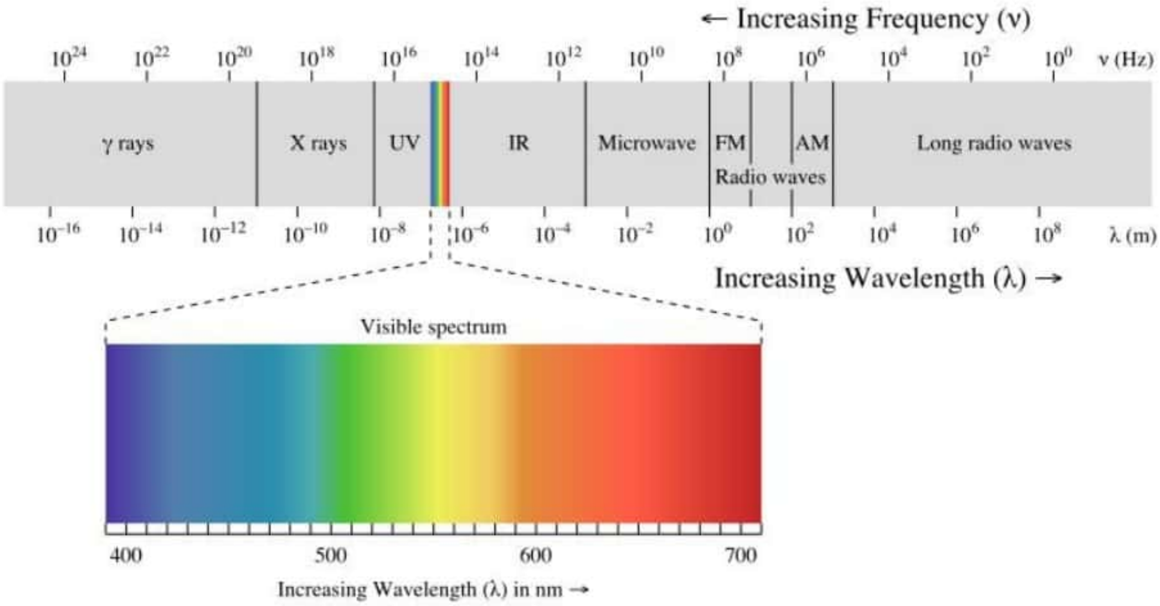
The electromagnetic spectrum

Electromagnetic waves can be classified and arranged according to their various wavelengths/frequencies; this classification is known as the electromagnetic spectrum. The following table shows us this spectrum, which consists of all the types of electromagnetic radiation that exist in our universe.



As we can see, the visible spectrum—that is, light that we can see with our eyes—makes up only a small fraction of the different types of radiation that exist. To the right of the visible spectrum, we find the types of energy that are lower in frequency (and thus longer in wavelength) than visible light. These types of energy include infrared (IR) rays (heat waves given off by thermal bodies), microwaves, and radio waves.

To the left of the visible spectrum, we have ultraviolet (UV) rays, X-rays, and gamma rays. These types of radiation are harmful to living organisms, due to their extremely high frequencies (and thus, high energies).

Radio and microwaves are used in radio and TV communication,

Infrared rays are used to
(i) Treat muscular straw.
(ii) For taking photographs' in fog or smoke.
(iii) In green house to keep plants warm.
(iv) In weather forecasting through infrared photography.

Ultraviolet rays are used
(i) In the study of molecular structure.
(ii) In sterilizing the surgical instruments.
(iii) In the detection of forged documents, £ringer prints.

