2025 Preliminary Examination H2 Physics Solution

Paper 1

1 **A** The vector sum of the two components is not R.

2 **A** The d will increase initially as Car Y moving slower and Car X. After that, Car Y will move with speed greater than Car X and the relative speed is increasing . Hence gradient is getter steeper.

3 **C** Net force up the slope

$$630-(15+30)g\sin 30° = (15+30)a$$

$$a = 9.095 \text{ m s}^{-2}$$

For the 15 kg crate, net force up the slope

$$R-15g\sin 30° = 15a$$

$$R = 15a + 15g\sin 30° = 15(9.095+9.81\sin 30°) = 210 \text{ N}$$

4 **B** Energy stored during the process is the area under the force-extension graph

$$= \frac{1}{2}(T_1+T_2)(e_2-e_1)$$

$$= \frac{1}{2}(T_1+T_2)[(x_2-x)-(x_1-x)]$$

$$= \frac{1}{2}(T_1+T_2)(x_2-x)$$

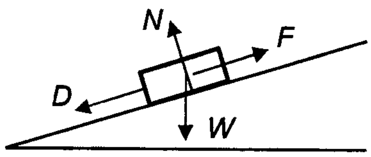
5 **A** For translational equilibrium, the net force has to be zero. Since the forces act in the opposite direction on the same object and have the same magnitude, the net force acting on the object is zero.
Option B: Even though the two forces act in opposite directions, they are spaced apart from each other which results in a torque or rotation. Hence, the object is not in equilibrium.
Option C: The direction of the torque of a couple depends on the direction of the two forces and is independent of the position of the pivot.
Option D: The pair of forces act on the same object, so they are not an action-reaction pair of forces.

6 **D**

$$F = -\frac{dU}{dx}$$

Magnitude of force = gradient of graph = $\dfrac{1.400-0.3125}{0.380-0.200}$ = 6.0 N

7 **D** Drag force, D = 250 N



Resolving forces along the slope

$$F = D + mg\sin\theta = 250 + \left(900 \times 9.81 \times \frac{1.0}{12}\right) = 985.75 \text{ N}$$

$$P = Fv = 985.75 \times 24 = 23.7 \text{ kW}$$

Alternative method:
P
= rate of work done against drag
+ rate of increase in GPE
= (250 × 24) + 900 × 9.81 × 2
= 23.7 kW

8 **B** At the top of the circle,

$$T + mg = \frac{mv^2}{r}$$

$$T = \frac{mv^2}{r} - mg = \frac{(0.10)(6.0)^2}{0.50} - (0.10)(9.81) = 6.2 \text{ N}$$

9 **B**

$$\phi = -G\frac{M}{r} = -G\left(\frac{1}{r}\right)(\text{volume} \times \text{density})$$

$$= -G\left(\frac{1}{r}\right)\left(\frac{4}{3}\pi r^3 \times \rho\right)$$

$$= -\frac{4}{3}\pi G\rho r^2$$

10 **B**

$$G\frac{Mm_Y}{R_Y^{\ 2}} = m_Y R_Y \omega_Y^{\ 2} \rightarrow \omega_Y^{\ 2} = G\frac{M}{R_Y^{\ 3}} \rightarrow \omega_Y = \sqrt{G\frac{M}{R_Y^{\ 3}}}$$

$$G\frac{Mm_X}{R_X^{\ 2}} = m_X R_X \omega_X^{\ 2} \rightarrow \omega_X^{\ 2} = G\frac{M}{R_X^{\ 3}} \rightarrow \omega_X = \sqrt{G\frac{M}{R_X^{\ 3}}}$$

$$\frac{\omega_Y}{\omega_X} = \sqrt{\frac{G\frac{M}{R_Y^{\ 3}}}{G\frac{M}{R_X^{\ 3}}}} = \sqrt{\frac{R_X^{\ 3}}{R_Y^{\ 3}}} = (3)^{3/2}$$

in the same time t, $\frac{\theta_Y}{\theta_X} = \frac{\omega_Y}{\omega_X} = (3)^{3/2}$

$\therefore \theta_Y = (3)^{3/2} \times 90° = 467.7°$

$467.7° - 360° = 107.7°$

Alternative method:

$T^2 \propto r^3$

$T_X^2 = k(3r)^3$

$T_Y^2 = k(r)^3$

$\left(\frac{T_X}{T_Y}\right)^2 = 3^3$

$T_X = 5.196 T_Y$

X takes ¼ period to move thought 90°.

$\frac{1}{4}T_X = 1.299 T_Y$

$\theta_Y = 0.299 \times 360 = 108°$

11 **C**

$$KE = \frac{1}{2}m\omega^2\left(x_0^{\ 2} - x^2\right)$$

$$PE = \frac{1}{2}m\omega^2 x^2$$

$$\frac{KE}{PE} = \frac{\left(x_0^{\ 2} - x^2\right)}{x^2} = 1$$

$$3.0^2 - x^2 = x^2$$

$$x = 2.1 \text{ m}$$

12 **D** The child on a swing is pushed at regular intervals matching the swing's natural frequency, and the amplitude of the swing increases each time. This is an example of resonance where the driving frequency matches the natural frequency of the system.

13 **C** Let the intensity of incident light be I_0. By Malus's law,

$I = I_0 \cos^2 30° \quad ... \quad (1)$

When filter is rotated anticlockwise by an angle of 45°, the transmission axis is 15° from the vertical. The new intensity I',

$I' = I_0 \cos^2 15° \quad ... \quad (2)$

(2) ÷ (1),

$\frac{I'}{I} = \left(\frac{\cos 15°}{\cos 30°}\right)^2$

$I' = 1.2I$

14 **C** Let length of tube be L. The wavelengths λ of the lowest frequencies of sound produced are:

$L = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \frac{7\lambda}{4}, ... = \left(\frac{2n-1}{4}\right)\lambda, \quad n \in ¢^+$

$\lambda = \frac{4L}{2n-1}$

$v = f\lambda$

$f = \frac{v}{\lambda}$

$= \left(\frac{2n-1}{4L}\right)v, \quad n \in ¢^+$

$= \frac{v}{4L}, \frac{3v}{4L}, \frac{5v}{4L}, \frac{7v}{4L}, ...$

$= f_0, 3f_0, 5f_0, 7f_0 \quad \left(\text{where the lowest frequency } f_0 = \frac{v}{4L}\right)$

Hence, the different frequencies,

$= 92 \text{ Hz}, 3 \times 92 \text{ Hz}, 5 \times 92 \text{ Hz}, 7 \times 92 \text{ Hz}, ...$

$= 92 \text{ Hz}, 276 \text{ Hz}, 460 \text{ Hz}, 644 \text{ Hz}, ...$

15 **A** $d \sin\theta = n\lambda$

$d \sin 50.8° = 3\lambda \quad ... \quad (1)$

For highest order, let θ = 90° (and sin 90° = 1).

