RAFFLES INSTITUTION
YEAR 5-6 PHYSICS DEPARTMENT

2015 A-Levels H2 Physics Suggested Solutions

Paper 1

1 **A** The amount of substance is a base quantity, and the mole (mol) is its SI unit. The other three quantities (charge, energy and force) are not base quantities.

2 **D** total distance travelled = area under the curve

$$= \frac{1}{2}\times 18\times 30 + 40\times 18 + \frac{1}{2}\times(18+24)\times 50 + \frac{1}{2}\times 24\times 30 = 2400 \text{ m}$$

average speed = total distance travelled / total time $= \dfrac{2400}{150} = 16 \text{ m s}^{-1}$

3 **C** The horizontal component of the velocity is 40 m s^{-1}, which is constant in time. The vertical component of the velocity after 3.0 seconds

$= u + gt = 0 + 9.81\times 3.0 = 29.43 \cong 30 \text{ m s}^{-1}$

$$v_{\text{fin}} = \sqrt{v_{\text{horizontal}}^2 + v_{\text{vertical}}^2} = \sqrt{30^2 + 40^2} = 50 \text{ m s}^{-1}$$

4 **A** The acceleration, given by (net force/mass), increases, since the net force (equal to the propelling force) is constant, whereas mass decreases due to the leakage.

Note that, since the water is leaked vertically down, it does not exert a horizontal force on the tanker.

5 **C** Since the collision is elastic, the initial kinetic energy and the final kinetic energy are equal:

$$\text{initial KE} = \text{final KE}$$

$$\frac{1}{2}mu_1^2 + \frac{1}{2}mu_2^2 = \frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2$$

$$u_1^2 + u_2^2 = v_1^2 + v_2^2$$

where, in the last equation, mass m is cancelled because both spheres have the same mass.

NOTE

If one considers the conservation of momentum instead, option **B** is also correct. Note that u_1, u_2, v_1, v_2 are speeds, not velocities. In order to apply conservation of momentum, one has to use velocities instead.

Taking rightwards as positive, the corresponding velocities are u_1, $-u_2$, v_1, v_2. Applying the principle of conservation of momentum, one has

$$mu_1 + m(-u_2) = mv_1 + mv_2$$

$$u_1 - u_2 = v_1 + v_2$$

which is option **B**.

6 **A** By Archimede's principle, upthrust on the barge = weight of water displaced, and by the principle of floatation, upthrust on the barge = weight of the barge.

Combining the above two principles, one has

weight of the water displaced = weight of the barge

Thus, as long as the water level remains the same everywhere, the bridge supports the same weight, regardless of the position of the barge.

7 **D** When the block of ice is fully submerged, the volume of water displaced is equal to the volume of the ice, hence

$$\text{upthrust} = \rho_{\text{water}} g V_{\text{ice}}$$

where we have applied the fact that the upthrust is equal to the weight of the liquid displaced.
When the ice is floating, the upthrust is equal to the weight of the ice, by the principle of floatation:

$$\text{upthrust} = \rho_{\text{ice}} g V_{\text{ice}}$$

Hence the ratio between the two upthrust is equal to the ratio between the density of water and that of ice:

$$\frac{\text{upthrust when fully submerged}}{\text{upthrust when floating}} = \frac{\rho_{\text{water}} g V_{\text{ice}}}{\rho_{\text{ice}} g V_{\text{ice}}} = \frac{1.0}{0.9} \approx 1.1$$

8 **C** When the speed is 20 m s^{-1}, the driving force F is solved using

$$\text{power output} = Fv$$

$$23 \times 10^3 = F \times 20$$

$$F = 1.15 \times 10^3 \text{ N}$$

The frictional force f at this speed is equal to the driving force:

$$f = 1.15 \times 10^3 \text{ N}$$

because the net force on the car is zero.

When the speed increases to 40 m s^{-1} (speed is doubled), because the frictional force is proportional to the square of the speed, the frictional force increases by a factor of 4. By N2L, since the velocity is again constant (net force is 0), the driving force is equal to this new frictional force

$$F_{\text{new}} = 4f = 4 \times 1.15 \times 10^3 = 4.6 \times 10^3 \text{ N}$$

The new power output is then

$$\text{new power output} = 4.6 \times 10^3 \times 40 = 184 \text{ kW}$$

9 **A** For the processes with no volume change, no work is done either on or by the gas. For the process with increasing volume, work is done by the gas, whereas for the process with decreasing volume, work is done on the gas (equal to the negative of the work done by the gas).

Hence

$$\text{net work done by the gas} = \text{work done by the gas} - \text{work done on the gas}$$

$$= 600(5-3) - 400(5-3) = 400 \text{ J}$$

where the work done in each process is given by

$$\text{work done} = p\Delta V$$

10 **C** The force the string acting on the sphere is along the string away from the sphere. By N3L, the force on the string by the sphere is in the opposite direction. This condition alone rules out options **A**, **B** and **D**.

The force due to the pole on the string must be equal in magnitude and opposite in direction to the force due to the sphere on the string. This is because the net force on the string must be zero. Note that the string is massless, hence it does not require a nonzero net force (the centripetal force) in order to undergo circular motion.

