2023 Preliminary Examinations H2 Physics Paper 3 Solutions

1 (a) (i) Gravitational force provides the centripetal force

$$\frac{GMm}{r^2} = m\omega^2 r$$

$$\omega^2 = \frac{GM}{r^3}$$

$$\omega = \sqrt{GM}\, r^{-\frac{3}{2}}$$

$$k = -\frac{3}{2} = -1.5$$

(ii)

$$\frac{\omega_2}{\omega_1} = (\frac{r_2}{r_1})^{-\frac{3}{2}}$$

$$\omega_2 = (\frac{2\pi}{24\times 3600})(\frac{6700}{42000})^{-\frac{3}{2}}$$

$\omega_2 = 1.14 \times 10^{-3}$ rad s^{-1}

(b) (i)

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \quad \Rightarrow \quad mv^2 = \frac{GMm}{r}$$

$$E_k = \frac{mv^2}{2} = \frac{GMm}{2r}$$

$$E_T = E_K + E_P$$

$$= \frac{GMm}{2r} + \left(-\frac{GMm}{r}\right)$$

$$= -\frac{GMm}{2r}$$

(ii)

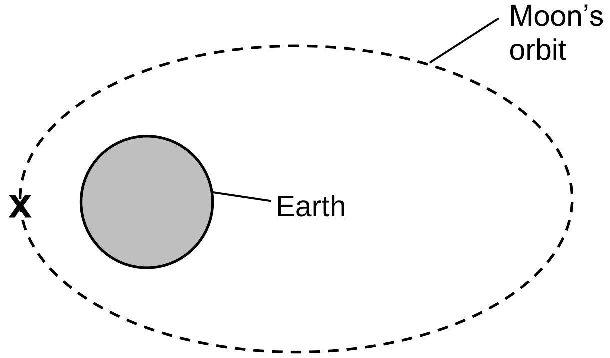
$$\Delta E_T = -\frac{GMm}{2r_2} - (-\frac{GMm}{2r_1})$$

$$= \frac{GMm}{2}(\frac{1}{r_1} - \frac{1}{r_2})$$

$$= \frac{(6.67\times10^{-11})(6.0\times10^{24})(700)}{2}(\frac{1}{4.2\times10^7} - \frac{1}{(3.0\times10^5 + 4.2\times10^7)})$$

$$= 2.37\times10^7 \text{ J}$$

(c)



$E_T = E_P + E_K$
(E_T and E_P are negative values, E_K is positive.)

E_T is constant, when Moon is nearest to the Earth, its E_P is smallest (more negative), hence E_K and speed is the largest.

OR By conservation of energy, when Moon is nearest to the Earth, its E_P is smallest (more negative), hence E_K and speed is the largest.

2 **(a)** **(i)** By $\frac{pV}{T} = \text{constant}$,

$$\frac{p_C V_C}{T_C} = \frac{p_B V_B}{T_B}$$

$$p_C = \frac{p_B V_B}{T_B} \times \frac{T_C}{V_C}$$

$$= \frac{\left(7.0 \times 10^5\right) \times 0.0015}{1260} \times \frac{960}{0.0040}$$

$$= 2.00 \times 10^5 \text{ Pa}$$

(ii) $W =$ Area under the graph

$$= \frac{1}{2}\left(7.0 + 2.0\right) \times 10^5 \times \left(4.0 - 1.5\right) \times 10^{-3}$$

$$= 1130 \text{ J}$$

(b)
1. The process is carried out slowly.
2. The walls of the engine are good conductors of heat.
3. The engine is surrounded by a heat reservoir at constant temperature.

Maximum 2 marks

(c)

change	work done on gas / J	heat supplied to gas / J	increase in internal energy / J
A → B	–1000	2625	1625
B → C	–1125	500	–625
C → D	0	–1000	–1000
D → A	555	–555	0

(d) During an explosion, the pressure at different points of the gas is not uniform. Hence, pressure is undefined and cannot be represented as a point or a curve on the p−V diagram.

