VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

| | |
|---|---|
| CANDIDATE NAME | **SOLUTION** |
| CLASS | |
| TUTOR'S NAME | |

# PHYSICS 9749/01

Paper 1 Multiple Choice

**22 September 2025**

**1 hour**

Additional Materials: Multiple Choice Answer Sheet

**READ THESE INSTRUCTIONS FIRST**

Write in soft pencil.
Do not use staples, paper clips, glue or correction fluid.
Write your name, class and tutor name in the spaces on the top of this page.

There are **thirty** questions on this paper. Answer **all** questions. For each question there are four possible answers **A**, **B**, **C** and **D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

**Read the instructions on the Answer Sheet very carefully.**

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

This document consists of **16** 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$^{-2}$ |



BP-625

**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 | $T / K = T / °C + 273.15$ |
| 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 | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| 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 | $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ |

 [Turn over



**1** The e.m.f. induced in a coil by a changing magnetic flux is equal to the rate of change of flux with time. Which is a unit for magnetic flux?

**A** kg $m^2$ $s^{-2}$ $A^{-1}$

**B** kg $m^2$ $s^{-2}$ A

**C** kg $m^2$ $s^2$ $A^{-1}$

**D** $m^2$ $s^{-2}$ $A^{-1}$

**Ans: A**
Using Faraday's Law,

$$E = -\frac{d\Phi}{dt}$$
$$\frac{P}{I} = -\frac{d\Phi}{dt}$$
$$\frac{P}{I}\Delta t = -\Delta\Phi$$

Unit for $\Phi = \frac{kg\ m^2\ s^{-2}\ s^{-1}}{A} s = kg\ m^2\ s^{-2}\ A^{-1}$

**2** What is a reasonable estimate for the volume of a wooden metre rule found in a school laboratory?

**A** 1.5 $cm^3$ **B** 15 $cm^3$ **C** 150 $cm^3$ **D** 1500 $cm^3$

**Ans: C**
Volume of wooden ruler
= l x b x h
= (100cm)(3 cm)(0.5 cm)
= 150 $cm^3$

**3** A student carried out an experiment to determine the resistivity $\rho$ of copper using a copper wire. The uncertainties in the measurements are shown.

uncertainty in length $l$ of wire = 0.2%
uncertainty in diameter $d$ of wire = 1.6%

The equation for resistivity $\rho$ is $\rho = \frac{\pi d^2 R}{4l}$.

He obtains a resistivity value of $(1.71 \pm 0.07) \times 10^{-8}\,\Omega$ m with its associated uncertainty.

What is the uncertainty in the measurement of resistance $R$ of the wire?

**A** 0.007% **B** 0.7% **C** 0.9% **D** 7%

**Ans: B**

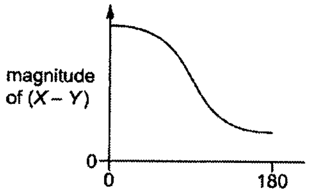
$$\frac{0.07}{1.71} = 2\left(\frac{1.6}{100}\right) + \frac{\Delta R}{R} + \frac{0.2}{100}$$
$$\frac{\Delta R}{R} = 0.007 = 0.7\%$$

Option A: If student forgets to convert to percentage.
Option C: If student includes 4 in percentage uncertainty to give 0.0009 = 0.9%
Option D: If student makes R the subject first and adds all the percentage uncertainty.

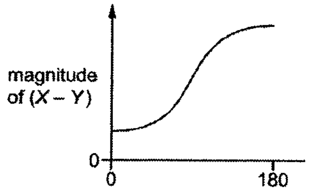
**4** $X$ and $Y$ are vectors. The magnitude of $X$ is less than the magnitude of $Y$. The vectors are initially in opposite directions.

As $Y$ is rotated through 180°, how does the magnitude of the vector $(X - Y)$ vary?

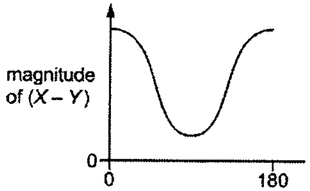
**A**



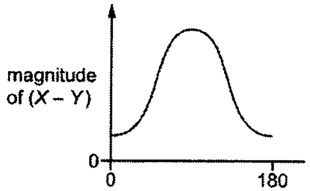

**B**




**C**




**D**

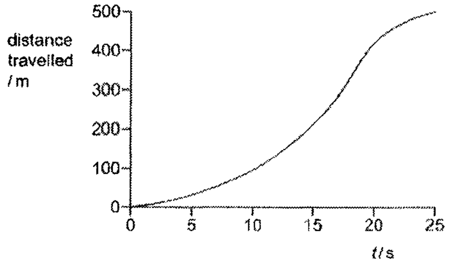



**Ans: A**
At an angle of 0°, X and Y are opposite in directions. Vector sum $(X - Y)$ is maximum.
At an angle of 180°, X and Y are in the same direction. Vector sum $(X - Y)$ is minimum.





**5** A car, starting from rest at time $t = 0$, travels along a road. The distance travelled from the starting point is measured over the next 25 seconds.




Which best describes the motion of the car?

**A** The maximum speed during the first 20 seconds is 10 m s$^{-1}$.

**B** At some instant during the first 20 seconds the speed is exactly 20 m s$^{-1}$.

**C** The average speed for the first 200 m of the journey is 20 m s$^{-1}$.

**D** The average speed between 20 and 25 seconds is greater than that between 15 and 20 seconds.

**Ans: B**
Option A is wrong as it covered 400 m in 20 s. The average speed is already at 20 m s$^{-1}$. Thus the max speed must be higher.
Option C is wrong. It took 15 s to cover 200 m. Thus, the average speed is 13.3 m s$^{-1}$.
Option D is wrong. From 20 to 25 s, 100 m was covered. From 15 to 20 s, 200 m was covered, thus the average speed from 15 to 20 s must be higher.
Option B is correct. The average speed over 20 s is 20 m s$^{-1}$. At 0 s, it started at a low speed, at 20 s the instantaneous speed is higher than 20 m s$^{-1}$. As speed is a continuous variable (no abrupt change, jumping from one value to another without going through values inbetween), thus at some instant during the 20 s, the speed must have been 20 m s$^{-1}$.

**6** A boy with a ball was in a stationary lift. When the lift starts to accelerate upwards at 1.2 m s$^{-2}$, the boy released the ball from a height of 1.5 m above the floor of the lift.

What is the time taken by the ball to hit the floor of the lift?

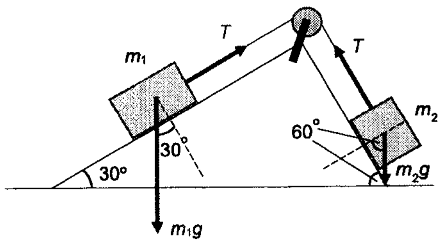
**A** 0.27 s **B** 0.52 s **C** 0.55 s **D** 0.59 s

**Ans: B**
The relative acceleration of the ball to the lift $= 1.2 + 9.81 = 11.01$ m s$^{-2}$
Using $\frac{\text{Eqn1}}{\text{Eqn2}}: \frac{s_{y1}}{s_{y2}} = \frac{t_1^2}{t_2^2}$, we get
$1.5 = \frac{1}{2}(11.01)t^2$
$t = 0.52$ s



BP~627

7 Two blocks of masses $m_1$ = 4.0 kg and $m_2$ = 1.0 kg are connected by a cord of negligible mass that passes over a frictionless pulley of negligible mass. The blocks slide on frictionless planes inclined at angles $\theta_1$ = 30° and $\theta_2$ = 60°.




What is the tension in the cord?

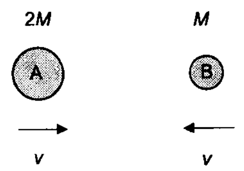
**A** 2.3 N **B** 5.8 N **C** 8.0 N **D** 10.7 N

**Ans: D**
Apply $F = ma$ to both masses:
$m_1 g\sin 30° - T = m_1 a$ ---(1)
$T - m_2 g\sin 60° = m_2 a$ ---(2)

Sub. $T$ from (2) into (1):
$m_1 g\sin 30° - (m_2 g\sin 60° + m_2 a) = m_1 a$
$(m_1 + m_2)a = g(m_1\sin 30° - m_2\sin 60°)$
$(4.0 + 1.0)a = 9.81(4.0\sin 30° - 1.0\sin 60°)$
$a = 2.22\ \text{m s}^{-2}$

Sub. Into (2):
$T - 9.81\sin 60° = 2.22$
$T = 10.7$ N

8 Two steel balls A and B of masses 2*M* and 1*M* respectively move towards each other with the same speed *v* and collide elastically.




What are the final velocities of the two balls in terms of *v*? Take the rightward direction as positive.





| | final velocity of ball A | final velocity of ball B |
|---|---|---|
| **A** | $\frac{4}{3}v$ | $\frac{7}{3}v$ |
| **B** | $-\frac{1}{3}v$ | $\frac{5}{3}v$ |
| **C** | $\frac{1}{3}v$ | $\frac{2}{3}v$ |
| **D** | $-v$ | $2v$ |

**Ans: B**
Let $v_1$ = final velocity of the ball A
Let $v_2$ = final velocity of the ball B
By Law of Conservation of Momentum,
$$2Mv + M(-v) = 2Mv_1 + Mv_2$$
$$2v_1 + v_2 = v \text{ ---(1)}$$
Since the collision is elastic,
initial velocity of B relative to A = −( final velocity of B relative to A )
$$(-v) - v = -(v_2 - v_1)$$
$$v_2 = v_1 + 2v \text{ ---(2)}$$
Sub. into (1):
$$2v_1 + (v_1 + 2v) = v$$
$$v_1 = -\frac{1}{3}v$$
Sub. into (2):
$$v_2 = -\frac{1}{3}v + 2v = \frac{5}{3}v$$

9 A metal block is suspended by a spring balance and is fully submerged in a liquid. When the liquid is replaced with a less dense fluid, the reading on the spring balance

**A** increases because upthrust decreases.

**B** increases because the object displaces less fluid.

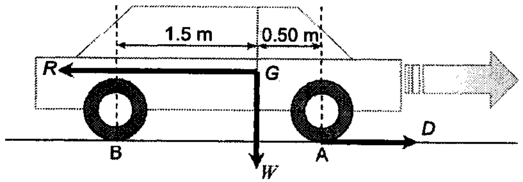
**C** remains the same because the volume of the block is unchanged.

**D** decreases because of the object changes

**Ans: A**

Less dense fluid means less upthrust on the metal block. Weight of object remains unchanged. At equilibrium, weight of object is equal to sum of upthrust and tension in spring balance. Smaller upthrust means larger tension in the spring balance.

10 The figure below represents the various forces acting on a car moving towards the right. The driving force, *D* acts on the front wheels and the total resistive force is represented by the force, *R*. The weight *W* of the car is 12000 N and it acts on the centre of mass, *G* which is 90 cm above the ground.




Given that the values of $D$ and $R$ are both 7000 N, what are the values of the normal reaction forces at A and at B acting on the wheels?

| | normal reaction force at A/ N | normal reaction force at B/ N |
|---|---|---|
| **A** | 8100 | 3900 |
| **B** | 6000 | 6000 |
| **C** | 6150 | 5850 |
| **D** | 5850 | 6150 |

Ans: D
Let $N_A$ and $N_B$ be the nomal contact forces at A and B respectively.
Taking moment about B,
$W(1.5) = R(0.90) + N_A(2.0)$
$N_A = \frac{(12000)(1.5) - (7000)(0.90)}{2.0}$
$= 5850$ N
Since vertical net force is zero, $N_A + N_B = 12000$
$\therefore N_B = 12000 - 5850 = 6150$ N

**11** A speed boat has two identical motors. When both motors are working, the speed boat attained a maximum speed of 36.0 m s$^{-1}$. Given that the drag force on the speed boat is proportional to the square of the speed, what is the maximum speed of the boat when only one motor is working.

