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Dual Nature of Matter and Radiation — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · PHYSICS · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take $h = 6.6 \times 10^{-34}$ J s, $c = 3 \times 10^{8}$ m/s, $e = 1.6 \times 10^{-19}$ C, $m_e = 9.1 \times 10^{-31}$ kg and $hc \approx 1240$ eV nm unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Photoelectric effect · Einstein's photoelectric equation · Particle nature of light · Matter waves and the de Broglie relation

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. Light of wavelength 400 nm falls on a metal surface whose work function is 2.5 eV. The maximum kinetic energy of the emitted photoelectrons is about

(1) 3.1 eV

(2) 0.6 eV

(3) 2.5 eV

(4) 0.3 eV

2. A metal is lit first with light of wavelength 300 nm and then with light of wavelength 400 nm. The difference between the two stopping potentials is about

(1) 1.03 V

(2) 0.52 V

(3) 4.13 V

(4) 3.10 V

3. The stopping potential for photoelectrons emitted from a metal by light of wavelength 400 nm is 1.5 V. The threshold wavelength of the metal is about

(1) 400 nm

(2) 620 nm

(3) 1000 nm

(4) 775 nm

4. The intensity of the light falling on a photosensitive surface is doubled, its frequency being kept the same (above the threshold). Then

(1) both the saturation current and the stopping potential double

(2) the saturation current is unchanged and the stopping potential doubles

(3) the saturation current doubles and the stopping potential is unchanged

(4) both stay the same

5. A graph of the stopping potential V_0 against the frequency ν of the incident light is drawn for a metal. Its slope is

(1) h/e

(2) e/h

(3) h

(4) φ/e

6. A laser emits light of wavelength 660 nm with a power of 10 mW. The number of photons it emits per second is about

(1) 3.3×10^{15}

(2) 1.0×10^{17}

(3) 6.6×10^{16}

(4) 3.3×10^{16}

7. Light of wavelength 400 nm ejects electrons from a metal of work function 2.5 eV. The maximum speed of the photoelectrons is about

(1) 2.1×10^5 m/s

(2) 6.5×10^5 m/s

(3) 4.6×10^5 m/s

(4) 9.2×10^5 m/s

8. Photoelectrons are emitted practically instantly (within about 10^{-9} s) even when the light is very faint. This observation

(1) is explained by the wave theory, because the energy of the wave is spread evenly over the surface

(2) supports the photon picture, in which each electron takes in the energy of one photon at once

(3) shows that the work function depends on the intensity

(4) shows that the stopping potential depends on the intensity

9. An electron is accelerated from rest through a potential difference of 150 V. Its de Broglie wavelength is about

(1) 0.01 nm

(2) 1 nm

(3) 0.5 nm

(4) 0.1 nm

10. A proton and an alpha particle have the same kinetic energy. The ratio of the de Broglie wavelength of the proton to that of the alpha particle is

(1) 2 : 1

(2) 1 : 2

(3) $\sqrt{2}$: 1

(4) 1 : 4

11. A neutron (mass 1.675×10^{-27} kg) has a kinetic energy equal to (3/2)kT at T = 300 K ($k = 1.38 \times 10^{-23}$ J/K). Its de Broglie wavelength is about

(1) 1.45 nm

(2) 0.145 nm

(3) 14.5 nm

(4) 0.0145 nm

12. A photon and an electron both have a wavelength of 1 nm. The ratio of the energy of the photon to the kinetic energy of the electron is

(1) 1

(2) about 8

(3) about 830

(4) about 8.3×10^4

13. The momentum of a photon of wavelength 500 nm is about

(1) 3.3×10^{-27} kg m/s

(2) 6.6×10^{-28} kg m/s

(3) 1.3×10^{-27} kg m/s

(4) 4.0×10^{-19} kg m/s

14. The potential difference through which an electron is accelerated from rest is made four times as large. Its de Broglie wavelength

(1) doubles

(2) becomes four times as large

(3) becomes one quarter as large

(4) halves

15. When light passes from air into glass, the energy of each of its photons

(1) stays the same

(2) decreases

(3) increases

(4) becomes zero

16. Metals A and B have work functions 2 eV and 4 eV. Light whose photons have energy 4.5 eV falls on each. The ratio of the maximum kinetic energy of the photoelectrons from A to that from B is

(1) 2

(2) 5

(3) 1/5

(4) 9/8

17. Photoelectrons leave an emitter with a maximum kinetic energy of 1.8 eV. The collector is held at a potential 1 V below the emitter. The maximum kinetic energy with which electrons reach the collector is

(1) 0.8 eV

(2) 2.8 eV

(3) 1.8 eV

(4) 1.0 eV

18. The kinetic energy of a free electron is increased by 44%. Its de Broglie wavelength

(1) increases by 20%

(2) decreases by 44%

(3) decreases by 20%

(4) decreases by about 16.7%

19. A red lamp (wavelength 700 nm) and a violet lamp (wavelength 400 nm) each emit 100 W of light. Which emits more photons per second, and in what ratio?

