SOLUTIONS TO 2008 PAPER 2

Q1

(a) Initial energy $= \frac{1}{2}mv_{initial}^2 = \frac{1}{2}(0.167)(25.0)^2$ $\frac{1}{2}$

Final energy $= mgh = (0.167)(9.81)(20.0)$ $\frac{1}{2}$

Energy lost $= \frac{1}{2}(0.167)(25.0)^2 - (0.167)(9.81)(20.0)$ 1

$= (0.167)[\frac{1}{2}(625.0) - (9.81)(20.0)]$

% loss of energy $= 100\dfrac{\cancel{(0.167)}[\frac{1}{2}(625.0) - (9.81)(20.0)]}{\frac{1}{2}\cancel{(0.167)}(25.0)^2} = \dfrac{116.3}{312.5} \times 100$

$= 37.2\%$ (note this is independent of the mass of the ball) 1

[3]

b)

(i) Let t_p and t_s be the times for the P and S waves, respectively, to travel D

Then

$D = 10^3 \times 5.50\, t_p$.

$D = 10^3 \times 3.00\, t_s$. 1

$10^{-3}D\left[\frac{1}{3.00} - \frac{1}{5.50}\right] = t_s - t_p = 15\times 60 + 17 = 917$ 1

$D = 10^3(917)\,\dfrac{16.50}{2.50}$

$D = 6052$ km 1

(ii) $T = 6052/800$ hrs.

$T = 7$ hrs 34 mins 1

(iii) After arrival of S wave time delay between P and S waves can be determined, and D calculated. The time before the arrival of the tsunami is then, the warning time t_w, given by

$$t_w = \left(\frac{D}{800} - \frac{D}{3.00\times 60\times 60}\right) \text{ hrs} \quad (D \text{ measured in km})$$

$= 1.16\times 10^{-3} D$ hrs $= 7.02$ hrs

The inhabitants therefore can be warned and have time to go to higher ground.

Seismometer can detect P and S wave. If it is linked to a computer the warning can be given almost immediately after the S wave arrival.

2

[6]

(c)

(i) Ignore 9·28 as it is clearly in error compared to other determinations 1

Average of 10 remaining values is $g = 9{\cdot}80$

(ii) Either apply modulus of deviation to 10 values, to obtain average/modulus of deviation of 0·04

OR RMS value gives 0·048

Accuracy of $\pm 0{\cdot}04$ or $\pm 0{\cdot}05$ acceptable 2

[4]

d) (i) The bolder in the boat displaces an equivalent weight of water of volume 1

ie M_B/ρ_W.

When thrown into the pond it displaces its own volume of water 1

ie M_B/ρ_B.

Thus the volume of water effectively reduces by $M_B(\rho_W^{-1} - \rho_B^{-1})$ 1

So the level of the water in the pond reduces by $A^{-1}M_B(\rho_W^{-1} - \rho_B^{-1})$ 1

(ii) There is no change in the water level as the timber block 1

displaces its own weight of water when in the boat and 1

when floating on the pond.

[6]

(e) If the water level to remain at the same height, a distance H below the support then if Δx is the decrease in level of water in container spring must contract by Δx; weight of water leaving container must be equal to reduction in force produced by spring. Thus, 1

$$(9.81)\ \pi\,(18\times10^{-2})^2\,\Delta x\,(10^3) = k\Delta x$$ 2

$$k = \pi\,(324)\,10^{-1}\,(9.81)$$

$$k = 9{\cdot}99\times10^2\ \mathrm{N\,m^{-1}}$$ 1

[4]

Let v = 60mph

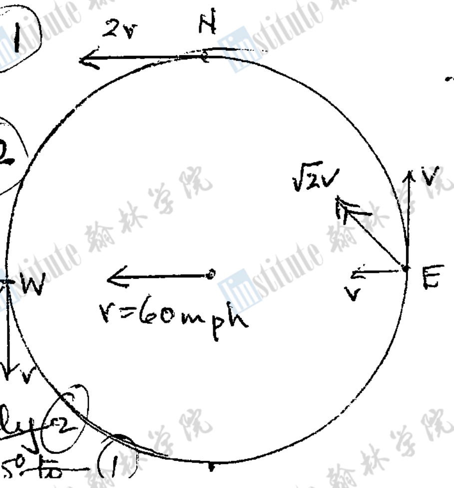
(f) (i) S at rest; due to sum of translational speed and rotational speed being equal and opposite (1)

N velocity 120mph sum of translational speed and rotational speed in same direction and of equal magnitude. (2)

E. two components v horizontally and v vertically upwards. (2)

Resultant velocity $v\sqrt{2}$ at 45° upwards to horizontal (1)

W two components v horizontally and v vertically (2) downwards. Resultant velocity $v\sqrt{2}$ at 45° to (1)



[9]

g) (i) $\lambda = \frac{c}{\nu} = \frac{3.00\times10^{8}}{2\times10^{10}} = \underline{0.015\,m = 1.5\,cm}$ 1

(ii) $E = (2.5\times10^{4})10^{-9} = \underline{2.5\times10^{-5}\,J}$ 1

(iii) $U = \frac{E}{\pi R^2 \ell}$ 1 where ℓ is length of pulse $\ell = c\Delta t = (3\times10^{8})10^{-9} = 0.30\,m$ 1

$= \frac{2.5\times10^{-5}}{\pi(0.06)^2(0.30)} = \underline{7.37\times10^{-3}\,Jm^{-3}}$ 1 3

(iv) $p = \frac{1}{c}U = \frac{7.37\times10^{-3}}{3\times10^{8}} = \underline{2.46\times10^{-11}\,Jsm^{-4}}$ 1

[6]

(h)

$F = (1.2)a$ $\quad$ a = acceleration

"$v = u + ft$"

