RAFFLES INSTITUTION
YEAR 5-6 PHYSICS DEPARTMENT

2020 A-Level H2 Physics Suggested Solutions

Paper 1

1 **B**

$$V = \frac{4}{3}\pi r^3$$

$$\left(\frac{\Delta V}{V} \times 100\%\right) = 3\left(\frac{\Delta r}{r} \times 100\%\right)$$

A graph of $\left(\frac{\Delta V}{V} \times 100\%\right)$ against $\left(\frac{\Delta r}{r} \times 100\%\right)$ will give a straight line graph through the origin.

2 **D**

The action-reaction forces in Newton's third law must be the same type and act on 2 different bodies.
Option D: The weight of a car and the normal contact force on it are 2 forces acting on one single body i.e. the car. In addition, weight is a gravitational force which is not of the same type of force as the normal contact force.

3 **D**

$$\text{stress} = \frac{\text{force}}{\text{area}} \text{ and strain} = \frac{\text{extension}}{\text{original length}}$$

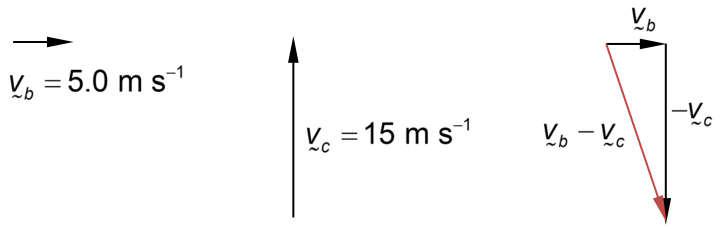
$$\begin{aligned}\text{units of area under graph} &= \text{units of } \frac{\text{force}}{\text{area}} \times \text{units of } \frac{\text{extension}}{\text{original length}} \\ &= \frac{\text{N}}{\text{m}^2} \times \frac{\text{m}}{\text{m}} \\ &= \frac{\text{J m}^{-1}}{\text{m}^2} \quad \text{(since work done} = \text{force} \times \text{displacement)} \\ &= \text{J m}^{-3}\end{aligned}$$

4 **A**

At $t = 0$, car X and car Y are at the same position.
When car Y overtakes car X at $t = T$, the displacement of both cars from their position at $t = 0$ is the same.
Since the area under the velocity-time graph gives the displacement,
area under graph of car Y = area under graph of car X

$$\text{P} + \text{Q} + \text{R} = \text{Q} + \text{R} + \text{S}$$
$$\text{P} = \text{S}$$

5 **C**

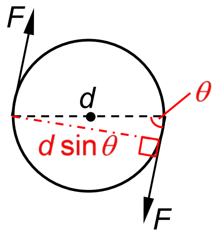


Note that $\left|\underset{\sim}{v}_c\right| = 3\left|\underset{\sim}{v}_b\right|$ and the velocity of the bicycle relative to the car is given by $\underset{\sim}{v}_b - \underset{\sim}{v}_c$.

6 **C**

Torque is a vector quantity. The statement in option C is unclear as the directions of the torques are not stated.
A correct statement should read 'The **anticlockwise** torque provided by the vertical forces is equal to the **clockwise** torque provided by the horizontal forces.'

7 **B**



torque of couple $= F \times$ perpendicular distance between the parallel forces

$= F \times d \sin\theta$

8 **A** When balloon is inflated with hot air,

total weight, W = weight of hot air + weight of basket and non inflated balloon

$= \rho_{120} Vg + mg$

upthrust on inflated balloon, U_{air} = weight of the atmospheric air displaced

$= \rho_{20} Vg$

Consider the free body diagram of the inflated balloon with basket.

$$U_{air} = W + 2T$$

$$T = \frac{U_{air} - W}{2}$$

$$= \frac{\rho_{20} Vg - (\rho_{120} Vg + mg)}{2}$$

$$= \frac{g}{2}\left[(1.204)(2800) - (0.898)(2800) - 700\right]$$

$$= 769.104$$

$$= 0.77 \text{ kN (2 s.f.)}$$

(The answer should be 0.769 kN if rounded off to 3 s.f. However, the answer given in the option is 0.770 kN. This will be the best option to choose.)

9 **D**

rate at which useful work is done by driving force $= Fv = (1.6 \times 10^3)(22)$ W

rate at which total thermal energy is produced $= \dfrac{3.3 \times 10^6}{60}$ W

$$\% \text{ efficiency} = \frac{(1.6 \times 10^3)(22)}{(3.3 \times 10^6)/60} = 64\ \%$$

10 **B**

$$a_c = r\omega^2$$

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

$$= (3.85 \times 10^8)\left(\frac{2\pi}{27.3 \times 24 \times 60 \times 60}\right)^2$$

$$= 2.73 \times 10^{-3} \text{ m s}^{-2}$$

11 **B** The minute hand takes 1 hour to make one round the clock.

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{60 \times 60} = 1.75 \times 10^{-3} \text{ rad s}^{-1}$$

12 A

$$U_{final} - U_{initial} = \left(-\frac{Gm_1m_2}{2r}\right) - \left(-\frac{Gm_1m_2}{r}\right)$$
$$= -\frac{Gm_1m_2}{2r} + \frac{2Gm_1m_2}{2r}$$
$$= \frac{Gm_1m_2}{2r}$$

Since $\frac{Gm_1m_2}{2r} > 0$, $U_{final} > U_{initial}$. Hence the increase in potential energy is $\frac{Gm_1m_2}{2r}$.