3 **(a)** For a to be minimum, the minimum intensity detected directly below it must be the 1st minimum from the central bright fringe. i.e., $n = 0.5\lambda$

$\therefore$ Path difference = 0.5 λ

$$\sqrt{2.00^2 + a^2} - 2.00 = 0.5\lambda$$

$$a^2 + \left(2.00\right)^2 = \left(2.00 + 0.5\lambda\right)^2$$

$$a^2 + 4 = 4 + 2\lambda + 0.25\lambda^2$$

$$a = \sqrt{4\lambda + 0.25\lambda^2}$$

$$= \sqrt{\left(750 \times 10^{-9}\right)\left(2 + 0.25\left(750 \times 10^{-9}\right)\right)} = \sqrt{1.50 \times 10^{-6}}$$

$$= 1.22474 \times 10^{-3} = 1.22 \times 10^{-3}$$

λ has to be substituted in at the last step and not earlier as calculator has insufficient number of digits.

OR Since the interference pattern is symmetrical about perpendicular bisector between S_1 and S_2,

$a = 0.5\Delta x + 0.5\Delta x = \Delta x$

OR

Distance (on the screen) between the central maximum and the 1st minimum is

$\frac{x}{2} = \frac{a}{2}$

$a = \frac{\lambda D}{\Delta x} = \frac{\lambda D}{a}$

$a^2 = \lambda D = \left(750\times10^{-9}\right)\left(2.00\right) = 1.50\times10^{-6}$

$a = 1.22474\times10^{-3} = 1.22\times10^{-3}$ m

(b) (i)

$v = \frac{3\Delta x}{(1.0)}$

$= 3\frac{\lambda D}{a}$

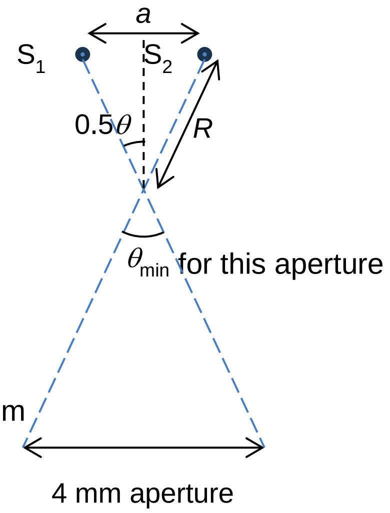
$= \frac{3\left(750\times10^{-9}\right)\left(2.00\right)}{1.2247\times10^{-3}}$

$= 3.67\times10^{-3}$ m s^{-1}

(ii) The frequency will <u>decrease</u>.

<u>$\Delta x = \frac{\lambda D}{a}$. D increases as the detector moves.</u> Hence, Δx increases and the detector has to move a corresponding longer distance to detect consecutive maxima.

(c) For images to be just resolved,



$\theta_{min} = \frac{\lambda}{b} = \frac{750\times10^{-9}}{4.0\times10^{-3}} = 1.875\times10^{-4}$ rad

$s = R\theta_{min}$

$R = \frac{a}{\theta_{min}} = \frac{1.22\times10^{-3}}{1.875\times10^{-4}} = 6.507$ m