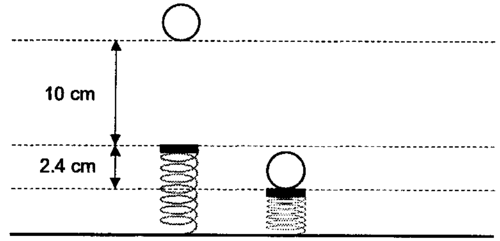
**A** 9.0 m s$^{-1}$ **B** 18.0 m s$^{-1}$ **C** 24.2 m s$^{-1}$ **D** 28.6 m s$^{-1}$

**Ans: D**
Using $P = F_{driving}v$
At max speed, $F_{driving} = \text{Drag Force} = kv^2$,
Thus $P = (kv^2)v = kv^3$
$\frac{P_1}{P_2} = \frac{v_1^3}{v_2^3}$
$\sqrt[3]{\frac{1}{2}} = \frac{v_1}{36}$, $v_1 = 28.6$ m s$^{-1}$





**12** A 20 g ball bearing is released from rest 10 cm above the top of an unstretched spring. It compresses the spring and comes to rest when the spring is compressed by 2.4 cm as shown in the figure below.




What is the spring constant of the spring?

**A** 2.0 N m$^{-1}$ **B** 8.6 N m$^{-1}$ **C** 68 N m$^{-1}$ **D** 84 N m$^{-1}$

**Ans: D**
Loss in GPE = gain in elastic potential energy
$mg(h + x) = \frac{1}{2}kx^2$
$(0.020)(9.81)(0.10 + 0.024) = \frac{1}{2}k(0.024)^2$
$k = 84$ N m$^{-1}$

**13** A stone of mass $m$ attached to a string is whirled in a vertical circle of radius $r$. At the top of the circle, the tension in the string is four times the stone's weight. At this point the stone's speed is

**A** $\sqrt{rg}$ **B** $\sqrt{3rg}$ **C** $\sqrt{4rg}$ **D** $\sqrt{5rg}$

Ans: D
At the top, net force = $mg + T$
$\frac{mv^2}{r} = mg + 4mg$
$v = \sqrt{5rg}$

**14** Satellites A and B of masses $m$ and $2m$ are placed in geostationary orbits of radii $r_A$ and $r_B$ about the Earth, where the radii are measured from the centre of the Earth to the respective satellites. Which of the following statements is correct?

**A** The radii $r_A$ and $r_B$ are the same.

**B** Both satellites have the same centripetal force.

**C** Both satellites have the same total energy.

**D** Both satellites have the same gravitational force.



BP~629

Ans: A

For geostationary orbit, $T$ = 24 hours

Gravitational force provides centripetal force, $\frac{GMm}{r^2} = mrw^2$

$w = \frac{2\pi}{T}$ so $\frac{GMm}{r^2} = mr(\frac{2\pi}{T})^2$

$\therefore T^2 \alpha\, r^3$ so orbital radii are the same for all geostationary satellites, independent of mass.

Gravitational force, centripetal force and total energy are dependent on mass.

**15** The escape speed of an oxygen molecule at the Earth's surface is $1.1 \times 10^4$ m s$^{-1}$. What is the escape speed at 4$R$ from the centre of the Earth, where $R$ is the radius of the Earth?

**A** $5.5 \times 10^3$ m s$^{-1}$ **B** $6.4 \times 10^3$ m s$^{-1}$ **C** $1.1 \times 10^4$ m s$^{-1}$ **D** $1.2 \times 10^4$ m s$^{-1}$

**Ans: A**

At the surface of Earth,

$$\frac{1}{2}mv_{esc}^{\ 2} = \frac{GMm}{R}$$

$$v_{esc} = 1.1\times10^4 = \sqrt{\frac{2GM}{R}}$$

At 4$R$ from Earth's centre,

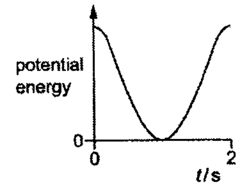
$$\frac{1}{2}mv_{esc}'^{2} = \frac{GMm}{4R}$$

$$v_{esc}' = \sqrt{\frac{2GM}{4R}} = 1.1\times10^4 \times \frac{1}{2} = 5.5\times10^3 \text{ m s}^{-1}$$



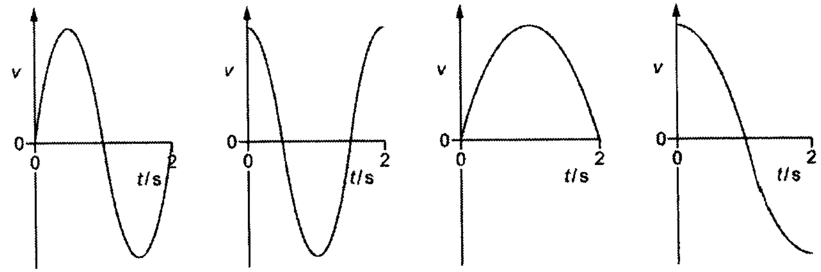


**16** A particle oscillates with simple harmonic motion. The graph shows the variation, with time $t$, of the potential energy of the particle from $t = 0$ to $t = 2$ s.




Which graph could represent the variation, with time $t$, of the velocity $v$ of the particle from $t = 0$ to $t = 2$ s?

A B C D




**Ans: C**

Observe that the given PE graph is drawn for half a period only as there are only 2 peaks seen.

$PE \propto \cos^2 \omega t$

$KE \propto \sin^2 \omega t$

$v \propto \sin \omega t \Rightarrow v = v_0 \sin \omega t$

Option C gives the $v$-$t$ graph is drawn for half a period only.

17 Two monoatomic ideal gases X and Y are mixed together in a sealed container. The molar mass of Y is twice that of X. At thermodynamic temperature $T$, the kinetic energy and root-mean-square speed of an atom of X are given by $E$ and $V$ respectively.

What is the kinetic energy and root-mean-square speed of an atom of Y at temperature $T$?

| | kinetic energy | root-mean-square speed |
|---|---|---|
| **A** | $E$ | $0.71V$ |
| **B** | $E$ | $V$ |
| **C** | $E$ | $1.4V$ |
| **D** | $2E$ | $0.71V$ |

**Ans: A**

In general, kinetic energy of monoatomic ideal gas $E = \frac{3}{2}kT$

When temperature is $T$, the KE of Y is $E$, independent of mass.

For X at temperature $T$,

$\frac{3}{2}kT = \frac{1}{2}mV^2$

For Y at temperature $T$,

$\frac{3}{2}k(T) = \frac{1}{2}(2m)V_y^2$

Comparing right hand side of equation

Thus, $V^2 = 2V_y^2$

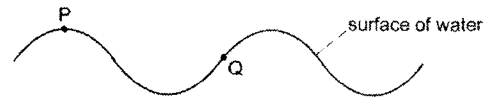
$V_y = \sqrt{\frac{1}{2}V^2} = 0.71V$



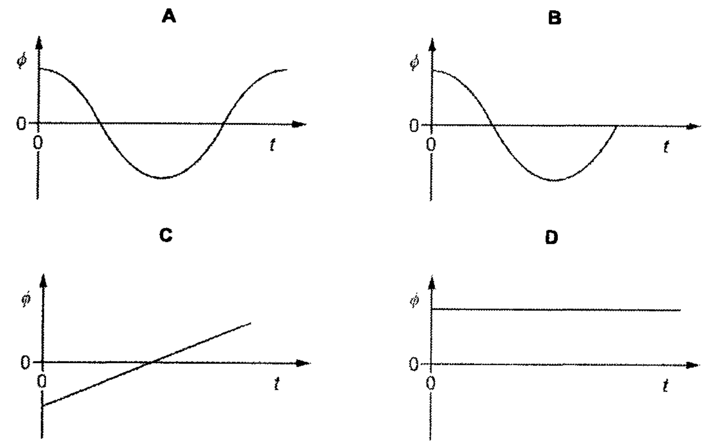


18 In a progressive water wave, two particles P and Q, on the surface of the water, are a fixed horizontal distance apart. P and Q oscillate vertically.

At time $t = 0$, the wave is as shown.




Which graph best represents the variation with time $t$ of the phase difference $\phi$ between the oscillation of the water particle P and the oscillation of the water particle Q?



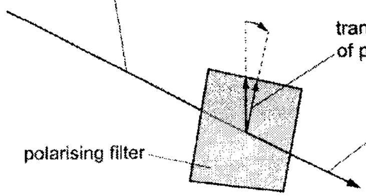

**Ans: D**

$\Delta\phi = \frac{\Delta x}{\lambda}2\pi$ is independent of $t$.



BP-631

**19** A beam of vertically polarised light is incident normally on a polarising filter. The filter can be rotated so that it is always in a plane perpendicular to the beam. The transmission axis of the filter is initially vertical.




The filter is first rotated clockwise by an angle of 30° so that the transmitted light waves have intensity $I_{30}$. The filter is then rotated clockwise by a further angle of 30°.

What is the new intensity of the transmitted light waves?

**A** $0.25I_{30}$ **B** $0.33I_{30}$ **C** $0.75I_{30}$ **D** $0.87I_{30}$

**Ans: B**

Let $I_0$ be the intensity of the light.

$I_{30} = I_0 \cos^2\theta = I_0 \cos^2 30° = 0.75I_0$

$I_{60} = I_0 \cos^2 60° = 0.25I_0$

Comparing, $I_{60} = 0.33I_{30}$





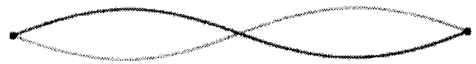
**20** Two waves of equal frequency and amplitude are travelling in opposite directions along a stretched string. When they meet, they form a stationary wave with three nodes and two antinodes. The frequency of both waves is doubled and a new stationary wave is formed.

How many antinodes are there in the new stationary wave?

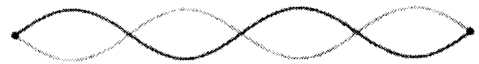
**A** 1 **B** 3 **C** 4 **D** 5

**Ans: C**

Standing wave with three nodes and two antinodes is as shown:



When frequency is doubled, the wavelength is halved. Standing wave is as shown:



Hence getting 4 antinodes.

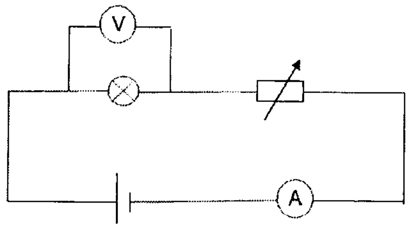
**21** A spherical water droplet with density 1000 kg $m^{-3}$ and diameter 1.20 μm is suspended in a uniform electric field. The electric field strength is 462 N $C^{-1}$ and is directed downwards. How many excess electrons does it have?

