



Oxford Cambridge and RSA

Friday 09 October 2020 – Morning

A Level Physics A

H556/01 Modelling physics

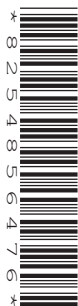
Time allowed: 2 hours 15 minutes

You must have:

- the Data, Formulae and Relationships Booklet

You can use:

- a scientific or graphical calculator
- a ruler (cm/mm)



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **32** pages.

ADVICE

- Read each question carefully before you start your answer.

2
SECTION A

You should spend a maximum of 30 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

- 1** An athlete is running at a speed of about 5 ms^{-1} .

What is a reasonable estimate for the kinetic energy of this athlete?

- A** 12 J
- B** 100 J
- C** 900 J
- D** 800 000 J

Your answer

C

[1]

- 2** Which pair of quantities have the same S.I. base units?

- A** force, strain
- B** force, stress
- C** pressure, stress
- D** strain, upthrust

Your answer

C

[1]

- 3** A tennis ball is hit with a racket. The force applied by the racket on the ball is F . The ball has a vertical path through the air.

Which statement is correct when the ball is at its **maximum** height?

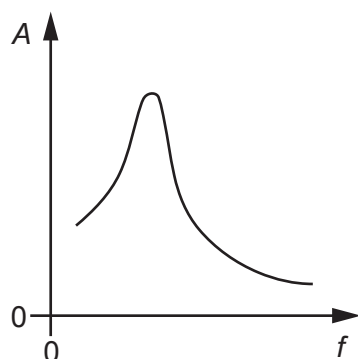
- A** The ball has a downward acceleration.
- B** The force acting on the ball is F .
- C** The ball experiences greatest drag.
- D** The weight of the ball is equal to the drag.

Your answer

A

[1]

- 4 An oscillator is forced to oscillate at different frequencies. The graph of amplitude A against driving frequency f for this oscillator is shown.



The damping on the oscillator is now **decreased**.

Which of the following statements is/are correct?

- 1 The amplitude of the oscillations at any frequency decreases.
- 2 The maximum amplitude occurs at a lower frequency.
- 3 The peak on the graph becomes thinner.

- A Only 1
 B Only 2
 C Only 3
 D 1, 2 and 3

Your answer

C

[1]

- 5 The gravitational force between two point-mass objects **X** and **Y** is F_1 .

The mass of **X** increases and the distance between **X** and **Y** is halved.

Which statement about the new gravitational force F_2 between these two objects is correct?

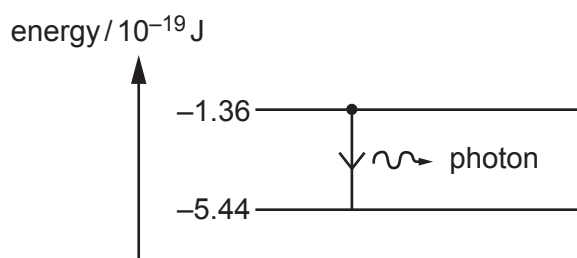
- A $0 < F_2 < 0.25F_1$
 B $F_2 > 4F_1$
 C $F_2 = F_1$
 D $2F_1 < F_2 < 4F_1$

Your answer

B

[1]

- 6 The diagram below shows two energy levels for the electron in the hydrogen atom.



The electron makes the transition shown by the arrow.

What is the wavelength of the photon emitted?

- A 293 nm
- B 366 nm
- C 488 nm
- D 1460 nm

Your answer

C

[1]

- 7 Recent analysis of the data collected from the Hubble and Gaia telescopes gave the Hubble constant a value of $73.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

What is this value, written to 2 significant figures, in s^{-1} ?

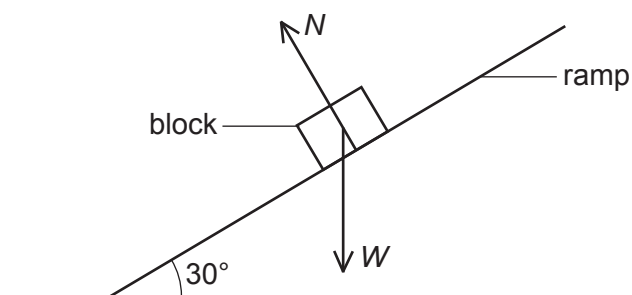
- A $2.4 \times 10^{-21} \text{ s}^{-1}$
- B $2.4 \times 10^{-18} \text{ s}^{-1}$
- C $2.4 \times 10^{-12} \text{ s}^{-1}$
- D $2.4 \times 10^{21} \text{ s}^{-1}$

Your answer

B

[1]

- 8 A wooden block is **stationary** on a ramp.



The diagram is **not** drawn to scale.

The block has weight W . The normal contact force on the block is N . The frictional force F on the block is not shown on the diagram.

Which triangle of forces diagram is correct?

- A**
-
- B**
-
- C**
-
- D**
-

Your answer

B

[1]

- 9 Laser light of wavelength of 640 nm is incident normally at a diffraction grating. The separation between adjacent lines (slits) is 3.3×10^{-6} m.

What is the **total** number of bright spots that can be observed in the diffraction pattern?

- A 5
- B 6
- C 10
- D 11

Your answer

D

[1]

- 10 A spring is stretched by hanging on it a variable mass m . The mass m is always at rest. The spring obeys Hooke's law.

What is the relationship between the elastic potential energy E in the spring and the mass m ?

- A $E \propto m^{-1}$
- B $E \propto m^{-2}$
- C $E \propto m$
- D $E \propto m^2$

Your answer

D

[1]

- 11 In astronomy, distance can be measured in different units.

Which one of the following distances is the **largest**?