OR

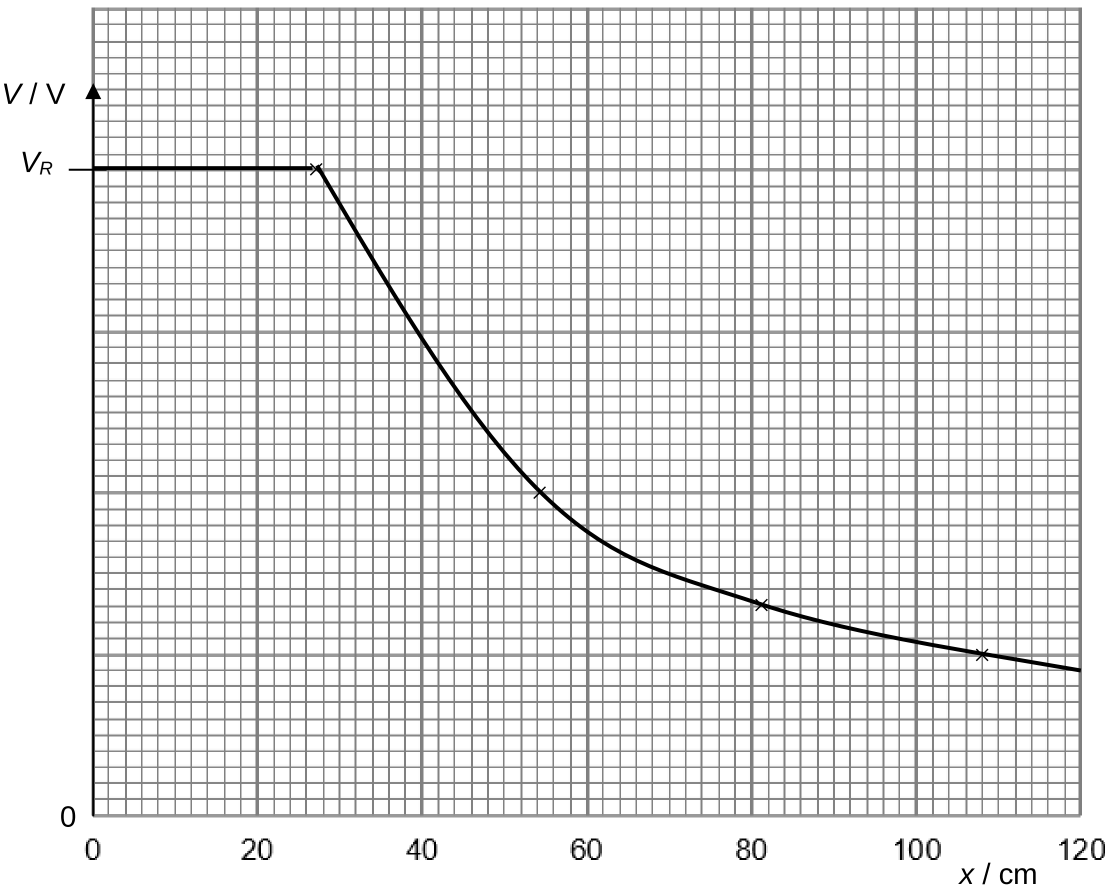
$\tan\left(\frac{1}{2}\theta_{min}\right) = \frac{\frac{1}{2}a}{R} \quad \Rightarrow R = \frac{\frac{1}{2}\left(1.22\times10^{-3}\right)}{\frac{1}{2}\left(1.875\times10^{-4}\right)} = 6.507$ m

4 (a) The electric potential at a point in an electric field is defined as <u>the work done per unit positive charge</u> by an external force <u>in bringing a small</u> test <u>charge from infinity</u> to that point.

(b) (i)

$$V_R = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$
$$= \frac{1}{4\pi\varepsilon_0}\frac{0.060\times10^{-6}}{0.27}$$
$$= 2.00\times10^{3}\ \text{V}$$

(ii)



At x = 27 cm, V is 40 small squares. Using $V \propto \frac{1}{r}$,

When x is 2 × 27 = 54 cm, V is 20 small squares.
When x is 3 × 27 = 81 cm, V is 13.3 small squares.
When x is 4 × 27 = 108 cm, V is 10 small squares.

(iii) The directions of E_A and E_B are both towards the right, in the same direction.

$$E_A = \frac{1}{4\pi\varepsilon_0}\frac{Q_A}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{0.060\times10^{-6}}{0.70^2} = 1.101\times10^{3}\ \text{N C}^{-1}$$

$$E_B = \frac{1}{4\pi\varepsilon_0}\frac{Q_B}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{0.035\times10^{-6}}{0.70^2} = 6.423\times10^{2}\ \text{N C}^{-1}$$

$E = E_A + E_B = 1.101 \times 10^3 + 6.423 \times 10^2$
$= 1.74 \times 10^3$ N C^{-1}

(iv) The charges on sphere A will redistribute such that there are more positive charges on the right side of sphere A.
Hence, the electric field strength due to sphere A will be greater in magnitude.

