Grade 12 Physics Model Paper 3

ANSWER KEY

Full marks 75 · 3 hours

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

A practice paper by Science Playground, made to CDC's Specification Grid 2078, Grade 12 Physics (Phy. 102); not an official CDC or NEB paper.

Group A Multiple choice — 11 marks

Question 1 — 11 × 1 = 11

a. **(iii)** It is proportional to the displacement and always directed towards the mean position.

b. **(ii)** The viscosity of a liquid decreases as its temperature rises.

c. **(ii)** 0.010 kg m²

d. **(ii)** into the internal energy of the gas, raising its temperature

e. **(ii)** 3.3 J/K

f. **(iii)** whether light travels faster or slower in water than in air

g. **(ii)** It is partially polarized.

h. **(iii)** The junction that was heated is now cooled, and the other heated.

i. **(iii)** Above its Curie temperature, iron loses its ferromagnetism and becomes paramagnetic.

j. **(iii)** 8.0 V

k. **(ii)** the becquerel

Group B Short answers, each on one content area — 40 marks

Question 2 — 5 marks

a. For an ideal fluid (incompressible and non-viscous) in steady flow, the sum of the pressure, the kinetic energy per unit volume and the potential energy per unit volume is the same at every point along a streamline: $P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$. **[1]**

Marking scheme

- $P + \frac{1}{2}\rho v^2 + \rho g h$ is constant along a streamline (steady flow of an ideal fluid).

b. By the equation of continuity, $A_1 v_1 = A_2 v_2$: the same volume must pass every section each second, so the water moves **faster** where the pipe is narrow. **[2]**

The pipe is horizontal, so $\rho g h$ is the same at both places, and by Bernoulli's equation $P + \frac{1}{2}\rho v^2$ stays constant. Where $\frac{1}{2}\rho v^2$ is larger, P must be **smaller**: the pressure falls in the narrow section.

Marking scheme

- Continuity: the water moves faster in the narrow section.
- With the height the same, $P + \frac{1}{2}\rho v^2$ is constant, so higher speed means lower pressure.

c. **No.** The water is not pushed out of the gap: the boats are pushed together by a **difference of pressure**, as Bernoulli's principle says. The water passing through the narrow channel between the boats moves faster (relative to them) than the water on their outer sides. Faster-moving water is at lower pressure, so the pressure on each boat's inner side is less than on its outer side, and the net force pushes the boats towards each other. This is why boats are told to keep apart when passing. **[2]**

Marking scheme

- The water between the boats flows faster, so its pressure is lower (Bernoulli).
- The greater pressure on the outer sides pushes the boats together; not because they move into a gap.

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Question 3 — 5 marks

a. The **radius of gyration** K of a body about an axis is the distance from the axis at which the whole mass of the body could be put without changing its moment of inertia: $I = MK^2$, so $K = \sqrt{I/M}$. **[1]**

Marking scheme

- The distance from the axis at which the whole mass gives the same moment of inertia, $I = MK^2$.

b. Rolling without slipping, $v = R\omega$, and the disc has $I = \frac{1}{2}MR^2$, so **[2]**

$$K = \tfrac{1}{2}Mv^2 + \tfrac{1}{2}I\omega^2 = \tfrac{1}{2}Mv^2 + \tfrac{1}{2}\left(\tfrac{1}{2}MR^2\right)\frac{v^2}{R^2} = \tfrac{1}{2}Mv^2\left(1 + \tfrac{1}{2}\right)$$

$$K = \tfrac{1}{2} \times 2.0 \times 3.0^2 \times 1.5 = 9.0 \times 1.5 = \mathbf{13.5\ J}$$

Marking scheme

- $K = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$ with $I = \frac{1}{2}MR^2$, $\omega = v/R$.
- K = 13.5 J.

c. **No.** Their translational energies are equal, $\frac{1}{2}Mv^2 = 9.0$ J each, but their rotational energies are not. **[2]** The sphere has $I = \frac{2}{5}MR^2$, less than the disc's $\frac{1}{2}MR^2$, because more of its mass is near the axis:

$$K_{\text{sphere}} = \tfrac{1}{2}Mv^2\left(1 + \tfrac{2}{5}\right) = 9.0 \times 1.4 = 12.6\ \text{J}$$

The disc has more kinetic energy, 13.5 J against 12.6 J.

