DUAL NATURE OF RADIATION

Image source: www.tes.com

PHOTO-ELECTRIC EFFECT

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Hertz’s and Lenard Observations

- UV rays
- Zn plate

PHOTOELECTRIC EFFECT

The emission of electrons from the metal surface when illuminated by a light of suitable frequency (or wavelength)

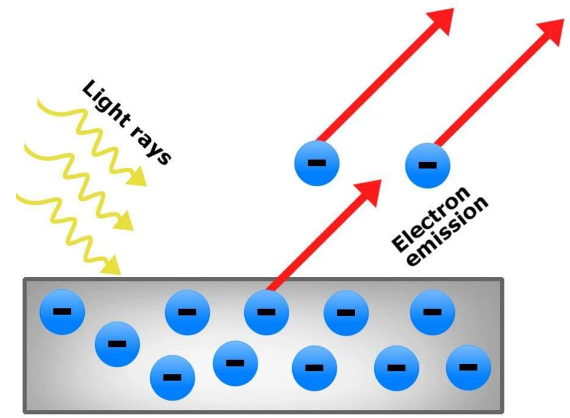
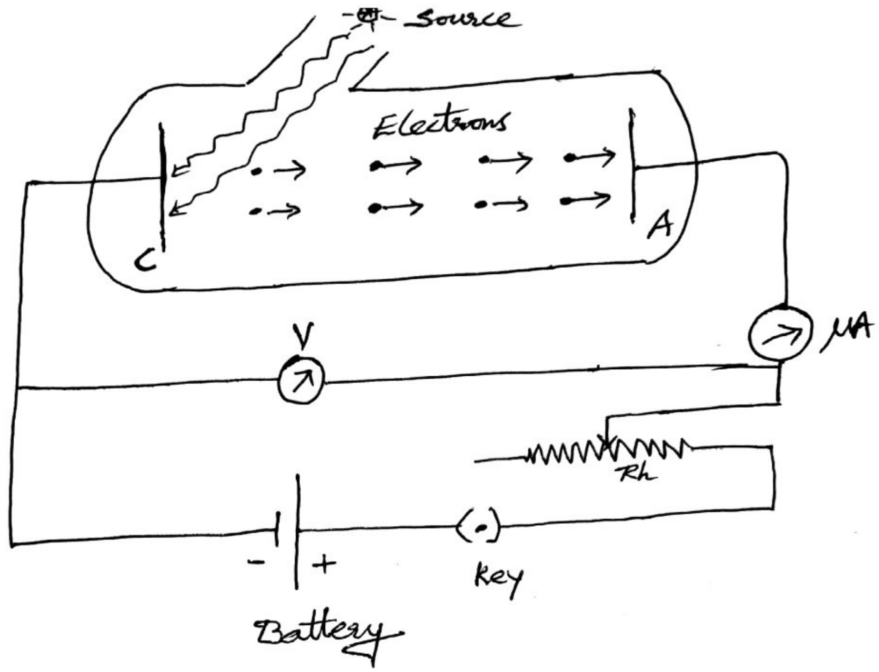


Image source: scienceabc.com

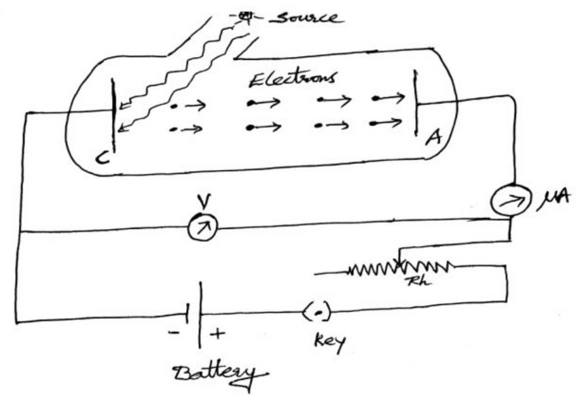
The emitted electrons are called as photoelectrons and phenomenon is called as photo-electric effect.

