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PHYSICS

BOOKS - HC VERMA PHYSICS (HINGLISH)

PHOTO ELECTRIC EFFECT AND WAVE PARTICLE DUALITY

Examples

1. Consider a parallel beam of light of wavelength 600nm and intensity 100W (m^{-2}). (a) Find the energy and linear momentum of each photon. (b) How many photons cross 1 cm^2 area perpendicular to the beam in one second?

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2. Find the maximum wavelength of light that can cause photoelectric effect in lithium.

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Example

1. A point source of monochromatic light of 1.0 mW is placed at a distance of 5.0 m from a metal surface. Light falls perpendicularly on the surface. Assume wave theory of light to hold and also that all the light falling on the circular area with radius $= 1.0 \times (10^{-9}) m$(which is few times the diameter of an atom) is absorbed by a single electron on the surface. Calculate the time required by the electron to receive sufficient energy to come out of the metal if the work function of the metal is 2.0e V.

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Worked Out Examples

1. How many photons are emitted per second by a 5m W laser source operating at 632.8nm?

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2. Light described at a place by te equation

$$E=\left(100\frac{V}{m}\right)\left[\sin\times\left(10^{15}s^{-1}t\right)+\sin\left(8\times10^{15}s^{-1}t\right)\right]$$

falls on a metal surface having work function 2.0 eV. Calculate the maximum kinetic energy of the photoelectrons.

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Work Out

1. A monochromatic source of light operating at 200W emits $4 \times (10^{20})$ photons per second. Find the wavelength of the light.

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2. A hydrogen atom moving at a speed v absorbs a photon of wavelength 122 nm and stops. Find the value of v. Mass of a hydrogen atom = ` 1.67 xx (10^-27)kg.

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3. A parallel beam of monochromatic light of wavelength 500nm is incident normally on a perfectly absorbing surface. The power through any cross- section of the beam is 10 W. Find (a) the number of photons absorbed per second by the surface and (b) the force exerted by the light beam on the surface.

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4. Figure shows a small, plane strip suspended from a fixed support through a string of length l. A continuous beam of monochromati clight is incident horizontally on the strip and is completely absorbed. The energy falling on the strip per unit time is W. (a) Find the deflection of the string from the vertical if the mirror stays in equilibrium. (b) If the strip is deflected slightly from its equilibrium position in the plane of the figure, what will be the time period of the resulting oscillations?

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5. A point source of light is placed at the centre of curvature of a hemispherical surface. The radius of curvature is r and the inner surface is completely reflecting. Find the force on the hemisphere due to the light falling on its if the source emits a power W.

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6. A perfectly reflecting solid sphere of radius r is kept in the path of a parallel beam of light of large aperture. If the beam carries an intensity I, find the force exerted by the beam on the sphere.

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7. Find the threshold wavelengths for photoelectric effect from a copper surface, a sodium surface and a cesium surface. The work functions of these metals are 4.5 e V, 2.3 eV and 1.9 eV respectively.

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8. Ultraviolet light of wavelength 280 nm is used in an experiment on photoelectric effect with lithium $(\varphi = 2.5eV)$ cathode. Find (a) the maximum kinetic energy of the photoelectrons and (b) the stopping potential.

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9. In a photoelectric experiment, it was found that the stopping potential decreases from 1.85 V to 0.82 V as the wavelength of the incident light is varied from 300nm to 400nm. Calculate the value of the Planck constant from these data.

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10. A beam of 450 nm light is incident on a metal having work function 2.0 eV and placed in a magnetic field B. The most energetic electrons emitted perpendicular to the field are bent in circular arcs of radius 20 cm. Find the value of B.

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11. A monochromatic light of wavelength λ is incident on a isolated metallic sphere of radius a. The threshol wavelength is λ_0 which is larger than λ. Find the number of photoelectrons emitted before the emission of photoelectrons will shop.

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Short Answer

1. Can we find the mass of a photon by the definition p =mv?

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2. Is it always true that for two sources of equal intensity, the number of photons emitted in a given time are equal?

