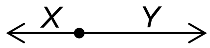
RAFFLES INSTITUTION
YEAR 5-6 PHYSICS DEPARTMENT

9749 H2 Physics
2022 GCE A-Level Suggested Solutions

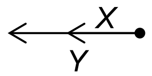
Paper 1

1 **A** Since X and Y are vectors, they can be positive or negative.
Given: $|X| < |Y|$

initially: $|X - Y| = |-x - y|$



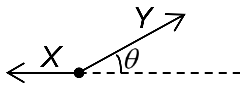
finally: $|X - Y| = |-x - (-y)| = |-x + y|$



$|-x - y| > |-x + y|$

Note: General equation

$$|X - Y| = \sqrt{(-x - y\cos\theta)^2 + (y\sin\theta)^2} = \sqrt{x^2 + 2xy\cos\theta + y^2}$$



As θ increases from $0°$ to $180°$, $|X - Y|$ decreases.

2 **C** $s_x = u_x t$

$100 = (u\cos\theta)t$

$2.0u\cos\theta = 100$ -----(1)

$v_y = u_y + a_y t$

$-u\sin\theta = u\sin\theta - g(2.0)$

$2u\sin\theta = 2.0g$ -----(2)

$\dfrac{(2)}{(1)}$: $\tan\theta = \dfrac{2.0(9.81)}{100}$

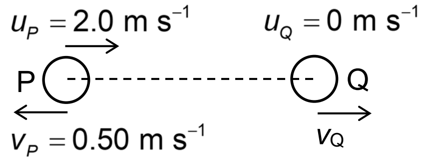
$$\theta = \tan^{-1}\left(\frac{2.0(9.81)}{100}\right) = 11.1° = 11°$$

3 **B** Since collision is elastic,

$u_P - u_Q = v_Q - v_P$

$2.0 - 0 = v_Q - (-0.50)$

$v_Q = 2.0 - 0.50 = 1.5 \text{ m s}^{-1}$



By conservation of momentum,

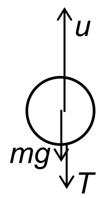
$m_P u_P + m_Q u_Q = m_P v_P + m_Q v_Q$

$m_P(2.0) + 0 = m_P(-0.50) + m_Q(1.5)$

$2.5m_P = 1.5m_Q$

$$\frac{m_P}{m_Q} = \frac{1.5}{2.5} = \frac{3/2}{5/2} = \frac{3}{5}$$

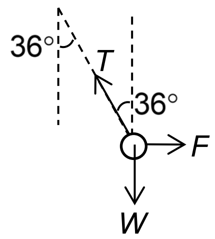
4 **B** Consider vertical equilibrium,



$$u = mg + T$$
$$T = u - mg$$

$$T = \rho_w V_w g - mg$$
$$= \rho_w \left(\frac{1}{2} \times \frac{4}{3}\pi r^3\right) g - mg$$
$$= \frac{2}{3}\pi r^3 \rho_w g - mg$$
$$= \frac{2}{3}\pi (0.500)^3 (1030)(9.81) - 200(9.81)$$
$$= 683.3 = 683 \text{ N}$$

5 **D** Consider horizontal equilibrium,



$$T \sin 36° = F$$
$$T \sin 36° = ke \quad \text{----- (1)}$$

Consider vertical equilibrium,
$$T \cos 36° = W \quad \text{----- (2)}$$

$$\frac{(1)}{(2)} \qquad \frac{\sin 36°}{\cos 36°} = \frac{ke}{W}$$
$$\tan 36° = \frac{ke}{W}$$
$$W = \frac{ke}{\tan 36°}$$
$$= \frac{25(0.060)}{\tan 36°}$$
$$= 2.065 = 2.1 \text{ N}$$

6 **C**
$$g = \frac{GM}{r^2} = \frac{G\rho V}{r^2}$$
$$\rho = \frac{gr^2}{GV}$$
$$= \frac{gr^2}{G\left(\frac{4}{3}\pi r^3\right)}$$
$$= \frac{3}{4} \times \frac{9.81}{\pi (6.67 \times 10^{-11})(6.37 \times 10^6)}$$
$$= 5512 = 5510 \text{ kg m}^{-3}$$

7 **B** Maximum height after 2 oscillations,

$h_2 = 0.60e^{-0.10(2)} = 0.60e^{-0.20}$

At maximum height, pendulum is momentarily at rest i.e. K.E. $= 0$

From initial height to maximum height after 2 oscillations, by conservation of energy,
work done against air resistance $=$ decrease in G.P.E.

$$\begin{aligned} &= mg\left(h_0 - h_2\right) \\ &= (0.40)(9.81)\left(0.60 - 0.60e^{-0.20}\right) \\ &= 0.4268 = 0.43 \text{ J} \end{aligned}$$

8 **C** Angular velocity is the rate of change of angular displacement, which is the same for every point on the disc.

Hence angular velocity is independent of the distance from the centre of the disc.

9 **C** Gravitational force on the satellite (mass m) by the Earth (mass M) provides the centripetal force.

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

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

$$r = \left(\frac{GMT^2}{4\pi^2}\right)^{1/3}$$

Option A is incorrect: From the equation above, r is independent of the mass m of the satellite.
Option B is incorrect: The orbital period of all geostationary satellites is 24 hours.
Option D is incorrect: $v = \omega r = \left(\frac{2\pi}{T}\right) r \quad \Rightarrow \quad v \propto r$
Option C is correct: The orbits of all geostationary satellites are in the same plane as the equator of the Earth and they orbit West to East, similar to the Earth's rotation.

10 **D** Gravitational potential is a scalar quantity.

$$\begin{aligned} \phi_P &= \phi_M + \phi_{4M} \\ &= \left(-\frac{GM}{d/2}\right) + \left(-\frac{G \times 4M}{d/2}\right) \\ &= -\frac{10GM}{d} \end{aligned}$$

11 A

$$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$$

$$\sqrt{\langle c^2 \rangle} = \sqrt{\frac{3pV}{Nm}} = \sqrt{\frac{3NkT}{Nm}} = \sqrt{\frac{3kT}{m}}$$

$$\sqrt{\langle c^2 \rangle} \propto \sqrt{T} \quad \Rightarrow \quad c_{rms} \propto \sqrt{T}$$

$$c_{rms_2} = \frac{\sqrt{T_2}}{\sqrt{T_1}} c_{rms_1}$$

$$= \sqrt{\frac{160 + 273.15}{80 + 273.15}} \times 350$$

$$= 387.6 = 390 \text{ m s}^{-1}$$

12 C

K.E. of 1 gas molecule, $E = \frac{3}{2}kT$

Total K.E. of gas, $E_T = \frac{3}{2}NkT$

Since temperature is constant, E_T is constant and $p_1V_1 = p_2V_2 = NkT$.