5 **(a)** $Q = It = 0.150 \times 20 \times 60 = 180$ C

(b) $V = IR = 0.150 \times 12 = 1.8$ V

(c) Using the potential divider principle,

$$\frac{12}{12 + R_{eff}} \times 6.0 = 1.8$$
$$12 + R_{eff} = 40$$
$$R_{eff} = 28\ \Omega$$

Since 33 Ω resistor and resistor R are arranged in parallel,

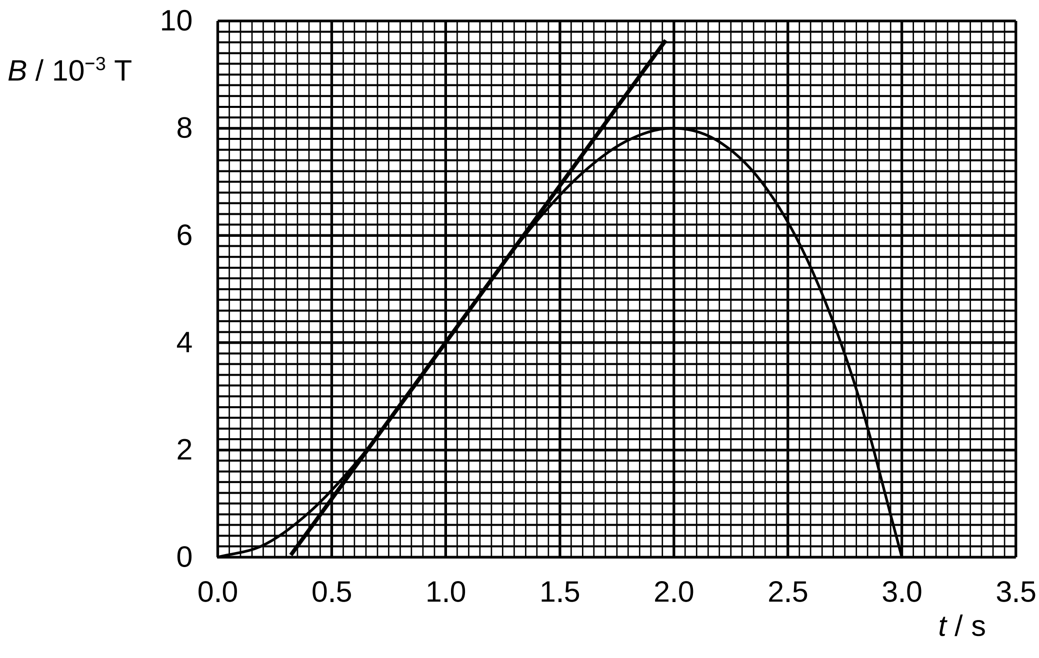
$$\frac{1}{33} + \frac{1}{R} = \frac{1}{28}$$
$$R = 185\ \Omega$$

(d) As the temperature of the thermistor increases, the resistance of the thermistor decreases.
The equivalent resistance across the parallel combination of thermistor and 33 Ω resistor will decrease and the effective resistance of the circuit will decrease.
The ammeter reading will increase.

6 **(a)** $\Phi = BAN$

$$= \left(8.0 \times 10^{-3}\right)\left(\pi \times 0.17^2\right) \times 30$$
$$= 0.0218\ \text{Wb}$$

(b)



Since induced e.m.f. $E = -\frac{d\Phi}{dt}$, the max. e.m.f. is induced when the flux linkage Φ is changing at the highest rate, and this corresponds to when time t = 1.0 s.

$$\text{Max } E = -\left(\frac{d\Phi}{dt}\right)_{\max} = -AN\left(\frac{dB}{dt}\right)_{\max}$$

where $\left(\frac{dB}{dt}\right)_{\max}$ is the gradient of the B vs t graph at t = 1.0 s