(1) the violet lamp, 7 : 4

(2) the red lamp, 7 : 4

(3) the red lamp, 4 : 7

(4) neither: they emit equal numbers

20. Light of frequency $1.5\nu_0$ falls on a metal whose threshold frequency is ν_0. If the frequency of the light is doubled, the maximum kinetic energy of the photoelectrons becomes

(1) 2 times as large

(2) 3 times as large

(3) 4 times as large

(4) 8 times as large

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

21. The threshold wavelength of a metal is 310 nm. When light of wavelength 155 nm falls on it, the stopping potential (in V) is _____ (to the nearest integer; take hc = 1240 eV nm).

Answer: _____

22. A source of monochromatic light of wavelength 600 nm emits 33 W. The number of photons it emits per second is x × 10^{19}. The value of x is _____.

Answer: _____

23. Ultraviolet light of wavelength 248 nm falls on a metal of work function 2.0 eV. The maximum kinetic energy (in eV) of the photoelectrons is _____ (to the nearest integer).

Answer: _____

24. The de Broglie wavelength (in pm) of an electron accelerated from rest through 10 kV is _____ (to the nearest integer; ignore relativistic effects).

Answer: _____

25. Light of wavelength 400 nm and power 2 mW falls on a photocathode. On average one photon in ten ejects an electron. The saturation photoelectric current (in μA) is _____ (to the nearest integer).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(2)	(1)	(4)	(3)	(1)	(4)	(3)	(2)	(4)	(1)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(2)	(3)	(3)	(4)	(1)	(2)	(1)	(4)	(2)	(3)

Q21	Q22	Q23	Q24	Q25
4	10	3	12	65

WORKED SOLUTIONS

Q1. Answer (2). Photon energy $hc/\lambda = 1240/400 \approx 3.1$ eV. $K_{max} = h\nu - \varphi = 3.1 - 2.5 = 0.6$ eV.

Q2. Answer (1). $eV_0 = hc/\lambda - \varphi$, so the work function cancels in the difference: $\Delta V_0 = (hc/e)(1/\lambda_1 - 1/\lambda_2) = 1240 \times (1/300 - 1/400)$ V ≈ 1.03 V.

Q3. Answer (4). $\varphi = hc/\lambda - eV_0 = 3.1 - 1.5 = 1.6$ eV. $\lambda_0 = hc/\varphi = 1240/1.6 \approx 775$ nm.

Q4. Answer (3). Twice the intensity at the same frequency means twice as many photons per second, each of the same energy. So twice as many electrons are emitted (saturation current doubles), but each has the same maximum energy $h\nu - \varphi$ (stopping potential unchanged).

Q5. Answer (1). $eV_0 = h\nu - \varphi$ gives $V_0 = (h/e)\nu - \varphi/e$: a straight line of slope h/e, the same for every metal. The intercept on the ν-axis is the threshold frequency.

Q6. Answer (4). Each photon carries $hc/\lambda = 6.6 \times 10^{-34} \times 3 \times 10^{8}/(660 \times 10^{-9}) = 3 \times 10^{-19}$ J. $N = P/(hc/\lambda) = 10^{-2}/(3 \times 10^{-19}) \approx 3.3 \times 10^{16}$ per second.

Q7. Answer (3). $K_{max} = 3.1 - 2.5 = 0.6$ eV $= 9.6 \times 10^{-20}$ J. $v = \sqrt{(2K/m)} = \sqrt{(2 \times 9.6 \times 10^{-20}/(9.1 \times 10^{-31}))} \approx 4.6 \times 10^{5}$ m/s.

Q8. Answer (2). On the wave picture, faint light spread over the whole surface would take a long time to give any one electron enough energy to escape. On the photon picture, energy arrives in packets of $h\nu$: an electron that absorbs one photon (with $h\nu > \varphi$) can leave at once, however few photons arrive.

Q9. Answer (4). $p = \sqrt{(2meV)}$ and $\lambda = h/p$, which gives $\lambda \approx 1.227/\sqrt{V}$ nm $= 1.227/\sqrt{150} \approx 0.1$ nm (about the spacing of atoms in a crystal).