Experimental study of Photoelectric effect:

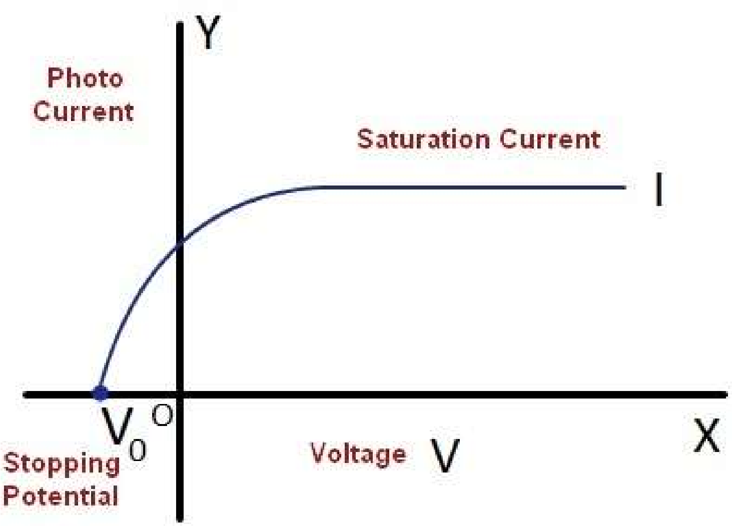


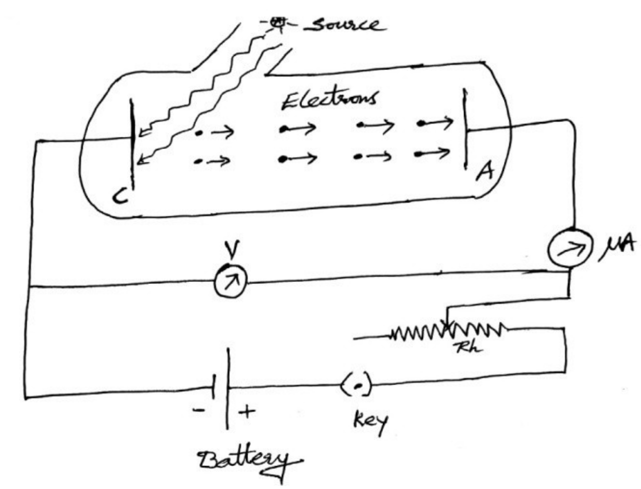
Factors effecting the photoelectric effect:

1. The potential difference between the two electrodes (V)
2. The intensity of incident radiation (I)
3. The frequency of incident radiation (ν)
4. Nature of photo metal used.



The potential difference between the two electrodes (V)





The negative potential at which the photoelectric current becomes zero

Intensity of incident radiation (I)

