#420541

Topic: Photons and Photoelectric Effect

The terminology of different parts of the electromagnetic spectrum is given in the text. Use the formula $E = h\nu$ (for energy of a quantum of radiation: photon) and obtain the photon energy in units of eV for different parts of the electromagnetic spectrum. In what way are the different scales of photon energies that you obtain related to the sources electromagnetic radiation?

Solution

Photon energy $(For\, \lambda\, =\, 1\, m)$

$$= \frac{6.63\, \times\, 10^{-34}\, \times\, 3\, \times 10^{8}}{1.6\, \times\, 10^{-19}}\, eV\, =\, 1.24\, \times\, 10^{-6}\, eV$$

Photon energy for other wavelengths in the figure for electromagnetic spectrum can be obtained by multiplying approximate powers often. Energy of a photon that a source produces indicates the spacings of the relevant energy levels of the source. For example, $\lambda\, =\, 10^{-12}$ corresponds to photon energy $=\, 1.24\, \times\, 10^{6}\, eV\, =\, 1.24\, MeV$

This indicates that nuclear energy levels (transition between which causes γ-ray emission) are typically spaced by 1 MeV or so. Similarly, a visible wavelength $\lambda\, =\, 5\, \times\, 10^{-7}\, r$ corresponds to photon energy= 2.5 eV. This implies that energy levels (transition between which gives visible radiation) are typically spaced by a few eV.

#421545

Topic: Stopping Potential and Einstein's Photoelectric Equation

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

Solution

Photoelectric cut-off voltage,$v_o = 1.5V$

The maximum kinetic energy of the emitted photoelectrons is given as-

$K_e = eV_o = 2.4 \times 10^{-19}\ J$

Therefore, the maximum kinetic energy of the photoelectrons emitted in the given experiment is$2.4 \times 10^{-19}\ J$

#421666

Topic: Dual Nature

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.

Solution

Power of sunlight per $m^2 = P = 1.388 \times 10^3 W/m^2$

Average $\lambda = 550 \times 10^{-9} m$

Let n be no. of photons per m^2 incident on earth per second.

$P = nE;\ E = hc/\lambda \Rightarrow n = 3.84 \times 10^{21}\ photons/m^2/s$

#421816

Topic: Photons and Photoelectric Effect

(a) An X-ray tube produces a continuous spectrum of radiation with its short wavelength end at 0.45 . What is the maximum energy of a photon in the radiation?

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

Solution

(a) $\lambda = 0.45 \times 10^{-10} m$

maximum energy is $E = hc/\lambda = 27.6 \times 10^3 eV = 27.6 keV$

(b) Accelerating voltage provides energy to the electrons for producing X-rays. To get a X-rays of 27.6 keV, the incident electrons must possess at least $27.6keV$ of kinetic electric energy. Hence, an accelerating voltage of the order of 30 keV is required for producing X-rays.

#421834

Topic: Photons and Photoelectric Effect

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.

(a) The number of photons emitted per second by a medium wave transmitter of 10 kW power, emitting radio waves of wave length 500 m.

(b) 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 ($10^{10}\ W\ m^2$). Take tl area of the pupil to be about $0.4\ cm^2$, and the average frequency of white light to be about $6\ \times\ 10^{14}\ Hz$

Solution

(a). $P = 10^4 W$

$E_1 = hc/\lambda = 3.96 \times 10^{-28}$

$P = nE \Rightarrow n = 3 \times 10^{31}\ photons/s$

We see that the energy of a radio photon is exceedingly small, and the number of photons emitted per second in a radio beam is enormously large. There is, therefore, negligible error involved in ignoring the existence of a minimum quantum of energy (photon) and treating the total energy of a radio wave as continuous.

(b). $I = 10^{-10} Wm^{-2}$

$A = 0.4 cm^2$

$E = h\nu = 3.96 \times 10^{-9}$

$I = nE$

$n = 2.52 \times 10^8 m^2/s$

$n_A = n \times A = 10^4 s^{-1}$

Though this number is not as large as in (a) above, it is large enough for us never to sense or count individual photons by our eye.

#421839

Topic: Stopping Potential and Einstein's Photoelectric Equation

Ultraviolet light of wavelength 2271 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 ($10^5\ W\ m^2$) red light of wavelength 6328 produced by a He-Ne laser?

Solution

$\phi_0\ =\ h\ e\ V_0\ =\ 6.7\ \times\ 10^{19}\ J\ =\ 4.2\ eV;\ _0\ =\ \dfrac{\phi_0}{h}\ =\ 1.0\ \times\ 10^{15}\ Hz;\ \lambda\ =\ 6328$ corresponds to $=\ 4.7\ \times\ 10^{14}\ Hz\ <\ _0$. The photo-cell will not respond howsoever higl be the intensity of laser light.

#421843

Topic: Stopping Potential and Einstein's Photoelectric Equation

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 i 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.

Solution

Let ϕ_o be the work function.

$eV_o = h\nu - \phi_o$

$\phi_o = 1.39 eV$

radiation wavelength emitted by iron $\lambda = 427.2 nm$

Let V_o' be the new stopping potential.

$eV_o' = (hc/\lambda) - \phi_o = 1.50 eV$

#421896

Topic: Photons and Photoelectric Effect

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 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 ?

Solution

It is found that the given incident frequency is greater than $\nu_0(Na)$, and $\nu_0(K)$; but less than $\nu_0(Mo)$, and $\nu_0(Ni)$. Therefore, Mo and Ni will not give photoelectric emissior If the laser is brought closer, intensity of radiation increases, but this does not affect the result regarding Mo and Ni. However, photoelectric current from Na and K will increas in proportion to intensity.