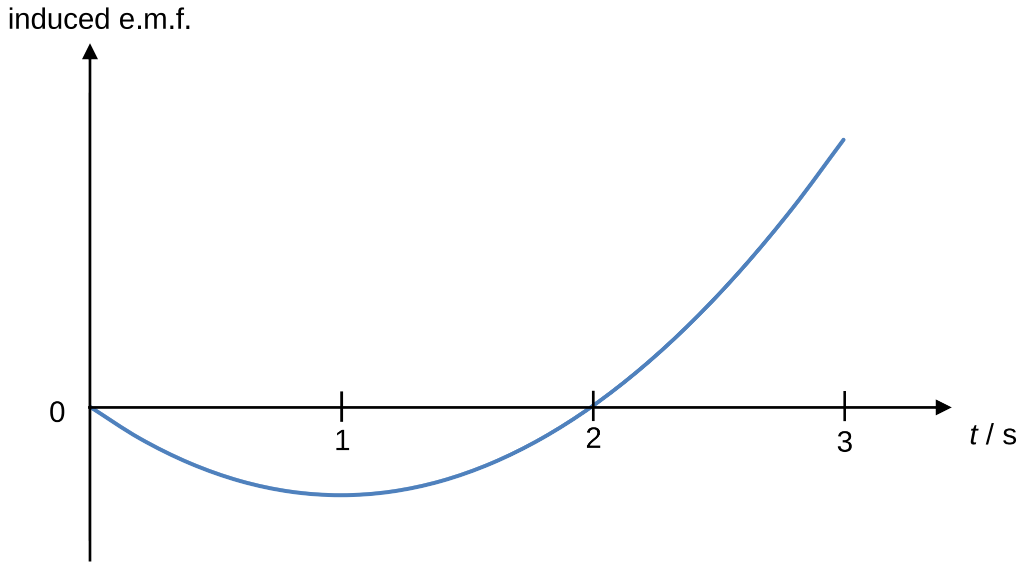
(As shown above) draw a tangent to the curve at t = 1.0 s.
Taking the points (1.35, 6.0) and (0.65, 2.0) on the tangent,

$$\text{gradient} = \left[\frac{6.0-2.0}{1.35-0.65}\right]\times 10^{-3} = 5.714\times 10^{-3}$$

$$E_{max} = -\pi \times 0.17^2 \times 30 \times 5.714\times 10^{-3}$$
$$= -0.0156 \text{ V}$$

(c) From t = 0 to 2.0 s, the magnetic flux density is increasing. Thus, by Lenz's Law, the <u>induced current produces an induced magnetic field upwards to oppose the increase in the magnetic flux in the coil</u>.
By right hand grip rule, the direction of the induced current is <u>anti-clockwise</u>.

(d)



7 **(a)** $\text{KE}_{\max} = eV_s$

$$= \left(1.60\times 10^{-19}\right)(1.1)$$
$$= 1.76\times 10^{-19} \text{ J}$$

(b)

$$f = \frac{c}{\lambda} = \frac{\left(3.00\times 10^{8}\right)}{450\times 10^{-9}}$$

$$hf = eV_s + \phi$$

$$\frac{\left(6.63\times 10^{-34}\right)\left(3.00\times 10^{8}\right)}{450\times 10^{-9}} = \left(1.6\times 10^{-19}\right)(1.1) + \phi$$

$$\phi = 2.66\times 10^{-19} \text{ J}$$

$$\phi = hf_0$$

$$f_0 = \frac{2.66\times 10^{-19}}{6.63\times 10^{-34}}$$

$$f_0 = 4.01\times 10^{14} \text{ Hz}$$

(c) The energy of the photons remains the same because as $E = hf$ and f is the same. Hence, by the photoelectric equation, the maximum kinetic energy of photoelectrons emitted will not be affected.

