Grade 12 Physics Model Paper 2

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. **(ii)** Pa s (N s/m²)

b. **(ii)** to give it a large moment of inertia, so that its speed changes little between the engine's strokes

c. **(iv)** 8 m/s

d. **(ii)** It increases, because it takes in heat and its molecules become less ordered.

e. **(ii)** 600 J

f. **(iii)** The speed of sound in a gas is proportional to the square root of its absolute temperature.

g. **(ii)** one eighth

h. **(ii)** Soft iron has a narrow hysteresis loop, so little energy is lost in each cycle of magnetization.

i. **(i)** They attract each other.

j. **(iii)** 0.4 V

k. **(ii)** that every charge is a whole-number multiple of a smallest charge, e

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

Question 2 — 5 marks

a. **Surface tension** of a liquid is the force per unit length acting at right angles to an imaginary line drawn on its surface, in the plane of the surface: $T = F/l$. Its SI unit is N/m. **[1]**

Marking scheme

- Force per unit length, at right angles to a line on the surface ($T = F/l$).

b. Surface tension makes a liquid's surface behave like a stretched skin that tries to make its area as small as possible, because a larger surface has more surface energy. **[2]**

For a given volume, a sphere has the least surface area of any shape. A small drop's weight is too little to flatten it, so surface tension pulls it into a sphere. (A large drop is flattened by its weight.)

Marking scheme

- Surface tension makes the surface contract to the smallest area (least surface energy).
- A sphere has the least area for a given volume, and in a small drop gravity is too weak to flatten it.

c. From $h = \dfrac{2T\cos\theta}{r\rho g}$, $h \propto 1/r$: in the narrower tube water would rise **6.0 cm** if it could. **[2]**

She is not right: the water does not overflow. It rises to the top of the 2.0 cm tube and stops there. The meniscus then flattens, making a larger radius of curvature R, so that the upward pull of surface tension holds up only a 2.0 cm column (hR stays constant). If water flowed out, the tube would be a machine giving energy for nothing.

Marking scheme

- $h \propto 1/r$: the rise would be 6.0 cm, more than the 2.0 cm of tube.
- No overflow: the water reaches the top and the meniscus's radius of curvature grows, so it stays there.

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Question 3 — 5 marks

a. **Resonance** is the large-amplitude oscillation of a body when it is driven by a periodic force whose frequency is equal to its own natural frequency. **[1]**

Marking scheme

- Oscillation with the largest amplitude when the driving frequency equals the natural frequency.

b. **[2]**

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{50}{0.50}} = 10\ \text{rad/s} \qquad T = \frac{2\pi}{\omega} = \frac{2\pi}{10} = \mathbf{0.63}\ \text{s}$$

The speed is greatest at the mean position: $v_{\max} = \omega A = 10 \times 0.10 = \mathbf{1.0\ m/s}$.

Marking scheme

- T = 2π√(m/k) = 0.63 s.
- $v_{\max} = \omega A = 1.0$ m/s.

c. The total energy is $E = \frac{1}{2}kA^2 = \frac{1}{2} \times 50 \times 0.10^2 = 0.25$ J. The potential energy at x is $\frac{1}{2}kx^2$, and the two energies are equal when it is half of the total: **[2]**

$$\tfrac{1}{2}kx^2 = \tfrac{1}{2}\left(\tfrac{1}{2}kA^2\right) \quad \Rightarrow \quad x = \frac{A}{\sqrt{2}} = \frac{0.10}{1.414} = 0.071\ \text{m}$$

He is not right. At 5 cm the potential energy is only a quarter of the total ($(\frac{1}{2})^2$). The energies are equal at **7.1 cm** from the mean position, because potential energy grows as x^2, not as x.

Marking scheme

- At 5 cm the PE is $\frac{1}{4}$ of the total, so he is not right (PE ∝ x²).
- Equal at $x = A/\sqrt{2} = 7.1$ cm.

