Question 1

(a)

$$V = \frac{2\pi r}{T}$$

$$= 2\pi \frac{26 \times 1\,\text{year} \times 3\times10^8}{240\times10^6 \times 1\,\text{year}}$$ ✓ appropriate units converted, or as shown,

$$= 2\pi \times \frac{78\times10^8}{2.4\times10^8}$$ ✓ correct ratio, or evaluated.

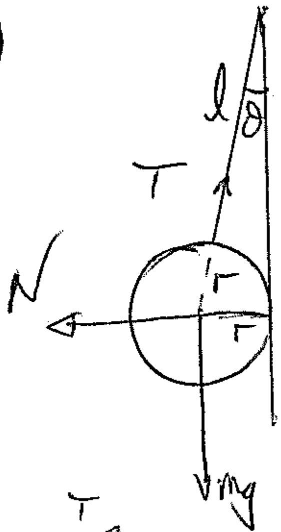
$$= 2\pi \times 32.5$$

$$= \underline{204\ \text{ms}^{-1}} = \underline{200\ \text{ms}^{-1}}$$ ✓

$$= \underline{65\pi\ \text{ms}^{-1}}$$

(3)

(b)



Smooth wall: mg through centre,
so N through centre
so T through centre.

so $\sin\theta = \frac{r}{r+l}$

$$= \frac{6}{6+9} = \underline{0.4}$$ ✓

Resolving vertically: $mg = T\cos\theta$ ✓

$$T = \frac{mg}{\cos\theta} = \frac{0.5\times9.81}{\cos 23.6^\circ}$$

$$= 5.35 = \underline{5.4\ N}$$ ✓

Angle wrong, lose a mark if used correctly.

(3)

(c) (i) $\frac{ds}{dt} = 6t^2 - 18t + 12$

$\dot{s} = 0 \Rightarrow \quad t_0^2 - 3t_0 + 2 = 0$

$t_0 = 1\,s,\ 2\,s$

(ii) $\frac{d^2s}{dt^2} = 12t - 18$

$\ddot{s} = 0 \Rightarrow \quad t_{a=0} = \frac{3}{2} = 1.5\ s$

(iii) $\dot{s}$ at $t = \frac{3}{2}\,s$

$\dot{s}_{a=0} = V = 6\left(\frac{3}{2}\right)^2 - 18\cdot\frac{3}{2} + 12$

$= -\frac{3}{2} = -1.5\ ms^{-1}$

(iv) $\ddot{s}$ at $t = 1\,s, 2\,s.$

$a_1 = 12t - 18 = -6\ ms^{-2}$

$a_2 = 12t - 18 = +6\ ms^{-2}$

4

(d) Substituting $\quad 100 = a.40 + b.40^2$ ①

$280 = a.80 + b.80^2$ ②

①×2 and subtract $\quad 80 = b(80^2 - 2.40^2)$

$1 = b(80 - 40)$

$b = \frac{1}{40}\ \frac{m}{(km\,h^{-1})^2}.$

In eqn. ① $\quad 100 = a.40 + \frac{1}{40}.40^2$

$a = 1.5\ \frac{m}{km\,h^{-1}}$

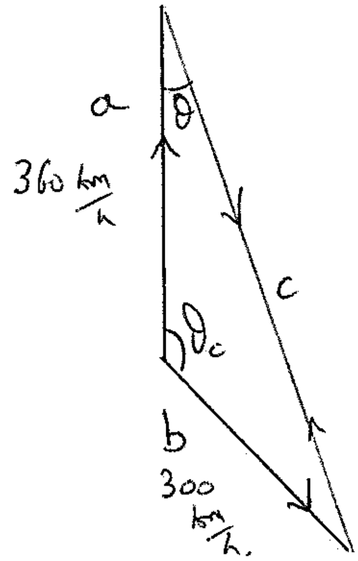
Now $\quad 500 = 1.5V + \frac{1}{40}.V^2$ — correct approach here even if a, b incorrect.

$40.500 = 60V + V^2 \Rightarrow V^2 + 60V - 20000 = 0$

$V = 114.6 = 115\ km/h$

$(\equiv 31.8\ ms^{-1} \approx 32\ ms^{-1})$ 4

(e)



Diagram

length, $a = \frac{2}{3} \times 360 = 240$ km

$b = \frac{2}{3} \times 300 = 200$ km

$\theta_c = 90 + 45 = 135°$

Cosine rule.

