S6 Physics Practice Paper (Set 3): circular motion and gravitation, simple harmonic motion, double-slit and grating interference, magnetic force and induced e.m.f., radioac

Level: S6 | Subject: Physics | Time: 75 min | Total: 100 marks | Items: 24

Question 1 Circular motion and gravitation

Take g = 9.81 m s^{-2} and GM = 3.99 × 10^{14} m^3 s^{-2} for the Earth. Give answers to 3 s.f.

1. A 1200 kg car rounds a flat curve of radius 50 m. The coefficient of static friction is 0.60. Find the maximum speed without skidding. (4 marks)

Answer: Friction supplies the centripetal force: $\mu mg = mv^2/r$, so $v = \sqrt{(\mu g r)} = 17.2$ m s^{-1} (independent of mass).

2. A satellite moves in a circular orbit of radius 7.0 × 10^6 m about the Earth's centre. Find its orbital speed. (4 marks)

Answer: $GMm/r^2 = mv^2/r$, so $v = \sqrt{(GM/r)} = 7.55 \times 10^3$ m s^{-1}.

3. For the same satellite, find its orbital period in minutes. (4 marks)

Answer: $T = 2\pi r/v \approx 5.83 \times 10^3$ s ≈ 97.1 min.

4. Find the gravitational field strength g′ at that orbit, and explain why astronauts feel weightless. (4 marks)

Answer: $g' = GM/r^2 = 8.14$ m s^{-2}. Astronaut and spacecraft free-fall together with the same centripetal acceleration, so the normal force is zero — g′ is not zero.

Question 2 Simple harmonic motion

A mass of 0.50 kg on a spring of force constant 20 N m^{-1} oscillates with amplitude 0.080 m.

5. Find the period of oscillation. (4 marks)

Answer: $\omega = \sqrt{(k/m)} = 6.32$ rad s^{-1}; $T = 2\pi/\omega = 0.994$ s.

6. Find the maximum speed. (4 marks)

Answer: $v_{max} = \omega A = 0.506$ m s^{-1}.

7. Find the maximum acceleration and state where it occurs. (4 marks)

Answer: $a_{max} = \omega^2 A = 3.20$ m s^{-2}, at the extreme positions.

8. When the displacement is 0.040 m, find the speed and the fraction of the total energy that is kinetic. (4 marks)

Answer: $v = \omega\sqrt{(A^2 - x^2)} = 0.438$ m s^{-1}; $E = \frac{1}{2}kA^2 = 0.064$ J, KE = 0.048 J, i.e. 75%.

Question 3 Interference and diffraction of light

The monochromatic light used has wavelength 600 nm.

9. In a Young's double-slit experiment the slit separation is 0.50 mm and the screen is 2.0 m away. Find the fringe spacing. (4 marks)

Answer: $\Delta y = \lambda D/d = 2.4 \times 10^{-3}$ m = 2.4 mm.

10. If the screen is moved to 3.0 m, find the new fringe spacing. (4 marks)

Answer: $\Delta y \propto D$, so Δy = 3.6 mm.

11. A grating of 500 lines per mm replaces the double slit. Find the diffraction angle of the first-order maximum. (5 marks)

Answer: $d = 2.0 \times 10^{-6}$ m; $\sin\theta = \lambda/d = 0.300$, $\theta = 17.5°$.

12. Find the highest order of maximum observable with this grating, and explain. (5 marks)

Answer: $\sin\theta = m\lambda/d \le 1$ gives $m \le d/\lambda = 3.33$, so the highest order is 3 ($m = 4$ would need $\sin\theta > 1$).

Question 4 Magnetic force and induced e.m.f.

Electron charge 1.6×10^{-19} C, electron mass 9.11×10^{-31} kg.

13. An electron enters a uniform 0.20 T field at 3.0×10^{6} m s^{-1} perpendicular to the field. Find the magnitude of the magnetic force on it. (4 marks)

Answer: $F = Bqv = 9.6 \times 10^{-14}$ N.

14. Find the radius of the electron's circular path in the field. (5 marks)

Answer: $r = mv/(qB) = 8.5 \times 10^{-5}$ m.

15. A 0.40 m rod moves at 2.5 m s^{-1} perpendicular to a 0.50 T field. Find the induced e.m.f. across it. (4 marks)

Answer: $\varepsilon = BLv$ = 0.50 V.

16. If the rod is connected across a 2.5 Ω resistor, find the current and the power dissipated. (4 marks)

Answer: I = 0.20 A; $P = \varepsilon I$ = 0.10 W.

Question 5 Radioactivity and nuclear energy

Take 1 u = 931.5 MeV.

17. A sample has initial activity 6400 Bq and half-life 8 days. Find the activity after 24 days. (4 marks)

Answer: 24 days = 3 half-lives, so $A = 6400/2^3$ = 800 Bq.

18. How long does the same sample take to fall to 400 Bq? (4 marks)

Answer: $1/16 = 1/2^4$, i.e. 4 half-lives = 32 days.

19. A nuclear reaction has a mass defect of 0.0030 u. Find the energy released in MeV. (5 marks)

Answer: $E = 0.0030 \times 931.5 = 2.79$ MeV.

20. Write the β^- decay equation of carbon-14 and identify the products. (4 marks)

Answer: ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ + anti-neutrino; Z increases by one, A unchanged, giving nitrogen-14.

Question 6 Power, efficiency and ideal gas

Take $R = 8.31$ J mol^{-1} K^{-1} and $k = 1.38 \times 10^{-23}$ J K^{-1}.

21. A motor with input power 2.0 kW raises a 150 kg load at a steady 0.80 m s^{-1}. Find its efficiency. (4 marks)

Answer: Useful power $= mgv = 1.18 \times 10^{3}$ W; efficiency = 59%.

22. 2.0 mol of ideal gas occupies 0.050 m^3 at 300 K. Find its pressure. (4 marks)

Answer: $p = nRT/V = 9.97 \times 10^{4}$ Pa.

23. If it is heated to 450 K at constant volume, find the new pressure. (4 marks)

Answer: At constant volume $p \propto T$, so $p_2 = 1.50 \times 10^{5}$ Pa.

24. Find the mean translational kinetic energy of a gas molecule at 450 K. (4 marks)

Answer: $\langle KE \rangle = (3/2)kT = 9.3 \times 10^{-21}$ J.
