. A 0.2 kg ball is released from rest at the top of a 5 m tall building. Find the de Broglie wavelength of the ball just before it strikes the ground. **Ans**. $\lambda_{ball} = 3.313 \times 10^{-23}$ m.
6. The energy spectrum emitted by a black body at different temperature is as shown in the figure below. Which of the following statements is NOT correct about the black body energy spectrum?



A) $T_1 < T_2 < T_3 < T_4$
B) $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4$
C) Black body radiate energy over the entire electromagnetic spectrum.
D) The wavelength corresponding to the maximum intensity increases with temperature.

The photoelectric effect and its characteristics

Photon:- is a single unit (quantum) of light or electromagnetic radiation.
Quantum:- is the smallest quantity of some physical quantity, such as energy that a system can possess according to the quantum theory.
Photoelectric effect:- is the release (emission) of electrons from a metal surface when a light (electromagnetic radiation) of a suitable frequency is incident on it.
If a radiation energy E = hf is hitting the surface of a clean metal, some of the energy is used to release electron from the surface of the metal and the remaining energy appears as the kinetic energy of the emitted electron.



The above figure is a schematic diagram of a photoelectric effect apparatus. An evacuated glass tube known as a photocell contains a metal plate E (the emitter) connected to the negative terminal of a variable power supply. Another metal plate, C (the collector), is maintained at a positive potential by the power supply. When the tube is kept in the dark, the ammeter reads zero, indicating that there is no current in the circuit. However, when plate E is illuminated by light having a wavelength shorter than some particular wavelength that depends on the material used to make plate E, a current is detected by the ammeter, indicating a flow of charges across the gap between E and C. This current arises from photoelectrons emitted from the negative plate E and collected at the positive plate C.

Photon energy = Energy to release electron + Kinetic energy of the electron

$hf = \varphi + \frac{1}{2} m_e V_{max}^2$ **Einstein's photoelectric equation**

Or $hf = hf_o + \frac{1}{2} m_e V_{max}^2$

$K.E_{max} = h(f - f_o)$

The stopping potential, V_s, which stops the motion of the emitted electron moving at a speed V_{max} is

$V_s e = \frac{1}{2} m_e V_{max}^2$ Or $V_s e = h(f - f_o)$

Where $\varphi = hf_0$ is the work function (minimum energy required to release the electron)
f_0 is the threshold frequency (minimum frequency)
f is frequency of the radiation
$e = 1.6 \times 10^{-19}$ C charge carried by an electron
$h = 6.626 \times 10^{-34}$ J.s **Planck's constant**
1 eV (electron volt) = 1.6×10^{-19} J

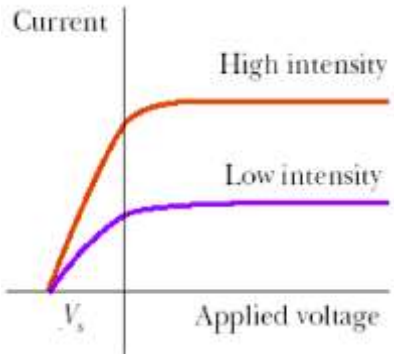
*The more intense the light, the greater the number of electrons emitted by the target metal.
*The higher the frequency of light, the greater will be the kinetic energy of the emitted electrons.

- Light with less than threshold frequency could not eject electrons.
- The threshold frequency is independent of the intensity of light.

Work Functions of Selected Metals

Metal	φ (eV)	Metal	φ (eV)
Na	2.46	Ag	4.73
Al	4.08	Pt	6.35
Cu	4.70	Pb	4.14
Zn	4.31	Fe	4.50

A plot of the photoelectric current versus the potential difference V between E and C for two light intensities is shown below. At large values of V, the current reaches a maximum value. In addition, the current increases as the incident light intensity increases, as you might expect.



Photoelectric current versus applied potential difference for two light intensities. The current increases with intensity, but reaches a saturation level for large values of *V*. At voltages equal to or less than *Vs* , where *Vs* is the stopping potential, the current is zero.