$c^2 = 240^2 + 200^2 - 2 \cdot 240 \cdot 200 \cos 135$

$c = 406.80$ km

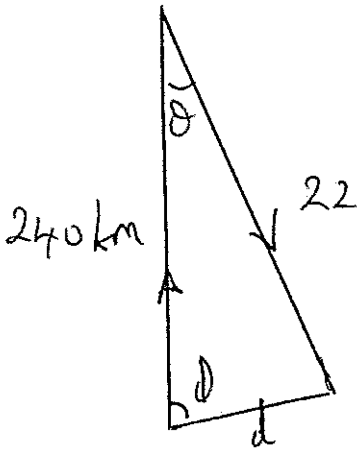
combined speed of approach along c is 660 km/h.

Time taken to meet is $\frac{406}{660} = 0.616$ h

$= 36.98$ minutes

In this time, plane 'a' travels $360 \times 0.616 = 221.9$ km

meeting point found.



From the top diagram using sine rule

$\frac{c}{\sin 135} = \frac{b}{\sin\theta}$ $\theta = 20.34°$

Then cosine rule,

$d^2 = 240^2 + 221.9^2 - 2 \cdot 240 \cdot 221.9 \cos 20.34°$

$d = 83.5$ km

Then $\frac{d}{\sin\theta} = \frac{221.9}{\sin\phi}$ $\phi = 67.5°$

[Need find two answers for 7 marks.
Either one or other gives 6 marks].

7

(f) $M = m_n$ $\quad 2m = m_d$.

n $\xrightarrow{u_0}$ deuteron

(i) Cons. of Mom. $\quad Mu_0 = m_d V_d + m_n V_n$

$$u = 2V_d + V_n \qquad (1)$$

Cons. of KE $\quad \frac{1}{2} Mu^2 = \frac{1}{2} 2m V_d^2 + \frac{1}{2} m V_n^2$

$$u^2 = 2V_d^2 + V_n^2 \qquad (2)$$

Solve: from (1), $\quad u - V_n = 2V_d \qquad (3)$

(2), $\quad (u - V_n)(u + V_n) = 2V_d^2 \qquad (4)$

Since $u \neq V_n$ or V_d is zero and there has been no interaction, then divide (3) and (4) to obtain $u + V_n = V_d$

With (3) to eliminate V_n, $\quad u - 2V_d = V_n = V_d - u$

$$2u = 3V_d$$

$$\frac{V_d}{u} = \frac{2}{3}$$

(ii) Initial KE is $\frac{1}{2} mu^2$

deuteron KE is $\frac{1}{2} 2m . V_d^2 = \frac{1}{2} 2m \frac{4}{9} . u^2$

$$\therefore \frac{KE_d}{KE_0} = \frac{8}{9} = 89\% = 0.889$$

(iii) $\frac{8}{9} KE_0$ is given to deuteron.

$\frac{1}{9} KE_0$ left with neutron after each collision.

After N collisions, $\left(\frac{1}{9}\right)^N . \times 10 \times 10^6 \text{ eV} = 10^{-2} \text{ eV}$

$$\frac{1}{9^N} = 10^{-9}$$

$$9^N = 10^9$$

$$N \log_{10} 9 = 9$$

$$N = 9.4.$$

$\therefore$ 10 collisions required

(This result is for head on collisions, but is similar to the general result)

6

(g)

R = weight of chain on table + rate of change of momentum. ✓
(ignore ± sign for direction of R).

In free fall, the links of the chain are accelerating down at the same rate so there is no force acting between the links. i.e. there is no tension to consider in the chain.

Starting from rest, when a length l of chain has fallen, it arrives at the table at speed v, and for const. accel, ✓
$$v^2 = 2gl.$$

Now, force due to impact, $F = \frac{dp}{dt} = V\frac{dm}{dt}$

[in a short time interval a mass dm arrives, but V changes to $V+dV \simeq V$]

so $F = \sqrt{2gl} \cdot \frac{(\mu V dt)}{dt}$ $= \mu V^2$

$F = 2gl\mu$ $= \underline{\mu g^2 t^2}$ ["$V = at$"].

