Class 12 Physics · Chapter 11: Dual Nature of Radiation and Matter

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. Very intense light of frequency below the threshold frequency of a metal falls on it for a long time. The photoelectrons emitted [1]

(a) are few, but of large kinetic energy
(b) are none at all
(c) are many, but of small kinetic energy
(d) appear only after a time that depends on the intensity

Answer: (b) Emission needs $h\nu > \phi_0$, that is $\nu > \nu_0$. Below ν_0 no electron is emitted, however intense the radiation or however long it falls, because each electron absorbs a single quantum, and one quantum is too small.

2. Which statement about photons is not correct? [1]

(a) A photon is deflected by a magnetic field.
(b) A photon of frequency ν has energy $h\nu$.
(c) In vacuum every photon travels at speed c.
(d) The number of photons may change in a collision with a particle.

Answer: (a) Photons are electrically neutral and are not deflected by electric or magnetic fields. The other three statements are photon properties: $E = h\nu$, speed c, and in a photon-particle collision the number of photons may not be conserved.

3. An uncharged zinc plate, mounted on an electroscope, is exposed to ultraviolet light. The plate [1]

(a) becomes negatively charged
(b) becomes positively charged
(c) stays uncharged
(d) first gains and then loses positive charge

Answer: (b) Ultraviolet light ejects negatively charged particles (electrons) from zinc, so an initially uncharged plate is left positively charged, as Hallwachs observed.

4. Light of frequency above the threshold, but of very low intensity, falls on a clean metal surface. Photoelectric emission begins [1]

(a) within about 10^{-9} s or less
(b) after a few seconds
(c) after several minutes, as energy builds up
(d) only after hours, unless the intensity is raised

Answer: (a) Above the threshold frequency emission starts without apparent time lag even for very dim radiation, in a time of the order of 10^{-9} s or less. A delay that grows as the intensity falls is what the wave picture predicts, and is not observed.

5. The light on a photosensitive surface is changed to one of higher frequency, its intensity kept the same. Compared with before, [1]

(a) the stopping potential is the same and the saturation current is larger
(b) both the stopping potential and the saturation current are larger
(c) the stopping potential is smaller in magnitude and the saturation current is the same
(d) the stopping potential is larger in magnitude and the saturation current is the same

Answer: (d) At the same intensity, curves for different frequencies reach the same saturation current, but the stopping potential is more negative for the higher frequency: the greater the frequency, the greater Kmax and hence V_0.

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6. Ultraviolet light of wavelength 300 nm falls on two metal plates, X of work function 2.3 eV and Y of work function 4.5 eV. Which plate emits photoelectrons, and with what maximum kinetic energy? What is the longest wavelength that would eject electrons from the other plate? ($h = 6.63 \times 10^{-34}$ J s, $e = 1.6 \times 10^{-19}$ C, $c = 3 \times 10^{8}$ m s^{-1}) [2]

Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3 \times 10^{8})/(300 \times 10^{-9}) = 6.63 \times 10^{-19}$ J $= 6.63 \times 10^{-19}/1.6 \times 10^{-19} \approx 4.1$ eV. Emission needs $E > \phi_0$, so only X emits, with Kmax = 4.1 − 2.3 ≈ 1.8 eV; Y (4.5 eV) does not. For Y, $\lambda_0 = hc/\phi_0 = (6.63 \times 10^{-34} \times 3 \times 10^{8})/(4.5 \times 1.6 \times 10^{-19}) \approx 2.8 \times 10^{-7}$ m = 276 nm; only light shorter than this ejects electrons from Y.

- $E \approx 4.1$ eV; only X emits, Kmax ≈ 1.8 eV (1)
- λ_0 for Y ≈ 276 nm (1)

7. On the wave picture of light, how long would one expect an electron to take to escape from a metal under very dim light? How does this compare with what is observed? [2]

In the wave picture the energy of the radiation is spread continuously over the whole wavefront and shared by a very large number of electrons, so each absorbs only a little per unit time; calculations estimate that an electron could take hours or more to gather the work function. Observed: above the threshold, emission starts instantaneously, in about 10^{-9} s or less, even for very dim light.

