H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

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| CANDIDATE NAME | |
| CLASS | |
| TUTOR'S NAME | |
| CENTRE NUMBER | S |
| INDEX NUMBER | |

# PHYSICS 9749/03

Paper 3 Longer Structured Questions

**20 September 2023**

**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.

**Section A**
Answer **all** questions.

**Section B**
Answer **one** question only.

You are advised to spend one and a half hours on Section A and half an hour on Section B.

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

| For Examiner's Use | |
|---|---|
| **Section A** | |
| **1** | **/ 8** |
| **2** | **/ 8** |
| **3** | **/ 8** |
| **4** | **/ 8** |
| **5** | **/ 8** |
| **6** | **/ 9** |
| **7** | **/ 11** |
| **Section B** | |
| **8** | **/ 20** |
| **9** | **/ 20** |
| **Total** | **/ 80** |

This document consists of **24** printed pages.

**Data**

| | |
|---|---|
| speed of light in free space | $c = 3.00 \times 10^{8}$ m s$^{-1}$ |
| permeability of free space | $\mu_0 = 4\pi \times 10^{-7}$ H m$^{-1}$ |
| permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}$ F m$^{-1}$ |
| | $(1 / (36\pi)) \times 10^{-9}$ F m$^{-1}$ |
| elementary charge | $e = 1.60 \times 10^{-19}$ C |
| the Planck constant | $h = 6.63 \times 10^{-34}$ J s |
| unified atomic mass constant | $u = 1.66 \times 10^{-27}$ kg |
| rest mass of electron | $m_e = 9.11 \times 10^{-31}$ kg |
| rest mass of proton | $m_p = 1.67 \times 10^{-27}$ kg |
| molar gas constant | $R = 8.31$ J K$^{-1}$ mol$^{-1}$ |
| the Avogadro constant | $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ |
| the Boltzmann constant | $k = 1.38 \times 10^{-23}$ J K$^{-1}$ |
| gravitational constant | $G = 6.67 \times 10^{-11}$ N m$^{2}$ kg$^{-2}$ |
| acceleration of free fall | $g = 9.81$ m s$^{-2}$ |

**Formulae**

| | |
|---|---|
| uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$ |
| | $v^2 = u^2 + 2as$ |
| work done on / by a gas | $W = p\Delta V$ |
| hydrostatic pressure | $p = \rho gh$ |
| gravitational potential | $\phi = -Gm / r$ |
| temperature | $T / \text{K} = T / {}^\circ\text{C} + 273.15$ |
| pressure of an ideal gas | $p = \frac{1}{3}\frac{Nm}{V} < c^2 >$ |
| mean translational kinetic energy of an ideal molecule | $E = \frac{3}{2}kT$ |
| 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 | $R = R_1 + R_2 + \ ...$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ ...$ |
| electric potential | $V = \frac{Q}{4\pi\varepsilon_0 r}$ |
| 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 | $B = \mu_0 nI$ |
| radioactive decay | $x = x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ |

## Section A

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

**1** **(a)** A student sets up the circuit shown in Fig. 1.1 to determine the resistivity of the metal of a resistance wire. He reads the current $I$ from the ammeter and the potential difference $V$ from the voltmeter.

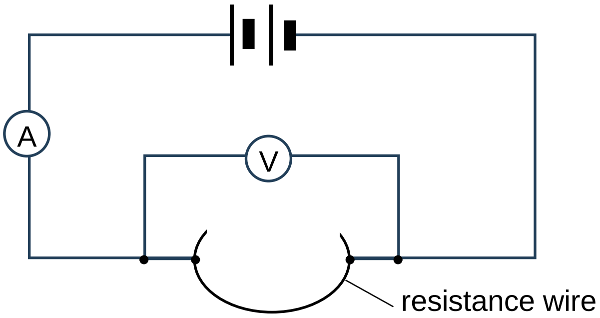


**Fig. 1.1**

**(i)** Determine the base units for resistance.

base units for resistance: ............................ [2]

**(ii)** The following readings were obtained for the experiment:

Reading of voltmeter = 1.30 ± 0.01 V
Reading of ammeter = 0.76 ± 0.01 A
Length of wire = 75.4 ± 0.2 cm
Diameter of wire = 0.54 ± 0.02 mm

Calculate, with its associated uncertainty, the value of the resistivity of the metal of the resistance wire, expressing your results to an appropriate number of significant figures.

$\rho$ = ............................ ± ............................ [4]

**(b)** A second student repeated the experiment in **(a)** with the same length of the wire. In this new experiment, the supply voltage was varied and several pairs of corresponding readings on the voltmeter and ammeter were tabulated. A graph showing the variation of the current in the wire with potential difference across the wire was then plotted.

Discuss how this procedure reduces the random error and systematic error that could have occurred.

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.................................................................................................................. [2]

[Total: 8]

**2** An object of mass 1.5 kg is released from a stationary hot air balloon. Fig. 2.1 shows how the vertical displacement of the object varies with time.

