

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE
NAME

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CLASS

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TUTOR'S
NAME

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PHYSICS

9478/02

Paper 2 Structured Questions

16 September 2026

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number in the spaces at the top of this page.

Write in dark blue or black pen on both sides of the paper.

You may use a HB pencil for any diagrams, graphs.

Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use	
1	/ 10
2	/ 8
3	/ 10
4	/ 14
5	/ 11
6	/ 22
Total	/ 75

Data

speed of light in free space

$$c = 3.00 \times 10^8 \text{ m s}^{-1}$$

permeability of free space

$$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$$

permittivity of free space

$$\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$$

elementary charge

$$\left(\frac{1}{4\pi\varepsilon_0}\right) = 8.99 \times 10^9 \text{ m F}^{-1}$$

$$e = 1.60 \times 10^{-19} \text{ C}$$

the Planck constant

$$h = 6.63 \times 10^{-34} \text{ J s}$$

unified atomic mass constant

$$u = 1.66 \times 10^{-27} \text{ kg}$$

rest mass of electron

$$m_e = 9.11 \times 10^{-31} \text{ kg}$$

rest mass of proton

$$m_p = 1.67 \times 10^{-27} \text{ kg}$$

molar gas constant

$$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$

Avogadro constant

$$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$$

Boltzmann constant

$$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

gravitational constant

$$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

acceleration of free fall

$$g = 9.81 \text{ m s}^{-2}$$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by gas	$W = p \Delta V$
pressure	$p = \frac{F}{A}$
gravitational potential	$\phi = -\frac{GM}{r}$
temperature	$T / K = T / ^\circ C + 273.15$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
mean translational kinetic energy of an ideal gas particle	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
energy in a capacitor	$U = \frac{1}{2}QV = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2}CV^2$
charging a capacitor	$Q = Q_0[1 - e^{-\frac{t}{\tau}}]$
discharging a capacitor	$Q = Q_0 e^{-\frac{t}{\tau}}$
RC time constant	$\tau = RC$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
energy states for quantum particle in a box	$E_n = \frac{h^2}{8mL^2} n^2$
radioactive decay	$x = x_0 e^{-\lambda t}$
radioactive decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Answer **all** the questions in the spaces provided.

- 1 (a) State the conditions required for a body to be in equilibrium.

The sum of forces acting on the body in any direction must be zero.

(The resultant force on the body is zero / No resultant force)

The sum of the moments of the forces about any point must be zero.

(The resultant moment (or torque) on the body about any axis is zero. / No resultant torque)

ER note: a small number did not sum the clockwise or anticlockwise moments or refer to the resultant or net force.

[2]

- (b) Block A of mass 1.7 kg is connected by a light inextensible string to a counterweight B of mass M via a system of two massless and frictionless pulleys P and Q. Block A is balanced on a smooth plane inclined at 45° .

Pulley Q is a double pulley made up of two fixed wheels of different radii attached to a common axle, with the radii of the smaller and larger wheels r and $3r$ respectively as shown in Fig. 1.1.

Many left out the terms “net” or “resultant”, just simply just stated that the sum of forces is zero which is insufficient.

Many mistakenly wrote momentum instead of moments!

For rotational equilibrium, it doesn't matter which point or axes you take (it holds for any point inside or outside of the body!). The resultant torque will still be zero. If you stated “about a point” or “a point on the body”, it's not general enough and no credit given.

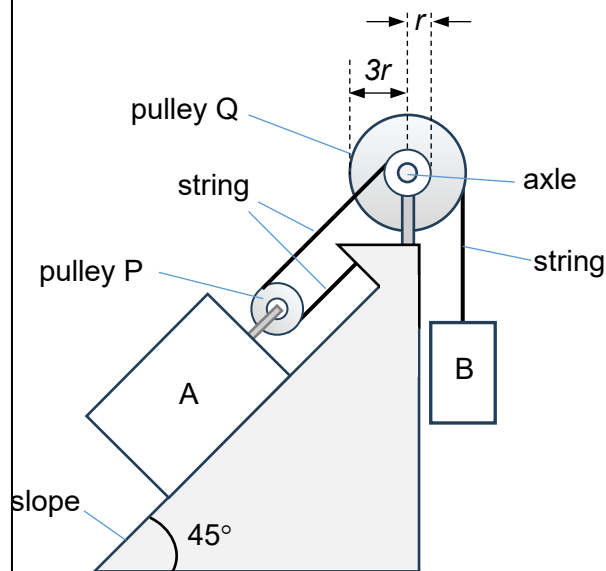


Fig.1.1

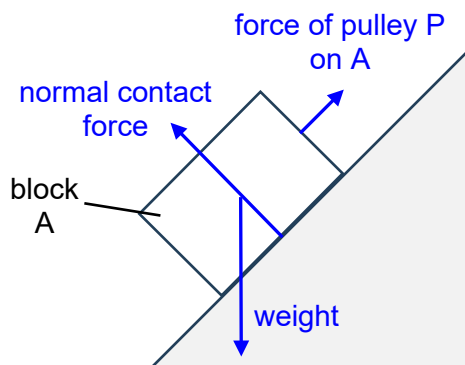
- (i) Block A is in equilibrium. In Fig. 1.2, draw and label all forces acting on block A.

Force of pulley on A must start from the edge of the block and not the CG. That is not the tension from the string!

Since object is in equilibrium, all forces must meet at the CG!

“Normal” alone is not accepted. Normal just means perpendicular and not a force. Many did not label the forces in full.

Lengths of the vectors should all balance out. Some lines were too short/long.



[B1] 3 correct forces
[B1] correct labels

Fig.1.2

[2]

(ii) Calculate the tension in the string connected to pulley P.

Block A is in equilibrium: $\sum F_{\parallel \text{ slope}} = 0$

$$m_A g \sin 45^\circ = 2T$$

$$T = \frac{m_A g \sin 45^\circ}{2} = \frac{(1.7)(9.81) \sin 45^\circ}{2} \quad [\text{M1}]$$

$$= 5.90 \text{ N} \quad [\text{A1}]$$

tension = 5.90 N N [2]

Badly done. Majority did not realise that the force from A is distributed between 2 strings. Most did not divide the force by 2.

(iii) Determine the mass M of counterweight B.

Taking pivot about axel, $\sum \tau = 0$

CW moments = ACW moments

$$m_B g(3r) = Tr$$

$$m_B = \frac{Tr}{g(3r)} = \frac{T}{3g} = \frac{5.90}{(3)(9.81)} \quad [\text{M1}]$$

$$= 0.200 \text{ N} \quad [\text{A1}]$$

$M =$ 0.200 kg kg [2]

Badly done. The two strings connecting A and B are not the same!!!