**A** $1.92 \times 10^{-17}$ **B** 120 **C** 192 **D** $1.20 \times 10^{11}$

Net force = 0
QE = mg
(nq)E = ρ (4/3) π $r^3$ g
n = (ρ (4/3) π $r^3$ g) / (qE)
= (1000 (4/3) π $(0.60\times10^{-6})^3$ g) / ($1.6\times10^{-19}$ × 462) = 120

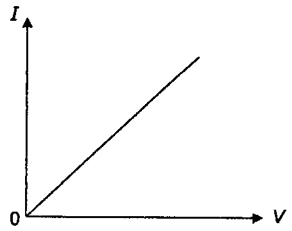
Ans: B

22 In the circuit shown below, the current can be varied by means of the rheostat.

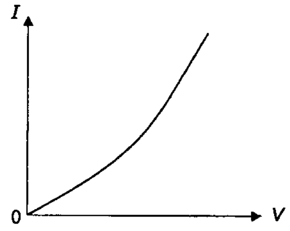



Which one of the following graphs best shows how the ammeter reading $I$ varies with the voltmeter reading $V$?

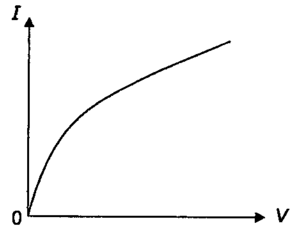
A



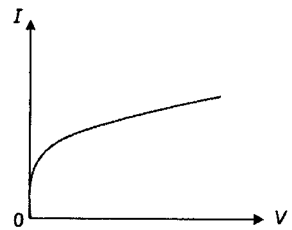

B




C




D



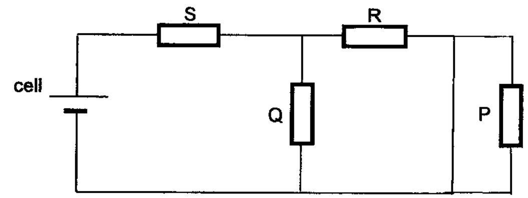

**Ans: C**

The resistance of the bulb increases with the temperature. Also, it is never zero (that's why D is wrong).





23 A cell is connected across four identical resistors P, Q, R and S. If the source is supplying a total power of 12.0 W, what is the power dissipated heat in resistor R?




**A** 2.0 W **B** 3.0 W **C** 4.0 W **D** 5.0 W

Ans: A

No current will flow through P.

Let the resistance of each resistor be $r$ and e.m.f. of source be $\varepsilon$.

Q and R are connected in parallel, so their effective resistance is $0.5r$

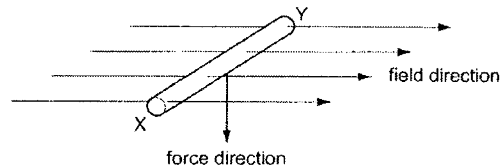
Total resistance of circuit is $1.5r$

Total power $P = \frac{\varepsilon^2}{1.5r} = 12.0$ W

By potential divider principle, voltage across R $= \frac{0.5r}{1.5r} \times \varepsilon = \frac{\varepsilon}{3}$

Power dissipated across resistor R, $P = \frac{(\frac{\varepsilon}{3})^2}{r} = \frac{\varepsilon^2}{9r} = 2.0$ W

24 A current-carrying conductor is placed at right angles to a uniform magnetic field of flux density 0.50 T. A 10 cm length of conductor lies within the field and experiences a force of 2.4 mN.




What is the direction of electron flow and rate of flow of electrons in the conductor?

| | direction of electron flow | rate of flow of electrons / s |
|---|---|---|
| **A** | X to Y | $4.8 \times 10^{-2}$ |
| **B** | Y to X | $4.8 \times 10^{-2}$ |
| **C** | X to Y | $3.0 \times 10^{17}$ |
| **D** | Y to X | $3.0 \times 10^{17}$ |

**Ans: D**



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Using FLHR, current is from X to Y. Direction of current flow is opposite to direction of electron flow.

$F_B = BIL$

$0.0024 = (0.50)(I)(0.10)$

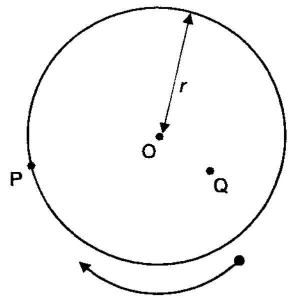
$I = 0.048$

$\frac{N}{t}e = 0.048$

$\frac{N}{t} = \frac{0.048}{1.60\times10^{-19}}$

$= 3.0\times10^{17}$

**25** An aluminium disc of radius *r* rotates about its centre at a constant speed. It is placed in a uniform magnetic field perpendicular to its surface. A steady electromotive force (e.m.f.) *E* is generated between the centre O and the rim at P.




What is the e.m.f. generated between points Q and P, where Q is a distance $\frac{r}{2}$ from the centre?

**A** zero **B** $\frac{E}{4}$ **C** $\frac{E}{2}$ **D** $\frac{3E}{4}$

**Ans: D**

E.m.f. between O and P is $E = B\pi r^2 f$

E.m.f. between O and Q is $E = B\pi\left(\frac{r}{2}\right)^2 f = \frac{E}{4}$

E.m.f. between Q and P is $E - \frac{E}{4} = \frac{3E}{4}$





**26** An alternating potential difference is connected across a pure resistor and the frequency *f* of the supply is varied, keeping the r.m.s voltage constant. The mean rate of production of heat in the resistor is

**A** proportional to *f*

**B** proportional to $f^{1/2}$

**C** inversely proportional to *f*

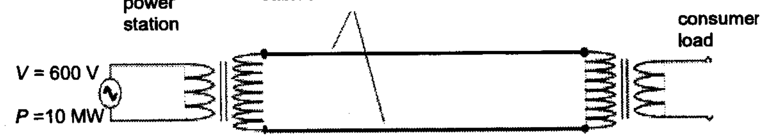
**D** independent of *f*

**Ans: D**

Mean rate of production of heat, $P = \frac{V_{rms}^2}{R}$

It is independent of *f*.

**27** A 10 MW nuclear power station produces electrical power at 600 V. It uses a step-up transformer with a turns ratio of 1: 200 to increase the voltage before transmitting it over long-distance cables of total resistance 15 Ω. At the consumer load, a second transformer steps down the voltage. You may assume the transfomers are ideal. What is the power lost as heat in the cables?




**A** 50 kW **B** 100 kW **C** 1.0 MW **D** 960 MW

Ans: B

At the step up transformer,

$\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$\frac{600}{V_s} = \frac{1}{200}$

$V_s = 1.2\times10^5$ V

For ideal transfomer,

power input = power output

$10\times10^6 = I_s(1.2\times10^5)$

$I_s = 83.3$ A

Power lost in cables,

$P = I_s^2 R$

$= (83.3)^2(15)$

$= 1.0\times10^5$ W

$= 100$ kW

**28** Calculate the wavelength of a particle of mass $1.88 \times 10^{-28}$ kg when traveling with a speed equal to 10% of the speed of light.

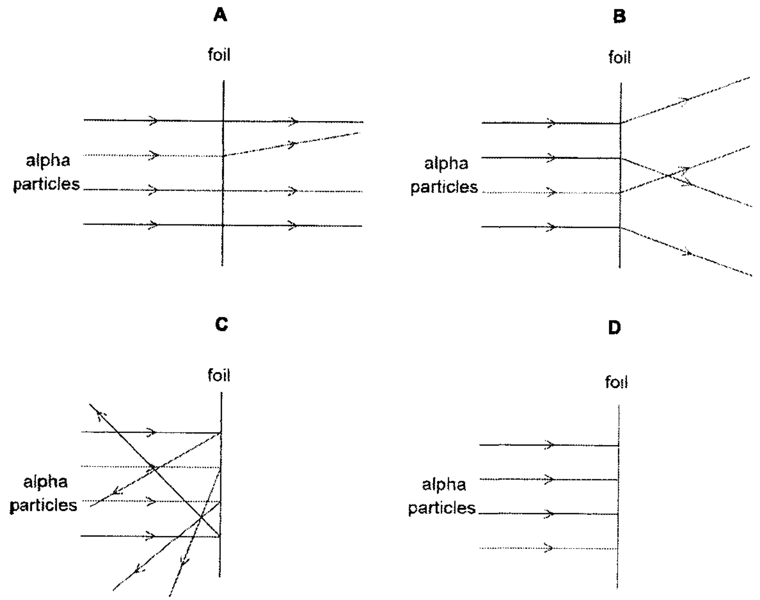
**A** $7.1 \times 10^{-9}$ m  **B** $4.4 \times 10^{-10}$ m  **C** $1.3 \times 10^{-12}$ m  **D** $1.2 \times 10^{-13}$ m

Ans: D
By de Broglie's theorem,

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{1.88 \times 10^{-28} \times 0.10 \times 3.0 \times 10^{8}} = 1.2 \times 10^{-13}\text{m}$$

**29** In the Rutherford alpha particle scattering experiment, alpha particles were directed at a thin gold foil. Which of the following shows how the majority of the alpha particles behave after reaching the foil?

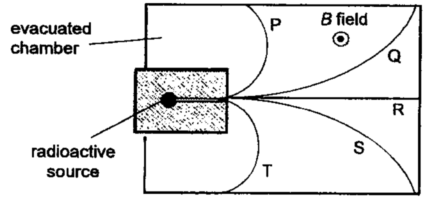



**Ans: A.** Most will go through undeflected





**30** A source undergoing alpha, beta and gamma decay is placed in an evacuated chamber with magnetic field directed out of the page. Which of the following represents the paths of the radiation particles emitted?




| | α-particle | β-particle | γ-ray |
|---|---|---|---|
| **A** | Q | T | R |
| **B** | S | P | R |
| **C** | T | R | S |
| **D** | S | T | Q |

**Ans: B**

α-particle: Positively charged, so will deflect downwards in the B-field (use FLHR).

β-particle: Negatively charged, so will deflect upwards in the B-field.

From $Bqv = mv^2/r$ → q/m is inversely proportional to r
(q/m) of α-particle < (q/m) of β-particle, so $r_\alpha > r_\beta$

γ-ray: Has no charge so it is not deflected

**End of Paper**



BP-635

VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME: **SOLUTION**

CLASS: ______ TUTOR NAME: ______

# PHYSICS 9749/02

Paper 2 Structured Questions

**16 September 2025**

**2 hours**

Candidates answer on the Question Paper.

No Additional Materials are required.

**READ THESE INSTRUCTIONS FIRST**

Write your name, class and tutor name 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.

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

| For Examiner's Use | |
|---|---|
| 1 | / 7 |
| 2 | / 8 |
| 3 | / 8 |
| 4 | / 9 |
| 5 | / 8 |
| 6 | / 12 |
| 7 | / 10 |
| 8 | / 19 |
| 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$^{-2}$ |



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**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 | $p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$ |
| 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 | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| 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 | $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ |





1 A golfer is practising his tee shot from a platform 7.0 m off the ground as shown in Fig. 1.1. The golf ball was launched at a speed of 50 m s$^{-1}$, 40° above the horizontal. Assume air resistance is negligible.

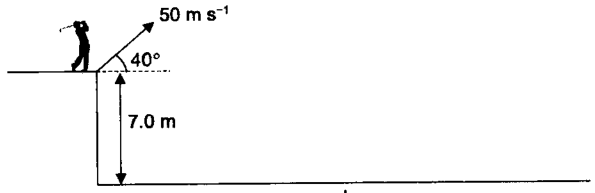


**Fig 1.1**

**(a)** Determine the maximum height above the ground attained by the ball.

Initial vertical velocity $u_y = 50 \sin 40^\circ = 32.139$ m s$^{-1}$ [1]

At the top of flight the vertical velocity $v_y = 0$ m s$^{-1}$

Can also solve via energy considerations

Using $v_y^2 = u_y^2 + 2as$, taking up as positive, we get

$0 = 32.139^2 + 2(-9.81)s$

$s = 52.647$ m [1]

Max height = 52.647+7.0 = 59.647 = 60 m [1]

maximum height = .......................................... m [3]

**(b)** Calculate the time of flight of the ball.

When ball touches the ground $s_y = -7.0$ m

Using $s_y = u_y t + \frac{1}{2}at^2$,

$-7 = 32.139t + \frac{1}{2}(-9.81)t^2$ [1]

$t = -0.211$ s (reject) or $t = 6.7639 = 6.8$ s [1]

time of flight = .......................................... s [2]

**(c)** A golf ball typically bounces a few times after a tee shot as shown in Fig. 1.2. The first time the ball touches the ground is indicated by A and the fourth time it touches the ground is indicated by B. Take the upward direction as positive.

