2021 Raffles Institution Preliminary Examinations – H2 Physics
Paper 3 – Suggested Solutions

1 (a) $t = \dfrac{v-u}{a}$

Sub into the 2nd equation

$$s = \frac{1}{2}(u+v)\left(\frac{v-u}{a}\right) = \frac{(v+u)(v-u)}{2a}$$ B1

$2as = v^2 - u^2$

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

Students are required to simplify the equation and not leave it in its raw form (eg $s = \frac{1}{2}(u+v)\left(\frac{v-u}{a}\right) = \frac{(v+u)(v-u)}{2a}$ and expect to get the full mark.

(b) Displacement required $= 3.0 + \dfrac{0.23}{2} - 2.1 = 1.015$ m B1

Minimum speed of release required means that velocity at 1.015 m is zero.

$v^2 = u^2 + 2as$ M1

$0 = u^2 + 2(-9.81)(1.015)$

$u = 4.46 \text{ m s}^{-1}$ A1

OR,

using conservation of energy

Loss in kinetic energy = Gain in GPE

$\frac{1}{2}mu_y^2 - 0 = mgh_f - mgh_i$

$\frac{1}{2}u_y^2 = g(h_f - h_i) = gs_y$

$u_y^2 = \sqrt{2(9.81)(1.015)}$

$u_y = 4.46 \text{ m s}^{-1}$

The displacement of the ball has to be taken with reference to a fixed point on the ball. Students are required to either calculate the displacement of the ball from the centre of the ball as it is released (2.1 m from the ground) to the centre of the ball as it enters the net (3.0 m from the ground + radius of the ball); or from the base of the ball (2.1 m from the ground minus the radius of the ball) to the hoop (3.0 m from the ground). A few students assumed height to be displacement.

(c) (i) Horizontally

$s_x = u_x t = ut\cos\theta$

$6.7 = u(1.3)\cos 50°$

$u = \dfrac{6.7}{1.3\cos 50°} = 8.02 \text{ m s}^{-1}$ M1

(ii) Vertically

$$s_y = u_y t + \frac{1}{2}a_y t^2 = ut\sin 50^\circ + \frac{1}{2}(-9.81)(1.3)^2$$

$$= 8.0\sin 50^\circ \times 1.3 + \frac{1}{2}(-9.81)(1.3)^2$$ M1

$$= -0.3226 \text{ m}$$ A1

height = 2.5 – 0.3226 = 2.18 m A1

Students should realise that displacement is a vector that takes into account the direction of velocity. Thus, there is no need to calculate the *displacement to the max height* and then the *displacement again from the max height* before adding everything together to find the final displacement.

Again, some students forgot to include the negative sign for acceleration (assuming up as positive) and ended up with 8.65 m (this is approximately 3 storeys high) and yet did not think that this number was plausible.

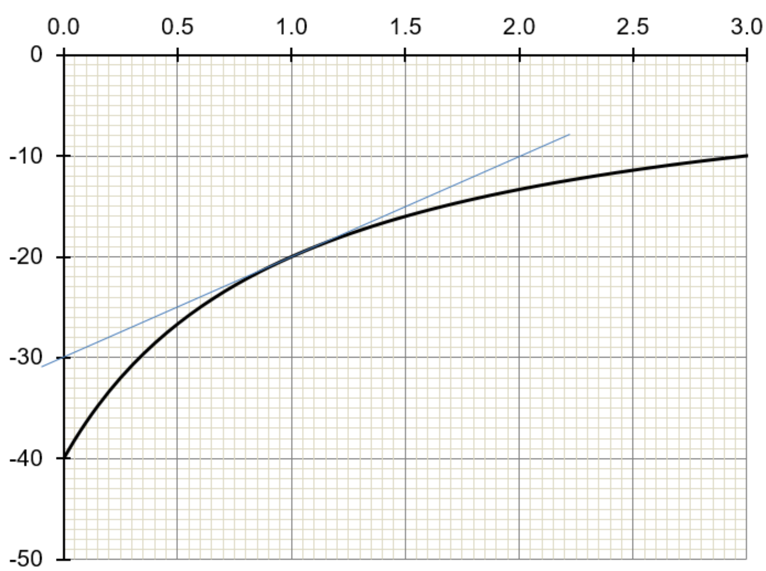
Some students also assumed that the ball travelled at constant speed. If this is so, the ball will not return to the ground.

