NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

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|---|---|---|---|
| CANDIDATE NAME | **SOLUTION** | | |
| CLASS | | TUTOR'S NAME | |
| CENTRE NUMBER | S | INDEX NUMBER | |

# PHYSICS 9749/03

Paper 3 Longer Structured Questions

**20 September 2021**

**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 or rough working.
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.

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 | |
|---|---|
| **Section A** | |
| **1** | **/ 8** |
| **2** | **/ 10** |
| **3** | **/ 8** |
| **4** | **/ 10** |
| **5** | **/ 8** |
| **6** | **/ 7** |
| **7** | **/ 9** |
| **Section B** | |
| **8** | **/ 20** |
| **9** | **/ 20** |
| **Total** | **/ 80** |

This document consists of **22** 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 | $T / \text{K} = T / °\text{C} + 273.15$ |
| pressure of an ideal gas | $p = \dfrac{1}{3}\dfrac{Nm}{V} < c^2 >$ |
| mean translational kinetic energy of an ideal molecule | $E = \dfrac{3}{2}kT$ |
| 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 | $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ |
| alternating current/voltage | $x = x_0 \sin \omega t$ |
| magnetic flux density due to a long straight wire | $B = \dfrac{\mu_0 I}{2\pi d}$ |
| magnetic flux density due to a flat circular coil | $B = \dfrac{\mu_0 NI}{2r}$ |
| magnetic flux density due to a long solenoid | $B = \mu_0 nI$ |
| radioactive decay | $x = x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$ |

## Section A

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

**1** The Poiseuille equation relating the volume flow rate $\frac{V}{t}$ of a fluid under laminar conditions through a horizontal tube of length $L$ and internal radius $r$ is

$$\frac{V}{t} = \frac{\pi p r^4}{8\eta L}$$

where $p$ is the pressure difference between the two ends of the tube and $\eta$ is the viscosity of the fluid.

**(a)** Show that the SI base units for $\eta$ is kg m$^{-1}$ s$^{-1}$.

$$[\eta] = \frac{[p][r]^4}{[L]\left[\frac{V}{t}\right]}$$

$$= \frac{\text{kg m}^{-1}\,\text{s}^{-2} \bullet \text{m}^4}{\text{m} \bullet \text{m}^3\,\text{s}^{-1}}$$

$$= \text{kg m}^{-1}\,\text{s}^{-1} \text{ (shown)}$$

[2]

**(b)** In an experiment to determine $\eta$ for water, a student recorded the following measurements in SI units, as shown in Table 1.1.

**Table 1.1**

| quantity | magnitude in SI units | percentage uncertainty / % |
|---|---|---|
| $\frac{V}{t}$ | $1.0 \times 10^{-6}$ | 3 |
| $p$ | 500 | 2 |
| $L$ | 0.20 | 0.5 |

The internal diameter of the tube was measured and recorded as (0.200 ± 0.002) cm.

**(i)** Calculate the percentage uncertainty in the internal radius $r$ of the tube.

$$d = 2r$$

$$\frac{\Delta d}{d} = \frac{\Delta r}{r}$$

$$\text{\% uncertainty} = \frac{0.002}{0.200} \times 100\%$$

$$= 1\% \text{ or } 1.0\% \text{ (1 or 2 s.f.) [A1]}$$

percentage uncertainty = ........................................ % [1]

**(ii)** Using the results in Table 1.1 and **(b)(i)**, determine $\eta$ with its associated uncertainty. Give your answer to an appropriate number of significant figures.

$$\eta = \frac{\pi p r^4}{8L\left(\frac{V}{t}\right)}$$

$$= \frac{\pi \times 500 \times \left(0.10 \times 10^{-2}\right)^4}{8 \times 0.20 \times 1.0 \times 10^{-6}}$$

$$= 9.817 \times 10^{-4} \text{ kg m}^{-1} \text{ s}^{-1} \quad \text{[C1]}$$

$$\frac{\Delta\eta}{\eta} = \frac{\Delta p}{p} + 4\frac{\Delta r}{r} + \frac{\Delta L}{L} + \frac{\Delta V/t}{V/t}$$

$$\frac{\Delta\eta}{\eta} = 0.02 + 4(0.01) + 0.005 + 0.03 \quad \text{[M1]}$$

$$= 0.095$$

$$\Delta\eta = 0.095 \times 9.817 \times 10^{-4}$$

$$= 9.326 \times 10^{-5}$$

$$= 9 \times 10^{-5} \text{ kg m}^{-1} \text{ s}^{-1} \text{ (1 s.f.)} \quad \text{[A1] recognise } \Delta\eta \text{ to 1 s.f.}$$

$$\eta \pm \Delta\eta = (9.8 \pm 0.9) \times 10^{-4} \text{ kg m}^{-1} \text{ s}^{-1} \quad \text{[A1] recognise } \eta \text{ to same d.p. as } \Delta\eta$$

$\eta$ = .............................. ± .............................. kg m$^{-1}$ s$^{-1}$ [4]

**(iii)** State and explain which measured quantity has the greatest contribution to the uncertainty of $\eta$.

Internal diameter or radius, because of the power of 4, so greatest contribution to the uncertainty of viscosity [B1]

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

[Total: 8]

**2** Two atoms X and Y, have masses 3*m* and 2*m* respectively. The 2 atoms move head-on towards each other with the same speed *v* as shown in Fig. 2.1.


**Fig. 2.1**

Fig 2.2 comprises two velocity-time graphs A and B, which show how the velocity of each atom varies. The interaction between the atoms is elastic.

