RAFFLES INSTITUTION
YEAR 5-6 PHYSICS DEPARTMENT

9749 H2 Physics
2024 GCE A-Level Suggested Solutions

Paper 1

1 **A** Approximate area $= \pi\left(4\times10^{2}\times10^{6}\right)^{2} = 5.0265\times10^{17}\ \text{m}^2$

$$= 5.0265\times10^{17}\times\left(10^{-9}\right)^{2}\ \text{Gm}^2$$

$$\approx 5\times10^{-1}\ \text{Gm}^2$$

2 **B** $\underline{0 \le t \le t_1}$

Acceleration has a positive and constant value. Object's velocity increases linearly in the positive direction. Gradient of $v-t$ graph is positive.

$\underline{t_1 \le t \le t_2}$

At $t = t_1$, acceleration immediately switches to a negative value and remains constant until $t = t_2$. Object's velocity decreases linearly in the positive direction. Gradient of $v-t$ graph is negative.

3 **C** Taking upward as positive,

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

$$0 = \left(15\sin 40^\circ\right)t + \frac{1}{2}\left(-1.62\right)t^2$$

$$t = 11.9\ \text{s}$$

4 **B** As the cylinder is in equilibrium and acted upon by three forces, the vector triangle formed by the three forces forms a close loop in one direction.

Options (**A**) and (**C**) are out.

5 **D** $\frac{W}{3} = kx$

$$k = \frac{W}{3x} \qquad \text{...... (1)}$$

$$W = kx'$$

$$x' = \frac{W}{k} = \frac{W}{W/3x} \quad \text{[substitute eqn(1) here]}$$

$$\therefore x' = 3x$$

6 **B** When specimen is stretched under the tensile load from zero to a maximum value, the work done by the tensile force on the specimen is area under OPQT.

When relaxed, the work done by the specimen is area under SRQT.

Hence the net work done on the specimen = area OPQT − area SRQT = area OPRS.

7 **C** Since the car is moving up the hill at a constant speed,
Forward driving force of the engine uphill = F + component of weight downhill

$$F_{\text{engine}} = 600 + 900 \times 9.81 \times \sin 10^\circ = 2133.14 \text{ N}$$

$$P_{\text{engine}} = 2133.14 \times 16 = 34130 \text{ W}$$
$$\approx 34 \text{ kW}$$

8 **D** Work done on the gas is when the gas is compressed by an external force and its volume decreases i.e. RS and SP.

9 **A**

Angular velocity $\omega = \dfrac{d\theta}{dt} = \dfrac{l/r}{t}$

$$= \frac{l}{rt}$$

10 **A** $a_c = r\omega^2$

$$= \left(\frac{1.3 \times 10^7}{2}\right)\left(\frac{2\pi}{24 \times 3600}\right)^2$$

$= 0.0344 \text{ m s}^{-2}$ towards the centre of the Earth.

11 **A**

As $\phi = -\dfrac{GM}{r}$ where M is the mass of the object and r is the distance between the object and points P or Q, the magnitudes of their individual gravitational potentials decrease as r increases.

$\Delta\phi = -\dfrac{GM}{r_Q} - \left(-\dfrac{GM}{r_P}\right) = \dfrac{GMd}{r_P r_Q}$ where $d = r_Q - r_P$.

As P and Q move away from the object while maintaining the same separation, d is unchanged but $r_P\, r_Q$ increases, hence $\Delta\phi$ decreases.

12 **A** The change in momentum of the particle after collision with the wall (shaded) $\Delta p = mv - (-mv) = 2mv$, taking leftward as the positive direction.

The average force that the particle exerts on the shaded wall = $\dfrac{\Delta p}{\Delta t} = \dfrac{2mv}{2x/v} = \dfrac{mv^2}{x}$.

13 **D** Heat loss by volume V of water = Heat gained by $V/4$ of water

$$V\rho c(60 - \theta) = \frac{V}{4}\rho c(\theta - 20)$$

$$\theta = 52^\circ \text{ C}$$

14 **C** At $t = 0$, $x = -x_0$, $E_K = 0$ J.

$$x = -x_0 \cos \omega t$$

$$v = \omega x_0 \sin \omega t$$

$$E_K = \frac{1}{2} m\omega^2 x_0^2 \sin^2 \omega t$$

15 **C** In critical damping, the mass will reach equilibrium in the shortest time without oscillating.

16 **C** $P = IA$

$$I \propto \frac{1}{r^2}$$

$$\frac{I_{mars}}{I_{earth}} = \left(\frac{r_{earth}}{r_{mars}}\right)^2$$

$$I_{mars} = \left(\frac{1.5\times10^{11}}{2.3\times10^{11}}\right)^2 \times \left(\frac{1300}{1.0}\right) = 552.93$$

Area of solar panel to receive the same power if satellite orbits around Mars

$1300 = 552.93 \times A$

$A = 2.35 \approx 2.4\ \text{m}^2$

17 **D** $A = A_0 \cos\phi$

$A = A_0 \cos 15° = 0.966A_0 \approx 0.97A_0$

18 **D**

19 **C** $I = nAv_d q = n\dfrac{\pi D^2}{4}v_d q$

For the same material, number density n is the same.
For equal current in both wires, drift velocity is higher for the wire with the smaller diameter and vice versa.

20 **B** Since $R = \dfrac{\rho L}{A}$, resistance R is minimum if L is minimum and A is maximum.

Hence $R_{min} = \dfrac{\rho x}{yz}$.

21 **A** E.m.f. of the cell connected across PQ, E = P.D. across the 2.0 Ω resistor,

$$E = \frac{2.0}{3.0}\times 0.60 = 0.40\ \text{V}$$

Polarity connected to P is negative.

22 **A** As temperature of the thermistor rises, its resistance decreases.
The total resistance of the circuit decreases. Current A1 increases. The p.d. across the thermistor decreases, hence current A2 decreases.