$d = n\lambda \quad ... \quad (2)$

(2) ÷ (1), $\frac{1}{\sin 50.8°} = \frac{n}{3}$

$n = \frac{3}{\sin 50.8°}$

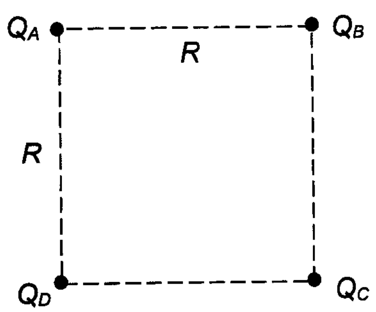
$n = 3.87$

Hence, highest order is 3.

16 **D** Molecules move with different speeds, which can be different from the root-mean-square speed.

17 **A** The water molecules collide with the walls of the bottle and rebound with greater velocities. Hence, the total microscopic kinetic energy of the water molecules increases.

18 **B**



$$EPE = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_AQ_B}{R} + \frac{Q_AQ_D}{R} + \frac{Q_AQ_C}{\sqrt{2}R} + \frac{Q_BQ_C}{R} + \frac{Q_BQ_D}{\sqrt{2}R} + \frac{Q_CQ_D}{R}\right)$$

$$EPE = \frac{1}{4\pi\varepsilon_0}\left[2\times\frac{(-1.0\times10^{-5})(5.0\times10^{-6})}{2} \times \frac{(-1.0\times10^{-5})(-1.0\times10^{-5})}{2\sqrt{2}} + 2\times\frac{(-1.0\times10^{-5})(5.0\times10^{-6})}{2} + \frac{(5.0\times10^{-6})(5.0\times10^{-6})}{2\sqrt{2}}\right]$$

$$= -0.50 \text{ J}$$

19 **D** A negatively charged particle moves from region of lower potential to region of higher potential.
Option A: This statement is correct at the mid-point between a charge of +Q and a charge of $-Q$.
Option B: This statement is correct at the mid-point between a charge of +Q and a charge of +Q.
Option C: E tends asymptotically toward zero as r increases. So, $\frac{dE}{dr}$ decreases as r increases.

20 **C**

$$I = nAvq = \frac{N_e}{V}Ave = \frac{N_e}{AL}Ave = \frac{N_e}{L}ve$$

$$I = \frac{4.8\times10^{22}}{0.20}\times3.2\times10^{-5}\times1.60\times10^{-19} = 1.2 \text{ A}$$

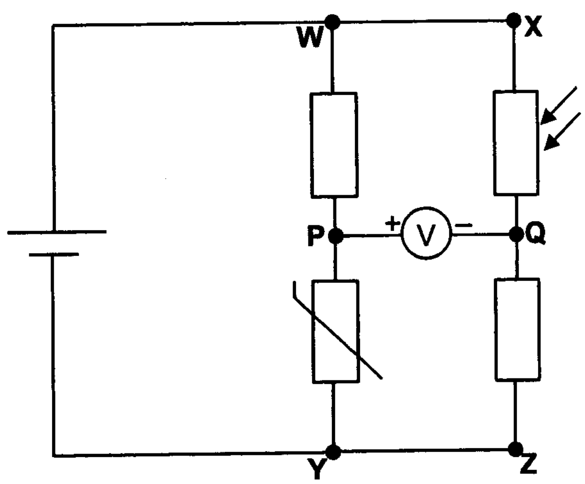
21 **B**

$$R_{eff} = \left(\frac{1}{2}+\frac{1}{5}+1\right)^{-1} = 0.5882\ \Omega$$

$$V = 5.0\times0.5882 = 2.9412 \text{ V}$$

$$I = \frac{2.9412}{2.0} = 1.5 \text{ A}$$

22 **A**



When temperature increases, R_{LDR} decreases, V_{PY} decreases, V_{WP} increases and V_P decreases.
When light intensity increases, $R_{thermistor}$ decreases, V_{XQ} decreases, V_Q increases.
Hence, $V_{PQ} = (V_P - V_Q)$ decreases.

23 **B** The magnitude of the magnetic force remains constant as the orientation of the magnetic field and direction of current does not change. The torque is not constant as the perpendicular distance between the couple will vary as the loop rotates.

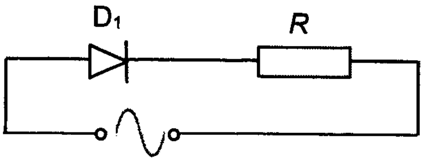
24 **D**

$$B = \mu_0 nI = (4\pi \times 10^{-7})\left(\frac{950}{0.80}\right)(2.0) = 2.985 \times 10^{-3}\ \text{T}$$

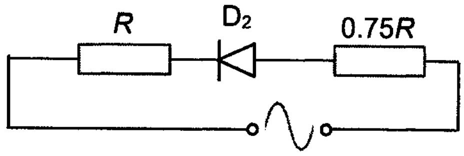
$$\varepsilon = \frac{\Delta NBA}{\Delta t} = \frac{2 \times 96 \times (2.985 \times 10^{-3}) \times (1.6 \times 10^{-3})}{0.24} = 3.8\ \text{mV}$$

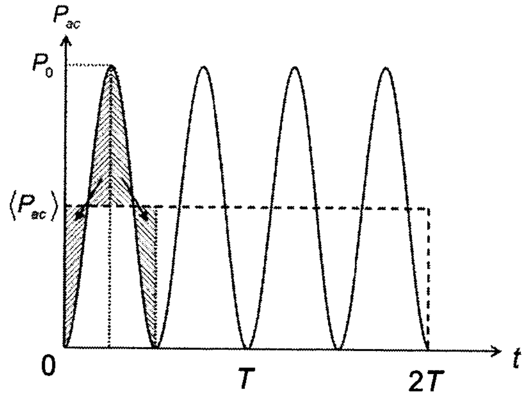
25 **B** The current in the wire produces a magnetic flux density into the plane of the paper in the circular coil. As the coil moves away, the magnetic flux linkage in the coil decreases. By Lenz law, the direction of the induced current is clockwise to oppose this decrease.
By conservation of energy, kinetic energy decreases as current is induced.

26 **C** For the first half cycle:
Only diode D1 is conducting and the effective resistance in the circuit is R.



In the second half cycle:
Only diode D2 is conducting and the effective resistance in the circuit is $1.75R$.





For half of a cycle,

$$\text{mean power} = \frac{1}{2}P_0 = \frac{V_0^2}{2R}$$

$$P = \frac{\frac{V_0^2}{2R} + \frac{V_0^2}{2(1.75R)}}{2} = 0.39\frac{V_0^2}{R}$$

27 **B** According to Heisenberg's uncertainty principle, $\Delta p_r \Delta r \geq h$.
Having a well-defined radius means $\Delta r = 0$, which means $\Delta p_r = \infty$.
Yet, based on the model, the radial momentum is zero.

28 **A** The sharp characteristic lines are due to inner-shell electron transitions in the target atoms; electrons knocked out by incident electrons, followed by higher-level electrons filling the vacancies and releasing energy as X-rays.