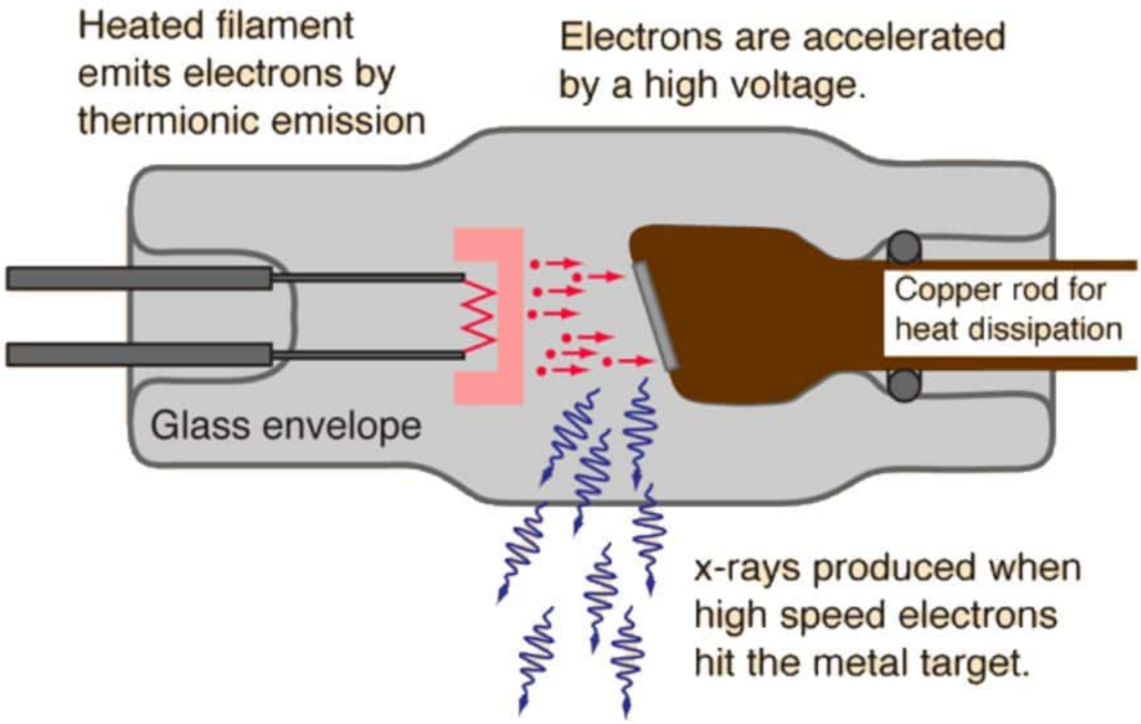
X-rays are used
(i) In detecting faults, cracks, flaws and holes in metal products.
(ii) In the study of crystal structure.
(iii) For the detection of pearls in oysters.

γ – rays are used for the study of nuclear structure. Gamma rays, being the highest in frequency and energy, are the most damaging. Luckily though, our atmosphere absorbs gamma rays from outer space, thereby protecting us from harm.

X-Rays

We can define X-Rays or X-radiation as a *form of electromagnetic radiation*. They are powerful waves of electromagnetic energy. Most of them have a wavelength ranging from 0.01 to 10 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz and energies in the range 100 eV to 100 keV. X-rays were discovered accidentally by German scientist Rontgen in 1895. The first Nobel Prize was awarded to Rontgen in 1901. This highly penetrating electromagnetic radiation has proved to be a very powerful tool to study the crystal structure, in material research, in the radiography of metals and in medical sciences.

They are produced when high-velocity electrons collide with the metal plates, thereby giving the energy as the X-Rays and themselves absorbed by the metal plate.



X-rays are produced when the electrons are suddenly decelerated upon collision with the metal target; these x-rays are commonly called brehmsstrahlung or "braking radiation". If the bombarding electrons have sufficient energy, they can knock an electron out of an inner shell of the target metal atoms. Then electrons from higher states drop down to fill the vacancy, emitting x-ray photons with precise energies determined by the electron energy levels. These x-rays are called characteristic x-rays.

Working of X-Rays

X-rays are basically a type of radiations. They are also sources of energy like light but are slightly different in nature. Light has lower frequency than the x-rays and while it is absorbed by the skin, x-rays have higher frequency and pass through the human body. As the radiations of x-rays pass through the body, the energy particles called photons are absorbed at different rates. This whole pattern is depicted on x-ray images. The skin appears as transparent and so is not visible in the images. The dense parts like bones appear as white areas in the image whereas the softer parts like the heart and lungs are visible as darker areas.