23 **C** Option A: electric force on electron acts perpendicularly out of plane of paper may cancel out the magnetic force acting perpendicularly into the page. It is possible that the electron moves horizontally straight from left to right.

Option B: electric force on electron acts in the opposite direction to the electric field strength. Its vertical component acts vertically downward which may be cancelled by vertically upward magnetic force on it. The horizontal component of electric force will cause the electron to accelerate horizontally from left to right.

Option D: electric force on electron accelerates it to the right whereas there is no magnetic force on it. It is possible that the electron moves horizontally straight from left to right.

*Note: Option B is also not possible. The magnetic force is greater than the electric force in the vertical direction since the velocity of the ion increases. Net vertical force is not zero.

24 **B** $T = \dfrac{2\pi r}{v} \Rightarrow v = \dfrac{2\pi r}{T}$.

Magnetic force on the particle provides for its centripetal force.

$$Bqv = mr\omega^2 = mr\left(\frac{4\pi^2}{T^2}\right)$$

$$\therefore T = \frac{2\pi m}{Bq}.$$

25 **D** Induced e.m.f. across the wing of the aircraft E = $Blv = 1.0 \times 10^{-5} \times 80 \times 150 = 0.12$ V

$$\left|\frac{\Delta\phi}{\Delta t}\right| = 0.12$$

$$\Delta\phi = 0.12 \times 60 = 7.2 \text{ Wb}$$

26 **B** Magnitude of a.c. voltage changes by $2V_0$ from $T/4$ to $3T/4$ for a sinusoidal voltage supply defined by $V = V_0 \sin\omega t$.
Fraction of a cycle = $3T/4 - T/4$ = T/2.

27 **A** Total resistance of the overhead cables $R = 2 \times 0.030 \times 100 = 6.0\ \Omega$

$$P_0 = IV_0$$
$$100 \times 10^6 = I \times 400000$$
$$I = 250 \text{ A}$$

Power loss $P_{loss} = 250^2 \times 6 = 375\ 000$ W
Power input to substation $P_i = 100 \times 10^6 - 375\ 000 = 99.625 \approx 99.63$ MW

28 **D** From De Broglie's relationship $p = \dfrac{h}{\lambda}$.
Photon energy $E = \dfrac{hc}{\lambda} = \dfrac{hc}{h/p} = pc$ where c is the speed of light in vacuum.

29 **B** From Heisenberg's uncertainty principle $\Delta x \Delta p \approx h \Rightarrow \Delta x(m\Delta v) \approx h$. There is a trade-off in the uncertainties of position (or displacement) and momentum (or velocity).
Options A, C and D are incorrect.

30 **D** Mass of an Fe-56 nucleus = $55.93493u - 28 \times 0.00055u = 55.92063u$

Mass of Fe-56 nucleus $= (26 \times 1.00728u + 30 \times 1.00867)u - 55.92063u = 0.52875u$

$$= 8.78 \times 10^{-28} \text{ kg}$$

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Paper 2

1 **(a)** Gain in $E_p = 27$

$$mg(h-0) = 27$$

$$h = \frac{27}{(0.43)(9.81)} \quad [1]$$

$$= 6.4 \text{ m} \quad [1]$$

(b) At maximum height: $v_y = 0$

$$0 = u_y^{\,2} - 2gh$$

$$u_y = \sqrt{2gh}$$

$$= \sqrt{2(9.81)(6.5)} \quad [1]$$

$$= 11.21 = 11 \text{ m s}^{-1} \text{ (shown)}$$

(c) **(i)**

$$u_x = \frac{u_y}{\sin 32°}\cos 32°$$

$$= \frac{11.2}{\tan 32°} \quad [1]$$

$$= 17.9 \text{ m s}^{-1} \quad [1]$$

By conservation of momentum

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

Since $u_2 = 0$

$$v = \frac{m_1u_1 + m_2u_2}{m_1 + m_2}$$

$$= \frac{(0.43)(17.9)}{0.43 + 0.67} \quad [1]$$

$$= 7.0 \text{ m s}^{-1} \quad [1]$$

(ii) As the horizontal velocity of the original object as it rises is greater than the horizontal velocity of the combined object as it falls, it will travel a greater horizontal distance given by the product of its horizontal velocity and time. [1]

Since both objects travel the same vertical height, the time taken for the original object to rise is equal to the time taken for the combined object to fall. [1]

2 **(a)** The molecules exert no intermolecular forces on one another except during collisions. [1]

(b) The internal energy of ideal gas consists only of the microscopic kinetic energy due to random motion of its molecules since the microscopic potential energy of ideal gas is zero. [1]

(c) (i) Total $E_k = \frac{3}{2}NkT$

$= \frac{3}{2}(2.50 \times 10^{23})(1.38 \times 10^{-23})(21 + 273.15)$ [1]

$= 1520$ J [1]

(ii) $W = -p\Delta V$

$= -(1.0 \times 10^{5})(6.3 \times 10^{-4})$ [1]

$= -63$ J

By the First Law of Thermodynamics,

$\Delta U = Q + W$

$Q = \Delta U - W$

$= \frac{3}{2}Nk\Delta T - W$

$= \frac{3}{2}(2.50 \times 10^{23})(1.38 \times 10^{-23})(15) - (-63)$ [1]

$= 141$ J [1]

Note:
The values of ΔT and ΔV given in the question are inconsistent with the ideal gas equation:

$p\Delta V = \left(1.0 \times 10^{5}\right) \times \left(6.3 \times 10^{-4}\right) = 63$ J
$Nk\Delta T = 2.50 \times 1.38 \times 15 = 51.75$ J

Hence, there are two other possible answers for Q, depending on whether you write $Nk\Delta T$ in terms of $p\Delta V$ or vice versa:

Using $\Delta U = \frac{3}{2}P\Delta V$, $Q = \frac{5}{2}p\Delta V = 158$ J
On the other hand, expressing ΔU and W in terms of $Nk\Delta T$, $Q = 129$ J

3 **(a) (i)** This is to ensure that the two progressive waves that superpose to form the resultant standing wave are <u>coherent</u> with the <u>same frequency and wavelength</u>. [1]

(ii) A <u>microphone</u> positioned along the line joining loudspeakers X and Y is connected to <u>an oscilloscope</u>. [1]

The microphone is moved slowly along the line joining loudspeakers X and Y. and the <u>positions of two consecutive signal maxima</u> are located. The distance between the consecutive maxima Δd is <u>measured with a metre ruler</u>. [1]

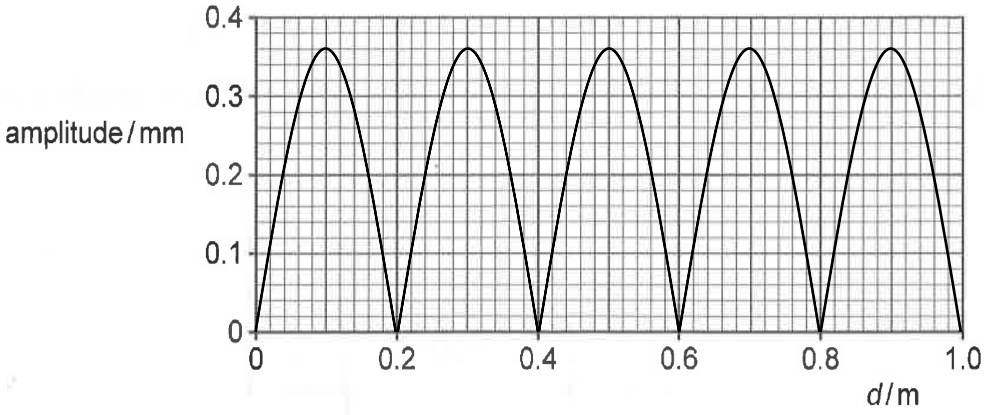
Since the distance between two consecutive maxima corresponds to half the wavelength, the <u>wavelength of sound is: $\lambda = 2\Delta d$</u> [1]

(b) **(i)** $v = f\lambda$

$f = \dfrac{340}{0.40}$ [1]

$= 850$ Hz [1]

(ii)



correct shape [1]
correct maximum amplitude [1]
correct distance between consecutive nodes/antinodes [1]
Accept $|\cos\theta|$

4 **(a)** From the graph, $V_0 = 4.8$ V , $T = 40.0$ ms

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{40.0\times10^{-3}} = 157 \text{ rad s}^{-1}$$ [1]

$$V = V_0 \sin(\omega t) = 4.8\sin(157t)$$ [1]

(b) **(i)**

$$R_{total} = R_{12\Omega} + \left(\frac{1}{R_{6\Omega}} + \frac{1}{R_{6\Omega}}\right)^{-1}$$

$$= 12 + \left(\frac{1}{6} + \frac{1}{6}\right)^{-1}$$ [1]

$$= 15\ \Omega$$

(ii)

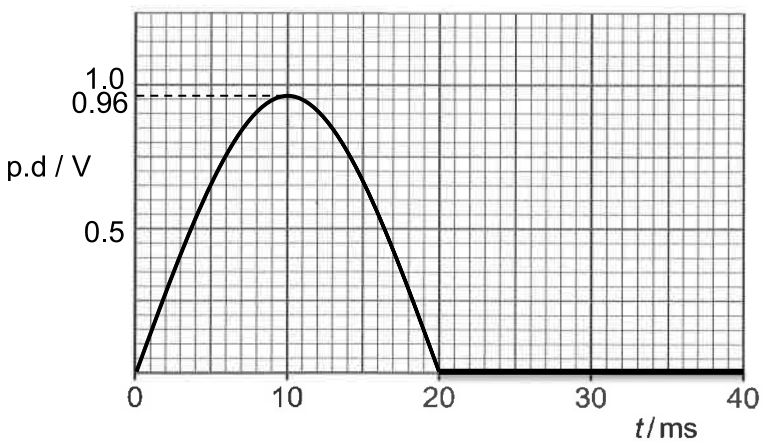
$$\langle P \rangle = \frac{1}{2}P_0$$

$$= \frac{1}{2}\frac{V_0^{\,2}}{R}$$

$$= \frac{1}{2}\frac{4.8^2}{15}$$

$$= 0.77 \text{ W}$$

(iii)



Positive half-cycle of the $V-t$ graph with correct peak voltage [1]
Voltage remains at 0 V for 20 ms (i.e. during the negative half-cycle) [1]

5 **(a)** For a long straight wire carrying a current I,

$$B=\frac{\mu_0 I}{2\pi d}$$

$$2.8\times10^{-4}=\frac{4\pi\times10^{-7}\times I}{2\pi\times8.5\times10^{-3}}$$

$$I=\frac{2.8\times10^{-4}\times2\pi\times8.5\times10^{-3}}{4\pi\times10^{-7}}$$

$$=11.9$$

$$=12\text{ A}$$ [1]

(b) **(i)** $F=BIL$

$$\frac{F}{L}=2.8\times10^{-4}\times9.2$$ [1]

$$=2.576\times10^{-3}$$

$$=2.6\times10^{-3}\text{ N m}^{-1}$$ [1]

(ii) Weight per unit length of rod $=63\times10^{-3}\times9.81$

$$=0.61803\text{ N m}^{-1}$$

When the rod is in equilibrium, the force exerted by the supports on the rod must be equal in magnitude to its weight.

