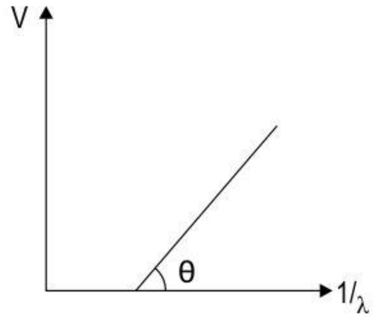
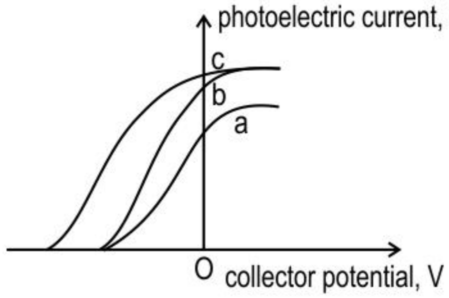
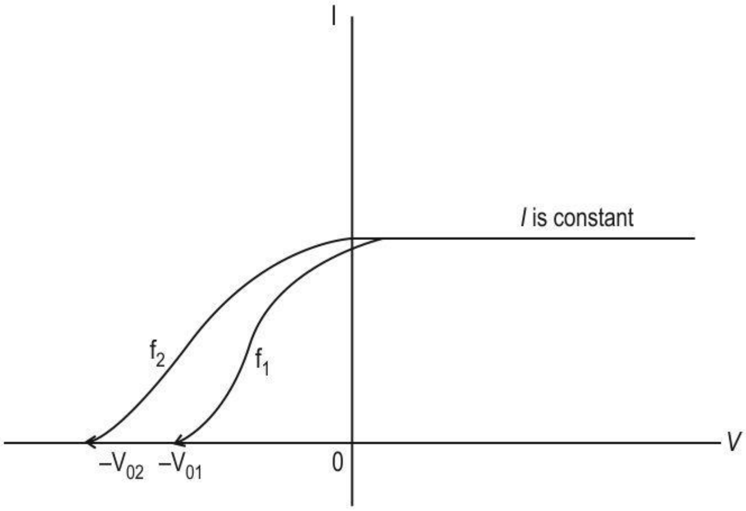
Dual Nature of Radiation and Matter

Q.No	Question	Marks
Multiple Choice Question		
Q.138	An electron and proton when accelerated through a certain potential difference get associated with de Broglie wavelengths λ_e and λ_p respectively. Consider the ratio of the mass of the proton (m_p) to the mass of the electron (m_e), m_p/m_e= 1837 Read the following statements carefully. I. If the two given particles have equal energies, then $\lambda_p/ \lambda_e = 1/\sqrt{1837}$ II. If the velocities of the two particles is v_e and v_p respectively, then $\lambda_p/ \lambda_e = \sqrt{(v_e/ 1837v_p)}$ III. If the accelerating potential V is the same for the two particles, then $\lambda_p/ \lambda_e = 1/ \sqrt{1837}$ Select the correct option. A. All statements are true B. All statements are false C. Only statements i & ii are correct D. Only statements I & III are correct	1
Q.139	A light of wavelength belonging to the blue region of the visible spectrum causes photoelectric emission in a metal. When light of wavelength belonging to the red region is incident on the metal, photoelectric emission does not take place. When an em wave belonging to IR region is incident on the metal, will photoelectric emission take place? Why/ why not? A. Yes, because IR rays are highly energetic. B. No, because IR rays cannot cause photoelectric emission. C. Yes, because IR rays have a higher frequency than red light. D. No, because IR rays have a longer wavelength than red light.	1
Q.140	Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R.	1

	Assertion (A): De Broglie's wavelength of a freely falling body keeps decreasing with time. Reason (R): The momentum of the freely falling body increases with time. Select the correct option: A. Both assertion and reason are true and reason is the correct explanation for assertion. B. Both assertion and reason are true but reason is not the correct explanation for assertion. C. Assertion is true but reason is false. D. Assertion is false but reason is true.	
Q.141	Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R. Assertion (A): The photoelectric effect supports the wave nature of light. Reason (R): There exists a maximum wavelength above which photoelectric emission does NOT take place. A. Both assertion and reason are true and reason is the correct explanation for assertion. B. Both assertion and reason are true but reason is not the correct explanation for assertion. C. Assertion is true but the reason is false. D. Assertion is false but the reason is true.	1
Q.142	Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R. Assertion (A): If electrons pass through a double-slit, an interference pattern is produced. Reason (R): Electrons behave as both particles and waves. Select the correct option. A. Both assertion and reason are true and reason is the correct explanation for assertion. B. Both assertion and reason are true but reason is not the correct explanation for assertion. C. Assertion is true but the reason is false. D. Assertion is false but the reason is true.	1