$0.40 = a(10)$ $\quad$ ie $a = 0.040\ ms^{-2}$

$\underline{F = 1.2(0.040) = 0.048}$ 1

vertical force $= F_V$ = Rate of change of momentum $= \frac{\text{Change in momentum in time } \Delta t}{\Delta t}$ 1

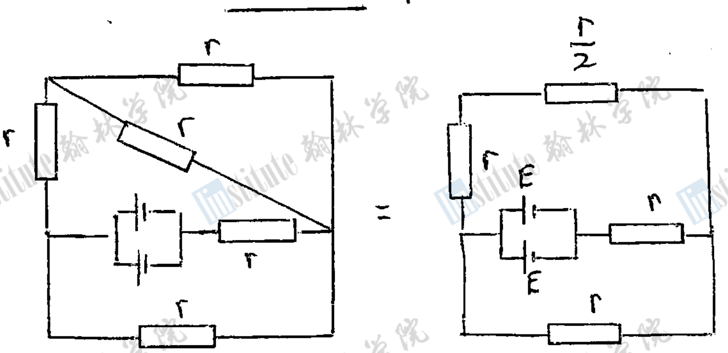
$= \frac{10^{-3}\,5.0\,\Delta t\,(10)}{\Delta t}$ 1 $= \underline{0.050\,N}$ 1 3

Horizontal force $= F_H = \frac{\text{Change in momentum in time } \Delta t}{\Delta t}$ 1 $= \frac{(5.0\times10^{-3})\Delta t\,(0.40)}{\Delta t}$ 1 3

$= \underline{2\times10^{-3}\,N}$ 1

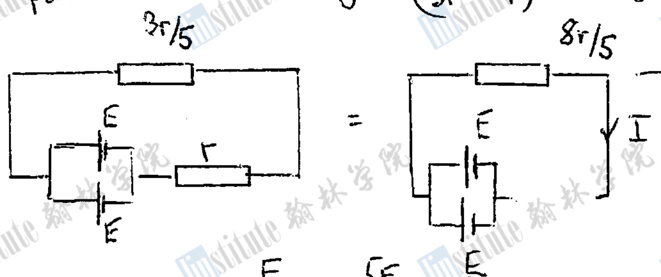
[7]

(j)



$\left(\frac{1}{r}+\frac{1}{r}\right)^{-1} = \frac{r}{2}$ 1

$\frac{3}{2}r$ in parallel with r gives $\left(\frac{2}{3r}+\frac{1}{r}\right)^{-1} = \frac{3r}{5}$ 1



1

Current $I = \frac{E}{(8r/5)} = \frac{5E}{8r}$ ✓ 1

$\therefore$ current thro' cell $= \frac{1}{2}\left(\frac{5E}{8r}\right) = \underline{\frac{5E}{16r}}$ 1

[5]

(k) mass difference Δm = $m(D) + m(T) - m(n) - m(He)$ 1

$= (5.03015 - 5.01127)\,u$

$= 0.01888\,(1.66\times10^{-27})$. kg. 1

Energy released $E = \Delta mc^2 = (0.01888)(1.66\times10^{-27})(3.00\times10^{8})^2$ 1

$= \underline{2.82\times10^{-12}\ \text{J}}$ 1

[4]

(l) (i) XY initially falls under gravity. This motion will induce a current in the rod as it is moving in a magnetic field, cutting lines of force. Therefore a Lorentz force acts on the rod, by Lenz's law, opposing the weight of the rod. The acceleration of the rod consequently is reduced until it becomes zero. The rod then moves with constant 'terminal' velocity. 2

(ii) Vertical force on rod $F_v = ILB = mg$ (1) when terminal velocity reaches 1

Emf induced $= BLv = IR$ 1

$\therefore v = \frac{IR}{BL} = \frac{R}{BL}\,\frac{mg}{LB}$ 1

$\underline{v = \frac{Rmg}{(BL)^2}}$ (2)

By applying the right hand rule the current is in direction $\underline{XY}$ 1

(iii) In time Δt XY falls a distance $v\Delta t$

P.E. lost = $\underline{mg(v\Delta t)}$ 1

Heat dissipated = $I^2R\Delta t = R\Delta t\left(\frac{mg}{LB}\right)^2$ from (1) 1

$= \underline{mgv\Delta t}$ from (2) 1

$\therefore$ $\underline{\text{P.E. lost = Heat dissipated}}$ 1

[10]

(m)

Q1 ? For stationary source and observer $c_s = \lambda f$. λ = wavelength, f = frequency

(m) (i) When the observer is stationary and the source is moving away from the observer the wave length λ_s increases from λ, as distance between wave crests increases by the distance the source moves during a period

$$\lambda_s = \lambda + \frac{v}{f}$$

where $f = 500$ Hz, $f\lambda = c_s$.

The wave velocity

$$c_s = \lambda_s f_s$$

$$\therefore \quad \frac{c_s}{f_s} = \lambda + \frac{v}{f}$$

$$= \frac{c_s}{f} + \frac{v}{f}$$

$$f_s = \frac{c_s f}{c_s + v}$$

$$f_s = \frac{(340)500}{340 + v} \quad (1)$$

Correct result with some explanation

3

(ii) At the wall, the source is moving towards the wall, the frequency received is obtained by replacing v by $(-v)$ in (1)

$$f_{wall} = \frac{(340)(500)}{340 - v}$$

Since the observer is stationary the frequency f_{wall} will be reflected and detected by him/her. ie $f_{reflected} = \frac{(340)500}{340 - v}$