Marking scheme

- Same translational KE, but the sphere's moment of inertia ($\frac{2}{5}MR^2$) is smaller than the disc's ($\frac{1}{2}MR^2$), so its rotational KE is smaller.
- Sphere 12.6 J against disc 13.5 J, so he is not right.

OR

a. A **damped oscillation** is one whose amplitude decreases with time, because its energy is lost to friction or the resistance of the surrounding air or liquid. **[1]**

Marking scheme

- An oscillation whose amplitude decreases with time as energy is lost to resistive forces.

b. At rest the spring's pull balances the weight: $ke = mg$, so $\frac{m}{k} = \frac{e}{g}$. Then **[2]**

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{e}{g}} = 2\pi\sqrt{\frac{0.049}{9.8}} = 2\pi \times 0.0707 = \mathbf{0.44\ s}$$

Marking scheme

- $ke = mg$, so $m/k = e/g$.
- T = 2π√(e/g) = 0.44 s.

c. **No.** The period of a mass on a spring is $T = 2\pi\sqrt{m/k}$, which has no g in it: the mass and the spring's stiffness are the same on the Moon, so the period is the same, 0.44 s. **[2]**

On the Moon the spring stretches only a sixth as much ($e = mg/k$), and $2\pi\sqrt{e/g}$ gives the same answer, since e and g fall together. (A pendulum's period would be longer on the Moon; a spring's is not.)

Marking scheme

- No: $T = 2\pi\sqrt{m/k}$ does not depend on g.
- The extension falls with g, so e/g, and the period, are unchanged.

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Question 4 — 5 marks

a. An **adiabatic process** is a thermodynamic process in which no heat enters or leaves the system ($Q = 0$): it happens in a perfectly insulated container, or so quickly that heat has no time to flow. **[1]**

Marking scheme

- A process with no heat exchanged with the surroundings, Q = 0.

b. For an isothermal change $PV =$ constant, so its slope is $\frac{dP}{dV} = -\frac{P}{V}$. For an adiabatic change $PV^{\gamma} =$ constant, so $\frac{dP}{dV} = -\gamma\frac{P}{V}$. **[2]**

Since γ > 1, the adiabatic slope is γ times the isothermal one. Physically, in an adiabatic compression the gas also heats up, so its pressure rises both because it is squeezed and because it gets hotter, faster than at a constant temperature.

Marking scheme

- Isothermal slope −P/V; adiabatic slope −γP/V.
- γ > 1, so the adiabatic is steeper (the gas also heats up when compressed).

c. **[1]**

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \quad \Rightarrow \quad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 300 \times 2^{0.4} = 300 \times 1.32 = \mathbf{396}\ \mathrm{K}\ (123\ ^\circ\mathrm{C})$$

Marking scheme

- $T_2 = T_1(V_1/V_2)^{\gamma-1} = 396$ K (123 °C).

d. **Isothermally.** In the adiabatic expansion the gas cools as it does work, so its pressure falls faster (the steeper curve). Under the isothermal curve, which stays higher, the area, the work done, is larger. **[1]**

Marking scheme

- Isothermal: its pressure stays higher (the adiabatic gas cools), so the area under its curve is larger.

Question 5 — 5 marks

a. **Coherent sources** are sources of light that give out waves of the same frequency (wavelength) with a constant phase difference between them. **[1]**

Marking scheme

- Same frequency and a constant phase difference.

b. **[2]**

$$\beta = \frac{\lambda D}{d} = \frac{600 \times 10^{-9} \times 1.0}{0.50 \times 10^{-3}} = 1.2 \times 10^{-3}\ \mathrm{m} = \mathbf{1.2}\ \mathrm{mm}$$

The third bright fringe is at $y_3 = 3\beta =$ **3.6 mm** from the center.