Example

1. The frequency of a photon is 6.2×10^{14} Hz. Calculate the energy of the photon. **Ans**. E =4.11×10^{-19} J
2. What minimum frequency light will eject photoelectrons from a copper surface? **Ans**.f_o=1.135×10^{15}Hz
3. An ultraviolet radiation of wavelength 200 *nm* falls on a magnesium. Calculate energy of the emitted electrons. **Ans**. E = 9.94×10^{-19} J
4. When a certain metal is illuminated with light of frequency 3×10^{15} Hz, a stopping potential of 7.0 V is required to stop the most energetic ejected electrons. What is the work function of this metal?
   Ans. φ = 8.678×10^{-19} V
5. An ultraviolet light is used to release electrons from a surface of lithium. If the stopping potential and the work function are 1.92 V and 2.93 eV respectively, what is the wavelength of the UV ray?
   Ans. λ = 2.56×10^{-7} m.
6. The work function of sodium metal is 2.46 eV. What is the longest wavelength light can cause photoelectron emission from sodium? **Ans**. λ = 5.11×10^{-7} m
7. A sodium surface is illuminated with light of wavelength 0.30μm. Calculate
   a) the energy of each photon in electron volts. **Ans**. E = 6.626×10^{-19} J = 4.14 eV
   b) the maximum kinetic energy of the ejected photoelectrons. **Ans**. KE_{max} = 1.68 Ev

Exercise

1. What p.d must be applied to stop a fast photoelectron emitted by a nickel surface (φ_{Nick} = 5.012 eV) under the action of UV light of wavelength 200 *nm*? **Ans**. V_s = 1.2 V
2. What is the increase in stopping potential for electrons emitted from a surface if the wavelength of the incident light is reduced from 400 *nm* to 360 *nm*? **Ans**. ΔV = 0.345 V

3. What wavelength of light would have to fall on sodium (φ_{Na} = 2.46 eV) if it is to emit electrons with a maximum speed of 10^6 m/s? **Ans**. $\lambda = 2.34 \times 10^{-7}$ m
4. Lithium, beryllium, and mercury have work functions of 2.30 eV, 3.90 eV, and 4.50 eV, respectively. If 400 *n*m light is incident on each of these metals, determine
   a) which metals exhibit the photoelectric effect. **Ans**. Lithium
   b) the maximum kinetic energy of the photoelectron. **Ans**. $KE_{max} = 1.2895 \times 10^{-19}$ J For Lithium
5. A light source of wavelength λ illuminates a metal and ejects photoelectrons with a maximum kinetic energy of 1 eV. A second light source of wavelength ½ λ ejects photoelectrons with a maximum kinetic energy of 4 eV. What is the work function of the metal? **Ans**. φ = 2 eV
6. Red light of wavelength 670 nm produces photoelectrons from a certain photoemissive material. Green light of wavelength 520 nm produces photoelectrons from the same material with 1.5 times the maximum kinetic energy. What is the material's work function? **Ans**. $\varphi = 3.13795 \times 10^{-20}$ J
7. Photons of wavelength 450 *nm* are incident on a metal. The most energetic electrons ejected from the metal are bent into a circular arc of radius 20 *cm* by a magnetic field with a magnitude of 2×10^{-5} T. What is the work function of the metal? **Ans**. $\varphi = 2.169 \times 10^{-19}$ J

Questions from national exam

1. Which one of the following statements is **true** about photoelectric effect?
   A) The number of photoelectrons emitted is proportional to the light frequency.
   B) Maximum kinetic energy increases with increasing frequency.
   C) Work function of metals is dependent on intensity.
   D) Photoelectric effect occur at any frequency.
2. When the intensity of light shining on a metal increases,
   A) the energy of photoelectrons, emitted, will increase.
   B) the number of photoelectrons, emitted, will increase.
   C) the threshold frequency for photoelectron emission will increase.
   D) the photoelectrons emitted will be deflected.
3. Which of the following is correct about the meaning of photon?
   A) Quantum of matter. C) Negatively charged particle.
   B) Positively charged particle. D) Quantum of light.
4. Which of the following phenomena most clearly demonstrates the wave nature of electrons?
   A) The photoelectric effect. C) The Compton effect.
   B) Blackbody radiation. D) Diffraction of electrons by crystals.

5. A common unit of energy in atomic physics is:
   A) Plank's constant. C) de Broglie wave length.
   B) electron volt. D) uncertainty principle.

6. In photoelectric effect, the energy of photoelectrons is proportional to the:
   A) frequency of light. C) speed of light.
   B) intensity of light. D) absorbance of the metal.

7. Which of the following phenomena clearly demonstrates the particle nature of light?
   A) Refraction of light by prism. C) Diffraction of light by double slit.
   B) The photoelectric effect. D) Dispersion of white light.

8. Which of the following has an electronvolt unit?
   (A) Charge (C) Potential difference
   (B) Energy (D) Electromagnetic intensity

9. When ultraviolet light is shone on a clean metal surface the surface will emit electrons. What is the necessary precondition for electrons to be ejected from the metal surface?
   A) The minimum energy required to release the electron is the same as the work function of the metal.
   B) The intensity of light must be high enough.
   C) The wavelength of the light has to be greater than that of ultraviolet light.
   D) The frequency of the metal has to be less than that of ultraviolet light.