29 **C** total energy of gamma photons = rest mass energy of the two particles

$$2E_\gamma = 2mc^2$$

$$E_\gamma = (9.11 \times 10^{-31})(3.0 \times 10^8)^2 = 8.2 \times 10^{-14}\ \text{J}$$

30 **D** energy released $= BE_{\text{product}} - BE_{\text{reactant}}$

$$= \left[(8.4\times144+8.5\times90)-(7.6\times235)\right]\times10^{6}\times1.6\times10^{-19}$$

$$= 3.02\times10^{-11}\text{ J}$$

2025 Preliminary Examination H2 Physics Paper 2 Solutions

1 **(a)**
$$\rho = \frac{m}{abc}$$
$$= \frac{0.234}{(5.13\times10^{-2})(11.38\times10^{-2})(1.72\times10^{-2})}$$
$$= 2330 \text{ kg m}^{-3}$$

(b)
$$\rho = \frac{m}{abc}$$
$$\frac{\Delta\rho}{\rho} = \frac{\Delta m}{m} + \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$
$$\Delta\rho = \left(\frac{0.002}{0.234} + \frac{0.01}{5.13} + \frac{0.01}{11.38} + \frac{0.01}{1.72}\right)(2330)$$
$$= 40 \text{ kg m}^{-3}$$
$$\rho = (2330 \pm 40) \text{ kg m}^{-3}$$

(c) zero error / incorrect calibration
of calipers / balance

2 **(a)** Let n be number of 5.0 g masses.

By principle of moments, take moments about the edge of the table,
Total anti-clockwise moments = total clockwise moments
$$(1.5)(9.81)\left(\frac{0.10}{2}\right) = (0.11)(9.81)(0.50-0.10) + n(5.0\times10^{-3})(9.81)(0.80)$$
$$n = 7.75$$
Therefore, the maximum number of masses is <u>7</u>.

(b) Let tension in string be T.

Consider forces acting on the metre rule and taking moments about the edge of the table,
string holding the 1.5 kg mass will cause a reduction of anti-clockwise moments
$$= T\left(\frac{0.10}{2}\right) = 0.050T$$
string attached to ruler at midpoint will cause a reduction of clockwise moments
$$= (T\sin 60°)(0.40) = 0.346T$$

Since the reduction of clockwise moments is greater, there will be a <u>net anticlockwise moment</u> acting on the metre rule.

Hence <u>**more**</u> 5.0 g masses can be placed (compared to **(a)**) before the cantilever topples.

3 **(a)** The <u>vertical displacement of the yoke</u> is <u>$r\sin(\omega t)$</u>.
Hence, the acceleration is $-\omega^2 r\sin(\omega t) = -\omega^2 x$, which is the defining equation of <u>simple harmonic motion</u>.

(b) (i) **1.** $v_0 = \omega y_0$

$= \omega r$

$= \left(\frac{2\pi}{0.40}\right)(0.080)$

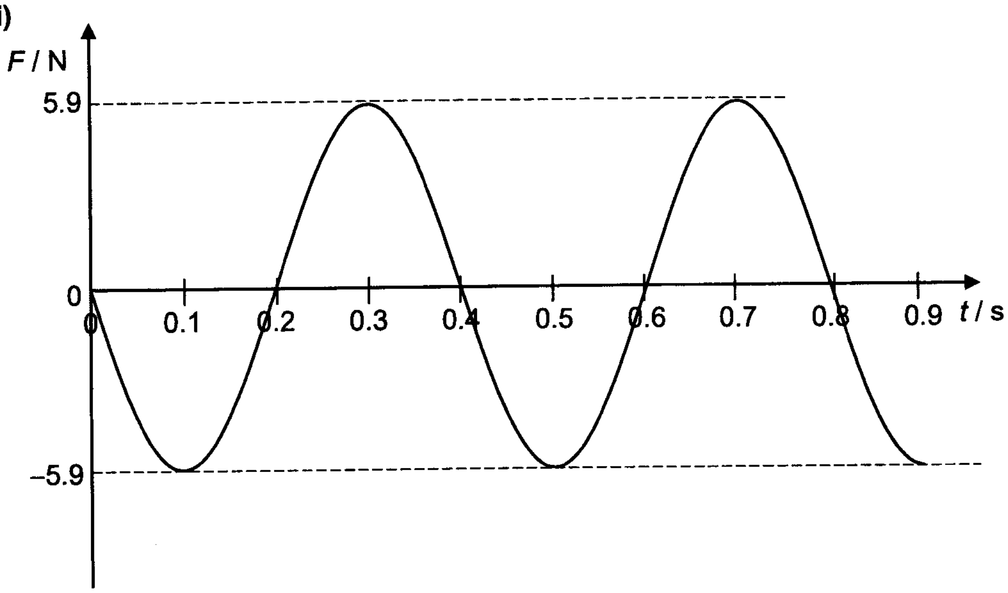
$= 1.3 \text{ m s}^{-1}$

2. $a_0 = \omega^2 y_0$ or $a_0 = \omega v_0$

$= \left(\frac{2\pi}{0.40}\right)^2 (0.080)$ or $= \left(\frac{2\pi}{0.40}\right)(1.3)$

$= 20 \text{ m s}^{-2}$ $= 20 \text{ m s}^{-2}$

(ii)



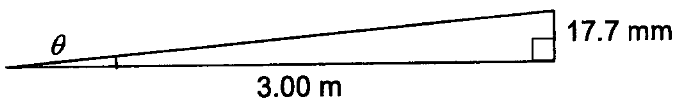
4 **(a)** **(i)** When the path difference between the waves that meet at the screen is integer multiple of wavelength of the light, they meet in phase and there is constructive interference, forming bright fringe.

When the path difference between the waves that meet at the screen is odd integer multiple of half wavelength of the light, they meet in antiphase and there is destructive interference, forming dark fringe.

correct path difference
meeting in phase / antiphase
constructive / destructive interference

(ii) The single slit diffraction pattern from each slit forms the envelope of the double slit interference pattern. Where the minima of the single slit diffraction pattern coincide with the bright fringes of the double slit interference pattern, these bright fringes cannot be observed and will be seen missing from the interference pattern.

(b) **(i)**



$b\sin\theta = \lambda$

$$b = \frac{\lambda}{\sin\theta}$$

$$= \frac{\lambda}{\tan\theta} \quad (\because \sin\theta \approx \theta \approx \tan\theta \text{ as } \theta \text{ is small})$$

$$= \frac{590\times10^{-9}}{\left(\frac{35.4\times10^{-3}}{2}\right)\left(\frac{1}{3.00}\right)}$$

$$= 1.00\times10^{-4} \text{ m}$$

$$= 0.100 \text{ mm}$$

(ii) According to the Rayleigh criterion, the two diffraction patterns are just distinguishable if the central maximum of one diffraction pattern coincides with the first minimum of the other (diffraction pattern).