2 **(a)** Gravitational potential at infinity is zero. B1

Since gravitational force is attractive in nature, to bring a mass from infinity to a point in the gravitational field, the direction of the external force is opposite to the direction of displacement of the mass. This results in negative work done by the external force B1

It is important that students include a statement that the work done by the external force is negative, rather than ending the explanation as external force is opposite in direction to the displacement of the test mass from infinity to the point in the gravitational field.
A common mistake among students is to write "The work done by the external force is in opposite direction to the displacement" when the entities that are in opposite directions should be force and displacement rather than work and displacement.

(b) **(i)**



acceleration $=$ gradient M1

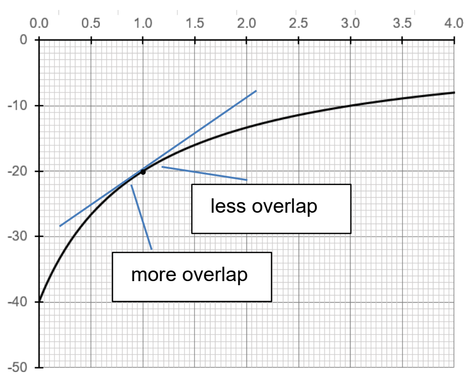
$$= \frac{\left[-10-(-30)\right]\times 10^{6}}{(2.00-0.00)\times 10^{7}}$$ A1

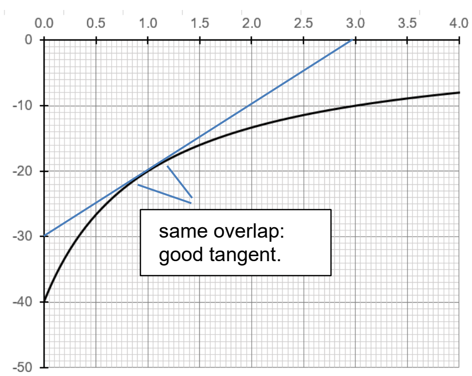
$= 1.00\ \text{m s}^{-2}$

Values ranging from 0.97 to 1.03 are accepted. Negative value for acceleration is also accepted.

Some students dangerously linked the formulae $g=\frac{GM}{r^2}$ and $\phi=-GM/r$ (many ignored the minus sign completely which is obviously wrong) using $\phi = gr$. Some even thought that this is the same formula as $GPE = mgh$. They can't be more wrong. The above relations are only correct for point masses (or any other spherical mass distributions) and don't work in general cases, eg for g and ϕ between **two** masses.

Many students also did not draw the tangent line accurately. A simple way to judge if the tangent is good is to see if the overlapping parts of the tangent and the curve on the left and right hand sides of the point of interest are balanced. Here are some examples:





(ii) Since acceleration is assumed to be constant,

$v^2 - u^2 = 2as$

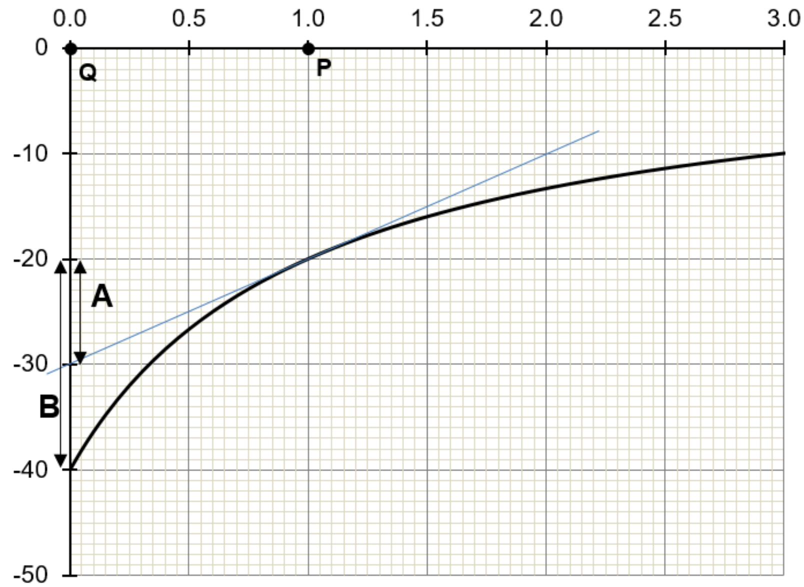
$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = mas$ M1