Heisenberg's Uncertainty Principle

Heisenberg's uncertainty principle states that **it is physically impossible to measure simultaneously the exact position and exact linear momentum of a particle**. If a measurement of the position of a particle is made with precision Δx and a simultaneous measurement of linear momentum is made with precision Δpx, then the product of the two uncertainties can never be smaller than $h/4\pi$:

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

If Δx is very small, then Δpx is large, and vice versa.

Example

1. If the uncertainty in the momentum of an electron is $\Delta p_x = 5 \times 10^{-25}$ kg.m/s, what is the minimum uncertainty Δx in its position? **Ans**. $\Delta x = 1.055 \times 10^{-10}$ m
2. Suppose that the uncertainty in the position of a particle is equal to its de Broglie wavelength. Show that the minimum momentum uncertainty is $\Delta p_x = \frac{p}{4\pi}$

Some properties of nucleus

The concept of the atomic nucleus was established by the experiment of Rutherford and his coworkers. All nuclei are composed of two types of particles: *protons and neutrons*. The only exception is the ordinary hydrogen nucleus, which has a single proton. In describing some of the properties of nuclei, such as their charge, mass, and radius, we make use of the following quantities:

- the **atomic number** *Z*, which equals the number of protons in the nucleus,
- the **neutron number** *N*, which equals the number of neutrons in the nucleus,
- the **mass number** *A*, which equals the number of nucleons in the nucleus.

The nuclei of all atoms of a particular element must contain the same number of protons, but they may contain different numbers of neutrons. Nuclei that are related in this way are called **isotopes**.

The isotopes of an element have the same *Z* value, but different *N* and *A* values.

Nuclear size

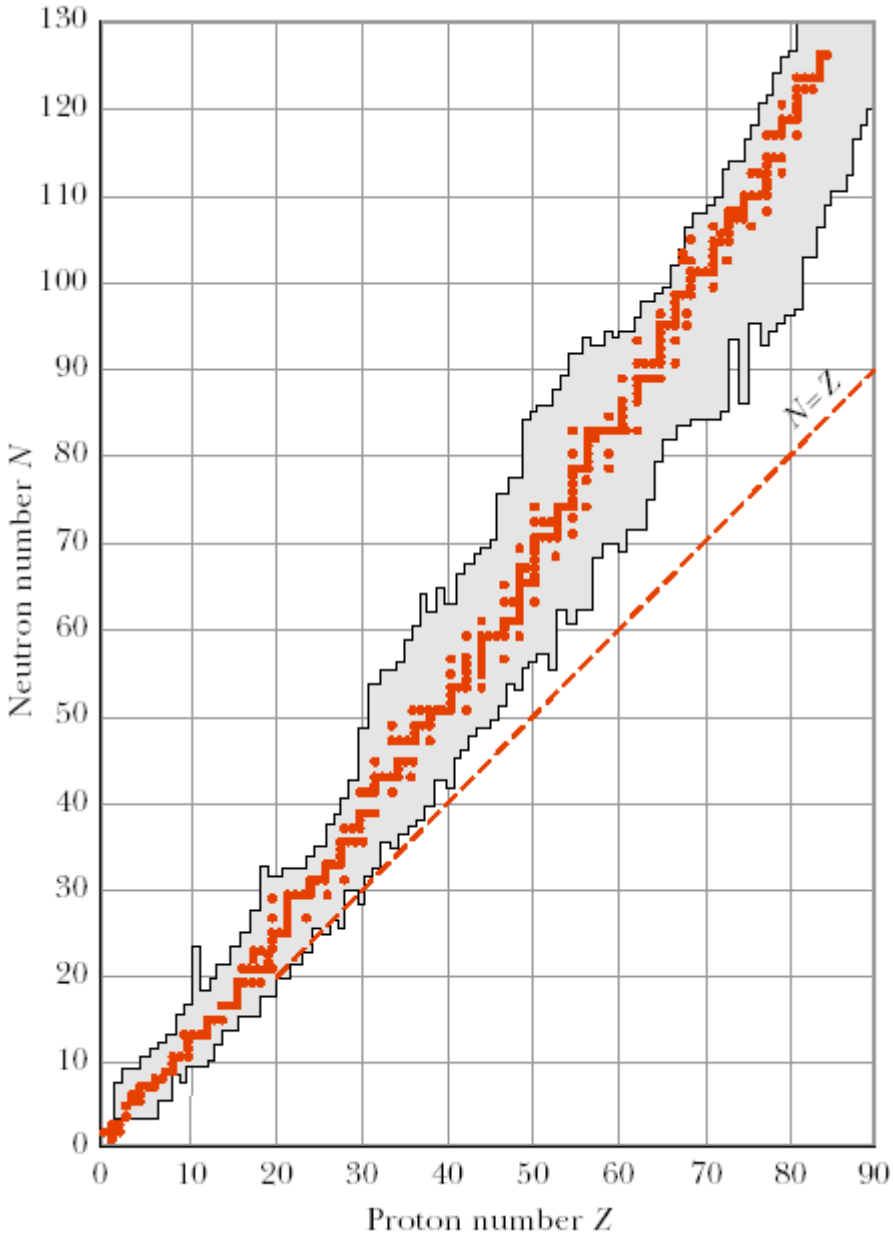
Experiments show that most nuclei are approximately spherical in shape. The approximate radius R of a nucleus of a mass number A is

