S6 Physics Practice Paper I Photoelectric effect, radioactive half-life, RC circuits, satellite orbits, Doppler effect, hydrogen energy levels

S6 Physics I Time allowed: 75 minutes I Total: 100 marks I 24 questions

Question 1: Photoelectric effect (18 marks)

Photoelectric effect

1. (a) Light of wavelength 400 nm falls on a metal surface of work function 2.20 eV. Taking $h = 6.63 \times 10^{-34}$ J s, $c = 3.00 \times 10^{8}$ m s^{-1} and 1 eV $= 1.60 \times 10^{-19}$ J, find the frequency of the light, the photon energy in J and in eV, and the maximum kinetic energy of the emitted photoelectrons. (6 marks)

> **Answer:** Frequency $f = c / \lambda = 3.00 \times 10^{8} / 400 \times 10^{-9} = 7.5 \times 10^{14}$ Hz. Photon energy $E = hf = 4.97 \times 10^{-19}$ J $= 3.11$ eV. Work function $= 2.20 \times 1.60 \times 10^{-19} = 3.52 \times 10^{-19}$ J. Maximum kinetic energy $= 1.45 \times 10^{-19}$ J $= 0.908$ eV.

2. (b) Find the threshold (cut-off) wavelength of this metal and explain why light of longer wavelength cannot eject photoelectrons. (5 marks)

> **Answer:** $\lambda_0 = hc / \phi = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / 3.52 \times 10^{-19} = 5.65 \times 10^{-7}$ m, about 565 nm. A longer wavelength means photon energy below the work function; one photon cannot supply enough energy, so no emission occurs however intense the light is.

3. (c) Find the stopping potential. If the intensity is doubled while the wavelength is unchanged, how does the stopping potential change? (4 marks)

> **Answer:** Stopping potential $V_s = KE_max / e = 1.45 \times 10^{-19} / 1.60 \times 10^{-19} = 0.908$ V. It depends only on photon energy and work function, not on intensity, so it stays 0.908 V; doubling the intensity only doubles the number of photoelectrons and hence the current.

4. (d) If light of wavelength 300 nm is used instead, find the maximum kinetic energy in eV and state the increase. (3 marks)

> **Answer:** $E = hc / \lambda = 6.63 \times 10^{-19}$ J $= 4.14$ eV. Maximum kinetic energy $= 4.14 - 2.20 = 1.94$ eV, an increase of about 1.04 eV over 0.908 eV.

Question 2: Radioactive decay and half-life (17 marks)

Radioactivity

5. (a) A sample has an initial activity of 8000 Bq and a half-life of 6.0 hours. How long does the activity take to fall to 1000 Bq? Show the formula and the steps. (6 marks)

> **Answer:** Using $A = A_0 \times (1/2)^n$: $1000 = 8000 \times (1/2)^n$, so $(1/2)^n = 1/8$ and $n = 3$ half-lives. Time $= 3 \times 6.0 = 18$ hours.

6. (b) After 4 half-lives, what percentage of the original nuclei has decayed? (4 marks)

Answer: Remaining fraction = $(1/2)^4 = 1/16 = 6.25\%$, so the decayed percentage is $100\% - 6.25\% = 93.75\%$.

7. (c) Find the decay constant λ in s^{-1}, correct to 3 significant figures. (4 marks)

Answer: Half-life = $6.0 \times 3600 = 21600$ s. $\lambda = \ln 2 / T_{½} = 0.693 / 21600 = 3.21 \times 10^{-5}\ s^{-1}$.

8. (d) What is the activity 24 hours after the start? (3 marks)

Answer: 24 hours is 4 half-lives, so activity = $8000 / 2^4 = 8000 / 16 = 500$ Bq.

Question 3: Capacitors and RC circuits (17 marks)

Electricity

9. (a) A 470 µF capacitor is connected across a 12 V d.c. supply. Find the charge stored. (5 marks)

Answer: $Q = CV = 470 \times 10^{-6} \times 12 = 5.64 \times 10^{-3}$ C, i.e. 5.64 mC.

10. (b) Find the energy stored in the capacitor at 12 V. (4 marks)

Answer: $E = ½CV^2 = 0.5 \times 470 \times 10^{-6} \times 144 = 0.0338$ J, i.e. 33.8 mJ.

11. (c) The capacitor discharges through a 22 kΩ resistor. Find the time constant and explain its meaning. (4 marks)

Answer: $\tau = RC = 22 \times 10^3 \times 470 \times 10^{-6} = 10.3$ s. The time constant is the time for the charge or voltage to fall to 1/e, about 37%, of its initial value.