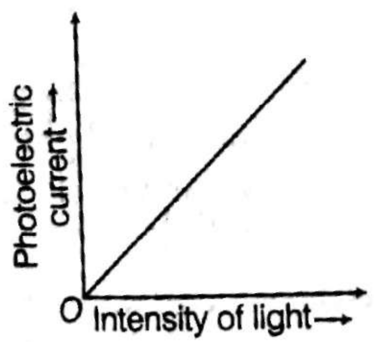
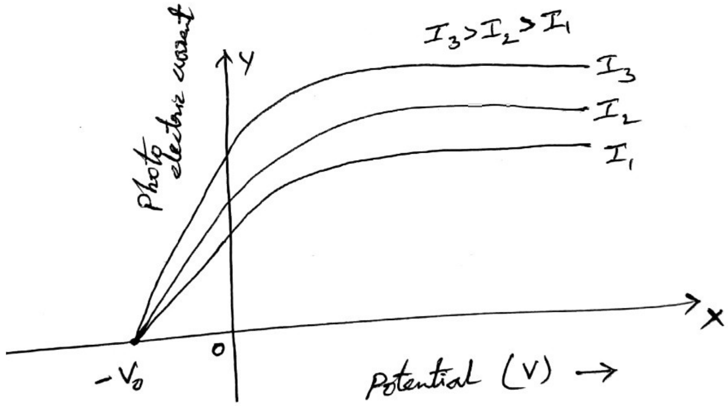
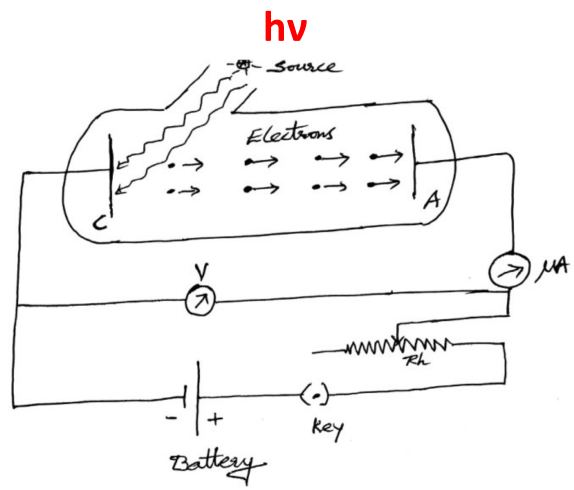


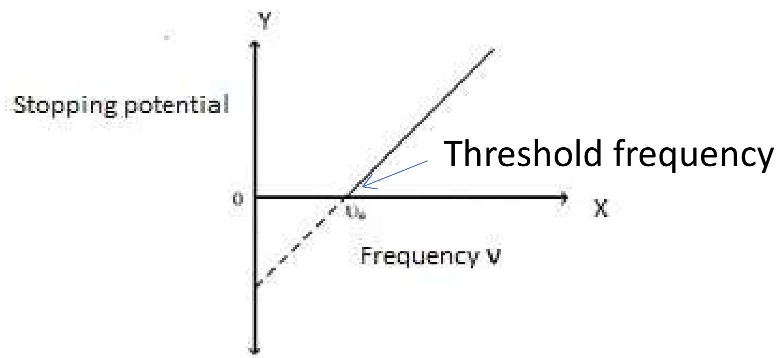
Photo current is proportional to the intensity of incident radiation

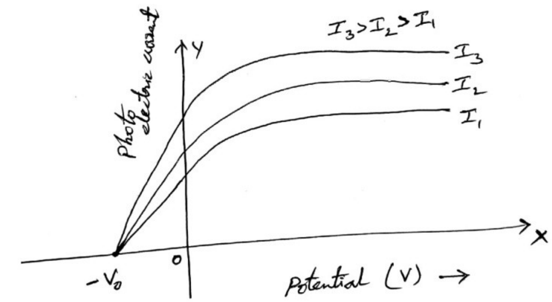




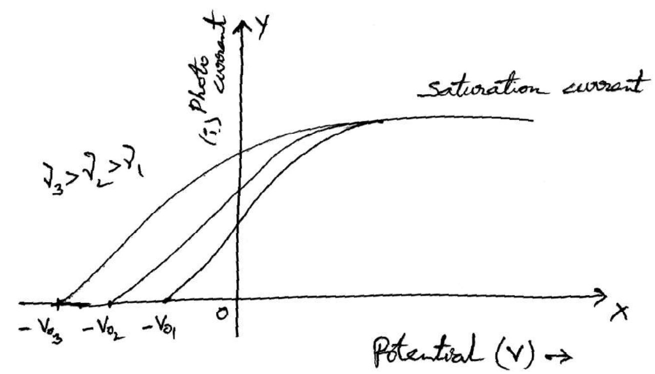
Stopping potential is independent of intensity of incident radiation
Saturation current is proportional to the intensity of incident radiation

The frequency of incident radiation (ν)