$= 2g\mu \cdot \frac{1}{2}gt^2$

["$s = \frac{1}{2}at^2$"]

$$\underline{F = \mu g^2 t^2}$$ ✓

Weight of chain on table, is $\mu l g$ ✓
$= \mu \frac{1}{2} g^2 t^2$

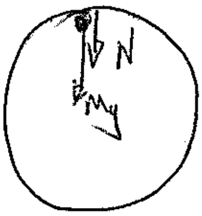
so $R =$ weight + rate of mom. change
$= \mu g^2 t^2 (\frac{1}{2} + 1)$

$R_{max} = \frac{3}{2} \mu g^2 t_{fin}^2$
$= \underline{3W}$ ✓ occurs at end of fall ✓

[there are several ways of solving this question]

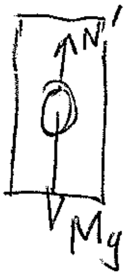
(6)

(h)



Resolving forces on the particle at the top,

$$N + mg = \frac{m v_{top}^2}{r}$$ ✓



For the block, the minimum force N' to raise the block is $N' = Mg$ ✓

by NIII, $N \cancel{+} N' = 0$

Hence $$Mg + mg = \frac{m v_{top}^2}{r}$$

and so $$v_{top}^2 = \frac{(M+m)gr}{m}$$ ✓

From conservation of Energy, for the particle, (object M may only move with negligible KE as we are finding the limiting speed).

$$\tfrac{1}{2} m v^2 = mg2r + \tfrac{1}{2} m v_{top}^2$$ ✓

i.e. $v^2 = 4gr + v_{top}^2$

Hence
$$\begin{aligned} v^2 &= 4gr + \frac{(M+m)gr}{m} \\ &= 4gr + \left(\frac{M}{m} + 1\right)gr \\ &= 5gr + \frac{M}{m} \cdot gr \\ &= gr\left(5 + \frac{M}{m}\right) \end{aligned}$$ any of these ✓

5

(i)

(i) By Kirchhoff II,

$$I = \frac{\text{sum of emfs}}{\text{sum of series resistors}}$$

$$= \frac{2.0 + 1.5}{5.0 + 3.0 + 1.0 + 0.5}$$

$$= \frac{7}{19} = 0.368 = \underline{\underline{0.37 \text{ A}}}.$$ ✓

(ii)

$$V_{2.0} = \mathcal{E} - Ir$$

$$= 2.0 - \frac{7}{19} \cdot 1$$

$$= \underline{\underline{1.6(3) \text{ V}}}$$ ✓

$$V_{1.5} = 1.5 - \frac{7}{19} \times 0.5$$

$$= \underline{\underline{1.3(2) \text{ V}}}$$ ✓

(iii)

$$\left.\begin{aligned} V_A &= +\frac{7}{19} \times 5 = +\underline{\underline{1.8(4) \text{ V}}} \\ V_B &= -\frac{7}{19} \times 3 = \underline{\underline{-1.1(1) \text{ V}}} \end{aligned}\right\} \text{both.}$$ ✓

sign required.

(4)

(j)