11 **B** The minute hand takes 1 hour (3600 seconds) to complete one revolution. The angular velocity is then

$$\omega = \frac{2\pi}{3600} = 1.75 \times 10^{-3}\ \text{rad s}^{-1}$$

Note that the angular velocity does not depend on the length of the minute hand (the radius of the circle).

12 **A** The meteorite initially has zero potential energy (since it is at a large distance from the planet, where φ is zero). The final potential energy of the meteorite is $m(\varphi$ at $R)$, which is negative, since (φ at R) is negative. The corresponding positive value is given by m(magnitude of φ at R).

By conservation of energy,

$$\begin{aligned}\text{Gain in KE} &= \text{Loss in GPE} \\ &= m(\text{magnitude of } \varphi \text{ at R}) - 0 \\ &= m(\text{magnitude of } \varphi \text{ at R})\end{aligned}$$

Note that the mass of the planet, M, should not appear in the expression, since it is built into the potential function φ.

13 **D** The net force acting on the satellite is equal to the difference between the gravitational attraction due to the Sun ($\frac{GM_S m}{R^2}$, the larger force), and that due to the Earth ($\frac{GM_E m}{r^2}$, the smaller force).

The net force acts as the centripetal force, which points towards the Sun (assumed to be stationary at the centre of the circle). The radius of the circular orbit of the satellite is R, hence

$$\text{centripetal force} = \frac{GM_S m}{R^2} - \frac{GM_E m}{r^2} = m \times R\omega^2$$

14 **A** For simple harmonic motion, one has

$$\text{acceleration} = -\,\omega^2 \times \text{displacement}$$

which fits the graph (a line with negative gradient passing through the origin).

15 **A** The KE at the centre position (the equilibrium position) is the maximum KE, which is given by

$$\text{Max KE} = \frac{1}{2} m {v_0}^2 = \frac{1}{2} \times 2.5 \times 1.2^2 = 1.8\ \text{J}$$

which rules out options **C** and **D**.

Between options **A** and **B**, the columns for GPE are identical. The decrease in GPE from top to bottom is given by $3.7 - (-3.7) = 7.4\ \text{J}$. By conservation of energy, elastic potential energy should increase by the same amount (because KE is zero for both top and bottom). Option **A** satisfies this condition, while option **B** does not.

16 **A** The first law of thermodynamics is

$$\Delta U = Q + W$$

where ΔU is the increase in internal energy of the system,
Q is the heat absorbed by the system,
W is the work done on the system.

Translating the options into equations using the above symbols, one has

A: $Q = \Delta U - W$
B: $Q = \Delta U + W$
C: $W = Q - \Delta U$
D: $W = \Delta U + Q$

Only option **A** is consistent with the original first law equation.

17 **C** **Method 1: ideal gas equation**
Before the tap is open:
For flask X, according to the deal gas equation, $p_X V_X = n_X RT$, $n_X = \dfrac{p_X V_X}{RT}$

Similarly, for flask Y, $p_Y V_Y = n_Y RT$, $n_Y = \dfrac{p_Y V_Y}{RT}$

Thus, one has $n_X + n_Y = \dfrac{p_X V_X + p_Y V_Y}{RT}$ (1)

After the tap is open:
By conservation of mass and the ideal gas equation, one has

$$n_X + n_Y = \frac{pV}{RT} \quad (2)$$

Combining Equations (1) and (2), one has

$$pV = p_X V_X + p_Y V_Y .$$

Method 2: internal energy
For an ideal gas of fixed mass, the internal energy is proportional to temperature: internal energy $\propto nRT = pV$. (For monoatomic gas, the constant of proportionality is 3/2.)
Thus, by conservation of energy,

internal energy in X + internal energy in Y $=$ total final internal energy

$$pV = p_X V_X + p_Y V_Y$$

18 **C** The pulse reaches point O after 1 s. At point O, the wave is reflected, after which it undergoes a phase shift of π (meaning that the downward displacement becomes upward and vice versa), and travels to the left.

At 1.5 s, the reflected pulse reaches point P, and at 2.0 s, the reflected pulse leaves point P.

Note that the small-displacement part of the pulse reaches point O first, so in the reflected wave travelling to the left, the small-displacement part is on the left. Hence, the small-displacement part of the pulse passes through point P first. The displacement of the small-displacement part was downward in the original wave. In the reflected wave it becomes upward, due to the π-phase shift. Similarly, the displacement of the large-displacement curve changes from upward in the original pulse to downward in the reflected pulse, and passes through point P after the small-displacement part.

19 **C** The intensity at 1.0 m from the source is

$$\text{intensity} = \frac{2.5}{4\pi \times 1.0^2} = 0.199 \text{ W m}^{-2}$$

It is known that the intensity is proportional to the square of the amplitude. Hence

$$\frac{A_{1\text{ m from source}}}{A_{1\text{ W}}} = \sqrt{\frac{I_{1\text{ m from source}}}{I_{1\text{ W}}}}$$

$$A_{1\text{ m from source}} = \sqrt{\frac{I_{1\text{ m from source}}}{I_{1\text{ W}}}} A_{1\text{ W}} = \sqrt{\frac{0.199}{1.0}} 4 = 1.8\ \mu\text{m}$$

20 **B** One of the conditions for stationary wave to form is that the two waves need to travel along the same line in opposite directions. Line PQ satisfies this condition (and all other conditions, please refer to lecture notes), whereas RS does not.