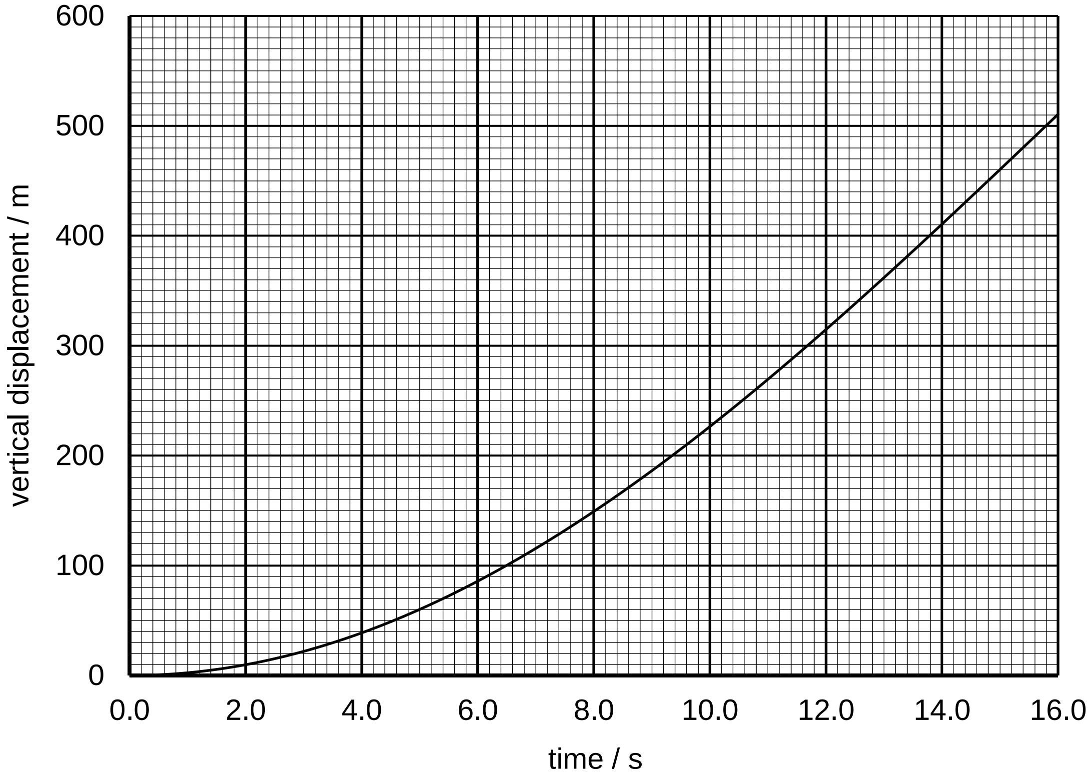


**Fig. 2.1**

**(a)** Calculate the change in gravitational potential energy $\Delta E_p$ of the object that occurred during the 16 s after it was released.

$\Delta E_p$ = **………………..** J [1]

**(b)** Using Fig. 2.1, determine the speed of the object at $t$ = 16 s.

speed = **………………..** m $s^{-1}$ [2]

**(c)** Calculate the change in kinetic energy $\Delta E_k$ of the object during the same period.

$\Delta E_k$ = **…………………..** J [1]

**(d)** Explain why $\Delta E_p$ and $\Delta E_k$ are not equal to one another.

……........…………………………………………………………………………………………………

………...…………………………………………………………………………………………….. [1]

**(e)** The object strikes the ground 16 s after it was released and penetrates 0.85 m into the ground. Determine the average resistive force acting on the object as it penetrates the ground.

average resistive force = **…………………..** N [3]

[Total: 8]

**3** Fig. 3.1 shows a 0.45 kg mass held on a horizontal air track by two identical springs that are initially unstretched. The mass is pulled 5.0 cm to the left and released. The mass oscillates horizontally on a cushion of air.

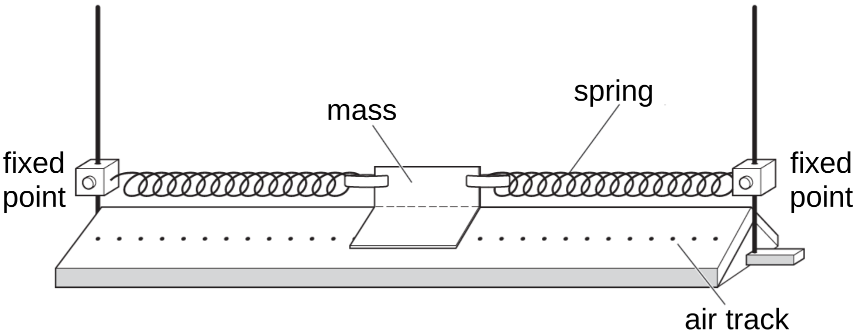


**Fig. 3.1**

**(a)** Explain why the mass oscillates with simple harmonic motion when displaced horizontally.

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………………………………………………………………………………………………………… [2]

The variation of kinetic energy with displacement *x* of the mass is shown in Fig. 3.2.

