PHYSICS

NCERT - NCERT PHYSICS(GUJRATI)

DUAL NATURE OF RADIATION AND MATTER

Example

1. Monochromatic light of frequency $6.0 \times 10^{14} Hz$ is produced by a laser. The power emitted is $2.0 \times 10^{-3} W$. (a) What is the energy of a photon in the light beam? (b) How many photons per second, on an average, are emitted by the source?

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2. The work function of caesium is 2.14 ev. Find (a) the threshold frequency for caesium, and (b) the wavelength of the incident light if the photocurrent is brought to zero by a stopping potential of 0.60 V.

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3. The wavelength of light in the visible region is about 390 nm for violet colour, about 550 nm (average wavelength) for yellowgreen colour and about 760 nm for red colour. (a) What are the energies of photons in (eV) at the (i) violet end, (ii) average wavelength, yellow-green colour, and (iii) red end of the visible spectrum? $\left(\text{Take h } = 6.63 \times 10^{-34} \text{ J s and 1 eV} = 1.6 \times 10^{-19} J.\right)$

(b) From which of the photosensitive materials with work functions listed in Table 11.1 and using the results of (i), (ii) and

(iii) of (a), can you build a photoelectric device that operates with visible light?

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4. What is the de Broglie wavelength associated with (a) an electron moving with a speed of $5.4 \times 10^6 m/s$, and (b) a ball of mass 150 g travelling at $30.0 m/s$?

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5. An electron, an $\alpha -$ particle, and a proton have the same kinetic energy. Which of these particles has the shortest de Broglie wavelength?

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6. A particle is moving three times as fast as an electron. The ratio of the de Broglie wavelength of the particle to that of the electron is 1.813×10^{-4}. Calculate the particle's mass and identify the particle.

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7. What is the de - Broglie wavelength associated with an electron, accelerated through a potential difference of 100 Volts ?

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Exercises

1. Find the

(a) maximum frequency, and

(b) minimum wavelength of X-rays produced by 30 kv electrons.

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2. 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

(a) maximum kinetic energy of the emitted electrons,

(b) Stopping potential, and

(c) maximum speed of the emitted photoelectrons?

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

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4. Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW.

(a) Find the energy and momentum of each photon in the light beam,

(b) 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), and

(c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

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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.

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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.

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7. 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. (a) What is the energy per photon associated with the sodium light? (b) At what rate are the photons delivered to the sphere?

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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.

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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?

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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?

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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.

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12. Calculate the

(a) momentum, and

(b) de Broglie wavelength of the electrons accelerated through a potential difference of 56 V.

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13. What is the

(a) momentum,

(b) speed, and

(c) de Broglie wavelength of an electron with kinetic energy of 120 eV.

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14. The wavelength of light from the spectral emission line of sodium is 589 nm. Find the kinetic energy at which

(a) an electron, and

(b) a neutron, would have the same de Broglie wavelength.

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15. What is the de Broglie wavelength of

(a) a bullet of mass 0.040 kg travelling at the speed of $1.0 km / s$,

(b) a ball of mass 0.060 kg moving at a speed of $1.0 m / s$, and

(c) a dust particle of mass $1.0 \times 10^{-9} kg$ drifting with a speed of $2.2 m / s$?

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16. An electron and a photon each have a wavelength of 1.00 nm. Find

(a) their momenta,

(b) the energy of the photon, and

(c) the kinetic energy of electron.

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

(b) Also find the de Broglie wavelength of a neutron, in thermal equilibrium with matter, having an average kinetic energy of (3/2) k T at 300 K.

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

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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-meansquare speed of molecules at this temperature. (Atomic mass of nitrogen = 14.0076 u)

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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 $1.76 \times 10^{11} C kg^{-1}$.

(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?

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21. (a) A monoenergetic electron beam with electron speed of $5.20 \times 10^{6} m s^{-1}$ is subject to a magnetic field of $1.30 \times 10^{-4} T$ normal to the beam velocity. What is the radius of the circle traced by the beam, given e/m for electron equals

$1.76 \times 10^{11} C kg^{-1}$.

(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?

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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 $(\sim 10^{-2} \text{ mm of Hg})$. 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.

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23. (a) An X-ray tube produces a continuous spectrum of radiation with its short wavelength end at 0.45Å. 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 ?

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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 $\gamma-$ rays of equal energy. What is the wavelength associated with each $\gamma-$ ray? $\left(1 \text{Bev} = 10^9 eV\right)$

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25. 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 radiowaves of wavelength 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 $(\sim 10^{-10} Wm^{-2})$. Take the area of the pupil to be about 0.4 cm2 , and the average frequency of white light to be about $6 \times 10^{14} Hz$

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26. Ultraviolet light of wavelength 2271Å from a 100 W mercury source irradiates a photo-cell made of molybdenum metal. If the stopping potential is $-1.3V$, estimate the work function of the metal. How would the photo-cell respond to a high intensity $\left(\sim 10^5 W m^2\right)$ red light of wavelength 6328Å produced by a He-Ne laser ?

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27. Monochromatic radiation of wavelength 640.2 nm $\left(1nm = 10^{-9}m\right)$ 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.

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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:

$\lambda_1 = 3650Å, \lambda_2 = 4047Å, \lambda_3 = 4358Å, \lambda_4 = 5461Å, \lambda_5 = 6907Å$

,

The stopping voltages, respectively, were measured to be:

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

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

[Note: You will notice that to get h from the data, you will need to know e (which you can take to be $1.6 \times 10^{-19}C$). Experiments of this kind on Na, Li, K, etc. were performed by

Millikan, who, using his own value of e (from the oil-drop experiment) confirmed Einstein's photoelectric equation and at the same time gave an independent estimate of the value of h.]

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29. The work function for the following metals is given: $Na : 2.75eV, K : 2.30eV, Mo : 4.17eV, Ni : 5.15ev$. Which of these metals will not give photoelectric emission for a radiation of wavelength 3300Å 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 ?

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30. Light of intensity $10^{-5} Wm^{-2}$ falls on a sodium photo-cell of surface area $2cm^2$. 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?

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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 1Å, which is of the order of inter-atomic spacing in the lattice) $\left(m_e = 9.11 \times 10^{-31} kg\right)$.

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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. $(m_n = 1.675 \times 10^{-27} kg)$

(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.

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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?

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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.)

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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.

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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 $2 \times 10^{-10}m$.

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37. 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?

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38. Answer the following questions:

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

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39. Answer the following questions:

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

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40. Answer the following questions:

(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?

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41. Answer the following questions:

(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 ν (and therefore, the value of the phase speed $\nu\lambda$) has no physical significance. Why?

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