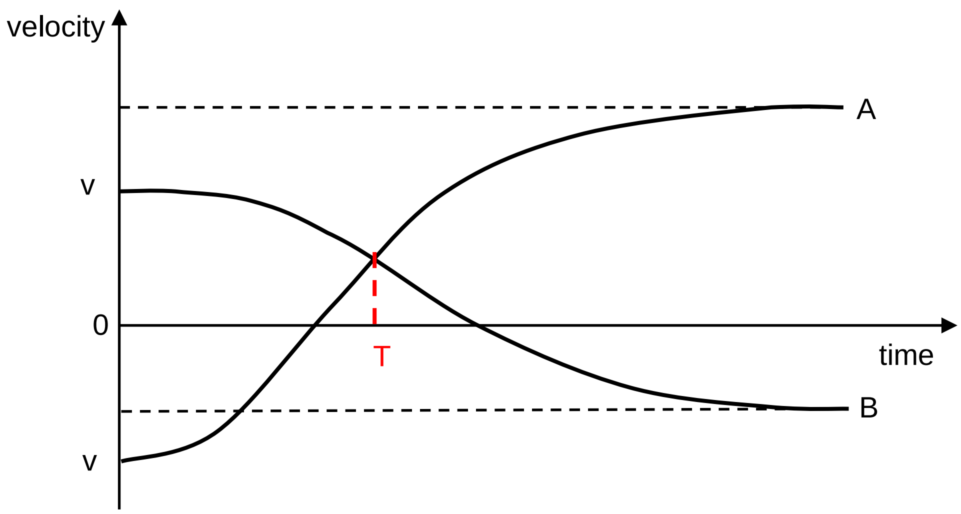


**Fig. 2.2** (not to scale)

**(a) (i)** Explain why it is not possible for the atoms to stop at the same instant.

Since the total momentum before the collision is *mv*, it is not possible for both atoms to stop at the same instant as then the total momentum of the system at that instant will be zero. This will violate the principle of conservation of momentum. [1]

**(ii)** At one instant during the interaction between the atoms, they are both traveling in the same direction with the same speed. Calculate this speed, in terms of *v*.

From the principle of Conservation of momentum:

Total initial momentum = total final momentum

$$3mv - 2mv = 3mu + 2mu$$
$$u = 0.2mv$$

speed = …………………….. [2]

**(b)** **(i)** State and explain, which of the curves A or B is the velocity-time sketch for atom Y.

Curve A is the velocity-time sketch for atom Y.

During the collision, by Newton's third law, X and Y will experience a force of equal magnitude and in opposite direction. Since the force on X and Y are the same, and the mass of Y is smaller, Y will experience a larger acceleration and the change in velocity for Y will be larger, which is curve A. [3]

For momentum to be conserved, the magnitude of the change in momentum of X is equal to the magnitude of change in momentum of Y. Since the mass of Y is smaller, the change in velocity for Y will be larger, which is the curve A.

**(ii)** On Fig. 2.2, mark the instant in time at which the atoms are at their distance of closest approach. Label this point **T**. [1]

**(iii)** Determine the final speed of each atom in terms of v.

Let $V_x$ be the final speed of X and $V_y$ be the final speed of Y.
Since the collision is elastic:
relative speed of approach = relative speed of separation,

$$v-(-v)=V_Y-V_X$$

$$2v=V_Y-V_X \quad .....(1)$$

By the principle of Conservation of momentum:

$$3mv-2mv=3mV_X+2mV_Y$$

$$v=3V_X+2V_Y \quad ......(2)$$

Solving equation (1) and (2):

$$V_X=-\,0.6v$$

$$V_Y=1.4v$$

final speed of X = ……………………..

final speed of Y = …………………….. [3]

[Total: 10]

**3** A 2.0 kg block on a track is released at A, 1.0 m above the ground as shown in Fig. 3.1. The track is frictionless except for the rough surface between B and C, which has a length of 2.0 m. The block travels down the track, hits the spring of force constant $k$ = 225 N m$^{-1}$ at D and compresses the spring by 0.20 m from its equilibrium position before coming to rest momentarily.

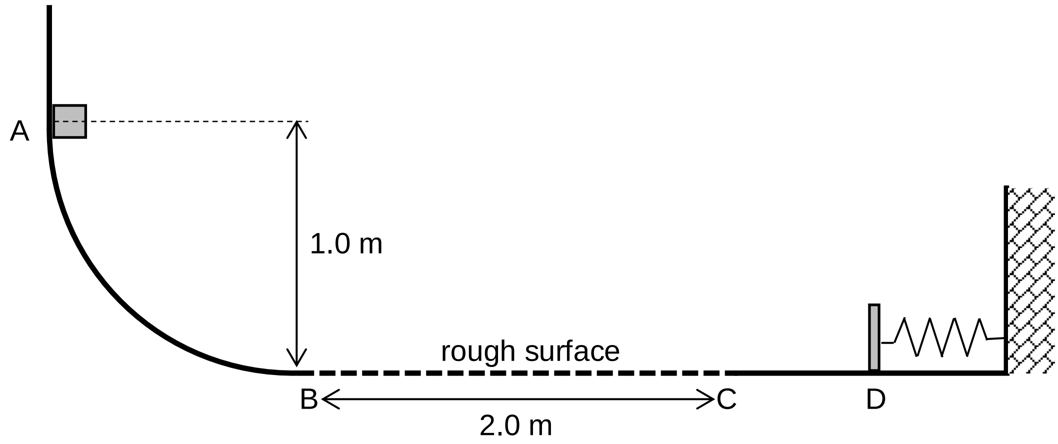


**Fig. 3.1**

**(a) (i)** Determine the speed of the block at B.

By the Principle of conservation of energy:

Loss in gravitational $E_P$ = Gain in $E_K$ [M1]

$$mgh = \frac{1}{2}mv^2 - 0$$

$$v = \sqrt{2gh}$$

$$= \sqrt{2(9.81)(1.0)} = 4.43 \text{ m s}^{-1}$$ [A1]

speed at B = .................... m s$^{-1}$ [2]

**(ii)** Calculate the maximum elastic potential energy stored in the spring.

Energy stored in spring $= \frac{1}{2}kx^2$

$$= \frac{1}{2}(225)(0.2)^2$$

$$= 4.5 \text{ J}$$ [A1]

elastic potential energy = .................... J [1]

**(iii)** Using your answers to **(a)(i)** and **(ii)**, determine the work done against friction when the block travels from B to C.