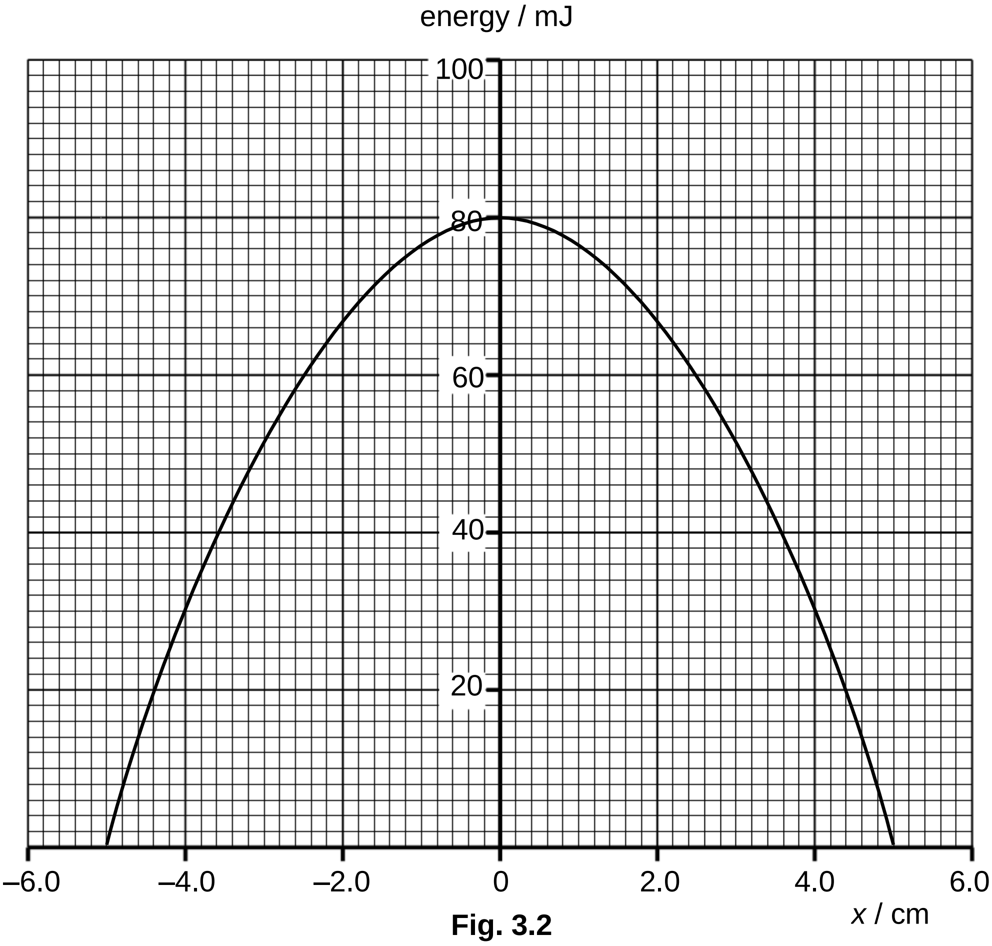


**Fig. 3.2**

**(b) (i)** Use Fig. 3.2 to determine the frequency of the oscillations.

frequency = .......................................... Hz [2]

**(ii)** Draw, on Fig. 3.2, a graph to show the variation of potential energy stored in the springs with displacement *x* of the mass. [1]

**(c)** The blower of the air track is switched off so that the mass is in direct contact with the track. One end of the spring is attached to a driver (oscillator) shown in Fig. 3.3. The amplitude of oscillation of the driver is kept constant.

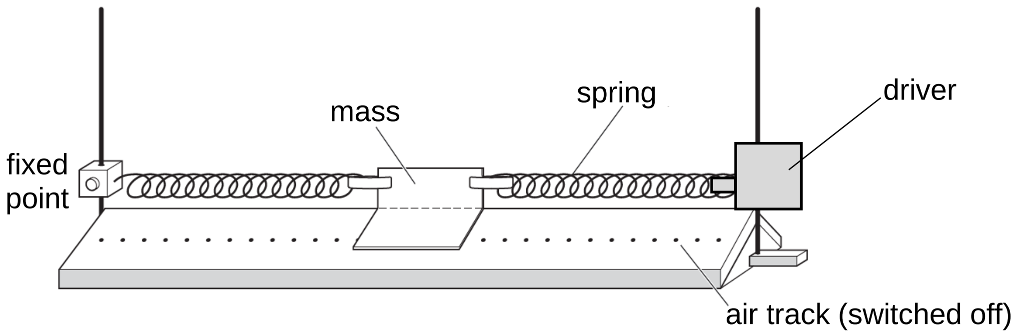


**Fig. 3.3**

The frequency of oscillations is gradually increased from zero. The variation of the amplitude of oscillation of the mass with driving frequency is shown in Fig. 3.4.

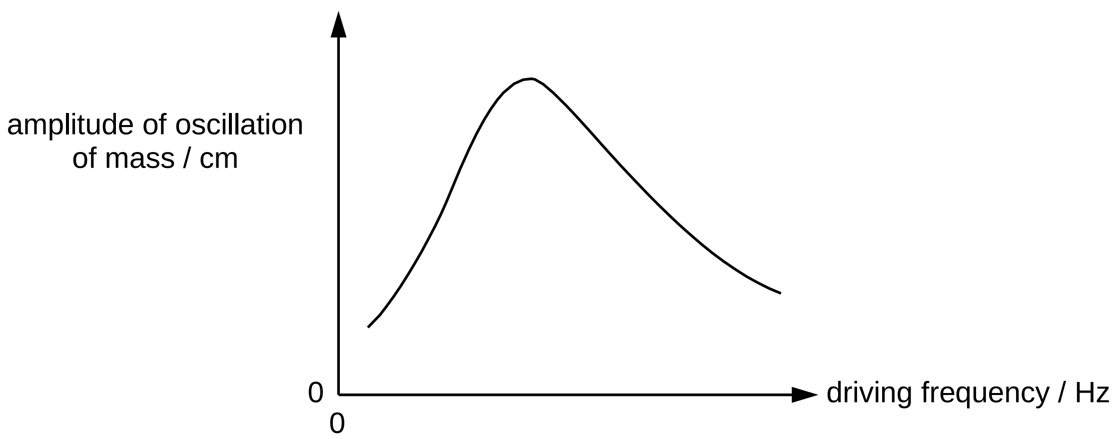


**Fig. 3.4**

**(i)** State how Fig. 3.4 shows that the mass is undergoing damped oscillations.

.......................................................................................................................

....................................................................................................................... [1]

**(ii)** The model in Fig. 3.3 and result in Fig. 3.4 can be applied to a practical situation.

Tall buildings, such as the Taipei 101 tower as shown in Fig. 3.5, are equipped with a damping system to reduce movement of the tower in strong winds. A mass in the form of a huge sphere on support cables oscillates with the tower to reduce the effect of the wind. The oscillations of the sphere are damped with oil-filled hydraulic pistons connected to the sphere.

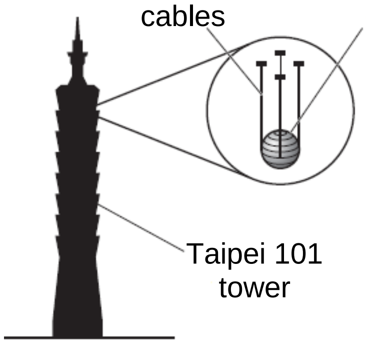


**Fig. 3.5**

Strong winds set the tower in oscillation. The natural frequency of oscillations of the tower is 0.15 Hz.

Suggest, by reference to energy transfer, why the frequency of the sphere-damping system must be close to 0.15 Hz to help reduce the motion of the tower.

