Q: 11.1 (b) Find the minimum wavelength of X-rays produced by $30\ kV$ electrons.

Answer:

From the relation $eV_0 = h\nu$, we have calculated the value of frequency in the previous questions, using that value and the following relation

$$\lambda = \frac{c}{\nu}$$
$$\lambda = \frac{3 \times 10^8}{7.25 \times 10^{18}}$$
$$\lambda = 0.04\ nm$$

Q: 11.2 (a) The work function of caesium metal is $2.14\ eV$. When light offrequency $6 \times 10^{14}\ Hz$ is incident on the metal surface, photoemission of electrons occurs. What is the maximum kinetic energy of the emitted electrons?

Answer:

The energy of the incident photons is E is given by

$$E = h\nu$$
$$E = \frac{6.62 \times 10^{-34} \times 6 \times 10^{14}}{1.6 \times 10^{-19}}$$
$$E = 2.48\ eV$$

Maximum Kinetic Energy is given by

$$KE_{max} = E - \phi_0$$
$$KE_{max} = 2.48 - 2.14$$
$$KE_{max} = 0.34\ eV$$

Q: 11.2 (b) The work function of caesium metal is $2.14\ eV$ When light of frequency $6 \times 10^{14}\ Hz$ is incident on the metal surface, photoemission of electrons occurs. What is the stopping potential

Answer:

The stopping potential depends on the maximum Kinetic Energy of the emitted electrons. Since maximum Kinetic energy is equal to 0.34 eV, stopping potential is the maximum kinetic energy by charge equal to 0.34 V.

Q: 11.2 (c) The work function of caesium metal is $2.14\ eV$. When light of frequency $6 \times 10^{14}\ Hz$ is incident on the metal surface, photoemission of electrons occurs. What is the maximum speed of the emitted photoelectrons?

Answer:

The electrons with the maximum kinetic energy of 0.34 eV will have the maximum speed

Q : 11.3 The photoelectric cut-off voltage in a certain experiment is $1.5\ V$. What is the maximum kinetic energy of photoelectrons emitted?

Answer:

Since the photoelectric cut-off voltage is 1.5 V. The maximum Kinetic Energy (eV) of photoelectrons emitted would be 1.5 eV.

KE_{max} =1.5 eV

KE_{mac} =2.4 $\times$ 10 $^{-19}$ J

Q: 11.4 (a) Monochromatic light of wavelength $632.8\ nm$ is produced by a helium-neon laser. The power emitted is $9.42\ mW$. Find the energy and momentum of each photon in the light beam.

Answer:

The energy of photons is given by the relation

Momentum is given by De Broglie's Equation

The energy of the photons in the light beam is 3.14×10^{-19} J and the momentum of the photons is 1.046×10^{-27} kg m s $^{-1}$.

Q: 11.4 (b) Monochromatic light of wavelength $632.8\ nm$ is produced by a helium-neon laser. The power emitted is $9.42\ mW$.

How many photons per second, on the average, arrive at a target irradiated by this beam? Assume the beam to have uniform cross-section which is less than the target area),

Answer:

Power of the light beam, P =9.42 mW

If n number of photons arrive at a target per second nE=P (E is the energy of one photon)

$$n = \frac{P}{E}$$
$$n = \frac{9.42 \times 10^{-3}}{3.14 \times 10^{-19}}$$
$$n = 3 \times 10^{16}$$

Q: 11.4 (c) Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW. How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

Answer:

Mass of Hydrogen Atom (m)=1.67 $\times$ 10 $^{-27}$ kg.

The speed at which hydrogen atom must travel to have momentum equal to that of the photons in the beam is v given by

$$v = \frac{p}{m}$$
$$v = \frac{1.05 \times 10^{-27}}{1.67 \times 10^{-27}}$$
$$v = 0.628\ ms^{-1}$$

Q: 11.5 The energy flux of sunlight reaching the surface of the earth is $1.388 \times 10^3\ W/m^2$. How many photons (nearly) per square metre are incident on the Earth per second? Assume that the photons in the sunlight have an average wavelength of $550\ nm$?

Answer:

Average Energy(E) of the photons reaching the surface of the Earth is given by

Energy flux(I) reaching the Earth's surface=1.388 $\times$ 10 ^{3} Wm $^{-2}$

Number of photons(n) incident on Earth's surface per metre square is

$$n = \frac{I}{E}$$
$$n = \frac{1.388 \times 10^{3}}{3.61 \times 10^{-19}}$$
$$n = 3.849 \times 10^{21}\ m^{-2}$$

Q : 11.6 In an experiment on photoelectric effect, the slope of the cut-off voltage versus frequency of incident light is found to be $4.12 \times 10^{-15} Vs$. Calculate the value of Planck's constant.