$= 1.0 \times 1.00 \times 1.0 \times 10^7$

$= 1.00 \times 10^7$ J A1

Students are reminded that they should show their formula to illustrate that they know the correct physics. A student who wrote $(1.0)(9.81\times 1.0\times 10^7)$ could be applying the wrong physics $GPE = m\phi = mgr$ commented earlier. Hence, only students who have illustrated that they understood the physics correctly are given full credit in this part.

(iii)



B1

B1

Despite the question stating clearly that candidates are use vertical arrows, many candidates used slanted arrows, showing that they do not know which part of the graph (the vertical axis!) indicates the change in gravitational potential. For those who understood the question, most of them drew the arrows accurately. A small number drew the arrows too short or too long and were penalised.

3 **(a)** The <u>thermodynamic</u> temperature of an ideal gas is <u>proportional</u> to the <u>mean kinetic energy</u> of the molecules of the gas. A1

"mean translational kinetic energy of an ideal gas molecule $E = \frac{3}{2}kT$" is provided in the Formulae list. Hence, it is important to state that the temperature is the "thermodynamic temperature".
Statements such as "An increase in the temperature will cause an increase in the mean kinetic energy of the molecules" are not acceptable as it does not mean that it is a linear relationship. The increase can be exponential or polynomial or any other functions.
Internal energy is not acceptable as this question is about the energy of the molecules. Internal energy is a macro term that applies to a system or gas.

(b) **(i)**

$$\frac{1}{2}m\left\langle c^2\right\rangle = \frac{3}{2}kT$$

$$\frac{1}{2}\times\frac{0.030}{6.02\times10^{23}}\times\left\langle c^2\right\rangle = \frac{3}{2}\times1.38\times10^{-23}\times\left(27+273.15\right)$$ M1

$$c = 499 \text{ m s}^{-1}$$ A1

A common mistake is to regard the mass of a molecule as 0.030 kg. Another common mistake is to regard the number of molecules to be 6.02×10^{23} or number of moles to be 1 when the gas is at a pressure of 1.0×10^5 and volume of 0.029 m^3.

(ii) $PV = nRT$

$1.0 \times 10^5 \times 0.029 = n \times 8.31 \times (27 + 273.15)$ M1

$n = 1.16$ B1

(iii) The root-mean-square speed of the molecules increases with temperature. B1

Since the volume of the oven remains the same, there is an increase in the number of collisions per unit time of the molecules and the walls of the oven, causing an increase in pressure. B1
Or
For each collision between a molecule and the wall of the oven, there is a greater change in momentum of the molecule. This leads to a greater force exerted on the wall and an increase in pressure.

Students should note that the number of marks for this question is only 2 marks and focus their explanations on what happens to the molecules when the temperature is increased. Explanations invoking Newton's Second and Third Laws can be included if the number of marks for this question is much more.