21 **C**

For 1st harmonic, $L = \frac{\lambda}{4} \Rightarrow f = \frac{v}{4L}$

For 3rd harmonic, $L = \frac{3\lambda}{4} \Rightarrow f = 3\left(\frac{v}{4L}\right)$

For 5th harmonic, $L = \frac{5\lambda}{4} \Rightarrow f = 5\left(\frac{v}{4L}\right)$

For 7th harmonic, $L = \frac{7\lambda}{4} \Rightarrow f = 7\left(\frac{v}{4L}\right)$

Thus the ratio of the first 4 frequencies must be in the ratio of 1:3:5:7

22 **D** $n\lambda = d\sin\theta$

$$d = \frac{n\lambda}{\sin\theta} = \frac{(2)(590\times10^{-9})}{\sin(21.5^\circ)} = 3.2\ \mu\text{m}$$

23 **B**

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

$$E = \frac{Q}{4\pi\varepsilon_0 r^2} = \frac{V}{r}$$

24 **B** Since the constant vertical electric force acting on the particle is increased, the vertical acceleration on the particle increases, resulting in a greater deflection of parabolic path and also a greater final velocity of the particle.

25 **A** Above 0.6 V, the ratio, $R = \frac{V}{I}$ decreases.

Note: from −1.5 V to 0 V, notice that there is a very small non zero current, thus option B is false.

26 **B** using current divider rule,

current flowing through 13 Ω resistor $= \frac{1.3}{13} \times 4 = 0.4$ A

total current flowing through battery $= 0.4 + 1.3 = 1.7$ A

$P = I^2 r$

$r = \dfrac{1.7}{1.7^2} = 0.588235$

resistance of unknown resistor $= \dfrac{V}{I} = \dfrac{2.0}{1.7} = 1.17647\ \Omega$

e.m.f. of battery $= IR_{total} = (1.7)\left(0.588235 + 1.17647 + \dfrac{1}{\dfrac{1}{4} + \dfrac{1}{13}}\right) = 8.2$ V

27 **B**

$$R = \frac{\rho l}{A} = \frac{(1.3 \times 10^{-8})(\pi)(\frac{1.5}{100})(30)}{\pi\left(\dfrac{\frac{0.5}{2}}{1000}\right)^2} = 9.4 \times 10^{-2}\ \Omega$$

28 **B** $V = IR$

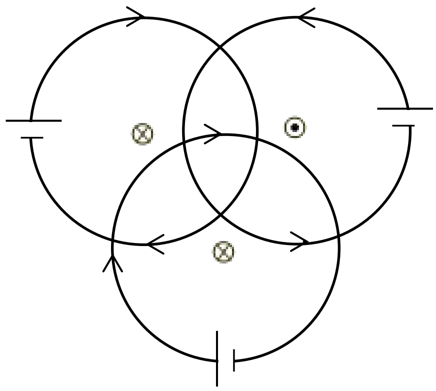
total resistance $= 3 + \left(\dfrac{1}{6} + \dfrac{1}{6}\right)^{-1} = 6\ \Omega$

current flowing through battery $= \dfrac{12}{6} = 2.0$ A

current in ammeter $= \dfrac{6}{12} \times 2.0 = 1.0$ A

29 **D** From graph, read off values of V for both resistors at 0.3 A
e.m.f of cell $= 1.0 + 1.5 = 2.5$ V
In parallel, potential difference across each of the resistors is 2.5 V
From graph, read of values of current when V = 2.5 V
current in cell
$= 0.5 + 0.5 = 1.0$ A

30 **B**



By right hand grip rule, direction of magnetic fields due to the 3 coils can be attained (as seen in figure above).

In region 5, field lines are all pointing into the paper, while in region 2, field lines are all pointing out of paper.

31 **B** As the electrons enter the velocity selector, they experience an upward electric force.

Using Fleming's Left Hand rule, the direction magnetic field must be in the direction of B in order for the magnetic force to be downwards.

32 **D** As the North pole approaches the coil, there is change in magnetic flux linkage and thus induced e.m.f. in the coil.

When the magnet is halfway through the coil, there is no change in magnetic flux linkage and thus no induced e.m.f.

As the magnet leaves the coil, South pole moves further and further away. By Lenz's Law and Right hand grip rule, the direction of induced e.m.f is in the opposite direction and thus negative.

33 **B** $V_{\text{rms}} = I_{\text{rms}}R$

$V_{\text{rms}} = \dfrac{V_0}{\sqrt{2}}$

when V_0 is doubled, V_{rms} is doubled

thus I_{rms} is doubled

$P_{\text{ave}} = \dfrac{P_0}{2} = \dfrac{V_0 I_0}{2}$

since I_{rms} is doubled, I_0 is also doubled,

thus mean power increases by factor of 4

34 **C** $I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}}$

$P_{\text{ave}} = I_{\text{rms}}{}^2 R = \left(\dfrac{5.0}{\sqrt{2}}\right)^2 (10) = 125\text{ W}$

35 **C** When white light passes through a diffraction grating, a coloured spectrum is seen. Since the white light passes through the sodium vapour, the electrons in the ground state of sodium vapour absorbs photons with energy equal to ΔE thus forming the dark lines.