(d)

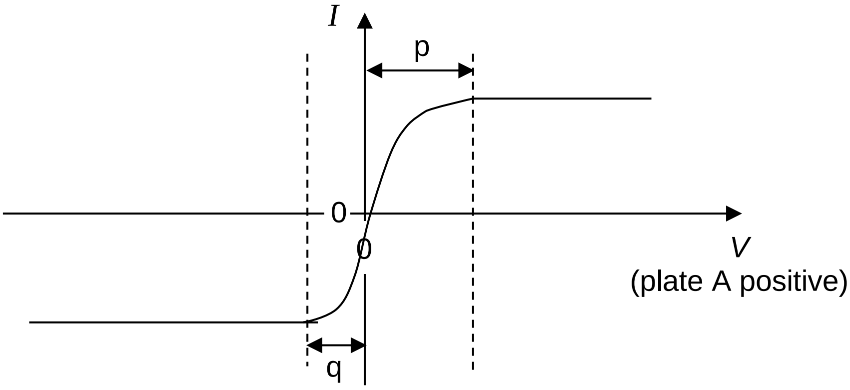
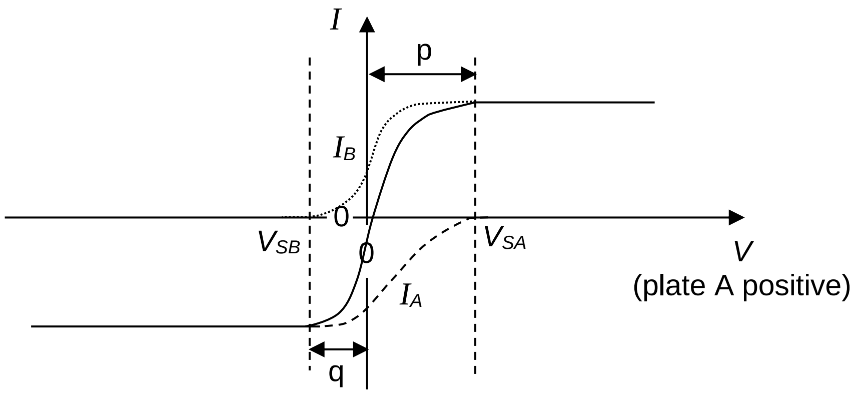


Fig. 7.3

Additional information:
Photoelectrons will be emitted from both plates.

Since plate A has a lower threshold frequency than plate B, photoelectrons emitted from plate A have higher maximum kinetic energy than plate B. Stopping potential of plate A, V_{SA} will be larger than that of plate B, V_{SB}.



8 **(a)** **(i)** $(F =) -kx$

(ii) By Newton's second law of motion,

$$F_{net} = ma$$
$$-kx = ma$$
$$a = -\frac{k}{m}x$$

Since both k and m are constants ($\frac{k}{m}$ is a constant), a and x satisfy the defining equation of simple harmonic motion i.e., $a = -\omega^2 x$ (where ω is constant), and the block oscillates with simple harmonic motion.

(iii) Comparing the equation obtained with $a = -\omega^2 x$,

$$\omega^2 = \frac{k}{m}$$

$$\left(\frac{2\pi}{T}\right)^2 = \frac{k}{m}$$

$$T = 2\pi\sqrt{\frac{m}{k}} \quad \text{(shown)}$$

(b) (i) 1. Let the speed right after collision be *v*, by principle of conservation of linear momentum,

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

$$m_B u_B = (m_A + m_B)v \quad (\because u_A = 0)$$

$$v = \left(\frac{m_B}{m_A + m_B}\right)u_B$$

$$= \left[\frac{18\times10^{-3}}{(35+18)\times10^{-3}}\right](5.3)$$

$$= 1.80 \text{ m s}^{-1}$$

By principle of conservation of energy,
loss in kinetic energy = gain in elastic potential energy

$$\cancel{\tfrac{1}{2}}(m_A + m_B)v^2 = \cancel{\tfrac{1}{2}}k x_{max}^{\ 2}$$

$$x_{max}^{\ 2} = \frac{(m_A + m_B)v^2}{k}$$

$$x_{max} = \sqrt{\frac{m_A + m_B}{k}}\,v$$

$$= \sqrt{\frac{[(35+18)\times10^{-3}]}{25}}(1.80)$$

$$= 0.0829 \text{ m}$$

2.