Percentage change per support $=\dfrac{2.576\times10^{-3}}{0.61803}\times100\%$ [1]

$$=0.4168$$

$$=0.42\%$$ [1]

(iii) Decrease.
By Fleming's Left-hand rule, the current-carrying rod experiences an upward magnetic force when in the magnetic field of the wire, thus reducing the upward forces exerted by the supports on the rod. [1]
OR
The magnetic force between two long straight conductors carrying currents in opposite directions is repulsive. Thus an upward magnetic force acts on the rod, reducing the upward forces exerted by the supports on the rod.

(iv) **1.** To the right. [1]

The magnetic flux density is directed out of the plane of the page at the rod's position (by right-hand grip rule). Applying Fleming's left-hand rule with the current in the upwards direction gives a force to the right on the rod. [1]

2. The magnetic force per unit length acting on the rod decreases with increasing distance from the wire (inversely proportional). [1]

6 **(a)** These observations show that all the positive charge of the atom are concentrated in a tiny space known as the nucleus. So that the nucleus exerts a large repulsive force on the positively charged $\alpha-$particles that come close to it. [1]

The nucleus must contain most of the mass of the atom so that the $\alpha-$particles are deflected through large angles instead of the nucleus. [1]

Hence, the atom consists mostly of empty space and a small, massive, positively charged nucleus. [1]

(b) By the Principle of conservation of energy,
Loss in kinetic energy = gain in electric potential energy [1]

$$1.23\times10^{-12}=\frac{q_1q_2}{4\pi\varepsilon_0 r}$$

$$1.23\times10^{-12}=\frac{79\times1.6\times10^{-19}\times2\times1.6\times10^{-19}}{4\pi\times8.85\times10^{-12}\times r} \quad [1]$$

$$r=2.9569\times10^{-14}$$
$$=2.96\times10^{-14}\text{ m} \quad [1]$$

7 **(a)** Each photon of the ultraviolet radiation will interact with one electron in the metal plate and passes all its energy to the electron. The electron uses the energy to leave the metal plate. [1]

Electrons at the surface of the metal plate will require the least amount of energy to leave the metal plate and are emitted with maximum kinetic energy. [1]

Electrons that are further from the surface of the metal plate, will require varying amounts of energy to reach the surface due to the varying number of collisions with other particles in the metal plate as they move to the surface. Due to the varying amounts of energy lost from the collisions, these electrons are emitted with varying amounts of kinetic energy that are smaller than the maximum kinetic energy. [1]

(b) Einstein's photoelectric equation,
$E_{photon} = \Phi + E_{k,\max}$

Since work function Φ is the minimum amount of energy needed for an electron to leave the surface of the metal plate,

$$\Phi = \frac{hc}{\lambda_{\max}} = E_{photon} - E_{k,\max}$$ [1]

$$\lambda_{\max} = \frac{hc}{E_{photon} - E_{k,\max}}$$

$$= \frac{\left(6.63\times10^{-34}\right)\left(3.00\times10^{8}\right)}{\left(7.95-3.48\right)\left(1.60\times10^{-19}\right)}$$ [1]

$$= 2.781\times10^{-7} = 2.78\times10^{-7}\text{ m}$$ [1]

(c) Intensity $I = \frac{dN_p}{dt}\frac{hf}{A}$ where $\frac{dN_p}{dt}$ is the rate of incidence of radiation photons on the metal plate, f is the frequency of the radiation and A is the surface area of the metal plate.
Since f and A are constants, a greater intensity means the rate of incidence of photons is greater. [1]

Since one photon interacts with one electron, the rate of emission of electrons from the metal plate is also greater, which leads to a shorter time taken for the metal plate to fully discharge. [1]

(d) The work function of the metal plate is constant. Hence the threshold or maximum wavelength of the photon required to emit an electron is constant. The wavelength of the infrared radiation is greater than the threshold wavelength. [1]

Hence the energy of each photon of the infrared radiation is smaller than the work function of the metal plate. Since one photon interacts with one electron, the electron will not have sufficient energy from the photon to leave the metal plate. [1]

8 **(a)** The half-life of plutonium (87.7 yr) is longer than the expected lifespan of Perseverance (14 yr) so the activity of plutonium and therefore electrical power output remains relatively constant. (This ensures that the electrical power output does not fall below the minimum power requirement during the normal operating lifespan of Perseverance.) [1]

(b) α-particle has low penetrating power so all its kinetic energy can be converted to heat within the RTG. [1]

(c) α-particles emitted by plutonium within the body will cause irreparable damage to cells within a human body due to its high ionizing power. [1] [1]

(d) **(i)** $^{238}_{94}\text{Pu} \rightarrow {}^{234}_{92}\text{U} + {}^{4}_{2}\alpha$ [1]

(ii) Energy released

$$E = \text{binding energy of product} - \text{binding energy of parent}$$
$$= 234 \times 7.601 + 4 \times 7.074 - 238 \times 7.568 \quad [1]$$
$$= 5.746 \text{ MeV}$$
$$= 9.19 \times 10^{-13} \text{ J} \quad [1]$$

(iii) Number of plutonium nuclei

$$N = \frac{\text{Mass}}{M} \times N_A = \frac{4.9}{0.276} \times 6.02 \times 10^{23} = 1.069 \times 10^{25} = 1.1 \times 10^{25} \quad [1]$$

Note: The molar mass of plutonium dioxide given in the question is for plutonium-244 dioxide. For plutonium-238 dioxide, the molar mass should be 270 g.