Answer:

The slope of the cut-off voltage versus frequency of incident light is given by h/e where h is Plank's constant and e is an electronic charge.

$$h = slope \times e$$

$$h = 4.12 \times 10^{-15} \times 1.6 \times 10^{-19}$$

$$h = 6.59210^{-34} Js$$

Q : 11.7 (a) A $100W$ sodium lamp radiates energy uniformly in all directions. The lamp is located at the centre of a large sphere that absorbs all the sodium light which is incident on it. The wavelength of the sodium light is $589\ nm$. What is the energy per photon associated with the sodium light?

Answer:

The energy of a photon is given by

$$E = \frac{hc}{\lambda}$$

where h is the Planks constant, c is the speed of the light and lambda is the wavelength

$$E = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{589 \times 10^{-9}}$$

$$E = 3.37 \times 10^{-19}\ J$$

Q: 11.7 (b) A $100W$ sodium lamp radiates energy uniformly in all directions. The lamp is located at the centre of a large sphere that absorbs all the sodium light which is incident on it. The wavelength of the sodium light is $589\ nm$. At what rate are the photons delivered to the sphere?

Answer:

Power of the sodium lamp=100W

The rate at which photons are delivered to the sphere is given by

$$R = \frac{P}{E}$$
$$R = \frac{100}{3.37 \times 10^{-19}}$$
$$R = 2.967 \times 10^{20}\ s^{-1}$$

Q: 11.8 The threshold frequency for a certain metal is $3.3 \times 10^{14}\ Hz$. If light of frequency $8.2 \times 10^{14}\ Hz$ is incident on the metal, predict the cutoff voltage for the photoelectric emission.

Answer:

Threshold frequency of the given metal(ν_0)= $3.3 \times 10^{14}\ Hz$

The work function of the given metal is

$$\phi_0 = h\nu_0$$
$$\phi_0 = 6.62 \times 10^{-34} \times 3.3 \times 10^{-14}$$
$$\phi_0 = 2.18 \times 10^{-19}\ J$$

The energy of the incident photons

$$E = h\nu$$
$$E = 6.62 \times 10^{-34} \times 8.2 \times 10^{14}$$
$$E = 5.42 \times 10^{-19}\ J$$

Maximum Kinetic Energy of the ejected photoelectrons is

$$E - \phi_0 = 3.24 \times 10^{-19}\ J$$
$$E - \phi_0 = 2.025\ eV$$

Therefore the cut off voltage is 2.025 eV

Q : 11.9 The work function for a certain metal is $4.2\ eV$. Will this metal give photoelectric emission for incident radiation of wavelength $330\ nm$?

Answer:

The energy of photons having 330 nm is

Since this is less than the work function of the metal there will be no photoelectric emission.

Q: 11.10 Light of frequency $7.21 \times 10^{14}\ Hz$ is incident on a metal surface. Electrons with a maximum speed of $6.0 \times 10^{5}\ m/s$ are ejected from the surface. What is the threshold frequency for photoemission of electrons?

Answer:

The energy of incident photons is E given by

$$E = h\nu$$
$$E = 6.62 \times 10^{-34} \times 7.21 \times 10^{14}$$
$$E = 4.77 \times 10^{-19}\ J$$

Maximum Kinetic Energy of ejected electrons is

Work Function of the given metal is

$$\phi_0 = E - KE_{max} = 3.13 \times 10^{-19}\ J$$

The threshold frequency is therefore given by

$$\nu_0 = \frac{\phi_0}{h}$$
$$\nu_0 = 4.728 \times 10^{14}\ Hz$$

Q: 11.11 Light of wavelength $488\ nm$ is produced by an argon laser which is used in the photoelectric effect. When light from this spectral line is incident on the emitter, the stopping (cut-off) potential of photoelectrons is $0.38\ V$. Find the work function of the material from which the emitter is made.

Answer:

The energy of incident photons is given by

Cut-off potential is 0.38 eV

Work function is therefore, 2.54-0.38= 2.16 eV

Q: 11.12 (a) Calculate the momentum of the electrons accelerated through a potential difference of $56\ V$.

Answer:

On being accelerated through a potential difference of 56 V the electrons would gain a certain Kinetic energy K.

The relation between Kinetic Energy and Momentum(p) is given by

Q: 11.12 (b) Calculate the de Broglie wavelength of the electrons accelerated through a potential difference of $56\ V$.

Answer:

De Broglie wavelength is given by the De Broglie relation as

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.62\times 10^{-34}}{4.038\times 10^{-24}}$$
$$\lambda = 0.164\ nm$$

the wavelength is 0.164 nm

Q: 11.13 (a) What is the momentum of an electron with kinetic energy of $120\ eV$.

Answer:

The relation between momentum and kinetic energy is

Q: 11.13 (b) What is the speed of an electron with kinetic energy of $120\ eV$.