Work done against friction $= E_{K(initial)} - E_{P(spring)}$

$$= \frac{1}{2}(2.0)(4.43)^2 - 4.5$$ [M1]

$$= 15.1 \text{ J}$$ [A1]

work done against friction = .................... J [2]

**(b)** The block subsequently rebounds and moves towards B after the spring un-compresses itself. Determine the distance along the track from C where the block finally stops.

$$\text{frictional force} = \frac{15.1}{2.0} = 7.56 \text{ N} \quad [M1]$$

If all the energy stored in the spring is used to do work against friction,

$$W = fd$$

$$4.5 = (7.56)d \quad [M1]$$

$$d = 0.596 \text{ m} \quad [A1]$$

distance from C = ……………….. m [3]

[Total: 8]

**4** A laser produces a narrow beam of coherent light of wavelength 632 nm. The beam is incident normally on a diffraction grating, as shown in Fig. 4.1.

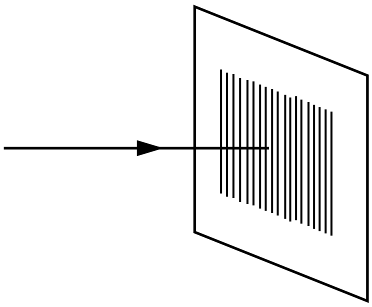

**Fig. 4.1**

**(a)** Describe how diffraction of light takes place at the grating.

The grating consists of many slits/openings and diffraction take place when the light incident on the grating spread as they pass through each slit/opening in the grating.

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

**(b)** The diffraction pattern on the screen is shown in Fig. 4.2. The brightest spot is O. The two bright spots closest to O is 3.5 cm away from O.

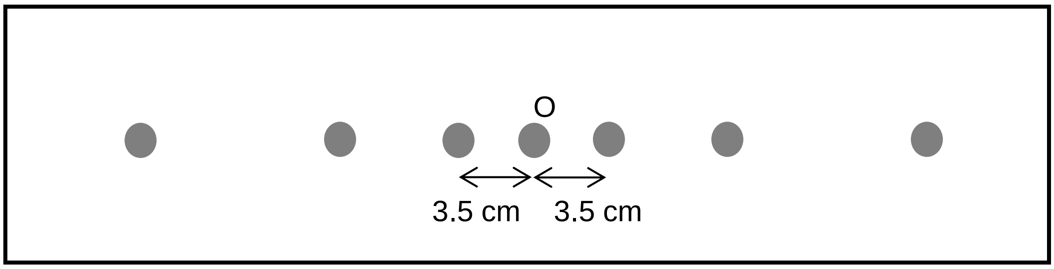


**Fig. 4.2 (Not to scale)**

The diffraction grating is placed 10 cm from the screen.

Determine the number of lines per metre on the grating.

$\tan\theta = \frac{3.5}{10}$ [M1]

$d \sin\theta = (1)\lambda$ [M1]

*no of lines per metre* $= \frac{1}{d} = 5.23 \times 10^{5}$ [A1]

number of lines per metre = .......................................... [3]

**(c)** A second laser is directed normally to another diffraction grating with the same number of lines as in **(b)**.

Describe and explain how the new appearance of the diffraction grating pattern will allow the following to be deduced.

**(i)** the wavelength of the second laser

If the distance the first order bright spots and the brightest spot at O is increased, the angle of diffraction will increases . Hence the wavelength of the second laser will be longer compared to the first laser.

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

**(ii)** the orientation of the diffraction grating.

The direction of spreading of the bright spots is always perpendicular to the orientation of the slits in the grating. If the bright spots formed on the screen is spread vertically instead of horizontally, this imply that the orientation of the slits for the diffraction grating [1] is rotated by 90 degree as the slits is now horizontally instead of vertical.

**(d)** The diffraction grating in **(c)** is added directly in front of the first grating such that the orientation of the two diffraction gratings are perpendicular to each other. The diffraction pattern in Fig. 4.3 is observed.

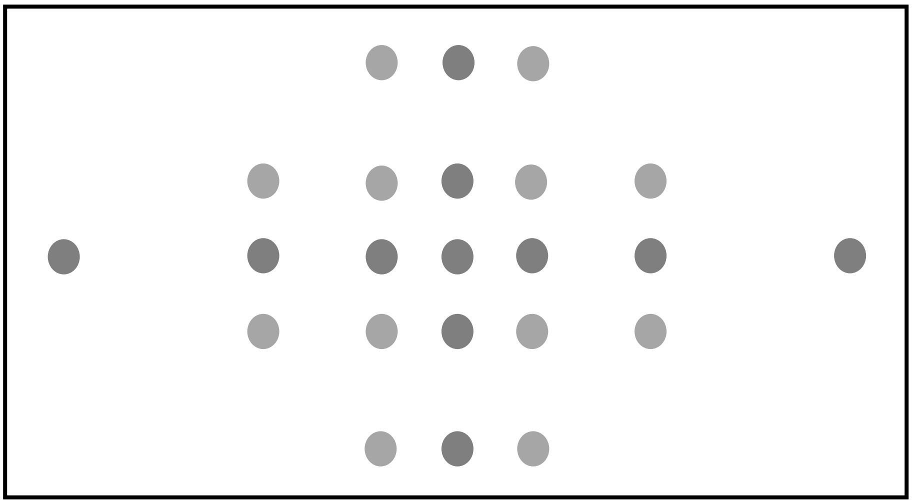

**Fig. 4.3**

Suggest how the pattern in Fig. 4.3 is formed.