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3. What is the speed of a photon with respect to another photon if (a) the two photons are going in the same direction and (b) they are going in opposite directions?

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4. Can a photon be deflected by an electric field ? By a magnetic field ?

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5. A hot body is placed in a closed room maintained at a lower temperature. Is the number of photons in the room increasing?

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6. Should the energy of a photon be called its kinetic energy or its internal energy?

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7. In an experiment on photoelectric effect, a photon is incident on an electron from one direction and the photoelectron is emitted almost in the opposite direction. Does this violate conservation of momentum ?

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8. It is found that yellow light does not eject photoelectrons from a metal. Is it advisable to try with orange light? With green light?

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9. It is found that photosynthesis starts in certain plants when exposed to the sunlight but it does not start if the plant is exposed only to infrared light. Explain.

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10. The threshold wavelength of a metal is (` lambda_0). Light of wavelength slightly less than lambda_0 is incident on an insulated plate made of this metal. It is found that photoelectrons are emitted for sometimes and after that the emission stops. Explain.

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11. Is $p = \frac{E}{c}$ valid for electrons?

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12. Consider the de Broglie wavelength of an electron and a proton. Which wavelength is smaller if the two particles have (a) the same speed (b) the same momentum (c) the same energy?

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13. If an electron has a wavelength, does it also have a colour?

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Objective 1

1. Planck constant has the same dimensions as

A. force xx time

B. force xx distance

C. force xx speed

D. force xx distance xx time.

Answer: D

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2. Two photons having

A. equal wavelengths have equal linear momenta

B. equal energies have equal linear momenta

C. equal frequencies have equal linear momenta

D. equal linear momenta have equal wavelengths.

Answer: D

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3. Let p and E denote the linear momentum and energy of a photon. If the wavelength is decreased,

A. both p and E increase

B. p increases and E decreases

C. p decreases and E increases

D. both p and E decrease.

Answer: A

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4. Let `(n_r) and (n_b) be respectively the number of photons emitted by a red bulb and a blue blub of equal power in a given time.

A. $n_r = n_b$

B. $n_r < n_b$

C. $n_r > n_b$

D. The information is insufficient to get a relation between (n_r) and (n_b).

Answer: C

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5. The equation E=pc is valid

A. for an electron as well as for a photon

B. for an electron but not for a photon

C. for a photon but not for an electron

D. neither for an electron nor for a photon.

Answer: C

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6. The work function of a metal is hv_0. Light of frequency v falls on this metal. The photoelectric effect will take place only if

A. vge(v_0)

B. vgt$(2v_0)$

C. vlt(v_0)

D. vlt$\frac{v_0}{2}$.

Answer: A

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7. Light of wavelength λ falls on metal having work functions hc/λ_0 . Photoelectric effect will take place only if :

A. $\lambda \geq (\lambda_0)$

B. $\lambda \geq 2\lambda_0$

C. $\lambda \leq \lambda_0$

D. $\lambda < \frac{\lambda_0}{2}$

Answer: C

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8. When stopping potential is applied in an experiment on photoelectric effect, no photo current is observed. This means that

A. the emission of photoelectrons is stopped

B. the photoelectrons are emitted but are re-absorbed by the emitter metal

C. the photoelectrons are accumulated near the collector plate

D. the photoelectrons are dispersed from the sides of the apparatus.

Answer: B

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9. If the frequency of light in a photoelectric experiment is doubled the stopping potential will

A. be doubled

B. be halved

C. become more than double

D. become less than double

Answer: C

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10. The frequency and intensity of a light source are both doubled. Consider the following statements

A. The saturation photocurrent remains almost the same

B. The maximum kinetic energy of the photoelectrons is double

A. Both A and B are true.

B. A is true but B is false.

C. A is false but B is true

D. Both A and B are false.

Answer: B

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11. A point source of light is used in a photoelectric effect. If the source is removed farther from the emitted metal, the stopping potential

