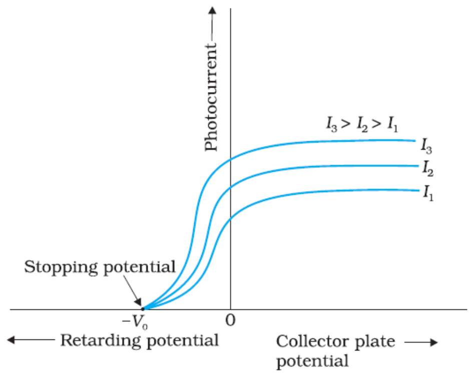
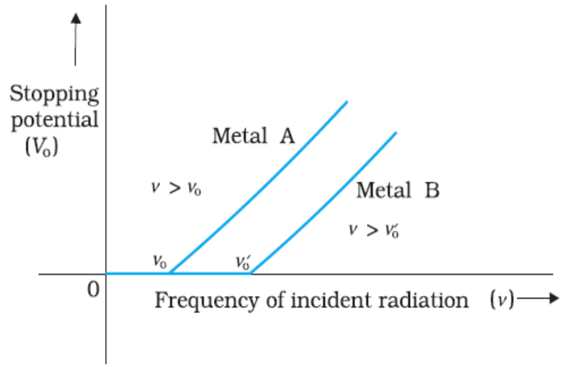
11. DUAL NATURE OF RADIATION AND MATTER

Very short answer and short answer questions

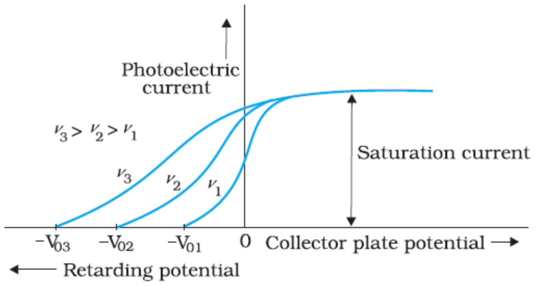
1. **Define work function of a metal?**
   The minimum energy required for an electron to escape from the metal surface is called the work function of the metal
2. **Define 1eV**
   1eV is the energy gained by an electron when it is accelerated through a potential difference of one volt.
3. **Define thermionic emission?**
   Emission of electron from a metal surface when it is heated to sufficiently high temperature is called thermionic emission.
4. **Define field emission?**
   Emission of electron from metal surface when it is subjected to high electric field (of the order of 10^8V) is called field emission.
5. **Define photoelectric emission?**
   Emission of electrons from metal surface, when it is illuminated with light of suitable frequency is called photoelectric effect.
6. **Who discovered photoelectric effect?**
   Henrich Hertz discovered photoelectric effect.
7. **Define threshold frequency of a metal?**
   Threshold frequency of a metal is the minimum cut-off frequency of incident light below which no photoelectric emission takes place irrespective of intensity of incident light.
8. **How photo electric current depends on intensity of incident light?**
   Above threshold frequency, photoelectric current is directly proportional to intensity of incident light.
9. **What do you mean by saturation current?**
   As the potential of collector is increased for a radiation of certain high frequency and intensity, photoelectric current increases and reaches to a maximum constant value. This constant current is called saturation current.
10. **Define stopping potential of a given photosensitive metal?**
    Stopping potential of a photosensitive metal is defined as the minimum negative potential applied to the collector at which the photoelectric current just drops zero.
11. **Give the mathematical relation between stopping potential and maximum kinetic energy of photoelectron.**
    $K_{\max} = eV_o$
    $K_{\max} = \max imum\, kinetic\, energy$
    $e = Ch\arg e\, of\ electron$
    $V_o = Magnitude\, of\ stopping\ potential$
12. **Give the graphical representation of the variation of photoelectric current with collector plate potential.**



13. Represent the variation of stopping potential with frequency of incident light graphically.



14. **Give the graphical representation of effect of frequency of incident radiation on stopping potential** .



15. Define quanta?

Radiation energy is made up of discrete unit of energy called quanta.

16. What is a de-Broglie wave?

A wave associated with moving particle is called de-Broglie wave.