- A 4.22×10^{16} m
- B 1.91 pc
- C 3.42 ly
- D 593 AU

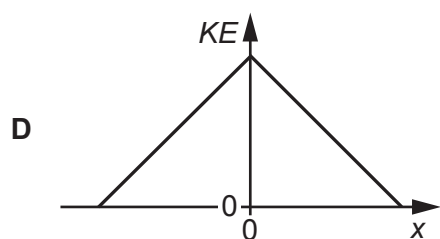
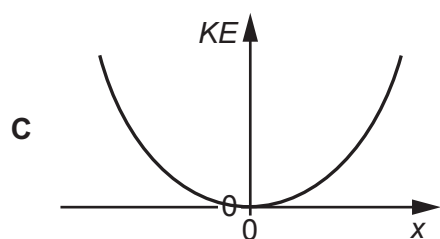
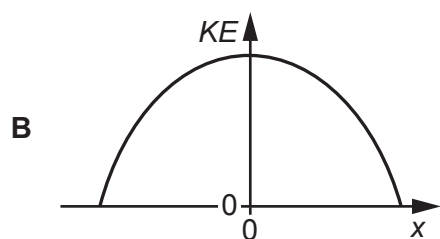
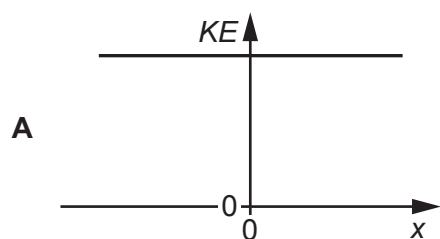
Your answer

B

[1]

12 An oscillator is executing simple harmonic motion.

Which graph of kinetic energy KE against displacement x is correct for this oscillator?



Your answer

B

[1]

- 13 The Young modulus E of a metal can be determined using the expression $E = \frac{4F}{\varepsilon\pi d^2}$, where F is the tension in the wire, d is the diameter of the wire and ε is the strain of the wire.

Here is some data.

Quantity	Percentage uncertainty
F	5.3
ε	1.2
d	1.0

What is the percentage uncertainty in the calculated value of E ?

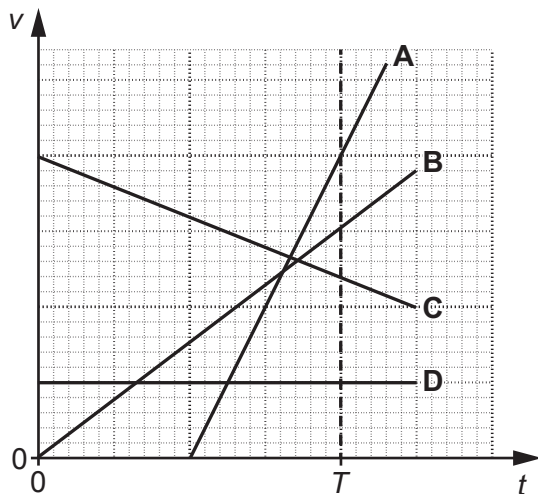
- A 2.1%
 B 6.4%
 C 7.5%
 D 8.5%

Your answer

D

[1]

- 14 The velocity v against time t graphs for four objects **A**, **B**, **C** and **D** are shown below.



Which object travels the greatest distance between $t = 0$ and $t = T$?

Your answer

C

[1]

- 15 The kinetic theory of matter is a model used to describe the behaviour of particles (atoms or molecules) in an ideal gas. There are a number of assumptions made in the kinetic model for an ideal gas.

Which one of the following assumptions is **not** correct?

- A The collisions of particles with each other and the container walls are perfectly inelastic.
- B The electrostatic forces between particles are negligible except during collisions.
- C The particles occupy negligible volume compared to the volume of the gas.
- D There are a large number of particles in random motion.

Your answer

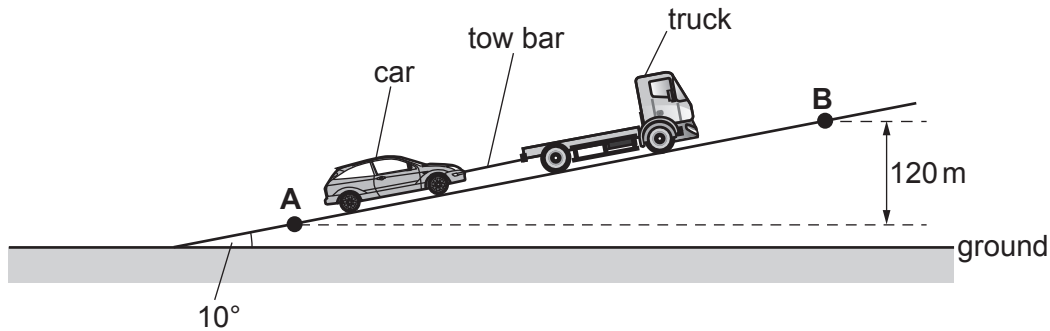
A

[1]

SECTION B

Answer **all** the questions.

- 16 A truck pulls a car up a slope at a **constant** speed.
The truck and the car are joined with a steel tow bar, as shown in the diagram.



The diagram is **not** drawn to scale.

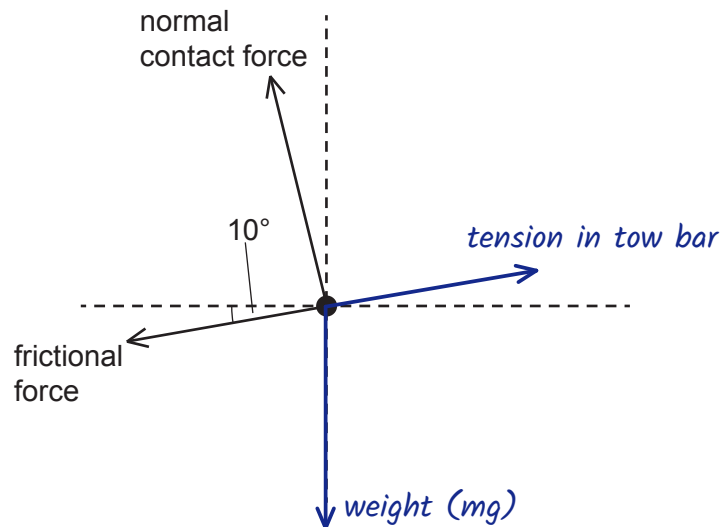
The slope is 10° to the horizontal ground.

The mass of the car is 1100 kg.

The car travels from **A** to **B**. The vertical distance between **A** and **B** is 120 m.

- (a) There are four forces acting on the **car** travelling up the slope.

Complete the free-body diagram below for the car and label the missing forces.



[2]

- (b) Show that the component of the weight of the car W_s acting down the slope is about 1900 N.

$$W_s = mg \sin 10^\circ = 1100 \times 9.81 \times \sin 10^\circ$$

$$W_s = 1874 \text{ N} \approx 1900 \text{ N}$$

[1]

- (c) The total frictional force acting on the car as it travels up the slope is 300 N.