13 A

$$g = \frac{GM}{r^2} = \frac{\left(6.67\times10^{-11}\right)\left(2.0\times10^{31}\right)}{\left(150\times10^6\times10^3\right)^2} = 5.9\times10^{-2}\ \text{N kg}^{-1}$$

14 B

$pV = nRT$

$\frac{pV}{T} = \text{constant}$

From L to M, pressure is constant. Hence $\frac{V}{T} = \text{constant}$. Graph of *T* against *V* is a straight-line graph through the origin.

$$\frac{p_MV_M}{T_M} = \frac{p_NV_N}{T_N}$$
$$\frac{\left(2.0\times10^6\right)(0.003)}{T_M} = \frac{\left(0.8\times10^6\right)(0.005)}{T_N}$$
$$\frac{6000}{T_M} = \frac{4000}{T_N}$$

$T_M = 1.5\ T_N$. Graph of *T* against *V* should show that *T* decreases as *V* increases.

15 B

First law of thermodynamics: $\Delta U = Q + W$

Experiment 1:

$\Delta U_1 = +\Delta Q + 0$

$\Delta U_1 = +\Delta Q$

Hence, option B is correct and option A is incorrect.

Experiment 2:

$\Delta U_2 = +\Delta Q + \left(-W_2\right)$

$\Delta U_2 = +\Delta Q - W_2$

Option D is incorrect since $\Delta U_2 < \Delta U_1$

$W_2 = +\Delta Q - \Delta U_2$

Option C is incorrect.

16 **A**

$\omega = \dfrac{2\pi}{T}$ and $T = 2\pi\sqrt{\dfrac{L}{g}}$

Since L and g remain constant, T and ω remain constant.

E = max. PE = max. KE

$E = \dfrac{1}{2}m{v_{\max}}^2 = \dfrac{1}{2}m\omega^2x^2$

When max. P.E. is reduced by $E/4$:

$E - \dfrac{E}{4} = \dfrac{1}{2}m\omega^2{x_1}^2$ where x_1 is the new amplitude

$\dfrac{3}{4}\left(\dfrac{1}{2}m\omega^2x^2\right) = \dfrac{1}{2}m\omega^2{x_1}^2$

$x_1 = \sqrt{\dfrac{3}{4}}x$

change in amplitude $= x - \sqrt{\dfrac{3}{4}}x = 0.134x$

17 **C**

The two waves are $\dfrac{1}{4}T$ apart.

$\phi = \dfrac{T/4}{T} \times 2\pi = \dfrac{\pi}{2}$ rad

18 **C**

distance between 2 consecutive compression points $= \lambda$

$v = f\lambda$

$f = \dfrac{v}{\lambda} = \dfrac{12}{12-4} = 1.5$ Hz

19 **D**

Since D is much greater than the slit width, the angle of diffraction is small.
For single slit first minima: $b\sin\theta = \lambda$

Since θ is small,
$\sin\theta \approx \theta$

$\theta \approx \dfrac{\lambda}{b} = \dfrac{c/f}{b} = \dfrac{c}{fb}$

For small angles,

$x \approx D(2\theta) = 2D\left(\dfrac{c}{fb}\right)$

$b = \dfrac{2Dc}{fx}$

20 **C**

$V = \dfrac{Q}{4\pi\varepsilon_0 d}$

$V_1 = \dfrac{Q}{4\pi\varepsilon_0(d/2)} = 2\left(\dfrac{Q}{4\pi\varepsilon_0 d}\right) = 2V$

21 **A**

$$E = \frac{Q}{4\pi\varepsilon_0 r^2} = \left(\frac{Q}{4\pi\varepsilon_0}\right)\frac{1}{r^2}$$

Plotting a graph of E against $\frac{1}{r^2}$, gradient = $\frac{Q}{4\pi\varepsilon_0}$ and y-intercept = 0.

$Q = 4\pi\varepsilon_0 \times \text{gradient}$

22 **B**

$$R = \rho\frac{L}{A} = \rho\frac{L}{\pi(d/2)^2} = \frac{4\rho L}{\pi d^2}$$

Since ρ and L are constants, $R = k\left(\frac{1}{d^2}\right)$ where $k = \frac{4\rho L}{\pi}$ is a constant.

Since X and Y are in parallel, the p.d. V across each element is the same.

$$P = \frac{V^2}{R} = V^2\left(\frac{d^2}{k}\right) = \frac{V^2}{k}d^2 \quad \Rightarrow \quad P \propto d^2 \quad \Rightarrow \quad d \propto \sqrt{P}$$

$$\frac{d_x}{d_y} = \sqrt{\frac{P_x}{P_y}} = \sqrt{\frac{1.0}{1.5}} = 0.816 = 0.82$$

23 **A**

circuit 1: $I_1 = \dfrac{E}{2R + r}$

circuit 2: $I_2 = \dfrac{E}{R/2 + r}$

$$I_2 = 3I_1$$

$$\frac{E}{R/2 + r} = 3\left(\frac{E}{2R + r}\right)$$

$$2R + r = 3(R/2 + r)$$

$$2R + r = \frac{3}{2}R + 3r$$

$$r = \frac{R}{4}$$

24 **B**

Option B:
By the potential divider principle, the p.d. across each R is 3.0 V.
When X is at Y, the p.d. across X and Y is zero.
When X is at the other side of R, p.d. across X and Y is 3.0 V.

Option A:
The p.d. across X and Y will vary from 3.0 V to 6.0 V.

Option C:
The p.d. across X and Y will always be 6.0 V.

Option D:
The p.d. across X and Y will vary from 3.0 V to 6.0 V.