When the light is incident on the first grating, the pattern shown in Fig. 4.2 will be seen. Each bright spots then acts as source of light for the second grating which results in the pattern formed in Fig. 4.3. The intensity of the bright spots at the corners is much lower compared to the middle portion as they are produced by diffraction of the higher order bright spots in Fig. 4.2 or they are spread twice by each grating . [2]

**(e)** A student sets up the apparatus in Fig. 4.1 but rotates the diffraction grating by 45° such the laser is no longer normal to the grating.

Suggest and explain whether the position of the brightest spot O in Fig. 4.2 will change.

The position of the bright spot O will not change as the path difference between light coming from adjacent slits in the grating remains zero.

[1]

[Total: 10]

**5** Two stars A and B are separated by a distance of $1.2 \times 10^{10}$ m as shown in Fig. 5.1. $x$ is the distance from the centre of star A, in the direction toward the centre of star B.

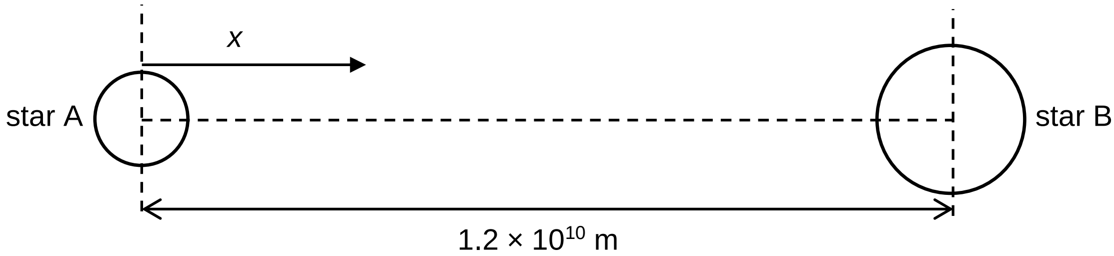


**Fig. 5.1**

The variation with $x$ of the gravitational potential $\phi$ due to the two stars along the line joining their centres is shown in Fig. 5.2.

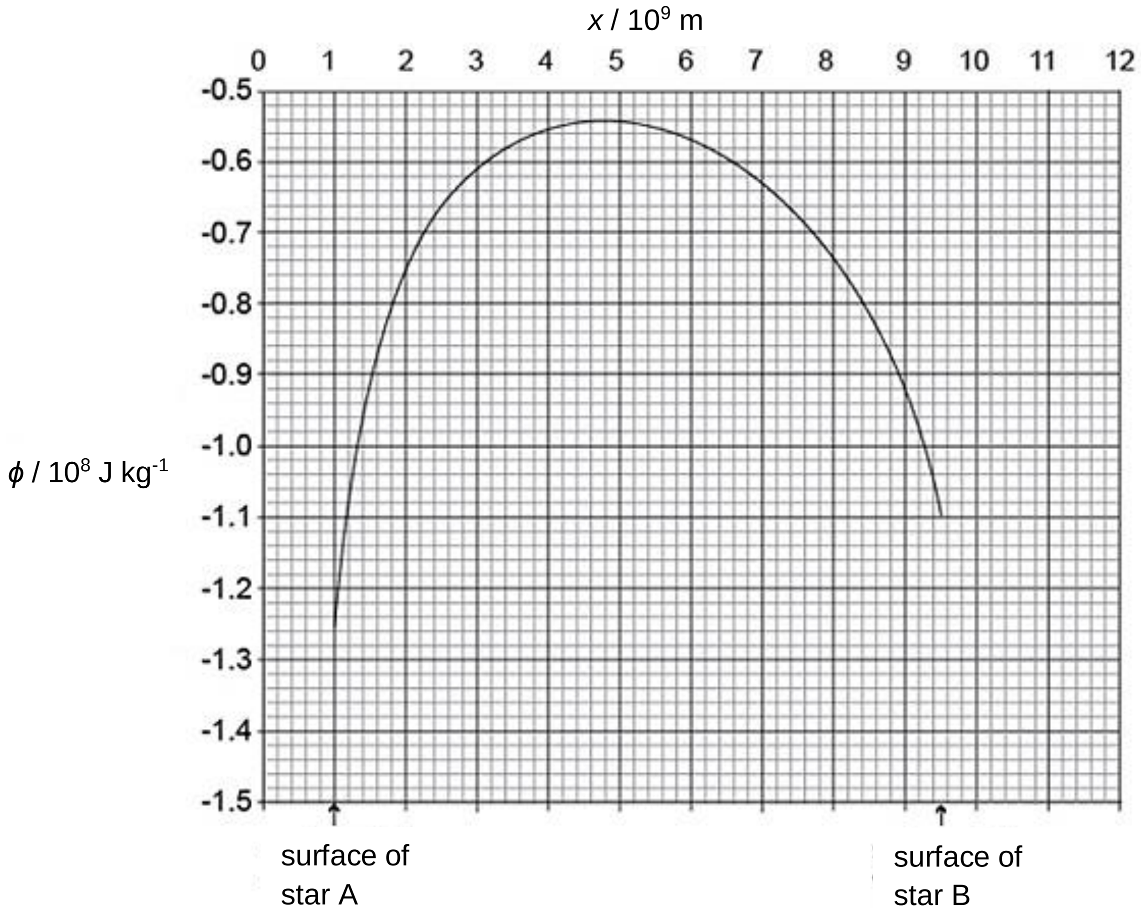


**Fig. 5.2**

A body is launched with kinetic energy $E_K$ from the surface of star B.