OR

a. The **moment of inertia** of a body about an axis is the sum of the products of the mass of each particle of the body and the square of its distance from the axis: $I = \sum mr^2$. It measures how hard the body is to set turning or to stop. **[1]**

Marking scheme

- $I = \sum mr^2$ about the axis.

b. **[2]**

$$\alpha = \frac{\tau}{I} = \frac{10}{2.0} = \mathbf{5.0}\ \text{rad/s}^2$$

After 4.0 s, $\omega = \alpha t = 5.0 \times 4.0 = 20$ rad/s, so

$$K = \tfrac{1}{2}I\omega^2 = \tfrac{1}{2} \times 2.0 \times 20^2 = \mathbf{400}\ \text{J}$$

Marking scheme

- $\alpha = \tau/I = 5.0$ rad/s².
- ω = 20 rad/s and K = ½Iω² = 400 J.

c. The clay is dropped straight down, so it applies no external torque about the axis, and the angular momentum $I\omega$ of wheel and clay together stays the same. The clay adds to the moment of inertia, so the **angular velocity decreases**. **[2]**

The **kinetic energy decreases** too: with $L = I\omega$ constant, $K = \frac{L^2}{2I}$, which falls as I grows. The lost energy goes into heat and sound while friction drags the clay up to the wheel's speed.

Marking scheme

- Angular momentum conserved (no external torque); I increases, so ω decreases.

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- K = L²/2I decreases; the energy lost becomes heat as the clay is dragged up to speed.

Question 4 — 5 marks

a. It is impossible to construct a heat engine, working in a cycle, that takes heat from a single source and converts all of it into work, without rejecting any heat to a colder sink. **[1]**

Marking scheme

- No engine working in a cycle can turn all the heat from a source into work without giving some to a sink.

b. An engine working in a cycle must return to its starting state, so after taking in heat Q_1 and expanding it must be brought back; this can only be done by giving out some heat Q_2 to a colder sink (the Kelvin–Planck statement). Its efficiency is $\eta = 1 - \dfrac{Q_2}{Q_1}$, and since Q_2 can never be zero, η is always less than 1. Even an ideal Carnot engine has $\eta = 1 - T_2/T_1$, which would be 100% only with a sink at absolute zero, which cannot be reached. **[2]**

Marking scheme

- Some heat Q_2 must always be rejected to a sink, so $\eta = 1 - Q_2/Q_1 < 1$.
- Even the Carnot efficiency $1 - T_2/T_1$ needs $T_2 = 0$ K to reach 100%, which is impossible.

c. $T_2 = 273 - 13 = 260$ K, $T_1 = 273 + 27 = 300$ K. **[1]**

$$\beta = \frac{T_2}{T_1 - T_2} = \frac{260}{300 - 260} = \frac{260}{40} = \mathbf{6.5}$$

Marking scheme

- $\beta = T_2/(T_1 - T_2) = 6.5$.

d. **No, the kitchen will get warmer.** With the door open, the heat the freezer takes from its inside comes from the kitchen, and it gives out to the kitchen that heat **plus** the work done by its compressor ($Q_1 = Q_2 + W$). So the kitchen gains heat equal to the work done. **[1]**

Marking scheme

- No: it returns to the kitchen the heat it takes plus the compressor's work, so the kitchen warms.

Question 5 — 5 marks

a. When unpolarized light falls on a transparent surface at the polarizing angle i_p, the reflected light is completely plane-polarized, and the tangent of the polarizing angle equals the refractive index of the medium: $\mu = \tan i_p$. **[1]**

Marking scheme

- $\mu = \tan i_p$, at which the reflected light is completely polarized.

b. **[2]**

$$\tan i_p = \mu = 1.5 \qquad i_p = \tan^{-1} 1.5 = \mathbf{56.3^\circ}$$

At the polarizing angle the reflected and refracted rays are at right angles, so $i_p + r = 90^\circ$: $r = 90^\circ - 56.3^\circ = \mathbf{33.7°}$.

Marking scheme

- $i_p = \tan^{-1} 1.5 = 56.3^\circ$.
- r = 90° − 56.3° = 33.7°.

c. Light reflected from the flat, horizontal water surface is partly polarized, vibrating mostly **horizontally**, parallel to the surface (completely so at Brewster's angle, about 53° for water). Ordinary dark glasses cut all light by the same fraction, glare and scene alike. **[2]**

A polaroid with its axis **vertical** blocks the horizontal vibrations, so it removes most of the glare while still passing half of the unpolarized light from the rest of the scene.

Marking scheme

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- The glare from water is polarized mostly horizontally (parallel to the surface); dark glasses dim everything equally.
- A polaroid with its axis vertical blocks that horizontal vibration, so it cuts the glare but not the rest.