A. will increase

B. will decrease

C. will remain constant

D. will either increase or decrease

Answer: C

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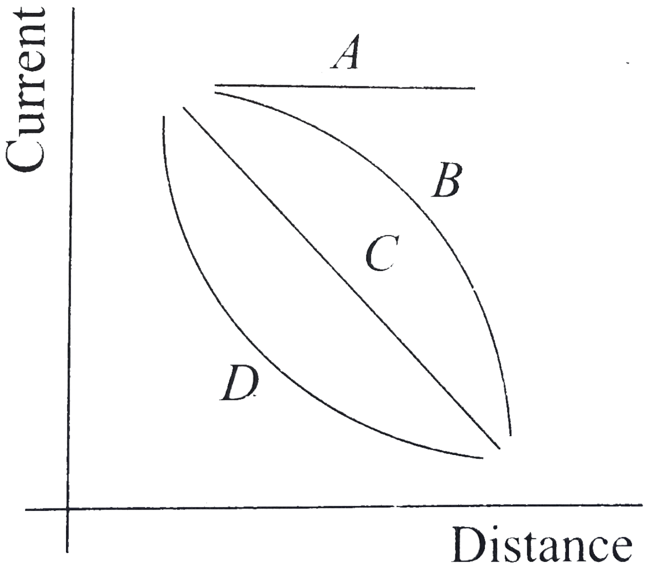
12.



A point source causes photoelectric effect from a small metal plate. Which of the curves in Fig. may represent the saturation photo-current as a function of the distance between the source and the metal?

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13. A non-monochromatic light is used in an experiment on photoelectric effect. The stopping potential

A. is related to the mean wavelength

B. is related to the longest wavelength

C. is related to the shortest wavelength

D. is not related to the wavelength

Answer: C

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14. A proton and an electron are accelerated by the same potential difference, let λ_e and λ_p denote the de-Broglie wavelengths of the electron and the proton respectively

A. $\lambda_e = \lambda_p$

B. $\lambda_e < \lambda_p$

C. $\lambda_e > \lambda_p$

D. The relation between λ_e and λ_p depends on the accelerating potential difference

Answer: C

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Objective 2

1. When the intensity of a light source is increased

(a) the number of photons emitted by the source in unit time increases

(b) the total energy of the photons emitted per unit time increases

(c) more energetic photons are emitted

(d) faster photons are emitted

A. the number of photons emitted by the source in unit time increases

B. the total energy of the photons emitted per unit time increases

C. more energetic photons are emitted

D. faster photons are emitted

Answer: A::B

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2. Photoelectric effect supports quantum nature of light because

(a) there is a minimum frequency of light below which no photo electrons are emitted

(b) the maximum kinetic energy of photo electrons depends only on the frequency of light and not on its intensity

(c) even when the metal surface is faintly illuminated, the photo electrons leave the surface immediately

(d) electric charge of the photo electrons is quantised

A. there is a minimum frequency below which no photoelectrons are emitted

B. the maximum kinetic energy of photoelectrons depends only on the frequency of light and not on its intensity

C. even when the metal surface is faintly illuminated the photoelectrons leave the surface immediately.

D. electric charge of the photoelectrons is quantized.

Answer: A::B::C

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3. A phot of energy hv is absorbed by a free electron of a metal having work function $\phi < hv$

A. the electron is sure to come out.

B. The electron is sure to come out with a kinetic energy $(hv - \varphi)$.

C. Either the electron does not come out or it comes out with a kinetic energy $(hv - \varphi)$.

D. It may come out with a kinetic energy less than $(hv - \varphi)$

Answer: D

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4. If the wavelength of light in an experiment on photoelectric effect is doubled,

