

### Multiple Choice Questions I

11.1. A particle is dropped from a height  $H$ . The de Broglie wavelength of the particle as a function of height is proportional to

- (a)  $H$
- (b)  $H^{1/2}$
- (c)  $H^0$
- (d)  $H^{-1/2}$

Answer:

The correct answer is d)  $H^{-1/2}$

11.2. The wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy is nearly

- (a) 1.2 nm
- (b)  $1.2 \times 10^{-3}$  nm
- (c)  $1.2 \times 10^{-6}$  nm
- (d)  $1.2 \times 10^1$  nm

Answer:

The correct answer is b)  $1.2 \times 10^{-3}$  nm

11.3. Consider a beam of electrons (each electron with energy  $E_0$ ) incident on a metal surface kept in an evacuated chamber. Then

- (a) no electrons will be emitted as only photons can emit electrons
- (b) electrons can be emitted but all with an energy,  $E_0$
- (c) electrons can be emitted with any energy, with a maximum of  $E_0 - \phi$  ( $\phi$  is the work function)
- (d) electrons can be emitted with any energy, with a maximum of  $E_0$

Answer:

The correct answer is d) electrons can be emitted with any energy, with a maximum of  $E_0$

11.4. Consider Fig. 11.7 in the NCERT text book of physics for Class XII. Suppose the voltage applied to A is increased. The diffracted beam will have the maximum at a value of  $\theta$  that

- (a) will be larger than the earlier value
- (b) will be the same as the earlier value
- (c) will be less than the earlier value
- (d) will depend on the target

Answer:

The correct answer is c) will be less than the earlier value

11.5. A proton, a neutron, an electron and an  $\alpha$ -particle have same energy. Then their de Broglie wavelengths compare as

- (a)  $\lambda_p = \lambda_n > \lambda_e > \lambda_\alpha$
- (b)  $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$
- (c)  $\lambda_e < \lambda_p = \lambda_n > \lambda_\alpha$
- (d)  $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$

Answer:

The correct answer is b)  $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$

11.6. An electron is moving with an initial velocity  $v = v_0 \hat{i}$  and is in a magnetic field  $B = B_0 \hat{j}$

Then it's de Broglie wavelength

- (a) remains constant
- (b) increases with time
- (c) decreases with time
- (d) increases and decreases periodically

Answer:

The correct answer is a) remains constant

11.7. An electron (mass  $m$ ) with an initial velocity  $v = v_0 \hat{i}$  is in an electric field  $E = -E_0 \hat{i}$ . It's de Broglie wavelength at time  $t$  is given by

a)

$$\frac{\lambda_0}{1 + \frac{eE_0 t}{m v_0}}$$

b)

$$\lambda_0 \left(1 + \frac{eE_0 t}{m v_0}\right)$$

c)  $\lambda_0$

d)  $\lambda_0 t$

Answer:

$$\frac{\lambda_0}{1 + \frac{eE_0 t}{m v_0}}$$

The correct answer is a)

11.8. An electron (mass  $m$ ) with an initial velocity  $v = v_0 \hat{i}$  is in an electric field  $E = E_0 \hat{j}$ . If  $\lambda_0 = h/mv_0$ , it's de Broglie wavelength at time  $t$  is given by

a)  $\lambda_0$

b)

$$\lambda_0 \sqrt{1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}}$$

c)

$$\frac{\lambda_0}{\sqrt{1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}}}$$

d)

$$\frac{\lambda_0}{1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}}$$

**Answer:**

$$\frac{\lambda_0}{\sqrt{1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}}}$$

The correct answer is c)

### Multiple Choice Questions II

**11.9. Relativistic corrections become necessary when the expression for the kinetic energy  $1/2 mv^2$ , becomes comparable with  $mc^2$ , where  $m$  is the mass of the particle. At what de Broglie wavelength will relativistic corrections become important for an electron?**

- (a)  $\lambda = 10\text{nm}$
- (b)  $\lambda = 10^{-1}\text{nm}$
- (c)  $\lambda = 10^{-4}\text{nm}$
- (d)  $\lambda = 10^{-6}\text{nm}$

**Answer:**

The correct answer is

- c)  $\lambda = 10^{-4}\text{nm}$
- d)  $\lambda = 10^{-6}\text{nm}$

**11.10. Two particles A1 and A2 of masses  $m_1, m_2$  ( $m_1 > m_2$ ) have the same de Broglie wavelength. Then**

- (a) their momenta are the same
- (b) their energies are the same
- (c) energy of A1 is less than the energy of A2
- (d) energy of A1 is more than the energy of A2