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....................................................................................................................... [2]

[Total: 8]

**4** Coherent light of wavelength 590 nm is incident normally on a double slit, as shown in Fig. 4.1.

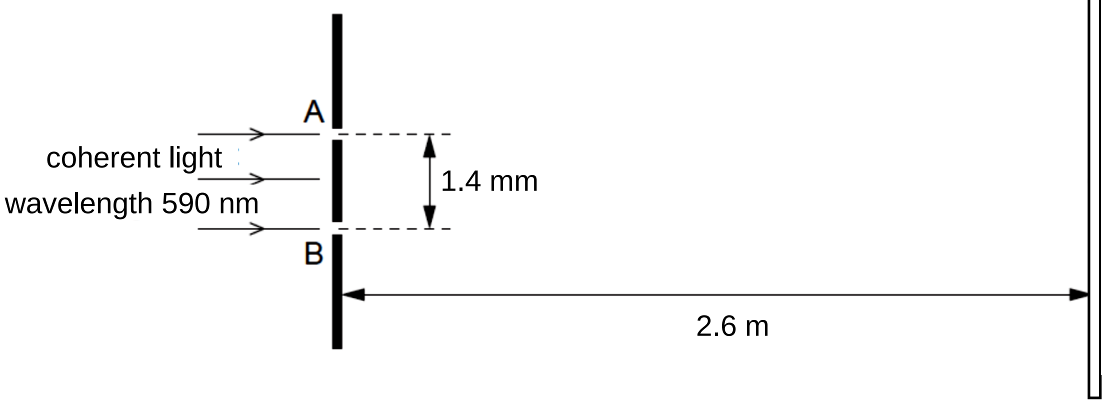


**Fig. 4.1**

The separation of the slits A and B is 1.4 mm and the width of each slit is 0.15mm. A screen is placed parallel to the slits at a distance 2.6 m away.

**(a)** One of the slits is covered.

Calculate the width of the central maximum formed on the screen by diffraction through the uncovered slit.

width = .......................................... cm [3]

**(b)** Now, both slits are uncovered.

**(i)** State Rayleigh's criterion.

..........................................................................................................

..........................................................................................................

.......................................................................................................... [2]

**(ii)** Use Rayleigh's criterion to explain whether the diffraction pattern produced by the two slits are seen as on the screen as separate.

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.......................................................................................................... [3]

[Total: 8]

**5** Fig. 5.1 shows the arrangement of the apparatus used in the measurement of the magnetic flux density between the poles of a U-shaped magnet. The magnet rests on top of an electronic balance. A stiff rectangular frame measuring 8.0 cm by 5.0 cm carries a current $I$ between the magnetic poles. The bottom edge of the frame is lowered into the region between the poles of the U-shaped magnet and is entirely within the uniform magnetic field.

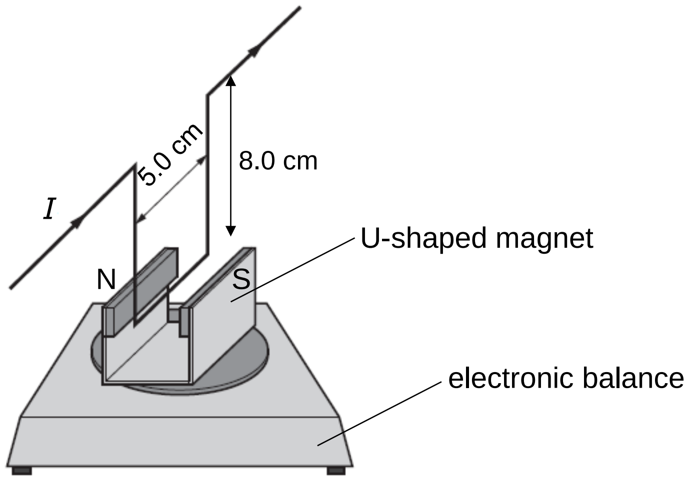


**Fig. 5.1**

Fig. 5.2 shows the apparatus when viewed from the front. The poles of the U-shaped magnet have been indicated.

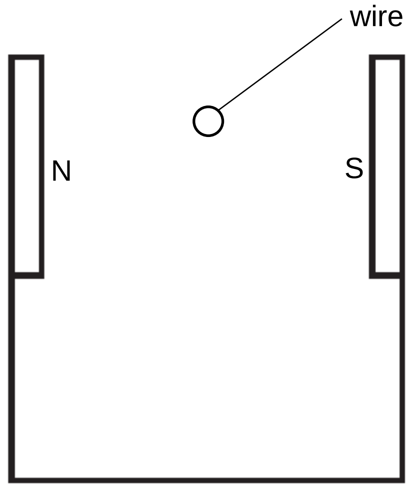


**Fig. 5.2**

**(a)** **(i)** Draw, on Fig. 5.2, a vertical force acting on the wire when current passes through it. Label the force *F*. [1]

**(ii)** When current passes through the wire, the balance reading changes.

Explain why there is a change in reading, and whether the change is an increase or decrease.

..................................................................................................................

.................................................................................................................. [2]

**(b)** The current $I$ is varied and the change in the balance reading is recorded as shown in Fig. 5.3.

| | **Change in balance reading / g** | | | | |
|---|---|---|---|---|---|
| ***I* / A** | **Trial 1** | **Trial 2** | **Trial 3** | **Mean change / g** | ***F* / × $10^{-3}$ N** |
| 0.5 | 0.08 | 0.05 | 0.06 | 0.06 | 0.6 |
| 1.0 | 0.14 | 0.16 | 0.16 | 0.15 | 1.5 |
| 1.5 | 0.22 | 0.20 | 0.23 | 0.22 | 2.2 |
| 2.0 | 0.31 | 0.29 | 0.31 | 0.30 | 2.9 |
| 2.5 | 0.38 | 0.39 | | 0.37 | 3.6 |
| 3.0 | 0.44 | 0.48 | 0.48 | | |