This is a moments question, and you need to take time to identify what is happening within the system. Most student simply equated the tension to the weight of B which does not make any sense.

(iv) Suggest and explain a change that can be made to the pulley such that block A will accelerate up the slope.

The larger wheel of the double pulley can be made larger with the smaller wheel remaining constant / more than 3 times larger than the smaller wheel. [M1]

This is so that the clockwise moment will be larger than the anticlockwise moment / net clockwise torque causing the block A to slide up the slope. [A1]

[2]

You need to read the question carefully and answer it. The question explicitly asked for changes that can be made to the pulley, so any answer not related to the pulley is not accepted.

Since this is moments question, the main aim is to make the system have a net clockwise moment, the easiest is to increase the $3r$ radius to some value larger. Many did not state clearly which part of the pulley's radius is to be changed. (can also change the radius r to be smaller).

Many jumped straight to the conclusion that tension on A will be greater, which wasn't awarded credit as the main physics of having a net clockwise moment is missing.

- 2 A plane is flying with a velocity of 240 m s^{-1} at an angle of 30° with respect to the horizontal, as shown in Fig. 2.1. At an altitude of 2.0 km , a projectile is released from the plane. The projectile hits the target on the ground. Assume air resistance is negligible.

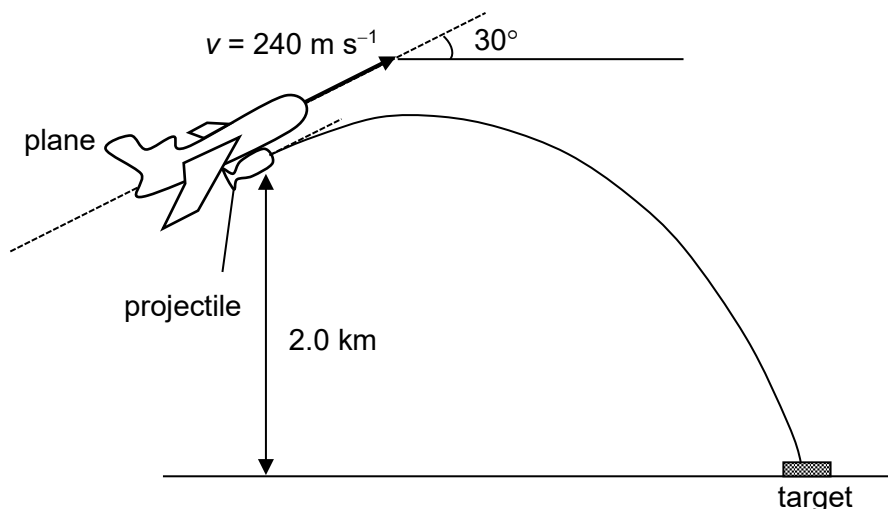


Fig. 2.1

- (a) Determine the horizontal displacement of the projectile from the point of release to the target.

$$\begin{aligned}
 s_y &= u_y t + \frac{1}{2} a_y t^2 \\
 -2000 &= (240 \sin 30^\circ) t + \frac{1}{2} (-9.81) t^2 \quad [\text{C1}] \\
 4.905 t^2 - 120 t - 2000 &= 0 \\
 t &= -11.38 \text{ (reject)}, 35.8413 \text{ s} \\
 s_x &= u_x t \\
 &= (240 \cos 30^\circ)(35.8413) \quad [\text{C1}] \\
 &= 7400 \text{ m} \quad [\text{A1}]
 \end{aligned}$$

Comments:

Many break up the motion into parts and use EOM to solve. There is no need for such tedious solution.

horizontal displacement = m [3]

- (b) Determine the speed of the projectile just before it hits the target.

$$\begin{aligned}
 v_y &= u_y + a_y t \\
 &= (240 \sin 30^\circ) + (-9.81)(35.84) \\
 &= -231.6 \\
 v &= \sqrt{v_x^2 + v_y^2} \\
 &= \sqrt{240^2 \cos^2 30^\circ + 231.6^2} \quad [\text{C1}] \\
 &= 311.2 \approx 310 \text{ m s}^{-1} \quad [\text{A1}]
 \end{aligned}$$

$$\begin{aligned}
 \text{OR } \frac{1}{2} m v_f^2 &= \frac{1}{2} m (240)^2 + m (9.81)(2000) \quad [\text{C1}] \\
 v_f &= 311.2 \approx 310 \text{ m s}^{-1} \quad [\text{A1}]
 \end{aligned}$$

speed = m s⁻¹ [2]

- (c) (i) Without further calculation, on Fig. 2.2, sketch the variation of vertical velocity v_y with time t of the projectile from the time it was released to the time it hits the target. Label this line **P**. Include values on your axes. [1]