17. What is the experimental outcome of Davisson and Germer experiment?

Davisson and Germer provided experimental proof for the wave nature of matter particle and verified the de-Broglie's expression for wavelength of matter wave.

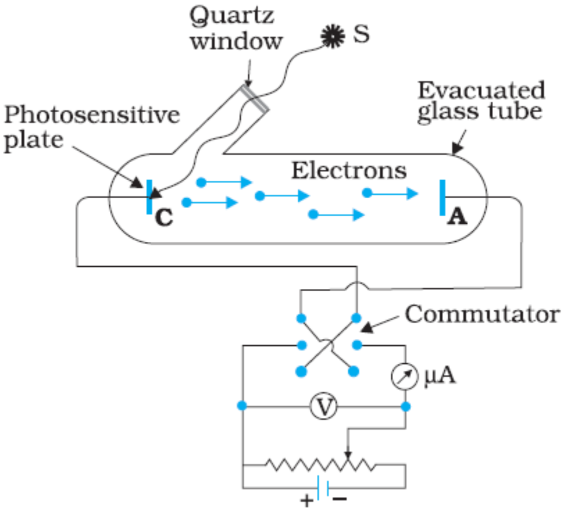
18. What happens to the kinetic energy of photoelectrons if the intensity of incident radiation is increased?

Kinetic energy remains same as kinetic energy is independent of intensity of incident radiation

19. **Why sufficiently powerful AM radio signal cannot produce photoelectric effect?**

The energy of radio photon is less than the work function of any metal so even sufficiently powerful AM radio signal cannot produce photoelectric effect.

20. Give the labeled schematic representation of experimental arrangement for the study of photoelectric effect.



21. Name the factors on which maximum kinetic energy of photoelectrons depends.

Maximum kinetic energy of photoelectrons depends on the nature of the emitter and the frequency of incident radiation.

22. Give the Einstein's photoelectric equation and explain the terms.

Einstein's photoelectric equation is given by

$$K_{\max} = h\nu - \phi_o$$

$$where \ \ K_{\max} = Maximum\, kinetic\, energy$$

$$\phi_o = Work \ \ function$$

$$h = plank's\, constant$$

$$\nu = Frequency\, of \ \ incident\, radiation$$

23. What is the threshold frequency of a photon for photoelectric emission from a metal of work function 1eV

$$Threshold \ \ frequency = \frac{\phi_o}{h} = \frac{1x1.6x10^{-19}}{6.625x10^{-34}} = 2.41x10^{14}\, Hz$$

24. Why the photoelectrons emitted from a metal surface for a certain radiation have different energies even if work function of metal is a constant?

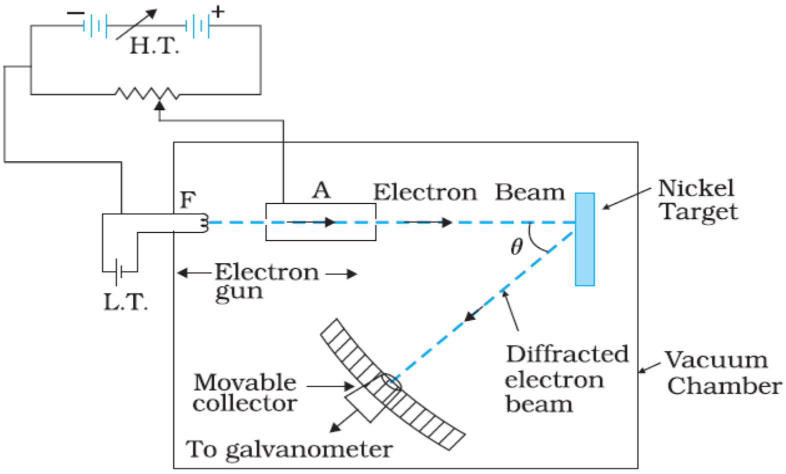
Work function is the minimum energy required for the electron in the highest level of the conduction band to get out of the metal. Not all electrons in the metal belong to this level. They occupy a continuous band of levels. Consequently, for the same incident radiation, electrons knocked off from different levels come out with different energies.

25. What is the significance of the slope of graph of stopping potential of an emitter verses frequency of incident radiation?

