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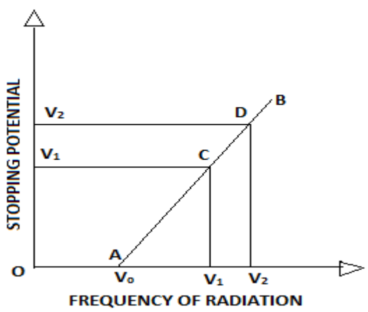
Class: 12
Subject: Physic s
Topic: Duel Nature of Matter And Radiation
No. of Questions: 30

1. Draw a graph to show the variation of stopping potential with frequency of radiation incident on a metal plate. How can the value of Planck's constant be determined from this graph?

Sol.



The variation of stopping potential with the frequency of radiation, incident on a metal plate is a straight line AB as shown in Fig. 7.25.

Take two points C and D on the graph. Note down the corresponding frequency of radiation ($v_1$and v_2) and stopping potential (V_1 and V_2)

Then, $e V_1 = hv_1 - \Phi_o$ and $e V_2 = hv_2 - \Phi_o$

$\therefore$ $e (V_2 - V_1) = h (v_2 - v_1)$ or $h=\frac{e(V_2-V_1)}{v_2-v_1}$.

Thus Planck's constant can be determined.

2. Green light ejects photoelectrons from a given photosensitive surface where as yellow light does not. What will happen in case of violet an red light? Give reason for your answer.

Sol.

The photoelectrons can be emitted from a metal surface if the frequency of incident radiation is more than threshold frequency, i.e, more than that of green light for the given surface. As frequency of violet light is more than that of green light, hence violet light will eject photoelectrons. But the frequency of red light is less than that of the green light, hence red light cannot eject photoelectrons from the given surface.

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3. Answer the following questions:
   A. quarks inside protons and neutrons are thought to carry fractional charges [(+2/3) e : (-1/3) e]. Why do they not show up in Millikan's oil-drop experiment?
   B. What is so special about the combination e/m? Why do we not simply talk of e and m separately?
   C. Why should gases be insulators at ordinary pressures and start conducting at very low pressure?

   D. Every metal has a definite work function. Why do all photoelectrons not come out with the same energy if incident radiation is monochromatic? Why is there an energy distribution of photoelectrons?
   E. The energy and momentum of an electron are related to the frequency and wavelength of the associated matter wave by the relations : $E = h\nu$, $p = h/\lambda$
   But while the value of λ is physically significant, the value of v (and therefore, the value of phase speed v λ) has no physical significance. Why?

Sol.

A. The quarks having fractional charges are thought to be confined within a proton and a neutron. These quarks are bound by forces. These forces become stronger when the quarks are tried to be pulled apart. That is why, the quarks always remain together. It is due to this reason that though fractional charges does exist in nature but the observable charges are always integral multiple of charge of electron.
B. The motion of electron in the electric and magnetic field is related with the basic equations

$$eV = \frac{1}{2}mv^2 \qquad \text{and } B\,ev = \frac{mv^2}{r}$$

All thee equations involve e and m together, i.e., there is no equation in which e or m occurring alone. As a result of it, we study e/m of electron and do not talk of e and m separately far and electron.

C. At ordinary pressures a few positive ions and electrons produced by the ionization of the gas molecules by energetic rays (like X-rays, γ-rays, cosmic rays etc. coming from outer space and entering the earth's atmosphere) are not able to reach their respective electrodes, even at high voltages, due to their frequent collision with gas molecules and recombinations. That is why the gases at ordinary pressures are insulators.
At low pressures, the density of the gas decreases hence the mean free path of the gas molecules become large. Now under the effect of external high voltage, the ions acquire sufficient energy before they collide with molecules causing further ionization Due to it, the number of ions in the gas increases and it becomes a conductor.

D. By work function of a metal, we mean the minimum energy required for the electron in the highest level of conduction band to get out of the metal. Since all the electrons in the metal do not belong to that level but they occupy a continuous band of levels, therefore, for the given incident radiation, electrons

E. Debroglie wavelength associated with the moving particle is

$$\lambda = \frac{h}{p}$$

Or $p = \frac{h}{\lambda}$

Energy of the wave E is E = hv= $\frac{hc}{\lambda}$

Energy of moving particle $= \frac{1}{2}\frac{p^2}{2m} = \frac{1}{2}\frac{(h/\lambda)^2}{m} = \frac{1}{2}\frac{h^2}{\lambda^2 m}$

the

For the relations of E and p, we note that λ is physically significant but v has no direct physical significance.