(iv) Initial power output

$$P_0 = \lambda N \times E = \frac{\ln 2}{87.7 \times 365 \times 24 \times 60 \times 60} \times 1.069 \times 10^{25} \times 9.19 \times 10^{-13} \quad [1]$$
$$= 2460 \text{ W} \quad [1]$$

(v) The mass number decreases by 32 from 238 to 206 when ${}^{238}_{94}\text{Pu}$ decays eventually to ${}^{206}_{82}\text{Pb}$. This implies there are 8 α-particles emitted with an expected decrease of 16 in atomic number. [1]
The atomic number decreases only by 12 implying that 4 β-particles (${}^{0}_{-1}\text{e}$) are emitted. [1]

(e) **(i)** A quantity *x* undergoing exponential decrease implies that the rate of change of the quantity is directly proportional to the quantity itself, i.e., $dx/dt = -kx$ where *k* is a positive constant. [1]

(ii) Electrical power output at end of lifespan of Perseverance

$$P = P_{0,\text{RTG}} \times \exp(-\lambda t) = 110 \times \exp\left(-\tfrac{\ln 2}{87.7} \times 14\right) = 98.5 \text{ W} \quad [1]\ [1]$$

Two other alternative methods:

$$P = P_{0,\text{RTG}} \times \left(\tfrac{1}{2}\right)^{14/87.7} = 110 \times \left(\tfrac{1}{2}\right)^{14/87.7} = 98.5 \text{ W}$$

$$P = P_{0,\text{RTG}} \times (0.9921)^{14} == 98.4 \text{ W}$$

(f) e.m.f. of thermocouple

$$\text{e.m.f.} = \Delta S \Delta T = \left[240 - (-200)\right] \times 10^{-6} \times (1273 - 573) = 0.308 \text{ V} \quad [1]$$

(g) Gravitational field strength on surface of Earth

$$g_E = \frac{GM_E}{r_E^2}$$ [1]

Gravitational field strength on surface of Mars

$$g_M = \frac{GM_M}{r_M^2} = \frac{M_M}{M_E} \cdot \frac{r_E^2}{r_M^2} \cdot g_E = \frac{1.88^2}{9.30} \times 9.81 = 3.73 \text{ N kg}^{-1}$$ [1] [1]

(h) **(i)** Store the energy produced by the RTG in a rechargeable battery so that it can be later used to supply energy electrically at a rate of 300W. [1]

(ii) Time required to produce 5.37 g of oxygen

$$t = 12400 \times \frac{300}{110} = 33818 \text{ s} = 9.4 \text{ h}$$ [1] [1]

Correct calculation in s – [1]
Correct conversion to h – [1]

(iii) Using $pV = nRT$,

$$V = \frac{nRT}{p} = \frac{5.37/32 \times 8.31 \times (273.15 - 60)}{610} = 0.487 \text{ m}^3$$ [1]

Correct number of moles of oxygen – [1]

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Paper 3

1 **(a)** **(i)** Increase in kinetic energy $= KE_f - KE_i$

$$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$= \frac{1}{2}(0.060)\left(30^2 - 19^2\right)$$ [1]

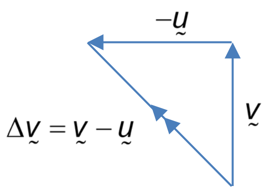
$$= 16.17$$

$$= 16.2 \text{ J}$$ [1]

(ii) $|\Delta v| = \sqrt{v^2 + u^2}$

$= \sqrt{30^2 + 19^2}$

$= 35.51 \text{ m s}^{-1}$



[1]

By Newton's 2nd Law, $\langle F \rangle = \frac{\Delta p}{\Delta t}$

$$= \frac{(0.060)35.51}{16 \times 10^{-3}}$$ [1]

$$= 133.17$$

$$= 133 \text{ N}$$ [1]

* $\frac{\Delta p}{\Delta t}$ gives the net force which is the vector sum of the force of the racket and the weight of the ball. However since the weight is 0.59 N which is much less than 133 N so it can be neglected.

(b) Besides changing the kinetic energy of the ball, the work done by the racket also changes the potential energy of the ball and that of the racket:

1. Work done by the racket is converted to elastic potential energy of the ball when it deforms during contact. Some of this potential energy is converted to thermal energy when it returns to its original shape. [1]

2. Work done by the racket is converted to sound energy when the racket hits the ball. [1]

3. Work done by the racket is converted to gravitational potential energy of the ball during contact.

Accept any reasonable answers.

2 **(a)** By Newton's 2nd Law, the centripetal force on the satellite that allows it to move in a uniform circular motion is provided by the gravitational force of attraction between the satellite and the planet. [1]

[2]

$$F_C = F_G$$

$$\frac{mv^2}{(R+h)} = \frac{GMm}{(R+h)^2}$$ [correct expressions for F_C and F_G]

$$\frac{1}{2}mv^2 = \frac{GMm}{2(R+h)}$$ (shown)

(b) $E_K = \dfrac{GMm}{2(R+h)}$

$E_P = -\dfrac{GMm}{(R+h)}$ [1]

$E_T = E_K + E_P$

$= \dfrac{GMm}{2(R+h)} - \dfrac{GMm}{(R+h)}$ [1]

$= -\dfrac{GMm}{2(R+h)}$ [1]

(c) From (a), $\dfrac{1}{2}mv^2 = \dfrac{GMm}{2(R+h)}$

Hence, $v = \sqrt{\dfrac{GM}{(R+h)}}$ [1]

$= \sqrt{\dfrac{(6.67\times10^{-11})(7.35\times10^{22})}{(1.74\times10^{6}+110\times10^{3})}}$ [1]

$= 1628$

$= 1630 \text{ m s}^{-1}$ [1]

(d) **(i)** From (a) $E_K = \dfrac{GMm}{2(R+h)}$, satellite P's kinetic energy is higher than that of S since P is at a lower height h. [1] [1]

(ii) From (b) $E_T = -\dfrac{GMm}{2(R+h)}$, satellite P's total energy is lower than that of S since P is at a lower height h. [1] [1]