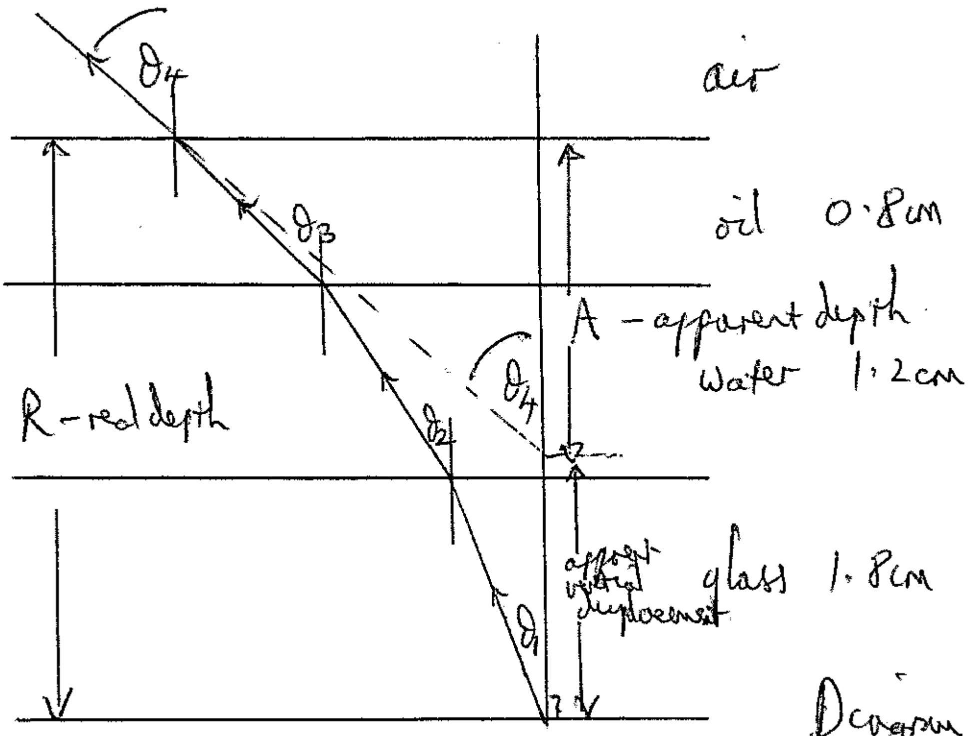


Diagram ✓ with ray drawn.
$\theta_1 < \theta_2 < \theta_3 < \theta_4$, and indication of apparent depth }. ✓

From Snell's Law.

$$1.5 \sin\theta_1 = 1.3 \sin\theta_2$$
$$1.3 \sin\theta_2 = 1.1 \sin\theta_3$$
$$1.1 \sin\theta_3 = 1.0 \sin\theta_4$$

✓

So, $\sin\theta_4 = 1.5 \sin\theta_1$

Now, $A \cdot \tan\theta_4 = 1.8 \sin\theta_1 + 1.2 \sin\theta_2 + 0.8 \sin\theta_3$ ✓

$$= \frac{1.8}{1.5}\sin\theta_4 + \frac{1.2}{1.3}\sin\theta_4 + \frac{0.8}{1.1}\sin\theta_4$$

For small angles, $\tan\theta_4 \simeq \sin\theta_4$ ✓

$$\therefore A = \frac{1.8}{1.5} + \frac{1.2}{1.3} + \frac{0.8}{1.1}$$
$$= \underline{2.85 \text{ cm}}$$

$R = 1.8 + 1.2 + 0.8 = \underline{3.8 \text{ cm}}$

Hence, vertical displacement is $\underline{0.95 \text{ cm}}$ } any two of these ✓✓

(7)

Alternative solution

Diagram required – Diagram ✓ with ray drawn

$\theta_1 < \theta_2 < \theta_3 < \theta_4$ and indication of apparent depth } ✓

A_g apparent depth in glass $= \frac{n_w}{n_g} \cdot R_g \leftarrow$ real depth in glass. ✓

Then,

$$A_w = \frac{n_{oil}}{n_w}\left(R_w + A_g\right)$$

$$A_{oil} = \frac{n_{air}}{n_{oil}}\left(R_{oil} + A_w\right)$$

Putting these together,

$$A = A_{oil} = \frac{n_{air}}{n_{oil}}\left(R_{oil} + \frac{n_{oil}}{n_w}\left(R_w + \frac{n_w}{n_g}R_g\right)\right). \checkmark$$

$$= \frac{n_{air}}{n_{oil}} \cdot R_{oil} + \frac{n_{air}}{n_w} R_w + \frac{n_{air}}{\cancel{n_{oil}}} \cdot \frac{\cancel{n_{oil}}}{\cancel{n_w}} \cdot \frac{\cancel{n_w}}{n_g} \cdot R_g$$

$$= \frac{R_{oil}}{n_{oil}} + \frac{R_w}{n_w} + \frac{R_g}{n_g} \checkmark$$

$$= \frac{0.8}{1.1} + \frac{1.2}{1.3} + \frac{1.8}{1.5}$$

$= \underline{2.85 \text{ cm}}$

$R = 1.8 + 1.2 + 0.8 = \underline{3.8 \text{ cm}}$

Vertical displacement $= \underline{0.95 \text{ cm.}}$

] any two of these ✓✓

(k)

Supply the same energy means the same $\underline{mgh}$ ✓

$$g_E = \frac{GM_E}{R_E^2}$$

$$M_E = \rho_E \cdot \frac{4}{3}\pi R_E^3$$

mark for either but not both.

$$\therefore \frac{g_E}{g_P} = \frac{G}{R_E^2} \cdot \rho_E R_E^3 \times \frac{R_P^2}{G\rho_P R_P^3}$$

✓ expression for g_E, g_P.