**Answer:**

The correct answer is

- a) their momenta are the same
- c) energy of A1 is less than the energy of A2

**11.11. The de Broglie wavelength of a photon is twice the de Broglie wavelength of an electron. The speed of the electron is  $v_e = c/100$ . Then**

- (a)  $E_e/E_p = 10^{-4}$
- (b)  $E_e/E_p = 10^{-2}$
- (c)  $P_e/m_e c = 10^{-2}$
- (d)  $P_e/m_e c = 10^{-4}$

**Answer:**

The correct answer is

- b)  $E_e/E_p = 10^{-2}$
- c)  $P_e/m_e c = 10^{-2}$

**11.12. Photons absorbed in matter are converted to heat. A source emitting  $n$  photon/sec of frequency  $\nu$  is**

used to convert 1kg of ice at 0°C to water at 0°C. Then, the time T taken for the conversion

- (a) decreases with increasing n, with v fixed
- (b) decreases with n fixed, v increasing
- (c) remains constant with n and v changing such that  $nv = \text{constant}$
- (d) increases when the product  $nv$  increases

**Answer:**

The correct answer is

- a) decreases with increasing n, with v fixed
- b) decreases with n fixed, v increasing
- c) remains constant with n and v changing such that  $nv = \text{constant}$

**11.13.** A particle moves in a closed orbit around the origin, due to a force which is directed towards the origin. The de Broglie wavelength of the particle varies cyclically between two values  $\lambda_1, \lambda_2$  with  $\lambda_1 > \lambda_2$ . Which of the following statement are true?

- (a) The particle could be moving in a circular orbit with origin as centre
- (b) The particle could be moving in an elliptic orbit with origin as its focus
- (c) When the de Broglie wave length is  $\lambda_1$ , the particle is nearer the origin than when its value is  $\lambda_2$
- (d) When the de Broglie wavelength is  $\lambda_2$ , the particle is nearer the origin than when its value is  $\lambda_1$

**Answer:**

The correct answer is

- b) The particle could be moving in an elliptic orbit with origin as its focus
- d) When the de Broglie wavelength is  $\lambda_2$ , the particle is nearer the origin than when its value is  $\lambda_1$

### Very Short Answers

**11.14.** A proton and an  $\alpha$ -particle are accelerated, using the same potential difference. How are the deBroglie wavelengths  $\lambda_p$  and  $\lambda_\alpha$  related to each other?

**Answer:**

The proton and  $\alpha$ -particle are accelerated at the same potential difference.

$$\lambda = h/\sqrt{2mqv}$$

$\lambda$  is proportional to  $1/\sqrt{mq}$

$$\lambda_p/\lambda_\alpha = \sqrt{m_\alpha q_\alpha/m_p q_p} = \sqrt{8}$$

Therefore, the wavelength of proton is  $\sqrt{8}$  times the wavelength of  $\alpha$ -particle.

**11.15. (i)** In the explanation of photo electric effect, we assume one photon of frequency  $\nu$  collides with an electron and transfers its energy. This leads to the equation for the maximum energy  $E_{\text{max}}$  of the emitted electron as  $E_{\text{max}} = h\nu - \phi_0$  where  $\phi_0$  is the work function of the metal. If an electron absorbs 2 photons (each of frequency  $\nu$ ) what will be the maximum energy for the emitted electron?

**(ii)** Why is this fact (two photon absorption) not taken into consideration in our discussion of the stopping potential?

**Answer:**

i) From the question, the energy absorbed by the electron is two photons with frequency  $\nu$  and  $\nu' = 2\nu$  where  $\nu'$  is the frequency from the emitted electron.

$$E_{\text{max}} = h\nu - \phi_0$$

ii) The emission is negligible as the chances of the same photon absorbing the energy is very low.

**11.16.** There are materials which absorb photons of shorter wavelength and emit photons of longer wavelength. Can there be stable substances which absorb photons of larger wavelength and emit light of

**shorter wavelength.**

**Answer:**

The wavelength of the photon increases when the frequency decreases. There are two possible cases and they are; case one in which the photons have a smaller wavelength and the energy is consumed against work function. In case two, the photons might have a longer wavelength and emit photons with shorter and lesser energy.

**11.17. Do all the electrons that absorb a photon come out as photoelectrons?**

**Answer:**

No, not all electrons that are absorbed as a photon come out as a photoelectron.