Answer:

The relation between speed and kinetic energy of a particle is

Q: 11.13 (c) What is the de Broglie wavelength of an electron with kinetic energy of $120\ eV$

Answer:

De Broglie wavelength is given by

The de Broglie wavelength associated with the electron is 0.112 nm

Q: 11.14 (a) The wavelength of light from the spectral emission line of sodium is $589\ nm$. Find the kinetic energy at which an electron would have the same de Broglie wavelength.

Answer:

The momentum of a particle with de Broglie wavelength of 589 nm is

$$p = \frac{h}{\lambda}$$
$$p = \frac{6.62 \times 10^{-34}}{589 \times 10^{-9}}$$
$$p = 1.12 \times 10^{-27}\ kg\ m\ s^{-1}$$

The Kinetic Energy of an electron moving with above-mentioned momentum is

Q: 11.14 (b) The wavelength of light from the spectral emission line of sodium is $589\ nm$. Find the kinetic energy at which a neutron would have the same de Broglie wavelength.

Answer:

The momentum of the neutron would be the same as that of the electron.

The kinetic energy of neutron would be

Q: 11.15 (a) What is the de Broglie wavelength of a bullet of mass $0.040\ kg$ travelling at the speed of $1.0\ km/s$.

Answer:

The momentum of the bullet is

$$p = mv$$
$$p = 0.04 \times 10^{3}$$
$$p = 40\ kg\ m\ s^{-1}$$

De Broglie wavelength is

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.62 \times 10^{-34}}{40}$$
$$\lambda = 1.655 \times 10^{-35}\ m$$

Q: 11.15 (b) What is the de Broglie wavelength of a ball of mass $0.060\ kg$ moving at a speed of $1.0\ m/s$.

Answer:

The momentum of the ball is

$$p = mv$$
$$p = 0.06\ kg\ m\ s^{-1}$$

De Broglie wavelength is

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.62 \times 10^{-34}}{0.06}$$
$$\lambda = 1.1 \times 10^{-32}\ m$$

Q: 11.15 (c) What is the de Broglie wavelength of a dust particle of mass $1.0 \times 10^{-9}\ kg$ drifting with a speed of $2.2\ m/s$?

Answer:

The momentum of the dust particle is

$$p = mv$$
$$p = 10^{-9} \times 2.2$$
$$p = 2.2 \times 10^{-9} kg\ m\ s^{-1}$$

De Broglie wavelength is

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.62 \times 10^{-34}}{2.2 \times 10^{-9}}$$
$$\lambda = 3.01 \times 10^{-25}\ m$$

Q: 11.16 (a) An electron and a photon each have a wavelength of $1.00\ nm$. Find their momenta.

Answer:

Their momenta depend only on the de Broglie wavelength, therefore, it will be the same for both the electron and the photon

$$p = \frac{h}{\lambda}$$
$$p = \frac{6.62 \times 10^{-34}}{10^{-9}}$$
$$p = 6.62 \times 10^{-25} kg\ m\ s^{-1}$$

Q: 11.16 (b) An electron and a photon each have a wavelength of $1.00\ nm$. Find the energy of the photon.

Answer:

The energy of the photon is given by

$$E = \frac{hc}{\lambda}$$

h is the Planks constant, c is the speed of the light and lambda is the wavelength

$$E = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{10^{-9}}$$

$$E = 1.86 \times 10^{-16}\ J$$

Q: 11.16 (c) An electron and a photon each have a wavelength of $1.00\ nm$. Find the kinetic energy of electron.

Answer:

The kinetic energy of the electron is. In the below equation p is the momentum

Q: 11.17 (a) For what kinetic energy of a neutron will the associated de Broglie wavelength be $1.40 \times 10^{-10}\ m$?

Answer:

For the given wavelength momentum of the neutron will be p given by

$$p = \frac{h}{\lambda}$$
$$p = \frac{6.62 \times 10^{-34}}{1.4 \times 10^{-10}}$$
$$p = 4.728 \times 10^{-24} kg\ m\ s^{-1}$$

The kinetic energy K would therefore be

$$K = \frac{p^2}{2m}$$
$$K = \frac{(4.728 \times 10^{-24})^2}{2 \times 1.675 \times 10^{-27}}$$
$$K = 6.67 \times 10^{-21} J$$

Q : 11.17 (b) Also find the de Broglie wavelength of a neutron, in thermal equilibrium with matter, having an average kinetic energy of $(3/2)\ kT$ at $300\ K$.

Answer:

The kinetic energy of the neutron is

$$K = \frac{3}{2}kT$$
$$K = \frac{3}{2} \times 1.38 \times 10^{-23} \times 300$$
$$K = 6.21 \times 10^{-21} J$$

Where k Boltzmann's Constant is 1.38×10^{-23} J/K

The momentum of the neutron will be p

Associated De Broglie wavelength is

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.62 \times 10^{-34}}{4.56 \times 10^{-24}}$$
$$\lambda = 1.45 \times 10^{-10} m$$

De Broglie wavelength of the neutron is 0.145 nm.