$$E_T = \frac{3}{2}NkT = \frac{3}{2}p_2V_2 = \frac{3}{2}p_1V_1 = \frac{3}{2}\left(1.0 \times 10^5\right)\left(0.010\right) = 1500 \text{ J}$$

13 B

decrease in K.E. = increase in thermal energy

$$\frac{50}{100}\left(\frac{1}{2}mv^2\right) = mc\left(\Delta\theta\right)$$

$$\Delta\theta = \frac{50}{100}\left(\frac{1}{2}v^2\right)\left(\frac{1}{c}\right) = \frac{v^2}{4c}$$

14 C

$$x = x_0 \sin \omega t$$

$$v = \frac{dx}{dt}$$

$$= \omega x_0 \cos \omega t$$

$$= \left(\frac{2\pi}{T}\right) x_0 \cos\left(\frac{2\pi}{T}\right)t$$

$$= \left(\frac{2\pi}{5.0}\right) 0.30 \cos\left(\frac{2\pi}{5.0}\right)t$$

$$= 0.377 \cos 1.26t = 0.38 \cos 1.3t$$

15 A

Resonance occurs for forced oscillations when the driver's frequency is close to the natural frequency of the oscillating system. There is maximum transfer of energy and the oscillating system oscillates with maximum amplitude.

Options B, C and D are examples of forced oscillations under a periodic driving force and resonance is possible.
Option A is not an example of resonance. The diaphragm of the loudspeaker is vibrated (pushed or pulled) by the interaction of the electromagnetic coil attached to it and a permanent magnet. This interaction, which affects the amplitude of the vibrations, is dependent on how the current through the electromagnetic coil changes. The frequency of the push and pull of the magnets do not need to match the natural frequency of the diaphragm to produce large amplitudes.
https://electronics.howstuffworks.com/gadgets/audio-music/vibration-speakers.htm

16 **D** From Diagram 1: $\lambda = 0.8$ m
From Diagram 2: $T = 0.2$ s

$$v = f\lambda = \frac{\lambda}{T} = \frac{0.8}{0.2} = 4.0 \text{ m s}^{-1}$$

17 **B** From oscilloscope: $T = 6 \text{ div} \times \left(0.050 \times 10^{-3}\right)$ s

$$f = \frac{1}{T} = \frac{1}{6 \times \left(0.050 \times 10^{-3}\right)} = 3.333 \text{ kHz} = 3.3 \text{ kHz}$$

$\lambda = 2 \times \text{antinodal distance} = 2 \times 5.0 = 10$ cm

18 **B**

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

Option A: $x_A = \dfrac{\left(700 \times 10^{-9}\right)(15)}{4.0 \times 10^{-3}} = 0.000175 \times 15$ m

Option B: $x_B = \dfrac{\left(20 \times 10^{-3}\right)(15)}{50 \times 10^{-3}} = 0.4 \times 15$ m

Option C: $x_C = \dfrac{\left(450 \times 10^{-9}\right)(15)}{2.0 \times 10^{-3}} = 0.000225 \times 15$ m

Option D: $x_D = \dfrac{\left(10 \times 10^{-3}\right)(15)}{200 \times 10^{-3}} = 0.05 \times 15$ m

19 **A** In the uniform electric field, the proton experiences a constant electric force and acceleration that acts vertically downwards.

$$F_E = ma_y$$

$$a_y = \frac{F_E}{m} = \frac{Eq}{m} = \frac{Ve}{dm}$$

Horizontally:

$$s_x = u_x t$$

$$y = vt$$

$$t = \frac{y}{v}$$

Vertically:

$$s_y = u_y t + \frac{1}{2} a_y t^2$$

$$x = 0 + \frac{1}{2}\left(\frac{Ve}{dm}\right)\left(\frac{y}{v}\right)^2 = \frac{eVy^2}{2mdv^2}$$

20 **A**

$$I = Anvq = \pi\left(\frac{d}{2}\right)^2 nvq = \frac{1}{4}\pi ned^2 v$$

$$v = \frac{4I}{\pi ne}\frac{1}{d^2}$$

Since $\dfrac{4I}{\pi ne}$ is a constant, $K = \dfrac{4I}{\pi ne}$.

$$v = \frac{K}{d^2}$$

21 **D**

Equivalent resistance of P and voltmeter, $R_{P//V} = \left(\frac{1}{R_P} + \frac{1}{R_V}\right)^{-1} = \left(\frac{1}{R_V} + \frac{1}{R_V}\right)^{-1} = \frac{R_V}{2}$

$$\frac{R_{P//V}}{R_Q} = \frac{6.0}{3.0}$$

$$\frac{R_V/2}{R_Q} = \frac{6.0}{3.0}$$

$$\frac{R_V}{R_Q} = \frac{6.0}{3.0} \times 2 = 4.0$$

22 **B**

$$V_{wire} = \left(84 \times 10^{-2}\right) \times 14.3 \text{ V}$$

$$E = \frac{65}{84} \times V_{wire} = \frac{65}{84} \times \left(84 \times 10^{-2}\right) \times 14.3 = 9.295 = 9.3 \text{ V}$$

23 **C**

By Newton's third law,
force on X by Y = – force on Y by X
i.e. the force on each wire is equal in magnitude and opposite in direction

Currents in the same direction will attract due to the interaction between the magnetic fields of the currents.

24 **D**

$$F = BIL \sin\left(90° - \theta\right) = BIL \cos\theta$$

The graph of F against θ is a cosine graph.

25 **B**

$$\phi = BA\cos\left(90° - 60°\right)$$
$$= BA\cos 30°$$
$$= \left(65 \times 10^{-6}\right)\left(12 \times 10^{-4}\right)\cos 30°$$
$$= 6.754 \times 10^{-8} = 6.8 \times 10^{-8} \text{ Wb}$$

26 **A**

peak current $= I_0$

r.m.s current $= \sqrt{\frac{I_0^{\,2} T}{T}} = I_0$

27 **B**

$$E = -\frac{d\Phi}{dt} = -\frac{d\left(NBA\cos\omega t\right)}{dt} = NBA\omega \sin\omega t$$

$$E' = -\frac{d\Phi}{dt} = -\frac{d\left(NBA\cos\frac{\omega}{2}t\right)}{dt} = \frac{1}{2}NBA\omega\sin\frac{\omega}{2}t$$

$$I_0 = \frac{E_0}{R} = \frac{NBA\omega}{R} = 2 \text{ A}$$

$$I_0' = \frac{E_0'}{R} = \frac{\frac{1}{2}NBA\omega}{R} = \frac{1}{2} \times 2 = 1 \text{ A}$$

$$P_m = I_{rms}^{\,2}R = \left(\frac{I_0'}{\sqrt{2}}\right)^2 R = \frac{1}{2} \times 20 = 10 \text{ W}$$

28 **A**

$$E=\frac{1}{2}mv^2=\frac{1}{2}\frac{(mv)^2}{m}=\frac{1}{2}\frac{p^2}{m}$$

$$p=\sqrt{2Em}$$

$$\lambda=\frac{h}{p}=\frac{h}{\sqrt{2Em}}$$

$$\lambda'=\frac{h}{p'}=\frac{h}{\sqrt{2(9E)m}}=\frac{h}{3\sqrt{2Em}}=\frac{\lambda}{3}$$

29 **C** $n_p=83$ and $n_n=212-83=129$

$$\Delta m=\left(83M_p+129M_n\right)-M$$

Mass defect is the difference in the mass of the nucleus and the total mass of its constituents (protons and neutrons).