Marking scheme

- β = λD/d = 1.2 mm.
- $y_3 = 3\beta$ = 3.6 mm.

c. **No: the fringes disappear.** Interference needs light from two coherent sources overlapping on the screen, adding where the waves are in phase and canceling where they are out of phase. With one slit covered there is only one source, so there is nothing to interfere with, and the dark fringes are gone. **[2]**

A dark fringe was a place where the waves from the two slits arrived half a wavelength out of step and canceled. One wave cannot cancel itself, so nothing on the screen goes dark any more: there are no bright and dark bands of width 1.2 mm, only a broad, fairly even patch of light from the one slit.

Marking scheme

- No: interference needs two coherent sources, so with one slit the fringes disappear.
- The dark fringes were where two waves canceled; one wave alone cannot cancel, so only a broad patch of light is left.

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Question 6 — 5 marks

a. When a magnetic field is applied at right angles to a current-carrying conductor, a potential difference is set up across the conductor, at right angles to both the current and the field. This is the **Hall effect**, and the potential difference is the **Hall voltage**. **[1]**

Marking scheme

- A voltage across a current-carrying conductor in a magnetic field, at right angles to both current and field.

b. **[3]**

$$V_H = \frac{BI}{net} = \frac{1.0 \times 5.0}{8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-4}} = \frac{5.0}{1.36 \times 10^{6}} = \mathbf{3.7 \times 10^{-6}}\ \mathrm{V}$$

Only about 4 μV, even with a large current in a strong field: far too small to measure easily against the noise, so **her plan is not sensible**.

She should use a thin slice of **semiconductor**. V_H is inversely proportional to n, and a semiconductor has far fewer carriers (about 10^{22} per m³ against copper's 10^{29}), so for the same current the carriers drift much faster and the Hall voltage is far larger, millivolts with a small current. Real Hall probes are made this way.

Marking scheme

- Uses $V_H = BI/(net)$ with the given values.
- $V_H = 3.7 \times 10^{-6}$ V.
- Too small to be a useful meter; a semiconductor, with far fewer carriers (V_H ∝ 1/n), gives a much larger Hall voltage.

c. **No, it would be reversed.** In a p-type semiconductor the current is carried by holes, which are positive, moving in the direction of the current. The magnetic force pushes them to the same face of the strip that the electrons in copper were pushed to, but they make that face positive instead of negative. (This is how the Hall effect tells the sign of the charge carriers.) **[1]**

Marking scheme

- No: positive holes are pushed to the same face as electrons would be, so that face becomes positive and the sign reverses.

Question 7 — 5 marks

a. **Kirchhoff's first law (current law):** the algebraic sum of the currents meeting at a junction is zero: the total current entering a junction equals the total current leaving it, $\sum I = 0$. **[2]**

Kirchhoff's second law (voltage law): in any closed loop of a circuit, the algebraic sum of the e.m.f.s equals the algebraic sum of the products of current and resistance, $\sum E = \sum IR$.

Marking scheme

- First law: the sum of currents at a junction is zero (current in = current out).
- Second law: round a closed loop, ΣE = ΣIR.

b. At the balance point no current flows through the cell, so there is no drop across its internal resistance and the potentiometer measures its full e.m.f. A voltmeter always draws some current, so it reads the terminal p.d., a little less than the e.m.f. **[1]**

Marking scheme

- At balance the cell gives no current, so no drop across its internal resistance; a voltmeter draws current and reads less.

c. Any two of these: **[2]**

1. The e.m.f. of the cell being measured is **greater than the p.d. across the whole wire**: the driver cell is too weak, or too much resistance is in the rheostat.
2. The **positive terminal** of the cell being measured is not joined to the same end of the wire as the driver cell's positive terminal, so the two p.d.s add instead of opposing.

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3. A loose connection or broken wire in the driver circuit, so no current flows through the wire.

Marking scheme

- One correct reason (e.g. the cell's e.m.f. is more than the p.d. across the wire).
- A second correct reason (e.g. the positive terminals not joined to the same end).