Calculate the force provided by the tow bar on the car.

$$\text{constant speed so resultant force} = 0$$

$$\text{force} = W_s + \text{friction} = 1900 + 300 = 2200 \text{ N}$$

force = ... 2200 N [1]

- (d) Calculate the work done by the force provided by the tow bar as the car travels from A to B.

$$\text{distance along slope} = 120 / \sin 10^\circ = 691 \text{ m}$$

$$\text{work done} = F \times d = 2200 \times 691$$

$$\text{work done} = 1.5 \times 10^6 \text{ J}$$

work done = ... 1.5×10^6 J [3]

- (e) The steel tow bar used to pull the car has length 0.50 m and diameter 1.2×10^{-2} m. The Young modulus of steel is 2.0×10^{11} Pa.

Calculate the extension x of the tow bar as the car travels up the slope.

$$A = \pi d^2/4 = \pi \times 0.0060^2 = 1.13 \times 10^{-4} \text{ m}^2$$

$$\text{stress} = F / A = 2200 / 1.13 \times 10^{-4} = 1.95 \times 10^7 \text{ Pa}$$

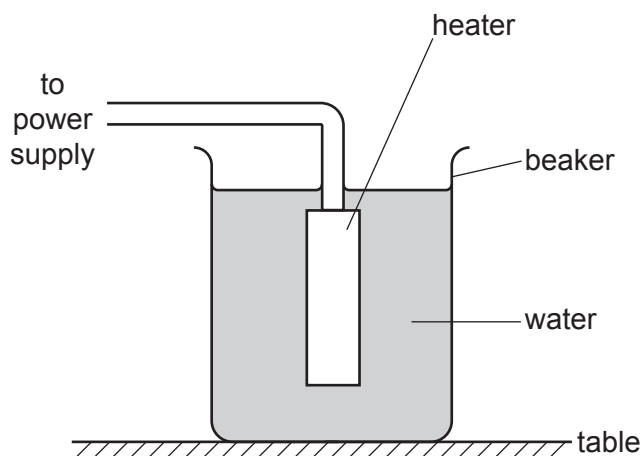
$$\text{strain} = \text{stress} / E = 1.95 \times 10^7 / 2.0 \times 10^{11} = 9.7 \times 10^{-5}$$

$$x = \text{strain} \times L = 9.7 \times 10^{-5} \times 0.50$$

$$x = 4.9 \times 10^{-5} \text{ m}$$

$$x = \dots 4.9 \times 10^{-5} \dots \text{ m [3]}$$

- 17 (a) A heater is used to heat water in a beaker.



- (i) Before switching on, the metal heater and the water are both at room temperature.

Describe the motion of the atoms of the metal heater and of the water molecules.

The atoms of the metal heater vibrate about fixed positions.

The water molecules move randomly and have translational kinetic energy (they move past each other).

Both are at the same temperature, so the metal atoms and the water molecules have the same mean kinetic energy.

[3]

- (ii) The heater is now switched on.
 The power of the heater is 200 W.
 The mass of the water in the beaker is 500 g.
 It takes 10.0 minutes to increase the temperature of the water in the beaker from 20 °C to 60 °C.

Calculate the energy transferred from the water to the **beaker and the surroundings**.

- specific heat capacity of water = 4200 J kg⁻¹ K⁻¹

$$\text{energy from heater} = Pt = 200 \times 10.0 \times 60 = 120\,000 \text{ J}$$

$$\text{energy to water} = mc\Delta\theta = 0.500 \times 4200 \times 40 = 84\,000 \text{ J}$$

$$\text{energy transferred} = 120\,000 - 84\,000 = 3.6 \times 10^4 \text{ J}$$

energy transferred = *3.6 × 10⁴* J [3]

- (b)* A student is carrying out an experiment to determine the specific latent heat of fusion L_f of ice. The student has two sets of apparatus next to each other on the laboratory bench, as shown in Fig. 17.1 and Fig. 17.2.

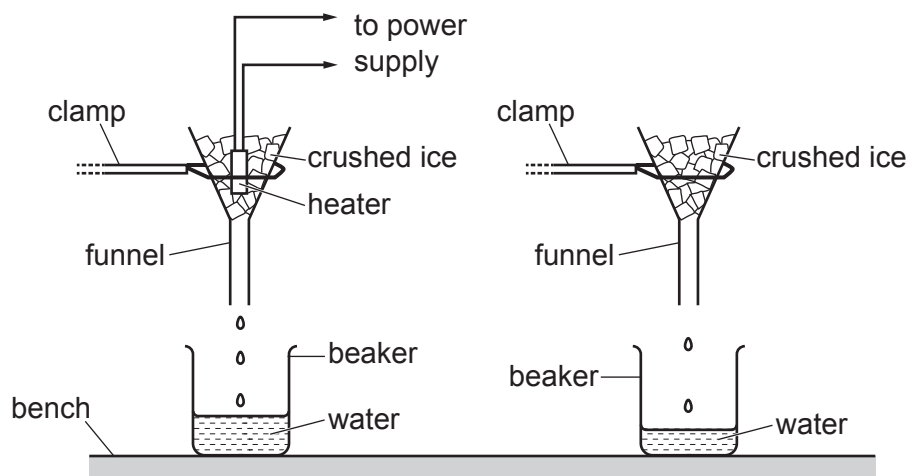


Fig. 17.1

Fig. 17.2

Both funnels are identical and have the same mass of crushed ice at 0°C .

The current in the heater is 5.0A and the potential difference across it is 12V .

Fig. 17.3 shows the variation of mass of water m collected in each beaker with time t .