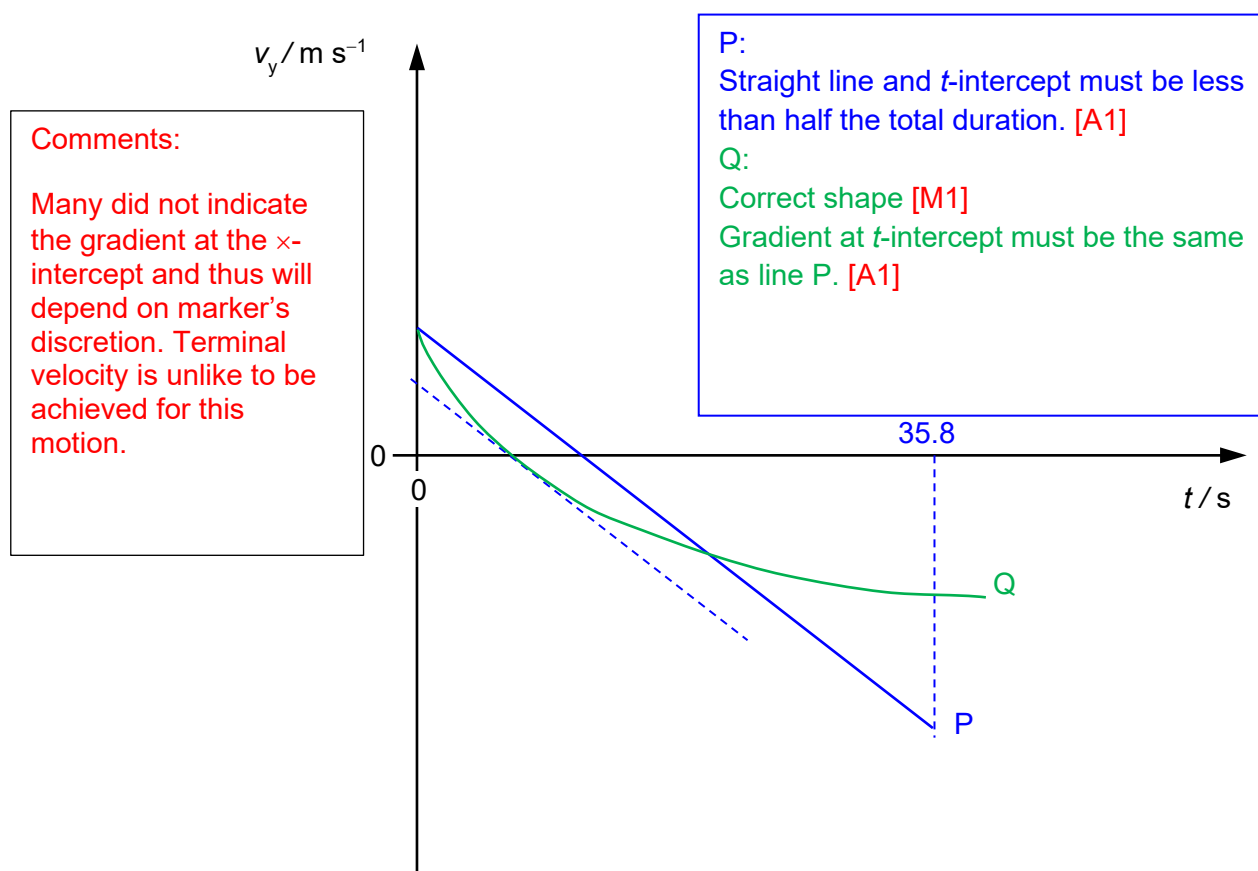


Fig. 2.2

- (ii) On Fig. 2.2, sketch the variation of vertical velocity v_y with time t of the projectile if air resistance was **not** negligible. Label this line **Q**. No calculations are required. [2]

[Total: 8]

- 3 (a) PQRS comprises of a rough slope PQR of height 1.1 m, and smooth horizontal surface RS. PQR of total surface length 2.7 m is made up of a straight section PQ and curved section QR as shown in Fig. 3.1.

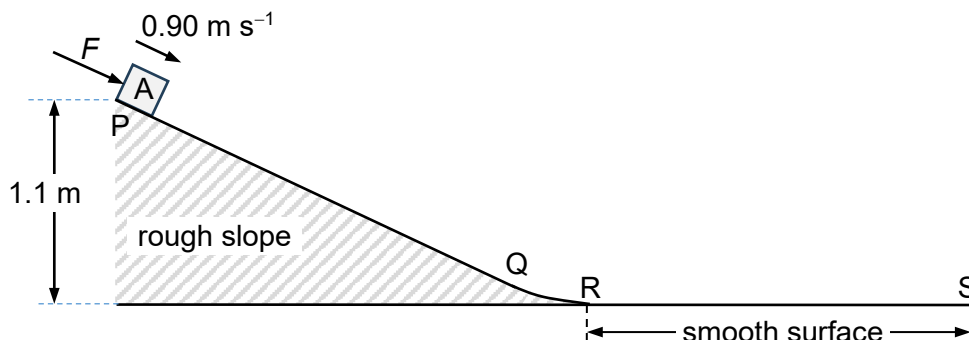


Fig. 3.1

Block A of mass 2.0 kg has an initial speed of 0.90 m s^{-1} at point P on rough slope. A force F is applied to block A as it moves along PQR. The magnitude of the F is 11 N and its direction is the same as the object's velocity at any instant along surface PQR.

The frictional force between the block A and the surface PQR may be taken to be constant at 6.4 N.

- (i) Determine the speed of the block when it reaches R.

gain in KE = WD by gravitational force + WD by F – WD by friction

$$= mgh + F \cdot s - F_{\text{friction}} \cdot s$$

$$= (2.0)(9.81)(1.1) + (11)(2.7) - (6.4)(2.7) \quad [\text{B1}]$$

$$= 34.002 = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$v = \sqrt{\frac{2(34.002)}{m} + u^2}$$

$$= \sqrt{\frac{(2)(34.002)}{2.0} + (0.90)^2} \quad [\text{B1}]$$

$$= 5.9 \text{ m s}^{-1} \quad [\text{A1}]$$

Badly done. Force and friction acts only along PQR! Acceleration is not constant along length QR as there is a curvature of the slope (NOT CIRCULAR MOTION!)

Many students either left out GPE, friction or the applied force. There is huge confusion as to what contributes to the gain in KE or take energy away from the system. There is also initial KE in the system.

speed = m s^{-1} [3]

- (ii) Use Newton's second law to explain how the speed of block A varies along PQRS.

Along PQ the net force given by $(F + \text{component of weight parallel to slope } W_{\parallel} - \text{friction}) = ma$. (acceleration is constant and) Speed increases as $F_{\text{net}} > 0$ (as $F > \text{friction}$).

For the section QR, as $W_{\parallel}$ decreases to zero as the slope flattens out, F_{net} is still > 0 , speed of block increases further (at a decreasing rate).

$(F_{\text{net}}$ goes from $(F + \text{component of weight parallel to slope } W_{\parallel} - \text{friction})$ to $(F - \text{friction})$

For RS, the block moves at constant speed as $F_{\text{net}} = 0$, no applied force and no friction between surfaces.

[3]

Badly done. Force and friction acts only along PQR! Acceleration is not constant along length QR as there is a curvature of the slope (NOT CIRCULAR MOTION!)

You only need to use the idea of N2L and not quote the entire N2L. Most forgot about the component of weight parallel to the slope and assumed that the net force is just 4.6N.

Question is asking about speed, many just left their answers in terms of acceleration.

It is required to split the answer into 3 sections PQ, QR and the RS.

PQ. There its F, friction and component of weight. For QR, the component of weight along the slope decreases due to the curved slope so net force decreases.

Many spoke about components of Normal contact force (!?!?!?) There is no component of N along the slope – they are perpendicular to each other!

RS: net force is zero!