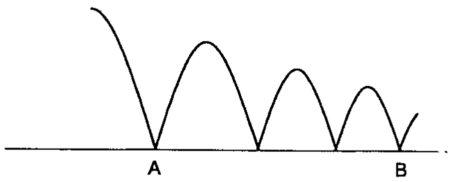


**Fig. 1.2**

Sketch, on Fig. 1.3, a graph to show the variation with time of the vertical velocity of the ball between from the instant it leaves A to the instant it reaches B.

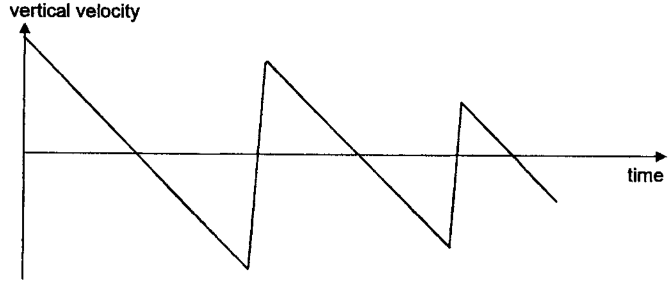


**Fig. 1.3**

3 parallel lines, same gradient, in between bounces; with vertical lines (or very slight slant) when ball is in contact with ground. [1]
Speed after rebound is lower than speed before rebound and area above and below graph are equal [1]

[2]

[Total: 7]





**2 (a)** Define Newton's second law.

The rate of change of momentum of a body is proportional to the resultant external force acting on it and is in the direction of the resultant force.

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

**(b)** A light rope is attached to a 120 kg box on the ground. The other end of the rope runs over a light frictionless pulley.

A 80 kg man climbs up the free-hanging rope. As the man climbs up the rope, he pulls on the rope hard enough to cause himself to accelerate upwards. The only point of contact between the rope and the man occurs at his hands.

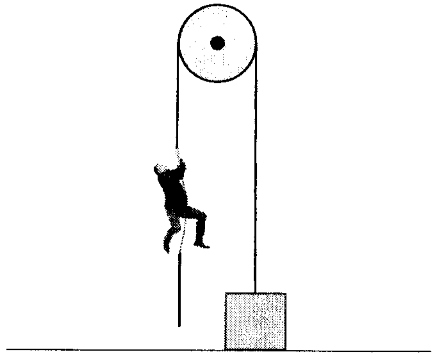

**Fig. 2.1**

**(i)** Draw, on the outline of the man in Fig. 2.2, the forces acting on the man as he climbs.

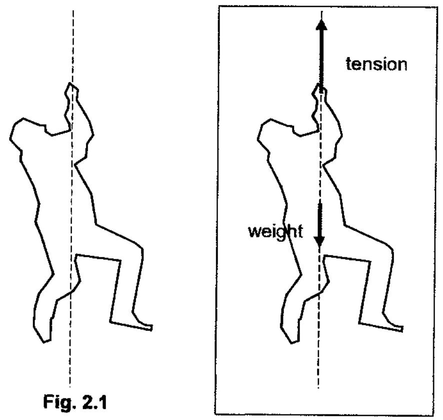


**Fig. 2.1**

[1]



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**(ii)** If the man climbs the rope with an acceleration of 8.0 m s$^{-2}$, determine the acceleration of the box.

Let $m$ = mass of man.
Let $M$ = mass of box.

Apply $F = ma$ to man:
$T - mg = m\,a_{man}$
$T = m\,(g + a_{man})$ ---(1)

Apply $F = ma$ to box:
$T - Mg = M\,a_{box}$ ---(2)

Sub. $T$ from (1) into (2):
$m\,(g + a_{man}) - Mg = M\,a_{box}$
$80\,(9.81 + 8.0) - 120 \times 9.81 = 120\,a_{box}$
$a_{box}$ = 2.1 m s$^{-2}$.

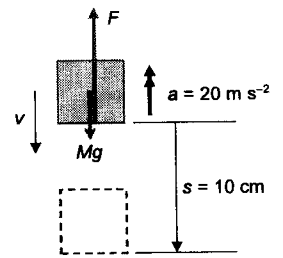
acceleration = .......................................... m s$^{-2}$ [2]

**(c)** The man releases the rope and the box falls. The box hits the ground with a speed of 2.0 m s$^{-1}$ and sinks into the ground over a vertical distance of 10 cm before coming to a stop.

Calculate the force exerted by the ground on the box during the deceleration.

$v^2 = u^2 + 2as$
$0 = 2.0^2 + 2a(0.10)$
$a = -20$ m s$^{-2}$

Apply $F = ma$ to box:
$F - Mg = Ma$
$F - 120 \times 9.81 = 120 \times 20$
$F$ = 3600 N




force = .......................................... N [3]

[Total: 8]





**3** A peg is fixed to the rim of a vertical turntable of radius $r$ rotating with a constant angular speed $\omega$, as shown in Fig. 3.1.

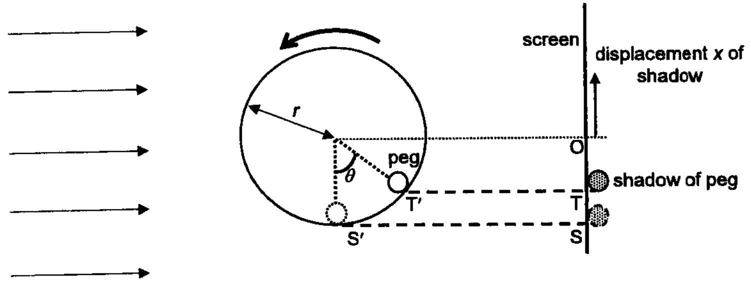



**Fig. 3.1**

A parallel beam of light is incident on the turntable such that the shadow of the peg is observed on the screen. Initially, the peg is at position S' and its shadow is at S. After time $t$, the peg moves through an angle of $\theta$ and it is positioned at T' while its shadow is at T.

The displacement $x$ of the shadow from O is shown in Fig. 3.1 where the upward direction is taken to be positive.

**(a) (i)** Express the angular displacement $\theta$ of the peg in terms of $\omega$ and $t$.

$\theta = \omega t$

[1]

**(ii)** Write down an expression for the displacement $x$ of the shadow on the screen in terms of $\omega$, $t$ and $r$.

$x = -r\cos\omega t$

[1]

**(iii)** Hence, prove that the shadow of the peg is moving in simple harmonic motion. Explain your working.

$x = -r\cos\omega t$

$v = \frac{dx}{dt} = r\omega\sin\omega t$

$a = \frac{dv}{dt} = r\omega^2\cos\omega t = -\omega^2(-r\cos\omega t) = -\omega^2 x$

which is the defining equation of a simple harmonic motion.

[2]

**(b)** The turntable has a radius of 20.0 cm and angular speed of 3.5 rad s$^{-1}$. For the motion of the shadow on the screen,

**(i)** calculate the acceleration of the shadow when the shadow is instantaneously at rest,

$a = -\omega^2 x$
$= -3.5^2(0.200)$
$= -2.45\ \text{m s}^{-2}$

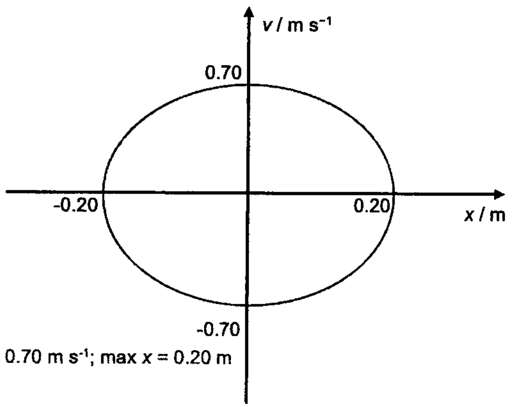
acceleration = .......................................... m s$^{-2}$ [1]

**(ii)** determine the velocity of the shadow as it passes through O,

$v_{max} = \omega x_0$
$= 3.5(0.200)$
$= 0.700\ \text{m s}^{-1}$

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

**(iii)** sketch the variation with displacement $x$ of the velocity $v$ of the shadow.




max $v$ (y intercept) = 0.70 m s$^{-1}$; max $x$ = 0.20 m

[2]

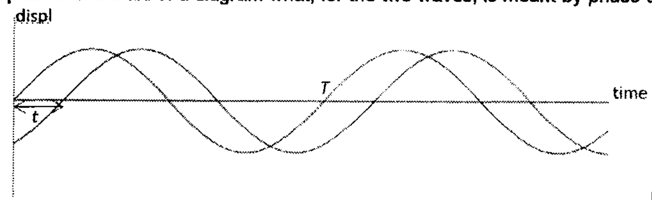
[Total: 8]





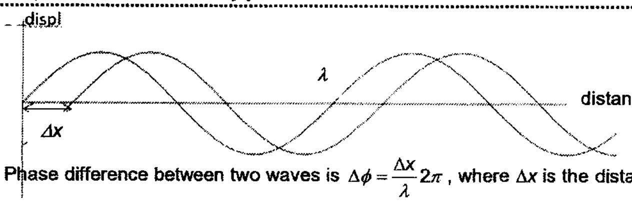
**4 (a)** Two waves are of the same frequency.

Explain with the aid of a diagram what, for the two waves, is meant by *phase difference*.




[1]

Phase difference between two waves is $\Delta\phi = \frac{\Delta t}{T}2\pi$, where $\Delta t$ is the time between two corresponding points, e.g. crest and crest or trough and trough on the two waves, and $T$ is the period of the wave. [1] [2]




Phase difference between two waves is $\Delta\phi = \frac{\Delta x}{\lambda}2\pi$, where $\Delta x$ is the distance between two corresponding points, e.g. crest and crest or trough and trough on the two waves, and $\lambda$ is the wavelength of the wave. [1] [1]

**(b)** Monochromatic light is incident normally on a double slit as shown in Fig. 4.1. Light passes through the two slits B and C and is incident on the screen.

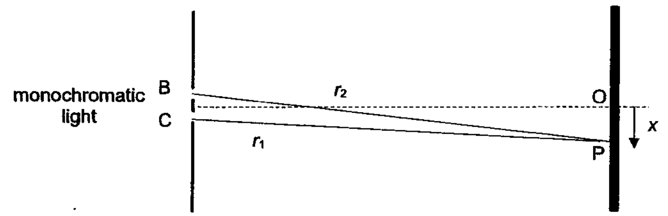



**Fig. 4.1**

The centre of the interference pattern formed on the screen is at O. The separation between the fringes is $y$.

$r_1$ and $r_2$ are two waves arriving at P.

**(i) 1.** Deduce the relationship between the phase difference of the two waves arriving at point P and the distance $x$ from point O.