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

Sol.

The free electron in metal is bound by some restraining forces. Due to which it can not come out of its own. Some energy is to be spent in ejecting the free electron from the surface of metal which is equal to work function of metal. It means, some of the energy of incident photon is spent in liberating the electron from the surface of metal and remaining energy of incident photon is used in imparting the K. E. to the emitted electron. As the maximum K. E. of the emitted photoelectron is less than the energy of incident photon, hence it is not possible for a photon to be completely absorbed by a free electron.

5. Radiation has dual nature, i.e., it possesses the properties of both; wave and particle. This prompted de-Broglie to predict dual nature of moving material particles. Thus waves are associated with moving material particles which are called matter waves. The wavelength of matter waves is given by $\lambda = \frac{h}{mv}$, where m is the mass, v is the speed of the particle and h is Planck's constant.

Read the above paragraph and answer the following questions:

(i) How was the wave nature of electron established?

(ii) What are the de-Broglie wavelength associated with a particle (i) at rest (ii) moving with infinite speed?

(iii) What are the basic values displayed by this study?

Sol.

(i) Davission and Germer observed diffraction patterns of slow moving electrons. And G. P. Thomason observed diffraction pattern of fast moving electrons. As diffraction is essentially a wave phenomenon, therefore, it was concluded that wave must be associated with moving electrons.

(ii) (a) At rest, v = 0, $\lambda = \frac{h}{mv} = \frac{h}{m \times 0} = \infty$

(b) Particle moving with inifinite speed, $v = \infty$

$$\lambda = \frac{h}{mv} = \frac{h}{m \times \infty} = 0$$

(iii) The dual nature of moving material particles reveals in a way the nature of almighty God. He is in a visible form (i.e., Sakar) like a visible particle and also without any form (i.e., NIrakar) like a wave. It depends on us how we realize Him.

6. “Know your face beauty through complexion meter” was one of the stall on a science exhibition. A student interested to know his/her face beauty was made to stand on a platform and light from a lamp was made to fall on his/her face. The reading of complexion meter indicated the face beauty of the student which might be very fair, fair, semifair, semidark and dark, etc.
Of the student passage and answer the following questions:
(i) What is the basic concept used in the working of complexion meter?
(ii) How is the face beauty recorded by face complexion meter?
(iii) What basic values do you learn from the above study?

Sol.

(i) The basic concept used in the working of complexion meter is photoelectric effect.
(ii) The reading of complexion meter depends on the current generated from the light reflected from the face. Fairer the colour more is the light reflected and vice versa.
(iii) Complexion meters judge your face beauty only. The inner beauty of a person is judged by the virtues he or she possesses. In my opinion, inner beauty is much more valuable than the face beauty.

7. Blue light can eject electrons from a photo-sensitive surface while orange light can not. Will violet and red light eject electrons from the same surface?

Sol.

The photoelectrons can be emitted from a metal surface if the frequency of incident radiation is more than the threshold frequency, i.e., more than that of blue light for give surface. As frequency of violet light is more than that of blue light, hence violet light will eject photoelectrons. But the frequency of red light being less than the blue light,can not eject photoelectrons from the given surface.

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8. Draw a graph showing the variation of stopping potential with frequency of the incident radiation. What does the slope of the line with frequency axis indicated?

Sol.

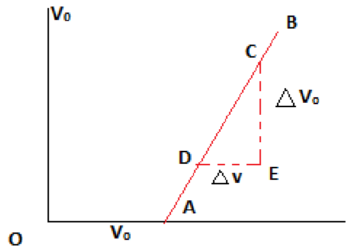

Figure 7.17

The variation between stopping potential V_o and frequency v of the incident radiation on a photosensitive surface is a st. line AB as shown in Fig. 7.17.

Here, slope of line $AB = \frac{\Delta v_o}{\Delta v}$

From Einstein photoelectric equation, $e\Delta V_o = hv - \Phi_o$

Differentiating it, we get $e\Delta v_o = h \Delta v$ or $\frac{\Delta v_o}{\Delta v} = \frac{h}{e}$

∴ Slope of the line $AB = \frac{\Delta V_O}{\Delta V} = \frac{H}{E}$

Here h is Planck's constant and e is the electronic charge.