This means the minimum angular separation θ_{min} of the two central maxima for the patterns to be resolved is $\theta_{min} \approx \frac{\lambda}{b} = \frac{590\times10^{-9}}{0.100\times10^{-3}} = 0.0059$ rad.

Since the angle between the two beams of light is smaller than 0.0059 rad, the two diffraction patterns are unresolved.

5 **(a)** gas that obeys $pV \propto T$ for all values of p, V and T
where p is pressure, V is volume and T is thermodynamic temperature

(b)

$$n = \frac{pV}{RT}$$

$$= \frac{(1.6\times10^{6})(0.20)}{8.31(22+273.15)}$$

$$= 130 \text{ mol}$$

(c) $\frac{1}{2}Mc_{r.m.s.}^2 = \frac{3}{2}RT$ (where M is the molar mass)

$$c_{r.m.s.} = \sqrt{\frac{3RT}{M}}$$

$$= \sqrt{\frac{3(8.31)(22+273.15)}{4.2\times10^{-2}}}$$

$$= 420 \text{ m s}^{-1}$$

(d) When gas reaches equilibrium with surroundings, its pressure is 3.6×10^4 Pa.

$$n' = \frac{p'V}{RT'} = \frac{(3.6\times10^{4})(0.20)}{8.31(-50+273.15)} = 3.8827 \text{ mol}$$

$$m = 3.8827(4.2\times10^{-2}) = 0.16 \text{ kg}$$

6 **(a)** The amount of energy transformed from **chemical** to electrical per unit charge (driven around a complete circuit).

(b) $R_{PR} = \frac{\rho \ell}{A} + \frac{\rho \ell'}{A'}$

$= (5.0 \times 10^{-7}) \left[\frac{90 \times 10^{-2}}{5.7 \times 10^{-8}} + \frac{10 \times 10^{-2}}{\left(\frac{80}{100} \right)(5.7 \times 10^{-8})} \right]$

$= 8.9912$

$= 9.0\ \Omega$

(c) (i) $I = \frac{V}{R}$

$= \frac{9.0}{8.9912 + 25}$

$= 0.26\ \text{A}$

(ii) When galvanometer shows a null reading, $V_{PQ} = E$.

$E = IR_{PQ}$

$= 0.26477(5.0 \times 10^{-7}) \left[\frac{65 \times 10^{-2}}{5.7 \times 10^{-8}} + \frac{10 \times 10^{-2}}{\left(\frac{80}{100} \right)(5.7 \times 10^{-8})} \right]$

$= 1.8\ \text{V}$

Alternatively,

$R_{PQ} = (5.0 \times 10^{-7}) \left[\frac{65 \times 10^{-2}}{5.7 \times 10^{-8}} + \frac{10 \times 10^{-2}}{\left(\frac{80}{100} \right)(5.7 \times 10^{-8})} \right] = 6.7982\ \Omega$

$E = \left(\frac{R_{PQ}}{R_{PR} + R_{\text{variable resistor}}} \right) \times 9.0$

$= \left(\frac{6.7982}{8.9912 + 25} \right) \times 9.0$

$= 1.8\ \text{V}$

(d) (i) As there is <u>no current in the solar cell</u>, <u>potential difference (p.d.) across its internal resistance is zero</u>. Hence, the terminal p.d. of the solar cell is equal to E and $V_{PQ} = E$.

(ii) The <u>resistance</u> of a potentiometer of uniform cross-sectional area is <u>smaller</u> and therefore the <u>potential difference</u> across the potentiometer is now <u>smaller</u>. Hence, the balance length would be <u>longer</u> $V_{PQ} = \left(\frac{L_{PQ}}{L_{PR}} \right) V_{PR}$.

or

The <u>potential drop</u> across the first 75 cm of the potentiometer wire is now <u>lower</u> as the <u>resistance</u> across it is <u>lower</u>. Hence, <u>balance length</u> would be <u>longer</u>.

7 (a) (i) Nuclei that have the same number of protons but different number of neutrons.

(ii) Time taken for the number of undecayed nuclei to be reduced to half its original number.
or
Time for activity to halve.

(b) (i) $^{40}_{19}K \rightarrow ^{40}_{20}Ca + ^{0}_{-1}\beta^{-} +$ antineutrino (or neutrino)
one mark each for each correct decay product including mass and atomic numbers

(ii)
$$E = (\Delta m)c^2$$
$$= (39.963998 - 39.962591)(1.66\times10^{-27})(3.00\times10^{8})^2$$
$$= 2.102058\times10^{-13}\text{ J}$$
$$= 1.31\text{ MeV}$$

(c) The ratio of potassium to argon to calcium is 2:1:9.

$$N = N_0 e^{-\lambda t}$$
$$\ln\left(\frac{N}{N_0}\right) = -\lambda t$$
$$t = \frac{1}{\lambda}\ln\left(\frac{N_0}{N}\right)$$
$$= \frac{t_{1/2}}{\ln 2}\ln\left(\frac{N_0}{N}\right)$$
$$= \frac{1.25\times10^{9}}{\ln 2}\ln\left(\frac{2+1+9}{2}\right)$$
$$= 3.23\times10^{9}\text{ years}$$

8 (a) (i) Time taken to reach the top $t = \left(\frac{900}{2.5}\right)$

Let n be the number of passengers.
P = rate of gain of gravitational potential energy of passengers
$$= \frac{nmgh}{t}$$
$$= \frac{2(24)(75)(9.81)(300)}{\left(\frac{900}{2.5}\right)}$$
$$= 29430 = 29000\text{ W}$$

Alternatively, the vertical speed of the $(v\sin\theta)$, can be used instead
$$P = Fv$$
$$= (nmg\sin\theta)v = nmgv\sin\theta$$
$$= [2(24)](75)(9.81)(2.5)\left(\frac{300}{900}\right)$$
$$= 29430 = 29000\text{ W}$$

(ii) Any one point from:
It does not account for:
1. energy losses due to friction in the moving parts of the chair lift
2. drag forces acting on the moving chairs, which vary with wind conditions.
3. additional ski equipment which would result in the average mass being more than 75 kg

(b) (i) $N = mg\cos\theta = (75)(9.81)\cos 9.0° = 726.69 \text{ N} = 730 \text{ N}$
Alternatively,
from the graph $a_g = 1.540$ (acceptable range $a_g = 1.525$ to 1.550),

$$N = \frac{ma_g}{\tan 9°} = \frac{(75)(1.540)}{\tan 9°} = 729.24 = 730 \text{ N}$$

or

$$N = \sqrt{(mg)^2 - (ma_g)^2} = \sqrt{[(75)(9.81)]^2 - [(75)(1.540)]^2} = 726.63 = 730 \text{ N}$$

(ii) $f = \mu N = 0.080(726.69)$
$= 58.135 = 58 \text{ N}$

(iii)
$$mg\sin\theta - f = ma$$
$$75(9.81)\sin 9.0° - 58.135 = 75a$$
$$a = 0.76 \text{ m s}^{-2}$$