**11.18. There are two sources of light, each emitting with a power of 100 W. One emits X-rays of wavelength 1nm and the other visible light at 500 nm. Find the ratio of number of photons of X-rays to the photons of visible light of the given wavelength?**

**Answer:**

$$E_x = hv_x$$

$$E_v = hv_v$$

Let  $n_x$  and  $n_v$  be the no. of photons from x-rays and visible light are of equal energies and they emit 100 W power.

$$n_x hv_x = n_v hv_v$$

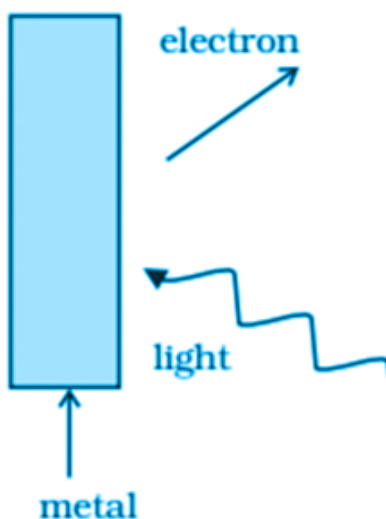
$$n_x/n_v = v_v/v_x = \lambda_x/\lambda_v$$

$$n_x/n_v = 1 \text{ nm}/500 \text{ nm}$$

$$n_x:n_v = 1:500$$

### Short Answers

**11.19. Consider the figure given for photoemission. How would you reconcile with momentum-conservation? Note light (photons) have momentum in a different direction than the emitted electrons.**



**Answer:**

When the photons strike the metal surface, there is a transfer of momentum to the atoms on the metal surface

which results in decrease in speed of the photons. The momentum of photons is transferred to the nucleus and electrons on the metal surface. The electrons emitted are in the opposite direction that of the photons. Nevertheless, the total momentum transferred by the photons and electrons will be equal.

**11.20. Consider a metal exposed to light of wavelength 600 nm. The maximum energy of the electron doubles when light of wavelength 400 nm is used. Find the work function in eV.**

**Answer:**

Let  $K_1$  and  $K_2$  be the maximum energy emitted by the electrons when 600 and 400 nm wavelength is used.

$$K_2 = 2K_1$$

Therefore, the work function,  $\phi = 1.03 \text{ eV}$

**11.21. Assuming an electron is confined to a 1nm wide region, find the uncertainty in momentum using Heisenberg Uncertainty principle. You can assume the uncertainty in position  $\Delta x$  as 1nm. Assuming  $p = \Delta p$ , find the energy of the electron in electron volts.**

**Answer:**

As the electrons rotate in a circular path,  $\Delta r = 1 \text{ nm} = 10^{-9} \text{ m}$

$$\Delta p = h/\Delta x$$

$$\Delta p = (331/314) \times 10^{-25}$$

$$E = 1/2 mv^2 = \Delta p^2/2m$$

$$E = 3.8 \times 10^{-2} \text{ eV}$$

**11.22. Two monochromatic beams A and B of equal intensity I, hit a screen. The number of photons hitting the screen by beam A is twice that by beam B. Then what inference can you make about their frequencies?**

**Answer:**

Let  $n_A$  be the no. of photons falling per second from beam A and  $n_B$  be the no. of photons falling per second from beam B.

Given,

No. of photons hitting the screen by A is twice that of B

$$\text{Therefore, } n_A = 2n_B$$

$$\text{Energy from the beam A} = hv_A$$

$$\text{Energy from the beam B} = hv_B$$

$$\text{Intensity} = I = n_A v_A = n_B v_B$$

$$v_B = 2v_A$$

**11.23. Two particles A and B of de Broglie wavelengths  $\lambda_1$  and  $\lambda_2$  combine to form a particle C. The process conserves momentum. Find the de Broglie wavelength of the particle C. (The motion is one dimensional).**

**Answer:**

According to de-Broglie wavelengths,

$$\lambda = h/p$$

$$p = h/\lambda$$

$$p_1 = h/\lambda_1$$

$$p_2 = h/\lambda_2$$

$$p_3 = h/\lambda_3$$

There are 4 possible cases and they are:

Case 1: When  $p_1$  and  $p_2$  are positive, then  $\lambda_3 = \lambda_1 \lambda_2 / \lambda_1 + \lambda_2$

Case 2: When  $p_1$  and  $p_2$  are negative, then  $\lambda_3 = \lambda_1 \lambda_2 / \lambda_1 - \lambda_2$

Case 3: When  $p_1 > 0$  and  $p_2 < 0$ , then  $\lambda_3 = \lambda_1 \lambda_2 / \lambda_2 - \lambda_1$

Case 4: When  $p_1 < 0$  and  $p_2 > 0$ , then  $\lambda_3 = \lambda_1 \lambda_2 / \lambda_1 - \lambda_2$

**11.24.** A neutron beam of energy  $E$  scatters from atoms on a surface with a spacing  $d = 0.1\text{nm}$ . The first maximum of intensity in the reflected beam occurs at  $\theta = 30^\circ$ . What is the kinetic energy  $E$  of the beam in eV?