30 **C** $^{238}\text{U}\rightarrow\,^{234}\text{Th}+\,^4_2\text{He}$

Energy released is from the mass difference between the reactants and products.

$$E=\Delta mc^2$$

$$=\left(M_U-\left(M_{Th}+M_{He}\right)\right)c^2$$

$$=(238.1249-234.1165-4.0026)\left(1.66\times10^{-27}\right)\left(3.00\times10^{8}\right)^2$$

$$=8.665\times10^{-13}=8.7\times10^{-13}\text{ J}$$

Paper 2

1 **(a)** Period of oscillation

$$T = \frac{t}{10} = 0.72\text{ s}$$

Since $T = 2\pi\sqrt{\frac{m}{k}}$

$$k = 4\pi^2\left(\frac{m}{T^2}\right) = 4\pi^2\left(\frac{0.120}{0.72^2}\right) = 9.1385\text{ N m}^{-1}$$ [1]

Uncertainty in k

$$\Delta k = \left(\frac{\Delta m}{m} + 2\frac{\Delta T}{T}\right)\times k = \left(\frac{\Delta m}{m} + 2\frac{\Delta t}{t}\right)\times k$$ [1]

$$= \left[0.01 + 2\left(\frac{0.2}{7.2}\right)\right]\times 9.1385 = 0.599 = 0.6\text{ N m}^{-1}\text{ (1 s.f.)}$$ [1]

Therefore

$$k = (9.1 \pm 0.6)\text{ N m}^{-1}$$ [1]

(b) **(i)** Method 1

From the graph, $x_0 = 0.16\text{ m}$, $v_0 = 1.4\text{ m s}^{-1}$. [1]

$$a_0 = \frac{v_0^2}{x_0} = \frac{1.4^2}{0.16}$$ [1]

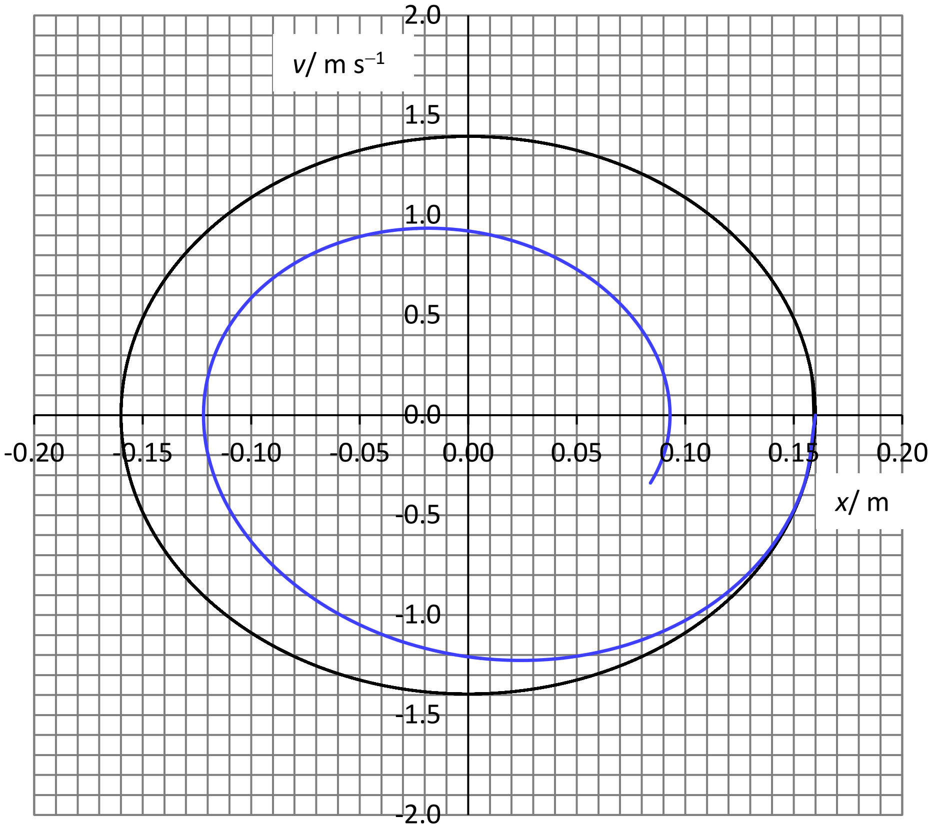
$$= 12.3\text{ m s}^{-2}$$ [1]

Method 2

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.72} = 8.73\text{ rad s}^{-1}$$ [or $\omega = \frac{v_0}{x_0}$] [1]

$$a_0 = \omega^2 x_0 = 8.73^2 \times 0.16 = 12.2\text{ m s}^{-2}$$ [1]

(ii)



[1] – decrease in displacement and speed.
[1] – correct direction and correct starting position.

[Starting position at (0.16,0.0) as the passage implies downward displacement as positive.]

2 **(a)** **(i)** A vector quantity is one which has both magnitude and direction. [1]

(ii) Any vector quantity such as force, displacement, velocity, momentum etc. [1]

(b) **(i)** Component of weight along slope

$$W = mg\sin 35° = 16\sin 35° = 9.177 \approx 9.18 \text{ N}$$ [1]

(ii) Since the object slides down the slope at constant speed,

frictional force $f = W$

[1]

Force needed to pull object up along slope with constant velocity

$$P = f + W = 2W = 2 \times 9.18 = 18.36 = 18.4 \text{ N}$$ [1]

(c) **(i)** Impulse on X $= m_X \Delta v_X$ [1]

$$= 0.22 \times (3.50 - 2.60) = 0.198 \text{ N s}$$ [1]

(ii) Method 1

Impulse on Y = –impulse on X

$$0.40 \times (v_Y - 3.3) = -0.198$$ [1]

$$v_Y = 3.3 - \frac{0.198}{0.40} = 2.81 \text{ m s}^{-1}$$ [1]