(i) the photoelectric emission will not take place

(ii) the photoelectric emission may or may not take place

(iii) the stopping potential will increase

(iv) the stopping potential will decrease

A. the photoelectric emission will not take place

B. the photoelectrons emission may or may not take place

C. the stopping potential will increase

D. the stopping potential will decrease

Answer: B::D

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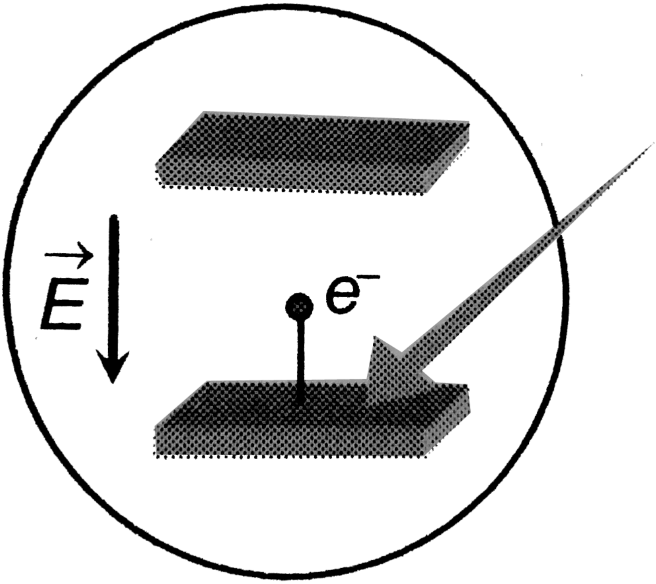
5. The collector plate in an experiment on photoelectric effect is kept vertically above the emitter plate . Light source is put on and a saturation photo current is recorded . An electric field is switched on which has a vertically downward direction . Then



A. The photocurrent will increased

B. The kinetic energy of the electrons will increase.

C. The stopping potential will decrease.

D. The threshold wavelength will increase.

Answer: A

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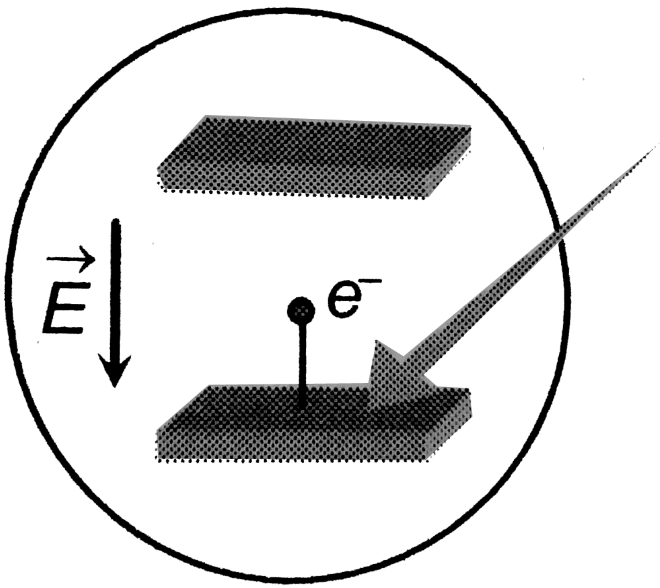
6. The collector plate in an experiment on photoelectric effect is kept vertically above the emitter plate . Light source is put on and a saturation photo current is recorded . An electric field is switched on which has a vertically downward direction . Then



A. The photocurrent will increased

B. The kinetic energy of the electrons will increase.

C. The stopping potential will decrease.

D. The threshold wavelength will increase.

Answer: B

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7. In which of the following cases the heavier of the two particles has a smaller de-Broglie wavelength ? The two particles

A. move with the same speed

B. move with the same linear momentum

C. move with the same kinetic energy

D. have fallen through the same height

Answer: A::C::D

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Exercises

1. Visible light has wavelengths in the range of 400 nm to 780nm. Calculate the range of energy of the photons of visible light.

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2. Calculate the momentum of a photon of light of wavelength 500nm .

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3. An atom absorbs a photon of wavelength 500nm and emits another photon of wavelength 700nm. Find the net energy absorbed by the atom in the process.

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4. Calculate the number of photons emitted per second by a 10 W sodium vapour lamp. Assume that 60% of the consumed energy is converted into light. Wavelengths of sodium light =590nm.

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5. When the sun is directly overhead, the surface of the earth receives $1.4 \times 10^3 Wm^{-2}$ of sunlight. Assume that the light is monochromatic with average wavelength 500mn and that no light is absorbed in between the sun and the earth's surface. The distance between the sun and the earth is 1.5×10^{11} m. (a) Calculate the number of photons falling per second on each square metre of earth's surface directly below the sun. (b) How many photons are there in each cubic metre near the earth's surface at any instant? (c) How many photons does the sun emit per second?