Question 8 — 5 marks

a. The beam is undeflected when the two forces balance, $eE = evB$: **[3]**

$$v = \frac{E}{B} = \frac{2.65 \times 10^{4}}{1.0 \times 10^{-3}} = \mathbf{2.65 \times 10^{7}}\ \mathrm{m/s}$$

The accelerating p.d. gave them this kinetic energy, $eV = \tfrac{1}{2}mv^2$, so

$$\frac{e}{m} = \frac{v^2}{2V} = \frac{(2.65 \times 10^{7})^2}{2 \times 2000} = \mathbf{1.76 \times 10^{11}}\ \mathrm{C/kg}$$

Marking scheme

- v = E/B = 2.65 × 10^7 m/s.
- $eV = \tfrac{1}{2}mv^2$, so e/m = v^2/2V (or E^2/2VB^2).
- e/m = 1.76 × 10^{11} C/kg.

b. Millikan's oil drop experiment measured the charge e (1.6×10^{-19} C) on its own. Dividing it by e/m (1.76×10^{11} C/kg) gave the electron's mass, 9.1×10^{-31} kg. **[2]**

Even Thomson's rough measurements showed e/m about a thousand times larger than for a hydrogen ion, the lightest particle then known (today's values give about 1,800 times). With a charge of the same size, this meant the electron is far **lighter than a hydrogen atom**: a particle smaller than any atom, part of every atom.

Marking scheme

- Millikan measured e; m = e ÷ (e/m) = 9.1 × 10^{-31} kg.
- e/m far larger than a hydrogen ion's (about a thousand times, as Thomson found): the electron is a particle much lighter than any atom.

Question 9 — 5 marks

a. Any three of these: **[3]**

1. They are ripples of space-time itself, predicted by Einstein in 1916 from his general theory of relativity.
2. They travel at the speed of light.
3. They are made by massive objects accelerating violently, such as black holes or neutron stars colliding, or a star exploding.
4. A passing wave stretches space in one direction and squeezes it at right angles, back and forth.
5. They need no medium and pass through matter almost unchanged.
6. They are extremely weak by the time they reach the Earth.

Marking scheme

- One correct property.
- A second correct property.
- A third correct property.

b. The wave travels at the speed of light, so the greatest gap (the wave arriving along the line joining them) is **[2]**

$$t = \frac{3.0 \times 10^{6}}{3 \times 10^{8}} = 0.010\ \mathrm{s} = \mathbf{10\ ms}$$

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Change of arm length: $\Delta L = 10^{-21} \times 4000 = \mathbf{4 \times 10^{-18}}\ \mathrm{m}$, a few thousandths of the width of a proton.

Marking scheme

- t = 3.0 × 10^{6} ÷ 3 × 10^{8} = 10 ms.
- ΔL = 10^{-21} × 4,000 = 4 × 10^{-18} m.

OR

a. [3]

Junction diode	Zener diode
Lightly doped, with a wide depletion layer	Heavily doped, with a thin depletion layer
Used in forward bias, mostly as a rectifier	Used in reverse bias, in the breakdown region
Damaged by the large current at breakdown	Designed to work at breakdown without damage
Used to turn a.c. into d.c.	Used to hold a voltage steady (voltage regulator)

Marking scheme

- One correct difference.
- A second correct difference.
- A third correct difference.

b. The Zener holds 5.0 V across itself and the load, so the resistor has $12 - 5.0 = 7.0$ V across it: **[2]**

$$I = \frac{7.0}{350} = 0.020\ \mathrm{A} = \mathbf{20\ mA}$$

The load takes $\dfrac{5.0}{500} = 10$ mA, so the Zener carries $20 - 10 = \mathbf{10\ mA}$.

Marking scheme

- Current through the resistor = 7.0/350 = 20 mA.
- Load 10 mA, so the Zener carries 10 mA.