Q: 11.18 Show that the wavelength of electromagnetic radiation is equal to the de Broglie wavelength of its quantum (photon).

Answer:

For a photon we know that it's momentum (p) and Energy (E) are related by following equation

E=pc

we also know

$$E = h\nu$$

Therefore the De Broglie wavelength is

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{h}{E/c}$$
$$\lambda = \frac{hc}{h\nu}$$
$$\lambda = \frac{c}{\nu}$$

The above de Broglie wavelength is equal to the wavelength of electromagnetic radiation.

Q: 11.19 What is the de Broglie wavelength of a nitrogen molecule in air at $300\ K$? Assume that the molecule is moving with the root-mean-square speed of molecules at this temperature. (Atomic mass of nitrogen $= 14.0076\ \mu$)

Answer:

Since the molecule is moving with the root-mean-square speed the kinetic energy K will be given by

K=3/2 kT where k is the Boltzmann's constant and T is the absolute Temperature

In the given case Kinetic Energy of a Nitrogen molecule will be

$$K = \frac{3}{2} \times 1.38 \times 10^{-23} \times 300$$
$$K = 6.21 \times 10^{-21} J$$

Mass of Nitrogen molecule = $2 \times 14.0076 \times 1.66 \times 10^{-27} = 4.65 \times 10^{-26}$ kg

The momentum of the molecule is

$$p = \sqrt{2mK}$$
$$p = \sqrt{2 \times 4.65 \times 10^{-26} \times 6.21 \times 10^{-21}}$$
$$p = 2.4 \times 10^{-23} kg\ m\ s^{-1}$$

Associated De Broglie wavelength is

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.62 \times 10^{-34}}{2.4 \times 10^{-23}}$$
$$\lambda = 2.75 \times 10^{-11}\ m$$

The nitrogen molecule will have a De Broglie wavelength of 0.0275 nm.

NCERT solutions for class 12 physics chapter 11 dual nature of radiation and matter additional exercise

Q: 11.20 (a) Estimate the speed with which electrons emitted from a heated emitter of an evacuated tube impinge on the collector maintained at a potential difference of $500\ V$ with respect to the emitter. Ignore the small initial speeds of the electrons. The specific charge of the electron, i.e., its e/m is given to be $1.76 \times 10^{11}\ kg^{-1}$.

Answer:

The kinetic energy of an electron accelerated through Potential Difference V is K=eV where e the electronic charge.

Speed of the electrons after being accelerated through a potential difference of 500 V will be

Specific charge is $e/m_e = 1.366 \times 10^{11}$ C/kg

Q: 11.20 (b) Use the same formula you employ in (a) to obtain electron speed for an collector potential of 10 MV. Do you see what is wrong? In what way is the formula to be modified?

Answer:

Using the same formula we get the speed of electrons to be 1.88 $\times$ 10 ^{9} m/s. This is wrong because the speed of the electron is coming out to be more than the speed of light. This discrepancy is occurring because the electron will be travelling at very large speed and in such cases(relativistic) the mass of the object cannot be taken to be the same as the rest mass.

In such a case

$$m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

where m is the relativistic mass, m $_0$ is the rest mass of the body, v is the very high speed at which the body is travelling and c is the speed of light.

Q : 11.21 (a) A monoenergetic electron beam with electron speed of $5.20\times10^{6}\ ms^{-1}$ is subject to a magnetic field of $1.30\times10^{-4}\ T$ normal to the beam velocity. What is the radius of the circle traced by the beam, given e/m for electron equals $1.76\times10^{11}\ Ckg^{-1}$.

Answer:

The force due to the magnetic field on the electron will be F $_b$ =evB (since the angle between the velocity and magnetic field is 90 ^{o})

This F $_b$ acts as the centripetal force required for circular motion. Therefore

Q: 11.21 (b) Is the formula you employ in (a) valid for calculating radius of the path of a $20\ MeV$ electron beam? If not, in what way is it modified?

Answer:

The formula used in (a) can not be used. As the electron would be travelling at a very high speed we can not take its mass to be equal to its rest mass as its motion won't be within the non-relativistic limits.

The value for the mass of the electron would get modified to

$$m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

where m is the relativistic mass, m_0 is the rest mass of the body, v is the very high speed at which the body is travelling and c is the speed of light.

The radius of the circular path would be

$$r=\frac{m_e v}{eB\sqrt{1-\frac{v^2}{c^2}}}$$

Q: 11.22 An electron gun with its collector at a potential of $100\ V$ fires out electrons in a spherical bulb containing hydrogen gas at low pressure ($\sim 10^{-2}\ mm$ of Hg). A magnetic field of $2.83\times 10^{4}\ T$ curves the path of the electrons in a circular orbit of radius $12.0\ cm$ (The path can be viewed because the gas ions in the path focus the beam by attracting electrons, and emitting light by electron capture; this method is known as the 'fine beam tube' method.) . Determine e/m from the data.