25 **B** The electric field strength and the electric force between the plates is constant.

upwards electric force on electron, $F = m_e a$

$$a = \frac{F}{m_e} = \frac{Ee}{m_e} = \frac{\Delta V}{d}\frac{e}{m_e}$$

Horizontally:

$$s_x = u_x t$$

$$t = \frac{s_x}{u_x} = \frac{5.00 \times 10^{-2}}{1.97 \times 10^{7}} \text{ s}$$

Vertically:

$$s_y = \frac{1}{2}at^2$$

$$\Delta h = \frac{1}{2}\left(\frac{\Delta V}{d}\frac{e}{m_e}\right)\left(\frac{5.00 \times 10^{-2}}{1.97 \times 10^{7}}\right)^2$$

$$= \frac{1}{2}\left(\frac{3.00 \times 10^{3}}{10.0 \times 10^{-2}} \times \frac{1.60 \times 10^{-19}}{9.11 \times 10^{-31}}\right)\left(\frac{5.00 \times 10^{-2}}{1.97 \times 10^{7}}\right)^2$$

$$= 1.70 \times 10^{-2} \text{ m}$$

26 **D** $\Phi = N\phi = NBA = 10\left(2.1 \times 10^{-5}\right)\left(20 \times 20\right) = 8.4 \times 10^{-2} \text{ T m}^2$

27 **C**

$$P_{ave} = I_{rms}{}^2 R$$

$$I_{rms} = \sqrt{\frac{P_{ave}}{R}} = \sqrt{\frac{P}{R}}$$

28 **D** Since a photon is emitted, $E_1 > E_2$.

energy of photon, $\left(E_1 - E_2\right) = \dfrac{hc}{\lambda}$

$$\lambda = \frac{hc}{\left(E_1 - E_2\right)}$$

29 **A**

$$\Delta E = \left(\Delta m\right)c^2$$

$$\Delta E = \left[\left(m_U + m_n\right) - \left(m_{Ba} + m_{Kr} + 3m_n\right)\right]c^2$$

$$= \left[235.04 - 2\left(1.01\right) - 140.91 - 91.91\right]\left(1.66 \times 10^{-27}\right)\left(3.00 \times 10^{8}\right)^2$$

$$= 2.988 \times 10^{-11}$$

$$= 3.0 \times 10^{-11} \text{ J}$$

30 **D** Number of nuclei remaining = $5.00 \times 10^{12} - 3.00 \times 10^{12} = 2.00 \times 10^{12}$

$$N = N_0 e^{-\lambda t}$$

$$2.00 \times 10^{12} = 5.00 \times 10^{12} \times e^{-1.15 \times 10^{-8} t}$$

$$\ln\left(\frac{2}{5}\right) = -1.15 \times 10^{-8} t$$

$$t = 7.97 \times 10^{7} \text{ s}$$

Paper 2

1 (a) The cyclist moves at a constant speed because the air resistance acting on him is equal in magnitude and opposite in direction to the driving force exerted by the ground on him. [1]
Hence, no net force acts on the cyclist and he moves at constant speed in a straight line i.e. constant velocity (in accordance with Newton's first law). [1]

(b)
$$F = \frac{1}{2}c_D\rho A v^2 \Rightarrow v = \sqrt{\frac{2F}{c_D\rho A}} = 11.411$$ [1]

$$\frac{\Delta v}{v} = \frac{1}{2}\frac{\Delta F}{F} + \frac{1}{2}\frac{\Delta c_D}{c_D} + \frac{1}{2}\frac{\Delta \rho}{\rho} + \frac{1}{2}\frac{\Delta A}{A}$$ [1]

$$= \frac{1}{2}\frac{2}{22} + \frac{1}{2}\frac{0.01}{0.88} + \frac{1}{2}\frac{0.1}{1.2} + \frac{1}{2}\frac{0.02}{0.32} = 0.124$$
$$\Delta v = 0.124(11.411) = 1.4 = 1 \text{ (1 s.f.)}$$ [1]

$$\text{speed} = 11 \pm 1 \text{ m s}^{-1}$$ [1]

(c) (i) Work done $W = F \cdot s = \frac{1}{2}c_D\rho A v^2 s$ for a constant force F [1]

$$\text{Power} = \frac{dW}{dt} = \frac{1}{2}c_D\rho A v^2 \frac{ds}{dt} = \frac{1}{2}c_D\rho A v^3$$ [1]

(ii) $$\text{Power} = \frac{1}{2}c_D\rho A v^3 = \frac{1}{2}(0.88)(1.2)(0.32)(11.411)^3 = 251 \text{ W} \approx 250 \text{ W}$$ [1]
(If v = 11 used, Power $=$ 225 W)

2 (a) Gravitational potential at a point in a gravitational field is defined as the work done per unit mass by an external force in bringing a small test mass from infinity to that point. [1]

(b)
$$\Delta E_P = E_f - E_i = -GMm\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$$ [1]

$$= -GMm\left(\frac{1}{2.7\times10^7} - \frac{1}{6.4\times10^6}\right) = 7.63\times10^{10}\text{ J} \approx 7.6\times10^{10}\text{ J}$$ [1]

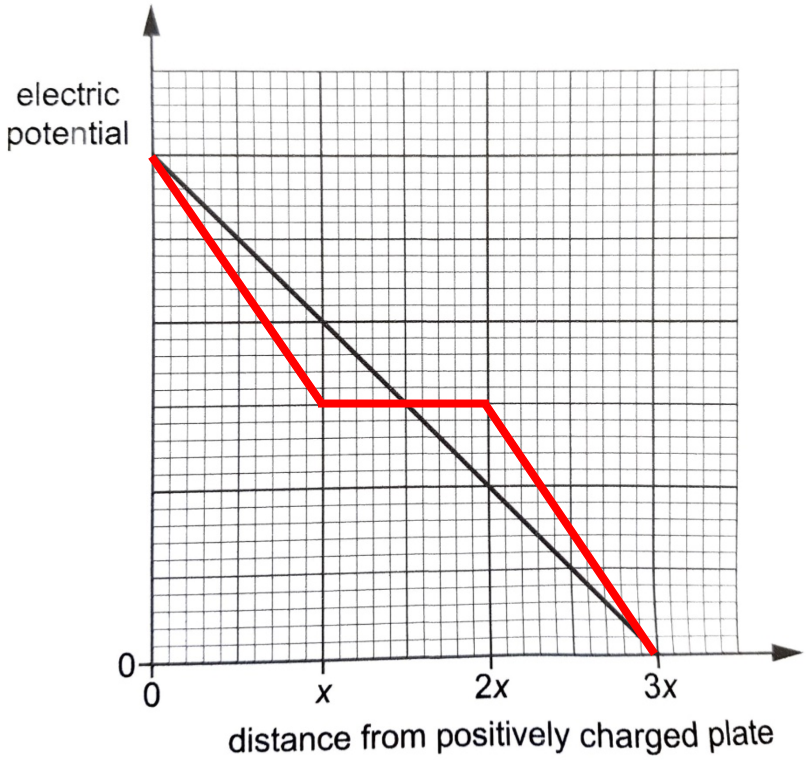
(c) (i) Centripetal force is provided by gravitational force. [1]
$$F_C = F_G$$
$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$ [1]
$$\therefore E_K = \frac{1}{2}mv^2 = \frac{1}{2}\frac{GMm}{r^2}r = \frac{GMm}{2r}$$