Group C Long answers, each on one content area — 24 marks

Question 10 — 8 marks

a. The first minimum is at $a \sin\theta = \lambda$: **[2]**

$$\sin\theta = \frac{500 \times 10^{-9}}{0.20 \times 10^{-3}} = 2.5 \times 10^{-3} \quad \Rightarrow \quad \theta = 2.5 \times 10^{-3}\ \mathrm{rad}\ (0.14^\circ)$$

The central band runs from the first minimum on one side to the first on the other:

$$w = \frac{2\lambda D}{a} = \frac{2 \times 500 \times 10^{-9} \times 2.0}{0.20 \times 10^{-3}} = 1.0 \times 10^{-2}\ \mathrm{m} = \mathbf{10\ mm}$$

Marking scheme

- sin θ = λ/a = 2.5 × 10^{-3} (θ = 0.14°).
- Central band width = 2λD/a = 10 mm.

b. **[2]**

$$\theta = \frac{1.22\lambda}{D} = \frac{1.22 \times 550 \times 10^{-9}}{3.0 \times 10^{-3}} = \mathbf{2.2 \times 10^{-4}}\ \mathrm{rad}$$

The lights are just resolved when they make this angle at her eye: $\theta = \dfrac{s}{x}$, so

$$x = \frac{s}{\theta} = \frac{1.4}{2.24 \times 10^{-4}} = \mathbf{6.3 \times 10^{3}}\ \mathrm{m}\ (6.3\ \mathrm{km})$$

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Marking scheme

- θ = 1.22λ/D = 2.2 × 10^{-4} rad.
- x = s/θ ≈ 6.3 km.

c. **No: it gets wider.** The first minimum is at $\sin\theta = \lambda/a$, so the smaller the slit width a, the larger the angle, and the wider the central band ($w = 2\lambda D/a$). Halving the slit doubles the band's width. Light is spread out more by a narrower opening; the band also gets dimmer, because less light passes. **[2]**

Marking scheme

- sin θ = λ/a: a smaller a gives a larger angle.
- So the central band widens (w ∝ 1/a), though it gets dimmer.

d. Light from a star passing through a round aperture spreads into a disc, and two stars can be told apart only if their angle exceeds $1.22\lambda/D$. A larger aperture D makes this angle smaller, so a mirror many meters across **resolves** finer detail (and also gathers more light, to see fainter objects). **[2]**

Radio waves of 21 cm are about 400,000 times longer than light of 550 nm ($0.21/550 \times 10^{-9} \approx 3.8 \times 10^5$), so for the same resolution D must be that many times larger: radio telescopes are dishes hundreds of meters wide, or many dishes linked across a continent to act as one.

Marking scheme

- θ = 1.22λ/D: a larger D gives a smaller angle, so finer detail is resolved.
- Radio wavelengths are far longer, so D must be far larger for the same resolution.

OR

a. Newton (isothermal): **[2]**

$$v = \sqrt{\frac{P}{\rho}} = \sqrt{\frac{1.01 \times 10^5}{1.29}} = \mathbf{280}\ \mathrm{m/s}$$

Laplace (adiabatic):

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{1.4} \times 280 = \mathbf{331}\ \mathrm{m/s}$$

Marking scheme

- Newton: v = √(P/ρ) = 280 m/s.
- Laplace: v = √(γP/ρ) = 331 m/s.

b. **[2]**

$$v_{27} = v_0\sqrt{\frac{T}{T_0}} = 331\sqrt{\frac{300}{273}} = 331 \times 1.048 = \mathbf{347}\ \mathrm{m/s}$$

The speed rises by $347 - 331 = 16$ m/s over 27 °C, about **0.6 m/s for each degree Celsius**.

Marking scheme

- v = 331√(300/273) = 347 m/s.
- About 0.6 m/s per °C.

c. In a sound wave the air is compressed and rarefied hundreds of times a second. A compression warms the air a little and a rarefaction cools it, and air is a poor conductor of heat, so in so short a time no heat can flow between them to even out the temperature. **[2]**

The changes are therefore **adiabatic**, not isothermal: the compressed air is warmer and pushes back harder, which makes the effective elasticity γP instead of P, and the speed $\sqrt{\gamma}$ times greater.