36 **A** Both *p* and *x* must be in the same direction.

37 **NA**

38 **NA**

39 **D** ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{144}_{56}\text{Ba} + {}^{x}_{y}\text{Z} + 2\,{}^{1}_{0}\text{n}$

$x = 235 + 1 - 144 - 2 = 90$

$y = 92 - 56 = 36$

no of neutrons $= 90 - 36 = 54$

40 **B**

$C = C_0 e^{-\lambda t}$

$61.6 - 8.3 = (77.3 - 8.3)e^{-\lambda(280)}$

$\lambda = 9.22 \times 10^{-4}$

$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

$t_{\frac{1}{2}} = 752\ \text{s}$

Paper 2 Structured Questions

1 (a)

Energy stored $= \frac{1}{2}Fx$ OR $(\text{Area under graph} \times g)$

$= \frac{1}{2}(0.450)(9.81)(0.70-0.40)$

$= 0.662175$

$= 0.662$ J

(b) (i) At the point of release (l = 40 cm), the mass has maximum gravitational potential energy and zero kinetic energy and elastic potential energy.

As it falls from l = 40 cm to l = 60 cm, the gravitational potential energy is converted into kinetic energy and elastic potential energy.

From l = 60 cm to the lowest position, the gravitational potential energy and kinetic energy are converted into elastic potential energy.

At the lowest position, the mass has minimum gravitational potential energy, zero kinetic energy and maximum elastic potential energy.

(ii) By the principle of conservation of energy, from l = 40 cm to l = 70 cm,

Loss in GPE = Gain in KE + Gain in EPE

$$(0.300)(9.81)(0.300) = \frac{1}{2}(0.300)\left(v^2 - 0\right) + 0.662175$$

$v = 1.21$ m s^{-1}

(iii) $F = kx$

$$k = \frac{(0.45)(9.81)}{0.30}$$

$k = 14.715$ N m^{-1}

Let h be the distance fallen by the mass

By the principle of conservation of energy,

Loss in GPE = Gain in KE + Gain in EPE

$$(0.300)(9.81)h = 0 + \frac{1}{2}kh^2$$

$h = 0.400$ m

2 (a)

$$\text{gradient} = \frac{2.50-1.25}{12.0-6.0} = \frac{1.25}{6}$$

using $y = mx + c$, and substituting $(12.0, 2.50)$ into the eqn,

$$2.50 = \left(\frac{1.25}{6}\right)(12.0) + c$$

$c = 0$

Since y-intercept is zero and the graph is a straight line, I is proportional to V.

(You can also use two sets of readings and show that $\frac{V_1}{I_1} = \frac{V_2}{I_2}$)

(b) **(i)** resistance of $X = \frac{R}{I} = \frac{12}{2.5} = 4.8\ \Omega$

(ii) **1.** $I_{AB} = \frac{12}{4.0 + 5.0} = 1.33$ A

2. $I_X = \frac{12}{4.8 + 2.7} = 1.60$ A

(iii) $R_{AC} = \frac{3}{4} R_{AB} = 3.0\ \Omega$

potential difference acoss AC, $V_{AC} = 3.0 \times 1.33 = 3.99$ V

$\therefore$ potential at pt C, $V_c = 12 - 3.99 = 8.01$ V

potential difference across X, $V_X = 4.8 \times 1.6 = 7.68$ V

$\therefore$ potential at pt D, $V_D = 12 - 7.68 = 4.32$ V

potential difference between CD, $V_{CD} = 8.01 - 4.32 = 3.69$ V

3 **(a)** For electrons to be emitted from M, each photon of electromagnetic radiation must lose its energy ($E = hf$) completely to an electron and this energy must be equal to or more than the minimum energy required to release an electron from M, i.e. the work function.

(b) **(i)** The electrons are emitted from M with a range of kinetic energies. In order to reduce current to zero, a minimum potential difference, V_s is needed to convert the kinetic energy of the most energetic electrons into electrical potential energy before they reach C.

Note (not required in answer):
At all pd > V_s, there would still be some electrons reaching plate C

(ii) When V is positive, all the emitted electrons are attracted to electrode C. Hence the current is at a maximum and there is no further increase in current.

Note (not required in answer):
Current depends on rate of emission of electrons from plate M only. Even if V is made more positive, the number of electrons emitted per unit time remains unchanged as it depends on the intensity of the incident radiation.