- (b) Block X of mass 0.27 kg moves with a speed 0.67 m s^{-1} on a smooth horizontal surface. Block Y of mass 0.34 kg moves with speed 0.46 m s^{-1} in the opposite direction. A light spring of natural length 13.0 cm and force constant 120 N m^{-1} is attached to block Y as shown in Fig. 3.2.

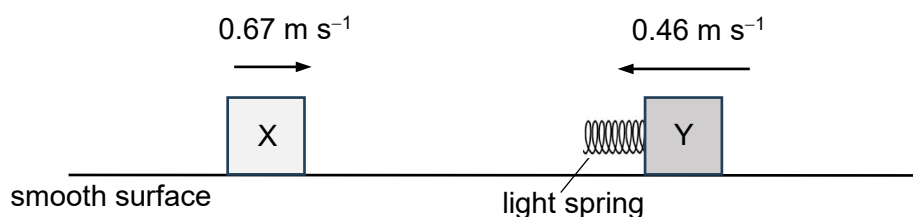


Fig. 3.2

When block X collides elastically head-on with block Y, there will be an instant when the spring experiences maximum compression.

Determine the closest distance of approach of the two blocks.

At closest distance of approach, both block moves with the same speed. [C1]
Taking rightwards as positive

$$m_A u_A + m_B u_B = (m_A + m_B) v$$

$$v = \frac{m_A u_A + m_B u_B}{m_A + m_B} = \frac{(0.27)(0.67) + (0.34)(-0.46)}{0.27 + 0.34} \quad [C1]$$

$$= 0.0402 \text{ m s}^{-1}$$

Difference in KE before collision and max compression = EPE stored in spring

$$\left(\frac{1}{2} m_A u_A^2 + \frac{1}{2} m_B u_B^2 \right) - \frac{1}{2} (m_A + m_B) v^2 = \frac{1}{2} k x^2$$

$$\left(\frac{1}{2} (0.27)(0.67)^2 + \frac{1}{2} (0.34)(-0.46)^2 \right) - \frac{1}{2} (0.27 + 0.34)(0.0402)^2 = \frac{1}{2} (120) x^2 \quad [C1]$$

$$x = 0.0400 \text{ m}$$

closest distance of approach = $L_0 - x$

$$= 0.130 - 0.040 = 0.090 \text{ m} \quad [A1]$$

Comments:

The bulk of the marks are related to the fact that the masses are at the same speed when the spring is at maximum compression. So not knowing that cost students most, if not all, the marks.

Small handful of students tried to incorrectly calculate total KE

$$\text{Total KE} = \frac{p_{net}^2}{2m_{total}} = \frac{((0.27)(0.67) + (0.34)(-0.46))^2}{2(0.27 + 0.34)}.$$

closest distance of approach = m [4]

[Total: 10]

- 4 (a) (i) State **one** difference and **one** similarity between the oscillations of a stationary sound wave and a progressive sound wave.

Difference: ● In stationary sound waves, particles oscillate (except at the nodes where it is 0) with varying amplitudes from 0 to a maximum at the antinodes. In progressive sound waves, all particles oscillate with the same amplitude.

● In stationary sound waves, particles between adjacent nodes oscillate in phase while particles in adjacent segments oscillate in antiphase. In progressive sound waves, particles oscillate at different phases within one wavelength [B1] Differences must be in terms of phase or amplitude variations of a particle's oscillation NOT in terms of the whole wave (e.g. comparing energy transfers)

Similarity: In both waves, particles are oscillating in simple harmonic motion/about their equilibrium positions with the same frequency as the wave [B1] ignore longitudinal or cannot be polarised

- (ii) Fig. 4.1 represents the displacement-time graph of two progressive sound waves travelling together through the same space.

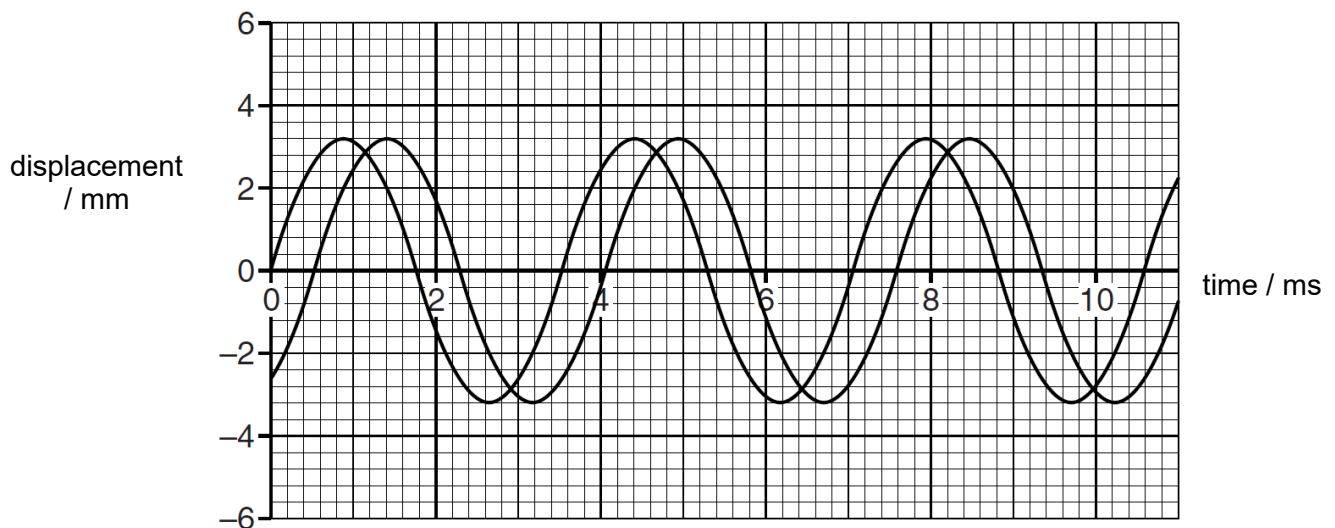


Fig. 4.1

1. State and explain whether Fig. 4.1 shows that the waves are coherent.

The waves are coherent because there is a constant time lag / constant period / constant frequency which indicates a constant phase difference [B1] apply evidence from graph of Fig. 4.1 to show coherence and not just mention "constant phase difference" only. [1]

NOT "same distance between the crests" since axis is given in time

2. Use Fig. 4.1 to determine the phase difference between the waves.

$$\begin{aligned}\Delta\phi &= \frac{\Delta t}{T} \times 2\pi \\ &= \frac{0.5}{3.5} \times 2\pi \quad \text{OR} \quad \frac{2.5 \text{ sq}}{17.5 \text{ sq}} \times 2\pi \\ &= 0.898 \text{ rad} \quad [\text{A1}]\end{aligned}$$

S.f. penalty for answers in fractions or in terms of π

phase difference = rad [1]

- (iii) A sound wave travels along the axis of a tube that is open at both ends, as shown in Fig. 4.2. A stationary sound wave is formed in the tube.

