- A certain minimum amount of energy is required to begiven to an electron to pull it out from the surface of the metal. Thisminimum energy required by an electron to escape from the metal surfaceis called the work function of the metal. The minimum energy required for the electron emission from the metalsurface can be supplied to the free electrons by any one of the followingphysical processes:
    - Thermionic emission: By suitably heating, sufficient thermal energy can be imparted to the free electrons to enable them to come out of themetal.
    - Field emission: By applying a very strong electric field (of the order of 10^8 V m^{-1}) to a metal, electrons can be pulled out of the metal, as in aspark plug.
    - Photo-electric emission: When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface. Thesephoto(light)-generated electrons are called photoelectrons.

- Photoelectric effect is the phenomenon of emission of electrons by metalswhen illuminated by light of suitable frequency. Certain metals respondto ultraviolet light while others are sensitive even to the visible light.Photoelectric effect involves conversion of light energy into electricalenergy. It follows the law of conservation of energy. The photoelectricemission is an instantaneous process and possesses certain specialfeatures.
- Photoelectric current depends on
  (i) the intensity of incident light,the number of photoelectrons emitted per second is directly proportional to the intensity of incident radiation.
  (ii) the potential difference applied between the two electrodes,for a given frequency of the incident radiation, the stopping potential is independent of its intensity.
  (i) the nature of the emitter material.

- The stopping potential (*Vo*) depends on (i) the frequency of incidentlight, and (ii) the nature of the emitter material. For a given frequencyof incident light, it is independent of its intensity. The stopping potentialis directly related to the maximum kinetic energy of electrons emitted:
  $eV_0 = (1/2)\, mv_{max}^2 = K_{max}$

- Below a certain frequency (threshold frequency) ν_0, characteristic ofthe metal, no photoelectric emission takes place, no matter how largethe intensity may be.
- The classical wave theory could not explain the main features ofphotoelectric effect. Its picture of continuous absorption of energy fromradiation could not explain the independence of K_{max} on intensity, theexistence of νo and the instantaneous nature of the process. Einsteinexplained these features on the basis of photon picture of light.According to this, light is composed of discrete packets of energy calledquanta or photons. Each photon carries an energy E (= h ν) andmomentum p (= h/λ), which depend on the frequency (ν) of incidentlight and not on its intensity. Photoelectric emission from the metalsurface occurs due to absorption of a photon by an electron.
- Einstein's photoelectric equation is in accordance with the energyconservation law as applied to the photon absorption by an electron inthe metal. The maximum kinetic energy (1/2)m v2is equal tothe photon energy (hν) minus the work function ϕ0 (= hν0) of thetarget metal:

$V_0e = h\nu - \phi_0 = h(\nu - \nu_0)$

This photoelectric equation explains all the features of the photoelectriceffect. Millikan's first precise measurements confirmed the Einstein'sphotoelectric equation and obtained an accurate value of Planck's constant *h*. This led to the acceptance of particle or photon description(nature) of electromagnetic radiation, introduced by Einstein.

- Radiation has dual nature: wave and particle. The nature of experimentdetermines whether a wave or particle description is best suited forunderstanding the experimental result. Reasoning that radiation andmatter should be symmetrical in nature, Louis Victor de Broglieattributed a wave-like character to matter (material particles). The wavesassociated with the moving material particles are called matter wavesor de Broglie waves.

- **PARTICLE NATURE OF LIGHT: THE PHOTON**
    - In interaction of radiation with matter, radiation behaves as if it ismade up of particles called photons.
    - Each photon has energy E (=hν) and momentum p (= h ν/c), andspeed c, the speed of light.
    - All photons of light of a particular frequency ν, or wavelength λ, havethe same energy E (=hν = hc/λ) and momentum p (= hν/c = h/λ),whatever the intensity of radiation may be. By increasing the intensityof light of given wavelength, there is only an increase in the number ofphotons per second crossing a given area, with

each photon havingthe same energy. Thus, photon energy is independent of intensity ofradiation.

- Photons are electrically neutral and are not deflected by electric andmagnetic fields.

- In a photon-particle collision (such as photon-electron collision), thetotal energy and total momentum are conserved. However, the number of photons may not be conserved in a collision. The photon may beabsorbed or a new photon may be created.

- **WAVE NATURE OF MATTER**

The de Broglie wavelength (λ) associated with a moving particle is relatedto its momentum p as: $\lambda = h/p$. The dualism of matter is inherent in thede Broglie relation which contains a wave concept (λ) and a particle concept (p). The de Broglie wavelength is independent of the charge and nature ofthe material particle. It is significant

measurable (of the order of theatomic-planes spacing in crystals) only in case of sub-atomic particleslike electrons, protons, etc. (due to smallness of their masses and hence,momenta). However, it is indeed very small, quite beyond measurement,in case of macroscopic objects, commonly encountered in everyday life.

The matter–wave picture elegantly incorporated the **Heisenberg's uncertainty principle**. According to the principle, it is not possible to measure both the position and momentum of an electron (or any other particle) at the same time exactly. There is always some uncertainty (Δx) in the specification of position and some uncertainty (Δp) in the specification of momentum.

- Electron diffraction experiments by Davisson and Germer, and by G. P.Thomson, as well as many later experiments, have verified and confirmedthe wave-nature of electrons. The de Broglie hypothesis of matter wavessupports the Bohr's concept of stationary orbits.