The slope of graph of stopping potential of an emitter verses frequency of incident radiation is observed to be a constant.

The value of slope is measured to be h/e which is independent of nature of emitter. Millikan calculated the value of h with the help of experimental value of slope and known value of e. The calculated value observed to be matching with Plank's constant exactly.

26. Draw labeled schematics diagram to show the experimental arrangement of Davisson and Germer experiment.



27. Mention the relation for de-Broglie wavelength.

According to de-Broglie theory, wavelength of matter wave associated with particle of momentum p (p=mv) is given by

$$\lambda = \frac{h}{p} \text{..................(2)}$$

28. Give the relationship between the accelerating potential and the de-Broglie wavelength associated with a charged particle.

de-Broglie wavelength associated with a charged particle is given $\lambda = \frac{h}{\sqrt{2mqV}}$

Where

q=charge of the particle

V=potential through particle is accelerated

m=mass of the particle

__Long answer questions__

1. **Explain Hallwachs' and Lenard's experimental observations.**

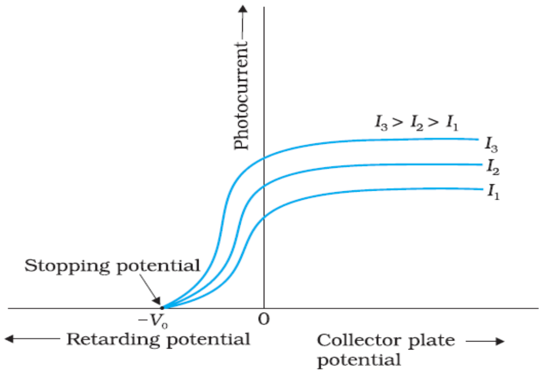
Wilhelm Hallwachs and Philipp Lenard conducted a detailed study of the phenomenon of photoelectric emission.

Lenard observed that when ultraviolet radiations were allowed to fall on the emitter plate of an evacuated glass tube enclosing two electrodes (metal plates), current flows in the circuit. As soon as the ultraviolet radiation is stopped, the current flow also stops. Thus, light falling on the surface of the emitter causes current in the external circuit.

Hallwachs observed that the uncharged zinc plate became positively charged when it is irradiated by ultraviolet light. Also positive charge on a positively charged zinc plate gets enhanced when it is illuminated by ultraviolet light. From the experimental observations he concluded that zinc plate emits negatively charged particles under the action of ultraviolet light.

2. **Explain the effect of photoelectric current with collector plate potential**

   Photoelectric current increases with increase in accelerating (positive) potential.
   At some stage, for a certain positive potential of plate A, the photoelectric current becomes maximum or saturates. If potential of plate A is further increased, the photocurrent remains same. This maximum value of the photoelectric current is called *saturation current.*



   When the potential of the collector plate is made more and more negative (retarding) with respect to the plate emitter, the electrons are repelled and only the most energetic electrons reach the collector.

   The photocurrent decreases rapidly until it drops to zero at a certain sharply defined, critical value of the negative potential V_0 .
   For a particular frequency of incident radiation, *the minimum negative (retarding) potential V_0 given to the collector plate for which the photoelectrons are completely stopped from reaching collector or photocurrent becomes zero is called the cut-off or stopping potential*.

3. **Mention the experimental observations of photoelectric effect.**
   (i) For a given photosensitive material and frequency of incident radiation(above the threshold frequency), the photoelectric current is directly proportional to the intensity of incident light .
   (ii) For a given photosensitive material and frequency of incident radiation, saturation current is found to be proportional to the intensity of incident radiation whereas the stopping potential is independent of its intensity.
   (iii) For a given photosensitive material, there exists a certain minimum cut-off frequency of the incident radiation, called the *threshold frequency*, below which no emission of photoelectrons takes place, no matter how intense the incident light is. Above the threshold v frequency, the stopping potential and the maximum kinetic energy of the emitted photoelectrons increases linearly with the frequency of the incident radiation, but is independent of its intensity.
   (iv) The photoelectric emission is an instantaneous process, irrespective of intensity of the incident radiation.