(iv) $PV = nRT$

$1.0 \times 10^5 \times 0.029 = n_2 \times 8.31 \times (220 + 273.15)$

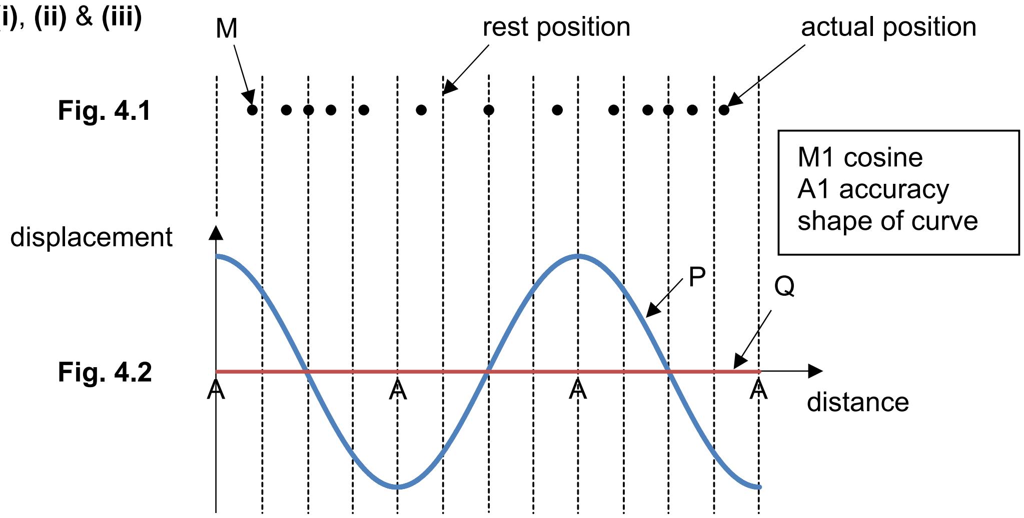
$n_2 = 0.7076$ M1

mass of air = $(1.163 - 0.7076) \times 0.030 = 1.37 \times 10^{-2}$ kg A1

4 (a) (i), (ii) & (iii)

Fig. 4.1

Fig. 4.2



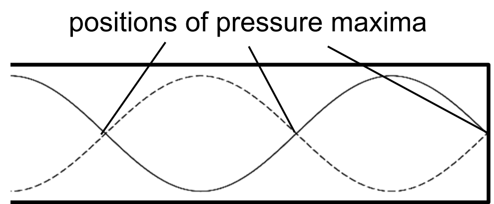
Many students ignored the 'standing wave' mentioned in the question, and treated it as a progressive wave. Note that, since we are plotting the actual displacements of the particles, we are plotting the waveform of the standing wave, NOT that of the underlying progressive waves (incident and reflected waves, for example). When we observe a standing wave, we cannot observe the underlying progressive waves, we can only see the superposition of the two, which is the standing wave! Some plotted the graph in a haphazard manner (not smooth), which is penalized.

(b) **(i)** The <u>incident wave reflects off the wall</u> of the pipe at the end, producing a wave of the same amplitude, wavelength and frequency travelling in the opposite direction. B1 B1

The <u>reflected wave interferes with subsequent incident wave</u>, to produce nodes and antinodes at different positions of the pipe, depending on the path difference between the two waves.

Many students did not explain clearly which two waves are interfering. Some students' answers made it sound as if the reflected wave interferes with itself before it was reflected. These latter answers are given the benefit of the doubt. Ideally, one needs to phrase it as 'subsequent incident waves' to make it clearer.

(ii)



C1

The positions of maxima correspond to pressure antinodes (displacement nodes). As shown in the picture above, three positions of maxima imply that the length of the pipe is equal to 5/4 wavelengths. C1

$$\frac{5}{4}\lambda = 0.40 \Rightarrow \lambda = 0.32 \text{ m}$$ A1

Many students took the distance between consecutive antinodes (or nodes) as one whole wavelength, whereas in fact it is half a wavelength. Some got the waveform (that yields three maxima) wrong. Also, it is important to note that the maxima detected by the oscilloscope (points of large sound) are at pressure antinodes, which correspond to displacement nodes.

(iii) $v = f\lambda = 1060 \times 0.32 = 339 \text{ m s}^{-1}$ B1

5 **(a)** e.m.f. = 3.0 V. B1

(b)

$$V_T = E - Ir$$

$$2.20 = 3.00 - 1.60 \times r$$ M1

$$r = \frac{3.00 - 2.20}{1.60} = 0.50\ \Omega$$ A1

(c) **(i)** power = IV = 1.60 × 2.20 = 3.52 W B1

Some students confused power delivered with power loss and ended up calculating the loss in power across the internal resistance.

(ii) $\text{efficiency} = \dfrac{\text{power delivered to lamp}}{\text{total power}} = \dfrac{IV}{IE} = \dfrac{V}{E}$

$= \dfrac{2.20}{3.00}$ M1

$= 73.3\%$ A1

Common mistakes were to calculate - the power loss as a fraction of the total power - power delivered minus power loss over power delivered Students also confused the values of current with that of potential difference.

6 (a) The magnetic flux density of a magnetic field is numerically equal to the force per unit length acting on a long straight conductor carrying a unit current at right angles to the magnetic field. B1

(b) (i) Since the α-particle is positively charged, electric force is acting downwards. M1

The magnetic force acting on the α-particle must be upwards for it to be traveling undeflected. By Fleming's Left hand rule, the magnetic field is pointing into the page. A1

Some students did not mention Fleming's Left Hand Rule and thus did not receive full credit.