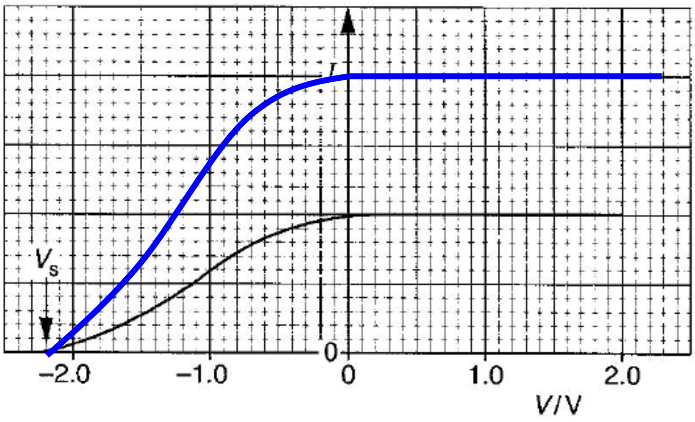
(c) From Fig. 3.2, $|V_s|$= 2.20 V

$$hf = \phi + eV_s$$

$$6.63 \times 10^{-34} \times f = 1.8 \times 1.6 \times 10^{-19} + 1.6 \times 10^{-19} \times 2.20$$

$$f = 9.65 \times 10^{14}\ \text{Hz}$$

(d)



The maximum current should be doubled. –B1
Minimum V_s remains the same. – B1

4 **(a)**

$$a_c = r\omega^2$$
$$= \left(4.22\times10^5\times10^3\right)\left(\frac{2\pi}{1.53\times10^5}\right)^2$$
$$= 0.712 \text{ m s}^{-2}$$

(b) **(i)** At the position of the moon, the gravitational force due to Jupiter is the only force acting on the moon. Hence, the gravitational force acts as the centripetal force of the moon. Hence, $F_G = F_C$.

Since the gravitational force is due to the gravitational field strength ($F_G = Mg$) and the centripetal force causes centripetal acceleration ($F_C = Ma_c$), $g = a_C$, i.e., both gravitational field strength and centripetal acceleration have the same magnitude and direction.

(ii)

$$a_c = g = \frac{GM}{r^2}$$
$$\therefore \left(\frac{r_o}{r_a}\right)^2 = \left(\frac{g_a}{g_o}\right)$$
$$\frac{r_o}{r_a} = \sqrt{\frac{g_a}{g_o}} = \sqrt{\frac{3.87}{0.712}}$$
$$= 2.33$$

5 **(a)** **(i)**

$$F_{\text{on A due to field}} = Q_A E$$
$$= 2\left(1.6\times10^{-19}\right)\left(1.5\times10^5\right)$$
$$= 4.8\times10^{-14} \text{ N}$$

(ii)

$$F_{\text{on A due to B}} = \frac{Q_A Q_B}{4\pi\varepsilon_0 r^2}$$
$$= \frac{\left[2\left(1.6\times10^{-19}\right)\right]^2}{4\pi\varepsilon_0\times(4.0\times10^{-12})^2}$$
$$= 5.75\times10^{-5} \text{ N}$$

(b) The electrostatic force on B due to A is equal and opposite to that on A due to B. Hence they add up to zero.

Also, since A and B carry charges of equal magnitude but opposite in sign, the force on both charges due to the external electric field are also equal and opposite. Hence, there is no net force on the molecule due to the field.

Resultant force on the system of two charges = 0 + 0 = 0.

(c) Torque = $F \times d$
$= 4.80 \times 10^{-14} \times 4.0 \times 10^{-12} \times \sin 60°$
$= 1.66 \times 10^{-25}$ Nm

6 **(a)** ${}^{128}_{54}\text{D}$

(b)
$$C = C_o e^{-\lambda t}$$
$$\frac{C_{t=2000s}}{C_{t=6000s}} = \frac{e^{-2000\lambda}}{e^{-6000\lambda}}$$
$$\ln\left(\frac{175}{28}\right) = -2000\lambda - (-6000\lambda)$$
$$= 4000\lambda$$
$$= 4000\left(\frac{\ln 2}{t_{1/2}}\right)$$
$$t_{1/2} = 1512 \text{ s}$$
$$\approx 1510 \text{ s}$$

7 **(a)** **(i)** If k, M and b are constant and $s = -3$, then

$$\frac{y_1}{y_2} = \left(\frac{d_1}{d_2}\right)^{-3} = \left(\frac{5.00}{6.00}\right)^{-3} = 1.728$$

For l = 0.400 m, $\frac{y_1}{y_2} = \frac{0.021}{0.012} = 1.75$

For l = 0.600 m, $\frac{y_1}{y_2} = \frac{0.073}{0.042} = 1.74$

For l = 0.900 m, $\frac{y_1}{y_2} = \frac{0.257}{0.148} = 1.74$

Since $\frac{y_1}{y_2} \approx 1.728$ for all three values of l, we conclude that $s = -3$.

(ii)

ln (y_1 / m)	ln (l / m)
–3.170	–0.693

(iii) Correct plot
Correct best fit line

(iv) Using points, (-0.12, -1.40) and (-0.80, -3.52)

Gradient = $\dfrac{-3.52-(-1.40)}{-0.80-(-0.12)} = 3.12$

(v) From the given expression $y = k\,Mg\,l^r\,d^s\,b^{-1}$

$\ln y = r \ln l + \ln (k\,M\,g\,d^s\,b^{-1})$

The graph supports the expression since it is a straight line graph where the gradient is r and y-intercept is $\ln (k\,M\,g\,d^s\,b^{-1})$.