Q10. Answer (1). $\lambda = h/\sqrt{(2mK)}$. With K the same, $\lambda \propto 1/\sqrt{m}$ and $m_\alpha = 4m_p$, so $\lambda_p/\lambda_\alpha = \sqrt{4} = 2$.

Q11. Answer (2). $K = 1.5 \times 1.38 \times 10^{-23} \times 300 = 6.2 \times 10^{-21}$ J. $p = \sqrt{(2mK)} = \sqrt{(2 \times 1.675 \times 10^{-27} \times 6.2 \times 10^{-21})} \approx 4.56 \times 10^{-24}$ kg m/s. $\lambda = h/p \approx 1.45 \times 10^{-10}$ m $= 0.145$ nm, which is why thermal neutrons are diffracted by crystals.

Q12. Answer (3). Photon: $E = hc/\lambda$. Electron: $K = p^2/(2m) = h^2/(2m\lambda^2)$. Ratio $= 2mc\lambda/h = 2 \times 9.1 \times 10^{-31} \times 3 \times 10^{8} \times 10^{-9}/(6.6 \times 10^{-34}) \approx 830$: the photon has 1.24 keV, the electron only 1.5 eV.

Q13. Answer (3). $p = h/\lambda = 6.6 \times 10^{-34}/(5 \times 10^{-7}) \approx 1.3 \times 10^{-27}$ kg m/s. (4.0×10^{-19} is its energy in joules.)

Q14. Answer (4). $K = eV$, $p = \sqrt{(2meV)}$ and $\lambda = h/p \propto 1/\sqrt{V}$. Four times V gives half the wavelength (non-relativistic).

Q15. Answer (1). Photon energy is $E = h\nu$, and the frequency is fixed by the source and does not change at the boundary. The speed and wavelength fall in glass, but $E = h\nu$ stays the same.

Q16. Answer (2). $K_A = 4.5 - 2 = 2.5$ eV and $K_B = 4.5 - 4 = 0.5$ eV. Ratio 5.

Q17. Answer (1). Moving towards a point 1 V lower in potential, each electron (charge −e) loses 1 eV of kinetic energy. 1.8 − 1 = 0.8 eV. (With the collector 1 V above the emitter the answer would be 2.8 eV.)

Q18. Answer (4). $\lambda \propto 1/\sqrt{K}$. With K × 1.44, λ is divided by $\sqrt{1.44} = 1.2$: $\lambda' = \lambda/1.2 = 0.833\lambda$, a decrease of about 16.7% (not 20%).

Q19. Answer (2). $N = P\lambda/(hc)$. With equal power, $N \propto \lambda$: $N_{red}/N_{violet} = 700/400 = 7 : 4$. Red photons carry less energy each, so more of them are needed for the same power.

Q20. Answer (3). Before: $K = h(1.5\nu_0) - h\nu_0 = 0.5h\nu_0$. After: $K = h(3\nu_0) - h\nu_0 = 2h\nu_0$. Ratio 4, not 2, because the work function is subtracted each time.

Q21. Answer 4. $\varphi = 1240/310 = 4$ eV. $h\nu = 1240/155 = 8$ eV. $eV_0 = 8 - 4 = 4$ eV, so $V_0 = 4$ V.

Q22. Answer 10. Each photon carries $hc/\lambda = 6.6 \times 10^{-34} \times 3 \times 10^{8}/(6 \times 10^{-7}) = 3.3 \times 10^{-19}$ J. $N = 33/(3.3 \times 10^{-19}) = 10^{20} = 10 \times 10^{19}$ per second.

Q23. Answer 3. $h\nu = hc/\lambda \approx 1240/248 = 5.0$ eV. $K_{max} = 5.0 - 2.0 = 3.0$ eV.

Q24. Answer 12. $p = \sqrt{(2meV)} = \sqrt{(2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 10^{4})} = 5.40 \times 10^{-23}$ kg m/s. $\lambda = h/p = 6.6 \times 10^{-34}/5.40 \times 10^{-23} \approx 1.22 \times 10^{-11}$ m = 12 pm.

Q25. Answer 65. Photons per second $N = P\lambda/(hc) = 2 \times 10^{-3} \times 4 \times 10^{-7}/(6.6 \times 10^{-34} \times 3 \times 10^{8}) = 4.04 \times 10^{15}$. Electrons per second 4.04×10^{14}, so $I = 4.04 \times 10^{14} \times 1.6 \times 10^{-19} \approx 6.5 \times 10^{-5}$ A = 65 μA.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer from E = hν, Einstein's photoelectric equation and λ = h/p in SI units, with the motion of electrons in a retarding field integrated step by step.