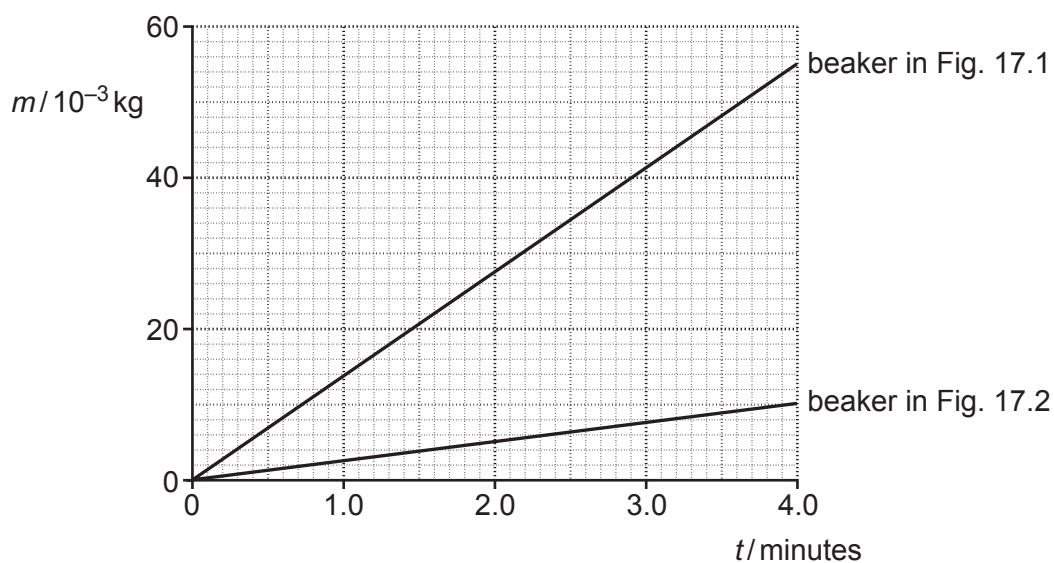


Fig. 17.3

Describe and explain the shape of the two graphs in **Fig. 17.3** and use them to determine the specific latent heat of fusion L_f of ice. [6]

Both graphs are straight lines through the origin, so $m \propto t$; the ice melts at a constant rate because energy is supplied to the ice at a constant rate in both funnels.

Fig. 17.2 is a control; its ice is heated only by the surroundings (the air in the room). The ice in Fig. 17.1 gains energy from the heater and from the surroundings, so its graph has a greater gradient (greater rate of melting).

Subtracting the control removes the energy from the surroundings, so the extra mass melted is due to the heater alone.

At $t = 4.0 \text{ min} = 240 \text{ s}$; $m = 55 \times 10^{-3} \text{ kg}$ (Fig. 17.1) and $10 \times 10^{-3} \text{ kg}$ (Fig. 17.2), so $\Delta m = 45 \times 10^{-3} \text{ kg}$.

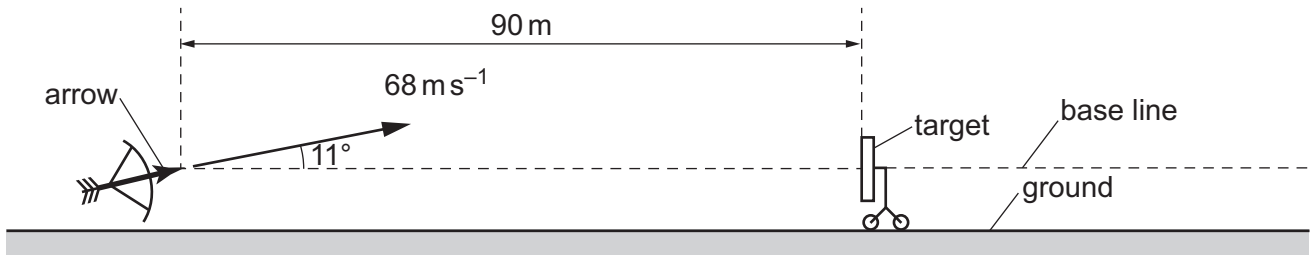
Energy from heater $\Delta E = VIt = 12 \times 5.0 \times 240 = 14\,400 \text{ J}$.

$\Delta E = mL_f$, so $L_f = 14\,400 / 45 \times 10^{-3} = 3.2 \times 10^5 \text{ J kg}^{-1}$.

Check with the gradients: $2.29 \times 10^{-4} - 0.42 \times 10^{-4} = 1.88 \times 10^{-4} \text{ kg s}^{-1}$, so $L_f = VI / \Delta \text{gradient} = 60 / 1.88 \times 10^{-4} = 3.2 \times 10^5 \text{ J kg}^{-1}$.

Additional answer space if required

- 18 An archer fires an arrow towards a target as shown below.



The diagram is **not** drawn to scale.

The centre of the target is at the same height as the initial position of the arrow.

The target is a distance of 90 m from the arrow.

The arrow has an initial velocity of 68 m s^{-1} and is fired at an angle of 11° to the horizontal.

Air resistance has negligible effect on the motion of the arrow.

- (a) Describe how the kinetic energy of the arrow changes during its journey from when it is fired until it reaches its maximum height.

The kinetic energy decreases as the arrow rises (KE is transferred to GPE).....

At maximum height the KE is a minimum but not zero, as the arrow still

has its horizontal velocity.

[2]

- (b) Show that the time taken for the arrow to reach its maximum height is about 1.3 s .

$$\text{vertical component } u = 68 \sin 11^\circ = 13.0 \text{ m s}^{-1}$$

$$\text{at max height } v = 0: v = u - gt$$

$$t = 13.0 / 9.81 = 1.32 \text{ s} \approx 1.3 \text{ s}$$

[2]

- (c) The arrow misses the target.

Calculate the horizontal distance, measured along the base line, by which the arrow misses the target.

$$\text{time of flight } t = 2 \times 1.3 = 2.6 \text{ s}$$

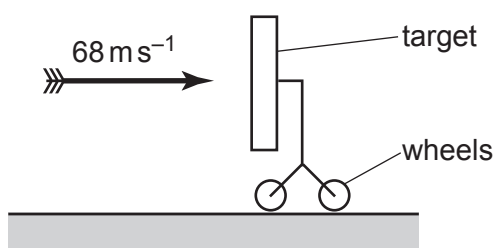
$$\text{horizontal velocity} = 68 \cos 11^\circ = 66.8 \text{ m s}^{-1}$$

$$x = 66.8 \times 2.6 = 174 \text{ m}$$

$$\text{distance missed} = 174 - 90 = 84 \text{ m}$$

horizontal distance = 84 m [3]

- (d) The arrow is now fired horizontally at 68 m s^{-1} into the target at very close range.



The arrow sticks into the target. The collision between the arrow and the target is inelastic.