The lowest frequency possible for the stationary sound wave in this tube is f .

On Fig. 4.2, mark all the positions of the displacement nodes (use the letter N) and the displacement antinodes (use the letter A) of a stationary sound wave for a frequency of $2f$.

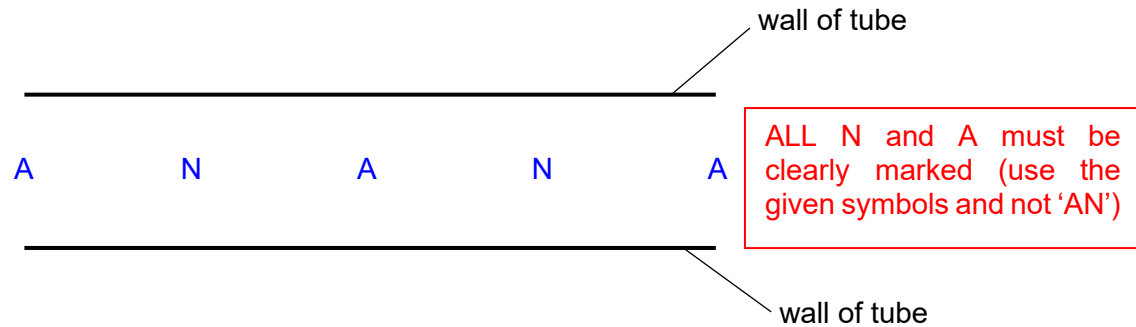


Fig. 4.2

[1]

- (iv) With reference to the movement of air molecules on either side of a displacement node, explain why there is maximum variation in pressure at the nodes.

Particles on either side of a displacement node are moving in opposite directions [B1] ignore antinodes so at one moment the pressure increases to a maximum (particles on either side are closest to node) AND at the next moment the pressure decreases to a minimum (particles on either side furthest from node) therefore pressure varies from a maximum to minimum $\rightarrow$ hence maximum variation [B1] idea of pressure to the separation of neighbouring particles of the node. Ignore compressions and rarefactions only. [2]

- (b) Fig. 4.3 shows the arrangement for an experiment involving superposition of microwaves.

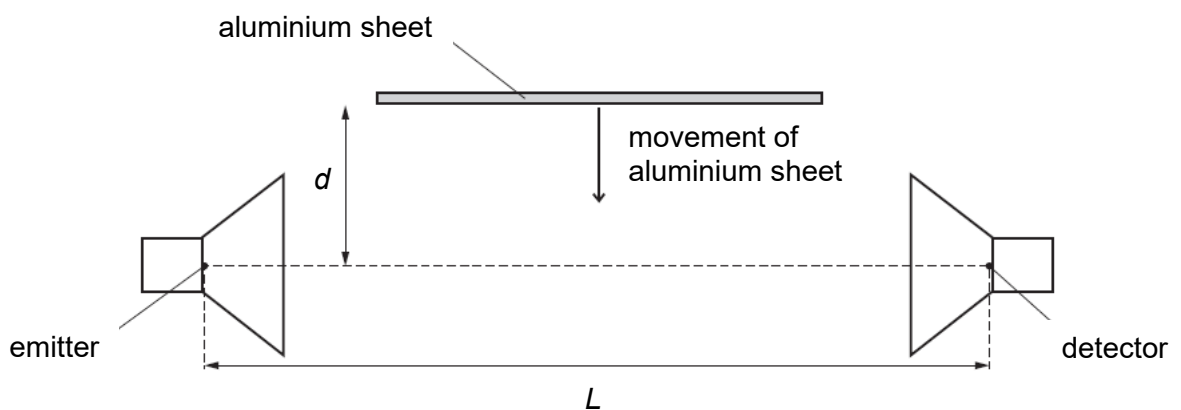


Fig. 4.3 (not to scale)

A microwave emitter and detector face each other with a distance L apart. A reflecting aluminium sheet is placed at a vertical distance d above the direct path between the emitter and the detector.

- (i) When the aluminium sheet is moved in the direction shown by the arrow, the intensity of microwaves received by the detector fluctuates.

Describe and explain this variation in the microwave intensity.

Reducing d changes the path difference between the direct and reflected wave so the phase difference changes [B1] idea of path diff / phase diff between direct and reflected wave NOT stationary wave formed by the reflected wave travelling in opposite direction
 Constructive interference leading to maximum intensity (occurs when path difference is a whole number of wavelengths) AND destructive interference leading to minimum intensity (occurs when path difference is odd number of half-wavelengths) [B1] idea of constructive and destructive interference leading to intensity variations stated [2]

- (ii) As d decreases, the microwave detector has a maximum reading at $d = 21.2$ cm and the next maximum at $d = 17.7$ cm. The distance L stays constant at 80.0 cm.

Determine the wavelength λ of the microwaves.

$$\begin{aligned} \text{reflected path} &= 2\sqrt{\left(\frac{L}{2}\right)^2 + d^2} \quad \text{[C1]} && \text{Use of Pythagoras theorem to calculate reflected path} \\ \text{path difference} &= 2\sqrt{\left(\frac{L}{2}\right)^2 + d^2} - L \\ 2\sqrt{\left(\frac{0.800}{2}\right)^2 + 0.212^2} - 0.800 &= (n+1)\lambda \quad \text{---(1)} \\ 0.1054 &= (n+1)\lambda \\ 2\sqrt{\left(\frac{0.800}{2}\right)^2 + 0.177^2} - 0.800 &= n\lambda \quad \text{---(2)} \\ 0.0748 &= n\lambda \end{aligned}$$

[M1] for correct path differences seen

$$\lambda = 0.1054 - 0.0748 = 0.0306 \text{ m} \quad \text{[A1]} \quad \text{correct method leading to correct ans}$$

$$\lambda = \dots\dots\dots \text{ m} \quad \text{[3]}$$

- (iii) Microwaves undergo a phase change of π rad when they reflect.

When d is much less than the wavelength of the microwaves, it is observed that the detector reading is a minimum.