$$= \frac{\rho_E R_E}{\rho_P R_P}$$

$$= \frac{\rho_E}{\frac{2}{3}\rho_E} \cdot \frac{R_E}{2R_E}$$

$$= \frac{3}{4}.$$ ✓

And $g_E h_E = g_P h_P$

So, $\frac{h_P}{h_E} = \frac{g_E}{g_P}$

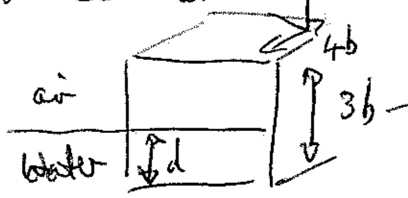
$$h_P = \frac{3}{4} \cdot 1$$

$$= \frac{3}{4} = 0.75 \text{ m}$$ ✓

(4)

$$g_P = G \cdot \frac{2}{3}\left(\frac{M}{R^3}\right) \cdot (2R) = \frac{4}{3} g_E.$$

(l) Method A. The oil has the same density of the block, so a height b of the block is neutrally buoyant in depth, d, of oil. So Consider only a block $3b$ high floating in water alone.



length of block is l.

$$\text{weight of block} = 3 \times 4 . b^2 . l \ \tfrac{2}{3} \rho . g$$

$$\text{weight of water displaced} = d . 4b . l \rho g$$

By Archimedes, these are equal in equilibrium.

$$\text{Hence} \quad \cancel{3} . \cancel{4} . b^2 \cancel{l} \ \cancel{\tfrac{2}{3}} \cancel{\rho g} = d . \cancel{4} b . \cancel{l} \cancel{\rho g}$$

$$d = 2b.$$

And b lies within the oil,

so $3b$ is submerged, $\underline{75\%}$.

(4)

Method B Including the oil.

$$\text{Weight of block} = \cancel{3} \times 4 . b^2 l . \tfrac{2}{3} \rho g$$

$$\text{Weight of liquid displaced} = \underset{\text{(oil)}}{b . 4b l \tfrac{2}{3} \rho g} + \underset{\text{(water)}}{d \, 4b l \rho g}$$

equating, as these two are equal in equilibrium by Archimedes.

$$\text{Then} \qquad b . \tfrac{2}{3} + d = 4b . \tfrac{2}{3}$$

$$d = 2b$$

and depth of oil is b.

so $3b$ is submerged, $\underline{75\%}$

(4)

(m) Assumption:
For the two systems at any given equal temperature, the cooling method is the same, so the rate of loss of thermal energy is the same at that temperature.
The time taken is proportional to the thermal energy lost. (assumption)
Not rate of energy loss $\propto T$ ✗

Water + calorimeter:

$$\Delta Q_{w+c} = \rho_w \cdot V_w \cdot c_w (40-15) + m_c \cdot c_c (40-15)$$

$$= 1.0 \times 80 \times 4.2 \times 25 + 150 \times 0.4 \times 25$$

$$= 8400 + 1500$$

$$= \underline{9900\ \text{J}}$$

$$\Delta Q_{e+c} = 0.8 \times 80 \times c_e (40-15) + 150 \times 0.4 \times 25$$

$$= 1600\, c_e + 1500$$

and using the rate of cooling assumption.

$$\Delta Q_{w+c} = R \times 12 \quad \text{at 'average' rate } R.$$

and $\Delta Q_{e+c} = R \times 8$

use of rate to relate cooling.

So $\frac{12}{8} = \frac{99\cancel{00}}{16\cancel{00}c_e + 15\cancel{00}}$

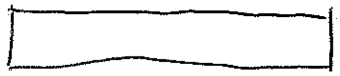
$\therefore 12 \cdot 16\, c_e + 12 \cdot 15 = 8 \cdot 99.$

$$c_e = \frac{612}{192} = 3.19\ \frac{\text{J}}{\text{g}\,^\circ\text{C}}$$

$$= \underline{3190\ \frac{\text{J}}{\text{kg}\,^\circ\text{C}}}$$

5

(m)



girder expands by δl with a temp inc. linear exp. $= \frac{\delta l}{l} \cdot \frac{1}{\Delta T}$

$$\delta l = \text{linear exp} \times l \, \Delta T$$
$$= 1.2 \times 10^{-7} \times 4.0 \times (20 - 5)$$
$$= \underline{7.2 \times 10^{-6} \text{ m}}$$ ✓