Correct result with some explanation

Alternatively

Source image in wall move at speed v towards observer giving a frequency (1) with v replaced by $(-v)$

$$f_{reflected} = \frac{(340)(500)}{340 - v}$$

3

(iii) The Doppler frequency therefore gives

$$30 = \frac{(340)(500)}{340 - v} - \frac{(340)(500)}{340 + v} \quad 1$$

$$= (340)(500)\left[\frac{1}{340 - v} - \frac{1}{340 + v}\right] = \frac{(340)(500)}{(340^2 - v^2)} 2v$$

Working 2

$$\therefore (340)^2 - v^2 = \frac{(340)(500)}{30} 2v$$

$$v^2 + \frac{(340)(500)}{15} v - (340)^2 = 0$$

As $\frac{v}{340} \ll 1$ neglect $\left(\frac{v}{340}\right)^2$

$$v \approx \frac{15(340)}{500}$$

$$\left(\frac{v}{\ldots}\right)^2 + \frac{500}{15} v - 1 = 0 \qquad = 10.2 \text{ ms}^{-1} \quad 1$$

(ii) If N_0 atoms of each isotope existed at the formation of the Earth and N atoms of U^{235} currently exist then if the age of the Earth, in years, is T:

U^{238}: $140N = N_0 e^{-\lambda_1 T}$ (A) λ_1 is decay constant for U^{238} 1

U^{235}: $N = N_0 e^{-\lambda_2 T}$ (B) λ_2 is decay constant for U^{235} 1

where $\lambda_1 = \dfrac{\ln 2}{4.5 \times 10^9}$ years^{-1} 1

$\lambda_2 = \dfrac{\ln 2}{7.1 \times 10^8}$ years^{-1} 1

Dividing (A) by (B) $140 = e^{(\lambda_2 - \lambda_1)T}$ 1

$\therefore \ln(140) = (\lambda_2 - \lambda_1)T$ 1

$4.942 = \ln 2 \left(\dfrac{1}{7.1 \times 10^8} - \dfrac{1}{4.5 \times 10^9} \right) T$

$= 0.6931 \, (14.08 - 2.222) \, 10^{-10} \, T$

$= 0.6931 \, (11.86) \, 10^{-10} \, T$

$\underline{T = 6.0 \times 10^9 \text{ years}}$ 1

7

Q2

(a) (i) r_3 is in parallel with (r_1+r_2)

$$R_1 = r_4+r_5+\left(\frac{1}{r_3}+\frac{1}{r_1+r_2}\right)^{-1}$$
$$= 2r+\left(\frac{1}{r}+\frac{1}{2r}\right)^{-1}$$
$$= 2r+\tfrac{2}{3}r$$
$$\underline{R_1 = 2\tfrac{2}{3}r} \qquad 1$$

(ii) r_3 in parallel with r_1

$$R_2 = r_4+r_5+\left(\frac{1}{r_3}+\frac{1}{r_1}\right)^{-1}$$
$$= 2r+\frac{r}{2}$$
$$\underline{R_2 = 2\tfrac{1}{2}r} \qquad 1$$

(iii) A 'wheatstone bridge' system of resistors in series with r_5
As all resistors of resistance r no current passes through r_2
(r_4+r_3) in parallel with (r_6+r_1), which are in series with r_2 $\qquad 2$

$$R_3 = \left(\frac{1}{2r}+\frac{1}{2r}\right)^{-1}+r$$
$$\underline{R_3 = 2r} \qquad 1$$

$\boxed{5}$

(b) (i) $$R_{AB} = r_4+r_5+\left(\frac{1}{r_3}+\frac{1}{r_2+r_1}\right)^{-1} = r_4+r_5+\frac{r_3(r_2+r_1)}{(r_1+r_2+r_3)} \qquad (1)$$
$$= \frac{(r_4+r_5)(r_1+r_2+r_3)+r_3(r_2+r_1)}{(r_1+r_2+r_3)} \qquad (2) \qquad 1$$

(ii) If $R_{AB} = 7\frac{3}{13} = \frac{94}{13}$ $\qquad (3)$

comparing (2) and (3)
$$(r_1+r_2+r_3) = 13 \qquad 1$$

(iii) $$R_{AB} = r_4+r_5+\frac{r_3(r_1+r_2+r_3-r_3)}{(r_1+r_2+r_3)}$$
$$= r_4+r_5+\frac{r_3(13-r_3)}{13}$$
$$\underline{R_{AB} = n_1+n_2+\frac{n_3(13-n_3)}{13}}$$
where n_1, n_2 and n_3 are integers as r_4, r_5 and r_3 are integers $\qquad 2$

(iv) $$p = \frac{n_3(13-n_3)}{13}$$

$n_3=1$ $\quad p = 12/13$
$n_3=2$ $\quad p = 22/13 = 1\,9/13$
$n_3=3$ $\quad p = 30/13 = 2\,4/13$
$n_3=4$ $\quad p = 36/13 = 2\,10/13$
$n_3=5$ $\quad p = 40/13 = 3\,1/13$
$n_3=6$ $\quad p = 42/13 = 3\,3/13$ $\qquad 1$

Q2 (iv) $n_3 = 6$ for R_{AB} as the only p value with $3/13$ which is required as $R_{AB} = 7\frac{3}{13}$ 1

$\therefore r_3 = 6$ $R_{AC} = 6\frac{9}{13}$ ie $n_3 = 2$

(v) Thus as $p = 3\frac{3}{13}$ for R_{AB},

$n_1 + n_2 = 4$ as $R_{AB} = n_1 + n_2 + 3\frac{3}{13} = 7\frac{3}{13}$

So either $n_1 = 1$ and $n_2 = 3$ so $r_4 = 1$ & $r_5 = 3$ A 2

or $n_2 = 3$ and $n_1 = 1$ $r_4 = 3$ $r_5 = 1$ ($n_1 = n_2 = 2$ not possible as no two resistors equal)