Answer:

The kinetic energy of an electron after being accelerated through a potential difference of V volts is eV where e is the electronic charge.

The speed of the electron will become

$$v = \sqrt{\frac{2eV}{m_e}}$$

Since the magnetic field curves, the path of the electron in circular orbit the electron's velocity must be perpendicular to the magnetic field.

The force due to the magnetic field is therefore F_b =evB

This magnetic force acts as a centripetal force. Therefore

Q: 11.23 (a) An X-ray tube produces a continuous spectrum of radiation with its short wavelength end at $0.45\dot{A}$. What is the maximum energy of a photon in the radiation?

Answer:

The wavelength of photons with maximum energy=0.45 A°

Energy of the photons is

Q: 11.23 (b) From your answer to (a), guess what order of accelerating voltage (for electrons) is required in such a tube?

Answer:

In such a tube where X-ray of energy 27.6 keV is to be produced the electrons should be having an energy about the same value and therefore accelerating voltage should be of order 30 KeV.

Q: 11.24 In an accelerator experiment on high-energy collisions of electrons with positrons, a certain event is interpreted as annihilation of an electron-positron pair of total energy $10.2\ BeV$ into two γ -rays of equal energy. What is the wavelength associated with each γ -ray? ($1\ BeV = 10^9\ eV$)

Answer:

The total energy of 2 γ rays=10.2 BeV

The average energy of 1 γ ray, E=5.1 BeV

The wavelength of the gamma-ray is given by

Q: 11.25 (a) Estimating the following two numbers should be interesting. The first number will tell you why radio engineers do not need to worry much about photons! The second number tells you why our eye can never ‘count photons’, even in barely detectable light. The number of photons emitted per second by a Medium wave transmitter of $10\ kW$ power, emitting radiowaves of wavelength $500\ m$.

Answer:

The power emitted by the transmitter(P) =10kW

Wavelengths of photons being emiited=500 m

The energy of one photon is E

$$E = \frac{hc}{\lambda}$$
$$E = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{500}$$
$$E = 3.96 \times 10^{-28} J$$

Number of photons emitted per second(n) is given by

$$n = \frac{P}{E}$$
$$n = \frac{10000}{3.96 \times 10^{-28}}$$
$$n = 2.525 \times 10^{31} s^{-1}$$

Q: 11.25 (b) Estimating the following two numbers should be interesting. The first number will tell you why radio engineers do not need to worry much about photons! The second number tells you why our eye can never 'count photons', even in barely detectable light.The number of photons entering the pupil of our eye per second corresponding to the minimum intensity of white light that we humans can perceive $(\sim 10^{-10}\ Wm^{2})$. Take the area of the pupil to be about 0.4 cm2, and the average frequency of white light to be about $6 \times 10^{14}\ Hz$.

Answer:

The minimum perceivable intensity of white light(I)=10^{-10} Wm^{-2}

Area of the pupil(A)=0.4 cm^{2} =4 $\times$ 10^{-5} m^{2}

Power of light falling on our eyes at minimum perceivable intensity is P

P=IA

P=$10^{-10} \times 4 \times 10^{-5}$

P=4 $\times$ 10 $^{-15}$ W

The average frequency of white light(ν)=6 $\times$ 10 ^{14} Hz

The average energy of a photon in white light is

$$E = h\nu$$
$$E = 6.62 \times 10^{-34} \times 6 \times 10^{14}$$
$$E = 3.972 \times 10^{-19} J$$

Number of photons reaching our eyes is n

$$n = \frac{P}{E}$$
$$n = \frac{4 \times 10^{-15}}{3.972 \times 10^{-19}}$$
$$n = 1.008 \times 10^{4} s^{-1}$$

Q: 11.26 Ultraviolet light of wavelength $2271\ \dot{A}$ from a $100\ W$ mercury source irradiates a photo-cell made of molybdenum metal. If the stopping potential is $-1.3\ V$, estimate the work function of the metal. How would the photo-cell respond to a high intensity $(\sim 10^5\ Wm^2)$ red light of wavelength $6382\ \dot{A}$ produced by a $He - Ne$ laser?

Answer:

The energy of the incident photons is E given by

Since stopping potential is -1.3 V work function is

$$\phi_0 = 5.465 - 1.3$$
$$\phi_0 = 4.165 eV$$

The energy of photons which red light consists of is E $_R$

Since the energy of the photons which red light consists of have less energy than the work function, there will be no photoelectric emission when they are incident.

Q: 11.27 Monochromatic radiation of wavelength $640.2\ nm$ $(1\ nm = 10^{-9}\ m)$ from a neon lamp irradiates photosensitive material made of caesium on tungsten. The stopping voltage is measured to be $0.54\ V$. The source is replaced by an iron source and its $427.2\ nm$ line irradiates the same photo-cell. Predict the new stopping voltage.