The body then arrives at the surface of the star A.

**(a)** Define *gravitational potential* at a point.

Gravitational potential at a point in a gravitational field is the work done per unit mass by an external agent in bringing a small test mass from infinity to that point. [B1] [1]

**(b)** Use Fig. 5.2 to explain whether the kinetic energy of the body when it arrives at the surface of star A is less than, equal to, or larger than $E_k$.

The potential at the surface of A is smaller than that of B, hence there is a loss in potential energy.[B1] By conservation of energy, the body will have a gain in kinetic energy. Hence the kinetic energy of the body at A is larger than $E_k$. [B1] [2]

**(c)** State and explain the distance $x$ at which the resultant gravitational field strength due to the two stars is zero.

The magnitude of the potential gradient is equal to the gravitational field strength, which is zero at $x = 4.8 \times 10^9$ m. [M1]

$x = 4.8 \times 10^9$ m (allow answers in the range of 4.6 to 5.0) [A1] [2]

**(d)** Determine the ratio $\dfrac{\text{average density of star A}}{\text{average density of star B}}$.

$$\left.\begin{aligned}&\text{At } x = 4.8\times10^9 \text{ m,}\\ &\Sigma g = 0\\ &g_A = g_B\end{aligned}\right\} \quad [\text{M1}]$$

$$\frac{GM_A}{r_A^2} = \frac{GM_B}{r_B^2}$$

$$\frac{G\rho_A \frac{4}{3}\pi R_A^3}{r_A^2} = \frac{G\rho_B \frac{4}{3}\pi R_B^3}{r_B^2}$$

$$\frac{\rho_A}{\rho_B} = \frac{R_B^3 r_A^2}{R_A^3 r_B^2} = \frac{(2.5\times10^9)^3(4.8\times10^9)^2}{(1.0\times10^9)^3[(12.0-4.8)\times10^9]^2} \quad [\text{M1}]$$

$$\frac{\rho_A}{\rho_B} = 6.9 \quad [\text{A1}]$$

Alternatively,

$$\frac{\phi_A}{\phi_B} = \frac{-\frac{GM_A}{r_{AA}} + (-\frac{GM_B}{r_{BA}})}{-\frac{GM_A}{r_{AB}} + (-\frac{GM_B}{r_{BB}})}$$

$$\frac{-1.26\times10^8}{-1.10\times10^8} = \frac{\frac{M_A}{1.0\times10^9} + \frac{M_B}{11.0\times10^9}}{\frac{M_A}{9.5\times10^9} + \frac{M_B}{2.5\times10^9}}$$

$$\frac{M_A}{M_B} = 0.4176$$

$$\frac{\rho_A}{\rho_B} = \frac{M_A}{M_B} \times \frac{V_B}{V_A} = \frac{M_A}{M_B} \times \frac{\frac{4}{3}\pi {R_B}^3}{\frac{4}{3}\pi {R_A}^3}$$

$$= \frac{M_A}{M_B} \times \frac{{R_B}^3}{{R_A}^3} = 0.4176 \times \frac{(2.5\times10^9)^3}{(1.0\times10^9)^3} = 6.5$$

ratio = .......................................... [3]

[Total: 8]

**6** A power supply is connected across a load as shown in Fig. 6.1.

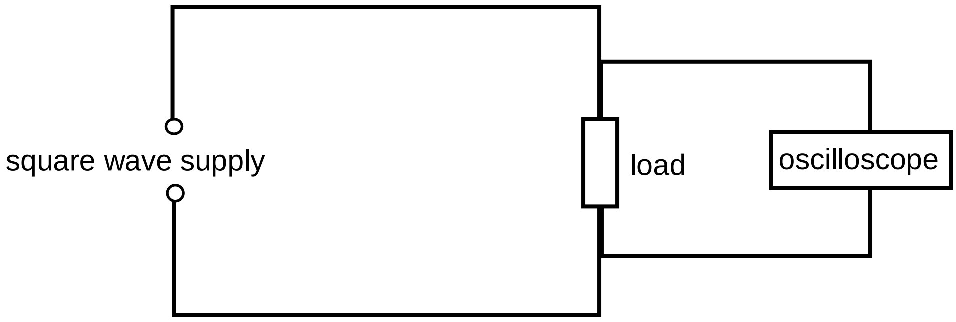


**Fig. 6.1**

The power supply provides a square wave voltage that cycles between + 7.0 V and – 7.0 V as shown on the oscilloscope display in Fig. 6.2.