Method 2
By the principle of conservation of momentum,

$$m_X u_X + m_Y u_Y = m_X v_X + m_Y v_Y$$ [1]

$$v_Y = \frac{m_Y u_Y - m_X \Delta v_X}{m_Y} = \frac{0.40 \times 3.3 - 0.198}{0.40} = 2.81 \text{ m s}^{-1}$$ [1]

(iii) Method 1
Distance travelled during time of contact is area under graph in same time interval. [1]

$$s = \tfrac{1}{2} \times 0.20 \times (2.6 + 3.5) = 0.61 \text{ m}$$ [1]

Method 2
Acceleration of X during collision,

$$a = \frac{3.5 - 2.6}{0.2} = 4.5 \text{ m s}^{-2}$$ [1]

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

$$s = \frac{v^2 - u^2}{2a} = \frac{3.5^2 - 2.6^2}{2 \times 4.5} = 0.61 \text{ m}$$ [1]

3 (a) In both cases, the force, and hence the acceleration experienced, is constant in both magnitude and direction. [1]
Hence, both paths will be parabolic. [1]

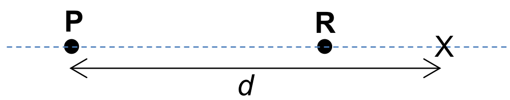
(b) (i) The gravitational force between the protons is attractive whereas the electric force between the protons (like charges) is repulsive. [1]
Hence the forces have opposite signs.

(ii) For the same separation, the gravitational force (between the protons) is very much smaller (~25 orders of magnitude) than the electric force (between the protons). [1]
So, the axes on both graphs are not drawn to the same scale. [1]

(c) (i) At any point along the line between P and R, the resultant electric field is the vector sum of the electric field due to P and R.
Since the electric field due to P and R are both directed to the right, the resultant electric field cannot be zero. [1]

(ii) The electric potential at any point along the line between P and R is the scalar addition of the electric potential due to P and R.
Since the electric potential due to P and R are opposite in signs, there is a point (nearer to R) where the resultant electric potential is zero. [1]

(iii)



Let X be the point where there is no resultant force on the electron. d is the distance of the electron from P.

At X:

$$\frac{Q_P e}{4\pi\varepsilon_o d^2} = \frac{Q_R e}{4\pi\varepsilon_o \left(d - 0.06\right)^2}$$ [1]

Rearranging,

$$\frac{d}{\left(d - 0.060\right)} = \sqrt{\frac{Q_P}{Q_R}} = \sqrt{\frac{6.5}{0.45}}$$

$\Rightarrow$ $d = 3.8\left(d - 0.060\right)$

Solving,

$$d = 0.0814 \text{ m}$$ [1]

4 **(a)** A gas consists of a large number of molecules in <u>continuous random motion in the vessel</u>. [1]
When a molecule hits the wall, it experiences <u>change in momentum</u> due to the <u>force exerted by the wall</u>, according to Newton's 2nd law. By Newton's 3rd law, the molecule exerts <u>an equal but opposite force</u> on the wall. [1]
The <u>average total force per unit area</u> exerted by all the molecules on the wall is the pressure on the wall. [1]

(b) **(i)** The separation between the particles is <u>very much larger</u> than the diameter of each particle such that the volume of the particles is negligible compared to the volume of the vessel. [1]

(ii) Using $PV = NkT$, volume occupied by each particle

$$\frac{V}{N} = \frac{kT}{P}$$ [1]

Separation between particles

$$d = \sqrt[3]{\frac{V}{N}} = \sqrt[3]{\frac{kT}{P}} = \sqrt[3]{\frac{1.38\times10^{-23}\times298}{180}}$$ [1]

$$= 2.84\times10^{-8} \text{ m}$$ [1]

(iii) The distance between particles of the gas is <u>2 orders of magnitude larger</u> than the diameter of a gas particle. [1]
The assumption stated in **(b)(i)** is <u>valid</u>.

5 **(a)** Any two of the following: [2]

Property	**Progressive Wave**	**Stationary Wave**
Energy	Transports energy.	Does not transport energy.
Amplitude	Every point oscillates with the same amplitude.	Amplitude varies from 0 at the nodes to the maximum at the antinodes.
Phase	All particles within one wavelength have different phases.	All particles between two adjacent nodes have the same phase. Particles in adjacent segments have a phase difference of π rad.

(b) Incident microwaves is reflected by the metal plate. [1]
The incident and reflected microwaves superpose to produce stationary wave. [1]

(c) **(i)** Since the source is a point source, the amplitude of the wave is inversely proportional to the distance from the source. [1]
Hence, the amplitude of the incident wave is larger than the amplitude of the reflected wave. [1]
The incomplete cancellation of the waves at the minima resulted in non-zero amplitude and non-zero intensity (proportional to square of amplitude). [1]

(ii) Wavelength of the microwaves is the distance between first and third maxima.

$$\lambda = 6.2 - 1.0 = 5.2 \text{ cm}$$ [1]

(iii) Frequency of the microwaves

$$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8}{0.052}$$ [1]

$$= 5.8 \times 10^9 \text{ Hz}$$ [1]

6 **(a)** Half-life of a radioactive isotope is the time taken for the number of undecayed nuclei to be reduced to half its original number. [1]

(b) At the steeper part of the graph, the activity of the sample is greater with a smaller percentage uncertainty. [1]
This results in smaller percentage uncertainty in the calculation of the half-life of the isotope.

(c) The initial momentum of the system is zero. [1]
For the total momentum of the system to be conserved (remains at zero), another particle is emitted. [1]

OR

The initial momentum of the system is zero. [1]
The total momentum of the nucleus and beta particle is not zero since their momenta are not opposite in direction. This shows that another particle is emitted. [1]

(d) **(i)** $^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\overline{\nu}$ [3]

1 mark each for nucleon number and proton number.
1 mark for neutrino.