(vi) r = gradient = 3 (nearest integer)

(b) Using (–0.12, –1.40)

$$\ln y = r\ln l + \ln\left(kMgd^{-3}b^{-1}\right)$$

$$(-1.40) = (3.12)(-0.12) + \ln\left(\frac{k(0.500)(9.81)}{(5.00\times10^{-3})^3(3.00\times10^{-2})^1}\right)$$

$$-1.0256 = \ln\left(\frac{k(0.500)(9.81)}{(5.00\times10^{-3})^3(3.00\times10^{-2})^1}\right)$$

$$\left(\frac{k(0.500)(9.81)}{(5.00\times10^{-3})^3(3.00\times10^{-2})^1}\right) = e^{-1.0256}$$

$$k = 2.7\times10^{-10} \approx 3\times10^{-10}$$

(c) **(i)** Since b, k, M, d, l, s and r are all constant, The equation given shows that the acceleration of the load is always directly proportional to the displacement and is opposite in direction to the displacement.

The motion is therefore simple harmonic.

(ii)

$$\omega^2 = \left(\frac{2\pi}{T}\right)^2 = \frac{3.00\times10^{-2}}{(3\times10^{-10})(0.500)(5.00\times10^{-3})^{-3}(0.600)^3}$$

$$T = 0.584\text{ s}$$

Paper 3 Structured Questions

1 **(a)** Resultant force acting on the system is zero, i.e., translational equilibrium.

Resultant torque/moment on the system about any axis is zero, i.e., rotational equilibrium.

(b) **(i)** A ball falling vertically with constant speed experiences zero acceleration. Therefore, the resultant force acting on the ball is zero.

So the ball is in equilibrium.

(ii) For the satellite to perform circular motion around the Earth, the satellite must experience a centripetal acceleration (toward the centre of the Earth).
The centripetal acceleration is provided by the gravitational force between the Earth and satellite.
Therefore, a resultant force acts on the satellite and hence it is not in equilibrium.

2 **(a)** Since $x = \frac{\lambda D}{a}$,

$$\lambda = \frac{xa}{D} = \frac{1.4 \times 10^{-3} \times 0.95 \times 10^{-3}}{2.1}$$
$$= 6.33 \times 10^{-7} \text{ m}$$

(b) As the light from the two slits have unequal intensities, their amplitudes are not the same.

At positions of constructive interference (bright fringes), the resultant amplitude will be smaller than before due to the decreased amplitude of the dimmer slit. Hence, the bright fringes become less bright.

At the positions of destructive interference (dark fringes), there will not be complete cancellation due to the unequal amplitudes of the light from the two slits. Hence, the dark fringes are not completely dark.

Hence, the contrast of the fringe pattern will be reduced compared to the original one.

(c) The diffraction of light passing through the wider slits decreases.

There is little or no overlapping of the diffracted light such that no interference takes place. Hence no fringes are observed.

3 **(a)** Using $E = IR_{total}$,

$$E = I\left(R_T + 1500\right)$$

Rearranging,

$$R_T = \frac{E}{I} - 1500 = \frac{6.00}{1.60 \times 10^{-3}} - 1500 = 2250\ \Omega$$

From the graph,

$$t = 14.0^\circ\text{C}$$

(b) As temperature increases, the resistance of the thermistor decreases as seen in Fig. 3.2.

This causes an increase in the current as the total resistance of the circuit decreases.

As a result, there is an increased heating effect through the thermistor which would eventually damage it

Comment:
The cooling fins are employed to improve heat dissipation so that thermal equilibrium with the surrounding is attained at a lower temperature.

4 **(a)** One tesla is the uniform magnetic flux density which, acting normally to a long straight wire carrying a current of 1 ampere, causes a force per unit length of $1\ \text{N m}^{-1}$ on the conductor.

(b) **(i)** Inside the magnetic field, the particle experiences a magnetic force that is always perpendicular to its velocity. The force causes an acceleration which changes the direction of motion of the particle but the speed remains constant.

Since the magnitude of the force (dependent on speed) remains constant, the radius of curvature of the arc is constant.

(ii) Since the particle travels in a circular arc,

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

Rearranging,

$$\begin{aligned} mv &= Bqr \\ &= 0.24 \times 1.6 \times 10^{-19} \times 0.062 \\ &= 2.38 \times 10^{-21}\ \text{N s} \end{aligned}$$

(c)