Alternatively,
From Fig. 8.4, when $\theta = 9.0°$ and $\alpha = 0°$, $a_g = 1.54 \text{ m s}^{-2}$.
$$ma_g - f = ma$$
$$75(1.54) - 58.135 = 75a$$
$$a = 0.76 \text{ m s}^{-2}$$

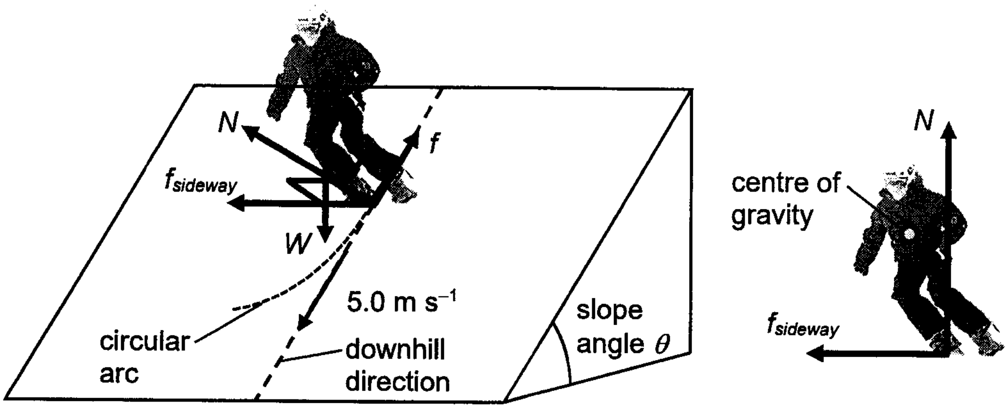
(c) (i) $f = \mu N = \mu mg\cos\theta = (0.12)(75)(9.81)\cos 22.0° = 81.861 = 82 \text{ N}$

(ii) In order to maintain constant speed, the acceleration of the skier is zero.
$$f = ma_g$$
$$a_g = \frac{f}{m} = \frac{81.861}{75}$$
$$= 1.0915 = 1.1 \text{ m s}^{-2}$$
From Fig. 8.4, the corresponding ski angle is 72.5°.

(iii) The skier can decrease the ski angle.

(d) (i) From Fig. 8.7, for hard snow, when $\beta = 61°$, $r = 9.2$ m.
$$F_C = \frac{mv^2}{r} = \frac{(75)(5.0)^2}{9.2}$$
$$= 200 \text{ N}$$

(ii) The centripetal force is provided by the sideway friction.
Taking moments about the centre of gravity of the skier, the moment due to the normal contact force must be equal to the moment due to the sideway friction.
As edge angle increases, the perpendicular distance of the line of action of normal contact force from the centre of mass of skier increases while the perpendicular distance of the line of action of sideway friction decreases. Hence, sideway friction increases.



Note:
Weight (*W*) and normal contact force (*N*) act in the vertical plane and do not provide the centripetal force.
As seen in Fig. 8.6, the skis do not sink into the snow and create a sloped surface that is parallel to the bottom of the skis.

2025 Preliminary Examination H2 Physics Paper 3 Solutions

1 (a) (i)

$$s = ut + \frac{1}{2}at^2$$

$$240 - 180 = 0 + \frac{1}{2}(9.81)t_1^2$$

$$t_1 = 3.497 \text{ s}$$

$$240 - 150 = 0 + \frac{1}{2}(9.81)t_2^2$$

$$t_2 = 4.284 \text{ s}$$

$$\text{time} = t_2 - t_1 = 4.284 - 3.497 = 0.787 \text{ s}$$

(ii) The time taken will be smaller/shorter as the average speed will be higher and the distance travelled remains the same.

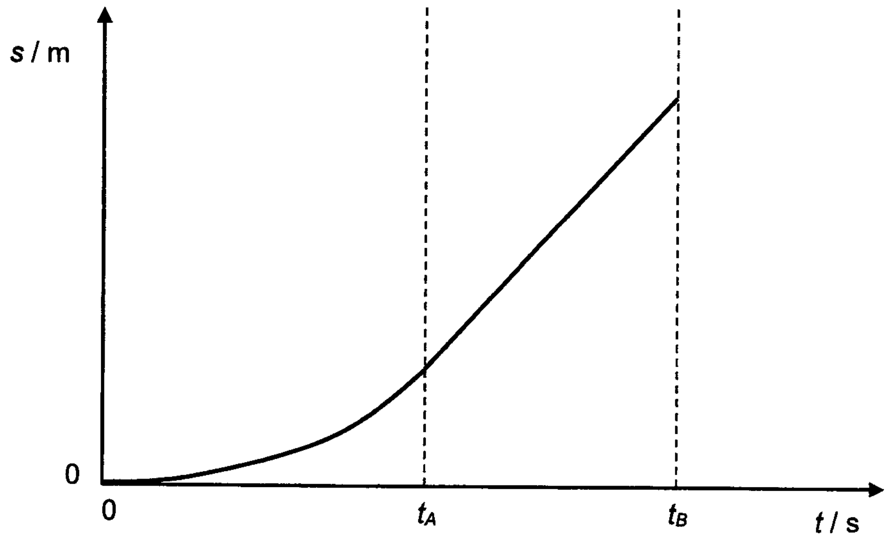
(iii)

$$v^2 = u^2 + 2as$$

$$v^2 = 0 + 2(9.81)(240)$$

$$v = 68.6 \text{ m s}^{-1}$$

(b)



B1 – Correct shape between 0 to t_A with zero gradient at $t = 0$
B1 – Constant gradient between $t = t_A$ and $t = t_B$ (no kink at t_A)

2 (a) The principle of conservation of momentum states that when bodies in a system interact, the total momentum of the system remains constant, provided no net external force acts on it.

(b) Taking velocity to the right as positive.

By the principle of conservation of momentum for bodies A and B,

$$p_i = p_f$$

$$m_A u_A + m_B u_B = m_A V_A + m_B V_B$$

$$(60)(11) + (90)(-5) = (60)V_A + (90)V_B$$

$$V_A + 1.5V_B = 3.5 \qquad \text{eq (1)}$$

Since collision is elastic,

$$u_A - u_B = V_B - V_A$$
$$(11) - (-5.0) = V_B - V_A$$
$$V_B - V_A = 16 \qquad \text{eq (2)}$$

eq (1) − 1.5 × eq (2):

$$2.5V_A = -20.5$$
$$V_A = -8.2 \text{ m s}^{-1} \qquad \text{(shown)}$$

(c) **(i)** area under $F - t$ graph $= m(v-u)$

$$\frac{1}{2} \times 0.40 \times F_{max} = (60)[1-(-8.2)]$$
$$F_{max} = 2760 \text{ N}$$

(ii) By adding soft padding to the walls,
so that the duration of collision can be lengthened (to reduce the maximum force experienced by the skaters when they hit the walls).