(ii) Decay constant

$$\lambda = \text{gradient} = \frac{(5.20-0)\times 10^{9}}{(6.80-0)\times 10^{18}} = 7.65\times 10^{-10}\ \text{s}^{-1}$$ [1]

Half-life

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{7.65\times 10^{-10}} = 9.06\times 10^{8}\ \text{s}$$ [1]

(e) Method 1
Number of atoms of J

$$N = \left(\frac{1}{2}\right)^{n} N_0 = \left(\frac{1}{2}\right)^{3.5} N_0 = 0.0884N_0$$ [1]

$$\frac{\text{number of atoms of J}}{\text{number of atoms of K}} = \frac{0.0884N_0}{N_0 - 0.0884N_0}$$ [1]

$$= 0.0970$$ [1]

Method 2

Number of atoms of J is given by $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{n}$ where n is the number of half-life. [1]

$$\frac{\text{number of atoms of K}}{\text{number of atoms of J}} = \frac{N_0 - N}{N} = \frac{N_0}{N} - 1 = 2^{n} - 1$$ [1]

$$\frac{\text{number of atoms of J}}{\text{number of atoms of K}} = \frac{1}{2^{n}-1} = \frac{1}{2^{3.5}-1} = 0.097$$ [1]

7 **(a)** **(i)** Ratio

$$\frac{\text{cost to travel 1.0 km in EV}}{\text{cost to travel 1.0 km in ICE}} = \frac{72 \div 400 \times 0.23}{80 \div 800} = 0.414$$ [1]

(ii) The weekly mileage of a typical Singapore car is only 290 km which is less than the expected range of 400 km for EV car. [1]

(i) Since the maximum charging current is 32 A and each cell has a maximum charging current of 2 A, there must be <u>16 parallel arrangements</u> of cells. [1]
The charge voltage is $7200 \div 32 = 225$ V. Since each cell has a maximum terminal voltage of 3.0 V, there must be <u>75 cells in series</u>. [1]
So, the minimum number of cells is <u>1200</u>. [1]

(ii) For every hour of charging, the EV can travel 40 km. [1]

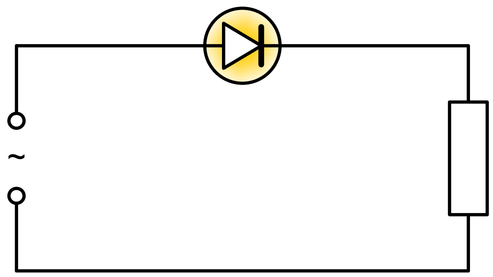
(iii) The specific energy of a battery is the <u>energy stored per unit mass</u>. [1]
For this battery, the energy stored is <u>141 W h per kg</u> of the cell.

(iv) Mass of battery

$$m = \frac{\text{total energy stored}}{\text{specific energy}} = \frac{72000}{141} = 511 \text{ kg}$$ [1]

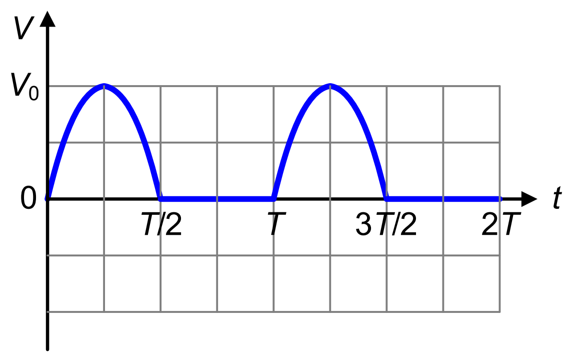
(v) Since the battery pack is very <u>heavy</u>, it is usually located at the <u>base</u> of the car between the wheels. This <u>lowers the centre of gravity</u> of the car and results in a more stable car. [1]

(c) **(i)**



[1]

(ii)



1 mark for half-wave rectified voltage.
1 mark for correct period.

(d) Total kinetic energy at 25 km h^{-1}

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2} \times 1685 \times 25^2 = 5.27 \times 10^5 \text{ J}$$ [1]

Assuming a range of 400 km for 72 kWh of stored battery energy, range of EV on regenerative braking

$$\text{range} = 5.27 \times 10^5 \times \frac{400}{72000 \times 3600}$$ [1]

$$= 0.813 \text{ km}$$ [1]

(e) (i) Wireless charging is based on electromagnetic induction. This requires a constantly changing magnetic field and hence the need to use an a.c. voltage. [1]

(ii) Magnetic flux linkage between the coils is strongest when the coils are as close together as possible. This will result in the most efficient transfer of electrical power. [1]

(f) (i) Maximum output torque = 395 N m.

$$\begin{aligned} \text{Torque} &= Fd \\ &= NBIl \times d \\ &= NBIA \\ &= 1200 \times B \times 96 \times 6.1 \times 10^{-3} \\ &= 702.72B \end{aligned}$$ [1] [1]

Hence,

$$B = \frac{395}{702.72} = 0.562 \text{ T}$$ [1]

(ii) This will give a more constant torque than the motor in Fig. 7.4 and the motor will turn at a more constant speed. [1]

Paper 3

1 **(a)** The inertia of a body can be described as its reluctance to start moving, or to change its motion once it has started. [1]

(b)
$$g = \frac{GM}{r^2}$$
$$= \frac{\left(6.67 \times 10^{-11}\right)\left(7.35 \times 10^{22}\right)}{\left(1.74 \times 10^{6}\right)^2}$$ [1]
$$= 1.619$$ [1]
$$= 1.62 \text{ N kg}^{-1} \text{ (shown)}$$

(c) **(i)** Force on gas
$$F_{gas} = v\frac{dm}{dt}$$

By Newton's 3rd law, the thrust generated on the rocket is equal in magnitude and opposite in direction to F_{gas} [1]

$$v = \frac{F_{gas}}{\frac{dm}{dt}}$$
$$= \frac{10.0 \times 10^3}{70.0}$$ [1]
$$= 143 \text{ m s}^{-1}$$ [1]

(ii) Mass of rocket after 15.0 s
$$m_f = 4000 - (15)(70.0) = 2950 \text{ kg}$$ [1]

By Newton's 2nd Law
$$F_T - mg = ma$$
$$a = \frac{F_T - m_f g}{m}$$
$$= \frac{10.0 \times 10^3 - (2950)(1.62)}{2950}$$ [1]
$$= 1.77 \text{ m s}^{-2}$$ [1]

(iii) The actual acceleration is greater that the value calculated in (c)(ii). [1]

The gravitational field strength g is not a constant as assumed. It is inversely proportional to the square of the distance r of the rocket from the planet's centre, i.e. $g \propto \frac{1}{r^2}$. Hence, the gravitational force acting on the rocket is less than the value calculated in (c)(ii) since g decreases as r increases. [1]

2 (a) $R = \frac{\rho L}{A}$

$\rho = \frac{RA}{L}$

$= \left(\frac{R}{L}\right)\left(\frac{\pi d^2}{4}\right)$ [1]

$= (1.73)\left(\frac{\pi\left(1.02\times10^{-3}\right)^2}{4}\right)$ [1]

$= 1.41\times10^{-6}\ \Omega\ \text{m}$ [1]

(b) (i)

time after being switched on / s	ΔU	q	w	
0–59	positive	negative	positive	[1]
60–100	zero	negative	positive	[1]

(ii) Since temp is constant, $\Delta U = 0$ [1]

Amount of heat supplied
$q = -VIt = (230)(12)(40) = -1.10\times10^5$ J [1]

According to the first law of thermodynamics, $\Delta U = q + w$
$w = -q = 1.10\times10^5$ J [1]

3 (a) (i) $\omega = 2\pi f$

$= \frac{2\pi(1200)}{60}$ [1]
[1]