$$R = 1.2 \times 10^{-15} \times A^{1/3} \text{ meter}$$

Nuclear Stability

There are about 260 stable nuclei; hundreds of others are unstable. A plot of *N* versus *Z* for a number of stable nuclei is given in figure below. Note that light nuclei are most stable if they contain equal numbers of protons and neutrons.

- For lighter nuclei, N = Z
- For heavier nuclei, N > Z.
- Nuclear heavier than Uranium are artificial.



A plot of the neutron number *N* versus the proton number *Z*. The dashed straight line corresponds to the condition *N* =*Z*, the so-called line of stability. The shaded area shows radioactive (unstable) nuclei.

Radioactivity

Radioactivity:- is the spontaneous disintegration of an unstable atomic nucleus with the release of *alpha-particles (**helium nuclei**), beta-particles (**electrons**) or gamma-radiation (**short wave electromagnetic waves**),* forming a lighter, more stable nucleus.

- Alpha Decay

If a nucleus emits an alpha particle (α), it loses two protons and two neutrons. Therefore, the neutron number *N* of a single nucleus decreases by 2, *Z* decreases by 2, and *A* decreases by 4.
The decay can be written symbolically as

$$^{A}_{Z}P \rightarrow ^{A-4}_{Z-2}D + \alpha + Energy$$

Where P and D represent the **parent** and the **daughter nuclei**, respectively.
As example, ^{238}U and ^{226}Ra are both alpha emitters and their decay processes are

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + \alpha + Energy$$

and

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + \alpha + Energy$$

- Beta Decay

Many radioactive nuclei emit (β) beta particles, electrons.
The decay can be written symbolically as

$$^{A}_{Z}P \rightarrow ^{A}_{Z+1}D + ^{0}_{-1}e + Energy$$

There are no electrons in the nucleus, so the process transforms a neutron into a proton plus an electron. The new proton is retained by the nucleus while the electron is emitted.
This process can be represented by the equation

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

Where $^{0}_{-1}e$ represents the emitted β particle (electron) with an atomic number –1 and a mass number of 0.
A typical beta decay event is

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

- Gamma Decay

Very often a nucleus that undergoes radioactive decay, α or β, is left in an excited energy state. The nucleus can then undergo a second decay to a lower energy state, perhaps even to the ground state, by emitting a high-energy photon. An atom emits radiation to release some extra energy when an electron "jumps" from a state of high energy to a state of lower energy. The photons emitted in the process are called **gamma rays**, which have very high energy relative to the energy of visible light.
We represent gamma decay by

$$^{A}_{Z}X^{*} \rightarrow ^{A}_{Z}X + \gamma + Energy$$

Where X is the chemical symbol for the nuclide and the asterisk indicates the exited state of a nuclide.

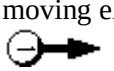
$$hf = E_i - E_f$$

Where E_i and E_f are energies of exited (initial) state and the ground (final) state, respectively.
Example.

$$^{12}_{6}C^{*} \rightarrow ^{12}_{6}C + \gamma \text{ +Energy}$$

Note:- There is a loss of energy, but ***not*** of charge.
Gamma ray photons are basically the same as X-ray photons. However, the term γ-ray is given to a photon emitted from the nucleus, while an identical photon emitted during an atomic electron transition is called X-ray.