(ii) $E_K = \dfrac{GMm}{2r} = \dfrac{GMm}{2\left(2.7\times10^{7}\right)} = 1.19\times10^{10}$ J [1]

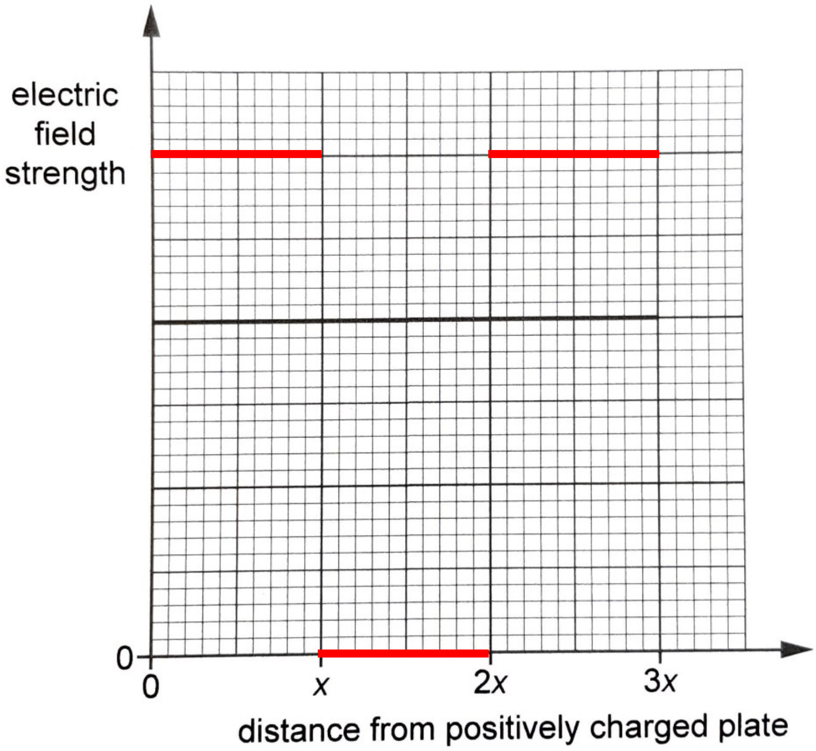
(iii) No, it is not correct.

The expression in **(c)(i)** is only the <u>kinetic energy of the satellite in orbit at a radius *r*</u>. However, when <u>launched from Earth, the satellite will be at a larger speed</u> and hence <u>has more kinetic energy</u> than just the orbital kinetic energy given by **(c)(i)**. [1] [1]

3 (a)



(b)



4 **(a)** Diffraction is the bending (or spreading) of waves after passing through an aperture or round an obstacle. [1]

(b) **1.** The waves from the two sources must be coherent (i.e. they have the same frequency and a constant phase difference). [2] (any two)

2. The waves must have similar amplitude (for a better contrast).

3. The waves must overlap and be of the same type (to produce regions of constructive and destructive interference).

4. For transverse waves, they must be unpolarised or polarised in the same plane. (This point applies to EM waves.)

(c) **(i)**

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

$$\text{gradient} = \frac{\lambda}{a} = \frac{(8.8 - 4.4)}{2.0 - 1.0} \times 10^{-3} = 4.4 \times 10^{-3}$$ [1]

$$\lambda = 4.4 \times 10^{-3}\left(0.12 \times 10^{-3}\right) = 5.28 \times 10^{-7} \text{ m}$$ [1]

(or just use any point on the graph for $\frac{\lambda}{a}$)

(ii) Amplitude of central bright fringe = $A+\frac{A}{2}=\frac{3A}{2}=1.5A$ [1]

Amplitude of adjacent dark fringe = $A-\frac{A}{2}=\frac{A}{2}=0.5A$ [1]

$\frac{I_{bright}}{I_{dark}} \propto \frac{A_{bright}{}^2}{A_{dark}{}^2}=\left(\frac{1.5A}{0.5A}\right)^2=9.0$ [1]

5 **(a)** $I=nAve=\left(5.9\times10^{28}\right)\pi\left(\frac{0.38\times10^{-3}}{2}\right)^2\left(7.2\times10^{-5}\right)\left(1.6\times10^{-19}\right)$ [1]

$=0.07708$ A

$I=\frac{Q}{t}\Rightarrow Q=0.07708\left(30\times60\right)=139\text{ C}\approx140\text{ C}$ [1]

(b) **(i) 1.** $V=V_0\sin\omega t$

$\omega=2\pi f=120\pi$

$\therefore f=60$ Hz [1]

(i) 2. $V_{rms}=\frac{V_0}{\sqrt{2}}=\frac{9.0}{\sqrt{2}}=6.36\text{ V}\approx6.4\text{ V}$ [1]