(vi) $R_{AC} = 6\frac{9}{13}$ so $n_3 = 2$ giving $\underline{r_2 = 2}$

$n_1 + n_2 + 1\frac{9}{13} = 6\frac{9}{13}$

$n_1 + n_2 = 5$ 2

So either $n_1 = 1$ $n_2 = 4$

or $n_1 = 2$ $n_2 = 3$

or $n_1 = 3$ $n_2 = 2$

or $n_1 = 4$ $n_2 = 1$

$r_4 = 1$ $r_6 = 4$

~~$r_4 = 2$ $r_6 = 3$~~

~~$r_4 = 3$ $r_6 = 2$~~

$r_4 = 4$ $r_6 = 1$

B 1

we can eliminate $r_4 = 2$ & $r_6 = 2$ as we have shown $r_2 = 2$. 3

Now $R_{BC} = 10\frac{1}{3}$ so $n_3 = 5$ ie $\underline{r_1 = 5}$

$n_1 + n_2 + 3\frac{1}{3} = 10\frac{1}{3}$

$n_1 + n_2 = 7$ 1

So $n_1 = 1$ $n_2 = 6$

$= 2$ $= 5$

$= 3$ $= 4$

$= 4$ $= 3$

$= 5$ $= 2$

$= 6$ $= 1$

$r_5 = 3$ $r_6 = 4$

$r_5 = 4$ $r_6 = 3$

C 1

As we have determine resistor 6, 5 and 2 these can be eliminated from this list 2

(Alternatively Returning to R_{AC} we can similarly eliminate)

To satisfy the remaining conditions C we require

$\underline{r_4 = 1,\ r_5 = 3,\ r_6 = 4}$ 2

[15]

Q3

(a) For circular motion with angular velocity ω_d about the centre of mass

$$M_s\left(\frac{d}{2}\right)\omega_d^2 = \frac{GM_s^2}{d^2}$$

$$d^3\omega_d^2 = 2GM_s \quad (1)$$ 1

For the Earth rotating about our Sun with angular velocity ω_{ES}, similarly,

$$\frac{GM_sM_E}{R_{ES}^2} = R_{ES}M_E\omega_{ES}^2$$

$$R_{ES}^3\omega_{ES}^2 = GM_s \quad (2)$$ 1

From (1) and (2)

$$\left(\frac{d}{R_{ES}}\right)^3 = \frac{2\omega_{ES}^2}{\omega_d^2}$$ 1

$$= 2\left(\frac{7}{365}\right)^2$$ as $\frac{\omega_d}{\omega_{ES}} = \frac{365}{7} = \frac{\text{year}}{\text{week}}$ 2

$$\frac{d}{R_{ES}} = \sqrt[3]{\left(\frac{7}{365}\right)^2 2}$$

$$\frac{d}{R_{ES}} = 0.090$$ 1

6

(b) (i) If $m_p = h/\lambda c$

$$\Delta U = -\frac{GM_Em_p}{R_E} - \frac{GM_sm_p}{R_{SE}} - \left[-\frac{GM_s}{R_s} - \frac{GM_E}{R_{SE}}\right]m_p$$

$$= Gm_p\left[-\frac{M_E}{R_E} - \frac{M_s}{R_{SE}} + \frac{M_s}{R_s} + \frac{M_E}{R_{SE}}\right]$$ 2

(ii) $$\Delta U = Gm_p\left[-O(10^{18}) - O(10^{19}) + O(10^{22}) + O(10^{13})\right]$$ 2

The first two terms and the last term can be neglected if only 2 sig. figs. required 1

(iii) Writing $\Delta U = Gm_pM_s/R_s$. (3) 1

Energy of photon $E_\lambda = \frac{hc}{\lambda}$.

If λ changes to $\lambda + \Delta\lambda$

$$E_{\lambda+\Delta\lambda} = \frac{hc}{\lambda+\Delta\lambda}$$

Change in energy $\Delta E = hc\left[\frac{1}{\lambda} - \frac{1}{\lambda+\Delta\lambda}\right]$ 1

$$= hc\frac{\Delta\lambda}{\lambda^2} \quad \text{approx.}$$ 1

$$\therefore \frac{hc}{\lambda}\left(\frac{\Delta\lambda}{\lambda}\right) = \frac{GM_s}{R_s}\left(\frac{h}{\lambda c}\right).$$ from (3) 1

$$\frac{\Delta\lambda}{\lambda} = \frac{GM_s}{R_s}\frac{1}{c^2} = \frac{(6.672\times10^{-11})(1.99\times10^{30})}{(6.96\times10^8)(3.00\times10^8)^2}$$ 1

Sub^n for G, M_s, R_s & c

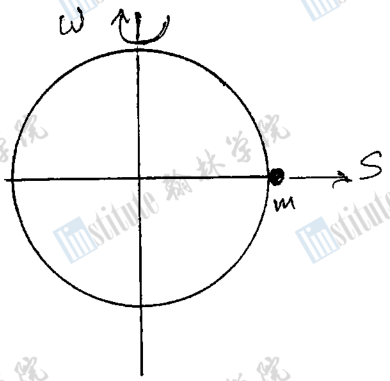
$$\frac{\Delta\lambda}{\lambda} = 2.1\times10^{-6}$$ 1

Q3 (c) This is due to the rotation of the Earth about its axis 1

At the pole there is no rotational force so for a mass m

$$mg_{pole} = \frac{GM_E m}{R_E^2}$$ where M_E is the mass of the Earth and R_E is the radius of the Earth

ie $$g_{pole} = \frac{GM_E}{R_E^2}$$ 1



At the equator, if the Earth has an angular velocity ω about its axis, and the reaction of the Earth on the mass is $S = m g_{equator}$

$$mR_E\omega^2 = -S + \frac{M_E m}{R_E^2}$$

$$g_{equator} = \frac{M_E}{R_E^2} - R_E\omega^2$$ 1

So $g_{equator}$ is less than g_{pole}

3

CORRECTION Q 4(a)