$= 126$ rad s^{-1}

(ii) By Newton's 2nd Law
$F - mg = mr\omega^2$ [1]

$F = mg + mr\omega^2$ [1]

$= 1.20\left[9.81 + (0.230)(126)^2\right]$

$= 4370$ N [1]

(iii) The force exerted by the drum on the towel while spinning is large (about 4370 N). By Newton's 3rd Law, force of the same magnitude is exerted by the spinning towel on the drum. [1]

This large force changes direction as the towel moves around, hence causing the washing machine to vibrate violently. [1]

Very large masses are placed at the base of washing machines to provide a large inertia to minimize the vibration and lower the CG to increase stability. [1]

(b) As the machine spins, there is no force acting on the water to provide for the centripetal force required to continue in circular motion when the water reaches the hole. [1]

Hence, water continues its motion in a straight line and leaves the drum through the holes tangentially. [1]

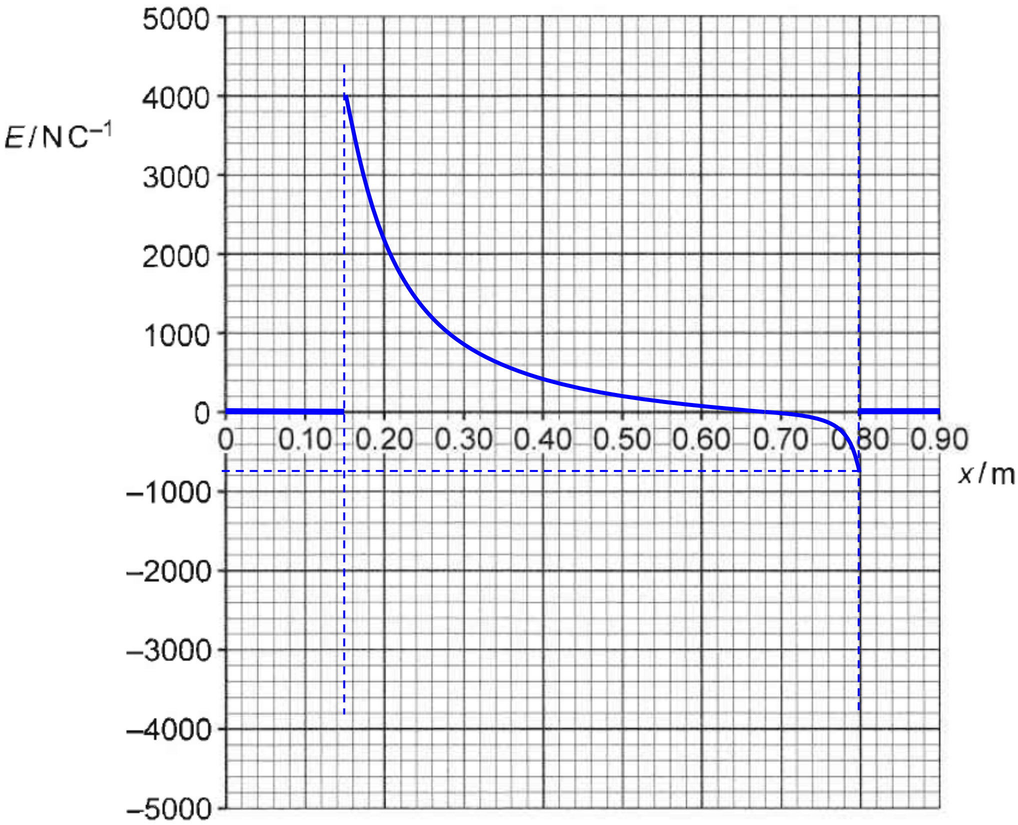
4 **(a)** From x = 0.15 m to x = 0.66 m, the potential decreases, showing that the electric field is pointing to the right. [1]
From x = 0.66 m to x = 0.80 m, the potential increases, showing that the electric field is pointing to the left.
Since the electric field changes direction, the two spheres have charges of the same sign. [1]
The charge on sphere A is positive. [1]

(b) Using $E = -\dfrac{dV}{dx}$

$$E_A = -\frac{dV}{dx} = -\left(\frac{700-300}{0.13-0.23}\right) = 4000 \text{ N C}^{-1}$$ [1]

$$E_B = -\frac{dV}{dx} = -\left(\frac{240-40}{0.84-0.58}\right) = -770 \text{ N C}^{-1}$$ [1]

$$\frac{dV}{dx} = 0 \text{ occurs at } r = 0.68 \text{ m}$$ [1]



E = 0 within each sphere [1]
Correct shape [1]

(c) **(i)**

$$V_A = \frac{Q}{4\pi\varepsilon_0 r}$$

$$= \frac{1.0 \times 10^{-8}}{4\pi\left(8.85 \times 10^{-12}\right)(0.15)}$$ [1]

$$= 599 \text{ V}$$ [1]

(ii) From Fig 4.2, the electric potential at the surface of sphere A is 620 V which is greater than the value obtained in (c)(i).

The potential graph in Fig 4.2 shows the scalar summation of the individual potentials due to both sphere A and sphere B i.e. [1]

$$V_{total} = \frac{Q_A}{4\pi\varepsilon_0 x} + \frac{Q_B}{4\pi\varepsilon_0\left(0.90 - x\right)}$$

where Q_A and Q_B are positive charges on spheres A and B respectively.

In (c)(i), only the electric potential of a single positive charge Q_A was calculated. In Fig 4.2, total potential at the surface of sphere A is larger as result of the additional positive electric potential contribution due to the positively charged sphere B at x = 0.15 m [1]

5 **(a)** When the switch is closed momentarily, the voltmeter registers a non-zero reading for a short period of time. [1]

The reading then drops back to zero. [1]

When the switch is re-opened, the voltmeter registers a non-zero reading for a short period of time that is of the opposite sign of the opposite sign, before going back to zero. [1]

(b) Faraday's law of electromagnetic induction states that the induced e.m.f. is proportional to the rate of change of magnetic flux linkage.