**Fig. 5.3**

**(i)** Complete the table in Fig. 5.3. [1]

**(ii)** On Fig. 5.4, plot the missing data point from the table in Fig. 5.3 and draw a line of best fit. [1]

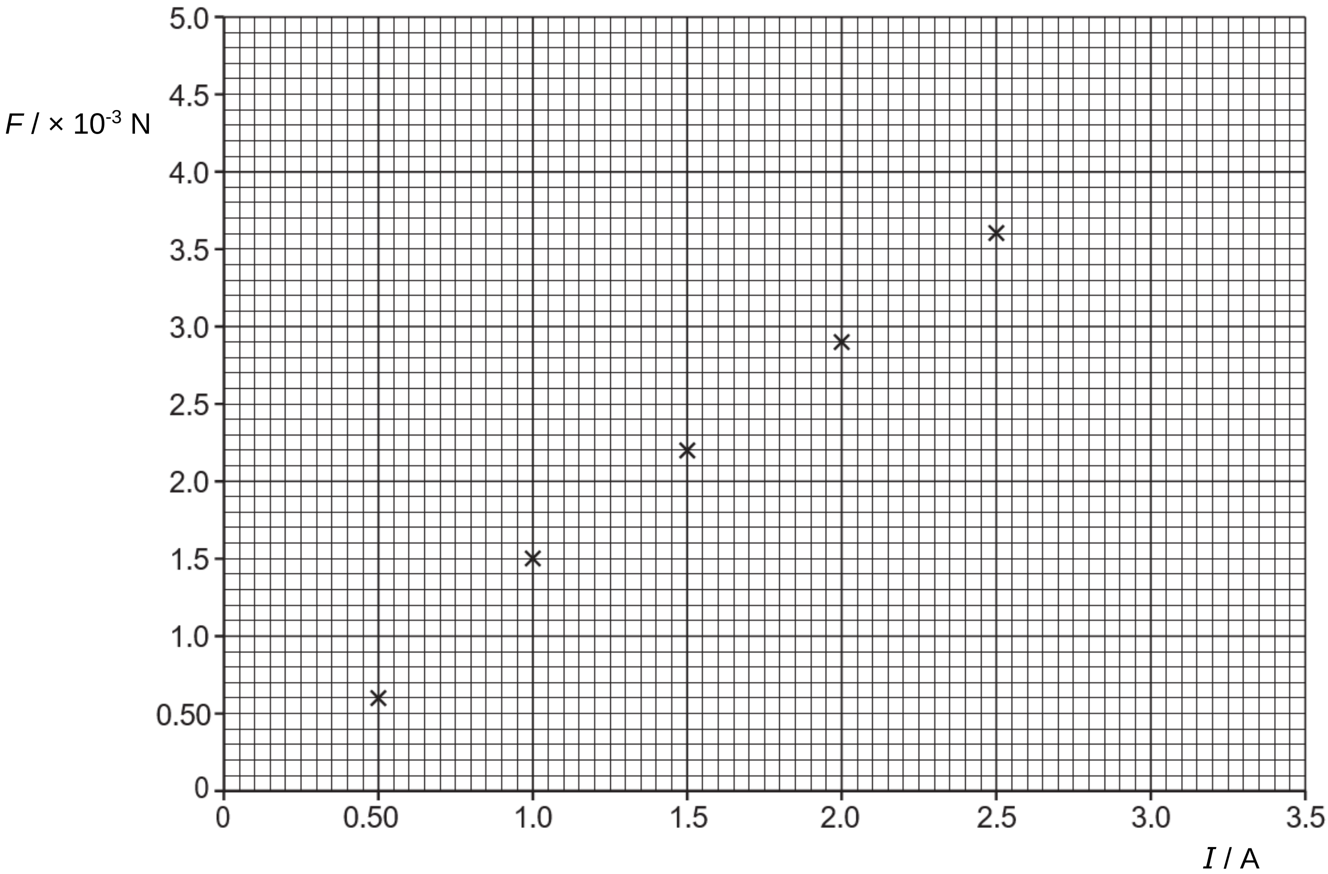


**Fig. 5.4**

**(iii)** Use your graph to determine the value of the magnetic flux density *B*, in mT, between the U-shaped magnet.

*B* = .......................................... mT [2]

**(iv)** The value of the magnetic flux density in **(b)(iii)** is slightly inaccurate for a reason which has nothing to do with human error or meter inaccuracies.

Suggest one reason that might be the cause of this inaccuracy.

...................................................................................................................

................................................................................................................ [1]

[Total: 8]

**6** An a.c. power supply is connected to a resistor *R*, as shown in Fig. 6.1.

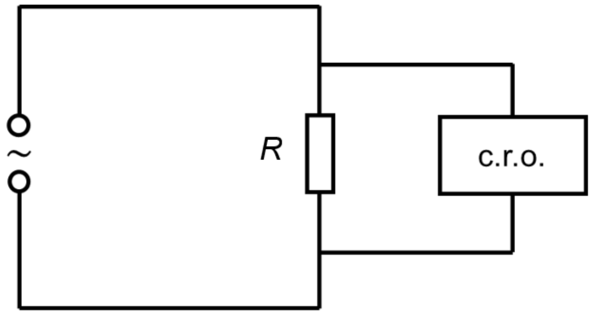


**Fig. 6.1**

A cathode ray oscilloscope (c.r.o.) is used to show the potential difference (p.d.) across *R*. The screen of the c.r.o. displays the variation with time of the p.d. across *R*, as shown in Fig. 6.2.

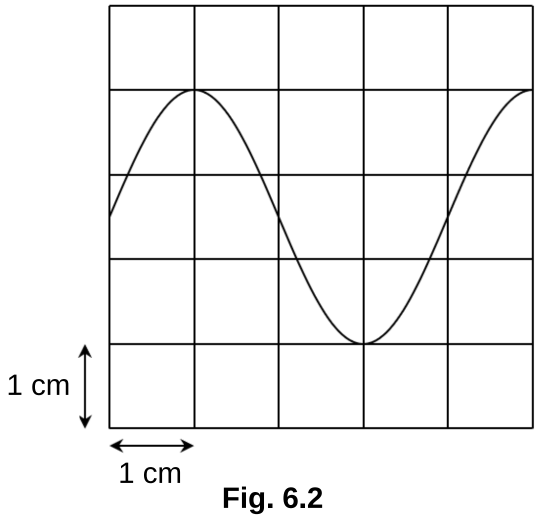


**Fig. 6.2**

**(a)** Explain, by reference to direct current, what is meant by the *root-mean-square* (r.m.s.) value of an alternating current.

…………………………………………………………………………………………………………

…………………………………………………………………………………………………………

……………………………………………………………………………………………………….. [2]

**(b)** The voltage $V$ of the power supply is given by the expression

$$V = 6.0\sin(100\pi t)$$

$V$ is measured in volts and the time $t$ is measured in seconds.

Determine the Y-gain and time-base of the c.r.o.