4 (a)

(i) Taking moments about P

$$2T\sin 30^\circ = 1.5(2.0)(9.81)\cos 30^\circ + (3.0)(100)(9.81)\cos 30^\circ$$ 3

$$T = (9.81)\cot 30^\circ [1.5 + 150]$$ 1

$$= \sqrt{3}\,(9.81) \quad 151.5$$ 1

$$\underline{T = 2.57 \times 10^3 N}$$ 1

(ii) Resolving horizontally $\underline{F_x = T = 2.57 \times 10^3 N}$ 1

Resolving vertically $F_y = (m+M)g = 1.02(9.81) =$

$\underline{F_y =} \quad \underline{1.00 \times 10^3 N}$ 1

[8]

(b) Let u and v be the horizontal and vertical components of initial velocity of bullet

Let also T be the time taken by the bullet to travel a horizontal distance L 1

Then $L = uT$ in this time $T = \frac{L}{u}$ is

Vertical height reached by bullet 2

$$h = vT - \tfrac{1}{2}gT^2 = v\left(\frac{L}{u}\right) - \tfrac{1}{2}g\left(\frac{L}{u}\right)^2$$ 1

This is a distance $(H-h)$ below B

$$H - h = H - v\left(\frac{L}{u}\right) + \tfrac{1}{2}g\left(\frac{L}{u}\right)^2 \quad (1)$$ 2

In this time pigeon has fallen a distance

$$\tfrac{1}{2}g\left(\frac{L}{u}\right)^2 \quad (2)$$

Now the initial condition requires direction of bullet aimed at B; 2

ie $\frac{v}{u} = \frac{H}{L}$ or $H = \frac{v}{u}L$ (3) 2

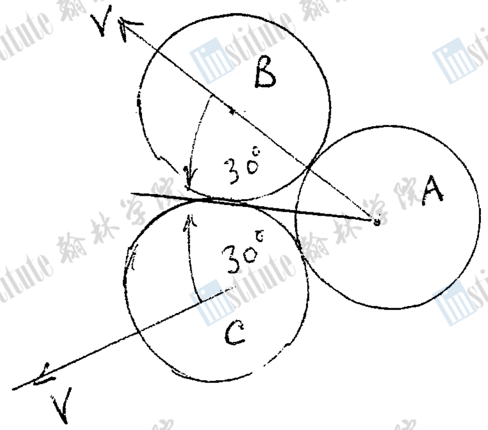
Sub^g (3) into (1) $H - h = \tfrac{1}{2}g\left(\frac{L}{u}\right)^2$. 2

This is identical to (2), so bullet strikes pigeon

[12]

I leave it up to the marker to assess an appropriate mark if an alternative method is applied.

Q5
(a)



By symmetry B and C have the same speed, v, after collision at an angle of 30° to the horizontal line of symmetry

Let A have (by symmetry) a speed u', in the direction of $\underline{u}$, after collision.

The conservation of momentum horizontally gives

$$mu = 2v\cos 30\, m + mu'$$ 1

$$u = 2v\frac{\sqrt{3}}{2} + u' \quad (1)$$

$$u = \sqrt{3}v + u'$$ 1

Conservation of energy gives 1

$$\frac{1}{2}mu^2 = 2\left(\frac{1}{2}mv^2\right) + \frac{1}{2}mu'^2$$ 1

$$u^2 = 2v^2 + u'^2 \quad (2)$$

Sub^g for u' from (1) into (2)

$$u^2 = 2v^2 + (u - \sqrt{3}v)^2 = 2v^2 + u^2 + 3v^2 - 2u\sqrt{3}v$$ 1

$$5v^2 = 2u\sqrt{3}v$$

As $v \neq 0$, $\underline{v = \frac{2}{5}\sqrt{3}u}$ (3) [$\underline{v}$ is 30° to horizontal for B and C as indicated in the diagram]. 1

Substituting for v from (3) into (1)

$$u' = u - \sqrt{3}v = u - \sqrt{3}\left(\frac{2}{5}\sqrt{3}\right)u$$

$$\underline{u' = -\frac{u}{5}}$$

ie its velocity is in opposite direction to $\underline{u}$ 2

[8]

Last part 2

10

Q 5

(b)

(i) $pV = nRT$ ① 1

$p(2V - yV) = nRT_f$

$pV(2-y) = nRT_f$ ② 1

(ii) $W = pyV$ ③ 2

$H = \frac{3}{2}Rn(T_f - T)$ ④ 2

(iii) From ③ + ④

$pyV = \frac{3}{2}Rn(T_f - T)$ ④ 2

From ① $p = \frac{nRT}{V}$

Sub^g into ② $nRT(2-y) = nRT_f$

Sub^g into ④ $\frac{nRT}{V}yV = \frac{3}{2}Rn(T_f - T)$

$nRTy = \frac{3}{2}Rn(T_f - T)$

$2\cancel{n}RT - \frac{3}{2}\cancel{R}\cancel{n}(T_f - T) = \cancel{n}RT_f$

$2\frac{T}{T_f} - \frac{3}{2}\left(1 - \frac{T}{T_f}\right) = 1$

$\frac{7}{2}\left(\frac{T}{T_f}\right) = \frac{5}{2}$

$\left(\frac{T}{T_f}\right) = \frac{5}{7}$

4

[/10]