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6. A parallel beam of monochromatic light of wavelength 663 nm is incident on a totally reflecting plane mirror. The angle of incidence is 60° and the number of photons striking the mirror per second is $(1.0 \times (10^{19}))$. Calculate the force exerted by the light beam on the mirror.

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7. A beam of white light is incident normally on a plane surface absorbing (70%) of the light and reflecting the rest. If the incident beam carries 10 W of power , find the force exerted by it on the surface .

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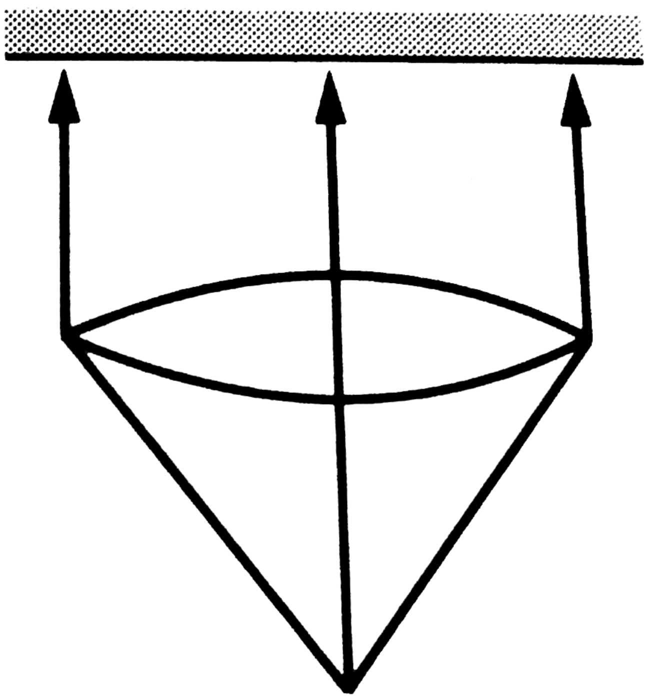
8. A totally reflecting, small plane mirror placed horizontally faces a parallel beam of lighy as shown in figure. The mass of the mirror is 20g. Assume that there is no absorption in the lens and that 30% of the light emitted by the source goes through the lens. Find the power of the source needed to support the weight of the mirror. Take ` g= 10 m s^-2.



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9. A 100 W light bulb is placed at the centre of a spherical chamber of radius 20cm. Assume that 60% of the energy supplied to the bulb is converted into light and that the surface of the chamber is perfectly absorbing. Find the pressure exerted by the light on the surface of the chamber.

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10. A sphere of radius 1.00 cm is placed in the path of a parallel beam of light of large aperture. The intensity of the light is 0.50 W cm^{-2}. If the sphere completely absorbs the radiation falling on it, find the force exerted by the light beam on the sphere.

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11. Consider the situation described in the previous problem. Show that the force on the sphere due to the light falling on it is the same even if the sphere is not perfectly absorbing.

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12. It is not possible for a photon to be completely absorbed by a free electron. Explain.

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13. Two neutral particles are kept 1m apart. Suppose by some mechanism some charge is transferred from one particle to the other and the electric potential energy lost is completely converted into a photon. Calculate the longest and the next smaller wavelength of the photon possible. $h = 6.63 \times 10^{-34} Js.$

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14. Find the maximum kinetic energy of the photoelectrons ejected when light of wavelength 350mn is incident on a cesium surface. Work function of cesium = $1.9 eV$.

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15. The work function of a photoelectric material is 4.0 e V. (a) What is the threshold wavelength? (b) find the wavelength of light for which the stopping potential is 2.5 V.

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16. Find the maximum magnitude of the linear momentum of a photoelectron emitted when light of wavelength 400 nm falls on a metal having work function 2.5e V.