**Answer:**

From Bragg's law,  $2d \sin \theta = n\lambda$

$$p = h/\lambda = 6.6 \times 10^{-24} \text{ kg m/s}$$

$$E = 1/2 mv^2 = p^2/2m$$

$$E = 0.085 \text{ eV}$$

### Long Answers

**11.25.** Consider a thin target ( $10^{-2}\text{m}$  square,  $10^{-3}\text{m}$  thickness) of sodium, which produces a photocurrent of  $100\mu\text{A}$  when a light of intensity  $100\text{W/m}^2$  ( $\lambda = 660\text{nm}$ ) falls on it. Find the probability that a photoelectron is produced when a photons strikes a sodium atom. [Take density of Na =  $0.97 \text{ kg/m}^3$ ].

**Answer:**

$$\text{Area} = 10^{-4} \text{ m}^2$$

$$\text{Thickness} = 10^{-3} \text{ m}$$

$$\text{Current} = 10^{-4} \text{ A}$$

$$\text{Intensity} = 100 \text{ W/m}^2$$

$$\text{Mass} = (\text{volume})(\text{density}) = 0.97 \times 10^{-4} \text{ gm}$$

$$\text{No. of target atoms} = 0.254 \times 10^{19}$$

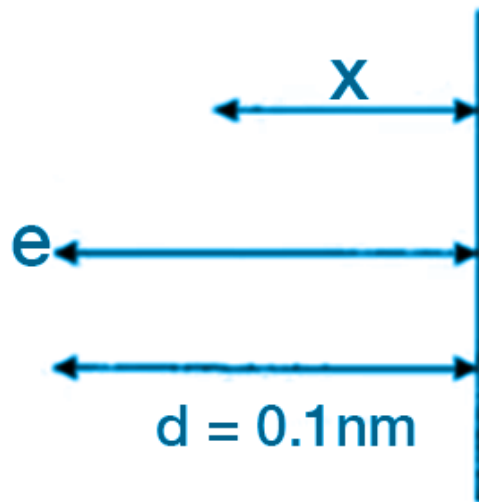
$$\text{Total energy} = nh\nu$$

$$\text{Where } n = 3.3 \times 10^{16}$$

$$\text{The probability of emission of photoelectrons is } 7.5 \times 10^{-21}$$

**11.26.** Consider an electron in front of metallic surface at a distance  $d$  (treated as an infinite plane surface). Assume the force of attraction by the plate is given as  $F = \frac{2\sigma q}{4\pi\epsilon_0 d^2}$ . Calculate work in taking the charge to an infinite distance from the plate. Taking  $d = 0.1\text{nm}$ , find the work done in electron volts. [Such a force law is not valid for  $d < 0.1\text{nm}$ ].

**Answer:**



The figure shows that an electron is displaced slowly. The distance covered by the electron is  $x$  and this happens by the means of an external force

$$F = \frac{q^2}{4 \times 4\pi\epsilon_0 d^2}$$

$$d = 0.1 \text{ nm} = 10^{-10} \text{ m}$$

Let  $x$  be the distance of the electron and the force of attraction on it be

$$F_x = \frac{q^2}{4 \times 4\pi\epsilon_0 d^2}$$

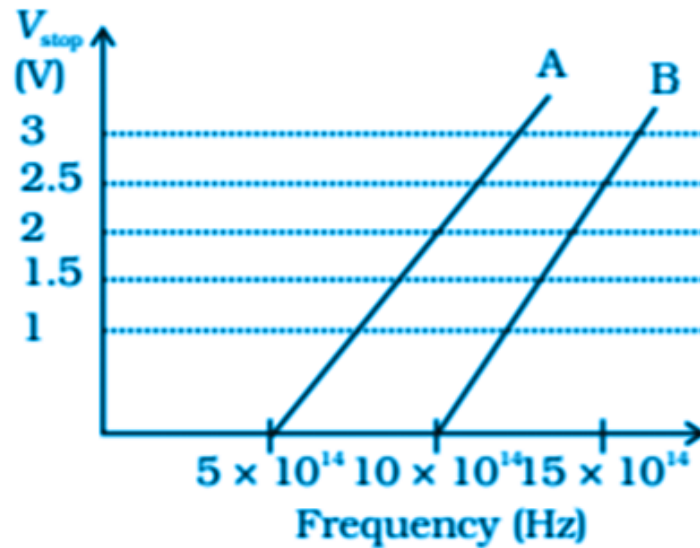
Therefore, work done by the external force is integral of force from  $d$  to infinity.