3 $x_0 = 0.160$ m

$\omega = 15.7$ rad s^{-1}

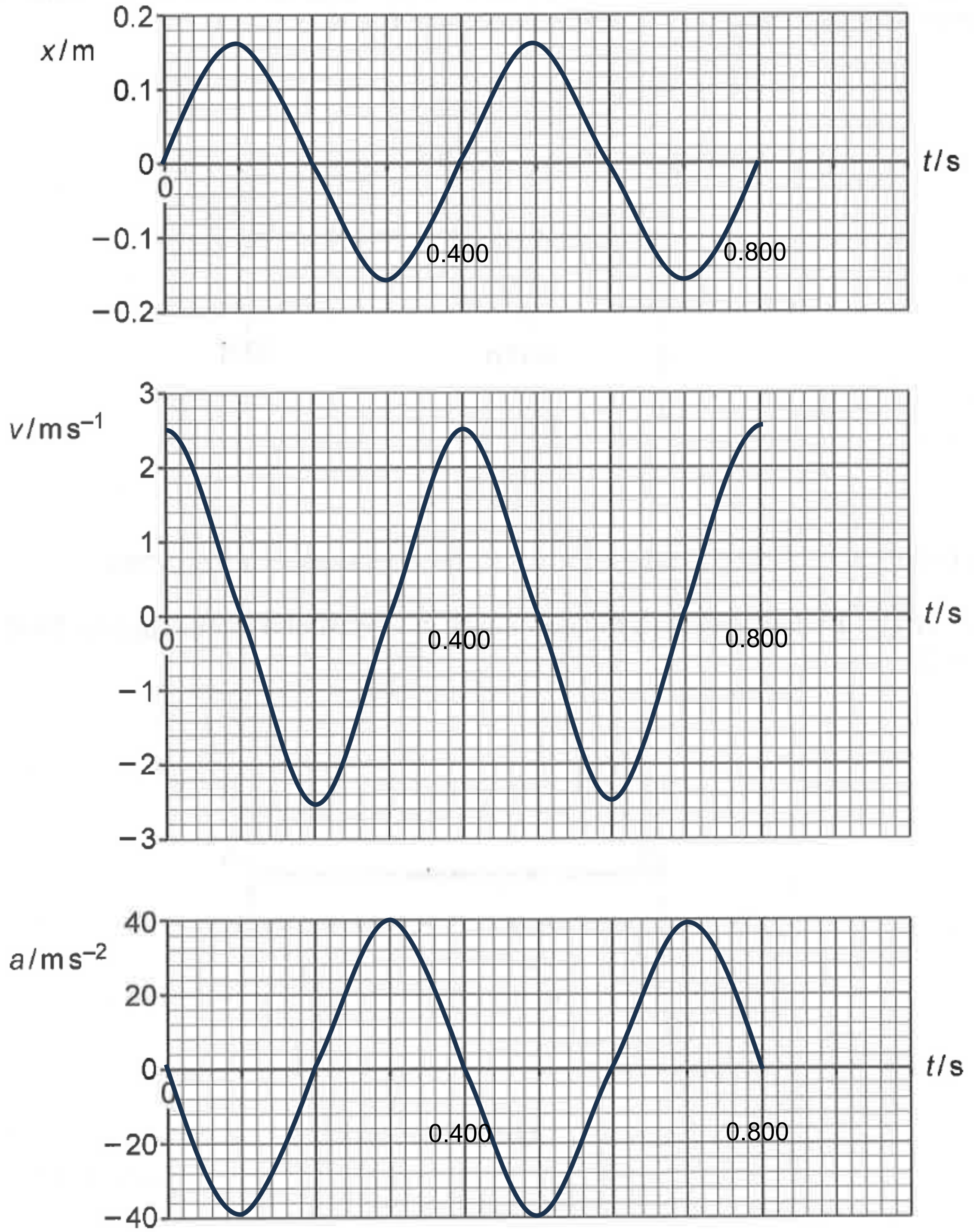
$T = \dfrac{2\pi}{15.7} = 0.400$ s

$v = \omega x_0 \cos(\omega t)$

$v_0 = \omega x_0 = 15.7 \times 0.160 = 2.51$ m s^{-1}

$a = -\omega^2 x_0 \sin(\omega t)$

$a_0 = \omega^2 x_0 = 15.7^2 \times 0.160 = 39.4$ m s^{-2}



[2]

[2]

[2]

4 **(a)** The centre of gravity of an object is the point where the weight of the object appears to act. [2]

(b) W.r.t. Fig. 4.1 and taking moments about A,

$Wx = 12 \times 3.0$

$Wx = 36$ –(1) [1]

W.r.t. Fig. 4.2 and taking moments about B,

$W(3.0 - x) = 16 \times 3.0$

$3.0W - Wx = 48$ –(2) [1]

$(1)+(2): 3.0W = 84$

$W = 28 \text{ N}$ [1]

From (1), $x = 36 / 28 = 1.29 \text{ m}$ [1]

(c) W.r.t. Fig. 4.3 and taking moments about B, the <u>perpendicular distances from B to the lines of action of weight and force *F* are reduced by the same factor of cos30°</u> (i.e. (3.0–*x*)cos30° and (3.0)cos30°, respectively). [1]

Hence, by the principle of moments, the equation is the same as equation (2) and the magnitude of force *F* is the <u>same</u> as Fig. 4.2. [1]

Proof:

$$W(3.0 - x)\cos 30° = F \times 3.0 \cos 30°$$
$$48 = 3.0F$$
$$F = 16 \text{ N}$$

5 **(a)** Pressure is defined as the force per unit area. $p = \dfrac{F}{A}$

Density is defined as the mass per unit volume. $\rho = \dfrac{m}{V} \to m = \rho V$ [1]

$$p = \frac{F}{A}$$
$$= \frac{\text{weight of fluid}}{A}$$
$$= \frac{mg}{A}$$ [1]
$$= \frac{(\rho V)g}{A}$$
$$= \frac{(\rho A h)g}{A}$$ [1]
$$= \rho g h \quad \text{(shown)}$$

(b) **(i)** $V = Ah$

$$h = \frac{V}{A} = \frac{370}{\pi(3.0)^2} = 13.1 \text{ cm} = 0.131 \text{ m}$$ [1]

(ii) $p = \rho hg$

$= (800)(0.131)(9.81) = 1130$ Pa [1]

(iii) The newton meter reads the tension in the string.