#421905

Topic: Stopping Potential and Einstein's Photoelectric Equation

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 fo 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?

Solution

Assume one conduction electron per atom. Effective atomic area $\sim 10^{-20}\ m^2$

2Number of electrons in 5 layers

$= \dfrac{5\times\ 2\times\ 10^{-4}\ m^2}{10^{-20}m^2}$

Incident power

$10^{-5}Wm{-}2\times\ 2\times\ 10^{-4}m^2 = 2\times 10{-}9$

In the wave picture, incident power is uniformly absorbed by all theelectrons continuously. Consequently, energy absorbed per second per electron

$= 2\times 1.62\ \times 10^{-9}/10^{17} = 2\times\ 10^{-26}W$Time required for photoelectric emission

$= 2\times\ 1.6\times\ 10^{-19}J/2\times\ 10^{-26}W = 1.6\times\ 10^{7}s$

which is about 0.5 year.

Implication: Experimentally, photoelectric emission is observed nearly instantaneously (109 s): Thus, the wave picture is in gross disagreement with experiment. In the photon-picture, energy of theradiation is not continuously shared by all the electrons in the toplayers. Rather, energy comes in discontinuous quanta. andabsorption of energy does no take place gradually. A photon is eithernot absorbed, or absorbed by an electron nearly instantly

#421910

Topic: Photons and Photoelectric Effect

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 wave length of the probe equal to 1 A° which is of the order of inter-atomic spacing in the lattice) ($m_e = 9.1110^{31}kg$).

Solution

For $\lambda = 1A^{\circ}$, electrons energy = 150 e V; photons energy = 12.4 keV. Thus, for the same wavelength, a photon has much greater energy than an electron.

#421925

Topic: Dual Nature

(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)

(b) Obtain the de Broglie wavelength associated with thermal neutrons at room temperature (27^oC). Hence, explain why a fast neutron beam needs to be thermalised with the environment before it can be used for neutron diffraction experiments.

Exercise 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 wave length of the probe equal to 1 A∘ which is of the order of inter-atomic spacing in the lattice) ($m_e = 9.11\times 10^{-31}kg$)

Solution

The relationship between the wavelength and the mass of a particle is

$\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2mK}}$

Thus, for same K, the wavelength is inversely proportional to the square root of mass as $1/\sqrt{m}$.

Now, $(\dfrac{m_n}{m_e}) =$ 1838.6, therefore for the same energy (150 eV)

(a) Wavelength of neutron = $1/\sqrt{1838.6}\ \times 10^{-10}m = 2.33\times 10^{-12}m$

The interatomic spacing is about a hundred times greater. A neutron beam of 150 eV energy is therefore not suitable for diffraction experiments.

(b) $\lambda = 1.45\times 10^{-10}m[use\lambda = [h/\sqrt{3mkT}]$which is comparable to interatomic spacing in a crystal.

Clearly, from (a) and (b) above, thermal neutrons are a suitable probe for diffraction experiments, so a high energy neutron beam should be first thermalised before using it for diffraction.

#421933

Topic: Dual Nature

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 numeric 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?

Solution

$\lambda = 5.5 \times 10^{-12} m(yellow\ light) = 5.9 \times 10^{-7}$m

Resolving Power (RP) is inversely proportional to wavelength. Thus, RP of an electron microscope is about 10^5 times that of an optical microscope. In practice, differences in other (geometrical) factor can change this comparison somewhat.

#421983

Topic: Dual Nature

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.

Solution

$\lambda = \dfrac{h}{\sqrt{3mkT}} : m_{11e} = \dfrac{4 \times 10^3}{6 \times 10^{23}}$

$\lambda = 0.73 \times 10^{-10}$m.

Mean sepration, r =$(V/N^{\frac{1}{3}})$= $(kT/p)^{\frac{1}{3}}$

for T = 300 K , p = 1.01$\times 10^5 Pa, r = 3.4 \times 10^{-9} m$

$r >> \lambda$

#422010

Topic: Dual Nature

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 Millikans 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 pressures?

(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 v, p = $\dfrac{h}{\lambda}$.

But while the value of λ is physically significant, the value of ν (and therefore, the value of the phase speed n λ) has no physical significance. Why?

Solution

(a) Quarks are thought to be confined within a proton or neutron by forces which grow stronger if one tries to pull them apart. It, therefore, seems that though fractional charge may exist in nature, observable charges are still integral multiples of e.

(b) Both the basic relations, $e\,V = (1/2)m\,v^2$ or $e\,E = m\,a$ and $e\,B\,v = m\,v^2/r$, for electric and magnetic fields, respectively, show that the dynamics of electrons is determined not by e, and m separately but by the combination e/m .

(c) At low pressures, ions have a chance to reach their respective electrodes and constitute a current. At ordinary pressures, ions have no chance to do so because of collision with gas molecule and recombination.

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

(e) The absolute value of energy E (but not momentum p) of any particle is arbitrary to within an additive constant. Hence, while is physically significant, absolute value of of a matter wave of an electron has no direct physical meaning. The phase speed is likewise not physically significant. The group speed given by $\dfrac{dv}{d(1/\lambda)} = \dfrac{dE}{dp}\left(\dfrac{p^2}{2m}\right) = \dfrac{p}{m}$, is physically meaningful.