(ii) 1. $R_{eff}=12+\frac{(12)(6.0)}{12+6.0}=16\ \Omega$ [1]

$I_0=\frac{V_0}{R_{eff}}=\frac{9.0}{16}=0.5625\text{ A}=0.563\text{ A}\approx0.56\text{ A}$ [1] [1]

(ii) 2. $I_{rms}=\frac{I_0}{\sqrt{2}}=0.39775$ A

$I_{6.0}=\frac{12}{12+6.0}0.39775=0.26517$ A [1]

$P=I_{6.0}{}^2R=0.26517^2\left(6.0\right)=0.422\text{ W}\approx0.42\text{ W}$ [1]

6 **(a)** The magnetic flux density of a magnetic field is numerically equal to the force per unit length of a long straight conductor carrying a unit current at right angles to a uniform magnetic field. [1]

(b) Length of wire $L=N\pi D=520\pi\left(0.04\right)=65.345$ m [1]

$R=\rho\frac{L}{A}=\rho\frac{L}{\pi\left(\frac{d}{2}\right)^2}=1.7\times10^{-8}\frac{65.345}{\pi\left(\frac{0.46\times10^{-3}}{2}\right)^2}=6.6843\ \Omega\approx6.7\ \Omega$ [1] [1]

(c) $V=IR\Rightarrow I=\frac{24}{6.6843}=3.5905$ A [1]

$B=\mu_0 nI=\mu_0\frac{1}{0.46\times10^{-3}}3.5905=9.8086\times10^{-3}\text{ T}\approx9.8\times10^{-3}\text{ T}$ [1] [1]

(d) The wire will not experience any magnetic force due to the solenoid's magnetic flux density as the direction of the current is parallel (or anti-parallel) to the direction of the magnetic flux density inside the solenoid. [1]

7 (a) A photon is a quantum of electromagnetic energy, whose energy E is given by $E = hf$ where f is the frequency of the electromagnetic wave and h is Planck's constant. [1] [1]

(b) White light contains many different visible light frequencies. When it passes through the gas cloud, the atoms of the cool gas absorb photons of certain frequencies to transition from a lower energy level to a higher one. The energies of the photons absorbed must be equal to the energy difference between the two energy levels involved. [1] [1]

After the absorption, the excited atom will eventually return to the lower energy level by emitting the same photons. However, these emissions occur in all directions and therefore the intensities of the re-emitted light in the direction of the detector (or observer) are lowered. This lowering of intensities is seen as dark lines on the continuous spectrum. [1] [1]

(c) (i)

$$E = -\frac{13.6}{2^2} = -3.4 \text{ eV}$$ [1]

(ii)

$$\Delta E = \frac{hc}{\lambda} = -\frac{13.6}{3^2} - \left(-\frac{13.6}{2^2}\right) = 1.89 \text{ eV} = 3.02 \times 10^{-19} \text{ J}$$ [1] [1]

$$\lambda = \frac{hc}{\Delta E} = 6.58 \times 10^{-7} \text{ m}$$ [1]

(iii) An electron in an energy level is bound to the nucleus by the attractive Coulomb force. The total energy of such a bound system is negative. [1]

8 (a)

$$185 \text{ kmh}^{-1} = \frac{185 \times 1000}{60 \times 60} \text{ m s}^{-1}$$ [1]

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

$$\therefore a = \frac{v^2 - u^2}{2s} = \frac{0 - \left(\frac{185 \times 1000}{60 \times 60}\right)^2}{2 \times 80} = -16.51 \approx -17 \text{ m s}^{-2}$$ [1]

(b) (i) The sideways acceleration of $4g$ is the maximum centripetal acceleration for the car to turn the tightest corner when travelling at the maximum speed, v_{max}. [1]

$$4g = \frac{{v_{max}}^2}{r}$$ [1]

$$v_{max} = \sqrt{4gr} = \sqrt{4g(30)} = 34.3 \text{ m s}^{-1} \approx 34 \text{ m s}^{-1}$$ [1]

(ii) When the tyres are heated, Fig. 8.1 shows that the coefficient of friction generally increases. This increases the frictional force between the tyre and road surfaces, which allows greater accelerations and cornering speeds for the car. [1] [1]

The heating softens the compound of the tyre, which allows the compound to fill in the gaps between the tyre and road surface as shown in Fig. 8.2, which increases the contact area as the weight of the car pushes the tyre down into the gaps on the uneven road surface. This is a factor in increasing the friction as it allows for a better "grip" between the tyre and the road surface, for the same reasons (greater acceleration and cornering speeds) mentioned before. [1]

(c) As the air flows over the wing, the air is deflected upwards and hence, it gains momentum in the upwards direction. By Newton's Second Law, this implies that the wing exerts a force upwards on the air. [1]

By Newton's Third Law, the air exerts a force downwards on the wing and hence the car. This force from the air pushes the car downwards, increasing the normal contact force between the car and the ground and hence increasing the apparent weight of the car. [1]

(d) (i) Taking moments about centre of gravity,

Clockwise moments = Anticlockwise moments

$$Dh + N_F x_F = N_R x_R \text{ .... (1)}$$ [1]

Analysing forces in the vertical direction,

$$N_F = W - N_R \text{ ....(2)}$$ [1]

Sub (2) into (1):

$$Dh + (W - N_R)x_F = N_R x_R$$

$$Dh + Wx_F = N_R x_F + N_R x_R = N_R(x_F + x_R)$$ [1]

$$N_R = \frac{Wx_F + Dh}{x_F + x_R}$$

(ii)

$$N_F = W - N_R = W - \frac{Wx_F + Dh}{x_F + x_R} = \frac{Wx_F + Wx_R}{x_F + x_R} - \frac{Wx_F + Dh}{x_F + x_R}$$ [1]

$$N_F = \frac{Wx_R - Dh}{x_F + x_R}$$

(iii) The driving force D provides for the acceleration of the car. Hence, when the car accelerates (D is non-zero), $N_R = \dfrac{Wx_F + Dh}{x_F + x_R}$ will increase (+ Dh in the numerator) while $N_F = \dfrac{Wx_R - Dh}{x_F + x_R}$ will decrease (− Dh in the numerator). [1] [1]

Hence, the weight has been transferred from the front wheels to the rear wheels (that is, there is a weight transfer between the front and rear wheels).