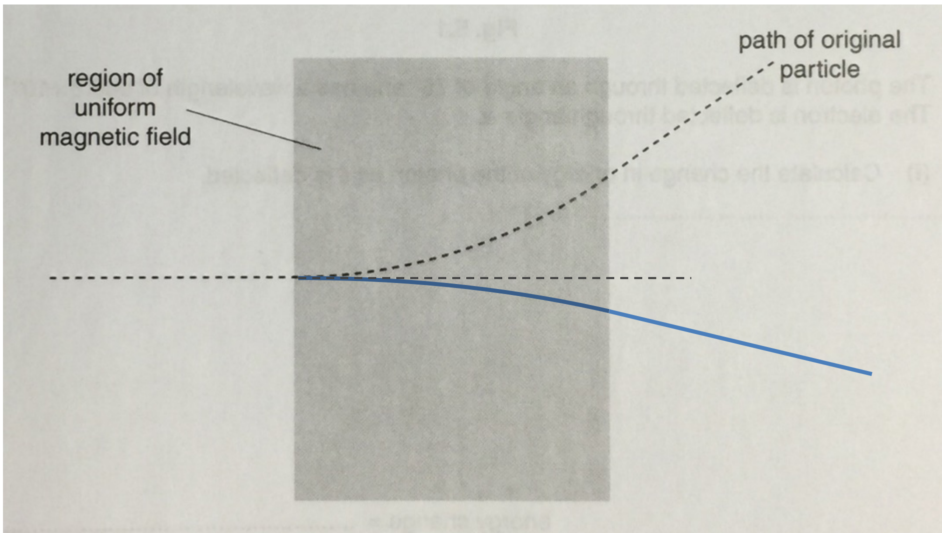


Fig. 4.2

1. Opposite in direction
2. Arc of larger radius
3. Smooth, straight path outside magnetic field

5 **(a)** A photon is a quantum of electromagnetic radiation or energy.

(b) **(i)** Change in energy of photon

$$\Delta E = \frac{hc}{\lambda'} - \frac{hc}{\lambda}$$
$$= 6.63 \times 10^{-34} \times 3.00 \times 10^{8} \times \left(\frac{1}{966.8 \times 10^{-12}} - \frac{1}{965.0 \times 10^{-12}} \right)$$
$$= -3.84 \times 10^{-19}\ \text{J}$$

(ii) By conservation of energy, the gain in kinetic energy of electron equals the loss in energy by photon,

$$E_K = 3.84 \times 10^{-19}\ \text{J}$$

So momentum of electron

$$p = \sqrt{2mE_K}$$
$$= \sqrt{2 \times 9.11 \times 10^{-31} \times 3.84 \times 10^{-19}}$$
$$= 8.36 \times 10^{-25}\ \text{N s} \qquad \text{[shown]}$$

(c) The total momentum of the system at right angles to the direction of the incident photon is always zero due to principle of conservation of momentum.

So the magnitude of the upward momentum of the photon is equal to the downward momentum of the electron.

$$\frac{h}{\lambda} \cdot \sin 75° = p \sin \alpha$$

Rearranging,

$$\alpha = \sin^{-1}\left(\frac{h}{p\lambda} \cdot \sin 75° \right)$$
$$= \sin^{-1}\left(\frac{6.63 \times 10^{-34}}{8.36 \times 10^{-25} \times 966.8 \times 10^{-12}} \cdot \sin 75° \right)$$
$$= 52.4°$$

6 **(a)** **(i)** Acceleration is the rate of change of velocity with respect to time.

(ii) At positions near the surface of the Earth, the distance from the centre of the Earth does not change significantly due to the very large radius of the Earth.
Since the gravitational field strength g at a point is inversely proportional to the square of the distance of the point from the centre of the Earth, g is approximately constant for distances close to the surface of the Earth.
The acceleration of free fall at a point is numerically equal to the gravitational field strength at the point. Hence, the acceleration is constant.

Comment
The rotation of Earth is ignored as geographical location was not mentioned.

(b) **(i)** The steel ball is very small and has a small cross sectional area and surface area. Hence, the drag force on it may be neglected.

(ii) **1.** Using $s = ut + \frac{1}{2}at^2$,

$$0.441 = \tfrac{1}{2} \times 9.81 \times t^2$$

So

$$t = \sqrt{\frac{2 \times 0.441}{9.81}} = 0.300 \text{ s}$$

2. Displacement of top of the steel ball from point of release is 55.4 cm.

$$t' = \sqrt{\frac{2 \times 0.554}{9.81}} = 0.336 \text{ s}$$

So $T = 0.336 - 0.300 = 0.036$ s

(c) Percentage uncertainty

$$\frac{\Delta T}{T} \times 100\% = \frac{0.003}{0.033} \times 100\%$$
$$= 9.1\%$$

(d) **(i)** The vertical displacement is less than 44.1 cm.

Hence the time of fall is shorter than that in **(b)(ii)1**.

(ii) Due to the residual magnetic effect, there is an upward magnetic force acting on the ball at the beginning of the fall.

So acceleration of the ball a short distance after release is lower than g. Hence it will take a longer time for the ball to fall to 44.1 cm mark.

(e) When the ball is first released, it does not experience any air resistance and its acceleration is g.

With increasing speed, the drag force on the ball due to air resistance increases. As a result, the net force on the ball decreases causing the acceleration of the ball to decrease.

Eventually, the drag force becomes numerically equal to the weight of the ball. There is no net force on the ball and its acceleration is zero.