Alpha (α) particle, beta (β) particle and gamma (γ) radiation

	Alpha, α	Beta, β	Gamma, γ
Nature	a helium nucleus 	a fast moving electron 	electromagnetic radiation of very high frequency and short wavelength 
Charge	the charge of 2 protons: +2e	the charge of an electron: – e	no charge
Mass	approximately 4u	is about 1/7000 of the α particle	Zero
Energy	kinetic energy	kinetic energy	Photo energy E = *hf*
Effect of :magnetic field	small deflection, suggests that relatively large mass	large deflection, suggests that relatively small mass	. does not consist particle . not deflected
:electric field	Deflects	Deflects	no deflection
Ionizing effect	highly ionizing	less ionizing than alpha	least ionizing radiation
Penetrating power	a few centimeters in air, completely blocked by paper and skin	several meters of air, thin sheet of aluminum will absorb	never completely absorbed by several centimeters of lead or several meters of concrete

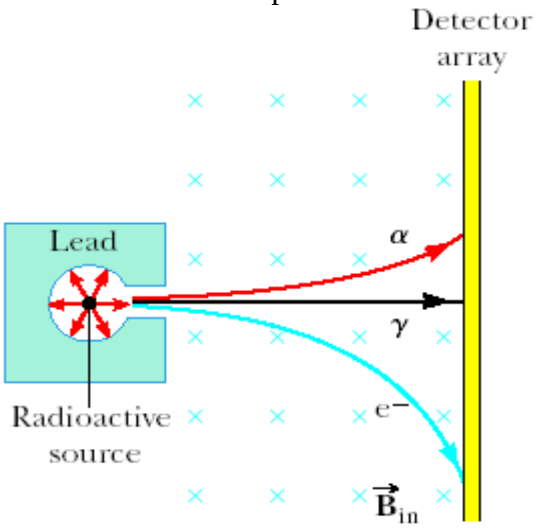
Example

1. An alpha particle has twice the charge of a beta particle. Why does the former deflect less than the latter when passing through a magnetic field, assuming they both have the same speed?

Hint: Compare the radii of α and β particles using magnetic force $F_B = qVB$ and centripetal force

$F_c = \frac{mV^2}{r^2}$ on both α and β particles.

Where q is charge of the particle
V is speed of each particle
B is magnetic field
m is mass of the particle
r is radius



2. Neutrons are highly penetrating because they
   A) are very thin and can slide between atoms.
   B) never strike an atom because they twist as the advance.
   C) always travel at extremely high speeds in comparison to protons or electrons.
   D) are neutral and do not lose energy via coulomb interaction with the atoms.

3. When the radioactive element $^{144}_{60}Nd$ decays to $^{140}_{58}Ce$, which one of the following particle is emitted?
   A) A beta particle. B) An alpha particl. C) A proton. D) A gamma ray.

4. Which statement is **NOT** correct about emissions from radioactive isotops?
   A) Alpha particls are positively charged and less penetrating than beta and gamma.
   B) Beta particls are negatively charged and more penetrating than alpha particles.
   C) Alpha emissions are least influenced by magnetic field.
   D) The most penetrating emissions are gamma particles.

5. In the following equation which represents a nuclear fission reaction , what is the particle represented by *X*?

$$^{235}U + {}^{1}_{0}n \rightarrow {}^{95}Rb + {}^{139}Cs + 2X + energy$$

A) Electron B) Proton C) Alphha particle D) Neutron

Half-life

The Half-life:- is defined as the time during which half of a given sample of identical nuclei will undergo decomposition. The half-life is a fixed number for each isotope.

Let N represent the population of radioactive nuclei.

The population decay rate (**the number of decays per second**) A is

$A = -\frac{dN}{dt}$ is called the **activity**

The SI unit of activity is the Becquerel (Bq). 1Bq = 1 emission/sec

The fractional reduction of the population during an infinitesimal time interval *dt* is

$\frac{-dN}{N} = \lambda\, dt$ Where λ is **decay (disintegration) constant**.

From the above two equations, the activity is proportional to the number of nuclei in the sample.

$A = \lambda N$

Isotopes with a large value λ decay rapidly; those with small λ decay slowly.

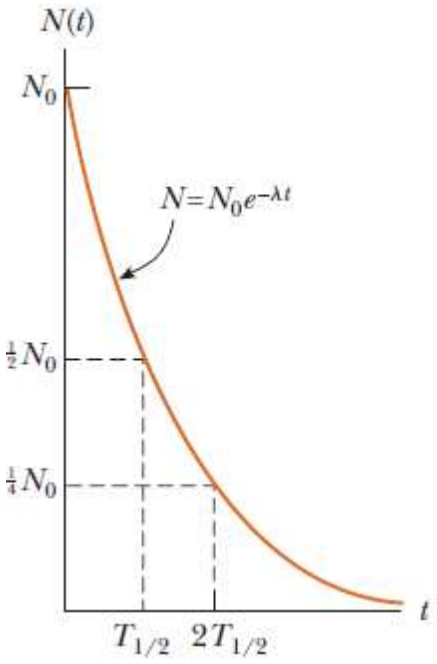
A general decay curve for a radioactive sample is shown in figure below.