Properties of X-Rays

- X-rays are electromagnetic waves with wavelength range 0.1Å to 100 Å
- X-rays are invisible.
- X-rays carry no charge, so they are not deflected by electric and magnetic fields.
- They travel in straight line with speed 3xl08ms_1 through vacuum.
- They obey phenomenon of interference, diffraction and polarisation of light.
- They ionise gases.
- They affect photographic plate.
- They can pass through flesh and blood but not through bones.
- They produce photoelectric effect and compton effect.
- They are not used in RADAR as they are not reflected by the target. .
- Rays can be used to detect diseases and to cure them.

Types of X-Rays

X-rays are classified into two types on the basis of penetrating power

Soft X-rays

- These types of X-rays produced when the potential difference across the cathode and target is less than 20000 V.
- They have low penetrating power.
- These are used in the field of medicine.
- These are having large wavelengths.

Hard X-rays

- These types of X-rays produced when the potential difference across the cathode and target is more than 30000 V.
- These rays are more penetrating than soft X-rays.
- They have low wavelength of the order of 1 Å
- These are used in the field of science and industry.
- These are having low wavelengths.

The photon

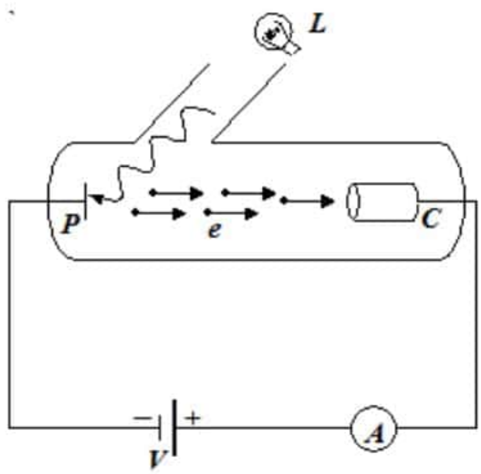
Planck's discoveries paved the way for the discovery of the photon. A photon is the elementary particle, or quantum, of light. As we will soon see, photons can be absorbed or emitted by atoms and molecules. When a photon is absorbed, its energy is transferred to that atom or molecule. Because energy is quantized, the photon's entire energy is transferred (remember that we cannot transfer fractions of quanta, which are the smallest possible individual "energy packets"). The reverse of this process is also true. When an atom or molecule loses energy, it emits a photon that carries an energy exactly equal to the loss in energy of the atom or molecule. This change in energy is directly proportional to the frequency of photon emitted or absorbed. This relationship is given by Planck's famous equation:

$$E=h\nu$$

Where, E is the energy of the photon absorbed or emitted (given in Joules, J), ν is frequency of the photon (given in Hertz, Hz), and *h* is Planck's constant, 6.626×10^{-34} Js

Photoelectric effect

The photoelectric effect is the process that involves the ejection or release of electrons from the surface of materials (generally a metal) when light falls on them. The emitted electrons are called as ***photoelectrons.*** The photoelectric effect is an important concept that enables us to clearly understand the quantum nature of light and electrons.



After continuous research in this field, the explanation for the photoelectric effect was successfully explained by Albert Einstein. He concluded that this effect occurred as a result of light energy being carried in discrete quantized packets. For this excellent work, he was honored with the Nobel Prize in 1921.

According to Einstein, each photon of energy E is

$E = h\nu$

Where E = Energy of photon in joule

h = planks constant (6.626×10^{-34} J.s)

ν = frequency of photon in Hz

Principle of Photoelectric Effect

The law of conservation of energy forms the basis for the photoelectric effect.

Minimum Condition for Photoelectric Effect

Threshold Frequency (γ_{th})

It is the minimum frequency of the incident light or radiation that will produce a photoelectric effect i.e. ejection of photoelectrons from a metal surface is known as threshold frequency for the metal. It is constant for a specific metal but may be different for different metals.