Answer:

The wavelength of photons emitted by the neon lamp=640.2 nm

The energy of photons emitted by the neon lamp is E given by

Stopping potential is 0.54 V

Work function is therefore

$$\phi_0 = 1.939 - 0.54$$
$$\phi_0 = 1.399eV$$

The wavelength of photons emitted by the iron source=427.2 nm

The energy of photons emitted by the ion source is

New stopping voltage is

$E_2 - \phi_0 = 2.905 - 1.399 = 1.506V$

Q: 11.28 A mercury lamp is a convenient source for studying frequency dependence of photoelectric emission since it gives a number of spectral lines ranging from the UV to the red end of the visible spectrum. In our experiment with rubidium photo-cell, the following lines from a mercury source were used:

The stopping voltages, respectively, were measured to be

$V_{01} = 1.28\ V, V_{02} = 0.95\ V, V_{03} = 0.74\ V, V_{04} = 0.16\ V, V_{05} = 0\ V.$

Determine the value of Planck's constant h , the threshold frequency and work function for the material.

Answer:

$$h\nu = \phi_0 + eV$$
$$V = (\frac{h}{e})\nu - \phi_0$$

where V is stopping potential, h is planks constant, e is electronic charge, ν is frequency of incident photons and ϕ_0 is work function of metal in electron Volts.

To calculate the planks constant from the above date we plot the stopping potential vs frequency graph

$$\nu_1 = \frac{c}{\lambda_1} = \frac{3 \times 10^8}{3650 \times 10^{-10}} = 8.219 \times 10^{14}\ Hz$$

$$\nu_2 = \frac{c}{\lambda_2} = \frac{3 \times 10^8}{4047 \times 10^{-10}} = 7.412 \times 10^{14}\ Hz$$

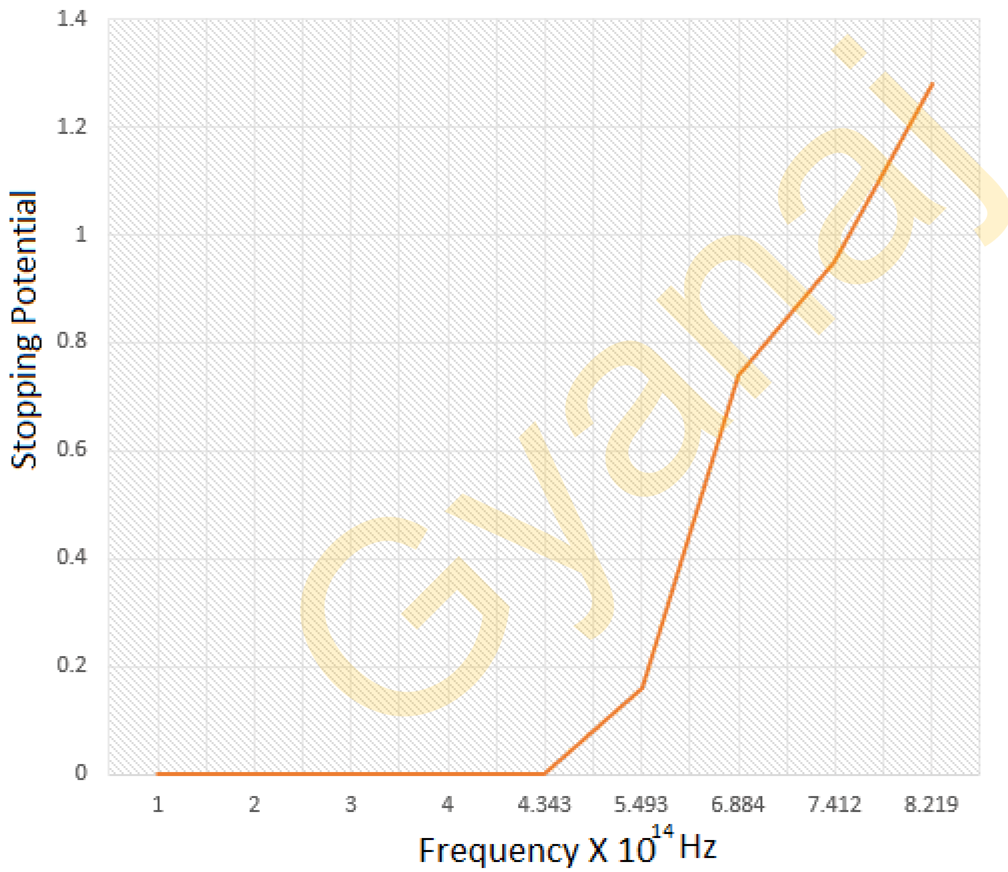
$$\nu_3 = \frac{c}{\lambda_3} = \frac{3 \times 10^8}{4358 \times 10^{-10}} = 6.884 \times 10^{14}\ Hz$$

$$\nu_4 = \frac{c}{\lambda_4} = \frac{3 \times 10^8}{5461 \times 10^{-10}} = 5.493 \times 10^{14} \ Hz$$

$$\nu_5 = \frac{c}{\lambda_5} = \frac{3 \times 10^8}{6907 \times 10^{-10}} = 4.343 \times 10^{14} \ Hz$$

$V_{01} = 1.28\ V, V_{02} = 0.95\ V, V_{03} = 0.74\ V, V_{04} = 0.16\ V, V_{05} = 0\ V.$

The plot we get is



From the above figure, we can see that the curve is almost a straight line.