Y-gain = ............................................... V / cm

time-base = ............................................... ms / cm [2]

**(c)** A diode is then connected in series with the resistor *R*, as shown in Fig. 6.3.

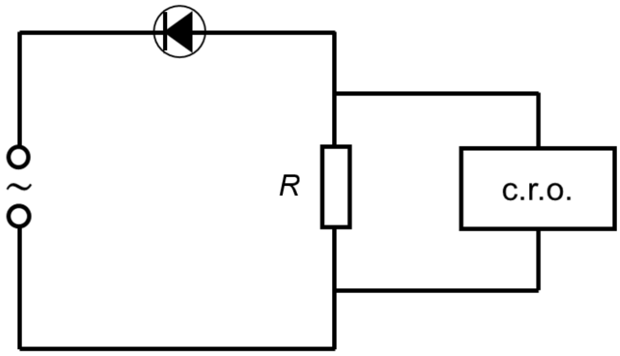


**Fig. 6.3**

**(i)** Sketch in Fig. 6.4, for 2 periods of the alternating p.d., the variation with time of the power *P* dissipated in *R* when *R* is 20 Ω, where *T* is the period. Indicate the peak power value in your sketch. [2]

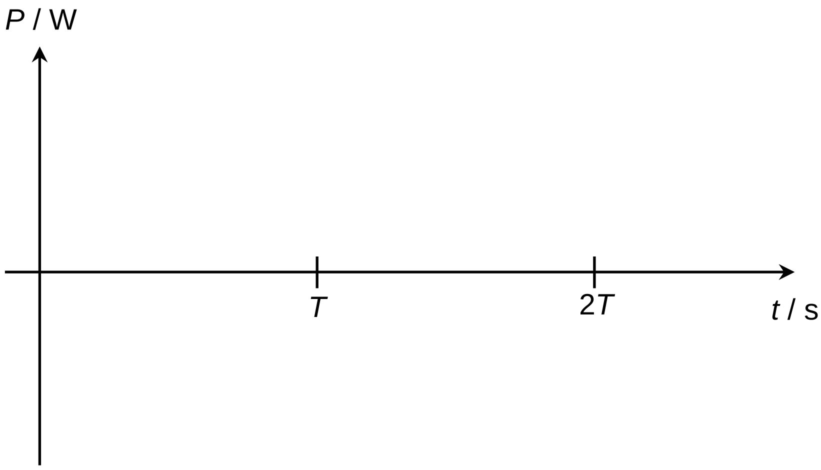


**Fig. 6.4**

**(ii)** Draw a line in Fig. 6.4 to represent the average power dissipated in *R*. Indicate its value on the y-axes. [1]

**(iii)** Calculate the root-mean-square current in *R*.

root-mean-square current = **…………………..** A [2]

[Total: 9]

**7** Fig. 7.1 shows what is observed when a parallel beam of electrons, accelerated by a potential difference V, is incident on a fluorescent screen.

**Fig. 7.1**

A carbon film is then placed perpendicularly to the path of the electron beam as shown in Fig. 7.2.

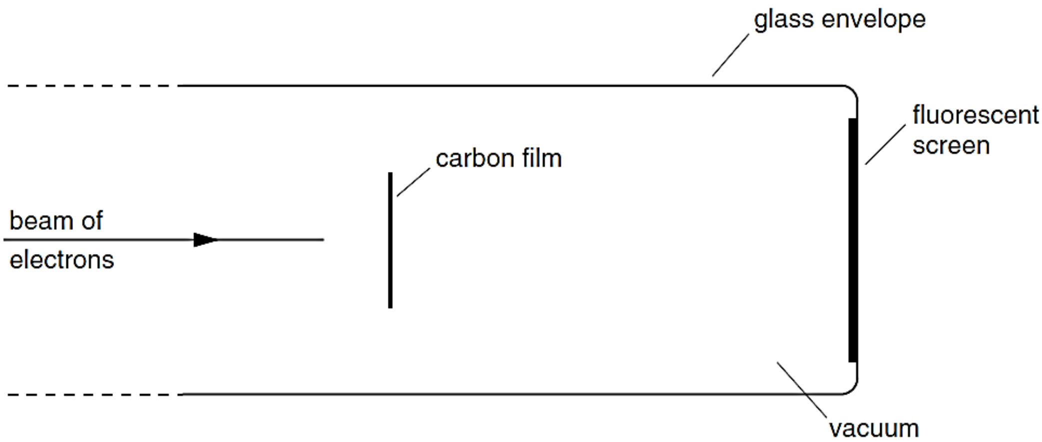


**Fig. 7.2**

The pattern observed on the screen is shown in Fig. 7.3.

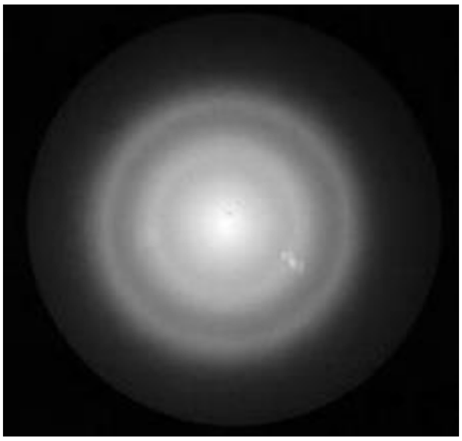

**Fig. 7.3**

**(a)** Identify and explain two key features in Fig. 7.3 that provide evidence for the wave nature of the electrons.

………..…………………………………………………………………………………………………

………..…………………………………………………………………………………………………

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………..……………………………………………………………………………………………….. [3]

**(b)** The electrons were accelerated through a potential difference of 2000 V.

**(i)** Calculate the momentum of an electron after being accelerated through a potential difference of 2000 V.

momentum = **…………………..** N s [2]

**(ii)** Hence, calculate the de Broglie wavelength of the electrons.

wavelength = **…………………..** m [2]

**(c)** State and explain the changes, if any, that is observed in the pattern on the screen when the following changes are made separately.