If γ = frequency of incident photon and γ_{th}= threshold frequency, then,

- If $\gamma < \gamma_{Th}$, there will be no ejection of photoelectron and, therefore, no photoelectric effect.
- If $\gamma = \gamma_{Th}$, photoelectrons are just ejected from the metal surface, in this case, the kinetic energy of the electron is zero
- If $\gamma > \gamma_{Th}$, then photoelectrons will come out of the surface along with kinetic energy

Threshold Wavelength (λ_{th})

During the emission of electrons, a metal surface corresponding to the greatest wavelength to incident light is known threshold wavelength.

$\lambda_{th} = c/\gamma_{th}$

For wavelengths above this threshold, there will be no photoelectron emission. For λ = wavelength of the incident photon, then

- If $\lambda < \lambda_{Th}$, then the photoelectric effect will take place and ejected electron will possess kinetic energy.
- If $\lambda = \lambda_{Th}$, then just photoelectric effect will take place and kinetic energy of ejected photoelectron will be zero.
- If $\lambda > \lambda_{Th}$, there will be no photoelectric effect.

Work Function or Threshold Energy (Φ)

The minimal energy of thermodynamic work that is needed to remove an electron from a conductor to a point in the vacuum immediately outside the surface of the conductor is known as work function/threshold energy

$\Phi = h\gamma_{th} = hc/\lambda_{th}$

The work function is the characteristic of a given metal. If E = energy of an incident photon, then

1. If $E < \Phi$, no photoelectric effect will take place.
2. If $E = \Phi$, just photoelectric effect will take place but the kinetic energy of ejected photoelectron will be zero
3. If E > photoelectron will be zero
4. If $E > \Phi$, the photoelectric effect will take place along with possession of the kinetic energy by the ejected electron.

Photoelectric Effect Formula

According to the Einstein explanation of the photoelectric effect is:

The energy of photon = energy needed to remove an electron + kinetic energy of the emitted electron

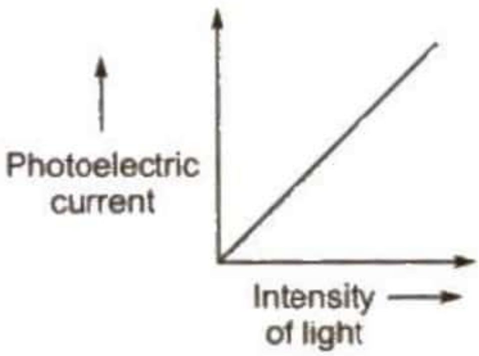
i.e. $h\nu = W + E$

Where,

- h is Planck's constant.
- ν is the frequency of the incident photon.
- W is a work function.
- E is the maximum kinetic energy of ejected electrons: $1/2\ mv^2$.

Laws of Photoelectric Effect

1. For a given metal and frequency of incident light, the photo electric current (the rate of emission of photoelectrons) is directly proportional to the intensity of incident light.



2. For a given metal, there is a certain minimum frequency, called **threshold frequency**, below which there is no emission of photo electrons takes place.

3. Above threshold frequency the maximum kinetic energy of photo electrons depends upon the frequency of incident light.

4. The photoelectric emission is an instantaneous process.

Einstein's Photoelectric Equation

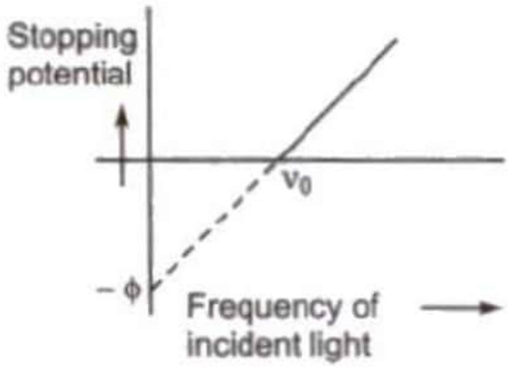
The maximum kinetic energy of photoelectrons

$(E_k)_{max} = h\nu - \varphi = h(\nu - \nu_o)$

Where, ν is frequency of incident light and ν_o is threshold frequency.

Stopping Potential

The minimum negative potential given to anode plate at which photoelectric current becomes zero is called stopping potential (V_0).



Maximum kinetic energy of photo electrons

$$(E_k)_{max} = 1 / 2\, mv^2_{max} = eV_0$$