Q.143	In a photoelectric effect experiment, the graph of stopping potential V versus reciprocal of wavelength λ of incident light for a given material is plotted below.  If the existing material is replaced with another material and the intensity of the light is increased, which of the following is most likely to happen? A. The slope theta of the line will increase. B. The slope theta of the line will decrease. C. There will not be any change in the graph. D. The line will cut the 1/λ axis at a different point.	1
Q.144	A certain device is designed that can generate current using the heat radiations emitted by the surrounding bodies. The frequency range of heat radiations is between 3×10^{11} Hz to 4×10^{14} Hz. What should be the maximum work function of this device so that it can generate current corresponding to all possible heat radiations? (Plank constant $h = 4.14 \times 10^{-15}$ eV Hz^{-1}) A. 0.1242×10^{-2} eV B. 12.42×10^{-2} eV C. 1.656 eV D. 16.56 eV	1
Q.145	Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R. Assertion(A): The number of photoelectrons ejected from a metal increases if the intensity of the light source is increased for a frequency greater than the threshold frequency. Reason(R): An increase in the intensity of light increases the energy of each photon. A. Both assertion and reason are true and reason is the correct explanation for assertion.	1

	B. Both assertion and reason are true but reason is not the correct explanation for assertion. C. Assertion is true but the reason is false. D. Assertion is false but the reason is true.	
Q.146	Study the following graphs between photoelectric current (i) vs. collector potential (V) for three different radiations a, b, and c of frequencies f_a, f_b, f_c respectively with corresponding intensities I_a, I_b, and I_c respectively falling on a given photosensitive surface.  Select the correct option. A. $f_a \neq f_b$; $I_a = I_b$ B. $f_b = f_c$; $I_b = I_c$ C. $f_a = f_b$; $I_a \neq I_c$ D. $f_b \neq f_c$; $I_b \neq I_c$	1
Q.147	ASSERTION: Electromagnetic wave picture of light can also explain the photoelectric effect in addition to the particle nature of light. REASON: Electric field of an em wave would cause the electrons in the metal to oscillate and tear free from the surface when the amplitude of the oscillation becomes large enough. Select the correct option. A. Both A and R are true and R is the correct explanation of A B. Both A and R are true and R is NOT the correct explanation of A C. A is true but R is false D. A is false and R is also false	1
Free Response Questions/Subjective Questions		
Q.148	The following graph shows the variation of photoelectric current (I) with a change in collector potential (V) for two different incident waves in a photoelectric effect experiment.	3

	 (a) Which of the two frequencies are greater, f_1 or f_2? Give reason. (b) The photoelectric current becomes constant and same for both the waves after a certain collector potential. What does this indicate?	
Q.149	Photoelectrons are emitted from a neutral spherical metal ball when it is illuminated by a light of wavelength 4×10^{15} Hz. The power of the light source is 3.313 mW. What is the maximum charge that can be acquired by this sphere in 2 s assuming there is no dielectric breakdown of the surrounding medium? (Assume that all the light is incident on the metal ball) ($h = 6.626 \times 10^{-34}$ J.s)	2
Q.150	Ambient light sensors are used in mobile phone devices to auto-adjust the brightness of the screen based on the surrounding brightness. A light sensor has to be able to detect a wide range of frequencies. A sensor can react with a photon energy of 1.82×10^{-19} J to 5.71×10^{-19} J to create mobile electrons. What will be the range of frequencies that the sensor is sensitive to? ($h = 6.67 \times 10^{-34}$ Js, $c = 3 \times 10^{8}$ m/s)	2
Q.151	(a) How does Einstein's photoelectric equation provide an explanation for the concept of the threshold frequency in the context of the photoelectric effect? (b) Why do all the electrons emitted during a photoelectric emission not have the same kinetic energy? Give any TWO reasons.	3
Q.152	A photoelectric emission apparatus with an unknown metal is irradiated with 200 nm light. The photocurrent becomes zero at the collector plate potential of –0.80 V. Determine the work function of the unknown metal. Take $h = 4.13 \times 10^{-15}$ eV-s.	2
Q.153	A monochromatic light of wavelength 240 nm falls on sodium metal surface that has threshold wavelength value as 360 nm. Determine the speed of the photoelectrons emitted from the sodium metal surface. Take hc ~ 2×10^{-16} J-nm and mass of photoelectron = 9×10^{-31} kg	2