- (i) Explain what is meant by an **inelastic collision**.

A collision in which kinetic energy is lost (KE is not conserved).

[1]

- (ii) The target is mounted on wheels. The target has a much larger mass than the mass of the arrow.

Using ideas of momentum, explain the velocity of the target immediately after the arrow sticks into the target.

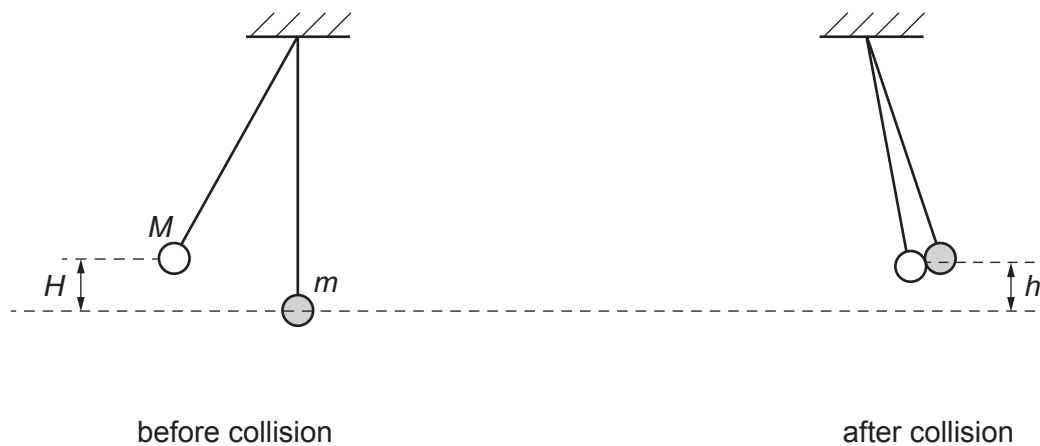
Momentum is conserved: the momentum of the arrow before =
momentum of arrow and target after.

So the target (with the arrow) moves to the right, in the original
direction of the arrow, but with a very small velocity, much smaller
than 68 m s^{-1} , because its mass is much larger.

[2]

- 19*** A student makes a pendulum using a length of string with a ball of adhesive putty which acts as a bob. The mass of this bob is M .
A similar second pendulum is constructed with the same length of string but with a bob of a smaller mass. The mass of this bob is m .

The arrangement of the pendulums is shown below.



The bob of mass M is pulled back to a vertical height of H from its rest position. It is released and collides with the bob of mass m . The two bobs then stick together and reach a maximum vertical height h from the rest position.

The height h is given by the equation $h = \left(\frac{M}{M+m} \right)^2 H$.

Describe how to perform an experiment to test the validity of this equation and how the data can be analysed. [6]

Hang both pendulums from a clamp stand with the same string length so that the bobs just touch at the lowest point. Measure the masses M and m with a top-pan balance.

Pull bob M back, keeping the string taut, to a height H above its rest position, measured to the centre of mass of the bob with a vertical metre rule (read at eye level, using a set square). Release it from rest without pushing it.

The bobs stick together. Film the motion with a video camera in front of the metre rule and play it back frame by frame to find the maximum height h of the centre of mass of the joined bobs (or use a motion sensor and data-logger).

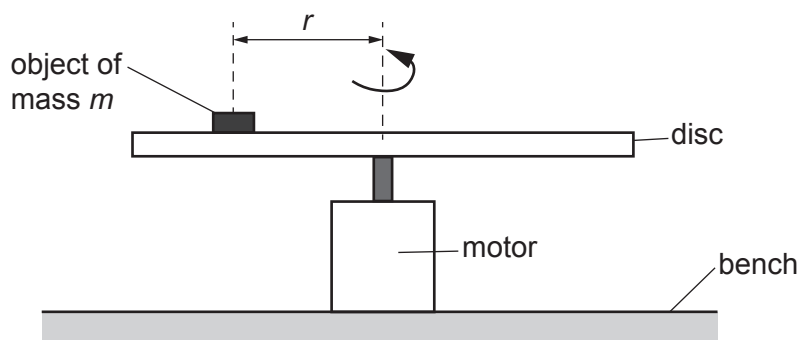
Repeat three times for the same H and find the mean h . Then repeat for at least six different values of H , keeping M , m and the string length constant.

Analysis: record H and mean h in a table and plot a graph of h (y-axis) against H (x-axis). If the equation is valid the line of best fit is a straight line through the origin.

Additional answer space if required

Determine the gradient using a large triangle. The equation predicts gradient = $(M / (M + m))^2$. Substitute the measured masses into this expression and compare it with the experimental gradient: if they agree within the uncertainties the equation is valid.

- 20 A small object of mass m is placed on a rotating horizontal metal disc at a distance r from the centre of the disc.



The frequency of rotation is adjusted using a motor attached to the disc.

The frequency of rotation of the disc is slowly increased from zero, until the object slips off. At this point, the friction F acting on the object is equal to the centripetal force.

The friction F is given by the expression $F = kmg$, where k is a constant and g is the acceleration of free fall. The constant k has no units.

- (a) Show that the frequency f at which the object slips off is given by the equation $f^2 = \left(\frac{gk}{4\pi^2}\right) \times \frac{1}{r}$.

$$F = m\omega^2 r \text{ and } \omega = 2\pi f, \text{ so } F = m(2\pi f)^2 r = 4\pi^2 m f^2 r$$