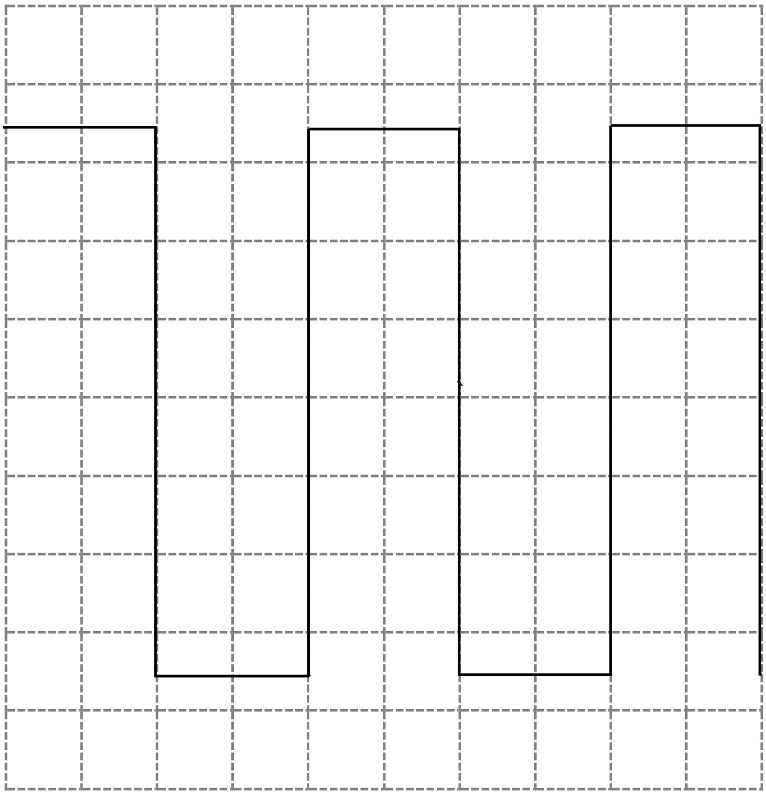

**Fig. 6.2**

**(a)** Determine the Y-gain for the oscilloscope based on the waveform shown in Fig. 6.2

$\frac{14.0}{7.0}$ [M1]

$= 2.0 V / div$ [A1]

Y-gain = .......................................... V / div [2]

**(b)** Determine the frequency of the square wave given that the time base is 5.0 ms / div.

$$f = \frac{1}{T} = \frac{1}{20 \times 10^{-3}} = 50 \text{ Hz} \qquad [B1]$$

frequency of square wave = .......................................... Hz [1]

**(c)** The root-mean-square value for the square wave in Fig. 6.2 is 7.0 V. Explain the significance of this value.

The value is the equivalent value of the steady direct voltage supply that will supply energy at the same average rate to the load as the square wave supply.

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

**(d)** A diode is used to achieve rectification of the square wave.

On Fig. 6.3, sketch the new waveform. The original waveform in Fig. 6.2 has been reproduced as the grey line shown. [1]

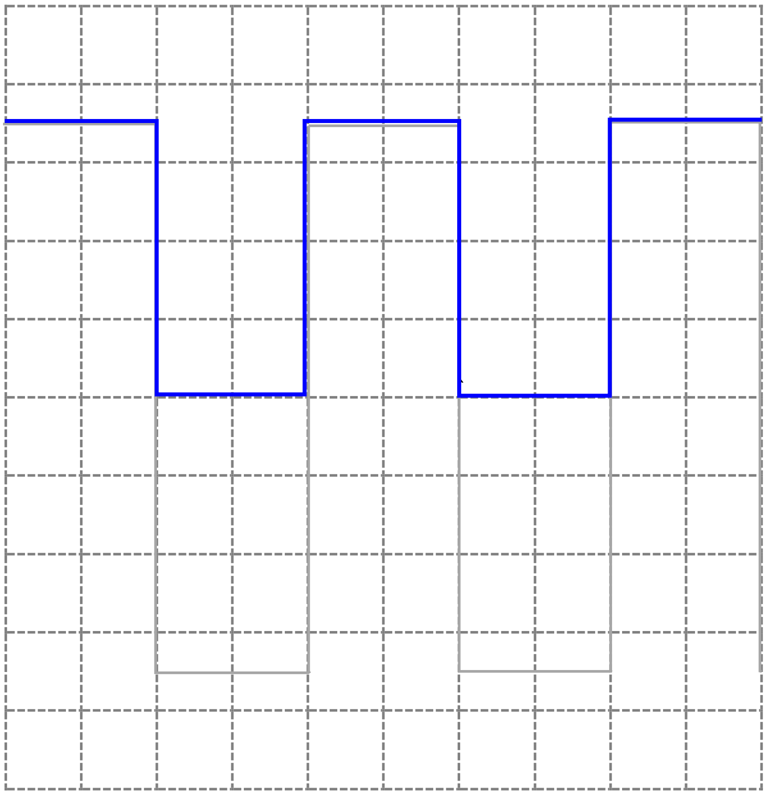

**Fig. 6.3**

**(e)** With the diode still in place, the power supply is replaced by another one which is sinusoidal. Determine the value of the peak voltage such that the average power dissipated in the load remains the same as the value given in **(c)**.

$Vpeak = Vrms \times 2$ =(7.0)(2) [M1]

$V_{peak} = 14\ V$ [A1]

peak voltage = .......................................... V [2]

[Total: 7]

**7 (a)** X-rays are produced in an X-ray tube when high-speed electrons are accelerated toward and hit a metal target. Fig. 7.1 shows the variation with wavelength of the intensity of X-ray radiation emitted.