The slope of the above graph will give the Plank's constant divided by the electronic charge. Planks constant calculated from the above chart is

$$h = \frac{(1.28 - 0.16) \times 1.6 \times 10^{-19}}{(8.214 - 5.493) \times 10^{14}}$$
$$h = 6.573 \times 10^{-34}\ Js$$

Planks constant calculated from the above chart is therefore $6.573 \times 10^{-34}\ Js$

Q: 11.29 The work function for the following metals is given: $Na : 2.75\ eV, K : 2.30\ eV, Mo : 4.17\ eV, Ni : 5.15\ eV.$

Which of these metals will not give photoelectric emission for a radiation of wavelength $3300\ \dot{A}$ from a $He - Cd$ laser placed $1\ m$ away from the photocell? What happens if the laser is brought nearer and placed $50\ cm$ away?

Answer:

The wavelength of the incident photons= $3300\dot{A}$

The energy of the incident photons is

Mo and Ni will not give photoelectric emission for radiation of wavelength $3300\ \dot{A}$ from a $He - Cd$.

If the laser is brought nearer no change will be there in case of Mo and Ni although there will be more photoelectrons in case of Na and K.

Q: 11.30 Light of intensity $10^{-5}\ Wm^{-2}$ falls on a sodium photo-cell of surface area $2\ cm^2$. Assuming that the top 5 layers of sodium absorb the incident energy, estimate time required for photoelectric emission in the wave-picture of radiation. The work function for the metal is given to be about $2\ eV$. What is the implication of your answer? (Effective atomic area of a sodium atom = 10^{-20} m ^{2})

Answer:

Intensity of Incident light(I) = $10^{-5}\ Wm^{-2}$

The surface area of the sodium photocell (A)=2 cm^2 = 2 $\times$ 10^{-4} m^2

The rate at which energy falls on the photo cell=IA=2 $\times$ 10^{-9} W

The rate at which each of the 5 surfaces absorbs energy= IA/5=4 $\times$ 10^{-10} W

Effective atomic area of a sodium atom (A')= 10^{-20} m^2

The rate at which each sodium atom absorbs energy is R given by

$$R = \frac{IA}{5} \times \frac{A'}{A}$$
$$R = \frac{10^{-5} \times 10^{-20}}{5}$$
$$R = 2 \times 10^{-26} J/s$$

The time required for photoelectric emission is

Q: 11.31 Crystal diffraction experiments can be performed using X-rays, or electrons accelerated through appropriate voltage. Which probe has greater energy? (For quantitative comparison, take the wavelength of the probe equal to $1\ \dot{A}$, which is of the order of inter-atomic spacing in the lattice) $(m_e = 9.11 \times 10^{-31}\ kg)$.

Answer:

According to De Broglie's equation

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

The kinetic energy of an electron with De Broglie wavelength $1\ \dot{A}$ is given by

The kinetic energy of photon having wavelength $1\ \dot{A}$ is

Therefore for the given wavelength, a photon has much higher energy than an electron.

Q:11.32 (a) Obtain the de Broglie wavelength of a neutron of kinetic energy $150\ eV$. As you have seen in Exercise 11.31, an electron beam of this energy is suitable for crystal diffraction experiments. Would a neutron beam of the same energy be equally suitable? Explain. $(m_n = 1.675 \times 10^{-27}\ kg)$

Answer:

Kinetic energy of the neutron(K)=150eV

De Broglie wavelength associated with the neutron is

Since an electron beam with the same energy has a wavelength much larger than the above-calculated wavelength of the neutron, a neutron beam of this energy is not suitable for crystal diffraction as the wavelength of the neutron is not of the order of the dimension of interatomic spacing.

Q: 11.32 (b) Obtain the de Broglie wavelength associated with thermal neutrons at room temperature $(27\ ^{\circ}C)$. Hence explain why a fast neutron beam needs to be thermalised with the environment before it can be used for neutron diffraction experiments.

Answer:

Absolute temperature = 273+27=300K

Boltzmann's Constant=1.38 $\times$ 10 $^{-23}$ J/mol/K

The de Broglie wavelength associated with the neutron is

Since this wavelength is comparable to the order of interatomic spacing of a crystal it can be used for diffraction experiments. The neutron beam is to be thermalised so that its de Broglie wavelength attains a value such that it becomes suitable for the crystal diffraction experiments.

