CLASS XII – PHYSICS (042)
STEP-BY-STEP SOLUTIONS AND MARKING SCHEME

Chapter 11: Dual Nature of Radiation and Matter – Practice Paper (35 Marks)

Answer key – Section A

Q.	1	2	3	4	5	6	7	8	9
Ans.	(c)	(b)	(a)	(d)	(b)	(c)	(a)	(b)	(d)

Marks are shown in square brackets. Equivalent correct methods are acceptable. Key relations: $E = h\nu = hc/\lambda$; $K_{max} = h\nu - \varphi_0 = eV_0$; $\nu_0 = \varphi_0/h$; $\lambda = h/p$; $p = h/\lambda$; $N = P/E$.

SECTION A

Q.1 (c)

Both curves stop at the same retarding potential (−2 V), so the maximum kinetic energy, and hence the frequency, is the same. The saturation currents are 20 µA and 10 µA, and saturation current is proportional to the number of photons per second, i.e. to the intensity. So beam 1 has twice the intensity of beam 2. **[1]**

Q.2 (b)

Slope of the graph = 1.6 eV/(4 × 10^{14} Hz) = 4 × 10^{-15} eV s = h. The line meets the axis at ν_0 = 6 × 10^{14} Hz. Work function $\varphi_0 = h\nu_0 = 4 \times 10^{-15} \times 6 \times 10^{14} = 2.4$ eV. (1.6 eV is K at 10 × 10^{14} Hz and 4.0 eV is hν there.) **[1]**

Q.3 (a)

Emission is possible only if ν exceeds the threshold frequency. The thresholds are 4, 6 and 8 (× 10^{14} Hz) for P, Q and R. Since 7 × 10^{14} Hz is greater than the thresholds of P and Q but less than that of R, emission occurs from P and Q only. **[1]**

Q.4 (d)

The current just becomes zero at the stopping potential, so $K_{max} = eV_0 = 1.5$ eV. $\varphi_0 = h\nu - K_{max} = 4.5 - 1.5 = 3.0$ eV. **[1]**

Q.5 (b)

$p = mv = 0.25 \times 4 = 1.0$ kg m s^{-1}. $\lambda = h/p = 6.6 \times 10^{-34}/1.0 = 6.6 \times 10^{-34}$ m, far too small to be observed. **[1]**

Q.6 (c)

Energy of a photon $E = hc/\lambda = (6.6 \times 10^{-34} \times 3 \times 10^{8})/(6.6 \times 10^{-7}) = 3 \times 10^{-19}$ J. Photons per second $N = P/E = (6 \times 10^{-3})/(3 \times 10^{-19}) = 2 \times 10^{16}$. **[1]**

Q.7 (a)

Momentum of the photon $p = h/\lambda = 6.6 \times 10^{-34}/(6 \times 10^{-7}) = 1.1 \times 10^{-27}$ kg m s^{-1}. On reflection it reverses, so the change = $p - (-p) = 2p = 2.2 \times 10^{-27}$ kg m s^{-1}. **[1]**

Q.8 (b)

A is true: V_0 is fixed by $K_{max} = h\nu - \varphi_0$, which does not depend on intensity. R is also true, but it does not explain A; the explanation is that K_{max} depends on the energy of a single photon, not on the number of photons. **[1]**

Q.9 (d)

A is false: below the threshold frequency no emission occurs, however intense the light is or however long it falls. R is true: one electron absorbs one photon, and energy of several photons is not pooled. **[1]**

SECTION B

Q.10

(a) A metal shows emission if the photon energy (3.0 eV) exceeds its work function. Cs (2.0 eV) and Na (2.5 eV) emit; Zn (4.3 eV) and Pt (5.6 eV) do not. **[1]**

(b) $K_{max} = h\nu - \varphi_0$: for Cs = 3.0 − 2.0 = 1.0 eV; for Na = 3.0 − 2.5 = 0.5 eV. **[1]**

Q.11

From the point (0.10, 1.23) on the straight line through the origin, $\lambda = 12.3/\sqrt{V}$ Å. (a) For V = 225 V, $1/\sqrt{V} = 1/15$, so $\lambda = 12.3/15 = 0.82$ Å. **[1]**

(b) For $\lambda = 0.41$ Å, $\sqrt{V} = 12.3/0.41 = 30$, so V = 900 V. **[1]**

Q.12

(A) (a) Photon energy of A = 1240/400 = 3.1 eV. The stopping potential of A is 0.6 V, so K_{max} = 0.6 eV. $\varphi_0 = 3.1 - 0.6 = 2.5$ eV. **[1]**

(b) For B the stopping potential is 1.5 V, so the photon energy = $\varphi_0 + 1.5 = 4.0$ eV. $\lambda = 1240/4.0 = 310$ nm. **[1]**

OR (B) Einstein's equation: $K_{max} = h\nu - \varphi_0$ (a photon of energy $h\nu$ gives all its energy to one electron). **[1]**

K_{max} cannot be negative, so emission needs $h\nu \geq \varphi_0$, i.e. $\nu \geq \nu_0 = \varphi_0/h$. Below ν_0 each photon has too little energy and an electron cannot gather energy from several photons, so a large intensity (many photons) does not help. **[1]**

Q.13

(a) Photon energy = 1240/496 = 2.5 eV = $2.5 \times 1.6 \times 10^{-19} = 4.0 \times 10^{-19}$ J. N = P/E = $(2.0 \times 10^{-3})/(4.0 \times 10^{-19}) = 5 \times 10^{15}$ photons per second. **[1]**