12. (d) How long after discharge begins does the voltage fall to 10% of its initial value? (4 marks)

Answer: $V = V_0 e^{(-t/\tau)}$, so $0.10 = e^{(-t/\tau)}$ and $t = \tau \ln 10 = 10.34 \times 2.303 = 23.8$ s.

Question 4: Satellite orbits and gravitation (17 marks)

Mechanics

13. (a) A satellite orbits at 400 km above the Earth. With Earth radius 6.37×10^6 m, Earth mass 5.97×10^{24} kg and $G = 6.67 \times 10^{-11}$ N m² kg⁻², find its orbital speed. (6 marks)

Answer: Orbital radius $r = 6.77 \times 10^6$ m. From $GMm/r^2 = mv^2/r$, $v = \sqrt{(GM/r)} = \sqrt{(6.67 \times 10^{-11} \times 5.97 \times 10^{24} / 6.77 \times 10^6)} = 7.67 \times 10^3\ m\ s^{-1}$.

14. (b) Find the orbital period in seconds and in minutes. (5 marks)

Answer: $T = 2\pi r / v = 2\pi \times 6.77 \times 10^6 / 7.67 \times 10^3 = 5.55 \times 10^3$ s, about 92 minutes.

15. (c) Find the gravitational field strength at that altitude and compare it with the value at the surface. (3 marks)

Answer: $g = GM / r^2 = 8.69\ N\ kg^{-1}$, about 11% less than the surface value of 9.81 N kg⁻¹.

16. (d) For the satellite to be geostationary (period 24 hours), must its orbital radius be larger or smaller, and what happens to its speed? Explain briefly. (3 marks)

Answer: Since $T = 2\pi r/v$ with $v = \sqrt{(GM/r)}$, a longer period needs a larger radius (about 4.2×10^7 m, i.e. 3.6×10^7 m above the surface), and a larger radius gives a smaller speed (about 3.1×10^3 m s^{-1}).

Question 5: Doppler effect (16 marks)

Waves

17. (a) A car sounding a 500 Hz horn approaches a stationary observer at 30 m s^{-1}. With sound speed 340 m s^{-1}, find the observed frequency. (5 marks)

Answer: $f' = f \times v / (v - v_s) = 500 \times 340 / 310 = 548$ Hz.

18. (b) After the car has passed and is moving away, what frequency is heard? (4 marks)

Answer: $f'' = f \times v / (v + v_s) = 500 \times 340 / 370 = 459$ Hz.

19. (c) Find the difference between the approaching and receding frequencies. (3 marks)

Answer: Difference = 548.4 – 459.5 = 88.9 Hz, about 89 Hz.

20. (d) A hydrogen line of rest wavelength 656.3 nm from a distant galaxy is measured at 669.4 nm on Earth. Find the redshift in nm and the recession speed as a fraction of c. (4 marks)

Answer: Redshift $\Delta\lambda = 13.1$ nm. From $\Delta\lambda / \lambda = v / c$, $v / c = 13.1 / 656.3 = 0.020$, so $v \approx 0.020c$.

Question 6: Atomic energy levels and spectra (15 marks)

Atomic physics

21. (a) A spectral line of hydrogen has wavelength 486 nm. Find the photon energy in J and in eV. (5 marks)

Answer: $E = hc / \lambda = 4.09 \times 10^{-19}$ J = 2.56 eV.

22. (b) For hydrogen, $E_2 = -3.40$ eV and $E_4 = -0.85$ eV. Show that the photon emitted in the n = 4 to n = 2 transition matches the line in (a). (4 marks)

Answer: Energy difference = –0.85 – (–3.40) = 2.55 eV, which agrees with 2.56 eV in (a) within rounding.

23. (c) A group of hydrogen atoms is excited to n = 4. What is the maximum number of spectral lines possible? (3 marks)

Answer: Number of downward transitions = $4 \times 3 / 2 = 6$: 4→3, 4→2, 4→1, 3→2, 3→1, 2→1.

24. (d) Find the wavelength of the photon emitted in the n = 4 to n = 1 transition and state its region. (3 marks)

Answer: Energy difference = 12.75 eV = 2.04×10^{-18} J. $\lambda = hc / E = 9.75 \times 10^{-8}$ m, about 97.5 nm, in the ultraviolet (Lyman series).