Q6

(a) (i) A photon of light penetrates metal surface and gives up its energy to an electron. Thus electron gains energy $E = h\nu$ where ν is the frequency of the light. In order to escape from the metal the electron requires an energy equal to or exceeding We. Thus those electrons detected have energies from zero to $(h\nu - We)$. If a potential V is required to suppress the current, ie highest energy electrons then

$$h\nu - We = Ve$$

or

$$\frac{hc}{\lambda} - We = Ve$$

$$V = \frac{hc}{e}\left(\frac{1}{\lambda}\right) - W \quad \text{—— } 1$$

Derivation & explanation 3

Note threshold frequency $\nu_0 = \frac{We}{h}$ when ie $V = 0$

4

(ii) The classical theory assumes that electrons can absorb an unlimited amount of wave energy, so that if the source of light is weak but is applied for a long time, even if $\nu < \nu_0$ electrons will be emitted. Quantum theory, and experiment, show that this is not so. 2

[6]

(b) (i)

V/V	$\lambda/10^{-9}$m	$1/\lambda$ 10^6m^{-1}
1.00	200	5.00
2.00	196	5.10
3.00	158	6.33
4.00	144	6.94

Table of values —— 1

Reasonable graph making full use of graph paper. —— 2.

(ii) FROM THE GRAPH

GRADIENT $\frac{hc}{e} = \frac{3.00}{2.42 \times 10^6} = 1.24 \times 10^{-6}$

$\therefore h = 1.24 \times 10^{-6} \left(\frac{e}{c}\right)$ Js

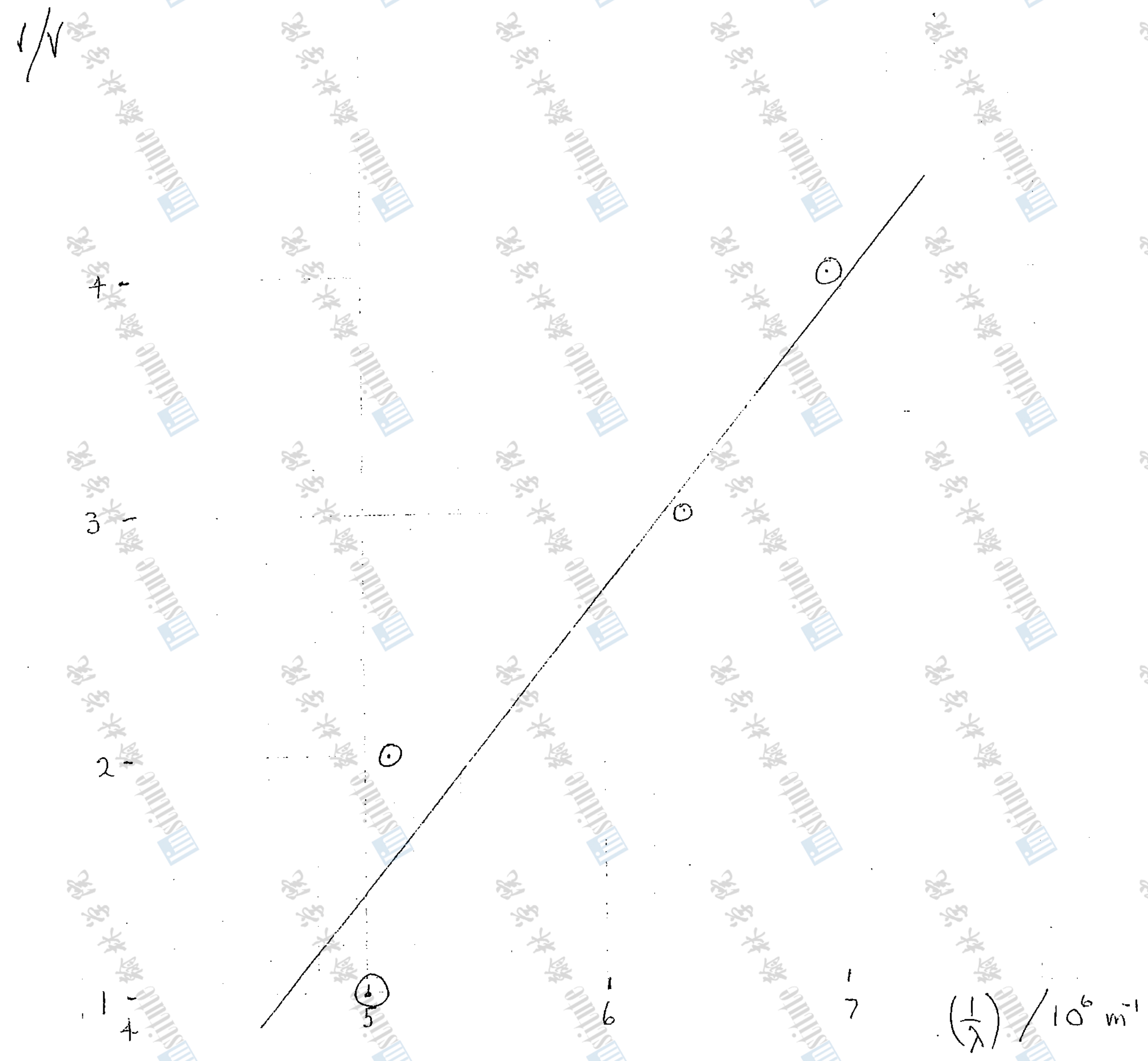
$= \frac{1.602 \times 10^{-19}}{2.998 \times 10^8} \; 1.24 \times 10^{-6}$ Js

$h = 6.62 \times 10^{-34}$ Js —— 2

ERROR: $\frac{3.00 \pm 0.1}{2.42 \times 10^6}$ in $\frac{hc}{e}$ ie 3%

$h = 6.62 \pm 0.2 \times 10^{-34}$ Js 1

Q6 PHOTOELECTRIC EFFECT.