Suggest why this observation demonstrates that microwaves must undergo a phase change on reflection from the aluminium sheet.

When d is much less, path difference becomes negligible or almost zero (as distance travelled by reflected wave is almost similar to incident wave) [B1] implication of small d on path difference seen
 This is supposed to produce a maximum reading due to constructive interference, but since a minimum was detected, it implies a phase change of π rad had occurred due to reflection [B1] idea that supposed to be C.I. but D.I. instead so must be due to phase change of π rad [2]

[Total: 14]

- 5 (a) State what is meant by the mass defect of a nucleus.

Mass defect is defined as the difference between the total mass of the separate nucleons
in a nucleus [B1] and the combined mass of the nucleus [B1]

Comments: The term “separate” is very important.

[2]

- (b) A stationary nucleus of uranium-238 (${}^{238}_{92}\text{U}$) undergoes alpha decay to produce an excited nucleus of thorium-234 (${}^{234}_{90}\text{Th}^*$). The kinetic energy of the emitted alpha particle is 4.151 MeV. A gamma-ray photon is then immediately emitted from the excited thorium nucleus after the alpha decay.

Assume that the rebound kinetic energy of the thorium nucleus is negligible.

Fig. 5.1 shows the masses of some of the nuclides involved in the decay reaction.

nuclide	nuclide mass/ u
${}^4_2\alpha$	4.000407
${}^{234}_{90}\text{Th}$	233.915174

Fig. 5.1

The total energy released in the decay of the nucleus of uranium-238 is 4.274 MeV.

(i) Calculate the mass, in u, of the uranium-238 nuclide.

$$\begin{aligned}
 E &= \Delta mc^2 \\
 4.274 \times 10^6 \times 1.60 \times 10^{-19} &= \Delta m(3.00 \times 10^8)^2 \quad [\text{C1}] \\
 \Delta m &= 7.598 \times 10^{-30} \text{ kg} \\
 &= \frac{7.598 \times 10^{-30}}{1.66 \times 10^{-27}} \text{ u} \\
 &= 0.004577 \text{ u} \\
 m_{\text{U}} &= 0.004577 + 233.915174 + 4.000407 \quad [\text{C1}] \\
 &= 237.920158 \text{ u} \quad (6 \text{ d.p.})[\text{A1}]
 \end{aligned}$$

Comments:

- Students incorrectly using $\Delta m = m_{\text{products}} - m_{\text{reactants}}$. Students were to check that energy is **released** from the reaction, implying that $\Delta m = m_{\text{reactants}} - m_{\text{products}}$. (wrong ans: 237.911004u)
- Compared to other theory paper chapters, using sf/dp rules is very important in Nuclear physics chapter due to the sf of the quantities given in such questions. That's how students are to know to leave their final answer in 6 dp. (and the answer obviously can't be 238 (3sf). Its already given in the question)
- For students who used (4.274 – 4.151) MeV, the energy coming from the mass defect supplies all the KE in the products **and** energy for gamma. That's why (4.274 - 4.151) MeV is used for the energy for gamma photon in the next question.
- Some tried to use binding energy to solve this question. (e.g. $BE_{\text{Th}} = 234(1.67 \times 10^{27}) - 233.915174(1.66 \times 10^{-27})$). The problem with this solution is that we don't have the mass of a neutron, which is slightly larger than a proton. So in general, though conceptually correct, this method is not advised to solve for questions which give mass data instead of binding energy data.

mass = u [3]

- (ii) Determine a value for the wavelength of the gamma radiation emitted during the decay of the uranium-238 nucleus.

$$\text{Total Energy released} = KE_{\text{Th}} + KE_{\alpha} + E_{\gamma}$$

$$4.274 \times 10^6 \times 1.60 \times 10^{-19} = 0 + 4.151 \times 10^6 \times 1.60 \times 10^{-19} + E_{\gamma} \quad [\text{C1}]$$

$$E_{\gamma} = 1.968 \times 10^{-14} = \frac{hc}{\lambda} \quad [\text{C1}]$$

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

$$\lambda = 1.011 \times 10^{-11} \text{ m (4.s.f.)} \quad [\text{A1}]$$

Comments:

Handful of students used $\lambda = \frac{h}{p}$. True, this formula is valid for photons. However, it is not valid to substitute $p = mv$ for photons, since photons do not have mass. TDLR: photons have momentum, but do not have mass. So $p = mv$ cannot be used on them.

wavelength = m [3]

- (iii) In practice, the rebound kinetic energy of the thorium nucleus is **not** negligible.

Explain, without further calculation, how your answer in (b)(ii) compares with the true wavelength of gamma radiation emitted during the decay of the uranium-238 nucleus.

With Thorium having some kinetic energy, the true energy of the gamma photon
would be smaller, so the true wavelength would be larger in practice ($E = \frac{hc}{\lambda}$). [B1]

Comments:

Some incorrectly thought that now that since the rebound KE for Th is significant, therefore the total energy released is not larger than 4.274 MeV. Whenever the question says that a previously made assumption is now wrong, students are to **take all the other data given in the question as still true**, (such as 4.274 and 4.151 MeV) and see what conclusion does that lead to.

[1]

- (c) Gamma radiation emitted during the decay of a sample of uranium-238 has a single wavelength.

Nuclei of cobalt-60 ($^{60}_{27}\text{Co}$) decay by beta emission and also emit gamma radiation in the process.

Suggest why there is **not** a single wavelength for the gamma radiation emitted during the decay of a sample of cobalt-60.

In cobalt-60 beta decay, (anti)neutrinos are emitted. [B1]

Total energy released is shared between the daughter nucleus, beta particle and (anti)neutrino. Since there are many ways that the energy can be divided among the three particles to satisfy the conservation principles, multiple possible energies for daughter nucleus will allow for multiple possible energies for gamma radiation and thus variable wavelengths. [B1]

[Total: 11]

Comments:

- Many students mentioned conservation of energy but not conservation of momentum to explain why there are multiple possibilities. Both are important to mention, as mathematically, these 2 conservation principles together are what leads to a 2 body decay (e.g. alpha decay) to only have one possible distribution of KE & momentum. (See Nuclear physics tutorial Q4b, 4c). But with 3 bodies, there are multiple possibilities to distribute the KE and momentum **and still** satisfy both conservation principles.
- Generally, it is recommended that students write (anti)neutrino instead of just neutrino.
- Many students stated beta decay having multiple possible energies as the starting point for their reasoning, instead of also explaining the origin for these possibilities.