(ii) $F = qE = (2)(1.60\times10^{-19})(500) = 1.60\times10^{-16}\ \text{N}$ B1

(iii) $KE = \dfrac{1}{2}mv^2$

$120\times1.60\times10^{-19} = \dfrac{1}{2}(6.64\times10^{-27})v^2$ M1

$v = 7.60\times10^4\ \text{m s}^{-1}$ A1

(iv) $qE = Bqv$

$E = Bv$

$500 = B(7.60\times10^4)$ M1

$B = 6.58\times10^{-3}\ \text{T}$ A1

(v) Since the mass of the proton is smaller than that of the α-particle, the velocity of the proton will be greater than that of the α-particle. M1
Both forces are proportional to charge. However, the magnetic force is also proportional to velocity. The magnetic force acting on the proton is greater than electric force. M1
Proton deflects upwards towards plate P. A1

Many students did not mention that both magnetic force and electric force are proportional to charge and thus, even when charge is halved, both forces change by the same ratio.

7 **(a)** **(i)** p of electron $= \sqrt{2mE_k}$

$= \sqrt{2(9.11\times10^{-31})(4.96\times10^{-24})}$ B1

$= 3.0\times10^{-27}$ kg m s^{-1}

(ii) de Broglie wavelength

$\lambda = \dfrac{h}{p}$

$= \dfrac{6.63\times10^{-34}}{3.0\times10^{-27}}$ M1

$= 2.2\times10^{-7}$ m A1

Some students used the value of KE of the electron as the energy of the UV photon. This is not correct.

(b) **(i)** An electron in an energy level is bound to the nucleus (or atom) by the attractive Coulomb force. The total energy of such a bound system is negative. A1

As the electron is bound to the nucleus, it will require that amount of energy (less the negative sign) as indicated by the energy level, to remove the electron from the atom to infinity. Students need to note the difference between this question and **Q2(a)**. In **Q2(a)**, the discussion is on "potential" or "potential energy", but in this question, **Q7(b)(i)**, the energy level represents "**total energy**" (and not just PE) that comprises the KE of the orbiting electron as well as the electric PE between electrons and the nucleus. For info, the KE is a positive value while the electric PE is a negative value. The sum of these two will give a negative **total energy** (as the PE is more negative than the KE is positive). Students who only discussed about the PE do not get the credit. Since this is only a 1-mark question, the focus is on the electron being bound to the nucleus by the attractive Coulomb force. If more marks are allocated to this question, students could then extend the discussion to "electric potential energy", the part about potential energy being zero at infinity, and the negative work done by external force in bringing the electron from infinity to the atom. Students who gave answers that the "*atom loses energy when transiting from high to low level, hence the energy levels must be negative*" failed to note that atom can still lose energy if the energy levels are positive, the higher level being more positive than the lower level. Hence such an argument is not valid.

(ii) 9.0 eV electron has sufficient energy to excite mercury atom from ground state to energy level of –1.57 eV (because –1.57 – (–10.38) = 8.81 eV). B1

As atom de-excites from –1.57 to –5.74 eV, a photon is emitted.

$$\frac{hc}{\lambda} = [-1.57 - (-5.74)] \times (1.6 \times 10^{-19})$$

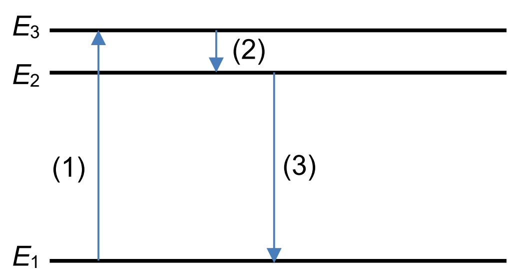
$$\lambda = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{6.672 \times 10^{-19}}$$ M1

$$\lambda = 2.98 \times 10^{-7}\,\text{m}$$ A1

Students need to show an understanding that the "*highest level*" that the mercury atom can be excited to is level corresponding to –1.57 eV. This step is often missing and hence students lose that credit.