**(i)** The potential difference used to accelerate the electrons is increased.

…………………………………………………………………………………………………………

…………………………………………………………………………………………………………

……………………………………………………………………………………………………….. [2]

**(ii)** The current of the electron beam is increased.

…………………………………………………………………………………………………………

…………………………………………………………………………………………………………

……………………………………………………………………………………………………….. [2]

[Total: 11]

## Section B

Answer **one** question from this section in the spaces provided.

**8** **(a)** Fig. 8.1 shows the variation of the gravitational potential $\phi$ with distance $d$ from the surface of Pluto along a line joining the centers of Pluto and Charon.

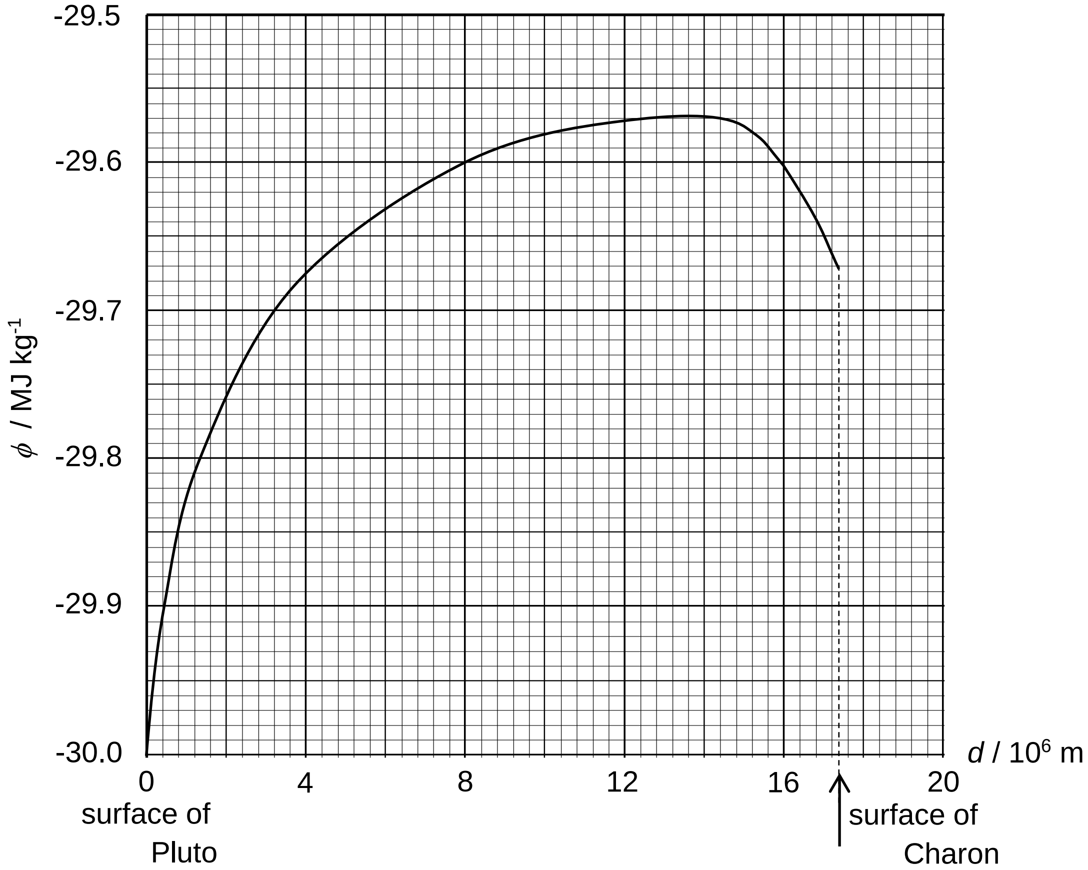


**Fig. 8.1**

The gravitational potential is taken as being zero at infinity.

**(i)** By considering the definition of gravitational potential, suggest why all values of $\phi$ in Fig. 8.1 are negative and explain how they may be obtained.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

……………………………………………………………………………………………… [2]

**(ii)** Explain how Fig. 8.1 can be used to determine the resultant gravitational force acting on an object with mass *m* placed at a point between Pluto and Charon.

…..……………………………………………………………………………………………

…..……………………………………………………………………………………………

…..…………………………………………………………………………………………….. [2]

**(iii)** A lump of rock of mass 5.0 kg is ejected from the surface of Charon such that it travels towards Pluto.

**1.** Using data from Fig. 8.1, determine the minimum speed of the rock as it hits the surface of Pluto.

minimum speed = **………………..** m $s^{-1}$ [3]

**2.** The rock is now projected from Pluto to Charon.

State and explain how its minimum speed when it hits the surface of Charon will be different from the answer in **(a)(iii)1**.

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…..……………………………………………………………………………………………

…..……………………………………………………………………………………………

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…..…………………………………………………………………………………………….. [2]

**(b)** In another isolated planetary system, X and Y are two stars of equal mass *M* and separated by a distance 2*L*. The two stars rotate about their common centre of mass.

**(i)** State Newton's Law of Gravitation.

…..……………………………………………………………………………………………

…..……………………………………………………………………………………………

…..…………………………………………………………………………………………….. [1]

**(ii)** Explain why the two stars will not collide with each other even though the gravitation force acting on each other are attractive.

…...……………………………………………………………………………………………

…...……………………………………………………………………………………………

…...………………………………………………………………………………………….. [2]

**(iii)** Derive an expression, in terms of *M*, *L* and the gravitational constant G, for the period *T* of their rotation.

[2]

**(c)** Fig. 8.2 shows three points A, B and C relative to the stars X and Y. All three points are equidistant from both X and Y and point B lies on the straight line joining the centres of mass of X and Y.