Question 6 — 5 marks

a. The magnetic flux density is **1 tesla** when a conductor 1 m long, carrying a current of 1 A at right angles to the field, experiences a force of 1 N (from $F = BIl$). (Equivalently, a charge of 1 C moving at 1 m/s at right angles to it feels 1 N.) **[1]**

Marking scheme

- 1 T: a force of 1 N on 1 m of wire carrying 1 A at right angles to the field.

b. The electric force qE and the magnetic force qvB on a proton act in opposite directions. A proton goes straight through when they are equal: **[3]**

$$qE = qvB \quad \Rightarrow \quad E = vB = 2.0 \times 10^5 \times 0.05 = \mathbf{1.0 \times 10^4}\ \mathrm{V/m}$$

The electric force does not depend on the speed, but the magnetic force is proportional to it. A slower proton feels a smaller magnetic force, so the electric force wins and it is turned towards the electric force's direction; a faster one feels a larger magnetic force and is turned the other way. A slit at the far end then passes only the protons with $v = E/B$.

Marking scheme

- Forces qE and qvB in opposite directions, equal for no deviation.
- E = vB = 1.0 × 10⁴ V/m.
- Magnetic force grows with speed: slower protons are pushed by the electric force, faster ones by the magnetic force, so only v = E/B passes the slit.

c. **Yes.** For an electron both the electric force eE and the magnetic force evB reverse direction, so they still oppose each other, and they are still equal when $v = E/B$: the balance does not depend on the charge or the mass. **[1]**

Marking scheme

- Yes: both forces reverse for a negative charge and stay equal at v = E/B, which has no charge or mass in it.

Question 7 — 5 marks

a. **Neutral temperature** (θ_n): the temperature of the hot junction at which the thermo e.m.f. of a thermocouple is a maximum. **[2]**

Temperature of inversion (θ_i): the temperature of the hot junction at which the thermo e.m.f. becomes zero and then reverses its direction.

Marking scheme

- Neutral temperature: hot-junction temperature of maximum thermo e.m.f.
- Temperature of inversion: hot-junction temperature at which the e.m.f. becomes zero and reverses.

b. The rate at which the e.m.f. changes with the hot junction's temperature, $dE/d\theta = \alpha + \beta\theta$, depends only on the two metals and on θ, not on the cold junction. The neutral temperature is where this slope is zero, $\theta_n = -\alpha/\beta$, so it is the same whatever the cold junction's temperature. **[1]**

Marking scheme

- θ_n is where $dE/d\theta = \alpha + \beta\theta = 0$, which depends only on the two metals.

c. **It is not damaged.** Above the neutral temperature, 270 °C, the thermo e.m.f. passes its maximum and falls as the hot junction gets hotter: the e.m.f.–temperature curve is a parabola, symmetric about θ_n. **[2]**

The neutral temperature is halfway between the cold junction and the temperature of inversion:

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$$\theta_i = 2\theta_n - \theta_c = 2 \times 270 - 20 = \mathbf{520}\ ^\circ\mathbf{C}$$

Marking scheme

- Not damaged: above θ_n = 270 °C the e.m.f. decreases (the curve is a parabola about θ_n).
- $\theta_i = 2\theta_n - \theta_c = 520$ °C.

Question 8

5 marks

a. The magnetic force $F = evB$ is always at right angles to the electron's velocity, so it changes only its direction, never its speed. A force of constant size always at right angles to the motion is a centripetal force: the path is a **circle**. **[3]**

$$evB = \frac{mv^2}{r} \quad \Rightarrow \quad r = \frac{mv}{eB} = \frac{9.1 \times 10^{-31} \times 2.0 \times 10^{7}}{1.6 \times 10^{-19} \times 2.0 \times 10^{-3}} = 5.7 \times 10^{-2}\ \text{m} = \mathbf{5.7}\ \text{cm}$$

Marking scheme

- The force evB is at right angles to v and constant in size, so it is a centripetal force: a circle.
- $evB = mv^2/r$, so r = mv/(eB).
- r = 5.7 × 10⁻² m (5.7 cm).

b. The radius **doubles** to 11.4 cm, since $r = \dfrac{mv}{eB} \propto v$. **[2]**

The time for one revolution **stays the same**:

$$T = \frac{2\pi r}{v} = \frac{2\pi m}{eB}$$

which has no v in it. The faster electron goes round a circle twice as long in the same time.

Marking scheme

- r ∝ v, so the radius doubles.
- T = 2πm/(eB) does not depend on v, so the time for one revolution is unchanged.