The number of nuclei remaining in a sample, N, after a fixed time, t is

$N = N_0\, e^{-\lambda t}$ Where N_0 is the initial number of nuclei in a sample

Substituting $A = \lambda N$ into $N = N_0\, e^{-\lambda t}$ we get

$A = A_0\, e^{-\lambda t}$ Where $A_0 = \lambda N_0$ is the initial activity at t = 0



The graph of N versus time t

The half-life is the time required for N to decrease by a factor of ½ . Since N = N_0 at t = 0

$N = \frac{1}{2} N_0$ at $t = T_{1/2}$. Substitute these values into

$N = N_0\, e^{-\lambda t}$ and $A = A_0\, e^{-\lambda t}$ we get

$$\frac{1}{2}N_0 = N_0 e^{-\lambda T_{1/2}} \quad \text{and} \quad \frac{1}{2}A_0 = A_0 e^{-\lambda T_{1/2}}$$

OR $$T_{1/2} = \frac{\ell n 2}{\lambda} = \frac{0.693}{\lambda}$$

Note that after an elapsed time of one half-life, $N_0/2$ radioactive nuclei remain; after two half-lives, half of these will have decayed and $N_0/4$ radioactive nuclei will be left; after three half-lives, $N_0/8$ will be left; and so on.

The *activity is reduced by half every half-life*, which is naturally the case because *activity is proportional to the number of remaining nuclei.*

Example

1. If $N_0 = 6.9 \times 10^{16}$ nuclei and $T_{1./2}$= 10 min, calculate
   a) the decay constant. **Ans**. $\lambda = 1.155 \times 10^{-3}$/sec
   b) the initial activity. **Ans**. $A = 7.97 \times 10^{13}$ Bq
   c) N after 1 hr. **Ans**. $N = 1.08 \times 10^{15}$ nuclei
   d) the activity after 1hr. **Ans**. $A = 1.24 \times 10^{12}$ Bq
2. A sample of 100 million atoms of carbon-14 has a decay constant of 3.84×10^{-12}/sec. Calculate
   a) its initial activity. **Ans**. $A = 3.84 \times 10^{-4}$ Bq
   b) the number of atoms remaining after 250 years. **Ans**. $N = 9.702 \times 10^{7}$ atoms
   c) its half-life. **Ans**. $t_{1/2} = 1.8046 \times 10^{11}$ sec = 5723 years
3. The unstable isotope of potassium ^{40}k has a half-life of 2.4×10^{8} years.
   a) What is the decay constant? **Ans**. $\lambda = 9.156 \times 10^{-17}$/sec
   b) How many decays occur per second in a sample containing 3.01×10^{16} atoms of ^{40}k? **Ans**. 2.76/sec
   c) What is its half-life? **Ans**. $t_{½} = 2.4 \times 10^{8}$ years
4. A sample of 2.66×10^{21} atoms of Radium has a half-life of 1600 years. Calculate
   a) the decay constant. **Ans**. $\lambda = 1.37 \times 10^{-11}$ /sec.
   b) the percent of atoms remaining after 2000 years. **Ans**. 42.1 %
5. Ten percent of a certain radioactive substance decays in 12 hours. What is
   a) the decay constant of the substance? **Ans**. $\lambda = 8.78 \times 10^{-3}$ .sec
   b) the half-life for the substance? **Ans**. $t_{½}$ = 79 hours

Exercise

1. After two half-lives have elapsed, what fraction of a radioactive sample has
   a) remained? **Ans**. N/4 b) decayed? **Ans**. ¾ N
2. After 2 days, the activity of a sample of an unknown type of radioactive material has decreased to 84.2% of the initial activity. What is the half-life of this material? **Ans**. $t_{1/2}$ = 8.06 days
3. If 20 percent of a substance decays in 40 sec, what is
   a) the decay constant? **Ans**. 5.575×10^{-3}/sec b) the half-life? **Ans**. $t_{1/2}$ = 124.3 sec
4. Uranium 238 has a half-life of 4.5×10^{9} years. What percent of uranium would be found un decayed after 4×10^{9} years? **Ans**. 54%
5. The half-life of radium 224 is 3.5 days. What fraction of the sample remains undecayed after fourteen days? (If needed use $\ell n2 = -\ell n(1/2) \approx 0.693$

   A)1/2 B) 1/4 C) 1/8 D)1/16

6. The activity of a radioactive source falls to one sixteenth of its original value in 32minutes. What is the half-life of this decay process?