Marking scheme

- The compressions and rarefactions are too fast, and air too poor a conductor, for heat to flow: the changes are adiabatic.
- So the elasticity is γP, not P, and the speed is √γ times Newton's.

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d. **No, it travels slightly faster.** A water molecule (18 g/mol) is lighter than the average molecule of dry air (29 g/mol), so at the same temperature and pressure moist air is **less dense** than dry air, not heavier. Since $v = \sqrt{\gamma P/\rho}$, a smaller density gives a higher speed. **[2]**

Marking scheme

- Water vapor is lighter than dry air (18 against 29 g/mol), so moist air is less dense.
- v ∝ 1/√ρ, so sound is slightly faster in humid air: he is not right.

Question 11 — 8 marks

a. The **power factor** is $\cos\phi$, where φ is the phase difference between the voltage and the current; the average power is $P = V_{\text{rms}} I_{\text{rms}} \cos\phi$, and $\cos\phi = R/Z$. **[2]**

In a pure resistor the current is in phase with the voltage, φ = 0, so cos φ = 1 and all the power is used. In a pure inductor the current lags by 90°, cos 90° = 0: energy stored in the field in one quarter-cycle is given back in the next, so no power is used on average.

Marking scheme

- Power factor = cos φ, in $P = V_{\text{rms}} I_{\text{rms}} \cos\phi$ (= R/Z).
- Resistor φ = 0, cos φ = 1; inductor φ = 90°, cos φ = 0, the energy stored and given back.

b. Both a resistor and an inductor limit an a.c. current. But a resistor turns the energy it takes into heat, I^2R, which is wasted. An inductor with very little resistance limits the current by its reactance, and the current through it is almost 90° out of phase with the voltage across it, so its power factor is nearly zero: it uses almost no power (a wattless current). So a choke saves energy and does not heat up. **[2]**

Marking scheme

- A resistor wastes power as heat (I²R).
- A choke limits the current by its reactance with a power factor near 0, so it wastes almost no power.

c. **[2]**

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{40^2 + 30^2} = \mathbf{50\ \Omega} \qquad I = \frac{V}{Z} = \frac{220}{50} = \mathbf{4.4\ A}$$

Power factor $\cos\phi = \dfrac{R}{Z} = \dfrac{40}{50} = \mathbf{0.8}$, and

$$P = VI\cos\phi = 220 \times 4.4 \times 0.8 = \mathbf{774\ W} \quad (= I^2R = 4.4^2 \times 40)$$

Marking scheme

- Z = 50 Ω and I = 4.4 A.
- cos φ = 0.8 and P = 774 W.

d. **Yes.** A capacitor with $X_C = X_L = 30\ \Omega$ cancels the coil's reactance (series resonance): $Z = R = 40\ \Omega$, and the current is in phase with the voltage (power factor 1). **[2]**

$$I = \frac{220}{40} = 5.5\ \text{A} \qquad P = I^2R = 5.5^2 \times 40 = 1210\ \text{W}$$

The power rises from 774 W to about **1,210 W**. A capacitor itself uses no power; it only lets more current flow.

Marking scheme

- With X_C = X_L, the circuit is at resonance: Z = R = 40 Ω, cos φ = 1.
- I = 5.5 A, P = 1,210 W, more than 774 W: she is right.

OR

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a. **Biot–Savart law:** the field dB due to a small element dl of a wire carrying current I, at a point at distance r, is $dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$, where θ is the angle between dl and the line to the point. **[2]**

At the center of a circular coil, every element is at the same distance r and at θ = 90°, and all their fields point the same way along the axis. Adding them over the circumference $2\pi r$ gives $B = \frac{\mu_0 I}{2r}$ for one turn, and N turns add N times: $B = \frac{\mu_0 NI}{2r}$, proportional to N and I, and to 1/r.

Marking scheme

- $dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$.
- At the center every element gives a field the same way at θ = 90°: summed, $B = \mu_0 NI/2r$.

b. In a **radial field** (made by curved pole pieces and a soft iron core), the plane of the coil is always parallel to the field, whatever its deflection. The torque on the coil is then always $NIAB$, its greatest value, and does not depend on the angle. **[2]**

At rest the magnetic torque is balanced by the spring's restoring torque kθ, so $NIAB = k\theta$ and $\theta \propto I$: the deflection is proportional to the current, and the scale is even (linear).