- wave picture: energy shared over the wavefront, time lag of hours or more (1)
- observed: no time lag, ~10^{-9} s or less (1)

8. A red lamp (wavelength 700 nm) and a violet lamp (wavelength 400 nm) each emit light energy at the same rate of 1.0 W. Which lamp emits more photons per second? Find the ratio of the two numbers. [2]

Number per second $N = P/E = P\lambda/hc$. At equal power $N \propto \lambda$, so the red lamp, whose photons each carry less energy, emits more photons per second. N(red)/N(violet) = 700/400 = 1.75.

- $N = P/E = P\lambda/hc$, so red emits more (1)
- ratio 1.75 (1)

9. Write Einstein's photoelectric equation. Use it to explain (i) why there is a threshold frequency, and (ii) why the maximum kinetic energy of photoelectrons does not depend on the intensity of light. [3]

$K_{max} = h\nu - \phi_0$, where an electron absorbs one quantum $h\nu$ and spends at least ϕ_0 to escape. (i) Kmax cannot be negative, so emission needs $h\nu > \phi_0$, that is $\nu > \nu_0 = \phi_0/h$; below ν_0 no single quantum has enough energy, however many quanta arrive. (ii) Intensity fixes the number of photons per second, not the energy of each; since one quantum is absorbed by one electron, Kmax is fixed by $h\nu$ and ϕ_0 alone.

- $K_{max} = h\nu - \phi_0$ with terms explained (1)
- threshold: $h\nu > \phi_0$ needed, $\nu_0 = \phi_0/h$ (1)
- intensity = photon number; one photon per electron (1)

10. Light of frequency ν_1 falling on a metal gives a stopping potential of 1.0 V. Light of frequency $1.5\nu_1$ on the same metal gives a stopping potential of 2.5 V. Find (a) the work function of the metal in eV, (b) ν_1, and (c) the threshold frequency. ($h = 6.63 \times 10^{-34}$ J s, $e = 1.6 \times 10^{-19}$ C) [3]

$eV_0 = h\nu - \phi_0$. In eV: $h\nu_1 = 1.0 + \phi_0$ and $1.5h\nu_1 = 2.5 + \phi_0$. Substituting, $1.5(1.0 + \phi_0) = 2.5 + \phi_0$, so $0.5\phi_0 = 1.0$ and (a) $\phi_0 = 2.0$ eV. (b) $h\nu_1 = 3.0$ eV, so $\nu_1 = 3.0 \times 1.6 \times 10^{-19}/6.63 \times 10^{-34} \approx 7.2 \times 10^{14}$ Hz. (c) $\nu_0 = \phi_0/h = 2.0 \times 1.6 \times 10^{-19}/6.63 \times 10^{-34} \approx 4.8 \times 10^{14}$ Hz.

- two equations, $\phi_0 = 2.0$ eV (1)
- $\nu_1 \approx 7.2 \times 10^{14}$ Hz (1)
- $\nu_0 \approx 4.8 \times 10^{14}$ Hz (1)

11. (a) What did J. J. Thomson measure for cathode ray particles, and why did his result suggest that these particles are universal? (b) Millikan found the elementary charge to be 1.602×10^{-19} C. Taking e/m = 1.76×10^{11} C kg^{-1}, find the mass of the electron. [3]

(a) Using mutually perpendicular electric and magnetic fields, Thomson measured the speed and the specific charge e/m of cathode ray particles. e/m was found to be the same whatever the cathode metal or the gas in the tube, which suggested that the particles are universal constituents of matter (electrons). (b) $m = e/(e/m) = 1.602 \times 10^{-19} / 1.76 \times 10^{11} \approx 9.1 \times 10^{-31}$ kg.

- speed and e/m measured with crossed fields (1)
- e/m independent of metal and gas, so universal (1)
- $m \approx 9.1 \times 10^{-31}$ kg (1)