Q6

(b) (ii) To determine W use a specific point on straight and $\left(\frac{hc}{e}\right)$ determined. Alternative methods acceptable.

At $V = 3.00$ $\quad \frac{1}{\lambda} = 6.24 \times 10^{+6}$. substituting into result in (a)

$$3.00 = 1.24 \times 10^{-6} (6.24 \times 10^{6}) - W$$

$$W = 7.49 - 3.00$$

$$\underline{W = 4.49 \ \text{V}} \qquad 1$$

Accuracy 3% ie $\underline{W = 4.49 \pm 0.13}$ 1

(iii) Threshold frequency $\nu_0 = \frac{We}{h}$

$$= \frac{4.49 (1.60 \times 10^{-19})}{6.62 \times 10^{-34}} \qquad 1$$

$$\underline{\nu_0 = 1.09 \times 10^{15} \ \text{Hz}} \pm 0.03 \times 10^{15} \ \text{Hz} \qquad 2$$

(iv) Doubling the intensity for $\nu < \nu_0$ no current produced 1

Doubling intensity for $\nu \geq \nu_0$. current doubles 1

This is a consequence of the fact that doubling the intensity doubles the number of photons of wavelength λ. explanation 1

If $\nu < \nu_0$, this will not enable the electrons to escape from the metal and consequently not produce a current.

If $\nu \geq \nu_0$ the number of electrons emitted will double and hence current doubles

[14]

Q7

t / days	Counts/min N	$\ln(N)$
0.5	7000	8.85
2.0	620	6.43
5.0	142	4.96
9.0	76	4.33
15.0	28	3.33

Part (iii) GRAPH

Table of values 1

Reasonable graph using all graph paper 2

Straight line tho' last 3 points 1

(a)(i) Equation for count rate N

$$N = \tfrac{3}{5} N_A e^{-\lambda_A t} + \tfrac{11}{100} N_B e^{-\lambda_B t}$$

2; $\lambda_A > \lambda_B$

(ii) For large t, as $\lambda_A > \lambda_B$, we can neglect $N_A e^{-\lambda_A t}$;

$$N \simeq \tfrac{11}{100} N_B e^{-\lambda_B t} \quad (1)$$

1

(iii) For large t plot $\ln(N)$ against t as, from (1),

$$\ln N = \ln\left(\tfrac{11}{100} N_B\right) - \lambda_B t$$

1

Thus $\ln(N)$ against t should be a straight line, gradient $-\lambda_B$ intercept $\ln\left(\tfrac{11}{100} N_B\right)$. 1

Care with units required

FROM THE GRAPH

GRADIENT $\lambda_B = \dfrac{2.84 - 0.14}{16.0} \quad \dfrac{2.70}{16.0} = (1.69 \pm 0.04)\,10^{-1}$ /da 2