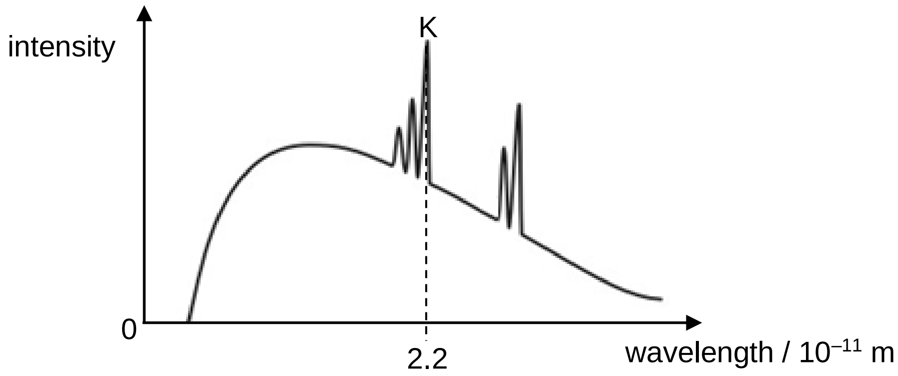


**Fig. 7.1**

**(i)** Explain why there is a continuous distribution of wavelengths.

X-ray **photons** produced when high-speed bombarding electrons lose kinetic energy when they collide with target metal atoms OR decelerate OR X-ray radiation produced when electrons accelerated [B1] – explain process of how X-ray photons are produced

Electrons lose a range/distribution of kinetic energies OR range/distribution of decelerations OR range/distribution of accelerations, so range/distribution of X-ray wavelengths emitted [B1] – explain why continuous wavelengths [2]

**(ii)** A series of characteristic lines shown by the high intensity peaks, such as K, are observed in Fig. 7.1.

**1.** Calculate the energy difference, in keV, associated with the characteristic line K.

$$\Delta E = \frac{hc}{\lambda}$$

$$= \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.2\times10^{-11}} \quad \text{[C1]}$$

$$= 9.04\times10^{-15}\ \text{J}$$

$$\frac{9.04\times10^{-15}}{1.6\times10^{-19}\times10^{3}} = 56.5\ \text{keV} \quad \text{[A1]}$$

energy difference = .......................................... keV [2]

**2.** Suggest why there are other series of characteristic lines produced at wavelengths longer than K.

Collision with high-speed bombarding electron causes inner shell electron to be knocked out, creating a vacancy refilled by outer shell electron. [B1] – describes the process of producing characteristic lines

Vacancy are in shells above K-shell, X-ray photons emitted when these vacancies are filled have smaller energy difference than K-series, hence longer wavelengths [2]

[B1] – explain why longer wavelengths

Question 7 continues on the following page.

**(b)** A simple model of an atom with one electron can be represented by the electron as a stationary wave confined in a box of length $1.0 \times 10^{-10}$ m equal to the diameter of the atom, as shown in Fig. 7.2.

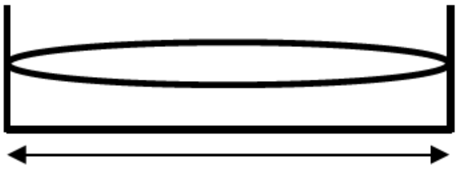


**Fig. 7.2**

**(i)** State the uncertainty in locating the position of the electron.

uncertainty in position = $1.0 \times 10^{-10}$ [A1] ........................................ m [1]
OR $5.0 \times 10^{-11}$

**(ii)** Calculate the uncertainty in the velocity of the electron.

$$\Delta x \Delta p \geq h$$

$$m\Delta v \geq \frac{h}{\Delta x}$$

$$\Delta v \geq \frac{6.63 \times 10^{-34}}{\left(9.11 \times 10^{-31}\right)\left(1.0 \times 10^{-10}\right)}$$

$$\Delta v \geq 7.3 \times 10^{6} \text{ m s}^{-1}$$ [B1]

uncertainty in velocity = ........................................ m s$^{-1}$ [1]

**(iii)** The diameter of a nucleus is $10^4$ times smaller than the diameter of an atom.
Using the model above, suggest why an electron cannot be found inside the nucleus.

The uncertainty in the electron's velocity would be $10^4$ times more ($7.3 \times 10^{10}$ m s$^{-1}$) exceeding the speed of light, hence not possible to find an electron inside the nucleus [B1]

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

[Total: 9]

## Section B

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

**8** This question is on the common last topic of Nuclear Physics and will not be assessed.

**9** A cycle of changes in pressure, volume and temperature of gas inside a cylinder of a petrol engine is illustrated in Fig. 9.1. The gas is assumed to be ideal.