Considering forces on the object,

$T + U = W$ [1]

$T = W - U$

$= 3.32 - (880)(130 \times 10^{-6})(9.81)$ [1]

$= 2.20$ N [1]

6 (a) Similarity: Both describe <u>energy conversion per unit charge</u>. [1]

Difference: Electromotive force is the electrical energy per unit charge <u>converted from other forms of energy</u> while potential difference is that <u>converted to other forms of energy</u>. [1] [1]

(b) (i) The cell has an internal resistance. Hence there is a <u>potential drop across the internal resistance</u>. The <u>voltmeter measures</u> the terminal potential difference which is the <u>potential drop subtracted from the e.m.f. of the cell</u>. (i.e. $\underline{V = E - Ir}$) [1] [1]

(ii) $R_{effective} = 3.0 + \left[(6.0 + 4.0)^{-1} + (10)^{-1}\right]^{-1} = 8.0\ \Omega$ [1]

$V = IR_{effective} = 0.15 \times 8.0 = 1.2$ V [1]

(iii) $R_{effective}$ in the circuit increases. Since $I = \dfrac{E}{R_{effective} + r}$, current decreases. [1]

Since $V = E - Ir$, when current I decreases, the reading on the voltmeter V increases. [1]

(iv) From the previous arrangement,

$V = E - Ir$

$1.2 = 1.5 - (0.15)r$ [1]

$r = 2.0\ \Omega$

For the new arrangement,

$R_{effective} = 3.0 + \left[(6.0 + 9.0)^{-1} + (10)^{-1}\right]^{-1} = 9.0\ \Omega$ [1]

$R_{effective} + r = 9.0 + 2.0 = 11.0\ \Omega$ [1]

Using potential divider principle, [1]

$$V_{across\ 10\Omega} = \frac{\left[(6.0 + 9.0)^{-1} + (10)^{-1}\right]^{-1}}{11.0} \times 1.5$$

$= 0.818$ V

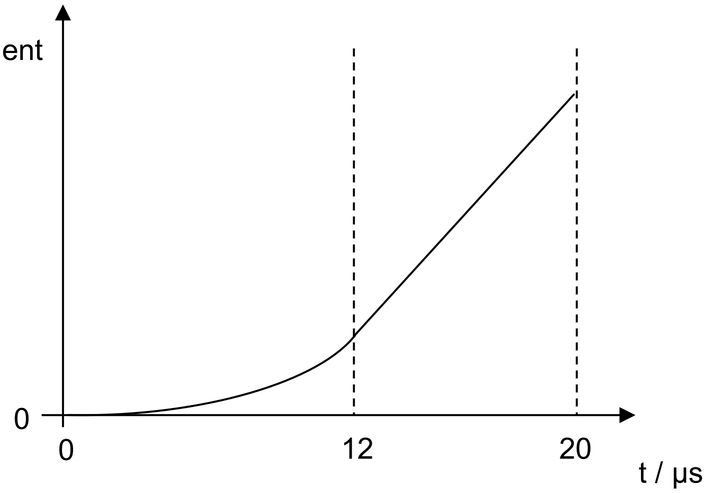
7 **(a)** Faraday's law of electromagnetic induction states that the induced emf is proportional to the rate of change of magnetic flux linkage. [1] [1]

(b) The unmagnetized block falls through tube B with acceleration of free fall.

When the magnetized block falls through tube A, there is a change of flux linkage in the regions of the tube above and below the block. Hence, Emf and current are induced as the block falls through. [1]

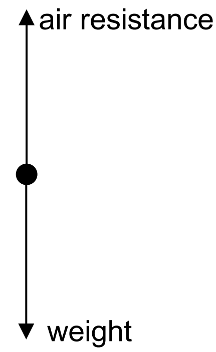
According to Lenz's Law, the direction of the induced current is such that it opposes the change causing it. The magnetic field produced by the induced current will oppose the motion of the steel block. Hence, there is an upward force exerted on the block, causing its acceleration to be less than the acceleration of free fall. Thus, the magnetized block takes a longer time to reach the bottom of tube A. [1] [1]

8 **(a)** **(i)**



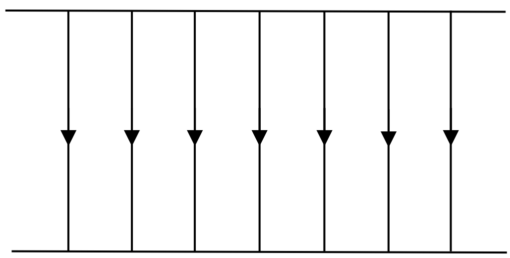
[1] – gradient of graph is initially zero at 0 μs.
[1] – gradient of graph increases with time to a maximum magnitude of v_0 at 12 μs.
[1] – graph is an upward-sloping straight line with gradient constant at the maximum magnitude of v_0

(ii)



[1] – both forces labeled correctly
[1] – both forces are of the same length

(b) (i)



[1] – equally spaced field lines
[1] – field lines pointing downwards

(ii) When the oil drop is falling in air at constant velocity v_0,

$$F_{\text{air resistance}} = W_{\text{oil}} = 8.2\times10^{-16}\times9.81 = 8.0442\times10^{-15}\text{ N}$$ [1]

When the oil drop is moving at constant velocity v_0 in the electric field

$$F_E = W_{\text{oil}} + F_{\text{air resistance}}$$

$$q\frac{\Delta V}{d} = 8.0442\times10^{-15} + 8.0442\times10^{-15}$$ [1]

$$q\frac{5030}{0.20} = 8.0442\times10^{-15} + 8.0442\times10^{-15}$$ [1]

$$q = 6.3970\times10^{-19}$$

$$= 6.4\times10^{-19}\text{ C}$$ [1]

Note: at same velocity v_0, magnitude of air resistance is the same.