3 **(a)** **(i)** Elastic potential energy of bow = area under graph

$= \frac{1}{2} \times 210 \times 0.60 = 63.0$ J

By conservation of energy, assuming that loss in elastic potential energy = gain in kinetic energy of the arrow

$$63.0 = \frac{1}{2} \times 32 \times 10^{-3} \times v^2$$
$$v = 62.7 \text{ m s}^{-1}$$

(ii) The force required to hold the compound bow at maximum draw is lower.

This allows easier aiming / more accurate aiming / archers to hold the bow steady for longer periods without tiring their muscles.

Alternative answer:
For the same draw, the compound bow has greater elastic potential energy and is able to shot an arrow with greater speed.

(b) The elastic potential energy of the bow, designed to be transferred to the arrow, instead dissipates as vibrations and noise within the bow's components.
This can cause broken strings and damage the bow.

(c) **(i)** By conservation of energy,
loss in kinetic energy = gain in gravitational potential energy

$$\left(\frac{1}{2} \times 32 \times 10^{-3} \times 52^2\right) - E_{K,final} = 32 \times 10^{-3} \times 9.81 \times (8.0 - 1.5)$$
$$43.264 - E_{K,final} = 2.040$$
$$E_{K,final} = 41.2 \text{ J}$$

(ii)

$$S_y = u_y t + \frac{1}{2}at^2$$

$$8.0 - 1.5 = (52 \times \sin 15)t + \frac{1}{2}(-9.81)t^2$$

$4.905t^2 - 13.459t + 6.5 = 0$

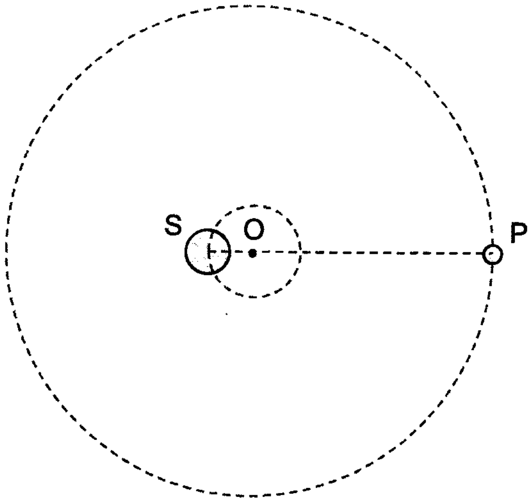
$t = 0.6256$ s or 2.118 s

$S_x = u_x t$

$= 52 \times \cos 15° \times 0.6256$

$= 31.4$ m

4 (a) (i)



(ii) Star S and planet P attract each other by Newton's law of gravitation. By Newton's third law, the force of attraction on star S by planet P is equal in magnitude and opposite in direction to the force of attraction on P by S. (The magnitude of this gravitational force of attraction is $\frac{GM_S M_P}{r^2}$.)
Since the only force acting on each star is this gravitational force of attraction, the gravitational force provides the centripetal force on each star.

Hence the magnitude of the centripetal force on each star is the same.

(iii) Since both S and P orbit at the same angular velocity ω,

$\cancel{M}(r_S \cancel{\omega}^2) = 0.12\cancel{M}(r_P \cancel{\omega}^2)$

$\frac{r_S}{r_P} = 0.12$

(b) (i) period $T = 1500$ days

$\omega = \frac{2\pi}{T} = \frac{2\pi}{1500 \times 24 \times 3600}$

$= 4.85 \times 10^{-8}$ rad s^{-1}

(ii) $r_S = \frac{v_S}{\omega} = \frac{70}{4.848 \times 10^{-8}} = 1.44 \times 10^9$ m

(iii) $\dfrac{r_S}{r_P} = 0.12 \quad \Rightarrow \quad r_P = \dfrac{r_S}{0.12}$

$$r_S + r_P = r_S\left(1 + \frac{1}{0.12}\right) = 1.444 \times 10^9 (9.333) = 1.35 \times 10^{10} \text{ m}$$

(iv) Gravitational force between S and P provides the centripetal force for their circular motion.

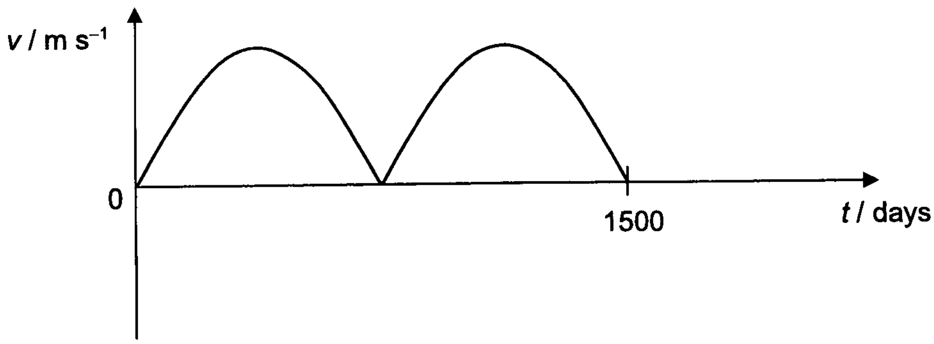
$$G\frac{M(0.12\cancel{M})}{(r_S + r_P)^2} = \cancel{M} r_S \omega^2$$

$$M = \frac{(r_S + r_P)^2 r_S \omega^2}{0.12G}$$

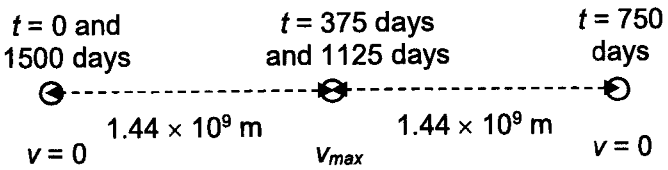
$$M = \frac{(1.348 \times 10^{10})^2 \times 1.444 \times 10^9 \times (4.848 \times 10^{-8})^2}{0.12 \times 6.67 \times 10^{-11}}$$

$$M = 7.71 \times 10^{25} \text{ kg}$$

(c)