Question 9

5 marks

a. **[3]**

P waves	S waves
Longitudinal: the rock moves back and forth along the direction of travel	Transverse: the rock moves at right angles to the direction of travel
Faster (about 6–8 km/s in the crust), so they arrive first	Slower (about 3–4.5 km/s), so they arrive second
Travel through solids, liquids and gases	Travel only through solids (not through the liquid outer core)

Marking scheme

- Longitudinal (P) and transverse (S).
- P faster and arriving first; S slower and arriving second.
- P through solids, liquids and gases; S only through solids.

b. Both waves leave the focus together and travel the same distance d: **[2]**

$$\frac{d}{3.5} - \frac{d}{6.0} = 20 \quad \Rightarrow \quad d\left(\frac{6.0 - 3.5}{3.5 \times 6.0}\right) = 20 \quad \Rightarrow \quad d \times \frac{2.5}{21} = 20$$

$$d = \frac{20 \times 21}{2.5} = \mathbf{168}\ \text{km}$$

Marking scheme

- $d/3.5 - d/6.0 = 20$.

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- d = 168 km.

OR

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

1. For each metal there is a threshold frequency: below it no electrons are emitted, however bright the light.
2. Emission begins instantly, with no measurable delay, even in very dim light.
3. The maximum kinetic energy of the photoelectrons depends on the frequency of the light, not on its intensity; it increases with the frequency.
4. Above the threshold frequency, the number of photoelectrons emitted per second (the photocurrent) is proportional to the intensity of the light.

Marking scheme

- One correct law.
- A second correct law.
- A third correct law.

b. **[2]**

$$E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{400 \times 10^{-9}} = 4.97 \times 10^{-19}\ \text{J} = \frac{4.97 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.10\ \text{eV}$$

By Einstein's equation, $K_{\max} = hf - \phi = 3.10 - 2.3 = \mathbf{0.80\ eV}$, so the stopping potential is **0.80 V**.

Marking scheme

- Photon energy hc/λ = 3.10 eV (4.97 × 10⁻¹⁹ J).
- $K_{\max} = 3.10 - 2.3 = 0.80$ eV; stopping potential 0.80 V.

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

Question 10 — 8 marks

a. **[2]**

$$L = 10 \log_{10} \frac{I}{I_0} = 10 \log_{10} \frac{10^{-5}}{10^{-12}} = 10 \log_{10} 10^{7} = 10 \times 7 = \mathbf{70}\ \text{dB}$$

Marking scheme

- $L = 10 \log_{10}(I/I_0)$.
- L = 70 dB.

b. Source moving, listener at rest: $f' = \dfrac{v}{v \mp v_s} f$. **[2]**

Coming towards her: $f' = \dfrac{340}{340 - 20} \times 500 = \dfrac{340}{320} \times 500 = \mathbf{531\ Hz}$.

Going away: $f'' = \dfrac{340}{340 + 20} \times 500 = \dfrac{340}{360} \times 500 = \mathbf{472\ Hz}$.

Marking scheme

- Approaching: f′ = 340/320 × 500 = 531 Hz.
- Receding: f″ = 340/360 × 500 = 472 Hz.

c. **No.** By the inverse square law, at twice the distance the intensity falls to a quarter, 2.5×10^{-6} W/m². The level depends on the logarithm of the intensity: **[2]**

$$L = 10 \log_{10} \frac{2.5 \times 10^{-6}}{10^{-12}} = 10 \times 6.40 = 64\ \text{dB}$$

It falls by only $10 \log_{10} 4 = 6$ dB, to about **64 dB**, not to 35 dB.

Marking scheme

- Intensity falls to a quarter (inverse square law), not the level to half.

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- The level falls by 10 log 4 ≈ 6 dB, to about 64 dB.

d. **No, slightly less.** With the listener moving towards a source at rest, $f' = \dfrac{v + v_o}{v} f = \dfrac{360}{340} \times 500 = 529$ Hz, not 531 Hz. The two cases are not the same, because sound travels in the air: a moving source changes the wavelength of the waves in the air, while a moving listener meets unchanged waves more often. Only the motion relative to the air matters, not just the relative motion of source and listener. **[2]**

Marking scheme

- No: listener moving gives f′ = (v + v₀)/v × f = 529 Hz, against 531 Hz.
- A moving source changes the wavelength in the air; a moving listener only meets the waves faster, so the cases differ.