   A) 2min B**)** 8min C) 4min D) 16min

7. The activity of radioactive substance reduces from 2000 Bq to 1000 Bq in 10^6 seconds. What is the decay constant ?

A) 6.93×10^5 decays/s B) 6.93×10^{-7} decays/s C) 2×10^5 decays/s D) 5×10^{-7} decays/s

Binding energy

The mass of a nucleus is less than the mass of its constituent nucleons. *The difference between the actual mass of a nucleus* and *the sum of the masses of its constituent nucleus* is known as ***mass defect (Δm)***.

The energy needed to decompose the nucleus, or the energy released when it is formed, is known as ***binding energy***.

$E = (\Delta m)\, c^2$ **Einstein's equation**

Where $c = 2.997\ 92 \times 10^8$ m/s

For atomic masses, it is convenient to define the **unified mass unit** u in such a way that the mass of one atom of the isotope ^{12}C is exactly 12 u, where 1 u $=1.660\ 559 \times 10^{-27}$ kg.

It is often convenient to express the particle's mass in terms of its energy equivalent. For one atomic mass unit, we have an energy equivalent of

$$E = m\, c^2 = (1.660\ 559 \times 10^{-27}\ \text{kg})\ (2.997\ 92 \times 10^8\ \text{m/s})^2$$
$$= 1.492\ 431 \times 10^{-10}\ \text{J}$$
$$= 931.5\ \text{MeV}$$

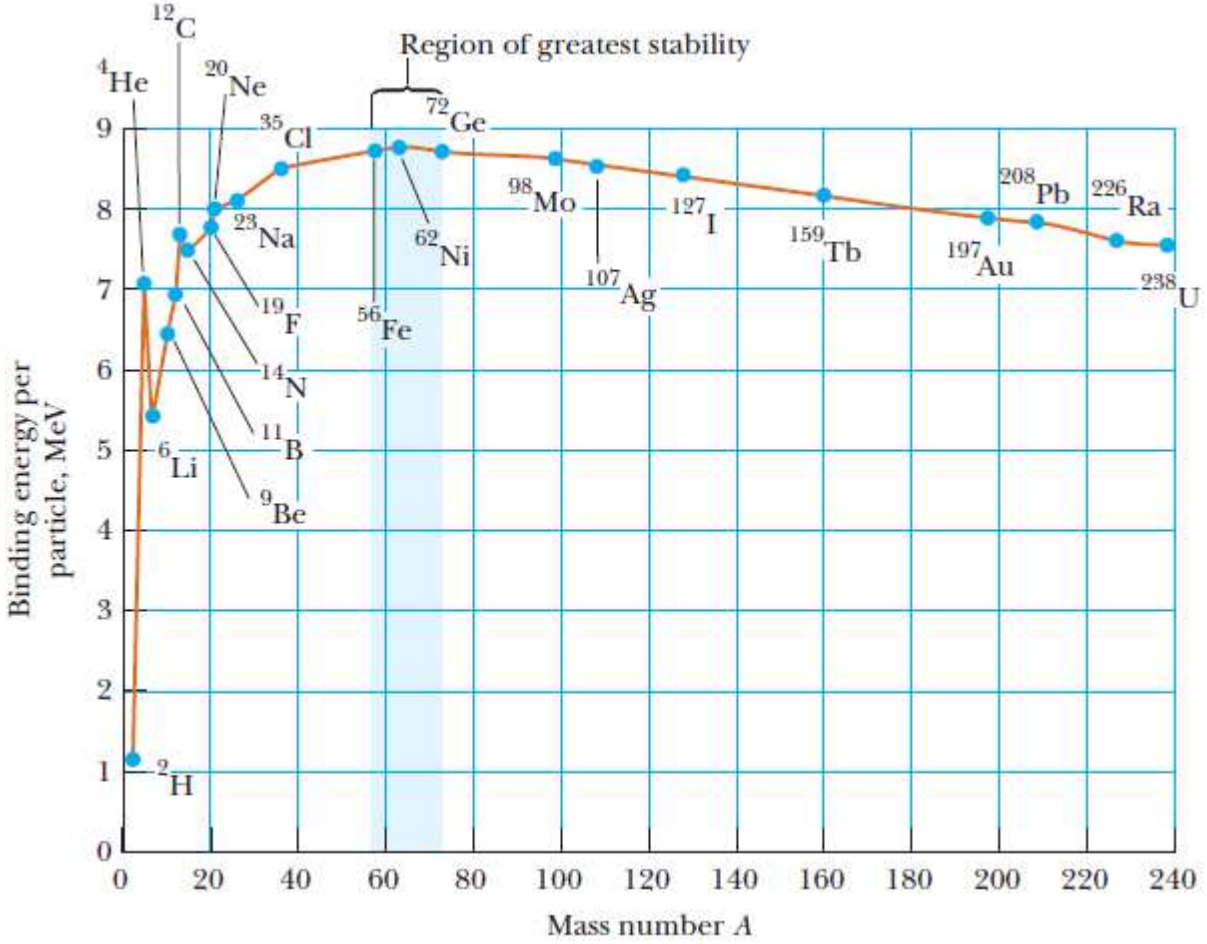
In calculations, nuclear physicists often express *mass* in terms of the unit Me V/c^2, where