INTERCEPT $\ln\left(\tfrac{11}{100} N_B\right) = [\ln N]_{t=0} = 5.83 \pm 0.06$

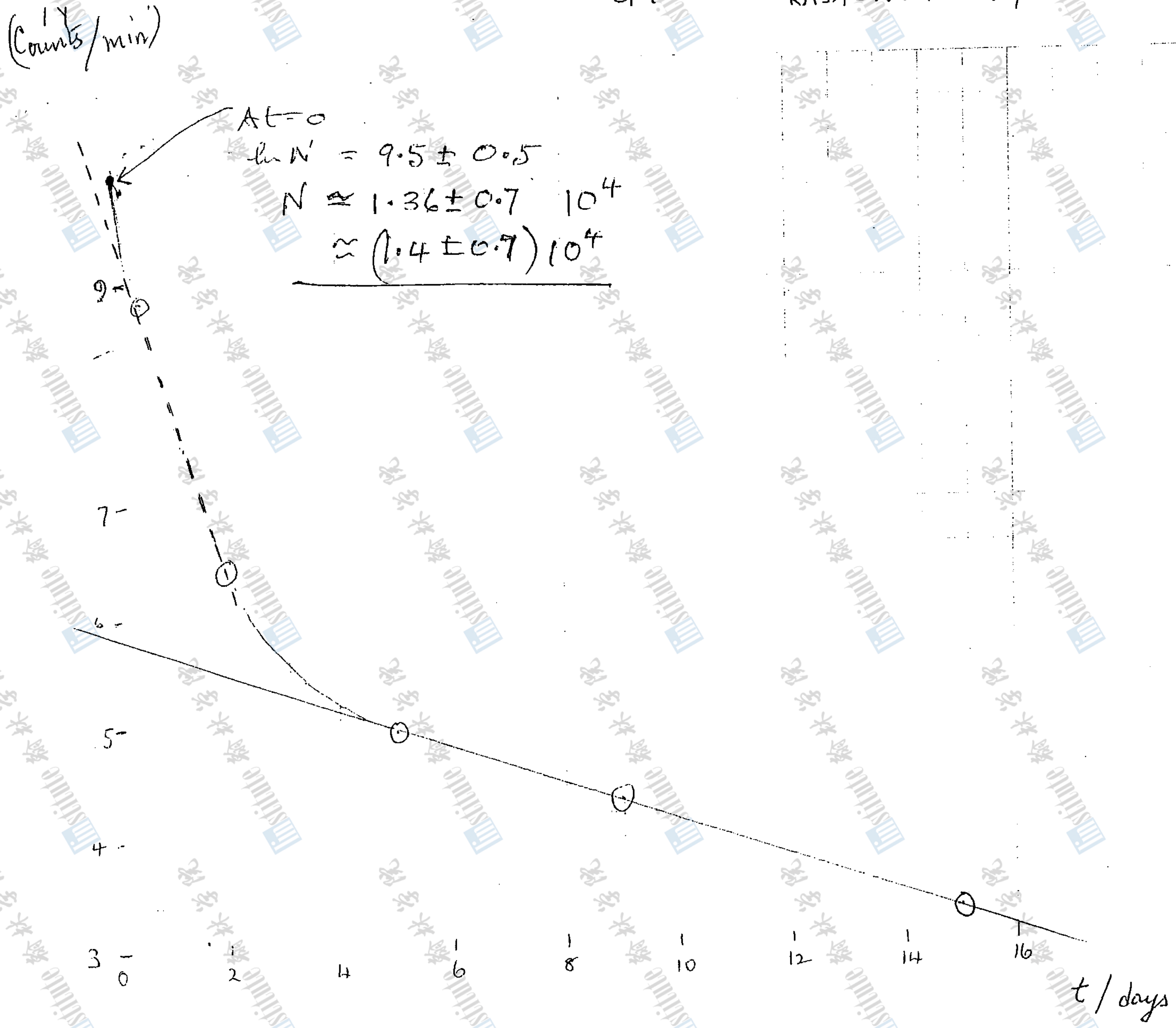
Thus

$N_B = (3.09 \pm 0.06)\,10^3$ ← counts/min 2

(iv) no. of B atoms initially $n(0)_B$

$N_B(0) = \lambda_B n_B(0)$: $n_B(0) = 3.09 \times 10^3 / [(1.69 \times 10^{-1}) * (24 \times 60)^{-1}]$ 1 2

$n_B = 3.09 \times 10^3 (1440) / 1.69 \times 10^{-1} = 2.63 \times 10^7 \pm .04 \times 10^7$ 1 [15]


ln Y (Counts/min)
At t=0
ln N' = 9.5 ± 0.5
N ≃ 1.36 ± 0.7 10^4
≃ (1.4 ± 0.7) 10^4
9
7
6
5
4
3
0
2
4
6
8
10
12
14
16
t / days

Q.7

(b) (i) $N = (1.4 \pm 0.7)10^4$.

$\therefore N_A = N - N_B$

$= (1.1 \pm 0.7)10^4$ 1

(ii) $7000 = \frac{3}{5}(1.1 \pm 0.7)10^4 e^{-\lambda_A/2} + \frac{11}{100} 3.09 \times 10^3 e^{-0.169/2}$ 1

$\downarrow$ 370

$=$

$6630 = \frac{3}{5}(1.1 \pm .7)10^4 e^{-\lambda_A/2}$ 1

$\frac{5}{3}(0.6630) = (1.1 \pm 0.7) e^{-\lambda_A/2}$

$\frac{1.105}{(1.1 \pm .7)} = e^{-\lambda_A/2}$

$\overset{+}{0.61} / \overset{-}{2.8} = e^{-\lambda_A/2}$

$\frac{\lambda_A}{2} = + \overset{+}{0.49} / \overset{-}{16}$

$\lambda_A = 1 \rightarrow 32$

$\lambda_A \simeq 16 \pm 15$. days^{-1} 2

[5]

Any answer from $1\,\text{day}^{-1}$ to $32\,\text{days}^{-1}$ acceptable.

Most likely $\sim 16\,\text{days}^{-1}$

Q8

(a) (i) $Ee = \frac{100}{0.001} \; 1.602\times10^{-19} \; N = \underline{1.602\times10^{-14} N}$ 2/

(ii) $\frac{mg}{Ee} = \frac{9.109\times10^{-31}(9.81)}{1.602\times10^{-14}} = \underline{5.6 \times 10^{-16}}$ 2/

(iii) $\frac{1}{2} m V_{max}^2 = 15\times10^3 e$

$V_{max}^2 = \frac{0.30\times10^5 (1.602\times10^{-19})}{9.109\times10^{-31}} = 5.276\times10^{15}$ 2

$\therefore \underline{V_{max} = 7.25\times10^7 \; ms^{-1}}$

(iv) Magnetic and electric forces but balance for horizontal motion: 2

$Ee = Bev\cos\theta$

$\underline{v\cos\theta = \frac{E}{B} = \frac{10^5}{0.010} = 10^7 \; ms^{-1}}$ 1

Thus a β particle travelling at angle θ satisfy this equation. 1

(v) $v = \frac{10^7}{\cos\theta}$ from (iv)

So as $\theta = 0 \rightarrow 90^\circ$, $v = 10^7 \rightarrow \infty \; ms^{-1}$ 1

However $V_{max} = 7.25\times10^7 ms^{-1}$ from (iii)

$\underline{\text{Consequently the range of } v = 10^7 \rightarrow 7.25\times10^7 \; ms^{-1}}$ 2

(vi) Now $\cos\theta = \frac{10^7}{v}$ from (iv) 1

where v has the range $10^7 \rightarrow 7.25\times10^7 \; ms^{-1}$ 1

Thus

$\cos\theta = 1 \rightarrow \frac{1}{7.25}$ 1

This gives

$\underline{\theta = 0 \rightarrow 82.07^\circ}$ 1

15

(b) Now as v has range $10^7 \rightarrow 7.25\times10^7 \; ms^{-1}$

$\frac{v}{c}$ has the range $3\times10^{-2} \rightarrow 2.4\times10^{-1}$ ~~ms~~ 3

Thus largest value of $\left(\frac{v}{c}\right)^2$ is 5.8×10^{-2}. This will alter the mass by 3%. Consequently the accuracy of the above results is only correct to about 3% for the fastest particles.
The slowest particles have a mass that differs from the rest mass by less than $1:10^3$ ie accurate to 0.1%

PTO

(ii) Rel. K.E = Energy at velocity v − Rest energy } 1

$$= mc^2 - m_0c^2$$

$$= m_0c^2\left[\left(1-v^2/c^2\right)^{-\frac{1}{2}} - 1\right]$$ } 1.

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