(e) (i)

$$\frac{1}{2}Mv^2 = mc\Delta\theta$$ [1]

$$\Delta\theta = \frac{Mv^2}{2mc} = \frac{750\left(185000/60\times 60\right)^2}{2(4\times 1.2)(1130)} = 183\text{ K} \approx 180\text{ K}$$ [1] [1]

(ii) It is assumed that all of the kinetic energy of the car is transferred and used to raise the temperature of the brakes, and that none of that energy is lost to the surroundings. [1]

(iii) 1. The small holes improve the heat dissipation of the brakes by increasing air flow and circulation, preventing damage due to high temperatures caused by friction when braking. [1]

2. The small holes improve brake performance by better allowing water or dust to escape by being squeezed out from the wheels instead of being trapped and forming a cushioning layer between the wheels and the brakes, which would reduce the frictional force. [1]

This is similar to having treads on tires, which allow water on the road to be squeezed into the treads and be pushed away.

Paper 3

1 **(a)** **(i)** Liquid pressure increases with increasing depth below the surface of the liquid, h', according to $p = \rho g h'$. [1]

Since force = pressure $\times$ area, the lower half of the sphere experiences an upward force while the upper half of the sphere experiences a downward force. [1]

Since the bottom half is at a larger depth h', the upward force is larger than the downward force, and the resultant of these forces is the upward upthrust. [1]

(ii) Upthrust = weight of fluid displaced [1]

$$= \text{density of fluid} \times \text{volume of object} \times g$$
$$= \rho_L V g$$ [1]

(b) Weight: horizontal line labelled W [1]
Upthrust: horizontal line labelled U, above line W [1]

(c) Vertical intercept > 0 [1]
Upward sloping straight line [1]

2 **(a)** The gas atoms move randomly in all possible directions, with a range of speeds. [1]
Thus, the velocities, which are vectors, of all the atoms will average out to be zero. [1]

(b)
$$pV = nRT$$
$$= \left(\frac{N}{N_A}\right)RT$$
$$= NkT$$ [1]
$$N = \frac{pV}{kT}$$
$$= \frac{(3.6\times10^5)(4.2\times10^{-3})}{(1.38\times10^{-23})(273+70)}$$ [1]
$$= 3.19\times10^{23}$$
$$= 3.2\times10^{23} \quad (\textit{shown})$$ [1]

(c) Volume of each gas atom
$$= \frac{4}{3}\pi\left(\frac{d}{2}\right)^3$$
$$= \frac{4}{3}\pi\left(\frac{2\times10^{-10}}{2}\right)^3$$
$$= 4.1887\times10^{-30}\,\text{m}^3$$
Volume of all the gas atoms = $(3.19 \times 10^{23})(4.1887 \times 10^{-30})$
= 1.34×10^{-6} m^3
$\approx 1 \times 10^{-6}$ m^3 (to 1 s.f.) [1]

(d) The volume of the gas atoms, 1×10^{-6} m^3 is much smaller than the volume occupied by the gas 4.2×10^{-3} m^3. [1]
The large distance between the gas atoms implies that the intermolecular forces will be negligible. [1]

(Note: The question says "provides evidence". So you need to refer to the numerical values of the pervious parts in answering this question.)

3 (a) (i) Time t_3 and time t_7 [1]

(ii) Time t_4 and time t_8 [1]

(b) (i)

$$f = \frac{4200}{1.0 \times 60} = 70\,\text{Hz}$$ [1]

(ii)

$$\begin{aligned} \omega &= 2\pi f \\ &= 2\pi(70) \\ &= 439.82\ \text{rads}^{-1} \end{aligned}$$ [1]

$$\begin{aligned} x_0 &= \frac{6-1}{2} \\ &= 2.5\ \text{cm} \\ &= 0.025\ \text{m} \end{aligned}$$ [1]

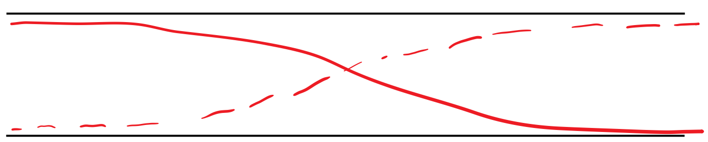
$$\begin{aligned} \text{Maximum acceleration} &= \omega^2 x_0 \\ &= (439.82)^2(0.025) \\ &= 4836.1\ \text{m s}^{-2} \\ &= 4840\ \text{m s}^{-2} \end{aligned}$$ [1]

(c)
- straight line graph with negative gradient passing through the origin [1]
- label units for the axes [1]
- a = – 4840 at x = 2.5cm, and a = 4840 at x = –2.5cm [1]

4 (a) A stationary wave is formed by the superposition of two progressive waves of the same type, frequency, amplitude and speed [1]
travelling along the same line but in opposite directions. [1]

(b) The representation shows the maximum and minimum displacements of the particles' oscillations along the length of the tube. [1]
It does not show the actual positions of the particles' oscillations, as the oscillations are parallel to the length of the tube and hence parallel to the direction of travel of waves, making it a longitudinal wave. [1]

(c)



Antinodes at the two ends [1]
Only one node [1]

(d) Let the length of the tube be L

In (c), $\lambda_1 = 2L$

In (d), $\lambda_2 = L$ [1]