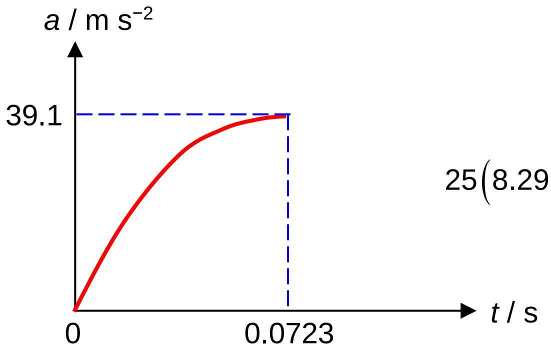
$$t = \frac{1}{4}T$$

$$= \frac{\pi}{2}\sqrt{\frac{m_A + m_B}{k}}$$

$$= \frac{\pi}{2}\sqrt{\frac{(35+18)\times10^{-3}}{25}}$$

$$= 0.0723 \text{ s}$$

(ii)



$$F = ma$$

$$kx_{max} = ma_{max}$$

$$25(8.29\times10^{-2}) = [(35+18)\times10^{-3}]a_{max}$$

$$a_{max} = 39.1 \text{ m s}^{-2}$$

(c) **(i)** Considering horizontal motion of block B, by Newton's second law of motion,

$$F_{net} = ma$$
$$f_0 = m_B a_0$$
$$a_0 = \frac{f_0}{m_B}$$
$$= \frac{9.5 \times 10^{-2}}{18 \times 10^{-3}}$$
$$= 5.2778 \text{ m s}^{-2}$$

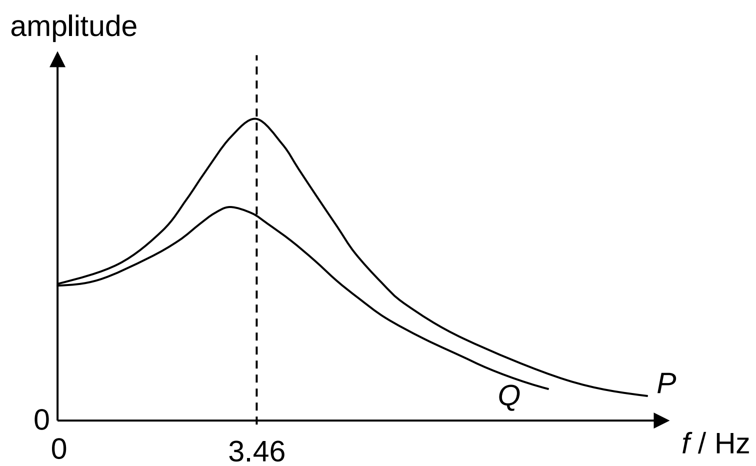
Considering horizontal motion of both blocks, by Newton's second law of motion,

$$F_{net} = ma$$
$$-kx = (m_A + m_B)a$$
$$a = -\left(\frac{k}{m_A + m_B}\right)x$$

$$x_0 = \left(\frac{m_A + m_B}{k}\right)a_0$$
$$= \frac{\left[(35 + 18) \times 10^{-3}\right](5.2778)}{25}$$
$$= 0.0112 \text{ m}$$

(ii) **1.** resonance occurs when driving frequency (or f) equals (or close to) natural frequency of oscillations of the blocks causing large amplitude of oscillations

2.
3.



$$T = 2\pi\sqrt{\frac{m}{k}}$$
$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$
$$= \frac{1}{2\pi}\sqrt{\frac{25}{(35 + 18) \times 10^{-3}}}$$
$$= 3.46 \text{ Hz}$$

For Q:
Correct shape and peak of Q lower than P and the left of P

9 **(a)** Charge distribution: Some of the alpha particles were observed to be scattered at large angles.
This shows that they encountered a positive charge exists in a very small volume known as the nucleus so that the coulomb repulsion is very large.
Mass distribution: Since the α particles are back scattered, the positive charge they collided with must also have a much larger mass, otherwise it would be the positive charges that were pushed away rather than the alpha particles scattered backward.
Hence, the mass of the atom also exists largely within a small volume (the nucleus)
Or