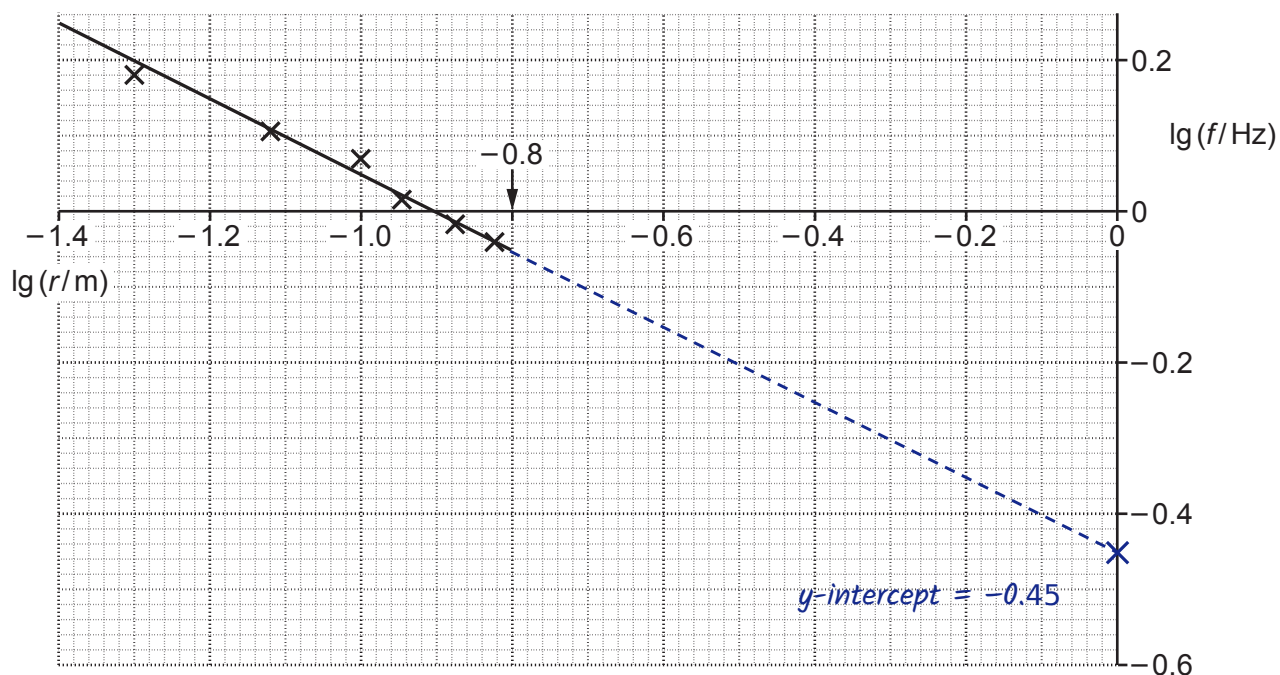
$$\text{friction} = \text{centripetal force: } kmg = 4\pi^2 m f^2 r$$

$$m \text{ cancels: } f^2 = kg / (4\pi^2 r)$$

$$f^2 = (gk / 4\pi^2) \times 1/r$$

[3]

(b) A student plots a graph of $\lg(f/\text{Hz})$ against $\lg(r/\text{m})$.



For this graph: $y\text{-intercept} = \frac{1}{2} \times \lg\left(\frac{gk}{4\pi^2}\right)$

Use the graph to determine the constant k . Write your answer to 2 significant figures.

line extended to $\lg(r/m) = 0$: $y\text{-intercept} = -0.45$

$\frac{1}{2} \lg(gk / 4\pi^2) = -0.45$, so $\lg(gk / 4\pi^2) = -0.90$

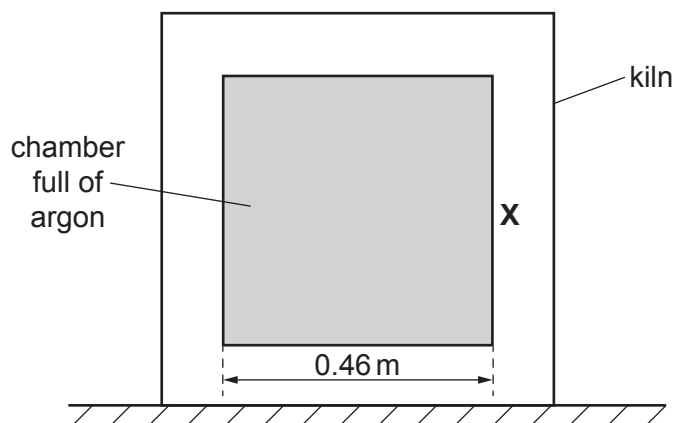
$gk / 4\pi^2 = 10^{-0.90} = 0.126$

$k = 0.126 \times 4\pi^2 / 9.81$

$k = 0.51$

$k = 0.51$ [4]

21 A kiln used to harden ceramics is shown below.



The internal chamber is a cube. Each side of this cube has length 0.46 m. The chamber is sealed and full of argon. Argon behaves as an ideal gas.

- (a) The kiln is initially at 20 °C.
The argon in the kiln has an initial pressure of 100 kPa.
- (i) Calculate the amount of argon n in the chamber in moles.

$$pV = nRT, V = 0.46^3 = 0.0973 \text{ m}^3, T = 293 \text{ K}$$

$$n = 100 \times 10^3 \times 0.0973 / (8.31 \times 293)$$

$$n = 4.0 \text{ mol}$$

$$n = \underline{4.0} \dots \dots \dots \text{ mol [2]}$$

- (ii) The temperature of the kiln is increased from 20 °C to 1300 °C.

Calculate the pressure in kPa at 1300 °C.

$$V \text{ constant so } p / T = \text{constant}$$

$$p / 1573 = 100 / 293 \text{ (} T = 1300 + 273 = 1573 \text{ K)}$$

$$p = 100 \times 1573 / 293 = 537 \text{ kPa} \approx 540 \text{ kPa}$$

$$\text{pressure} = \underline{540} \dots \dots \dots \text{ kPa [2]}$$

- (b) The temperature of the kiln is 1300 °C.

A single atom of argon is travelling horizontally towards the vertical side **X** of the chamber. The initial speed of this atom is 990 m s⁻¹. After collision, it rebounds at the same speed.

- (i) Calculate the change in momentum Δp of this atom.

- mass of argon atom = 6.6×10^{-26} kg

$$\Delta p = mv - (-mv) = 2mv$$

$$\Delta p = 2 \times 6.6 \times 10^{-26} \times 990 = 1.3 \times 10^{-22} \text{ kg m s}^{-1}$$

$$\Delta p = 1.3 \times 10^{-22} \text{ kg m s}^{-1} \quad [2]$$

- (ii) Assume that this atom does not collide with any other argon atoms inside the chamber. Instead, it travels horizontally, making repeated collisions with the opposite vertical walls of the chamber.