OR

a. Compare with $y = A\sin(\omega t - kx)$: $\omega = 200\pi$ rad/s and $k = 0.5\pi$ rad/m. **[2]**

$$f = \frac{\omega}{2\pi} = \frac{200\pi}{2\pi} = \mathbf{100\ Hz} \qquad \lambda = \frac{2\pi}{k} = \frac{2\pi}{0.5\pi} = \mathbf{4.0\ m}$$

Marking scheme

- f = ω/2π = 100 Hz.
- λ = 2π/k = 4.0 m.

b. Wave speed: $v = f\lambda = 100 \times 4.0 = \mathbf{400\ m/s}$ (or ω/k). **[2]**

Particle speed: $\dfrac{dy}{dt} = A\omega\cos(\omega t - kx)$, greatest $A\omega = 0.05 \times 200\pi = 10\pi = \mathbf{31.4\ m/s}$.

Marking scheme

- Wave speed v = fλ = 400 m/s.
- Greatest particle speed Aω = 31.4 m/s.

c. **[2]**

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x = \frac{2\pi}{4.0} \times 1.0 = \frac{\pi}{2}\ \text{rad}\ (90^\circ)$$

The two points are a quarter of a cycle out of step: when one is at its greatest displacement, the other is passing through its mean position.

Marking scheme

- Δφ = (2π/λ)Δx = π/2 (90°).
- They are a quarter of a cycle apart: one at an extreme while the other passes the mean position.

d. **No.** The wave carries energy and the disturbance along the rope at 400 m/s, but each particle only vibrates about its own mean position, at right angles to the rope (the wave is transverse), and is never carried along. A particle's speed also changes all the time, from 0 at its extremes to 31.4 m/s at its mean position, and has nothing to do with 400 m/s. **[2]**

Marking scheme

- No: the wave carries energy, not matter; each particle vibrates about its own mean position.
- The particle's speed varies from 0 to 31.4 m/s, across the rope, unrelated to the wave speed.

Question 11 — 8 marks

a. A transformer works on **mutual induction**. An alternating current in the primary coil sets up an alternating magnetic flux in the iron core, which links the secondary coil as well. The changing flux through the secondary induces an alternating e.m.f. in it, of the same frequency, and the e.m.f. per turn is the same in both coils, so $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$. **[2]**

Marking scheme

- Mutual induction: the primary's alternating current makes an alternating flux in the core, which links the secondary.

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- The changing flux induces an alternating e.m.f. in the secondary, in the ratio of the turns.

b. For a given power $P = VI$, a higher voltage means a smaller current in the line. The power lost as heat in the line's resistance is I^2R, so making the current, say, 50 times smaller cuts the loss 2,500 times. Thinner, cheaper wires can then be used, and transformers step the voltage down again near the users. **[2]**

Marking scheme

- For the same power, higher voltage means a smaller current (P = VI).
- The line loss I²R is then much smaller.

c. **[2]**

$$N_s = N_p \frac{V_s}{V_p} = 2500 \times \frac{220}{11\,000} = \mathbf{50\ \text{turns}}$$

For an ideal transformer $V_p I_p = V_s I_s = 4400$ W:

$$I_s = \frac{4400}{220} = \mathbf{20\ \text{A}} \qquad I_p = \frac{4400}{11\,000} = \mathbf{0.40\ \text{A}}$$

Marking scheme

- N_s = 50 turns.
- I_s = 20 A and I_p = 0.40 A.

d. A battery gives a **steady (d.c.)** current. While it flows steadily, the flux in the core is constant, and a constant flux induces no e.m.f. in the secondary (Faraday's law needs a **changing** flux), so the bulb stays dark. **[2]**

At the moment she connects or disconnects the battery, the primary current grows from zero or falls to zero, so the flux in the core changes for that instant. The changing flux induces a short pulse of e.m.f. in the secondary, which makes the flash. To keep the bulb lit she would need an **alternating** voltage on the primary, for example from an inverter.

Marking scheme

- A steady d.c. gives a constant flux, which induces no e.m.f. in the secondary: no light.
- Connecting or disconnecting changes the current and so the flux for an instant, inducing a brief e.m.f.: the flash.

Question 12 — 8 marks

a. **Forward bias** (p side to +): the applied voltage opposes the junction's potential barrier, so the depletion layer narrows. Once the voltage passes the barrier (about 0.7 V for silicon), majority carriers, holes from the p side and electrons from the n side, cross the junction easily: a large current. **[2]**

Reverse bias (p side to −): the applied voltage adds to the barrier and widens the depletion layer, so majority carriers cannot cross. Only a tiny current of minority carriers flows.