(a) Charge distribution: the positive charge of the atom exists in a very small space (the nucleus) at the centre of the atom.
Some (few) alpha particles are deflected by large angles.
Mass distribution: most of the mass of the atom exists in a very small space at the centre of the atom.
This is deduced from the fact that most alpha particles are able to travel through undeflected / Some alpha particles are deflected by large angles showing that the nucleus is more massive than alpha particles.

(b) **(i)** The probability of decay of a nucleus is unaffected by external factors (such as temperature, pressure or chemical composition).

(ii) The half-life of a radioactive nuclide is the time taken for the number of undecayed nuclei to be reduced to half its original number.

(iii) **1.** mass difference,

$$\Delta m = (239.052163 - 235.043930 - 4.003860)u = 0.004373\ u$$

$$\text{Energy released} = \Delta mc^2 = (0.004373)(1.66\times10^{-27})(3.00\times10^{8})^2$$

$$= 6.533262 \times 10^{-13}\text{ J}$$

$$= 6.5 \times 10^{-13}\text{ J (shown)}$$

2.

$$E_{released} = E_U + E_\alpha = \frac{1}{2}m_U v_U{}^2 + \frac{1}{2}m_\alpha v_\alpha{}^2$$

By principle of conservation of momentum,

$$0 = m_U v_U - m_\alpha v_\alpha$$

$$v_\alpha = \frac{m_U v_U}{m_\alpha}$$

$$E_{released} = \frac{1}{2}m_U v_U{}^2 + \frac{1}{2}m_\alpha\left(\frac{m_U v_U}{m_\alpha}\right)^2$$

$$v_U = \sqrt{\frac{2E_{released}}{m_U + \left(\frac{m_U{}^2}{m_\alpha}\right)}}$$

$$= \sqrt{\frac{2(6.533262\times10^{-13})}{\left(235.043930 + \frac{235.043930^2}{4.003860}\right)(1.66\times10^{-27})}}$$

$$= 2.3684 \times 10^5 = 2.37 \times 10^5\text{ m s}^{-1}$$

(iv) Alpha particles can easily be stopped by the outer layers of the skin due to their low penetrating power.

(c) **(i)** The number of undecayed nuclei decreases with time due to radioactive decay, and since activity is directly proportional to the number of undecayed nuclei ($A = \lambda N$), the activity decreases with time.

(ii) $A = A_0 e^{-\lambda t} \Rightarrow \ln A = -\lambda t + \ln A_0$

From the graph of ln A against t,

Gradient = $-\lambda$

$$= \frac{19.5 - 38.0}{(6.4 - 0.0) \times 10^5}$$

$$= -2.8906 \times 10^{-5}$$

$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{2.8906 \times 10^{-5}}$$

$$= 23979 = 2.40 \times 10^4 \text{ years}$$

(iii) Vertical-intercept = ln A_0 = 38.0

$A_0 = e^{38.0}$

$= 3.1856 \times 10^{16}$ year^{-1}

$A_0 = \lambda N_0$

$$N_0 = \frac{A_0}{\lambda} = \frac{3.1856 \times 10^{16}}{2.8906 \times 10^{-5}}$$

$= 1.1020 \times 10^{21}$

$= 1.10 \times 10^{21}$ (to 3 s.f.)

(d) $t_{\frac{1}{2},X} = 0.5 \times t_{\frac{1}{2},Pu}$

$\lambda_X = 2\lambda_{Pu}$

$A_{0,X} = 2A_{0,\,Pu}$

$\ln (A_{0,X}) = \ln (2A_{0,\,Pu}) = \ln (2) + \ln (A_{0,\,Pu}) = 0.69 + 38 = 38.69$

Straight line graph with twice the gradient as original graph
Vertical intercept is at 38.7 (approximately 38.5)