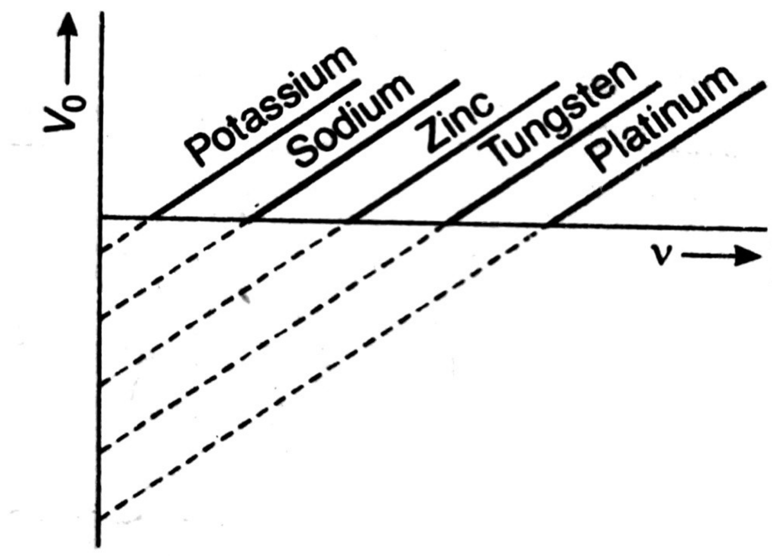




Minimum frequency required just to liberate electrons from the metal surface is called threshold frequency and the minimum energy required is called work function



Nature of photo metal used:



Work function is different for different metals

Fundamental laws of Photo-electric Emission:

- Photoelectric current is proportional to the intensity of incident radiation
- The minimum energy required just to liberate the electron from the metal surface is called work function
- The minimum frequency required just to liberate the electron form the photo metal is known as threshold frequency and the corresponding wavelength as threshold wavelength

- Maximum velocity or kinetic energy of the electron depends upon frequency of incident radiation
- Photo current independent of its temperature
- Stopping potential is directly proportional to frequency but independent of the intensity of incident radiation
- There is a time lag between the incident radiations and the emission of electrons, is less than 10^{-8} sec

EINSTEIN'S PHOTO-ELECTRIC EQUATION

Einstein's Photo-Electric Equation

1. A part of energy is utilized just to liberate the electron from the metal surface – **Work function = W_0**

2. The other part is used in giving kinetic energy to the electron

$$\frac{1}{2}mv^2$$

$$h\nu = W_0 + \frac{1}{2}mv^2 \longrightarrow (1)$$

Here $W_0 = h\nu_0$ $\quad$ ν_0 – threshold frequency

$$\therefore\ h\nu = h\nu_0 + \frac{1}{2}mv^2$$

$$\Rightarrow\ \frac{1}{2}mv^2 = h\nu - h\nu_0 = h[\nu - \nu_0] \rightarrow (2)$$