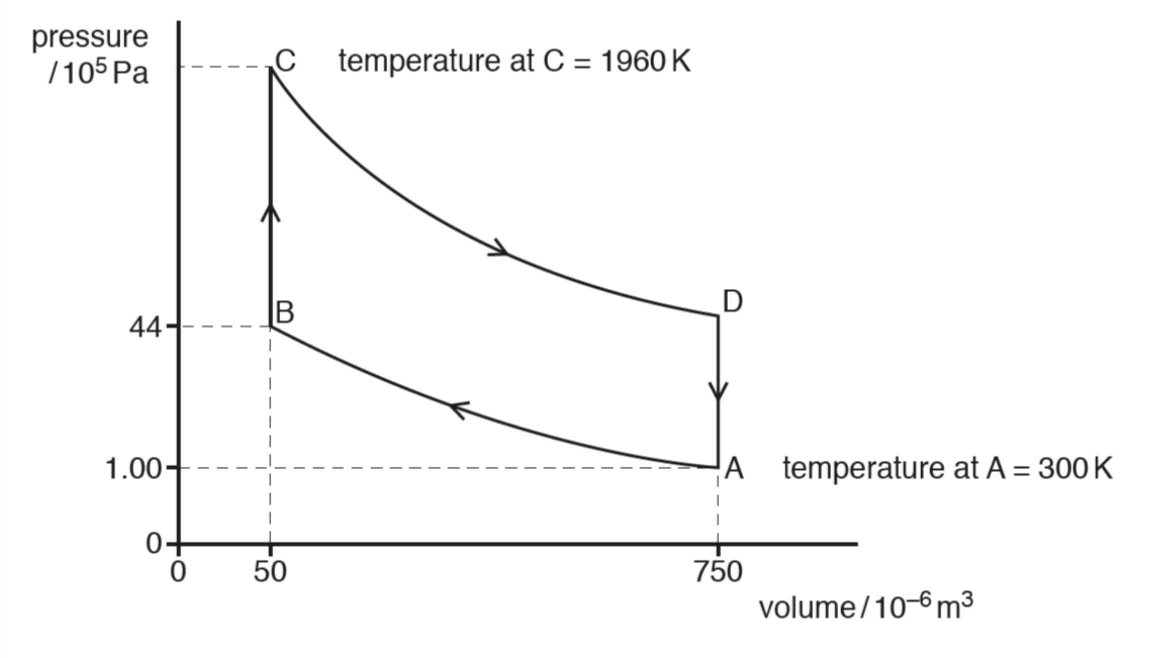


**Fig. 9.1** (not to scale)

There are four stages in the cycle.

| stage | description |
|---|---|
| A to B | Rapid compression of the gaseous petrol/air mixture with the temperature rising from 300 K at A. The pressure at B is $44 \times 10^5$ Pa. |
| B to C | The petrol/air mixture is exploded, resulting in an almost instant rise in pressure. At C the temperature is 1960 K. |
| C to D | Rapid expansion and cooling of the hot gases. |
| D to A | Return to the initial state of the cycle. |

**(a)** **(i)** Using appropriate values on Fig. 9.1, determine the number of moles present in the gases in the cycle.

$$pV = nRT$$

$$(1.00 \times 10^5)(750 \times 10^{-6}) = n(8.31)(300)$$

$$n = 0.030 \text{ moles}$$

number of moles = .......................................... mol [2]

**(ii)** Calculate the temperature of the gas at B.

$$pV = nRT$$
$$(44\times10^5)(50\times10^{-6}) = n(8.31)(T_B)$$
$$T_B = 880\text{ K}$$

or

$$\frac{p_AV_A}{T_A} = \frac{p_BV_B}{T_B}$$
$$\frac{(1.00\times10^5)(750\times10^{-6})}{300} = \frac{(44\times10^5)(50\times10^{-6})}{T_B}$$
$$T_B = 880\text{ K}$$

temperature = ........................................K [2]

**(iii)** Calculate the pressure of the gas at C.

$$p_CV_C = nRT_C$$
$$(P_C)(50\times10^{-6}) = n(8.31)(1960)$$
$$p_C = 9.8\times10^6\text{ Pa}$$

or

$$\frac{p_B}{T_B} = \frac{p_C}{T_C}$$
$$\frac{(44\times10^5)}{880} = \frac{p_C}{1960}$$
$$p_C = 9.8\times10^6\text{ Pa}$$

pressure = ........................................Pa [2]

**(iv)** State

**1.** the numerical value of work done by the gas from B to C,

$W_{BC} = 0$ [B1] ........................................ [1]

**2.** what is represented by the area ABCD enclosed by the graph.

It is the net work done [B1] BY the gas [B1] in one complete cycle

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

**(b)** Complete Table 9.1, which shows the work done on the gas, the heat supplied to the gas and the increase in internal energy of the gas, during the four stages in the cycle.

**Table 9.1**

| stage | work done **on** gas /J | heat supplied **to** gas /J | **increase** in internal energy of gas /J |
|---|---|---|---|
| A to B | + 360 | 0 | 360 |
| B to C | 0 | + 670 | 670 |
| C to D | – 810 | 0 | – 810 |
| D to A | 0 | – 220 | – 220 |

[4]

**(c)** The efficiency of this engine is the ratio of the net work done by the gas to the heat supplied to the gas. Calculate the efficiency of this cycle.

$$\text{Efficiency} = \frac{\text{work done by gas}}{\text{heat supplied}}$$
$$= \frac{810 - 360}{670}$$
$$= 67\%$$

efficiency = .......................................... [1]

**(d)** Using the First Law of Thermodynamics, explain whether the r.m.s. speed of the molecules of the gas will increase, decrease or remains the same when the gas expands rapidly from C to D.

In stage C to D, negative work is done on the gas (gas is expanded) AND no heat is supplied or removed from the gas (expansion is rapid). The change in internal energy is negative, meaning the internal energy DECREASES. [first law concluded DECREASE in U: B1]

This is an ideal gas, so the internal energy is equal to the microscopic kinetic energy (microscopic potential energy is zero) so the kinetic energy of the molecules will decrease and thus the root mean square speed of the molecules will decrease. [B1] [2]

**(e)** Explain, in terms of the collision of the molecules of the gas with the walls of the container, why an expansion results in a change in the kinetic energy of the molecules from C to D.

In stage C to D the gas is expanded, walls of the container do NEGATIVE WORK [B1] on the gas molecules during collision.

This means energy is removed from the gas molecules, so the kinetic energy of the molecules decreases. [B1] [2]

**(f)** Calculate the total kinetic energy of the molecules of the gas at C.

$$\Sigma K = N\left(\frac{3}{2}kT\right)$$
$$= (0.030 \times 6.02 \times 10^{23})\left(\frac{3}{2}\right)(1.38 \times 10^{-23})(1960)$$
$$= 732 \text{ J}$$

total kinetic energy = .......................................... J [2]

[Total: 20]

**End of Paper**