$1\ \text{u} = 931.5\ \text{MeV}/c^2$

Mass of

- One neutron is 1.6750×10^{-27}kg = 1.008 665 u = 939.57 MeV/c^2
- One proton is 1.6726×10^{-27}kg = 1.007 825 u = 938.79 MeV/c^2
- One electron is 9.109×10^{-31}kg = 5.486×10^{-4} u = 0.511 MeV/c^2

Binding energy per nucleon versus the mass number *A*. (Nuclei to the right of ^{208}Pb are unstable. The curve represents the binding energy for the most stable isotopes.)



Example

1. The nucleus of the deuterium atom consists of a proton and a neutron. If mass of a deuterium is 2.014 102u, calculate
   a) the mass defect. **Ans**. Δm =0.002388u, b) the deuteron's binding energy in MeV. **Ans**. E =2.2244 MeV
2. For carbon-12 ($^{12}_{6}C$), calculate
   a) the mass defect. **Ans**. Δm = 0.09894 u b) the binding energy. **Ans**. E = 92.16 MeV
3. Calculate the energy liberated in the beta decay of radioactive
   a) $^{14}_{6}C \rightarrow {}^{14}_{4}N$ if atomic masses of $^{14}_{6}C$ and $^{14}_{7}N$ are 14.003 242 u and 14.003 074 u respectively.
   Ans. 0.1565 MeV
   b) $^{40}_{19}K \rightarrow {}^{40}_{20}Ca$ if atomic masses of $^{40}_{19}K$ and $^{40}_{20}Ca$ are 39.963 999 u and 39.962 591 u respectively.
   Ans. 1.31 MeV

Nuclear Fission:- *is a nuclear reaction in which* ***a large-mass nucleus absorbs a neutron*** *and then* ***splits into two medium-mass nuclei*** *and* ***several neutrons***. Fission may occur spontaneously or as a result of striking large nuclei with low or moderate energy neutrons.

In such a reaction, **the total mass of the products is less than the original mass of the heavy nucleus**.

Typical reaction of this type are

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n + Energy$$

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2{}^{1}_{0}n + Energy$$

Nuclear Fusion:- *is a type of nuclear reaction in which* ***two-small nuclei combine*** *to produce* ***a single larger-mass nucleus*** *with the* ***release of large amount of energy***.

*The source of the sun's energy is a series of fusion reactions.

A possible fusion reaction involves deuterium and tritium nuclei fusing together to form helium.

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

Example

1. Find the value of X for the following equation which represents a nuclei fission reaction.

$$^{235}U + ^{1}_{0}n \rightarrow ^{X}Rb + ^{139}Cs + 2^{1}_{0}n$$ **Ans**. X = 95

2. Identify the unknown particle in this reaction:

$$^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{A}_{Z}X$$ **Ans**. $^{A}_{Z}X = ^{1}_{1}H$ (a neutral hydrogen atom)

3. Calculate the energy released in the following fission reactions.

a) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{98}_{40}Zr + ^{135}_{52}Te + 3^{1}_{0}n$.

Atomic masses of $^{235}_{92}U$, $^{98}_{40}Zr$ and $^{135}_{52}Te$ are 235.043 923 u, 97.9120 u and 134.908 7 u, respectively.

b) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{88}_{38}Sr + ^{136}_{54}Xe + 12^{1}_{0}n$

Atomic masses of $^{88}_{38}Sr$ and $^{136}_{54}Xe$ are 87.905 614 u and 135.907 220 u, respectively.

c) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$

Atomic masses of $^{141}_{56}Ba$ and $^{92}_{36}Kr$ are

4. When a beryllium target is bombarded with alpha particles, analysis of the experiment indicated that the following reaction occurred:

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{A}_{Z}X$$

What is $^{A}_{Z}X$ in this reaction? **Ans**. $^{A}_{Z}X = ^{1}_{0}n$ (a neutron)

~~*The End*~~