9. For three different materials, the variation of the stopping potential V_o and the wavelength λ of the incident light is shown by curves a, b and c in Fig. 7.18 Which material has maximum work function and which one has least work function?

Sol.

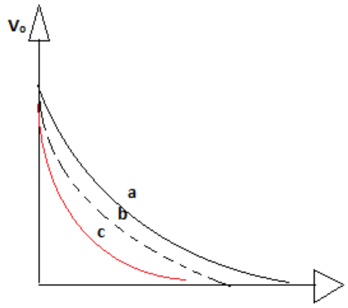

Figure 7.18

From the graph, we note that for the given incident light of wavelength λ, the material a has highest potential and material c has lowest stopping potential. As

$$eV_o = \frac{hc}{\lambda}\Phi_o$$

As stopping potential is the negative potential applies to collector w.r.t. emitter to stop the fastest photoelectron to reach the collector. Therefore, V_o is negative.

Therefore, for the given value of $\lambda, V_o \infty \Phi_o$ (in magnitude). Hence, the work function is maximum for metal a and least for metal c.

10. In a photoelectric effect experiment, graph between the stopping potential (V) and frequency (v) of the incident radiations on two different metal plates P and Q are shown in the Fig. 7.26. (i) Which of the two metal plates, P and Q has greater value of work function? (ii) What does the slope of the line depict?

Sol.

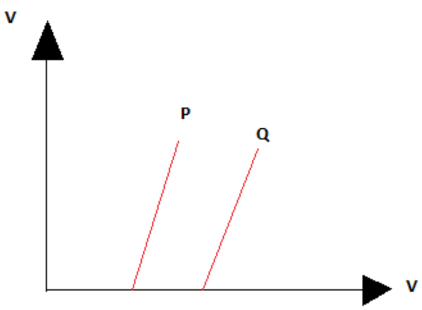

Figure 7.26

(i) As the threshold frequency is higher for metal Q than that of metal P, hence the work function$\Phi_o = hv_o, is$ greater for metal Q than That of P.

(ii) Slope of the line $\frac{\Delta V}{\Delta v} = \frac{h}{e}$

Where h is the Plank's constant and e is the electronic charge.

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11. The De Broglie wavelength of a neutron at 927°C is λ. What will be its wavelength at 27°C?

A. $\frac{\lambda}{2}$
B. λ
C. 2λ
D. 4λ

Right Answer Explanation:

We have seen above that $\lambda \propto \frac{1}{\sqrt{T}}$. Hence

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{T_1}{T_2}} = \sqrt{\frac{927+273}{27+273}} = 2$$

$\therefore$ $\lambda' = 2\lambda$. Hence the correct choice is (3).

12. The momentum of a photon of frequency v is

A. $\frac{hv}{c}$
B. hvc
C. $\frac{h}{cv}$
D. $\frac{v}{ch}$

Right Answer Explanation:

$c = \nu\lambda$ and $\lambda = h/p$. Therefore $p = \frac{h}{\lambda} = \frac{\nu h}{c}$. Hence the correct choice is (1).

13. A photon of energy 8 eV is incident on a metal surface of threshold frequency 1.6 $\times$ 10^{15} Hz. The kinetic energy (in eV) of the photoelectrons emitted is (take h = 6 $\times$ 10^{-34} Js)

A. 6
B. 1.6
C. 1.2
D. 2

Right Answer Explanation:

KE = $h\nu - h\nu_0$. Now $h\nu_0 = 6 \times 10^{-34} \times 1.6 \times 10^{15} = 9.6 \times 10^{-19}$ J = 6 eV.
Given $h\nu$ = 8 eV. Hence KE = 8 – 6 = 2 eV, which is choice (4).

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14. Which of the following is correct?

A. The current in a photo cell increases with increasing frequency.
B. The photo current is proportional to the applied voltage.
C. The photo current increases if the intensity of incident light is increased.
D. The stopping potential increases if the intensity of incident light is increased.

Right Answer Explanation:
The correct choice is (3).