Since the speed of sound remains constant,

$$f_1\lambda_1 = f_2\lambda_2$$

$$\frac{f_2}{f_1} = \frac{\lambda_1}{\lambda_2} = 2$$

$\Rightarrow \quad f_2 = 2 \times 540 = 1080 \approx 1100$ Hz [1]

5 **(a)** When V = 1.5 V, I = 0.200 A

$$R_1 = \frac{V_1}{I_1} = \frac{1.5}{0.200} = 7.5\Omega$$

When V = 3.0 V, I = 0.300 A

$$R_2 = \frac{V_2}{I_2} = \frac{3.0}{0.300} = 10.0\,\Omega$$ [1]

$\Rightarrow \quad \Delta R = 10.0 - 7.5 = 2.5\,\Omega$ [1]

(b) **(i)** From Fig. 5.1,

When I = 0.36 A, V = 4.50 V

$V_{14\Omega} = V_{5.0\,\Omega\ \&\ \text{lamp}}$
$= IR_{5.0\,\Omega} + V_{\text{lamp}}$
$= (0.36)(5.0) + 4.50$
$= 6.3$ V [1]

$$I_{14\Omega} = \frac{V_{14\Omega}}{R_{14\Omega}} = \frac{6.3}{14} = 0.45\,A$$ [1]

(ii)

$$\varepsilon = V_{14\Omega} + V_{internal}$$
$$= V_{14\Omega} + I_{total}r$$
$$r = \frac{\varepsilon - V_{14\Omega}}{I_{total}}$$
$$= \frac{7.5 - 6.3}{0.36 + 0.45}$$ [1]
$$= 1.4814$$
$$= 1.5\Omega$$ [1]

6 **(a)** Faraday's law of electromagnetic induction states that the induced electromotive force (e.m.f.) is directly proportional [1] to the rate of change of magnetic flux linkage. [1]

(b) **(i)** Draw tangent to graph at t = 1.0 s

$$\frac{dB}{dt} = \frac{(36.0 - 6.0) \times 10^{-3}}{1.60 - 1.10}$$ [1]

$$= 0.060 \text{ T s}^{-1}$$

$$= 6.0 \times 10^{-2} \text{ T s}^{-1} \text{ (shown)}$$ [1]

(ii)

$$\varepsilon_{induced} = \frac{d\Phi}{dt}$$

$$= \frac{d(NBA)}{dt}$$

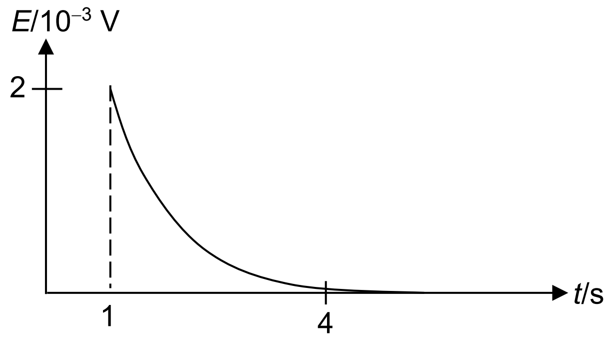
$$= NA\left(\frac{dB}{dt}\right)$$

$$= 140 \times 2.4 \times 10^{-4} \times (6.0 \times 10^{-2})$$ [1]

$$= 2.016 \times 10^{-3} \text{ V}$$

$$= 2.0 \times 10^{-3} \text{ V}$$ [1]

(iii)



$\varepsilon_{induced}$ = 0 V from t = 0 s to t = 1 s, and for t > 4.5 s

t = 2 s to t =4.5 s, $\varepsilon_{induced}$ decreases at decreasing rate from 2.02 mV [1]

Label of values and axes [1]

7 **(a)** **(i)** The binding energy of a nucleus is the <u>amount of energy required to separate to infinity all its constituent nucleons</u>, and is equal to the <u>mass defect of the nucleus multiplied by c^2, where c is the speed of light.</u> [1] [1]

(ii) Total mass of nucleons = 11(1.00814) + (23 – 11)(1.00898)
= 23.1973 u [1]

Mass defect = 23.1973 – 22.99706 [1]
= 0.20024 u

Binding energy per nucleon $= \dfrac{0.20024 \times 931.4}{23}$
= 8.109 MeV [1]

(b) **(i)** Mass change = $m_{Na\text{-}23} + m_n - m_{Na\text{-}24}$
$= 22.99706 + 1.00898 - 23.99857$
$= 7.47 \times 10^{-3}$ u (shown) [1]

(ii)
$$\lambda = \frac{hc}{E}$$
$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(7.47\times10^{-3})(931.4)(10^{6})(1.60\times10^{-19})}$$ [1]
$$= 1.7867\times10^{-13}\ \text{m}$$
$$= 1.79\times10^{-13}\ \text{m (to 3 s.f.)}$$ [1]

(c)
$$e^{-\lambda t} = \frac{A}{A_0}$$
$$-\lambda t = \ln\left(\frac{A}{A_0}\right)$$
$$\lambda = -\frac{1}{t}\ln\left(\frac{A}{A_0}\right)$$
$$= -\frac{1}{65}\ln\left(\frac{1}{20}\right)$$ [1]
$$= 0.046088$$
$$= 0.046\ \text{h}^{-1}$$ [1]

Note:
The above is what the teachers think the examiners are expecting from the candidates. However, to equate λt to the probability of decay in time t, λt must be much smaller than 1. In this question, t = 1 hour, so λt =0.046 isn't exactly very small and there is some error involved. In this case, the correct way to calculate the probability of decay per hour is to calculate the fractional number of atoms that do not decay in one hour, i.e., N/N_0, and then subtract it from 1:
$$\frac{N}{N_0} = \frac{A}{A_0} = \exp(-\lambda t) = \exp(-0.046088\times1) = 0.95496$$
Hence, probability of decay per hour
$$= \frac{\text{Number decayed in one hour}}{\text{Initial number}}$$
$$= \frac{N_0 - N}{N_0}$$
$$= 1 - \frac{N}{N_0}$$
$$= 0.04504$$

This is slightly different from the answer obtained in the first solution.