$$\boxed{v^2 \propto \nu}$$

Work done = Potententail × charge

$$\frac{1}{2}mv^2 = V_0 e$$ Work-Energy theorem

∴ Eqn (2) becomes

$$V_0 e = h\nu - h\nu_0$$

∴ Eqn ② becomes

$$V_0 e = h\nu - h\nu_0$$

$$\Rightarrow V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0$$

$$y = mx - c$$

$$m = \text{slope} = \frac{h}{e}$$

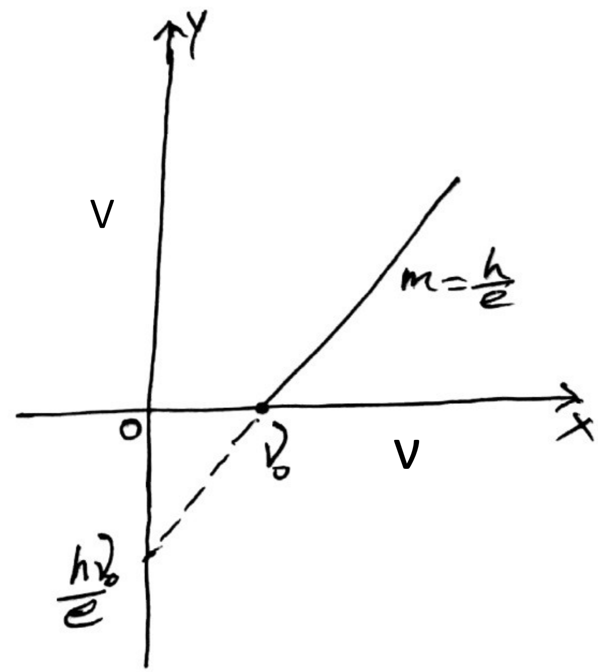


PHOTO-ELECTRIC EFFECT

NUMERICAL

A monochromatic source of light operating at 400W emits 8×10^{20} photons per sec. Find the wavelength of the light.

Given

Power $P = 400\ W$

Number of photons per sec $n = 8 \times 10^{20}$ /sec

$\lambda = ?$

$$E = h\nu = \frac{hc}{\lambda}$$

$$\Rightarrow \lambda = \frac{hc}{E}$$

$$P = nh\nu = nE$$

$$\Rightarrow E = \frac{P}{n}$$

Energy of each photon $E = \frac{400}{8 \times 10^{20}}$

$= 5 \times 10^{-19}\ J$

$\therefore$ Wavelength $\lambda = \dfrac{hc}{E}$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5 \times 10^{-19}}$$

$$= 4 \times 10^{-34+8+19}$$

$$= 4 \times 10^{-7} \, m$$

$$= 4000 \times 10^{-10} \, m \quad = \underline{\underline{4000 \, A^{\circ}}}$$

A monochromatic source of light operating at 200W emits 2×10^{20} photons per sec. Find the wavelength of the light.

Given

Power $P = 200W$

Number of photons per sec $n = 2 \times 10^{20}$ /sec

$\lambda = ?$

$$E = \frac{P}{n} = \frac{200}{2 \times 10^{20}} = 1 \times 10^{-18} J$$

$$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1 \times 10^{-18}}$$

$$= 20 \times 10^{-34+8+18}$$

$$= 20 \times 10^{-8}\ m$$

$$= 200 \times 10^{-9}\ m$$

$$= 200\,nm$$

What is the minimum frequency of light to get photo current from a metal surface having work function 2.2 eV?

Given

Work function $W_0 = 2.2\,eV$

$= 2.2 \times 1.6 \times 10^{-19}\,V$

$W_0 = h\nu_0$

$\Rightarrow \nu_0 = \frac{W_0}{h}$

$W_0 = h\nu_0$

$\Rightarrow \nu_0 = \frac{W_0}{h} = \frac{2.2 \times 1.6 \times 10^{-19}}{6.625 \times 10^{-34}} = \frac{3.52}{6.625} \times 10^{-19+34}$

$= 0.53 \times 10^{15}\,Hz$

$= 5.3 \times 10^{14}\,Hz$

What is the maximum wavelength of light to get photo current from a metal surface having work function 2.5 eV?

Given

Work function $W_0 = 2.5 \text{ eV} = 2.5 \times 1.6 \times 10^{-19} \text{ V}$

$\lambda_0 = ?$

$$W_0 = h\nu_0 = \frac{hc}{\lambda_0}$$

$$\Rightarrow \lambda_0 = \frac{hc}{W_0}$$

$$\Rightarrow \lambda_0 = \frac{hc}{W_0}$$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{2.5 \times 1.6 \times 10^{-19}}$$

$$= \frac{20}{4} \times 10^{-34+8+19}$$

$$= 5 \times 10^{-7} \text{ m}$$

$$= 5000 \times 10^{-10} \text{ m} = 5000 \text{ A}^{\circ}$$

The photo electric work function of Potassium is 2.3 eV. If light having a wavelength of 3100 A^0 falls on Potassium, find