- 1 Show that the atom makes about 1000 collisions with side **X** in a time interval of 1.0 s.

$$\text{time between collisions with X} = 2 \times 0.46 / 990 = 9.3 \times 10^{-4} \text{ s}$$

$$\text{number in 1.0 s} = 990 / (2 \times 0.46) = 1080 \approx 1000$$

[1]

- 2 Calculate the average force F on side **X** made by the atom.

$$F = \text{rate of change of momentum} = \Delta p / \Delta t$$

$$F = 1.3 \times 10^{-22} \times 1000 / 1.0$$

$$F = 1.3 \times 10^{-19} \text{ N}$$

$$F = 1.3 \times 10^{-19} \text{ N} \quad [2]$$

- (iii) Without calculation, explain how your answer to (ii)2 could be used to estimate the total pressure exerted by the atoms of the argon gas in the kiln.

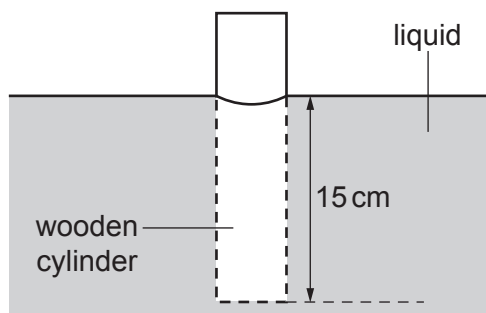
Multiply this force by the total number of argon atoms in the chamber

($N = nN_A$) to get the total force on side X, then use pressure = total

force / area (area of X = 0.46^2), $p = F / A$.

[2]

- 22 A long wooden cylinder is placed into a liquid and it floats as shown.



The length of the cylinder below the liquid level is 15 cm.

- (a) (i) State **Archimedes' principle**.

The upthrust on an object in a fluid is equal to the weight of the fluid it displaces.

[1]

- (ii) The pressure exerted by the liquid alone on the bottom of the cylinder is $1.9 \times 10^3 \text{ Pa}$.

Calculate the density ρ of the liquid.

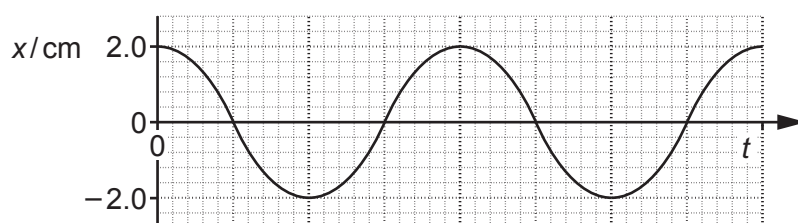
$$p = h\rho g$$

$$1.9 \times 10^3 = 0.15 \times \rho \times 9.81$$

$$\rho = 1.9 \times 10^3 / (0.15 \times 9.81) = 1.3 \times 10^3 \text{ kg m}^{-3}$$

$$\rho = \dots 1.3 \times 10^3 \dots \text{ kg m}^{-3} \quad [2]$$

- (b) The cylinder is pushed down into the liquid and then allowed to oscillate freely. The graph of displacement x against time t is shown below.



The cylinder oscillates with simple harmonic motion with frequency of 1.4 Hz.

- (i) Calculate the displacement, in cm, at time $t = 0.60$ s.

starts at maximum displacement: $x = A \cos(2\pi ft)$

$$x = 2.0 \cos(2\pi \times 1.4 \times 0.60) \text{ (radians)}$$

$$x = 1.07 \text{ cm} \approx 1.1 \text{ cm}$$

displacement = 1.1 cm [3]

- (ii) Calculate the maximum speed of the oscillating cylinder.

$$v_{\max} = 2\pi fA = 2\pi \times 1.4 \times 0.020$$

$$v_{\max} = 0.18 \text{ m s}^{-1}$$

maximum speed = 0.18 ms⁻¹ [2]

- (iii) The cylinder is now pushed down further into the liquid before being released.
As before, the cylinder oscillates with simple harmonic motion.

State the effect this has on

- 1 the amplitude

Larger (the amplitude increases).

- 2 the period.

Same (the period is unchanged).

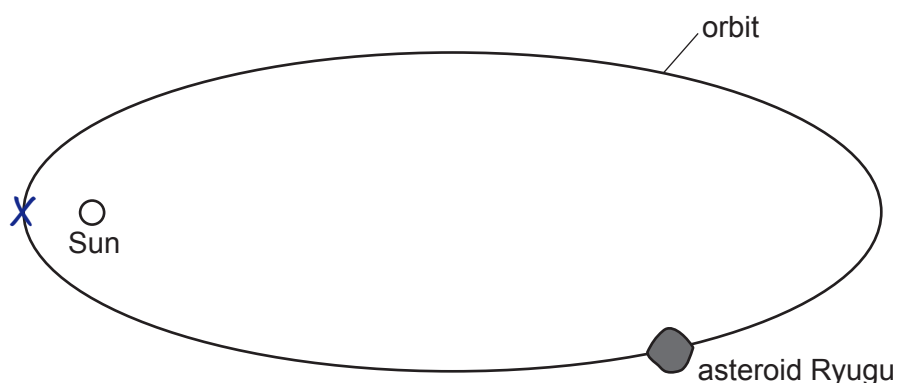
[2]

26
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23 In June 2018, the spacecraft Hayabusa2 arrived at an asteroid called Ryugu.

(a) The asteroid orbits the Sun in an elliptical orbit as shown below.