8 **(a)** **(i)** The relative speed of approach of the objects is larger [1]
than their relative speed of separation. [1]

(ii) The total kinetic energy before the collision is larger than the total kinetic energy after the collision. [1]

(b) Vertical distance from support before release = $L\cos\theta$

= (1.50) cos (21°)

= 1.4003 m [1]

Change in vertical height = Δh

= 1.50 – 1.4003

= 0.099629 m

Loss in E_p = Gain in E_k

$$mg\Delta h = \frac{1}{2}mv^2 - 0$$ [1]

$$v = \sqrt{2g\Delta h}$$

$$= \sqrt{2(9.81)(0.0099629)}$$ [1]

$$= 1.3981$$

$$= 1.4 \text{ m s}^{-1} \text{ (shown)}$$

(c) **(i)** By conservation of linear momentum,

$$m_A u_A + M(0) = m_A v_A + MV$$

$$0.096(1.4) + 0 = 0.096(-0.79) + MV$$ [1]

$$\Rightarrow \quad MV = 0.21 \text{ kg m s}^{-1}$$ [1]

(ii) Final E_k of system $= 0.86\times$ initial E_k

$$= 0.86 \times \left[\frac{1}{2}(0.096)(1.4)^2\right]$$

$$= 0.080689 \text{ J}$$ [1]

E_k of sphere B $= E_k$ of system $- E_k$ of sphere A

$$= 0.080689 - \frac{1}{2}\left(\frac{96}{1000}\right)(0.79)^2$$

$$= 0.050732$$

$$= 0.051 \text{ J}$$ [1]

(d) **(i)**

$$p = MV$$

$$E_k = \frac{1}{2}MV^2$$

Dividing the second equation by the first, [1]

$$\frac{1}{2}V = \frac{E_k}{p}$$ [1]

$$V = \frac{2E_k}{p}$$
$$= \frac{2(0.050732)}{0.21005}$$
$$= 0.48305 \text{ m s}^{-1}$$
$$= 0.48 \text{ m s}^{-1}$$

(ii)

$$M = \frac{p}{V}$$
$$= \frac{0.21005}{0.48305}$$ [1]
$$= 0.43483$$
$$= 0.43 \text{ kg}$$ [1]

(e) The two spheres cannot be stationary at the same time during the collision. [1]
If they were, the total momentum of the system would be zero at that moment. [1]
This violates the principle of conservation of momentum since the total momentum of the system is 0.096 × 1.4 = 0.13 kg m s^{-1} just before the collision. [1]

(f) Impulse = $m_A(v_A - u_A)$

$$= 0.096 \times [(-0.79) - (1.3981)]$$
$$= -0.20830 \text{ kg m s}^{-1}$$

Magnitude of impulse = 0.21 kg m s^{-1}

(g) Sphere A moves horizontally just before and just after collision from (b) and (c), hence the impulse is in the horizontal direction to the left. [1]
By conservation of momentum, the impulse on sphere B must be horizontally to the right, with no vertical component [1]
and hence the centres of sphere and point of contact are all horizontal.

9 **(a)** **(i)** A field of force due to a body's property (eg. charge, mass) is a region in space in which another body carrying that property [1]
experiences a force when it is placed in the field. [1]

(ii) 1. gravitational field [1]
2. gravitational field and electric field [1]

(b) **(i)**

$$\text{Time taken} = \frac{\Delta s}{v_x}$$
$$= \frac{0.12}{6.7 \times 10^{7}}$$
$$= 1.8 \times 10^{-9} \text{ s}$$ [1]

(ii) Electric Field $= \dfrac{\Delta V}{d} = \dfrac{960}{0.024} = 4.0 \times 10^4$ V [1]

$F_{net} \approx eE = 1.6 \times 10^{-19} \times 4.0 \times 10^4 = 6.4 \times 10^{15}$ N [1]

$a = \dfrac{F_{net}}{m} = \dfrac{6.4 \times 10^{-15}}{9.11 \times 10^{-31}} = 7.0 \times 10^{15}$ m s^{-2} [1]

(c) $s_y = u_y t + \dfrac{1}{2} a_y t^2$

$= 0 + \dfrac{1}{2}(7.0252 \times 10^{15})(1.7910 \times 10^{-9})^2$ [1]

$= 0.011267$ m

$= 1.1$ cm

Since $s_y < 1.2$ cm,
The electron will not collide with any of the plates. [1]

(d) **(i)** The magnetic force acting on the charged particle is always perpendicular to the direction of its motion. [1]
Furthermore, this force is constant in magnitude because the speed of the particle is constant. [1]
The force will acts as the centripetal force for the circular motion of the particle within the region of the magnetic field.

(ii) Magnetic force acts as the centripetal force

$Bev = \dfrac{mv^2}{r}$ [1]

$m = \dfrac{Ber}{v}$

$= \dfrac{(0.090)(1.60 \times 10^{-19})\left(\dfrac{0.148}{2}\right)}{\left(4.6 \times 10^4\right)}$ [1]

$= 2.3165 \times 10^{-24}$ kg [1]

$= \dfrac{2.3165 \times 10^{-24}}{1.66 \times 10^{-27}}$ u [1]

$= 13.954$ u

$= 14$ u

(e) **(i)** The path will have a smaller radius than the path in (d), as the centripetal force is the same but inertia (mass) is decreased. [1]

(ii) From **(d)(ii)**, $r = \dfrac{mv}{Bq}$ [1]

If the charge q is doubled but the mass remains the same, then the radius r and hence the diameter of the path is halved. [1]