6 Read the passage and answer the questions that follow.

The Juno spacecraft is launched by NASA in 2011, and its mission is to study Jupiter's origin, interior structure, atmosphere, and magnetosphere to understand the solar system's formation by measuring composition, gravity, and magnetic fields with its myriad of sensors on board.

This is also NASA's first mission to Jupiter to use solar panels rather than radioisotope thermoelectric generators (RTGs) for powering the spacecraft. Jupiter orbits the Sun at a much greater distance than Earth, making solar power generation a significant engineering challenge.

Solar radiation spreads out as it travels from the Sun. The solar intensity I at a distance d from the Sun follows the inverse square law. The solar intensity on Jupiter is only 3.72 % that on Earth. To compensate for the low intensity at Jupiter, Juno is equipped with three large solar array wings, as shown in Fig 6.1.

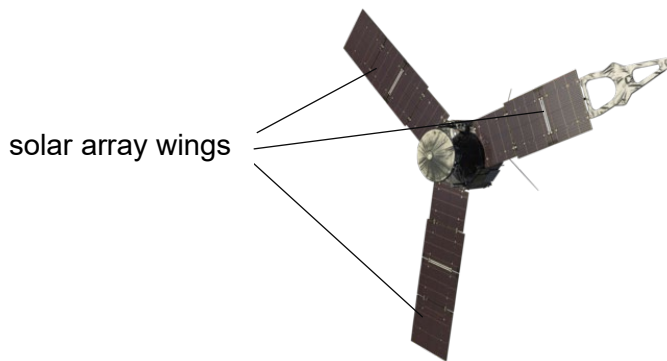


Fig. 6.1

The electrical power P generated by the solar panels on the wings is given by the equation:

$$P = I A \eta$$

where A is the total surface area of the solar panels and η is the efficiency of the solar cells. The efficiency of the cells is affected by the extremely low temperatures in the outer solar system.

Jupiter has an intense radiation belt above its equator that spans a distance of $2R_J$ to $10R_J$ from its centre, where R_J is the radius of Jupiter. Exposure to excessive radiation can cause damage to the spacecraft and its sensors. To minimize such exposure, Juno follows a highly elliptical polar (pole-to-pole) orbit, as shown in Fig 6.2.

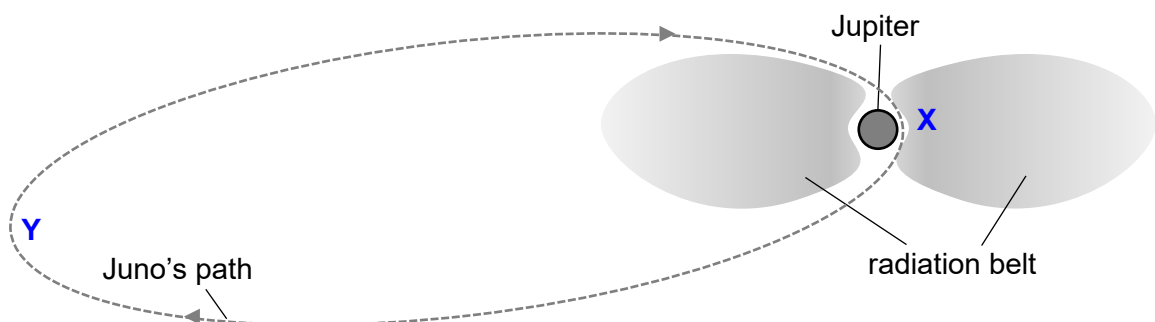


Fig. 6.2

Once Juno enters Jupiter's orbit, its propulsion system is turned off. It is subsequently used sparingly only to correct its path when necessary.

The distance of Juno from the centre of Jupiter in the first three months of 2017 is shown in Fig. 6.3.

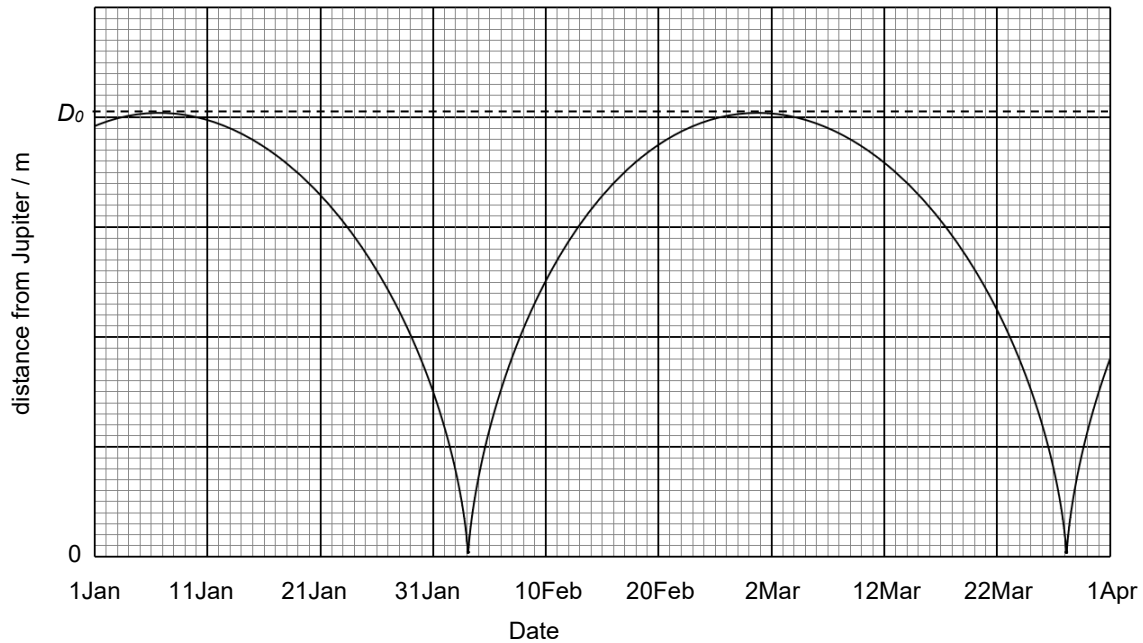


Fig. 6.3

Due to the vast distances involved, it took almost 5 years for Juno to enter Jupiter's orbit from Earth. Communication between Juno and Earth which is conducted via radio waves also experiences significant "light time" delay for signals.

Additional data for Earth, Jupiter and the Juno mission are provided in Table 6.4.