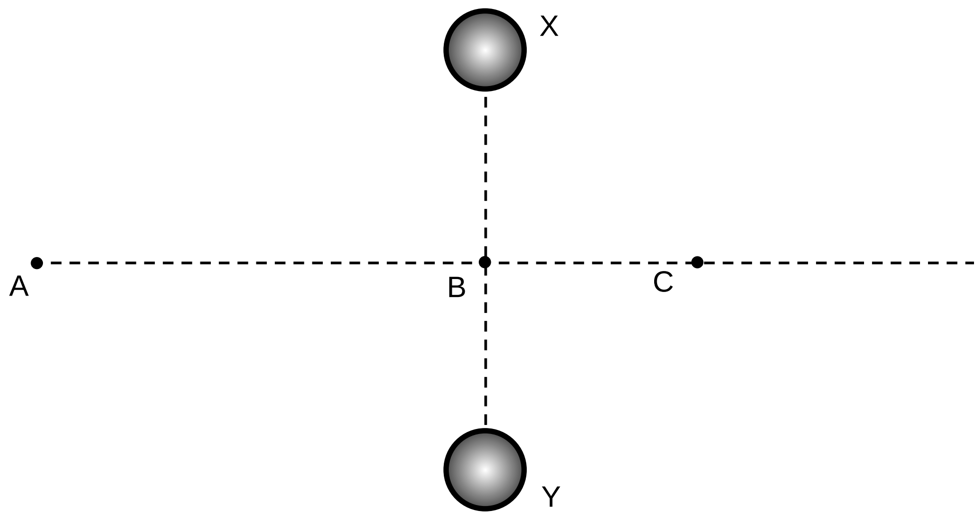


**Fig. 8.2**

**(i)** Draw arrows on Fig. 8.2 to represent the gravitational forces due to each star acting on a small mass placed separately at points A, B and C. The length of the arrow should be relative to their respective magnitudes. [2]

**(ii)** Fig. 8.3 shows another schematic of X and Y. P is a point equidistant from X and Y and is at a distance *s* from the straight line joining the centers of mass of X and Y.

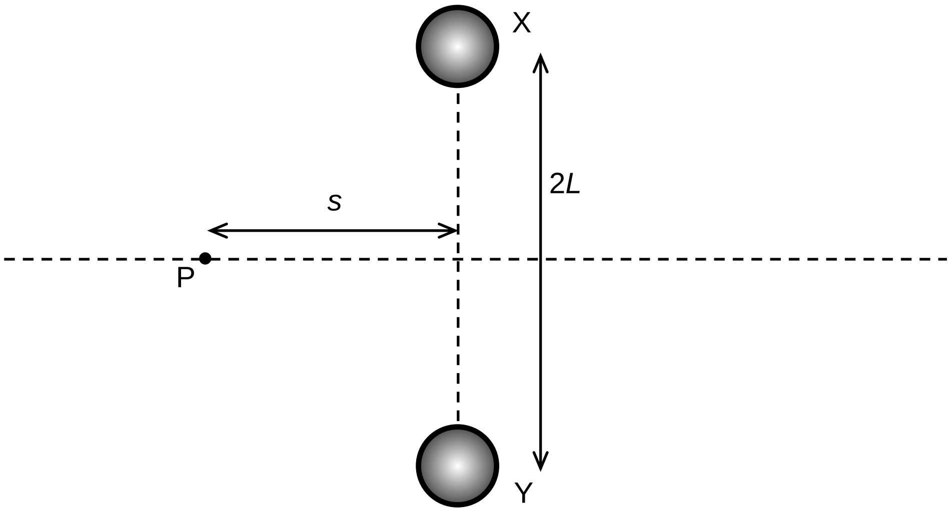


**Fig. 8.3**

**1.** Show that the magnitude of the resultant gravitational force acting on a mass *m* placed at P is

$$F_G = \frac{2GMms}{\left(s^2 + L^2\right)^{\frac{3}{2}}}$$

[2]

**2.** Hence, state and explain if the subsequent motion of a mass placed at rest at point P is simple harmonic.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

…………………………………………………………………………………………………… [2]

**9** **(a)** One assumption of the kinetic theory of gases is that the particles of the gas make perfectly elastic collisions among themselves and with the wall of the container. State two other assumptions of the kinetic theory of gases.

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……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

…………………………………………………………………………………………………………. [2]

**(b)** Consider a single molecule of mass *m* in a cuboidal container of internal side length L. The molecule is travelling with velocity *v* directly towards one of the walls W as shown in Fig 9.1.

Collisions between the molecule and the walls are elastic. This molecule makes multiple collisions in unit time. The pressure the molecule exerts on the wall is dependent on the frequency of the collisions with the wall.

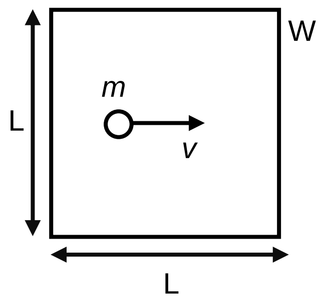


**Fig. 9.1**

Write expressions for

**(i)** the change in momentum of the molecule when it collides with wall W.

…………………………………………………………………………………………………. [1]

**(ii)** time between collisions of the molecule and the wall W.

…………………………………………………………………………………………………. [1]

**(iii)** the frequency of the collisions of the molecule with the wall W.

…………………………………………………………………………………………………. [1]

**(iv)** the average momentum change per unit time for this molecule.

…………………………………………………………………………………………………. [1]

**(v)** the average force on wall W as a result of impacts by the molecule.

………………………………………………………………………………………………

………………………………………………………………………………………………

……………………………………………………………………………………………… [2]

**(vi)** the average pressure of wall W.

……………………………………………………………………………………………… [1]

**(c)** A cuboidal container contains *N* molecules of an ideal gas has volume V and pressure *p* given by the relation

$$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$$

where *m* is the mass of each molecule.

Explain briefly how the expression in **(b)(vi)** leads to this relation.

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**(d)** **(i)** Use the equation of state for an ideal gas, together with the equation given in **(c)** to show that *K*, the average translational kinetic energy of a molecule is proportional to its absolute temperature [3]

**(ii)** Calculate , for oxygen and hydrogen at the same temperature, the ratio

$$\frac{\text{root mean square speed of a hydrogen molecule}}{\text{root mean square speed of an oxygen molecule}}.$$

The masses of the molecules are given the following table:

Mass of a hydrogen molecule = $3.34 \times 10^{-27}$ kg

Mass of an oxygen molecule = $5.34 \times 10^{-26}$ kg

Ratio = = **…………………..** N s [2]

**(iii)** Suggest why the atmosphere of the Earth contains very little hydrogen.

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