(b) Electrons emitted per second = $5 \times 10^{15}/100 = 5 \times 10^{13}$. Saturation current I = ne = $5 \times 10^{13} \times 1.6 \times 10^{-19} = 8 \times 10^{-6}$ A = 8 µA. **[1]**

SECTION C

Q.14

(a) Beams a and b have the same stopping potential (−2.0 V), so they have the same frequency. Their saturation currents are 20 µA and 10 µA, so the intensity of a is twice that of b. **[1]**

(b) Beams b and c have the same saturation current (10 µA), so they have the same intensity. Beam c has the greater stopping potential (3.5 V against 2.0 V), so it has the greater frequency. **[1]**

(c) $K_{max} = eV_0$: for a, K = 2.0 eV; for c, K = 3.5 eV. As φ_0 is the same, $h\nu_c - h\nu_b = K_c - K_b = 3.5 - 2.0 = 1.5$ eV. **[1]**

Q.15

(A) (a) $E_X = 1240/400 = 3.1$ eV; $E_Y = 1240/800 = 1.55$ eV. **[1]**

(b) Only X causes emission, since 3.1 eV > 2.0 eV while 1.55 eV < 2.0 eV, and no photon of Y can free an electron, however many arrive. The wave theory would predict that the very bright beam Y delivers more energy and should eject electrons (after enough time), while the dim X should not, which is the opposite of what is observed. **[1]**

(c) $K_{max} = 3.1 - 2.0 = 1.1$ eV. **[1]**

OR (B) De Broglie's hypothesis: a moving particle of momentum p has a wave associated with it, of wavelength $\lambda = h/p$. **[1]**

For a photon, $E = h\nu$ and $p = E/c = h\nu/c$. So $\lambda = h/p = c/\nu$, which is the wavelength of the radiation. **[1]**

For everyday objects the mass, and hence the momentum, is large, so $\lambda = h/p$ is far too small (h is very small) to be detected, and no wave effects are seen. **[1]**

Q.16

(a) $\lambda = 12.3/\sqrt{100} = 1.23$ Å. **[1]**

(b) The photon has the same λ, so $E = hc/\lambda = 12400$ eV Å/1.23 Å ≈ 10,000 eV ≈ 10 keV (about 10.1 keV). **[1]**

(c) $p = h/\lambda$ for both, so the momenta are equal. The photon has the greater energy: 10 keV against 100 eV (electron), about 100 times. **[1]**

SECTION D

Q.17

(i) (b). $V_0 = (h/e)\nu - \varphi_0/e$, so the slope = h/e. **[1]**

(ii) (b). The line meets the axis at 4.5×10^{14} Hz, and this is the threshold frequency. **[1]**

(iii) (b). Slope = $(2.0 - 0.8)/[(9.5 - 6.5) \times 10^{14}] = 4 \times 10^{-15}$ V s. $\varphi_0 = e \times \text{slope} \times \nu_0 = 4 \times 10^{-15} \times 4.5 \times 10^{14} = 1.8$ eV. **[1]**

(iv) (b). $h = e \times \text{slope} = 1.6 \times 10^{-19} \times 4 \times 10^{-15} = 6.4 \times 10^{-34}$ J s. **[1]**

OR (iv) (b). $\nu_0 = \varphi_0/h = 2.4/(4 \times 10^{-15}) = 6.0 \times 10^{14}$ Hz (the slope h/e is the same for every metal). **[1]**

SECTION E

Q.18

(A) (a) Light consists of photons, each of energy $h\nu$. One photon is absorbed by one electron. Part of the energy, φ_0, is used to leave the metal and the rest appears as kinetic energy. Energy conservation gives $h\nu = \varphi_0 + K_{max}$, i.e. $K_{max} = h\nu - \varphi_0 = eV_0$. **[1]**

(i) $K_{max} \geq 0$ requires $h\nu \geq \varphi_0$, i.e. $\nu \geq \nu_0 = \varphi_0/h$, the threshold frequency; below it no emission occurs. **[1]**

(ii) Intensity is the number of photons per second. More photons eject more electrons per second, so the saturation current rises from I_1 to I_3 in the graph. But each photon has the same energy $h\nu$, so K_{max} and V_0 (the common cut-off point $-V_0$) do not change. **[1]**

(b) $h\nu = 1240/248 = 5.0$ eV. $K_{max} = 5.0 - 2.0 = 3.0$ eV; stopping potential = 3.0 V; threshold wavelength $\lambda_0 = 1240/2.0 = 620$ nm. **[2]**

OR (B) (a) De Broglie's relation: $\lambda = h/p$. For the particle, the work done by the field = kinetic energy: $qV = p^2/2m$. **[1]**

So $p = \sqrt{(2mqV)}$. **[1]**

Therefore $\lambda = h/p = h/\sqrt{(2mqV)}$. **[1]**

(b)(i) For the same V, $\lambda \propto 1/\sqrt{(mq)}$. $\lambda_p/\lambda_\alpha = \sqrt{(4m \times 2e/(m \times e))} = \sqrt{8} = 2\sqrt{2}$, so the ratio is $2\sqrt{2} : 1$. **[1]**

(ii) For the same kinetic energy K, $p = \sqrt{(2mK)}$, so $\lambda \propto 1/\sqrt{m}$. $\lambda_p/\lambda_\alpha = \sqrt{(4m/m)} = 2$, so the ratio is $2 : 1$. **[1]**

— End of Solutions —