(iii)

$$\text{No. of electrons} = \frac{6.3970\times10^{-19}}{1.6\times10^{-19}} = 3.998 = 4$$ [1]

The electrons are transferred <u>to the oil drop</u>. [1]

(c) (i) The acceleration of the oil drop is due to the force exerted on it by the metal sphere.

$$F_E = \frac{q_1q_2}{4\pi\varepsilon_0r^2}$$

$$ma = \frac{q_1q_2}{4\pi\varepsilon_0r^2}$$ [1]

$$a = \frac{2.0\times10^{-6}\times1.1\times10^{-18}}{4\pi\times8.85\times10^{-12}\times0.15^2\times8.2\times10^{-16}}$$ [1]

$$= 1.0722\times10^3$$

$$= 1.1\times10^3\text{ m s}^{-2}$$ [1]

(ii) Initially, the oil drop will accelerate to the right nearly horizontally because the electric force is much larger than the weight. [1] [1]

As its distance from the sphere increases, the electric force becomes weaker as the electric force is inversely proportional to r^2. The direction of motion deviates more from the horizontal due to its weight. [1] [1]

When the oil drop is very far from the sphere, the electric force is negligible. The oil drop will accelerate vertically at 9.81 m s^{-2} [1]

Since both the sphere and oil drop are positively charged, the oil drop is repelled by the sphere and moves in a straight line away from the sphere.
As the electric force is inversely proportional to r^2, the oil drop experiences a decreasing repulsive force as it moves away from the sphere hence, acceleration of the oil drop decreases.
Thus, the oil drop's velocity increases at a decreasing rate as it moves further from the sphere.

9 **(a)** **(i)** The principle of superposition states that when two or more waves of the same kind meet at a point in space, the resultant displacement at that point is equal to the vector sum of the displacements of the individual waves at that point. [1] [1]

(ii) Coherent light waves are light waves that have the same frequency such that have a constant phase difference with one another. [1]

(b) **(i)** Since R is the second minimum,

path difference $= 3\left(\dfrac{1}{2}\lambda\right) = 1.5\lambda$ [1]

(ii) Light waves at slits A and B are in phase.
When the light waves from the slits arrive at R with a path difference of 1.5λ, they meet with a phase difference of π rad. [1]

There is destructive interference at R and the resultant intensity is minimum. [1]

(iii) fringe separation, $x = \dfrac{\lambda D}{a}$

$$\lambda = \frac{xa}{D}$$
$$= \frac{(2.9\times10^{-3})(0.60\times10^{-3})}{2.70}$$ [1]
$$= 6.4444\times10^{-7} = 6.44\times10^{-7}\text{ m}$$ [1]

(iv) The double-slit interference pattern is modulated by the two single-slit diffraction patterns. [1]

The single slit diffraction envelope has maximum intensity at P, with intensity decreasing from P on either side of P to the first minima at angle from the central axis given by $\theta = \sin^{-1}\dfrac{\lambda}{b}$, where b is the slit width of each slit. [1]
Hence intensity of the maxima of the interference pattern will also be maximum at P and with the intensity of the maxima decreasing with successive orders from P. [1]

(c) intensity $\propto$ amplitude^2 $\Rightarrow I = ka^2$

wave from slit A: $I = ka_A{}^2 \quad \Rightarrow \quad a_A = \sqrt{\dfrac{I}{k}}$ [1]

wave from slit B: $\dfrac{I}{2} = ka_B{}^2 \quad \Rightarrow \quad a_B = \sqrt{\dfrac{1}{2}\dfrac{I}{k}} = a_A\sqrt{\dfrac{1}{2}}$ [1]

Since at P there is constructive interference,

total amplitude at P $= a_A + a_B = a_A + a_A\sqrt{\dfrac{1}{2}} = a_A\left(1+\sqrt{\dfrac{1}{2}}\right) = \sqrt{\dfrac{I}{k}}\left(1+\sqrt{\dfrac{1}{2}}\right)$

intensity at P

$$= k\left[\sqrt{\frac{I}{k}}\left(1+\sqrt{\frac{1}{2}}\right)\right]^2$$ [1]

$$= k\left(\frac{I}{k}\right)\left(1+\sqrt{\frac{1}{2}}\right)^2$$

$$= 2.9142I = 2.91I$$ [1]

(d) **(i)** $d\sin\theta = n\lambda$

$$\lambda = \left(1.67\times10^{-6}\right)\left(\frac{1.12}{\sqrt{1.12^2+2.70^2}}\right)$$ [1] [1]

$$= 6.3987\times10^{-7} = 6.40\times10^{-7}\ \text{m}$$ [1]

Final answer for wavelength is given to 3 significant figures as all the values used in the calculation for it is in 3 significant figures.

(ii) The fractional uncertainty and hence the uncertainty of the wavelength in (d)(i) is smaller as the distance PS in (d)(i) is about 386 times larger than the fringe separation in (b)(iii). [1] [1]

Fractional uncertainty in the value of the wavelength in (b)(iii) is approximately

$$\frac{\Delta x}{x}+\frac{\Delta a}{a}+\frac{\Delta D}{D} = \frac{0.1}{2.9}+\frac{0.01}{0.60}+\frac{0.01}{2.70} = 0.054853 = 0.055.$$

Fractional uncertainty in the value of the wavelength in (d)(i) is approximately

$$\frac{\Delta PS}{PS}+\frac{\Delta d}{d}+\frac{\Delta D}{D} = \frac{0.01}{1.12}+\frac{0.01}{1.67}+\frac{0.01}{2.70} = 0.018620 = 0.019.$$