15. The slope of the graph of the frequency of incident light versus the stopping potential for a given metallic surface is

A. h
B. $\frac{h}{e}$
C. $\frac{e}{h}$
D. eh

Right Answer Explanation:

eV_0 = hv. Therefore, v = $\frac{e}{h}V_0$. Hence the slope of v versus V_0 graph is $\frac{e}{h}$ which is choice (3).

16. A proton and an alpha particle are accelerated to the same potential. Their de-Broglie wavelengths are in the ratio of

A. $\sqrt{2}$: 1
B. $2\sqrt{2}$: 1
C. 2 : 1
D. 4 : 1

Right Answer Explanation:

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The wavelength associated with a particle of charge q, mass m and accelerated through a potential difference V is given by

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

or $$V = \frac{h^2}{2mq\lambda^2}$$

for proton: $$V = \frac{h^2}{2m_p q_p \lambda^2}$$

For α-particle : $$V' = \frac{h^2}{2m_\alpha q_\alpha \lambda^2}$$

$$\therefore \quad \frac{V'}{V} = \frac{m_p}{m_\alpha} \times \frac{q_p}{q_\alpha} = \frac{1}{4} \times \frac{1}{2} = \frac{1}{8}$$

$(\because m_\alpha = 4\, m_p \text{ and } q_\alpha = 2q_p)$

Thus $V' = V/8$.

Refer to the solution. The correct choice is (2).

17. When the energy of the incident radiation is increased by 20%, the kinetic energy of the photoelectrons emitted from a metal increases from 0.5 eV to 0.8 eV. The work function of the metal is

A. 0.65 eV
B. eV
C. 1.3 eV
D. 1.5 eV

Right Answer Explanation:

$$h\nu = E + W_0 = 0.5 \text{ eV} + W_0 \qquad \text{(i)}$$

When the energy of the incident photon is increased by 20%, we have

$$\frac{6}{5}\, h\nu = E' + W_0 = 0.8 \text{ eV} + W_0 \qquad \text{(ii)}$$

Subtracting (ii) from (i), we get $h\nu = 1.5$ eV. Hence $W_0 = h\nu - 0.5 \text{ eV} = 1.5 \text{ eV} - 0.5 \text{ eV} = 1.0$ eV. Thus the correct choice is (2).

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18. The maximum kinetic energy of photoelectrons emitted from a surface when photons of energy 6 eV fall on it is 4 eV. The stopping potential is

A. 2 V
B. 6 V
C. 4 V
D. 10 V

Right Answer Explanation:
The stopping potential in volts = kinetic energy of the emitted photoelectrons in eV. Hence the correct choice is (2).

19. Photoelectric emission is observed from a metallic surface for frequencies v_1 and v_2 of the incident light ($v_1 > v_2$). If the maximum values of kinetic energy of the photoelectrons emitted in the two cases are in the ratio 1 : n, then the threshold frequency of the metallic surface is

A. $\frac{v_1 - v_2}{n-1}$
B. $\frac{nv_1 - v_2}{n-1}$
C. $\frac{nv_2 - v_1}{n-1}$
D. $\frac{v_1 - v_2}{n}$

Right Answer Explanation:
$E_1 = h(\nu_1 - \nu_0)$ and $E_2 = h(\nu_2 - \nu_0)$. Dividing them, we get

$$\frac{E_2}{E_1} = \frac{\nu_2 - \nu_0}{\nu_1 - \nu_0}$$

Given $E_2 = n E_1$. Hence, we have

$$n = \frac{\nu_2 - \nu_0}{\nu_1 - \nu_0}$$

which gives $\nu_0 = \frac{n\nu_1 - \nu_2}{(n-1)}$, which is choice (2).

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20. When a centimetre thick surface is illuminated with light of wavelength λ, the stopping potential is V. When the same surface is illuminated by light of wavelength 2 λ, the stopping potential is V/3. The threshold wavelength for the surface is

A. $\frac{4\lambda}{3}$
B. 4λ
C. 6λ
D. $\frac{8\lambda}{3}$

Right Answer Explanation:

$h\nu = eV + W_0$ or $eV = h\nu - W_0 = h\nu - h\nu_0$. Now $\nu = c/\lambda$ and $\nu_0 = c/\lambda_0$. Thus, for wavelength λ, we have

$$eV = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) \quad \text{(i)}$$

and for wavelength $\lambda' = 2\lambda$, we have ($\because V' = V/3$)

$$\frac{eV}{3} = hc\left(\frac{1}{2\lambda} - \frac{1}{\lambda_0}\right)$$

or

$$eV = 3hc\left(\frac{1}{2\lambda} - \frac{1}{\lambda_0}\right) \quad \text{(ii)}$$

From (i) and (ii) we have

$$\frac{1}{\lambda} - \frac{1}{\lambda_0} = 3\left(\frac{1}{2\lambda} - \frac{1}{\lambda_0}\right)$$

which gives $\lambda_0 = 4\lambda$. Hence the correct choice is (2).

21. According to Einstein's photoelectric equation, the plot of the kinetic energy of the emitted photo electrons from a metal vs frequency of the incident radiation gives a straight line whose slope

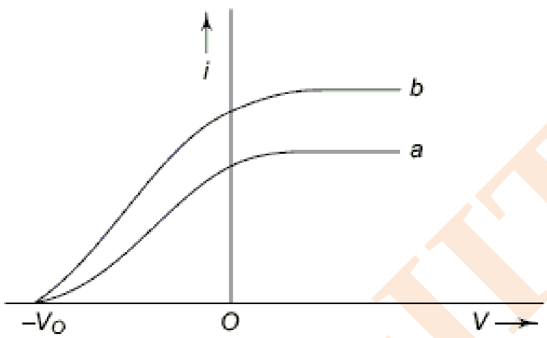
A. depends on the nature of the metal used
B. depends on the intensity of the radiation
C. depends both on the intensity of the radiation and the metal used
D. is the same for all metals and independent of the intensity of the radiation

Right Answer Explanation:
The kinetic energy of the emitted photoelectrons is given by

$$KE = h(\nu - \nu_0)$$

where ν is the frequency of the incident radiation, ν_0 is the threshold frequency and h is the Planck's constant. Hence the slope of the graph of KE Vs ν is h, the Planck's constant, which is a universal constant. Hence the correct choice is (4).

22. Figure shows the variation of photoelectric current (i) with anode potential (V) for a photosensitive surface for two radiations of intensities I_a and I_b and frequencies V_a and V_b for the curves a and b respectively. It follows from the graph that



A. $v_a = v_b$, $I_b < I_a$
B. $v_a = v_b$, $I_b > I_a$
C. $v_a < v_b$, $I_b > I_a$
D. $v_a < v_b$, $I_b = I_a$

Right Answer Explanation:
It follows from the figure that the stopping potential (V_0) is the same for the two radiations. We know that $eV_0 = E_{max}$ and $E_{max} = h\nu - W_0$. Since V_0 is the same, E_{max} and hence ν is the same for radiations a and b. Hence $\nu_a = \nu_b$. Since the saturation current is greater for radiation b than for radiation a, the intensity I_b is greater than I_a. Hence the correct choice is (2).

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23. What is the de Broglie wavelength of an electron of energy 180 eV? (Mass of electron = 9 × 10^{-31} kg and Planck's constant = 6.6 × 10^{-34} Js)

A. 0.5 Å
B. 0.9 Å
C. 1.3 Å
D. 1.8 Å

Right Answer Explanation:

$K = 180 \text{ eV} = 180 \times 1.6 \times 10^{-19} \text{ J} = 2.88 \times 10^{-17} \text{ J}.$

Now $\lambda = \frac{h}{\sqrt{2mK}}$

$$\lambda = \frac{6.6 \times 10^{-34}}{\left[2 \times 9 \times 10^{-31} \times 2.88 \times 10^{-17}\right]^{1/2}}$$

$$= \frac{6.6 \times 10^{-34}}{7.2 \times 10^{-24}} = 0.9 \times 10^{-10} \text{ m}$$

24. The threshold frequency for a certain photosensitive metal is v_0. When it is illuminated by light of frequency v = 2 v_0, the maximum velocity of photoelectrons is v_0. What will be the maximum velocity of the photoelectrons when the same metal is illuminated by light of frequency v = 5 v_0?