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17. When a metal plate is exposed to a monochromatic beam of light of wavelength 400nm, a negative potential of

1.1 V is needed to stop the photocurrent . Find the threshold wavelength for the metal.

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18. In an experiment on photoelectric effect, the stopping potential is measured for monochromatic light beams corresponding to different wavelength. The data collected are as follows:

wavelength (nm): 350 400 450 500 550

stopping potential (V): 1.45 1.00 0.66 0.38 0.16

Plot the stopping potential against inverse of wavelength on a graph paper and find (a) the Planck constant, (b) the work function of the emitter and (c) the threshold wavelength .

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19. The electric field associated with a monochromataic beam of light becomes zero, 2.4×10^{15} times per second. Find the maximum kinetic energy of the photoelectrons when this light falls on a metal surface whose work function is 2.0eV, $h = 6.63 \times 10^{-34} Js$.

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20. The electric field associated with a light wave is given by $E = E_0 \sin\left[\left(1.57x10^7 m^{-1}(x - ct)\right)\right]$. Find the stopping potential when this light is used in an experiment on photoelectric affect with a metal having work - function 1.9 eV.

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21. The electric field at a point associated with a light wave is

$$E = \left(100Vm^{-1}\right)\sin\left[\left(3 \cdot 0x10^{15}s^{-1}\right)t\right]\sin\left[\left(6 \cdot 0x10^{15}s^{-1}\right)t\right].$$

If this light falls on a metal surface having a work function of 2*0 eV, what will be the maximum kinetic energy of the photoelectrons?

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22. A monochromatic light source of intensity 5 m W emits $\left(8 \times 10^{15}\right)$ photons per second . This light ejects photoelectrons from a metal surface. The stopping potential for this setup is 2.0 V. Calculate the work function of the metal.

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23. A photographic film is coated with a silver bromide layer. When light falls on this film, silver bromide molecules dissociate and the film records the light there. A minimum of 0.6 e V is needed to dissociate a silver bromide molecule. Find the maximum wavelength of light that can be recorded by the film.

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24. In an experiment on photoelectric effect light of wavelength $400nm$ is incident on a metal plate at rate of $5W$. The potential of the collector plate is made sufficiently positive with respect to emitter so that the current reaches the saturation value. Assuming that on the average one out of every 10^6 photons is able to eject a photoelectron, find the photocurrent in the circuit.

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25. A silver ball of radius 4.8 cn is suspended by a thread in a cacuum chamber, Ultraviolet light of wavelength 200nm is incident on the ball for some time during which a total light energy of $1.0 \times \left(10^{-7}\right)$ J falls on the surface. Assuming that on the average one photon out of every ten thousand is able to eject a photoelectron, find the electric potential at the surface of the ball assuming zero potential at infinity. What is the potential at the centre of the ball?

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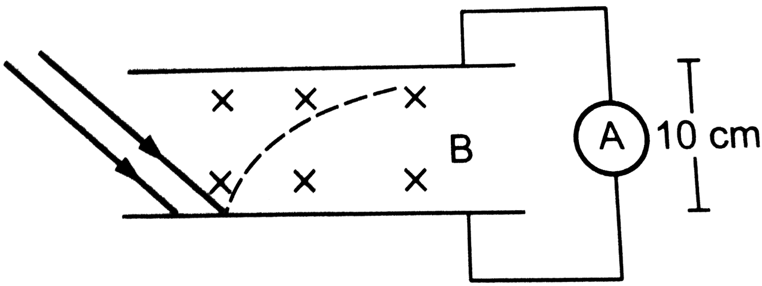
26. In an experiment on photoelectric effect, the emitter and the collector plates are placed at a separation of 10cm and are connected through an ammeter without any cell.



A magnetic field B exists parallel to the plates. The work function of the emitter is 2.39 e V and the light incident on it has wavelengths between 400nm and 600nm. Find the minimum value of B for which the current registered by the ammeter is zero. Neglect any effect of space charge.