Therefore, work done = 3.6 eV

**11.27. A student performs an experiment on photoelectric effect, using two materials A and B. A plot of  $V_{\text{stop}}$  vs  $\nu$  is given in the figure.**

**(i) Which material A or B has a higher work function?**

**(ii) Given the electric charge of an electron =  $1.6 \times 10^{-19}$  C, find the value of  $h$  obtained from the experiment for both A and B. Comment on whether it is consistent with Einstein's theory**



**Answer:**

i) The threshold frequency of A is

$$\nu_{OA} = 5 \times 10^{14} \text{ Hz}$$

The threshold frequency of B is

$$\nu_{OB} = 10 \times 10^{14} \text{ Hz}$$

Work function is  $\phi = h\nu_0$

$$\phi_{OA} / \phi_{OB} = 5 \times 10^{14} / 10 \times 10^{14} < 1$$

$$\phi_{OA} < \phi_{OB}$$

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**11.28. A particle A with a mass  $m_A$  is moving with a velocity  $v$  and hits a particle B (mass  $m_B$ ) at rest (one dimensional motion). Find the change in the de Broglie wavelength of the particle A. Treat the collision as elastic.**

**Answer:**

According to the law of conservation of momentum,

$$m_A v + m_B 0 = m_A v_1 + m_B v_2$$

$$m_A(v - v_1) = m_B v_2$$

$$1/2 m_A v^2 = 1/2 m_A v_1^2 + 1/2 m_B v_2^2$$

$$m_A(v - v_1)(v + v_1) = m_B v_2^2$$

$$v_1 = (m_A - m_B / m_A + m_B)v$$

$$v_2 = (2m_A / m_A + m_B)v$$

$$\lambda_{\text{initial}} = h / m_A v$$

$$\lambda_{\text{final}} = h / m_A v_1$$

$$\Delta\lambda = \lambda_{\text{final}} - \lambda_{\text{initial}} = h / m_A v (m_A + m_B / m_A - m_B) - 1$$

**11.29. Consider a 20 W bulb emitting light of wavelength  $5000 \text{ \AA}$  and shining on a metal surface kept at a distance 2m. Assume that the metal surface has work function of 2 eV and that each atom on the metal surface can be treated as a circular disk of radius  $1.5 \text{ \AA}$ .**

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- (i) Estimate no. of photons emitted by the bulb per second. [Assume no other losses]  
(ii) Will there be photoelectric emission?  
(iii) How much time would be required by the atomic disk to receive energy equal to work function (2 eV)?  
(iv) How many photons would atomic disk receive within time duration calculated in (iii) above?  
(v) Can you explain how photoelectric effect was observed instantaneously?

**Answer:**

Given,

$$P = 20W$$

$$\lambda = 5000 \text{ \AA} = 5000 \times 10^{-10} \text{ m}$$

$$d = 2\text{m}$$

$$\phi_0 = 2 \text{ eV}$$

$$r = 1.5 \times 10^{-10} \text{ m}$$

No. of photon emitted per second by the bulb =  $n' = dN/dt$

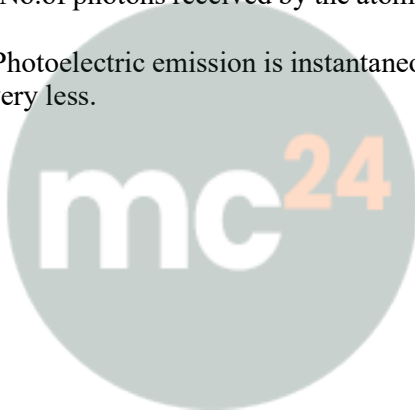
i) No. of photon emitted by bulb per second =  $n' = P \lambda / hc = 5 \times 10^{19} \text{ sec}$

ii) Energy of the incident photon =  $hc / \lambda = 2.48 \text{ eV}$

iii) Time required by the atomic disk to receive energy is = 28.4 sec

iv) No. of photons received by the atomic disk = 2

v) Photoelectric emission is instantaneous as the collision time between the free electron and the incident photon is very less.



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