A. $\sqrt{2}$ v_0
B. 2 v_0
C. 2$\sqrt{2}$ v_0
D. 4 v_0

Right Answer Explanation:

$\frac{1}{2} mv^2_{\max} = h(\nu - \nu_0)$. For light of frequency $\nu = 2\nu_0$

we have $\quad \frac{1}{2} mv_0^2 = h(2\nu_0 - \nu_0) = h\nu_0 \quad$ (i)

For light of frequency $\nu = 5\nu_0$, we have

$\frac{1}{2} mv^2 = h(5\nu_0 - \nu_0) = 4h\nu_0 \quad$ (ii)

Dividing (ii) by (i) we get $v^2 = 4v_0^2$ or $v = 2v_0$.
Hence the correct choice is (2).

25. When a certain photosensitive surface is illuminated with monochromatic light of frequency ν, the stopping potential for photoelectric current is $V_0/2$. When the same surface is illuminated by monochromatic light of frequency $\nu/2$, the stopping potential is V_0. The threshold frequency for photoelectric emission is

A. $\frac{2\nu}{3}$

B. $\frac{3\nu}{2}$

C. $\frac{3\nu}{5}$

D. $\frac{5\nu}{3}$

Right Answer Explanation:

$h\nu = h\nu_0 + eV$, where V is the stopping potential. For frequency ν, we have

$$h\nu = h\nu_0 + \frac{eV_0}{2} \qquad \text{(i)}$$

and for frequency $\nu/2$, we have

$$\frac{h\nu}{2} = h\nu_0 + eV_0 \qquad \text{(ii)}$$

From (i) and (ii) on eliminating V_0, we get $\nu_0 = 3\nu/2$. Hence the correct choice is (2).

26. A photon has energy E = hv and momentum p = $\frac{h}{\lambda}$. In terms of E and p, the speed of light is

A. Ep

B. $\sqrt{Ep}$

C. $\frac{p}{E}$

D. $\frac{E}{p}$

Right Answer Explanation:

$\frac{E}{p} = \frac{hv}{h/\lambda} = v\lambda$. Hence the correct choice is (4).

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27. The de-Brogile wavelength of an electron moving in the n^{th} Bohr orbit of radius r is given by

A. $\frac{2\pi r}{n}$
B. $n\pi r$
C. $\frac{nr}{2\pi}$
D. $\frac{nr}{\pi}$

Right Answer Explanation:

For nth Bohr orbit, $mvr = \frac{nh}{2\pi}$. The de-Broglie wavelength is

$$\lambda = \frac{h}{mv}$$

But $mv = \frac{nh}{2\pi r}$. Therefore,

$$\lambda = h \times \frac{2\pi r}{nh} = \frac{2\pi r}{n}$$ which is choice (1).

28. The momentum of a particle of mass m and charge q is equal to that of a photon of wavelength λ. The speed of the particle is given by

A. $\frac{h}{m\lambda}$
B. $\frac{h\lambda}{qm}$
C. $qh\lambda$
D. $\frac{mh}{\lambda}$

Right Answer Explanation:

Given $mv = \frac{h}{\lambda}$. Hence the correct choice is (1).

29. When a monochromatic source of light is at a distance of 0.2 m from a photoelectric cell, the cut-off voltage and the saturation current are respectively 0.6 V and 18 mA. If the same source is placed 0.6 m away from the cell, then

A. the stopping potential will be 0.2 V
B. the stopping potential will be 1.8 V
C. the saturation current will be 6.0 mA
D. the saturation current will be 2.0 mA

Right Answer Explanation:
The stopping potential depends on the frequency (or wavelength) of the incident electromagnetic wave and is independent of the distance of the source from photocell. Hence the stopping potential will still be 0.6 V. However, the saturation current varies as $1/r^2$, where r is the distance of the source from the photocell. Since r is increased by a factor of 3, the saturation current will decrease by a factor of $(3)^2 = 9$, i.e. it will be 18 mA/9 = 2 mA at r = 0.6 m. Hence the correct choice is (4).

30. The work function of a substance is 4.0 eV. The longest wavelength of light that can cause photoelectron emission from this substance is approximately

A. 540 nm
B. 400 nm
C. 310 nm
D. 220 nm

Right Answer Explanation:
$$\lambda_{max} = \frac{hc}{W_0} = \frac{6.626\times10^{-34}\times3\times10^{8}}{4.0\times1.6\times10^{-19}} = 3.10 \times 10^{7} \text{ m} = 310 \text{ nm}$$