Q:11.33 An electron microscope uses electrons accelerated by a voltage of $50\ kV$. Determine the de Broglie wavelength associated with the electrons. If other factors (such as numerical aperture, etc.) are taken to be roughly the same, how does the resolving power of an electron microscope compare with that of an optical microscope which uses yellow light?

Answer:

The potential difference through which electrons are accelerated(V)=50kV.

Kinetic energy(K) of the electrons would be eV where e is the electronic charge

The De Broglie wavelength associated with the electrons is

The wavelength of yellow light = 5.9 $\times$ 10 $^{-7}$ m

The calculated De Broglie wavelength of the electron microscope is about 10^{5} more than that of yellow light and since resolving power is inversely proportional to the wavelength the resolving power of electron microscope is roughly 10^{5} times than that of an optical microscope.

Q: 11.34 The wavelength of a probe is roughly a measure of the size of a structure that it can probe in some detail. The quark structure of protons and neutrons appears at the minute length-scale of $10^{-15}\ m$ or less. This structure was first probed in early 1970's using high energy electron beams produced by a linear accelerator at Stanford, USA. Guess what might have been the order of energy of these electron beams.

(Rest mass energy of electron $= 0.511\ MeV$.)

Answer:

Rest mass of the electron

$$= mc^2 = 0.511 MeV$$

Momentum

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

$$= \frac{6.63 \times^{-34}}{10^{-15}}$$

using the relativistic formula for energy

$$E^2 = (CP)^2 + (mc^2)^2$$

$$= (3 \times 10^8 \times 6.63 \times 10^{-19})^2 + (0.511 \times 1.6 \times 10^{-19})^2$$

$\approx 1.98 \times 10^{-10} J$

Q: 11.35 Find the typical de Broglie wavelength associated with a He atom in helium gas at room temperature ($27\ ^{\circ}C$) and 1 atm pressure, and compare it with the mean separation between two atoms under these conditions.

Answer:

The kinetic energy K of a He atom is given by

$$K = \frac{3}{2}kT$$

m $_{He}$ i.e. mass of one atom of He can be calculated as follows

(N $_{A}$ is the Avogadro's Number)

De Broglie wavelength is given by

The mean separation between two atoms is given by the relation

$$d = \left(\frac{V}{N}\right)^{\frac{1}{3}}$$

From the ideal gas equation we have

$$PV = nRT$$
$$PV = \frac{NRT}{N_A}$$
$$\frac{V}{N} = \frac{RT}{PN_A}$$

The mean separation is therefore

The mean separation is greater than the de Broglie wavelength.

Q: 11.36 Compute the typical de Broglie wavelength of an electron in a metal at $27\ ^{\circ}C$ and compare it with the mean separation between two electrons in a metal which is given to be about $2 \times 10^{-10}\ m$.

Answer:

The de Broglie wavelength associated with the electrons is

The de Broglie wavelength of the electrons is comparable to the mean separation between two electrons.

Answer the following questions:

Q: 11.37 (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?

Answer:

Quarks are thought to be tight within a proton or neutron by forces which grow tough if one tries to pull them apart. That is event though fractional charges may exist in nature, the observable charges are still integral multiples of the charge of the electron

Answer the following questions:

Q: 11.37 (b) What is so special about the combination e/m ? Why do we not simply talk of e and $m$separately?

Answer:

The speed of a charged particle is given by the relations

$$v=\sqrt{2K\left(\frac{e}{m}\right)}$$

or

$$v=Br\left(\frac{e}{m}\right)$$

As we can see the speed depends on the ratio e/m it is of such huge importance.

Answer the following questions:

Q: 11.37 (c) Why should gases be insulators at ordinary pressures and start conducting at very low pressures?

Answer:

At ordinary pressure due to a large number of collisions among themselves, the gases have no chance of reaching the electrodes while at very low pressure these collisions decrease exponentially and the gas molecules have a chance of reaching the respective electrodes and therefore are capable of conducting electricity.

Answer the following questions:

Q: 11.37 (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?

Answer:

The work function is defined as the minimum energy below which an electron will never be ejected from the metal. But when photons with high energy are incident it is possible that electrons from different orbits get ejected and would, therefore, come out of the atom with different kinetic energies.

Answer the following questions:

Q : 11.37 (e) The energy and momentum of an electron are related to the frequency and wavelength of the associated matter wave by the relations:

$$E = hv, p = \frac{h}{\lambda}$$

But while the value of λ is physically significant, the value of v (and therefore, the value of the phase speed $v\lambda$) has no physical significance. Why?

Answer:

The absolute energy has no significance because of the reference point being arbitrary and thus the inclusion of an arbitrary constant rendering the value of $\nu\lambda$ and . ν to have no physical significance as such.

The group speed is defined as

$$V_G = \frac{h}{\lambda m}$$

Due to the significance of the group speed the absolute value of wavelength has physical significance.