Marking scheme

- Forward bias lowers the barrier and narrows the depletion layer, so majority carriers flow: large current.
- Reverse bias raises the barrier and widens the layer: only a tiny minority-carrier current.

b. The four diodes are arranged in a bridge, with the a.c. across one diagonal and the load across the other. In one half-cycle, two opposite diodes are forward biased and conduct, while the other two are reverse biased: the current goes through the load in one direction. In the next half-cycle, the other pair conducts and the first pair blocks, and the paths are arranged so that the current again passes through the load **in the same direction**. Both halves of the wave are used: full-wave rectification. **[2]**

Marking scheme

- In each half-cycle one pair of diodes conducts and the other is reverse biased.
- The two pairs send the current through the load in the same direction, so both halves are used (full-wave).

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c. Peak of the a.c.: $V_0 = \sqrt{2}\,V_{\text{rms}} = 1.414 \times 12 = 17.0$ V. **[2]**

In a bridge, two diodes conduct at a time: $V_{\text{load}} = 17.0 - 2 \times 0.7 =$ **15.6 V**.

Marking scheme

- $V_0 = \sqrt{2} \times 12 = 17.0$ V.
- Load peak = 17.0 − 1.4 = 15.6 V (two diodes conducting).

d. The rectifier's output is **pulsating** d.c.: it goes from 0 up to the peak and back in each half-cycle. **[2]**
A large capacitor across the load charges up to the peak voltage while the output rises. As the output falls, the diodes stop conducting and the capacitor **discharges slowly** through the load, keeping the voltage up until the next peak recharges it, so the output only dips a little between peaks (a small ripple) instead of falling to zero.

A larger current means the capacitor's charge drains away faster between peaks ($\Delta V = \Delta Q/C = I\Delta t/C$), so the voltage **dips more**: the ripple grows. A larger capacitor would be needed to keep it small.

Marking scheme

- The capacitor charges to the peak and discharges slowly through the load between peaks, so only a small ripple is left.
- A larger current drains it faster between peaks, so the ripple grows (ΔV = IΔt/C).

OR

a. Radioactive decay is **random** and **spontaneous**: each nucleus has the same chance of decaying in a given second, whatever happens to its neighbors, and it is not affected by temperature, pressure or chemical combination. So the more undecayed nuclei there are, the more decay each second, in direct proportion: $\frac{dN}{dt} = -\lambda N$, where λ is the decay constant. **[2]**

Marking scheme

- Each nucleus has the same, fixed chance of decaying per second, independently of the others.
- So the number decaying per second is proportional to N: $dN/dt = -\lambda N$.

b. The mean life is the average lifetime of all the nuclei, $\tau = 1/\lambda$, while the half-life is the time for half of them to decay, $T_{1/2} = 0.693/\lambda$. So $\tau = T_{1/2}/0.693 = 1.44\,T_{1/2}$. **[2]**

Half the nuclei decay within one half-life, but the rest live on, some for many half-lives. These long-lived nuclei pull the average up, so the mean life is longer than the half-life.

Marking scheme

- $\tau = 1/\lambda$ and $T_{1/2} = 0.693/\lambda$, so $\tau = 1.44\,T_{1/2}$.
- Some nuclei survive many half-lives, raising the average above the half-life.

c. Take away the background from each reading to get the count rate of the sample itself: **[2]**

Time (hours)	0	1	2	3	4
Corrected count rate	1600	1131	800	566	400

The corrected rate halves from 1600 to 800 in 2 hours, and from 800 to 400 in the next 2 hours: the half-life is **2.0 hours**.

Marking scheme

- Background subtracted: 1600, 1131, 800, 566, 400.
- Half-life = 2.0 hours.

d. The background, 30 counts per minute, comes from cosmic rays and the surroundings and does not decay. Added to every reading, it makes the counts fall by **less than half** in each half-life (1630 to 830 in 2 hours is only to 51%), so the halving seems to take longer, and the half-life comes out too long. **[2]**

The error **grows** with time: as the sample's own count rate falls, the constant 30 counts per minute become a larger and larger part of each reading, and the raw count rate levels off at 30 instead of falling towards zero.

Marking scheme

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- The background does not decay; included in the readings, it makes them fall by less than half per half-life, so the half-life seems longer.
- The error grows later, as the background becomes a larger share of the falling count rate.

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