$\frac{\Delta\phi}{2\pi} = \frac{x}{y}$

$\Delta\phi = \frac{2\pi x}{y}$

[1]



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2. The waves have a phase difference of 12.6 radians when they meet at point P. Distance OP on the screen is 5.2 mm. Calculate the separation $y$ between the fringes.

$\Delta\phi = \frac{2\pi x}{y}$

$y = \frac{2\pi x}{\Delta\phi}$

$= \frac{2\pi \times 5.2}{12.6}$ [1]

$y = 2.6$ mm [1]

$y$ = ............................................ m [2]

**(ii)** The light is adjusted so that the intensity of the light passing through slit B is reduced to a quarter that through slit C. The intensity of light from slit C alone at O is $I$. Deduce in terms of $I$, the intensity of the light at O due to the two slits.

Intensity $I = kA^2$ where $k$ is a constant.

The amplitude of light from B is then $\frac{A}{2}$ [1]

The total intensity at O is thus $k\left(\frac{A}{2}+A\right)^2 = 2.25kA^2 = 2.25I$ [1]

intensity = ............................................ [2]

**(iii)** Sketch, on Fig. 4.2, a graph to show the variation with distance $x$ from point O of the intensity of light observed on the screen. Label your answer to **(b)(ii)** on Fig. 4.2. Ignore the single slit diffraction envelope.

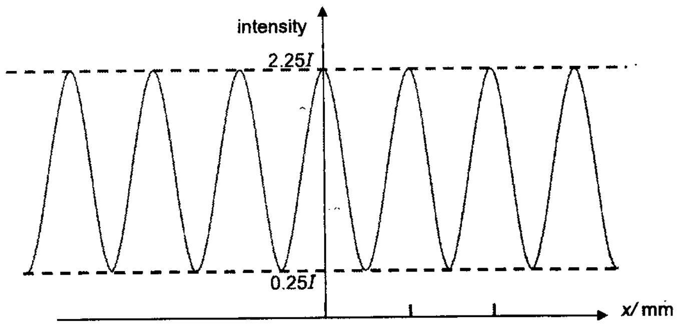



**Fig. 4.2**

[1m for max and min intensities at $2.25I$ and $0.25I$ respectively. 1m for constant fringe separation]

[2]

[Total: 9]





**5** Fig. 5.1 below shows an isolated, metal sphere in a region of vacuum that carries a negative electric charge.

E-field lines: directed radially towards centre of sphere, equally spaced around sphere, giving a symmetrical pattern. There should be no field lines inside sphere.

Equipotential lines: concentric circles perpendicular to field lines, spacing is further apart with distance from centre

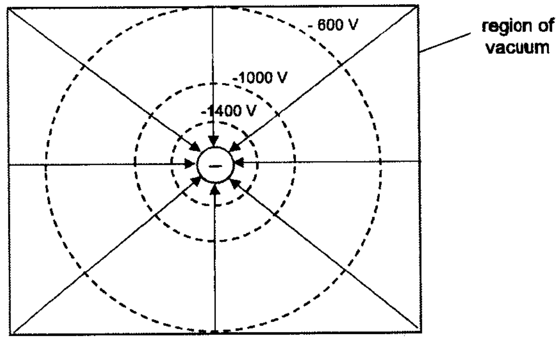


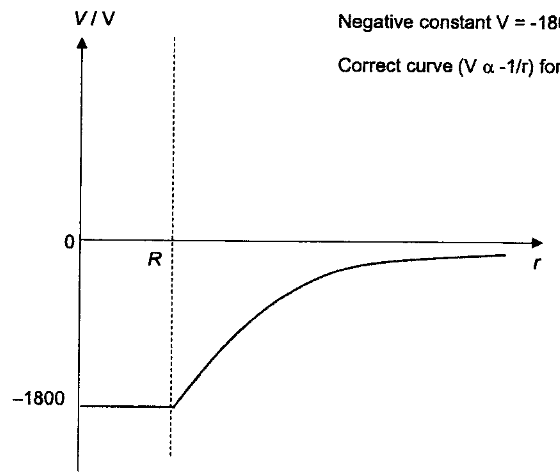

**Fig. 5.1 (not to scale)**

**(a)** The electric potential at the surface of the sphere is –1800 V. In the region of vacuum on Fig. 5.1, draw

**(i)** arrows to represent the electric field pattern outside the sphere [1]

**(ii)** dotted lines to represent three equipotential surfaces of –1400 V, –1000 V and –600 V outside the sphere. Label the potentials clearly. [1]

**(b)** On the axes given in Fig. 5.2, sketch a graph to show the variation with distance *r* from the centre of the sphere of the potential *V*. The dotted line is drawn at *r* = *R* where *R* is the radius of the sphere.




Negative constant V = -1800 V for r ≤ R [1]

Correct curve (V α -1/r) for r ≥ R [1]

**Fig. 5.2** [2]

**(c)** The sphere carries an electric charge of –9.0 nC and has a radius of 4.5 cm. An electron is initially at rest at the surface of the sphere.

**(i)** Describe the motion and path followed by the electron as it leaves the surface of the sphere.

Electron accelerates or speed increases [1]
as it moves radially outwards/perpendicular to surface of sphere (along a field line) [1]

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

**(ii)** Determine the speed of the electron when it reaches a point a distance 0.30 m from the centre of the sphere.

By conservation of energy,
Loss in EPE = gain in KE
q [ Q/(4πε₀ (0.045)) - Q/(4πε₀ (0.30)) ] = ½ m v² – 0 or q [ (-1800) - Q/(4πε (0.30)) ] = ½ m v² – 0

$(-1.6 \times 10^{-19}) \times (-9.0 \times 10^{-9}) \times [\, 1/(4\pi\varepsilon\,(0.045)) - 1/(4\pi\varepsilon\,(0.30))] = \tfrac{1}{2}(9.11 \times 10^{-31})\, v^2 - 0$ [1]
$v = 2.3 \times 10^{7}$ ms$^{-1}$ [1]

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

[Total: 8]





**6** **(a)** A length of copper wire of cross-sectional area $1.2 \times 10^{-6}$ m$^2$ carries a steady current of 2.5 A. The wire has a density of $8.9 \times 10^3$ kg m$^{-3}$. Assume the wire is made entirely of copper atoms, each contributing one free electron to conduction. The molar mass of copper is 63.5 g mol$^{-1}$.

Calculate the average drift velocity of the electrons in the wire.

$$\text{number density } n = \frac{\text{No. of atoms}}{\text{Volume}} = \frac{\text{mass}}{(\text{molar mass})(\text{Volume})} \times N_A = \frac{\text{density}}{\text{molar mass}} \times N_A = \frac{8.9 \times 10^3}{0.0635} \times 6.02 \times 10^{23} \quad [1]$$

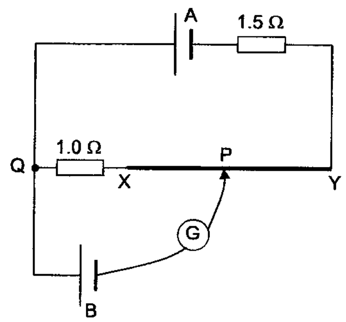
$$\text{Drift velocty } v = \frac{I}{neA} \quad [1]$$

$$= \frac{(2.5)(0.0635)}{(8.9 \times 10^3)(6.02 \times 10^{23})(1.6 \times 10^{-19})(1.2 \times 10^{-6})}$$

$$= 1.5 \times 10^{-4} \text{ m s}^{-1} \quad [1]$$

average drift velocity = .......................................... m s$^{-1}$ [3]

**(b)** In the circuit below, cell A has an e.m.f. 2.0 V and negligible internal resistance. Wire XY is 100.0 cm long with a resistance of 5.0 Ω.




**(i)** Distinguish between *electromotive force e.m.f.* and *potential difference p.d.* using energy considerations.

*E.m.f.* is the electrical energy converted from other forms of energy per unit charge delivered by the source. *P.d.* is the electrical energy converted to other forms of energy per unit charge when charges pass from one point to another. [1]



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**(ii)** Calculate the current flowing from Q to Y when the galvanometer registers a null deflection.

When the galvanometer registers a null deflection, no current in the lower circuit.

$I = \frac{2.0}{1.0+5.0+1.5}$ [1]

$= 0.27$ A [1]

current = .................................... A [2]

**(iii)** Cell B has an e.m.f. of 1.5 V. At balance point P,

**1.** show that resistance across X and P is 4.6 Ω,

At balance point, $V_{QP} = \varepsilon_B = 1.5$ V [1]

By the potential divider principle,

$V_{QP} = \frac{1.0+R_{XP}}{R_{total}} \times \varepsilon_A$

$1.5 = \frac{1.0+R_{XP}}{1.0+5.0+1.5} \times 2.0$ [1]

$R_{XP} = 4.625\ \Omega = 4.6\ \Omega$ (2 s.f.)

[2]

**2.** calculate the balance length XP.

$\frac{L_{XP}}{L_{XY}} = \frac{R_{XP}}{R_{XY}}$ [1]

$L_{XP} = \frac{4.625}{5.0} \times 1.0 = 0.925$ m [1]

length XP = .................................... m [2]

**(iv)** State and explain how the length XP in **(b)(iii)2.** will change if the internal resistance of cell A is not negligible.

From potential divider principle, the p.d. across the wire XY will now be smaller. [1]
Hence length XP will be longer. [1]
.................................................................................................[2]

[Total: 12]





**7** X-rays are produced when electrons accelerated by a large electrical potential difference impinge upon a metal target. The X-ray spectrum of copper shown in Fig. 7.1 is produced by bombarding a copper target with high-energy electrons. The spectrum consists of two main components: a continuous spectrum (bremsstrahlung) and a line spectrum (characteristic X-rays).

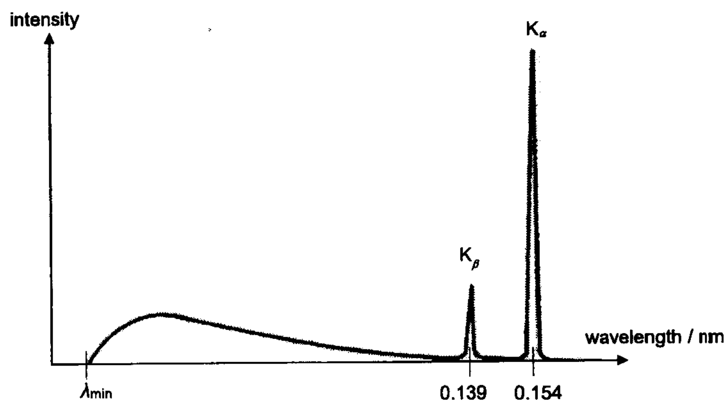



**Fig. 7.1**

**(a)** Explain the shape of:

**(i)** the continuous spectrum,

The bombarding electrons can lose any fraction of their initial kinetic energy, up to the maximum in a single interaction.[1] As a large number of electrons lose differing amounts of kinetic energies, X-ray photons of various wavelengths are emitted, resulting in a continuous X-ray spectrum represented by the solid line. [1] [2]

**(ii)** the sharp peaks in the spectrum.

When a fast bombarding electron knocks out an inner shell electron from a target atom, a vacancy is created. An electron in the outer shell de-excites to fill the vacancy, emitting an X-ray photon. [1] X-ray photons emitted in such de-excitations have energies that are equal to the energy differences between the energy levels of the two shells, hence producing X-rays of specific frequencies that appear as sharp peaks in the spectrum. [1] [2]

**(b) (i)** Calculate the energy of a $K_\alpha$ photon.

$K_\alpha$ photons have lower energy (and hence longer wavelength) than $K_\beta$ photons.