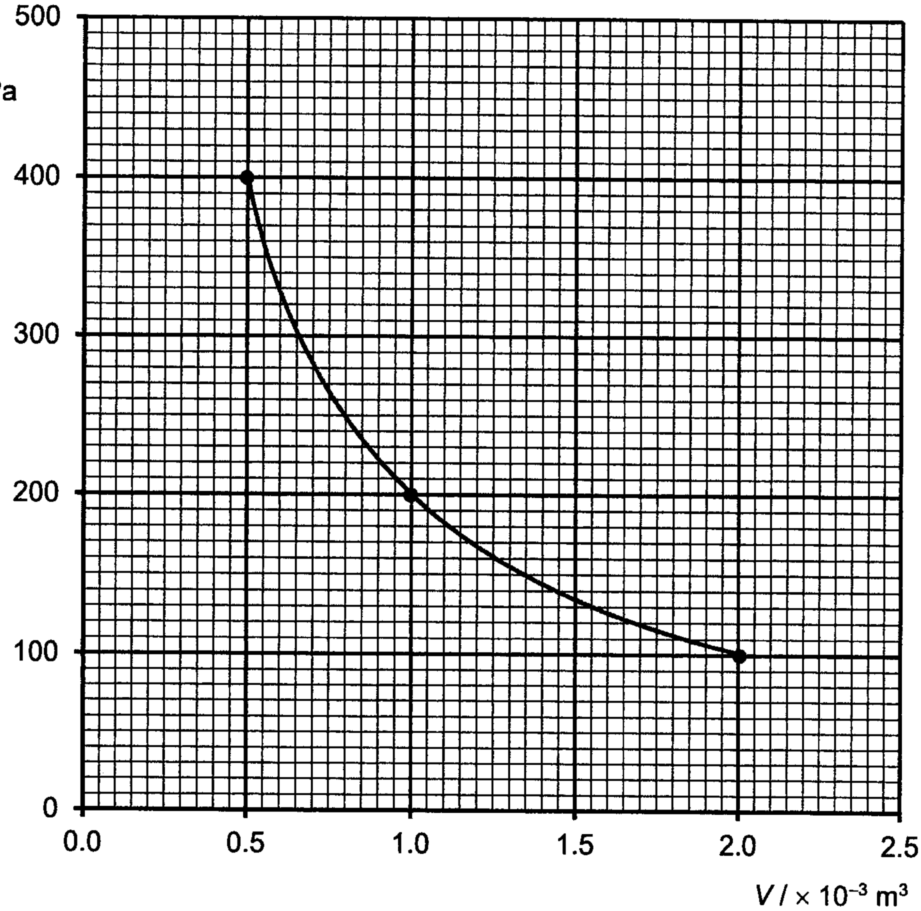


Note
Star S will appear to be moving in simple harmonic motion.



5 **(a)** The first law of thermodynamics states that the increase in internal energy of a system is equal to the sum of the heat supplied to the system and the work done on the system, and the internal energy of a system depends only on its state.

(b) (i)



(ii) Since the gas expands, the area under the graph gives the work done **by** the gas.
(or the negative work done **on** the gas)

Since internal energy is proportional to temperature, $\Delta U = 0$ as there is no change in temperature,

$0 = Q + W_{on}$

$Q = -W_{on}$ OR $Q = +W_{by}$

Hence, the amount of heat supplied to the gas is equal to the area under the curve AB.

(c) For experiment 1, the volume remains constant and work done on gas = 0
Hence, increase in internal energy is equal to heat supplied.

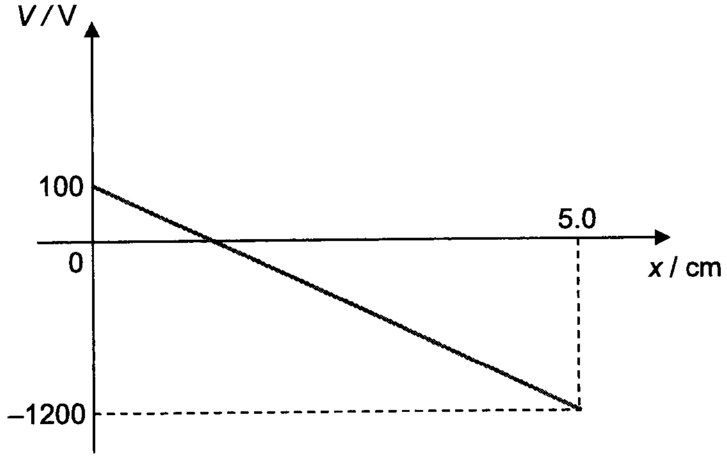
For experiment 2, the gas expands and work done on gas is negative.
Hence, increase in internal energy in experiment 2 is less than that of experiment 1. (increase in internal energy in experiment 2 is equal to heat supplied minus work done by gas)

Since internal energy is proportional to temperature, increase in temperature of experiment 2 is smaller than that in experiment 1 and gas in experiment 1 will have a higher final temperature.

OR For experiment 1, all the heat supplied was transferred into increasing the microscopic kinetic energy of the gas, whereas
For experiment 2, the heat supplied was transferred into increasing the microscopic kinetic energy of the gas as well as to do work against external pressure (the piston).
Since the amount of heat supplied is the same, the gain in kinetic energy for experiement 1 is higher and hence the gas in experiment 1 will have a higher final temperature.

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

(b)



(ii) The electric field strength is the negative of the gradient of the potential-distance graph in Fig. 6.2.

$$E = -\frac{dV}{dx}$$

$$= -\frac{-1200 - 100}{(5.0 \times 10^{-2}) - 0}$$

$$= 26000 \text{ N C}^{-1}$$

Alternative answer:

$$E = \frac{\Delta V}{d} = \frac{1300}{5.0 \times 10^{-2}}$$

$$= 26000 \text{ N C}^{-1}$$

(iii) $F_E = qE = ma$

$$a = \frac{qE}{m} = \frac{(1.60\times10^{-19})(26000)}{(131)(1.66\times10^{-27})} = 1.913\times10^{10}\ \text{m s}^{-2}$$

Since the electric field is uniform, the acceleration is also uniform.
Using kinematics equation,

$$v^2 = u^2 + 2as$$
$$= 0 + 2(1.913\times10^{10})(5.0\times10^{-2})$$
$$v = \sqrt{2(1.913\times10^{10})(5.0\times10^{-2})}$$
$$= 43700\ \text{m s}^{-1}$$

Alternative Answer:
By principle of conservation of energy,
gain in kinetic energy = loss of electric potential energy

$$\frac{1}{2}mv^2 - 0 = q(V_A - V_B)$$
$$\frac{1}{2}(131)(1.66\times10^{-27})v^2 = (1.60\times10^{-19})[100-(-1200)]$$
$$v = 43700\ \text{m s}^{-1}$$

(c) The positively charged xenon ions need to be neutralised so that they will not be attracted back towards the negatively charged plate B,
which will reduce / cancel the thrust on the spacecraft created by the ejection of the ions or reduce speed of xenon ions.

Note: If the exited ions feel an attractive force back towards the spacecraft, by Newton's 3rd Law, the spacecraft feels a force in the opposite direction towards the ions. The attractive force experienced by the spacecraft towards the ions is opposite in direction to its thrust. Hence, the thrust on the spacecraft is reduced, reducing the ion thruster's efficiency.

7 **(a)** The alternating current in the primary coil sets up a varying magnetic field/flux/flux linkage which links the primary coil with the secondary coil. This induces an alternating e.m.f./current in the secondary coil.

(b)
$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$
$$\frac{5.0}{V_P} = 0.022$$
$$V_P = 227\ \text{V r.m.s.}$$

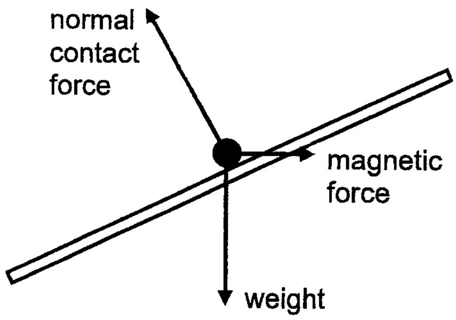
(c) **(i)** Max potential difference $= \sqrt{2}\times V_{rms}$
$$= \sqrt{2}\times5.0$$
$$= 7.07\ \text{V}$$

(ii) Zero
because diode is in reverse bias and there is no current in the circuit and by $V = IR$, no potential difference across R.