a) kinetic energy in eV of the most energetic electrons emitted

b) the stopping potential in volts

$$E = \frac{hc}{\lambda}$$

Given

Work function $W_0 = 2.3\ eV$

$$K_{max} = E - W_0$$

Wavelength $\lambda = 3100\ A^\circ$

$$\text{in eV} = \frac{E}{e} = \frac{hc}{\lambda e} = \frac{12400}{\lambda \text{ in } A^\circ}$$

$$\therefore E = \frac{12400}{3100} \text{ eV} = 4 \text{ eV}$$

(a) $\therefore K_{max} = 4 - 2.3 = 1.7 \text{ eV}$

(b) $K_{max} = eV_0$

$1.7 \cancel{e}V = \cancel{e}V_0$

$\therefore \underline{V_0 = 1.7 \text{ volt}}$

The photo electric work function of Potassium is 2.4 eV. If light having a wavelength of 2800 A^0 falls on Potassium, find

a) kinetic energy in eV of the most energetic electrons emitted

b) the stopping potential in volts

Given

Work function $W_0 = 2.4 eV$

Wavelength $\lambda = 2800 \mathring{A}$

$$E = \frac{12400}{\lambda} = \frac{12400}{2800} \simeq 4.4 eV$$

(a) $\therefore K_{max} = E - W_0 = 4.4 - 2.4 = 2 eV$

(8) $K_{max} = V_0 e$

$2 eV = V_0 e$

$\therefore V_0 = 2$ volt

PHOTOELECTRIC EFFECT

CONCEPTUAL QUESTIONS

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Can X–rays cause the photoelectric effect?

YES

Reason: **X – rays frequency is very high (more than UV rays). So X–ray photons can pick out electrons from any metal surface.**

Is photoelectric emission possible at all frequencies? Give reason.

No

Reason: If the frequency is less than threshold frequency, photoelectric effect cannot occur.

Work function of a metal is 4.5 eV. If a photons of energy 3.1 eV is incident on its surface, will the emission of electrons takes place? Justify your answer.

No

Reason: **Work function is the minimum energy required to liberate the electron from the metal surface. So, with less than work function of energy electron cannot come out of the metal surface.**

Work function of aluminum is 4.2 eV. If two photons each of energy 2.5 eV are incident on its surface, will the emission of electrons takes place? Justify your answer.

No

Reason: **At an instant an electron absorb only one photon. Here out of two photons, electron can take only one photon of energy i.e. 2.5 eV which is less than the work function of the metal. So, emission of electrons cannot take place.**

Out of microwaves, light with wavelength 4400 A^0, radio waves, ultraviolet rays and infra-red rays, which radiation will be most affective for emission of electrons form a metal surface.

Ultraviolet

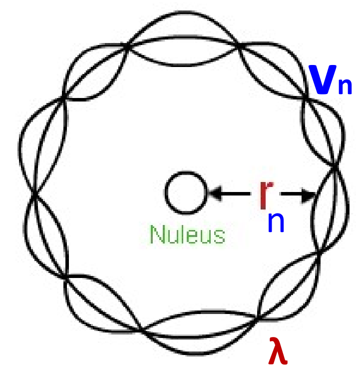
Reason: **Ultraviolet rays have high frequency among the given waves. So affective emission takes place with UV rays.**

DE-BROGLIE COMMENT ON BOHR THEORY

de-Broglie comment on Bohr Theory:

Circumference of the orbit $= 2\pi r_n$

For a possible orbit, $2\pi r_n = n\lambda$



According to de-Broglie wavelength, $\lambda = \dfrac{h}{mv_n}$

v_n - is speed of electron in n^{th} orbit.