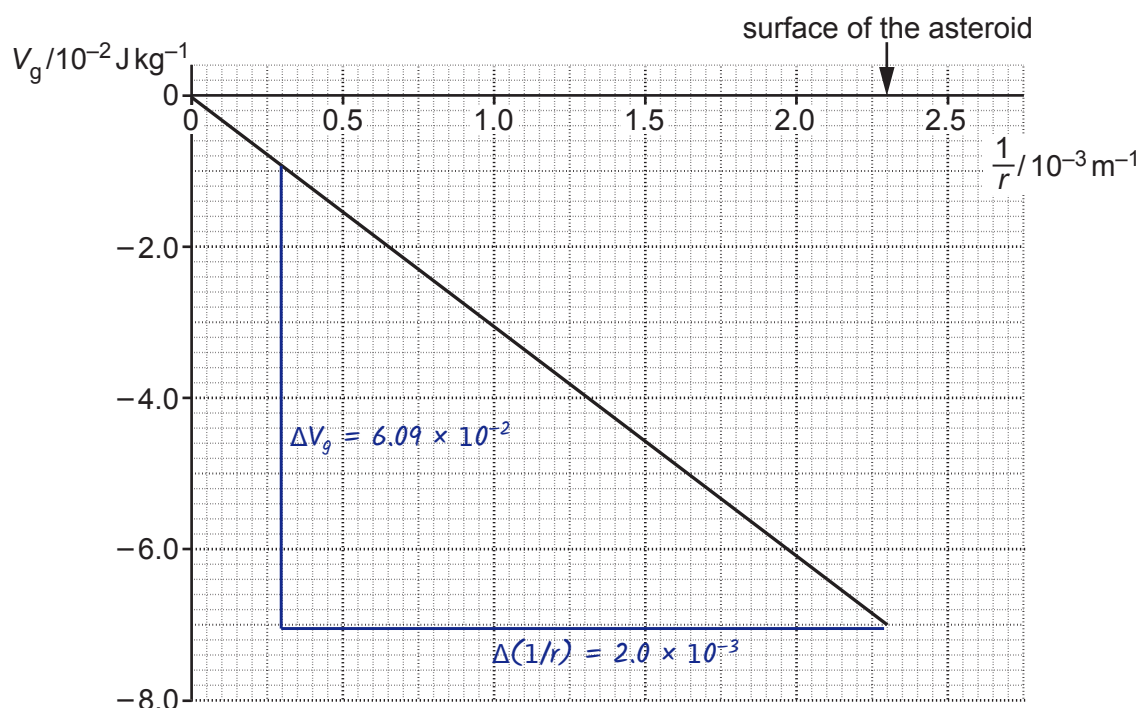


The diagram is **not** drawn to scale.

- (i) Indicate with a letter **X** on the orbit where the asteroid would be moving at maximum speed. [1]
- (ii) Use Kepler's **second law** to explain your answer to (a)(i).

*Kepler's second law: a line segment joining the asteroid to the Sun
sweeps out equal areas in equal time intervals. Closest to the Sun the
line is shortest, so the asteroid must travel a longer distance along its
orbit in the same time, so it moves fastest.* [2]

- (b) The gravitational potential at a distance r from the centre of the asteroid Ryugu is V_g . The graph of V_g against $\frac{1}{r}$ for the asteroid is shown below.



- (i) Define **gravitational potential**.

The work done per unit mass to move a (small) object from infinity to that point.

[1]

- (ii) Show that the magnitude of the gradient of the graph is equal to GM , where M is the mass of the asteroid and G is the gravitational constant.

$$V_g = -GM / r = -GM \times (1/r)$$

so V_g against $1/r$ is a straight line through the origin

with gradient $-GM$: magnitude of gradient = GM

[1]

- (iii) Use the gradient of the graph to show that the mass M of the asteroid is about 4.6×10^{11} kg.

$$\text{gradient} = -(7.0 - 0.913) \times 10^{-2} / (2.3 - 0.3) \times 10^{-3} = -30.4$$

$$GM = 30.4 \text{ J m kg}^{-1}$$

$$M = 30.4 / 6.67 \times 10^{-11} = 4.56 \times 10^{11} \text{ kg} \approx 4.6 \times 10^{11} \text{ kg}$$

$$M = \dots 4.6 \times 10^{11} \dots \text{ kg [2]}$$

- (c) In October 2018, the probe Mobile Asteroid Surface Scout (MASCOT) was released from **rest** from the Hayabusa2 spacecraft from a distance of 600 m from the centre of the asteroid.

Assume that the spacecraft was stationary relative to the asteroid when MASCOT was dropped.

Use information from (b) to calculate the speed of the impact v when MASCOT landed on the surface of the asteroid.

$$\text{surface: } 1/r = 2.3 \times 10^{-3} \text{ m}^{-1}; \text{ release: } 1/r = 1/600 \text{ m}^{-1}$$

$$\text{loss of GPE per kg} = \text{gain of KE per kg}$$

$$\frac{1}{2}v^2 = GM (1/R - 1/600)$$

$$\frac{1}{2}v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$$

$$\frac{1}{2}v^2 = 30.7 \times 6.33 \times 10^{-4} = 1.94 \times 10^{-2}$$

$$v = \sqrt{2 \times 1.94 \times 10^{-2}} = 0.20 \text{ m s}^{-1}$$

$$v = \dots 0.20 \dots \text{ m s}^{-1} \text{ [3]}$$

Question 24 is on page 30

- 24 (a) Our Sun will eventually become a red giant.

Describe and explain the next stages of evolution of our Sun.

The core runs out of helium, so there is a reduction in the energy released by fusion; fusion no longer takes place in the core.

The gravitational force is now greater than the outward force from radiation and gas pressure, so the core collapses. Fusion continues in a shell around the core.

The outer layers expand and cool and are then released (ejected) to form a planetary nebula.

The hot, dense core is left as a remnant: a white dwarf.

[4]

- (b) Rigel is a blue giant star in the constellation of Orion.

The table below shows some data about Rigel and about our Sun.

	Rigel	Sun
Surface temperature/K		5.8×10^3
Luminosity/W	4.62×10^{31}	3.85×10^{26}
Wavelength of emitted light at peak intensity/nm	240	500

- (i) Show that the surface temperature of Rigel is 12 000 K.

$$\text{Wien's law: } \lambda_{\max} T = \text{constant}$$

$$500 \times 5.8 \times 10^3 = 240 \times T$$

$$T = 500 \times 5.8 \times 10^3 / 240 = 12\,080\text{ K} \approx 12\,000\text{ K}$$

[2]

- (ii) Calculate the radius of Rigel.

$$L = 4\pi r^2 \sigma T^4$$

$$4.62 \times 10^{31} = 4\pi \times r^2 \times 5.67 \times 10^{-8} \times 12\,000^4$$

$$r^2 = 3.13 \times 10^{21}$$

$$r = 5.6 \times 10^{10} \text{ m}$$

radius = 5.6×10^{10} m [2]

- (c) An astronomer claims to have discovered a white dwarf with a mass twice that of our Sun.

Suggest why this claim must be incorrect.

A white dwarf cannot have a mass greater than 1.44 solar masses (the Chandrasekhar limit). [1]

END OF QUESTION PAPER

[illegible]

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