$\lambda = 0.154$ nm

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{0.154 \times 10^{-9}}$$

$E = 1.29 \times 10^{-15}$ J = 8070 eV

energy = .......................................... eV [1]

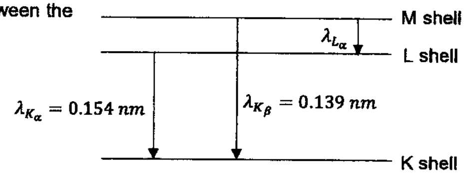
**(ii)** $L_\alpha$ photons are emitted when inner shell electrons de-excite from the M shell to the L shell. Calculate the wavelength of the $L_\alpha$ photon.

Comparing energies of photons emitted between the K, L and M shells, we see that:

$$\frac{hc}{\lambda_{K_\beta}} = \frac{hc}{\lambda_{K_\alpha}} + \frac{hc}{\lambda_{L_\alpha}}$$

$$\frac{1}{0.139} = \frac{1}{0.154} + \frac{1}{\lambda_{L_\alpha}}$$

$\lambda_{L\_\alpha} = 1.4$ nm




wavelength of $L_\alpha$ line = ........................ nm [2]

**(c)** The minimum wavelength $\lambda_{min}$ observed in the continuous spectrum depends on the accelerating voltage $V$ applied to the electrons. If the accelerating voltage is 30 kV, calculate $\lambda_{min}$.

Explain your working.

X-rays of wavelength $\lambda_{min}$ are emitted if all of the electron's KE is converted into a single photon:
Energy of photon = KE of bombarding electron

$$\frac{hc}{\lambda_{min}} = q\Delta V$$

$$\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{\lambda_{min}} = 1.6 \times 10^{-19} \times 30{,}000$$

$\lambda_{min} = 4.1 \times 10^{-11}$ = 0.041 nm

$\lambda_{min}$ = .......................................... nm [2]





**(d)** Explain why knowledge of the X-ray spectra of elements like copper can be used to identify the existence of these atoms in materials.

When such atoms within materials are excited (by electron bombardment), they will emit X-rays with energies equal to the difference between the higher and lower energy levels. As these energy levels are specific to each element, so the energies and wavelengths of characteristic peaks are also unique to each element. Thus, X-ray analysis can be performed on an unknown target to determine the elements present. [1]

[Total: 10]



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8 Wind energy is a renewable source of energy, harnessed from the kinetic energy of moving air. Since the late 1800s, windmills like the one shown in Fig. 8.1 have been used for milling grains.

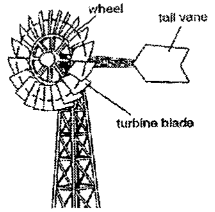


Fig. 8.1

Fig. 8.2 shows how the output power of these windmills varies with the overall diameter of the wheel for different wind speeds. The density of air is 1.3 kg $m^{-3}$.

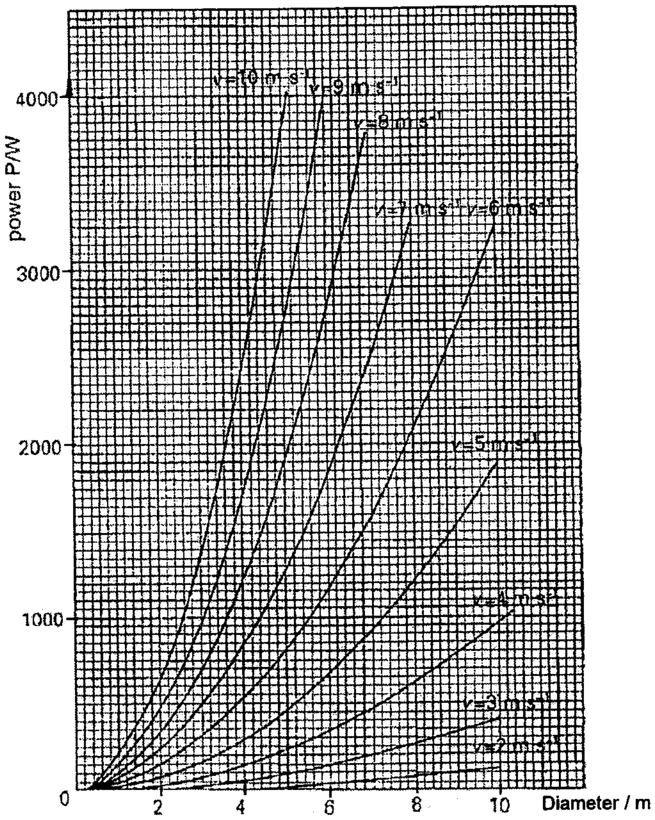


Fig. 8.2





Wind turbines are the modern evolutions of windmills. They have evolved from their multi-bladed predecessors to the modern 3-bladed version. Wind turbines have also increased in hub height and rotor diameter size in the last 45 years as shown in Fig. 8.3.

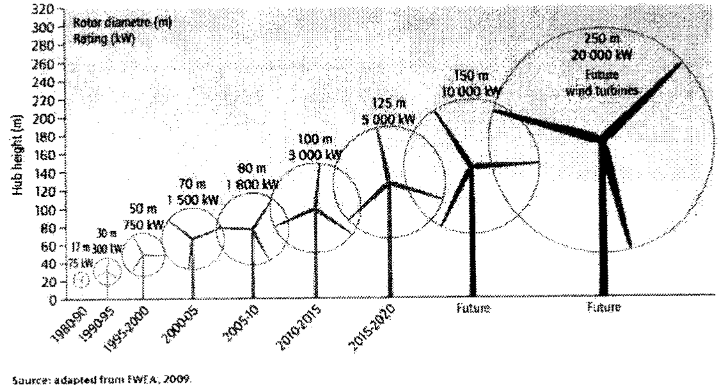


Fig. 8.3

Wind turbines have rotor hubs that can change the angle of attack of the rotor blades, which allows it to vary the amount of wind it catches. The nacelle houses a low-speed shaft that is connected to a gearbox which is in turn connected to a high-speed shaft before being connected to a generator. Parts of the wind turbine are shown in Fig. 8.4 below.

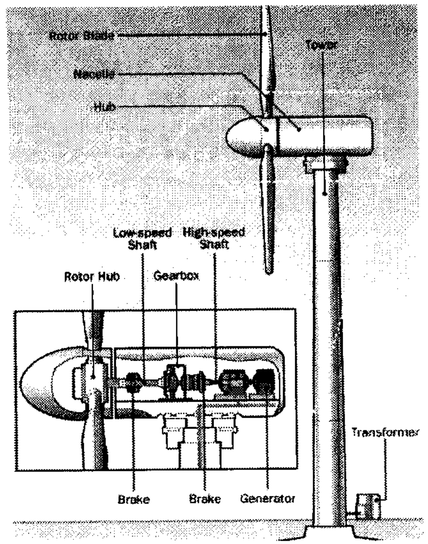


Fig. 8.4

The choice of location of wind turbines is an important factor to consider when building wind turbines. A table of average wind speed at various heights and locations are shown in Fig. 8.5.

| Height above ground / m | Wind speed / m $s^{-1}$ | |
|---|---|---|
| | On land | Offshore |
| 20 | 2.43 | 3.52 |
| 50 | 3.86 | 4.51 |
| 75 | 4.11 | 5.96 |
| 100 | 5.29 | 7.27 |
| 125 | 6.43 | 9.51 |

**Fig. 8.5**

**(a)** The windmill is most efficient when the wheel and turbine faces the oncoming wind head-on. With reference to Fig. 8.1, explain how the tail vane works.

When the wheel is not facing the wind head-on, **a force acts on the tail vane**, due to the wind, which **provides a moment**, turning the wheel to face the wind head-on. [1]

**(b)** By considering the kinetic energy possessed by a cylindrical volume of air, prove that the input power $P$ that can be harnessed by a windmill of cross-sectional area $A$ is given by

$$P=\frac{1}{2}\rho A v^3,$$

where $\rho$ is the density of air and $v$ is the velocity of air. Explain your working.

Consider a cylindrical volume of air of cross-sectional area $A$.
The total power $P$ possessed by this volume of air $V$ is the total KE of the air in this volume divided by the time it takes for an air particle of velocity $v$ to travel the length $L$ of cylinder.

$P=\frac{E}{t}=\frac{\frac{1}{2}(m)v^2}{t}$ [1]

$P=\frac{\frac{1}{2}(\rho V)v^2}{t}$ as $m=\rho V$

$P=\frac{\frac{1}{2}(\rho AL)v^2}{t}$ as the volume of a cylinder is $V=AL$ [1]

$P=\frac{1}{2}\rho A v^2\frac{(L)}{t}=\frac{1}{2}\rho A v^3$ (shown) as $v=\frac{(L)}{t}$ [1]

[3]





**(c)** **(i)** For a windmill of diameter 9.0 m, state the power produced by the windmill when the wind speed is 6.0 m $s^{-1}$.

Power = 2650 W

power = .................................... W [1]

**(ii)** Calculate the efficiency of a windmill of diameter 9.0 m when the wind speed is 6.0 m $s^{-1}$.

Total input power = $P=\frac{1}{2}\rho A v^3=0.5(1.3)\pi\left(\frac{9.0}{2}\right)^2(6)^3=8931.9$ W [1]

From Fig. 8.1, a 9.0 m diameter windmill, wind speed of 6.0 m $s^{-1}$, $P$ = 2650 W

Efficiency $=\frac{2650}{8931.9}\times100\%=29.67=30\%$ [1]

[2]

**(iii)** Suggest one reason for the loss in efficiency.

Any of the following: 1) Not all energy of air is captured, air still have KE to move past wheel 2) Resistive forces in the gears, 3) there are gaps in the wheel where air flows through

**(d)** **(i)** For the 3-bladed wind turbines built between 2010 to 2015, each typical rotor blade has an effective area of 120 $m^2$ that faces the wind head on. The dynamic wind pressure $p$ is given by

$$p=\frac{1}{2}\rho v^2$$

where $\rho$ is the density of air and $v$ is the speed of air.

1. State the hub height of a typical wind turbine built on land between 2010 to 2015.

hub height = 100 m (Fig. 8.3) m [1]

2. By considering the wind speed at the hub height in your answer in **(d)(i)1.**, estimate the moments acting on the wind turbine taken about the base of the tower when built on land.

mtd 1

wind speed at hub height on land = 5.29 m $s^{-1}$

Moment $=F\times$hub height $h$

$=p\times A\times h$

$=\frac{1}{2}\times\rho\times v^2\times A\times h$

$=0.5\times1.3\times5.29^2\times(120\times3)\times100$

$=6.54\times10^5$ N m

moment = .................................... N m [2]



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**3.** **Hence suggest why modern wind turbines typically have only 3 blades even though a multi-bladed windmill ensures that more wind energy is harnessed.**

Wind blowing on the rotors create a large moment about the base of the turbines. By having fewer blades, it reduces that chance of the wind turbines toppling over / falling / breaking. [1]

**(e)** **Explain how an increase in hub height and rotor diameter of wind turbines improves energy production.**

Taller towers place the hub height in regions with higher wind speeds (Fig 8.6) [1] Larger rotors sweep a greater area, which, using $P = \frac{1}{2}\rho A v^3$, increases the input power and thus allows the turbine to produce more energy. [1]

[2]

**(f)** **(i)** **Wind turbines typically spin at a rate of 10 to 20 rounds per minute. For a wind turbine with a rotor diameter of 250 m, calculate the speed at the tip of the blade if it were to spin at 30 rounds per minute.**

Frequency $f$ = 30 rounds per min = 30/60 = 0.50 Hz [1]

$v = r\omega = \frac{250}{2}(2\pi f) = 250\pi \times 0.50 = 393$ m s$^{-1}$ [1]

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

**(ii)** **Suggest why this rate of rotation is undesirable.**

At 30 rounds per minute, the tip of the blades exceeds the speed of sound. OR This causes structural damage to the blades or produces noise pollution or causes a sonic boom. [1]

**(g)** **Explain, using the laws of electromagnetic induction, why there is a need to convert the rate of rotation of the shaft to a high rate before connecting to the generator.**

Faraday's law states that the induced emf is proportional to the rate of change of magnetic flux linkage. The gearbox thus allows the generator to spin at higher rates, thus producing a larger emf. [1]

~~Since $P = V^2/R$, this means that more power is generated. [1]~~ [2]

[Total: 19]

**End of Paper**

VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME: **SOLUTION**

CLASS: 

TUTOR NAME: 

## PHYSICS 9749/03

Paper 3 Longer Structured Questions

**18 September 2025**

**2 hour**

Candidates answer on the Question Paper.