Young Modulus, $E = \frac{F}{A} \frac{1}{\delta l / l} = \frac{F}{A} \frac{l}{\delta l}$.

$$\therefore F = \frac{E A \delta l}{l}$$

correct unit change ✓

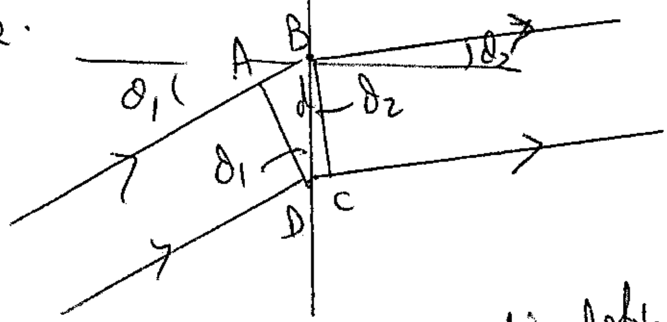
$$= 2.0 \times 10^{11} \times (30 \times 10^{-4}) \times \frac{7.2 \times 10^{-6}}{4.0}$$
$$= 1080 \text{ N}$$
$$= \underline{\underline{1100 \text{ N}}}$$ ✓

Idea relating the thermal expansion, δl, to the compressive force via Young Modulus ✓

(4)

(c) Alternative on next page.

(i)



[angles marked labelled
rays parallel ✓
• proper legible diagram ✓

Separation of slits, $d = \frac{1}{1.2\times10^6}$ m

(ii) path difference $= AB - CD$.

$= d(\sin\theta_1 - \sin\theta_2)$

$= n\lambda$ for maxima. ✓

(iii) for $\sin\theta_1 - \sin 73^\circ = n\lambda\, 1.2\times10^6$

and $\sin\theta_1 - \sin 14^\circ = (n\pm1).\lambda.\, 1.2\times10^{-6}$

Subtracting. $-\sin 14^\circ + \sin 73^\circ = \pm1.\lambda.1.2\times10^{-6}$

Thus $\sin 73^\circ - \sin 14^\circ = +1.\lambda.1.2\times10^{-6}$ ✓

So $\lambda = 595$ nm

(iv) $\boxed{\lambda\times1.2\times10^{-6} = 0.714}$

Hence $\sin\theta_1 = \sin 73^\circ + 0.714.n$ — No positive value of n works.

and $\sin\theta_1 = \sin 14^\circ + 0.714(n\pm1)$

So the diffracted rays must be the other side of the normal (below the horizontal in the top diagram.

[See the diagram on the next page].

So, $\sin\theta_1 + \sin 73^\circ = 2\times0.714$ $(n=2)$

$\sin\theta_1 + \sin 14^\circ = 1\times0.714$ $(n=1)$

$\theta_1 = 28(2)^\circ$. ✓

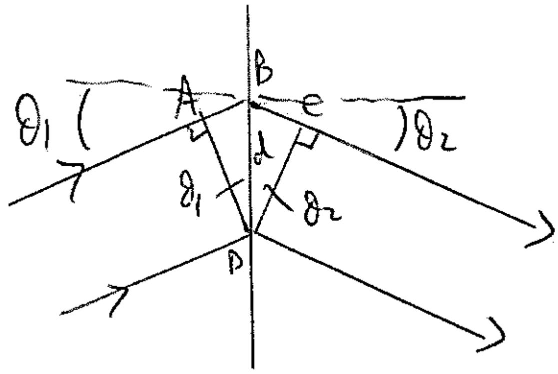
(v) For $n=3$, $\theta_2 > 90$ so no diffracted beam. ✓

Or, the undeflected beam emerging at $\theta_2 = 28^\circ$

(6)

Alternative

(i)



angles marked / labelled / parallel rays ✓

proper legible diagram ✓

(ii) separation of slits, $d = \frac{1}{1.2\times10^6}$ m

path difference $= AB + BC$

$= d(\sin\theta_1 + \sin\theta_2)$

$= n\lambda$ for maxima ✓

(iii) So, $\sin\theta_1 + \sin 73 = (n+1)\lambda \times 1.2\times10^6$

$\sin\theta_1 + \sin 14^\circ = n\lambda \times 1.2\times10^6$

subtracting $\sin 73 - \sin 14 = \lambda \times 1.2\times10^6$

$\underline{\lambda = 595 \text{ nm}}$ ✓

(iv) $(\lambda \times 1.2\times10^6 = 0.714)$

$\sin\theta_1 + \sin 14^\circ = n\, 0.714$

only possible value of n is 1 (or $\theta_1 > 90^\circ$)