4. **Explain the experimental observations with the help of Einstein's photoelectric equation.**
   a) According to Einstein's theory, the basic elementary process involved in photoelectric effect is the absorption of a light quantum by an electron. This process is instantaneous. Thus, irrespective of the intensity, photoelectric emission is instantaneous.
   b) According to Einstein's equation, $K_{\max} = h\nu - \phi_o$ $K_{\max}$ depends linearly on ν as ϕ_o is a constant for a given metal. Also $K_{\max}$ is independent of intensity of radiation. Above concepts are in good agreement with the experimental observation. This is due to the fact that according to Einstein's theory, photoelectric effect arises from the absorption of a single quantum of radiation by a single electron..
   c) $K_{\max}$ is always non-negative,
      $\Rightarrow$ Photoelectric emission is possible only if

$$h\nu > \phi_o$$

$$\nu > \nu_o \text{ where } \nu_o = \frac{\phi_o}{h}$$

      Thus, there exists a threshold frequency for the metal surface, below which no photoelectric emission possible, no matter how intense the incident radiation may be or how long it falls on the surface.
   d) Intensity of radiation is proportional to the number of energy quanta per unit area per unit time. The greater the number of energy quanta available, the greater is the number of electrons absorbing the

energy. Hence the number of electrons coming out of the metal is also higher. This explains why, for $\nu > \nu_o$, photoelectric current is proportional to intensity.

5. **Give the characteristics of photon.**

(i) In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.

(ii) Each photon has energy $E = h\nu$ where ν is the frequency, momentum $p = \frac{h\nu}{c}$ where *c is* the speed of light.

(iii) All photons of light of a particular frequency ν, or wavelength λ, have the same energy and momentum, whatever the intensity of radiation may be. By increasing the intensity of light of given wavelength, there is only an increase in the number of photons per second crossing a given area, with each photon having the same energy. Thus, photon energy is independent of intensity of radiation.

(iv) Photons are electrically neutral and are not deflected by electric and magnetic fields.

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

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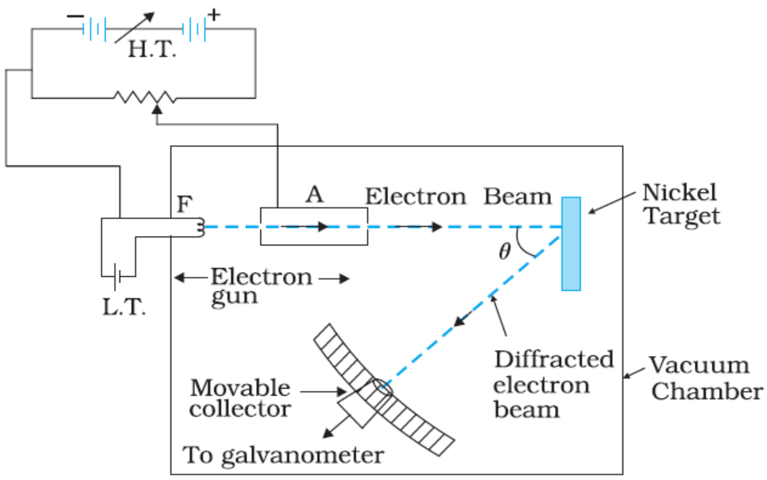
6. **Explain Davisson and Germer experiment.**



The experiment is performed by varying the accelerating voltage from 44 V to 68 V.

A strong peak observed in the intensity (*I*) of the scattered electron for an accelerating voltage of 54V at a scattering angle $\theta = 50^o$

The appearance of the peak in a particular direction is due to the constructive interference of electrons scattered from different layers of the regularly spaced atoms of the crystals.

From the electron diffraction theory, the wavelength of matter waves producing maxima at $\theta = 50^o$ is calculated to be λ = 0.165 nm.

According to de-Broglie theory $\lambda = \frac{1.227}{\sqrt{V}}$ nm

For V = 54 V

$$\lambda = \frac{1.227}{\sqrt{54}} = 0.167nm$$

Thus, there is an excellent agreement between the theoretical value and the experimentally obtained value of de Broglie wavelength. Davisson- Germer experiment thus strikingly confirms the wave nature of electrons, particles in general and the de Broglie relation.

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