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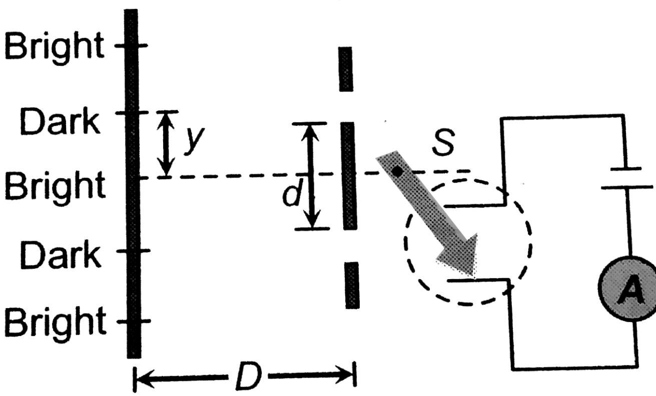
27. In the following arrangement $y = 1.0mm, d = 0.24mm$ and $D = 1.2m$. The work function of the material of the emitter is $2.2eV$. The stopping potential V needed to stop the photo current will be



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28. In a photoelectric experiment, the collector plate is at 2.0 V with respect to the emitter plate made of copper '(phi = 4.5)'. The emitter is illuminated by a source of monochromatic light of wavelength 200nm. Find the minimum and maximum kinetic energy of the photoelectrons reaching the collector.

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29. A small piece of cesium metal is kept at a distance of 20 cm form a large metal plate having a charge density of $1.0 \times (10^{-9}) C (m^{-2})$ on the surface facing the cesium piece. A monochromatic light of wavelength 400nm is incident on the cesium piece. Find the minimum and the maximum kinetic energy of the photoelectrons reaching the large metal plate. Neglect any change in electric field due to the small piece of cesium present.

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30. Consider the situation of the previous problem. Consider the fastest electron emitted parallel to the large metal plate. Find the displacement of this electron parallel to its initial velocity before it strikes the large metal plate.

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31. A horizontal cesium plate is moved vertically downward at a constant speed v in a room full of radiation of wavelength 250nm and above. What should be the minimum value of v so that the vertically upward component of velocity is nonpositive for each photoelectron?

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32. A small metal plate of work function ϕ is kept at a distance r from a singly ionised, fixed ion. A monochromatic light beam is incident on the metal plate and photoelectrons are emitted. Find maximum wavelength of the light beam so that some of that electrons may go round the ion along a circle.

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33. A light beam of wavelength $400nm$ is incident on a metal of work- function $2.2eV$. A particular electron absorbs a photon and makes 2 collisions before coming out of the metal

(a) Assuming that 10% of existing energy is lost to the metal in each collision find the final kinetic energy of this electron as it comes out of the metal.

(b) Under the same assumptions find the maximum number of collisions, the electron should suffer before it becomes unable to come out of the metal.

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Exercise

1. The work function of a metal is $2, 5 \times (10^{-19}) J$. (a) Find the threshold frequency for photoelectric emission. (b) If the metal is exposed to a light beam of frequency (6.0×10^{14}) Hz, what will be the stopping potential ?

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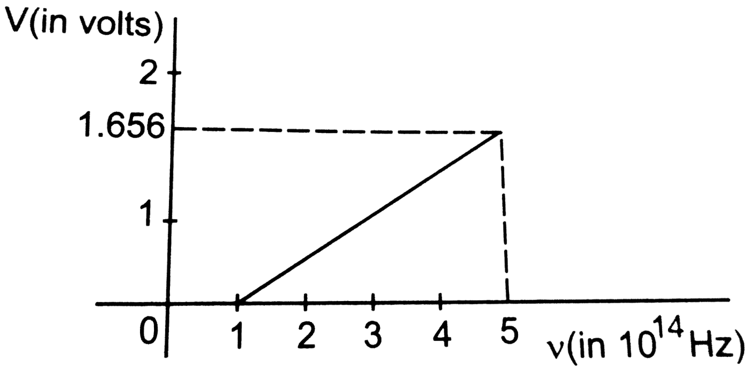
2. Figure is the plot of the stopping potential versus the frequency of the light used in an experiment on photoelectric effect. Find (a) the ratio h/e and (b) the work function.



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