When the switch is closed for a short time, circuit is closed and current flows through the primary coil. This causes the magnetic flux density in the primary coil to increase. [1]

The magnetic field is directed through the secondary coil by the iron core. [1]

This causes the magnetic flux linkage through the secondary coil to increase and hence, by Faraday’s Law, e.m.f. is induced in the secondary coil and the voltmeter registers a non-zero reading. [1]

When the current in the primary coil reaches a constant value, the magnetic flux linkage through the secondary coil is constant and hence, no e.m.f. is induced in the secondary coil. Thus, the voltmeter registers a reading for only a short period of time before going back to zero. [1]

When the switch is re-opened, the decrease in current and magnetic flux density in the primary coil causes the magnetic flux linkage through the secondary coil to decrease, and e.m.f. is once again induced momentarily in the secondary coil but of the opposite sign, before going back to zero. [1]

6 **(a)** From Fig. 6.2, at 20°C, $R = 60\ \Omega$ [1]

By potential divider formula,

$$V = 0.43 = \frac{r}{60 + r} 1.50$$ [1]

$$r = 24.112 = 24\ \Omega$$ [1]

(b) From Fig. 6.2, at 32°C, $R = 40\ \Omega$ [1]

$$\frac{1}{R_{eff}} = \frac{1}{24} + \frac{1}{40}$$

$$R_{eff} = 15\ \Omega$$ [1]

$$I = \frac{V}{R_{eff}} = \frac{1.50}{15} = 0.10\ \text{A}$$ [1]

7 **(a)** Coherent light waves are light waves with a constant phase difference between them. [1]

(b) Spacing between slits, $d = \frac{10^{-3}}{300} = 3.33 \times 10^{-6}$ m [1]

$$d \sin\theta = n\lambda$$

$$\left(3.33 \times 10^{-6}\right) \sin\theta = 2\left(640 \times 10^{-9}\right)$$ [1]

$$\sin\theta = 0.384$$

$$\theta = 22.582°$$

$$\tan\theta = \frac{x}{2.1}$$ [1]

$$x = 0.87336\ \text{m} = 87.3\ \text{cm}$$ [1]

8 **(a)** **(i)** The electric field strength at a point is defined as the electric force exerted per unit positive charge placed at that point. [1]

(ii) If it was not in a vacuum, the accelerated electrons may collide with air molecules present in the electron gun, which will cause the electrons to scatter and lose kinetic energy. [1]

The electrons would emerge from the gun with smaller velocities, which would result in the electrons not being able to form the desired circular path of the desired radius. [1]

The scattering would also cause some electrons to not even emerge from the hole in the anode as well, causing a less intense electron beam.

(iii) By conservation of energy,

gain in kinetic energy = loss in electric potential energy

$$\Delta KE = e\Delta V = 2.48 \times 10^{-16}$$ [1]

$$\Delta V = \frac{2.48 \times 10^{-16}}{1.6 \times 10^{-19}} = 1550\ \text{V}$$ [1]

(iv) This is because the electrons are produced from the heating filament with a range of speeds. [1]

Hence, after being accelerated over the same potential difference, they will end up with a range of speeds as well. [1]

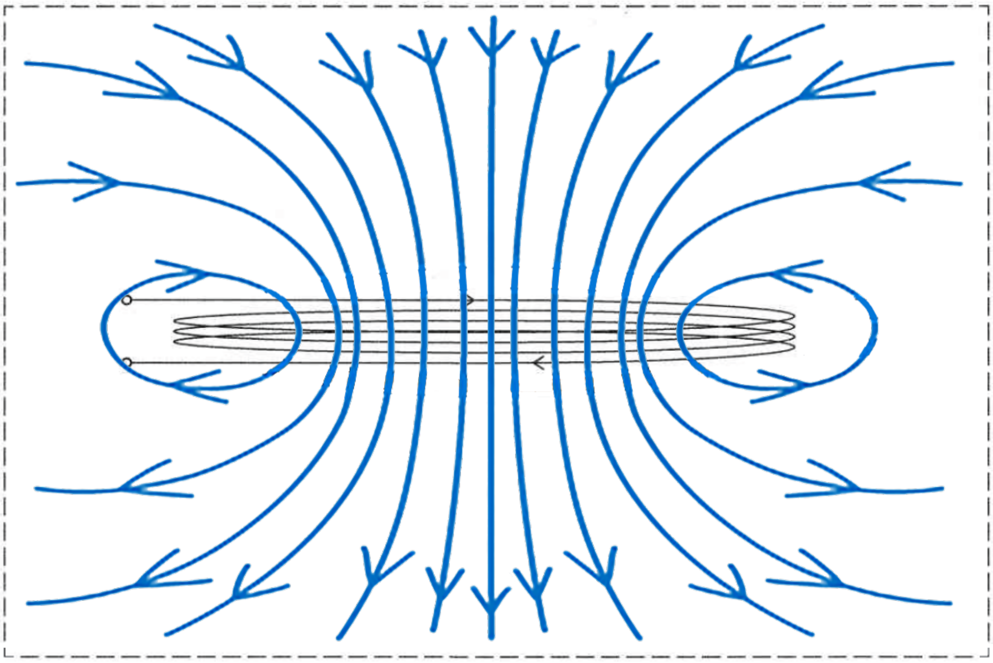
(Alternative: The electrons will collide among themselves. The collisions cause some electrons to transfer energy to other electrons. Hence, they arrive at the anode with unequal kinetic energy and unequal speeds.)

(b) (i)

$$B = \frac{\mu_0 N I}{2r} = \frac{\mu_0 (120)(3.5)}{2\left(\frac{0.30}{2}\right)}$$

$$= 1.7593 \times 10^{-3} = 1.76 \times 10^{-3} \text{ T}$$

(ii)



Field is pointing downwards, at least 5 lines between the loops at each end [1]
Field is up-down and left-right symmetrical [1]
Field perpendicular to plane of coil when it passes through the coil [1]

(c) (i) A charged particle (such as an electron) moving in a magnetic field experiences a magnetic force perpendicular to its velocity.

As the magnetic force is always perpendicular to the electron's velocity, the electron's speed (magnitude of velocity) remains constant. The force only acts to change the direction of the velocity at a constant rate. [1]

Since the speed of the electron is constant, the magnetic force is also constant in magnitude. [1]

This magnetic force, constant in magnitude and always perpendicular to the electron's velocity, will therefore act as a centripetal force on the electron, resulting in it moving in a circular path of constant radius. [1]

(ii) The magnetic force provides for the centripetal force on the electron. [1]

$$\frac{mv^2}{r} = Bqv$$

$$r = \frac{mv}{Bq} = \frac{(9.11\times10^{-31})(2.40\times10^{7})}{1.43(1.7593\times10^{-3})(1.6\times10^{-19})}$$ [1]

$$= 0.054317 = 0.0543 \text{ m}$$ [1]

(d) As the electron enters the magnetic field at an angle less than 90°, it will experience a centripetal force provided by the magnetic force acting on it due to its component of velocity perpendicular to the magnetic field. This will result in a circular path. [1]

However, the component of its velocity parallel to the magnetic field will be unaffected by the magnetic field. Hence, this component of its velocity will remain constant, and the electron will move at a constant velocity in a direction parallel (or anti-parallel) to the field lines. [1]

A combination of the circular path and the constant velocity results in the helical path shown.