(iii)

8 **(a)** the force per unit length per unit current exerted on a long straight conductor placed perpendicular to the magnetic field.

(b) **(i)**



M1 – all forces shown
A1 – all arrows labelled

(ii)

$$V = IR$$
$$6.0 = I \times 5.0$$
$$I = 1.2 \text{ A}$$

(iii)

$$F_{net} = 0$$
$$mg\sin\theta = BIL\cos\theta$$
$$m \times 9.81 \times \sin 30° = 0.021 \times 1.2 \times 1.5 \times \cos 30°$$
$$m = 6.67 \times 10^{-3} \text{ kg}$$

B1 – component of weight along slope
B1 – component of magnetic force along slope

(iv) When the cross-sectional area is doubled, the resistance will be halved, and the current will be doubled. Hence, the magnetic force will be doubled. However, the volume will also be doubled, and the mass will be doubled. There is no net force acting on rod XY and the rod remains at rest.

(c) **(i)** As the rod move down the slope, there is magnetic flux cutting, resulting in an induced e.m.f. across the rod.

(ii)

$$mgh = \frac{1}{2}mv^2$$
$$m \times 9.81 \times 0.020 \times \sin 30° = \frac{1}{2}mv^2$$
$$v = 0.44294 \text{ m s}^{-1}$$
$$\varepsilon = BLv\cos\theta$$
$$= (0.021)(1.5)(0.44294)\cos 30°$$
$$= 0.0121 \text{ V}$$

(iii) **1.** As the rod moves down the slope, the area and magnetic flux linkage decreases.
By Lenz's law, the direction of the induced current will be from P to Q to increase the magnetic flux linkage.

2. When the switch is closed, there will an induced current in the rod.
By conservation of energy, the loss in gravitational potential energy of the rod is equal to the gain in kinetic energy of the rod and heat generated by resistive heating.
Hence, there is a smaller gain in kinetic energy and a lower speed, resulting in smaller e.m.f. and the answer in (c)(ii) to be smaller.

9 **(a)** **(i)** Diffraction of light when passes through a single slit / Double-slit interference / Diffraction of light through a diffraction grating.

(ii) Photoelectric effect / Compton effect (not in syllabus)

(b) **(i)** The energies of the hydrogen atoms are quantized into discrete levels. When an atom transits from a higher energy level to a lower energy level, photons of energy equal to the difference in the two energy levels are emitted. Energy of photon is given by $E = \frac{hc}{\lambda}$. Hence, only photons of specific wavelengths are emitted.

(ii)

$$\text{Energy of photon of blue light} = \frac{hc}{\lambda}$$

$$= \frac{6.63\times10^{-34}\times3.00\times10^{8}}{4.86\times10^{-7}}$$

$$= 4.093\times10^{-19}\text{ J}$$

$$= 2.6\text{ eV}$$

Since the energy of the photon is higher than the work function energy photoemission will be observed.

(iii) **1.** Power of red light = Intensity × Area
= $6.80 \times 10^{3} \times 3.00 \times 10^{-4}$
= 2.04 W

2.

$$\text{Number of photons per second} = \frac{\text{Power}}{\text{Energy per photon}}$$

$$= \frac{2.04}{hc/\lambda}$$

$$= \frac{2.04\times4.86\times10^{-7}}{6.63\times10^{-34}\times3.0\times10^{8}}$$

$$= 4.98\times10^{18}$$

$$\text{Momentum of each photon} = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{4.86\times10^{-7}} = 1.364\times10^{-27}\text{ kg m s}^{-1}$$

$$\text{Total force} = 1.364\times10^{-27}\times4.98\times10^{18}$$

$$= 6.80\times10^{-9}\text{ N}$$

(c) **(i)** **1.**

$$\frac{1}{\lambda_n} = R\left(\frac{1}{4}-\frac{1}{n^2}\right)$$

$$\frac{1}{6.56\times10^{-7}} = 1.097\times10^{7}\left(\frac{1}{4}-\frac{1}{n^2}\right)$$

$$n = 3$$

2.

$$\frac{1}{\lambda_n} = R\left(\frac{1}{4}-\frac{1}{n^2}\right)$$

$$\frac{1}{4.86\times10^{-7}} = 1.097\times10^{7}\left(\frac{1}{4}-\frac{1}{n^2}\right)$$

$$n = 4$$

(ii) For shortest wavelength, $n = \infty$.

$$\frac{1}{\lambda_{min}} = R\left(\frac{1}{4} - \frac{1}{\infty}\right)$$

$$\lambda_{min} = 3.65 \times 10^{-7} \text{ m}$$

(iii)

$$E_n - E_2 = \frac{hc}{\lambda_n}$$

$$E_n - E_2 = hcR\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

$$E_n - E_2 = \frac{hcR}{2^2} - \frac{hcR}{n^2}$$

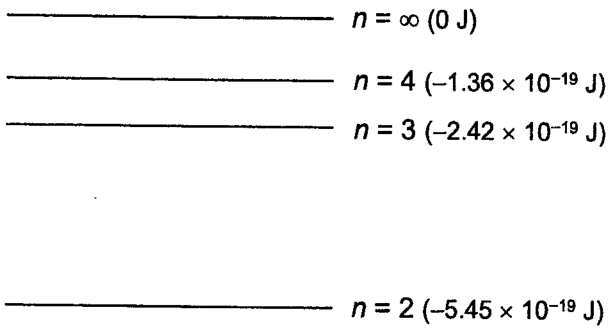
$$E_n - E_2 = -\frac{hcR}{n^2} - \left(-\frac{hcR}{2^2}\right)$$

$$\therefore E_n - \frac{hcR}{n^2} \quad \& \quad E_2 = -\frac{hcR}{2^2}$$

$$E_n = -\frac{1}{n^2}\left(6.63 \times 10^{-34}\right) \times \left(3.0 \times 10^{8}\right) \times \left(1.097 \times 10^{7}\right) = -\frac{2.18 \times 10^{-18}}{n^2}$$

Hence, the energy values are:

$n = 2$: -5.45×10^{-19} J
$n = 3$: -2.42×10^{-19} J
$n = 4$: -1.36×10^{-19} J



Alternative method

From E_∞ to E_2, $\Delta E = -\frac{hc}{\lambda} = -\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{3.646 \times 10^{-7}} = -5.455 \times 10^{-19}$ J

From E_3 to E_2, $\Delta E = -\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{6.56 \times 10^{-7}} = -3.032 \times 10^{-19}$ J

From E_4 to E_2, $\Delta E = -4.093 \times 10^{-19}$ J