One mistake that students made is not converting eV to joules.
Another common mistake is using the wrong energy levels in the calculation. Question asks for longest wavelength of UV, so it has to be between energy levels that have the smallest difference in values, and the energy of photon calculated should be within the UV range.

(iii)



B1

All directions and transitions must be correct to earn the credit.

One common mistake seen is students indicating emission of infrared/ red photon between levels E_1 and E_3. If E_1 and E_3 already represents energy of a UV photon for transition (1), it does not make sense that the same energy "gap" also represents that of infrared (or red) photon.

Wrong indication of the direction of arrows is another common mistake. Absorption of a photon causes the atom to transit to a higher energy level while emission of a photon is due to the atom transiting to a lower energy level.

Note that in terms of energy for the 3 photons mentioned in this question, UV photon is the most energetic, followed by visible red, and infra-red is least energetic amongst these three.

8 **(a)** Simple harmonic motion is defined as the motion of a particle (or body) about a fixed point such that its acceleration is proportional to its displacement from the fixed point and is always directed towards the point. B1 B1

(b) **(i)** $M = AL\rho$ A1

(ii) $\Delta p = h\rho g = 2x\rho g$ B1

$\Delta p = \dfrac{F}{A} \quad \Rightarrow \quad F = (\Delta p)A = 2xA\rho g$ B1

(iii) Since F is the restoring force, (F acts in the opposite direction to x)
$F = -2\,xA\rho g$ B1

$F = Ma$ where a is the acceleration

$\therefore -2xA\rho g = AL\rho \cdot a$

$\therefore a = \dfrac{-2xA\rho g}{AL\rho} = \dfrac{-2gx}{L}$ B1

$\therefore a \propto -x,$ since $\dfrac{2g}{L}$ is a constant B1

Hence the motion is s.h.m.

Generally, well done for this part. The negative sign should be included in the equation.

(iv) Since $a = -\omega^2 x$ and $a = -\dfrac{2gx}{L}$ B1

$\therefore \omega^2 = \dfrac{2g}{L} \Rightarrow \omega = \sqrt{\dfrac{2g}{L}}$

(c) **(i)** $\omega = \sqrt{\dfrac{2g}{L}} = \sqrt{\dfrac{2 \times 9.81}{0.92}} = 4.62 \text{ rad s}^{-1}$ A1

(ii) $T = \dfrac{2\pi}{\omega} = \dfrac{2\pi}{4.618} = 1.36 \text{ s}$ A1

(iii) $E_{K,\max} = \dfrac{1}{2}Mv_{\max}{}^2 = \dfrac{1}{2}M\omega^2 x_0{}^2$

$= \dfrac{1}{2}(1.2)(4.618)^2(0.080)^2$ M1

$= 0.0819 \text{ J}$ A1

(d) **(i)** Damping refers to the <u>loss of energy</u> in an oscillatory system (due to the presence of dissipative forces). B1

Quite a number of students could not answer this part correctly. Please be advised to study your lecture notes again.

(ii)

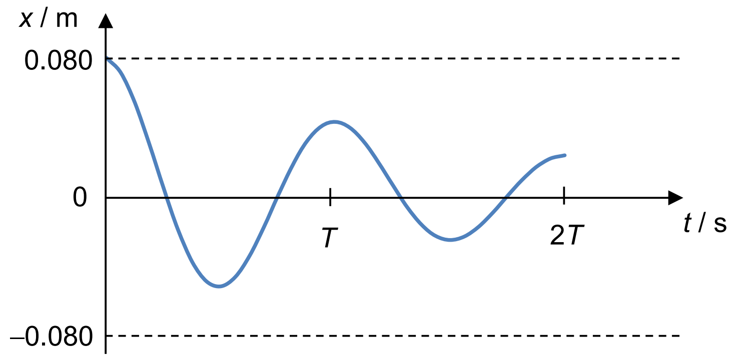


Fig. 8.3

cosine curve decreasing amplitude decrease in amplitude is gradual **Total [2] marks**, any mistake loses [1] mark

This part wasn't quite well done. Since there are viscous forces present, energy (total energy, and not just KE) is gradually lost and the amplitude will decrease exponentially with time.