9 **(a)** In the wave model of light, the maximum kinetic energy of emitted photoelectrons should increase with intensity of radiation as the incident light of higher intensity (and hence higher energy) should eject photoelectrons with greater kinetic energy. [1]

Similarly, since the energy of the wave is dependent on the square of its amplitude, the wave model predicts that if sufficiently intense light is used, the electrons would eventually be able to absorb enough energy to escape regardless of the frequency of light. Hence, there should not be any threshold frequency. [1]

However, in the particulate model of light, each photon (light particle) has an energy of hf, where f is the frequency. Emission of a photoelectron is due to a single photon being absorbed by an electron on the surface of the metal. Hence, if the photon energy is below the work function ϕ, i.e., $f < \phi/h$, photoemission is impossible. Hence, this explains a minimum threshold frequency for the incident photons. [1]

Finally, in the particulate model of light, for a constant frequency, increasing the intensity of light means increasing the rate of photons incident on the metal. However, as frequency is constant, the energy of each photon remains the same. Hence, increasing the intensity of radiation does not increase the kinetic energy of the photoelectrons, but only increases the rate of emission of photoelectrons. [1]

(b) Threshold frequency. [1]

(c)

$$\frac{hc}{\lambda} = KE_{\text{max}} + \Phi$$

$$KE_{\text{max}} = \frac{hc}{\lambda} - \Phi$$

$$= \frac{(6.63\times10^{-34})(3\times10^{8})}{210\times10^{-9}} - 4.33(1.6\times10^{-19})$$ [1] [1]

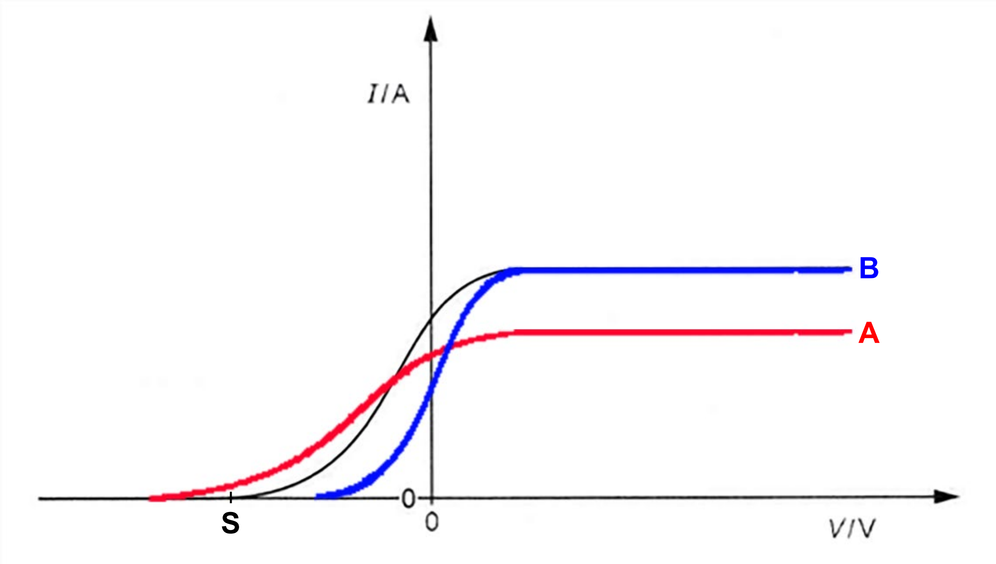
$$= 2.5434\times10^{-19} \text{ J} = 2.54\times10^{-19} \text{ J}$$ [1]

(d) $KE_{max} = eV_S$

$$V_S = \frac{2.5434 \times 10^{-19}}{1.6 \times 10^{-19}}$$ [1]

$= 1.5896 = 1.59$ V [1]

(e)



(i) Indicate S on the x-intercept [1]

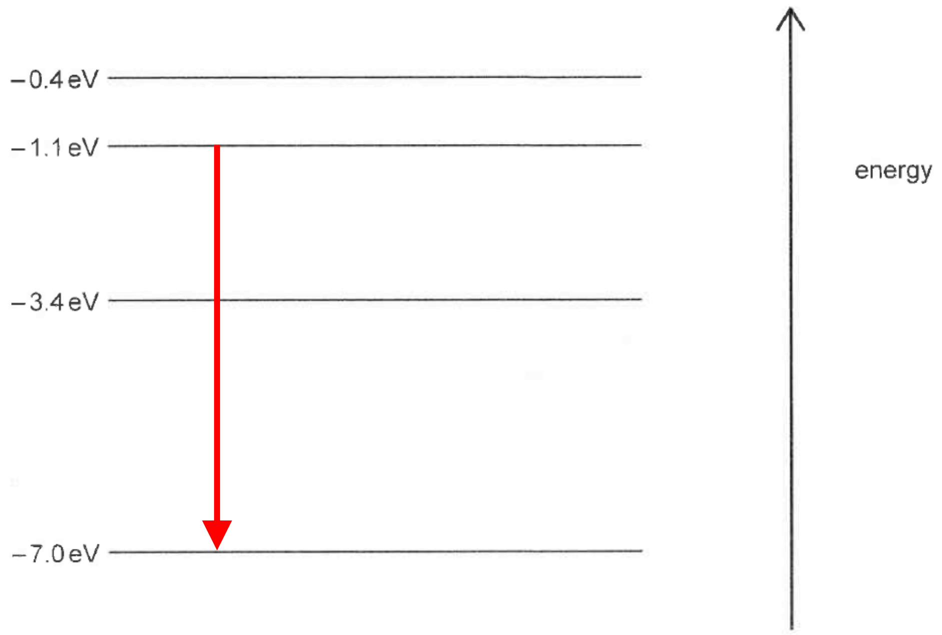
(ii) Lower saturated current (less photons per unit time) [1]
More negative x-intercept [1]

(iii) Less negative x-intercept, same saturated current [1]

(iv) When the values of *V* are negative enough (below stopping potential S), even the photoelectrons with the most kinetic energy are unable to travel from the zinc plate to the electrode due to the strong repulsive forces they experience. [1]

Hence, since current is the rate of flow of charge, the current is zero as the photoelectrons are unable to conduct current in the circuit. [1]

(f) **(i)** $\dfrac{hc}{\lambda} = 9.4714 \times 10^{-19}\ \text{J} = 5.9\ \text{eV}$



Correct direction (downwards) [1]
Correct levels (–1.1eV to –7.0 eV) [1]

(ii) The photon with the longest wavelength is the least energetic photon. Hence, it must be emitted by the transition between the two closest energy levels in the diagram (from – 0.4 eV to – 1.1 eV). [1]

$$E_i - E_f = \frac{hc}{\lambda} = (-0.4 + 1.1)(1.6 \times 10^{-19})$$

$\lambda = 1.7759 \times 10^{-6}\ \text{m} = 1.78 \times 10^{-6}\ \text{m}$ [1]