Answer key and Marking Scheme

Q.No	Answers	Marks
Q.138	D. Only statements I & III are correct	1
Q.139	D. No, because IR rays have a longer wavelength than red light.	1
Q.140	A. Both assertion and reason are true and reason is the correct explanation for assertion.	1
Q.141	D. Assertion is false but the reason is true.	1
Q.142	A. Both assertion and reason are true and reason is the correct explanation for assertion.	1
Q.143	D. The line will cut the $1/\lambda$ axis at a different point.	1
Q.144	A. 0.1242×10^{-2} eV	1
Q.145	C. Assertion is true but the reason is false.	1
Q.146	C. $f_a = f_b$; $I_a \neq I_c$	1
Q.147	D. A is false and R is also false	1
Q.148	(a) Higher the magnitude of stopping potential higher will be the frequency of incident wave. Thus $f_2>f_1$. [0.5 marks for correct reason] [0.5 marks for identifying greater frequency] (b) Constant current indicates that all the emitted electrons are collected by the collector plate and thus the current cannot increase further. The current being same for both the waves indicates that intensity of both the waves is the same. [1 mark for explaining why current becomes constant] [1 mark for explaining why current is same]	3
Q.149	Given: Frequency of light = $v = 4 \times 10^{15}$ Hz Power of source = P = 3.313 mW Time = t = 2 s	2

	Energy of each photon = hv = $6.626 \times 10^{-34} \times 4 \times 10^{15}$ J Total energy incident on sphere in 2 s = E = Pt = 3.313 mW × 2 s = 6.626×10^{-3} J Number of incident photons = n = E/ hv = $6.626 \times 10^{-3}/(6.626 \times 10^{-34} \times 4 \times 10^{15}) = 25 \times 10^{14}$ Maximum number of electrons that can be emitted by the sphere = Number of incident photons = 25×10^{14} Maximum charge that can be acquired by the sphere q = ne = $25 \times 10^{14} \times 1.6 \times 10^{-19}$ C = 400 μC [1 mark for calculating number of photons] [1 mark for calculating charge on sphere]	
Q.150	λ = hc/E λ1=6.67 x 10-34 x 3 x 108/1.82 x 10-19 = 1099.50 nm λ2=6.67 x 10-34 x 3 x 108/5.45 x 10-19 = 350.43 nm The sensor will be sensitive to wavelengths in the range of 350.43 nm to 1099.50 nm. (1 mark for the correct use formula and 1 mark for the correct answer.)	2
Q.151	(a) Einstein's photoelectric equation: $KE_{max} = hv - \Phi$ If hv < Φ, then the emitted electron's maximum kinetic energy (KE_{max}) would be negative, which is not physically meaningful. Thus, v > Φ/h for the photoelectric effect to take place. and we can also say $v_{th} = \Phi/h$ = Threshold frequency In summary, Einstein's photoelectric equation explains the threshold frequency by demonstrating that only photons with a frequency greater than this can cause a photoelectric effect which is in line with the experimental results. [1 mark for the correct explanation. Look for kinetic energy cannot be negative and thus v> Φ/h or Threshold frequency = Φ/h] (b) (i) Electrons in a material are bound to the atoms by different amounts of energy. Electrons closer to the surface have weaker binding energies compared	3

	to those deeper within the material. When a photon is absorbed, it needs to provide enough energy not just to overcome the work function (the energy required to escape the material) but also to overcome the electrons binding energy. (ii) Electrons might lose some of their kinetic energy due to interactions with other particles in the material before escaping. [1 mark for each correct reason]	
Q.152	Maximum KE of the emitted photoelectrons: $KE_{max} = e\ \Delta V = e \times 0.8 = 0.8\ eV$ [0.5 mark for correct calculation of KE_{max}] Work function = hν - KE_{max} = (h c/λ) - KE_{max} $= \frac{(4.13 \times 10^{-15} \times 3 \times 10^{8})}{\lambda} - KE_{max}$ $= \frac{12.40 \times 10^{-7}\ eV - m}{\lambda} - 0.8\ eV$ $= \frac{1240\ eV - nm}{200\ nm} - 0.8\ eV = 5.4\ eV$ [0.5 mark for correct formula of work function in terms of stopping potential] [1 mark for the correct final result of work function]	2
Q.153	Given λ_o = 360 nm and λ = 240 nm KE of the emitted photoelectrons K = ½ $mv^2 = E - \Phi_o$, where E is the energy of the incident light [1 mark for the correct equations] $\frac{1}{2} mv^2 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = hc\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right] = hc\left[\frac{1}{240} - \frac{1}{360}\right] = \frac{hc}{720}$ $v = \sqrt{\frac{2 \times hc}{m \times 720}} = \sqrt{\frac{2 \times 2 \times 10^{-16}}{9 \times 10^{-31} \times 720}}$ $v = 7.8 \times 10^5$ m/s [1 mark for the correct final result]	2