7 **(a)** **(i)** **1.** Peak potential difference

$$V_0 = \sqrt{2}V_{\text{rms}} = \sqrt{2} \times 17$$
$$= 24.0 \text{ V or } 24 \text{ V}$$

2. Frequency of supply

$$f = \frac{\omega}{2\pi} = \frac{380}{2\pi}$$
$$= 60.5 \text{ Hz or } 60 \text{ Hz}$$

(ii) The heating effect in the coil, $\langle P \rangle$, depends on the root mean square (rms) current, $I_{rms}{}^2$ which is the equivalent value of a steady direct current that would produce the same average power dissipation in the coil.

$$\underline{\langle P \rangle = I_{rms}{}^2 R}$$

where R is the resistance of the coil.

The average current is zero as the current is *alternating* in direction. But the rms current has a non-zero value.

(b) **(i)** The numerical value of the specific heat capacity of a substance is the quantity of heat required to raise the temperature of unit mass of the substance by one degree.

(ii) The intercept on the power axis suggests that there is heat loss to the surrounding through conduction or radiation.

(Note:
$P = mc\Delta T +$ rate of heat loss
When m = 0, P = rate of heat loss)

(iii) Solution 1:
Since $P = mc\Delta\theta + P_{\text{loss}}$, rearranging, we obtained

$$m = \frac{1}{c\Delta\theta}P - \frac{1}{c\Delta\theta}P_{\text{loss}}$$

The gradient of the graph of m against P is

$$\frac{1}{c\Delta\theta} = \frac{(3.50 - 1.80) \times 10^{-3}}{70.0 - 43.0} = 6.30 \times 10^{-5}$$

Therefore

$$c = \frac{1}{6.30 \times 10^{-5} \times 3.8} = 4180 \text{ J kg}^{-1} \text{ K}^{-1}$$

Solution 2:
Since $P = mc\Delta\theta + P_{\text{loss}}$, then

$$70.0 = 3.50 \times 10^{-3} c\Delta\theta + P_{\text{loss}} \quad (1)$$

$$43.0 = 1.80 \times 10^{-3} c\Delta\theta + P_{\text{loss}} \quad (2)$$

(1) – (2): $27.0 = 1.70 \times 10^{-3} c\Delta\theta$

$$c = \frac{27.0}{1.70 \times 10^{-3} \times 3.8} = 4180 \text{ J kg}^{-1} \text{ K}^{-1}$$

(c) A parallel line with a greater power intercept.

(same gradient, larger horizontal intercept because rate of heat loss depends on temperature difference between object and the surroundings)

(d) **(i)** The First Law of Thermodynamics states that the increase in the internal energy (ΔU) of a system is the sum of the work done on the system (W) and heat supplied to the system (Q) and the internal energy of a system depends only on its state.

(ii) According to the first law of thermodynamics, increase in internal energy ΔU is equal to the sum of the work done W on the system and the heat supplied Q to the system. i.e. $\Delta U = Q + W$, or $Q = \Delta U - W$

If two identical gases of unit mass are caused to have a unit rise in temperature, their increase in internal energy ΔU is the same.

At constant pressure, the heated gas is allowed to expand so that W is negative and therefore $Q > \Delta U$.

At constant volume, work done W is zero and therefore $Q = \Delta U$.

Since specific heat capacity is defined as the energy required to produce a unit rise in temperature in a unit mass of an object , the specific heat capacity at constant pressure is higher than that at constant volume.

8 (a) (i) Simple harmonic motion is defined as the motion of a particle about a fixed point such that its acceleration is proportional to its displacement from the fixed point and is directed towards that fixed point.

(ii) 1. The graph shows that the acceleration of the ball is always opposite in sign to its displacement.

This means that when the ball is displaced to the right, it will accelerate to the left; and when it is displaced to the left, it will accelerate to the right. Hence, it will be an oscillatory motion.

2. The graph shows that the acceleration of the ball is not proportional to its displacement from $x = 0$ as it is not a straight line passing through the origin.

(b) (i) 1. A longitudinal wave is one in which its particles oscillate in a direction parallel to the direction of energy transfer.

2. The speed of the wave is the distance travelled per unit time by the wave front.

(ii) 1. Period

$$T = \frac{1}{f} = \frac{1}{835}$$
$$= 1.20 \times 10^{-3} \text{ s}$$

2. Time interval

$$t_2 - t_1 = \tfrac{1}{2}T = 6.00 \times 10^{-4} \text{ s}$$

3. Maximum speed

$$v_{\max} = \omega x_0 = 2\pi \times 835 \times 610 \times 10^{-9}$$
$$= 3.20 \times 10^{-3} \text{ m s}^{-1}$$

4. Maximum vibrational kinetic energy

$$E_{max} = \tfrac{1}{2} m v_{max}^2 = \tfrac{1}{2} \times 5.3 \times 10^{26} \times \left(3.20 \times 10^{-3}\right)^2$$
$$= 2.71 \times 10^{-31} \text{ J}$$

(iii) The speed of vibration of air particles is much less than the speed of sound (~340 m s^{-1}).

This implies that when sound energy is transferred in a medium, the air particles themselves do not get transmitted with the wave. The air particles only oscillate about their equilibrium positions.

(c) **(i)** Vibration of a surface (e.g. diaphragm of speaker or the surface of a drum).

(ii) Pressure differences due to the proximity of air particles as they are made to oscillate due to the vibration of a surface.