Marking scheme

- In a radial field the coil's plane is always along the field, so the torque NIAB doesn't depend on the angle.
- So θ ∝ I (NIAB = kθ), giving a linear scale.

c. **[2]**

$$B = \frac{\mu_0 NI}{2r} = \frac{4\pi \times 10^{-7} \times 100 \times 0.50}{2 \times 0.050} = \frac{6.28 \times 10^{-5}}{0.10} = \mathbf{6.3 \times 10^{-4}}\ \mathrm{T}$$

Marking scheme

- Uses $B = \mu_0 NI/2r$ with r = 0.050 m.
- B = 6.3 × 10⁻⁴ T.

d. **Only the current sensitivity doubles.** Current sensitivity is $\frac{\theta}{I} = \frac{NBA}{k}$, so twice N gives twice the deflection per ampere. **[2]**

Voltage sensitivity is $\frac{\theta}{V} = \frac{NBA}{kR}$. Twice as many turns of the same wire is twice the length, so R doubles too, and the voltage sensitivity stays about the same.

Marking scheme

- Current sensitivity NBA/k doubles with N.
- Voltage sensitivity NBA/(kR) is unchanged, since R doubles with the wire's length.

Question 12 — 8 marks

a. **De Broglie's hypothesis** (1924): every moving particle has a wave linked with it, of wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$, where p is its momentum. **[2]**

Light was already known to behave both as a wave (interference, diffraction) and as particles, photons (the photoelectric effect). De Broglie proposed that matter is the same: particles such as electrons also behave as waves. So both radiation and matter have a **dual nature**, as waves and as particles.

Marking scheme

- $\lambda = h/mv$ for every moving particle.
- Dual: as light behaves as waves and particles, so does matter.

b. Diffraction is noticeable only when the spacing of the obstacles is about the same as the wavelength. An electron accelerated through about 100 V has a wavelength of about 1 Å (10⁻¹⁰ m), far smaller than the gap between the lines of any ruled grating. **[2]**

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The atoms of a crystal are regularly spaced about 1 Å apart, the right size, so a crystal acts as a natural grating. Electrons passed through or reflected from a crystal gave diffraction patterns, just as X-rays do, which proved they behave as waves.

Marking scheme

- Diffraction needs spacing about the wavelength; electrons' λ (about 1 Å) is far too small for a ruled grating.
- A crystal's atoms are about 1 Å apart, so it diffracts electrons, giving patterns like X-rays'.

c. [2]

$eV = \frac{p^2}{2m}$, so

$$p = \sqrt{2meV} = \sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 150} = 6.61 \times 10^{-24}\ \text{kg m/s}$$

$$\lambda = \frac{h}{p} = \frac{6.62 \times 10^{-34}}{6.61 \times 10^{-24}} = \mathbf{1.0 \times 10^{-10}}\ \text{m}\ (1.0\ \text{Å})$$

Marking scheme

- $p = \sqrt{2meV} = 6.61 \times 10^{-24}$ kg m/s.
- λ = h/p = 1.0 × 10⁻¹⁰ m.

d. [2]

$$\lambda = \frac{h}{mv} = \frac{6.62 \times 10^{-34}}{0.45 \times 20} = \frac{6.62 \times 10^{-34}}{9.0} = 7.4 \times 10^{-35}\ \text{m}$$

Diffraction is seen only when the opening is about the size of the wavelength. This wavelength is far smaller than a goal, or even a proton (about 10⁻¹⁵ m), so the ball's wave nature can never be noticed: for everyday bodies, h is so small that they behave as particles only.

Marking scheme

- λ = h/mv = 7.4 × 10⁻³⁵ m.
- Far too small compared with any opening (even a nucleus), so no diffraction is ever seen.

Science Playground, Katunje, Bhaktapur
Book a class visit: https://science-playground.com/booking