(iii)

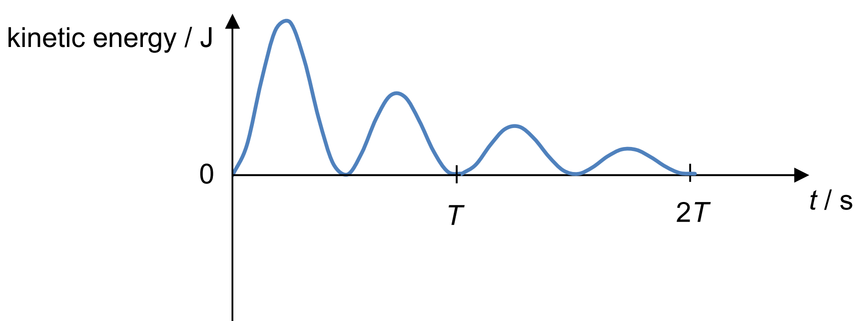


Fig. 8.4

sine^2 graph 2 peaks in 1 cycle decreasing peak, correct shape, no "Macdonald" shape **Total [2] marks**, any mistake loses [1] mark

This part wasn't well done. Many students drew the "MacDonald" curve. Remember, it's a sine^2 curve, so it is supposed to be a continuous curve (check this out using your GC) with no "kinks". Also, since there are viscous forces present, energy is gradually lost, so the subsequent peaks will decrease exponentially with time. Remember also that there are two peaks per cycle (KE peaks twice every cycle); and KE cannot be negative.

(e) Car suspension, B1
to reduce motion sickness of passengers B1
OR damping of oscillation of pointer in analogue meters, to allow readings to be taken more quickly
OR door closer, to close door without door slamming or swinging.
OR mass dampers in buildings

9 **(a)** **(i)** n = 2 B1

Y = proton / hydrogen nucleus B1

(ii) As there are many more protons than deuterons in the Sun, the reaction of two deuterons reacting to form a helim-4 is much less likely to occur than the reaction of step II. B1

(iii) $\Delta m = \left(4\times 1.007276 - 4.001506 - 2\times 0.000585\right)\left(1.66\times 10^{-27}\right)$

$= 4.387\times 10^{-29}$ kg M1

$E = \Delta mc^2 = 4.387\times 10^{-29}\times\left(3.00\times 10^{8}\right)^2$ M1

$= 3.95\times 10^{-12}$ J A1

(b) **(i)** Energy generated per second $= 1400\times 4\pi\left(1.5\times 10^{11}\right)^2$ M1

$= 3.96\times 10^{26}$ W A1

(ii) **1.** No. of reactions per second $= \dfrac{3.96\times 10^{26}}{3.95\times 10^{-12}} = 1.00\times 10^{38}$ A1

2. No. of protons at present $= \dfrac{2\times 10^{30}}{1.007276u} = 1.196\times 10^{57}$ M1

time taken $= \dfrac{1.196\times 10^{57}}{4(1.00\times 10^{38})} = 2.99\times 10^{18}$ s A1

(c) **(i)** It is the time taken for a sample of radioactive atoms to decay to half its original number. B1

(ii) ${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$ B1

(iii) **1.** As radioactivity is a random process, the number of decays per unit time is subjected to statistical fluctuations. The error is especially significant when the number of decays is low. By measuring over ten minutes, a larger number of decays is recorded and the random error due to statistical fluctuations is less significant. B1 B1

2. No. of carbon atoms in 33.3 g $= \dfrac{33.3}{12}\times 6.02\times 10^{23}$ M1

$= 1.67\times 10^{24}$

(shown)

No. of carbon-14 atoms at the beginning $= 1.67\times 10^{24}\times\left(1\times 10^{-12}\right)$ M1

$= 1.67\times 10^{12}$

Initial activity $= \lambda N_o$

$= \dfrac{\ln 2}{5730\times 365\times 86400}\times 1.67\times 10^{12}$

$= 6.41\ \mathrm{s}^{-1}$ M1

By $A = A_o\left(\frac{1}{2}\right)^{t/T_{1/2}}$, M1

$$\left(\frac{1}{2}\right)^{t/T_{1/2}} = \frac{0.4}{6.41} = 0.0624$$ A1

$$t = \left[\frac{\ln(0.0624)}{\ln(1/2)}\right] = 4.00T_{1/2} = 22900 \text{ years}$$