$\sin\theta_1 = 1 \times 0.714 - \sin 14^\circ$

$\underline{\theta_1 = 28^\circ}$ ✓

(v) For $n = 3$ $\theta_2 > 90^\circ$. So no 3rd diffracted beam ✓

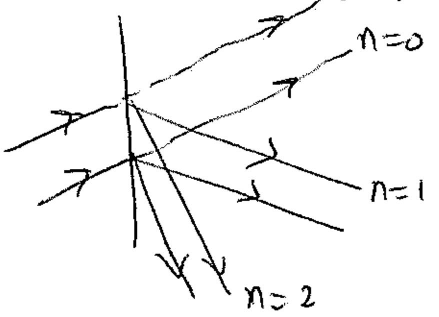
and none on the other side of the normal

as $\sin\theta_2 - \sin\theta_1 = n \times 0.714$

$1 - \sin 28 = 0.53$ so no n value possible.

or

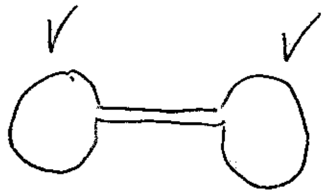
But the undiffracted beam at $\theta_2 = 28^\circ$ may be allowed as a 3rd beam. ✓



(6)

page 16

(p)



$100°C \rightarrow 50°C$ $\quad$ $100°C \rightarrow 150°C$

Initially, $\quad P_i \,.\, 2V = nRT_i \quad$ n is total moles of gas.

$$\text{so} \quad n = \frac{P_i \,.\, 2V}{RT_i}$$

Finally, $\quad n = \dfrac{P_f \,.\, V}{RT_{50}} + \dfrac{P_f V}{RT_{150}} \quad$ same final mass of gas.

Hence $\quad \dfrac{P_i 2V}{RT_i} = \dfrac{P_f V}{RT_{50}} + \dfrac{P_f V}{RT_{150}}$ $\quad$ ✓ relating initial and final through fixed mass (n) of gas.

$$\frac{2P_i}{T_i} = \frac{P_f}{T_{50}} + \frac{P_f}{T_{150}}$$

thus, $\quad \dfrac{2P_i}{P_f} = T_i\left(\dfrac{1}{T_{50}} + \dfrac{1}{T_{150}}\right) \quad$ ① $\quad$ ✓

And we also require the same P_f with temp T_f.

Then $\quad \dfrac{P_i 2V}{RT_i} = \dfrac{P_f 2V}{RT_f}$

so, $\quad \dfrac{P_i}{P_f} = \dfrac{T_i}{T_f} \quad$ ②

From ① and ②

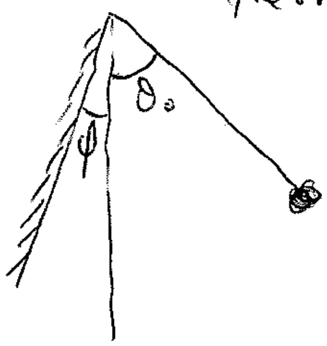
$$\frac{2T_i}{T_f} = T_i\left(\frac{1}{T_{50}} + \frac{1}{T_{150}}\right)$$

$$\frac{2}{T_f} = \frac{1}{323} + \frac{1}{423}$$ ✓ use of kelvin temperatures.

so that $\quad T_f = 366.3\ K$
$= 93.3°C$
$= 93°C$ $\quad$ ✓

4

(9) The small angles in the question mean this is SHM.



$\boxed{A}$ $\theta = \theta_0 \cos(\omega t)$ ✓

$[\theta = \theta_0 \text{ when } t = 0]$

$\omega = 2\pi f = \frac{2\pi}{T_0}$

Now, $-7 = 14 \cos\left(\frac{2\pi}{T_0} t\right)$ ✓

i.e. $-\frac{1}{2} = \cos\left(\frac{2\pi t}{T_0}\right)$ ✓

$\cos\frac{2\pi}{3} = \cos(120^\circ) = -\frac{1}{2}$ ✓

$\therefore$ $\frac{\cancel{2\pi}}{3} = \frac{\cancel{2\pi} t}{T_0}$

$t = T_0/3$ is the time to fall from $+14^\circ$ to -7°.