No Additional Materials are required.

**READ THESE INSTRUCTIONS FIRST**

Write your name, class and tutor name 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 | |
|---|---|
| 1 | / 7 |
| 2 | / 10 |
| 3 | / 8 |
| 4 | / 9 |
| 5 | / 7 |
| 6 | / 9 |
| 7 | / 10 |
| 8 | / 20 |
| 9 | / 20 |
| Total | / 83 |

This document consists of **23** 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$^{-2}$ |



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**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 | $p = \frac{1}{3}\frac{Nm}{V} < c^2 >$ |
| 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 | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| 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 | $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ |





1 Fig. 1.1 shows a 1000 N uniform thin rod being towed by a force $T$ and moving at constant horizontal velocity.

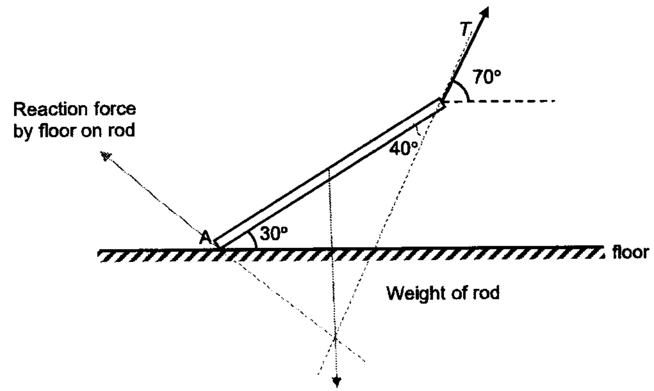


**Fig. 1.1**

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

A body is in equilibrium if the net force in any direction on the body is zero and the net torque about any axis on the body is zero.

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

**(b)** On Fig. 1.1, draw and label the **two** other forces acting on the rod. [2]

**(c)** Given angle $\theta$ is 70°, determine force $T$.

Let $L$ be the length of the rod.
Taking moment about A,
clockwise moment due to weight = $1000(\frac{L}{2}\cos 30°)$ [1]
anticlockwise moment due to force $T$ = $T(L\sin 40°)$ [1]
At equilibrium net moment is zero,
$1000(\frac{L}{2}\cos 30°) = T(L\sin 40°)$
$T = 670$ N [1]

force $T$ = .......................................... N [3]

[Total: 7]

**2** The International Space Station (ISS) orbits the Earth at a height of $4.1\times10^5$ m above the Earth's surface. The radius of the Earth is $6.37\times10^6$ m.

**(a)** Both the ISS and the astronauts inside it are in free fall. Explain why this makes the astronauts feel weightless

There is no contact force between the astronaut and the floor of the space station.

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

**(b) (i)** Calculate the value of the gravitational field strength $g$ at the height of the ISS above the Earth.

$g_0 = \frac{GM}{R^2}$, $g_0R^2 = GM$ [1]

$g = \frac{GM}{(R+h)^2}$, $g = \frac{g_0R^2}{(R+h)^2} = \frac{9.81\times(6.37\times10^6)^2}{(6.37\times10^6+4.1\times10^5)^2} = 8.66\ \text{N kg}^{-1}$ [1]

$g$ = .......... N kg$^{-1}$ [2]

**(ii)** State the value of the centripetal acceleration of ISS at this height.

$a_C$ = 8.66 m s$^{-2}$ [1]

**(iii)** The speed of the ISS in its orbit is 7.7 km s$^{-1}$. Show that the period of the ISS in its orbit is 92 minutes.

$vT = 2\pi(R+h)$ [1]

$7700T = 2\pi(6.37\times10^6 + 4.1\times10^5)$

$T = 92.2 = 92$ min [1]

[2]

**(iv)** The ISS is in a low Earth orbit. Suggest an advantage of this orbit as compared to higher orbits.

It requires less fuel to launch, and hence it is less expensive.

It is easier to access for maintenance and repair.

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

Higher resolution of images captured by ISS of features on the surface of the Earth.





**(c)** The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

7% of the energy of the sunlight incident on the cells is stored in the batteries. The total area of the cells facing the solar radiation is 2500 m$^2$. The intensity of solar radiation at the orbit of the ISS is 1.4 kW m$^{-2}$ outside of the Earth's shadow and zero inside it. The ISS passes through the Earth's shadow for 35 minutes during each orbit.

By reference to **(b)(iii)**, calculate the average power delivered to the batteries during one orbit.

Power stored in batteries
$= 0.07\times\text{Intensity}\times\text{Area} = 0.07\times1.4\times10^3\times2500 = 2.45\times10^5$ W [1]

Cells are in the Sun for 92 − 35 = 57 min [1]

Average power $= \frac{57}{92}\times2.45\times10^5 = 1.5\times10^5$ W [1]

average power = .......... W [3]

[Total: 10]

**3 (a)** Define the term *angular velocity*.

Angular velocity is the rate of change of angular displacement.

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

**(b)** A 10 kg baggage is left on a rotating baggage carousel at an airport as shown in Fig. 3.1.

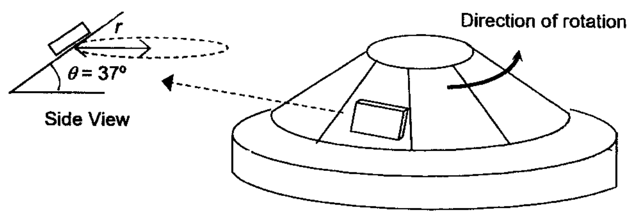


**Fig. 3.1**

The baggage stays at a fixed position on the slope of the carousel and rotates about in a circle of radius 10 m. The angle $\theta$ that the slanted surface makes with the horizontal is 37°. The frictional force acting on the baggage is 60 N. The baggage is moving in uniform circular motion.



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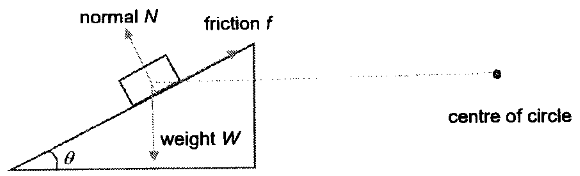
**(i)** Explain, using Newton's law(s) of motion, why the baggage will experience a net force towards the centre of the circle.

As the baggage is rotating at constant speed, according to Newton's First Law, a net force is needed to change the direction of motion. [1]

This change in direction of motion results in a rate of change of velocity (acceleration) directed towards the centre of rotation. By Newton's Second Law, the net force acts towards the centre of circle. [1]

[2]

**(ii)** Considering the forces acting on the baggage, show that the normal contact force is 78 N.




Consider forces perpendicular to slant surface,

$N = W\cos\theta$ [1]

$= (10 \times 9.81)\cos 37°$

$= 78.346$ [1]

$= 78$ N (to 2 s.f.)

[2]

**(iii)** Calculate the time required for the baggage to complete one full rotation.

Net force on baggage = $f\cos\theta - N\sin\theta$ [1]

$mr\omega^2 = f\cos\theta - N\sin\theta$

$mr\left(\frac{2\pi}{T}\right)^2 = f\cos\theta - N\sin\theta$ [1]

$T = 2\pi\sqrt{\frac{mr}{f\cos\theta - N\sin\theta}}$

$= 2\pi\sqrt{\frac{(10)(10)}{(60)\cos 37° - (78)\sin 37°}}$

$= 64$ s [1]

time = .................................... s [3]

[Total: 8]





**4 (a)** Explain what is meant by an *ideal gas*.

An ideal gas is a theoretical gas that obeys the equation of state $pV = nRT$ at all pressures $p$, volumes $V$ and thermodynamic temperatures $T$ for a fixed mass of gas. $R$ is the molar gas constant and $n$ is the amount of gas in moles. [1]

[1]

**(b)** Two vessels X and Y of volumes $10.0 \times 10^{-4}$ m$^3$ and $3.0 \times 10^{-4}$ m$^3$ are connected by a tube of negligible volume and kept at temperatures 200 K and 100 K respectively. Assume both vessels contain the same monatomic ideal gas.

Calculate the ratio of $\frac{\text{number of moles of gas in X}}{\text{number of moles of gas in Y}}$.

At steady state,
Pressure in X = Pressure in Y
Since $PV = nRT$ [1m for ideal gas equation and showing P are the same]

$\frac{PV_X}{PV_Y} = \frac{n_X RT_X}{n_Y RT_Y}$

$\frac{n_X}{n_Y} = \frac{V_X T_Y}{V_Y T_X}$

$\frac{n_X}{n_Y} = \frac{10.0 \times 10^{-4}}{3.0 \times 10^{-4}} \times \frac{100}{200} = \frac{5}{3} = 1.67$ [1]

ratio = .................................... [2]

**(c)** An ideal gas in a container with a movable piston is heated. At the same time, the volume is increased such that the temperature of the gas always remains constant. By considering the First Law of Thermodynamics, explain why the temperature of the gas remains constant even though it is heated.

The First Law of Thermodynamics states that the increase in internal energy $\Delta U$ is the sum of heat provided to the system $Q$ and the work done on the system $W$. [1]

If heat supplied Q is equal work done by gas ($W = -Q$), $\Delta U$ is zero. Since temperature of gas is proportional to internal energy, $T \propto U$, the temperature remains constant. [1] [2]

Also accept $\Delta T \propto \Delta U$

**(d)** Fig. 4.1 below shows how the pressure $p$ of the gas varies with its volume $V$ in part **(c)**. The volumes of the gas at initial and final states are $V_A$ and $V_B$ respectively. The pressures of the gas at initial and final are $p_A$ and $p_B$ respectively.

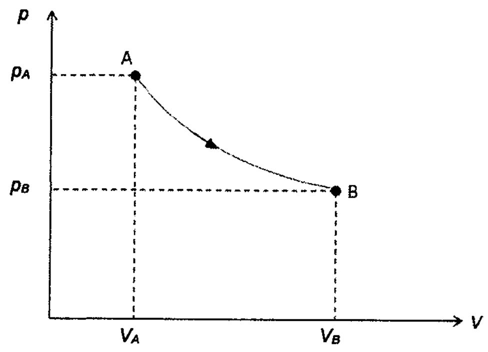



**Fig. 4.1**

The container in **(c)** is now insulated. The volume of the gas is increased to $V_B$ again.