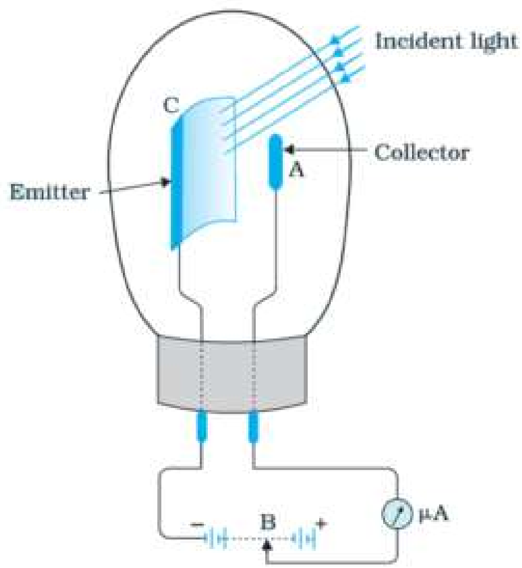
$$\therefore \quad 2\pi r_n = n \cdot \frac{h}{m v_n}$$

$$\Rightarrow \boxed{m v_n r_n = n \frac{h}{2\pi}}$$

Angular momentum of the electron revolving around the nucleus quantised

Photo Cell – Photo-electric Effect

Photo cell converts light energy into electrical energy.



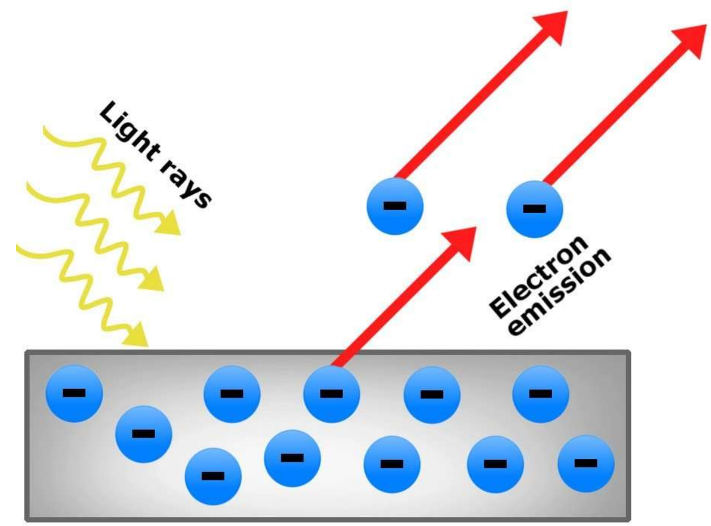


Image source: https://thefactfactor.com/ and https://www.tes.com/

A material particle in motion exhibits wavelike characteristics and the associated wave is called a **matter wave** or a **de Broglie wave.**

If m is the mass of a particle travelling with a speed v, the de Broglie wavelength λ of the wave associated with the particle, is given by $\lambda = \frac{h}{mv}$. It is independent of charge (if any) on the particle.

Expression for λ

- $\lambda_{\text{de Broglie}} = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE_k}}$, E_k = kinetic energy of the particle
- $\lambda_{\text{de Broglie}} = \frac{h}{\sqrt{2meV}}$, V = accelerating potential applied to the charged particle
- $\lambda_{\text{electron}} \simeq \sqrt{\frac{150}{V}}\ \text{Å} \simeq \frac{12.27}{\sqrt{V}}\ \text{Å} \simeq \frac{1.23}{\sqrt{V}}\,\text{nm}$ (V = accelerating potential)

The de Broglie wavelength λ associated with an electron is $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

Wave Nature of Matter

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

1. If the rest mass of a particle is m_0, its *de Broglie* wavelength is given by

$$\lambda = \frac{h\left(1 - \frac{v^2}{c^2}\right)^{1/2}}{m_0 v}$$

2. In terms of kinetic energy K, *de Broglie* wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mK}}$$

3. If a particle of charge q is accelerated through a potential difference V, its de Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

For an electron,

$$\lambda = \left(\frac{150}{V}\right)^{1/2} \text{Å}$$

4. For a gas molecule of mass m at temperature T kelvin, the *de Broglie* wavelength is given by

$$\lambda = \frac{h}{\sqrt{3mkT}}$$

where k is the Boltzmann constant.