The full period is $2t = \frac{2}{3} T_0$. ✓ (4)

(or other methods).

$\boxed{B}$ Use of $\sin(\omega t)$. At $t = 0$, $\theta = 0$. $\theta = \theta_0 \sin \omega t$ ✓

So we want the time to rise from $\theta = 0$ to $\theta = 7^\circ$

$7^\circ = 14^\circ \sin\left(\frac{2\pi t}{T_0}\right)$ ✓

$\sin\frac{\pi}{6} = \frac{1}{2}$. ✓

$\therefore$ $\frac{\pi}{6} = \frac{2\pi t}{T_0}$

So $t = T_0/12$.

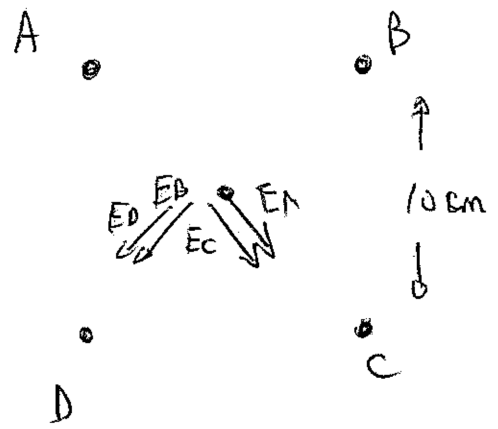
Double this to fall back down, and for the other half of the swing, add $T_0/2$.

So $t = 2 \times \frac{T_0}{12} + \frac{T_0}{2} = \frac{2}{3} T_0$ ✓

or variations on either of these approaches. (4)

(r)

(i)



Fields from A and C are parallel and along diagonal
" " B and D " " " " "

$$E_{AC} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{(10+12)\times10^{-9}}{(5\sqrt{2}\times10^{-2})^2}$$

$$= 8.99\times10^9 \frac{\times 22\times10^{-9}}{50\times10^{-4}} = \underline{39556\ N/C}$$

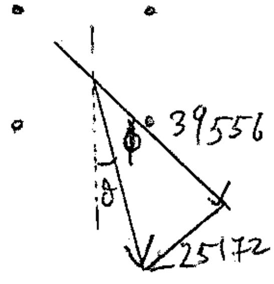
$$E_{BD} = \frac{1}{4\pi\varepsilon_0} \frac{(8+6)\times10^{-9}}{(5\sqrt{2}\times10^{-2})^2}$$

$$= 8.99\times10^9 \frac{(14)\times10^{-9}}{50\times10^{-4}} = \underline{25172\ N/C}$$

Resultant field strength $= \sqrt{E_{AC}^2 + E_{BD}^2}$

$= 46886\ N/C$

$= \underline{4.7\times10^4\ N/C}$



$$\tan\phi = \frac{25172}{39556}$$

$\phi = 32.5°$

$\therefore \underline{\theta = 12.5°}$

May quote as a bearing of 167° or 168°

May miss out the 8.99×10^9 of $\frac{1}{4\pi\varepsilon_0} \Rightarrow E_{total} = 4.7\ N/C$ (-1 mark)

or just use cm, losing a factor of 10^4 (-1 mark)

(ii)

$$V_{centre} = \frac{1}{4\pi\varepsilon_0} \frac{[10+8-12-6]\times10^{-9}}{5\sqrt{2}\times10^{-2}}$$

$$= \frac{8.99}{5\sqrt{2}\times10^{-2}} \times [0] = \underline{\underline{0}}$$

$$V_{midpoint} = \frac{1}{4\pi\varepsilon_0} \frac{[-12-6]\times10^{-9}}{5\times10^{-2}} + \frac{1}{4\pi\varepsilon_0} \frac{[10+8]\times10^{-9}}{(10^2+5^2)^{\frac{1}{2}}\times10^{-2}}$$

$$= \frac{8.99}{10^{-2}} \left(\frac{-18}{5} + \frac{18}{\sqrt{125}} \right)$$

$$= 8.99 \times 1800 \, (-0.1106)$$

$$= \underline{\underline{-1789 \text{ V}}}$$

WD in moving electron from centre to midpoint is

$$WD = -1789 \times 1.6 \times 10^{-19}$$

$$= \underline{\underline{\cancel{2}.86 \times 10^{-16} \text{ J}}}$$ (ignore the sign)

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