Property	Value
Mass of Jupiter M_J	$1.90 \times 10^{27} \text{ kg}$
Radius of Jupiter R_J	$7.15 \times 10^7 \text{ m}$
Mean distance* of Earth from the Sun d_E	$1.50 \times 10^{11} \text{ m}$
Solar intensity at Earth's distance I_E	1360 W m^{-2}
Total surface area of Juno's solar panels A	60 m^2
Efficiency of solar cells at Jupiter η	24%
Mass of Juno spacecraft m	3625 kg
Perijove (closest distance* to Jupiter) r_p	$1.06 R_J$
Apojove (furthest distance* from Jupiter) r_a	$113 R_J$

*center to center

Table 6.4

- (a) Explain why the solar intensity I follows an inverse square law as the distance d from the Sun increases.

Sun is taken as a point source, [B1] and the light radiates uniformly radially spherical

surface area is proportional to the square of distance from the Sun [B1]. Since intensity is

inversely proportional to area, it is inversely proportional to the square of the distance.

[2]

Comments: Many did not understand why the area can be assumed to be a sphere.

- (b) Using the relation in (a) and the data provided, show that the mean distance of Jupiter from the Sun is 7.78×10^{11} m.

$$\frac{\text{Intensity on Jupiter}}{\text{Intensity on Earth}} = 0.0372 = \left(\frac{\text{Distance of Earth}}{\text{Distance of Jupiter}} \right)^2 \quad [\text{B1}]$$

$$\text{Distance of Jupiter} = \frac{1.50 \times 10^{11}}{\sqrt{0.0372}} [\text{B1}] = 7.78 \times 10^{11} \text{ m}$$

Comments: This part is well done.

[2]

- (c) Calculate the total electrical power output generated by Juno's solar panels when Jupiter is at its mean distance from the Sun.

$$P = I A \eta = 50.6 \times 60 \times 0.24$$

$$= 729 \text{ W} [\text{A1}]$$

Comments: This part is well done. The common error is the decimal.

- (d) Suggest **one** reason, other than distance from the Sun, why the electrical power output might fluctuate during the mission.

Fluctuations in the temperature / Jupiter positioned between Juno and the Sun [A1]

[1]

Comments: The error should be found or deduced from the passage. Generic things should not be quoted, unless really no mention in the passage.

- (e) Determine from Fig. 6.3 the period of Juno's elliptical orbit.

$$86 - 33 = 53 \text{ days} [\text{A1}]$$

Comments: Working should be shown.

period = days [1]

- (f) Determine the value of D_0 in Fig. 6.3.

$$D_0 = \text{apojove} = 113 \times 7.15 \times 10^7 = 8.08 \times 10^9 \text{ m} \quad [\text{A1}]$$

$$D_0 = \dots\dots\dots \text{ m} \quad [1]$$

- (g) Explain why the sum of Juno's kinetic energy and gravitational potential energy remains constant when it is in orbit.

With the propulsion system turned off, the only force that acts on Juno is the gravitational force by Jupiter. Since there are no external forces [B1] on the system of Juno and Jupiter, total energy must remain constant. [1]

Just stating "no external work done" is not enough because it is not specific to the question.

- (h) Calculate the difference between the maximum and minimum values for the kinetic energy of Juno during an orbit.

Difference in max and min values of KE = Difference in max and min values of GPE [B1]

$$= -GM_J m_j \left(\frac{1}{r_a} - \frac{1}{r_p} \right)$$

$$= -6.67 \times 10^{-11} \times 1.90 \times 10^{27} \times 3625 \times \left(\frac{1}{8.08 \times 10^9} - \frac{1}{1.06 \times 7.15 \times 10^7} \right) [\text{B1}]$$

$$= 6.00 \times 10^{12} \text{ J} \quad [\text{A1}]$$

KE of Juno should not be calculated using $\frac{GM_J m_j}{2r}$ because Juno is not in a circular orbit.

$$\text{difference} = \dots\dots\dots \text{ J} \quad [3]$$

- (i) On Fig. 6.2, indicate point X at which Juno is moving with maximum speed and point Y at which it is moving with minimum speed. [1]

- (j) Explain using Fig. 6.2 and your answer in (i) how the highly elliptical orbit minimizes the spacecraft's exposure to Jupiter's intense radiation belt.

Fig. 6.2 shows that Juno is near or within the radiation belt for only a small portion of its orbit. [B1] In addition, from (i), its speed when it is near or within the radiation belt is the greatest, hence the time it spends in the region is further minimised. [B1]

Minimising the **time** in the radiation belt must be explicitly stated. [2]

- (k) For a body in a circular orbit, gravitational field strength g is always equal to $\frac{v^2}{r}$, where v is its linear speed and r is the radius of the orbit. In Juno's case, assume g is equal to $\frac{v^2}{r}$ at its perijove and its apojove. Use this relationship to calculate Juno's minimum speed.

Speed is minimum at the apojove:

$$g = \frac{GM_J}{r_a^2} = \frac{6.67 \times 10^{-11} \times 1.90 \times 10^{27}}{(8.08 \times 10^9)^2} \quad [B1] = 1.94 \times 10^{-3} \text{ N kg}^{-1}$$

$$\text{Since } g = \frac{v^2}{r}, v = \sqrt{gr} = \sqrt{1.94 \times 10^{-3} \times 8.08 \times 10^9} \quad [B1] = 3.96 \times 10^3 \text{ m s}^{-1} \quad [A1]$$

The solution must use the assumed relationship given.

minimum speed = m s⁻¹ [3]

- (l) Explain why the relationship $g = \frac{v^2}{r}$ does not hold in general for elliptical orbits.

Juno's distance from Jupiter is not constant. [B1]

When Juno is moving towards Jupiter, $g > v^2/r$. When Juno is moving away from Jupiter, $g < v^2/r$. [B1], OR Juno's velocity v is almost always not perpendicular to g , thus there is a component of v that is causing it to move closer or further away from Jupiter. [B1]

The difference between circular and elliptical orbits that leads to the applicability of the relationship must be explained.

- (m) Using the mean distances of Jupiter and of Earth from the Sun, estimate a minimum value for the "light time" delay for signals to travel from Jupiter to Earth.

$$\text{Minimum distance between Jupiter and Earth} = (7.78 - 1.50) \times 10^{11} = 6.28 \times 10^{11} \text{ m} \quad [B1]$$

$$\text{Minimum time taken} = \frac{6.28 \times 10^{11}}{3.0 \times 10^8} = 2100 \text{ s} \quad [A1]$$

delay = s [2]

[Total: 22]

End of Paper