**(i)** Use the First law of Thermodynamics to explain whether the final pressure is higher or lower than $p_B$.

The piston is insulated, thus it is an adiabatic expansion, $Q = 0$. [1]

Since it is an expansion, $W$ is negative. By First Law of Thermodynamics, $\Delta U = Q + W$, $W$ is negative, $Q = 0$, thus $\Delta U$ is negative. Hence temperature falls. [1]

By ideal gas equation $PV = nRT$ [1], for the same final volume but at a lower temperature, the pressure must be lower than $p_B$. [1]

[3]

**(ii)** Sketch, on Fig. 4.1, a graph to show the variation with volume of pressure of the gas as its volume increases in the insulated container. [1]

Pressure drops below $p_B$, with correct shape and direction of arrow clearly indicated.

[Total: 9]





**5** **(a)** The variation with time $t$ of the potential difference $V_1$ across a resistor is shown in Fig. 5.1.

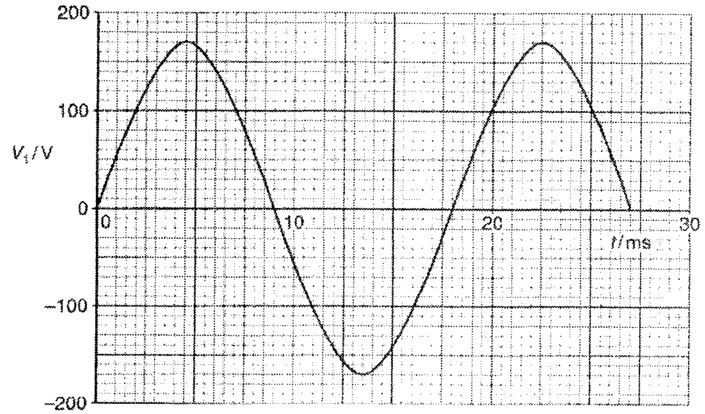



**Fig. 5.1**

The relation between $V_1$ and $t$ is given by

$$V_1 = V_0 \sin \omega t .$$

Use Fig. 5.1 to determine the root-mean-square voltage of $V_1$.

Mean-square voltage $= \langle V^2 \rangle = \frac{1}{2} V_0^2 = \frac{1}{2} \times 170^2 = 14450$

Root-mean-square voltage $= \sqrt{\langle V^2 \rangle} = \sqrt{14450} = 120$ V

root-mean-square voltage = ........................................ V [1]



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**(b)** The potential difference $V_1$ shown in Fig. 5.1 is connected to an ideal transformer, as shown in Fig. 5.2. The primary coil has 500 turns and the secondary coil has 20 turns. The secondary coil is connected to an open switch and a 15 Ω resistor.

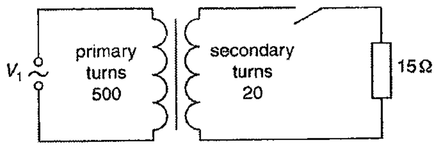


**Fig. 5.2**

The switch in the secondary circuit is now closed.

Determine

**(i)** the peak current in the 15 Ω resistor,

$\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Comparing peak voltages,

$\frac{V_s}{170} = \frac{20}{500}$

Peak secondary voltage = $V_s$ = 6.8 V

Peak current = $I = \frac{V}{R} = \frac{6.8}{15}$ = <u>0.45 A</u>

peak current = .......................................... A [2]

**(ii)** the mean power dissipated in the 15 Ω resistor.

r.m.s. secondary voltage = $V_{rms} = \frac{V_0}{\sqrt{(2)}} = \frac{6.8}{\sqrt{(2)}}$ = 4.8 V

Mean power dissipated in resistor = $\langle P \rangle = \left\langle \frac{V^2}{R} \right\rangle = \frac{V_{rms}^{\ 2}}{R} = \frac{4.8^2}{15}$ = <u>1.5 W</u>

mean power dissipated = .......................................... W [2]





**(c)** For a non-ideal transformer, suggest why thermal energy is generated in the soft iron core when the transformer is in use.

The magnetic flux generated by the primary coil changes with time continuously. [1] By Faraday's Law, this means that there is an induced e.m.f. within the soft iron core. This induced e.m.f. results in eddy currents in the core that produce heat due to joule heating. [1] ..........[2]

**[Total:7]**

6 A single-turn copper square frame of length $L$ is rotated with constant angular speed $\omega$ by an external torque in a constant magnetic field of flux density $B$. The frame rotates counter-clockwise about the axis of rotation as shown in Fig. 6.1.

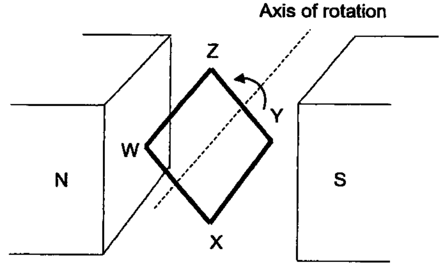


Fig. 6.1

Fig. 6.2 shows the side view of the coil when WX is at an angle $\theta$ above the horizontal.

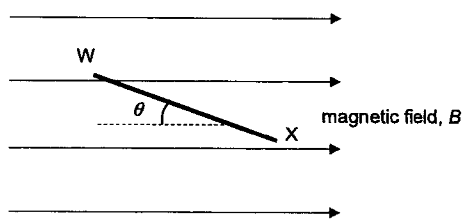


Fig. 6.2

**(a)** State the direction of the induced current in the frame.

In the direction WXYZW. [1] (accept WX) [1]

**(b)** Explain why an external torque is required to maintain the rotation of the frame at a constant angular speed.

The changing magnetic flux linkage produces an induced emf, and hence current due to Faraday's law. [1]

The force due to this induced current opposes the motion by Lenz' law. [1]

[2]





**(c) (i)** At the instant shown in Fig. 6.2, write down an expression for the flux linkage in the coil in terms of $B$, $\theta$ and $L$.

The flux through the frame is $\phi = (B\sin\theta)L^2$

[1]

**(ii)** Hence show that the magnitude of the induced e.m.f. in the coil at this instant is $|\varepsilon| = BL^2\omega\cos\theta$.

$\phi = BL^2 \sin\omega t$ [1]

By Faraday's Law,

$|\varepsilon| = \left|\frac{d\phi}{dt}\right| = BL^2\omega\cos\omega t = BL^2\omega\cos\theta$ [1]

[2]

**(d)** The resistance of the frame is 5.0 Ω and the length $L$ of the square frame is 0.20 m. The frame is rotated in the magnetic field of flux density 1.0 T at an angular frequency of 10 rad $s^{-1}$. Using your expression in **(c)(ii)**, calculate the average power dissipated in the frame.

$P = \frac{\varepsilon^2}{R}$

$P = \frac{B^2L^4\omega^2\cos^2\theta}{R} = \frac{B^2L^4\omega^2\cos^2\omega t}{R} = P_0\cos^2\omega t$ [1]

$<P> = \frac{P_0}{2}$ [1]

$<P> = \frac{B^2L^4\omega^2}{2R} = \frac{1.0^2 \times 0.20^4 \times 10^2}{2 \times 5.0} = 16$ mW [1]

average power dissipated = .................................... W [3]

[Total: 9]



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7 (a) (i) Describe the *photoelectric effect* in terms of energy.

When electromagnetic radiation is incident upon the surface of a material, if its frequency exceeds the threshold frequency of the material, then it is able to eject electrons from the surface. [1] Part of the energy of the incident photon is used to remove an electron and the remaining energy appears as the kinetic energy of the ejected electron. [1] ........................ [2]

(ii) Explain one way in which the photoelectric effect provides evidence for the particulate nature, and not wave nature, of electromagnetic radiation.

Experimental observations show that no electrons are emitted unless the frequency of the monochromatic incident light is greater than a minimum (threshold) value regardless of the light intensity. On the contrary, wave theory predicts that the photoelectric effect should occur for any frequency of the incident light, and that its intensity can be increased to cause photoelectron emission If the light frequency is too low. [1] This observation suggests that the energy of the incident light has a particulate nature in that each photon has a fixed amount of energy. If frequency of the incident photon is less than the threshold frequency of the target metal, energy of the incident photon is insufficient to overcome the work function of the metal. Increasing the intensity would only increase the number of photons arriving per unit time, but the energy of each photon remains insufficient to cause photoelectric effect. [1]

(b) The graph drawn in Fig. 7.1 shows how the maximum kinetic energy $E_k$ of a photoelectron from a particular material varies with the frequency $f$ of the electromagnetic radiation that causes the emission of photoelectrons.

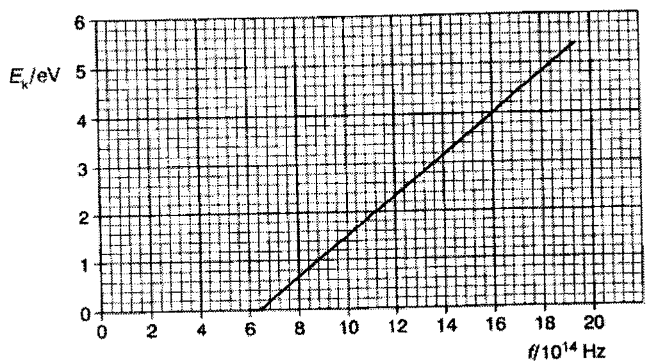


Fig. 7.1

(i) Use the graph to determine

1. the threshold frequency for this material,

At the threshold frequency, electrons are emitted with near-zero KE.
So, threshold frequency = $\underline{6.4 \times 10^{14}\text{ Hz}}$

threshold frequency = ........................ Hz [1]





2. the maximum kinetic energy of photoelectrons from this material when it is illuminated with electromagnetic radiation of frequency $18.0 \times 10^{14}$ Hz.

From graph, when f = $18.0 \times 10^{14}$ Hz,
Max KE = 4.8 eV [1]
= $4.8 \times 1.6 \times 10^{-19}$ J
= $7.68 \times 10^{-19}$ J [1]

OR
Using the photoelectric equation,
Photon energy = Work function + max. KE of electrons
$hf = \phi + KE_{max}$
At threshold frequency,
work function = photon energy
$\phi = hf_0$
$hf = hf_0 + KE_{max}$
$6.63\times10^{-34}\times18.0\times10^{14} = 6.63\times10^{-34}\times6.4\times10^{14} + KE_{max}$
$KE_{max} = \underline{7.7 \times 10^{-19}\text{ J}}$

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

(ii) Determine the minimum potential difference between the electrodes in the photoelectric experiment that is needed to reduce the photocurrent to zero.

Loss in KE = Gain in electric PE
$\Delta KE = q\Delta V$
$7.7\times10^{-19} = 1.6\times10^{-19}\times\Delta V$
$\Delta V = \underline{4.8\text{ V}}$

minimum potential difference = ........................ V [2]

(c) Electromagnetic waves have a wave nature as well as a particulate nature. This is known as the wave-particle duality. Describe an experiment in which particles exhibit wave nature.

Possible answers:
- When a beam of electrons passes through a thin film of graphite, concentric rings are seen on a fluorescent screen, revealing the occurrence of interference of electron matter waves.
- When a beam of electrons is reflected from a surface of atoms arranged in a regular pattern, constructive interference is observed in certain directions, showing that the electrons are behaving as waves as they interact with the atoms. [1]

[Total: 10]

## Section B

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

8 **(a)** State what is meant by the *binding energy* of a nucleus and how it is related to the mass defect.

Binding energy is the energy required to separate to infinity all the constituent nucleons in the nucleus.

It is (the energy equivalent of mass defect and) related to mass defect in the equation Binding energy = (mass defect) × $c^2$

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

**(b)** The binding energy graph on Fig. 8.1 shows the variation with nucleon number *A* of the binding energy per nucleon. Some common nuclides are plotted on the graph, with a few of them labelled as shown.

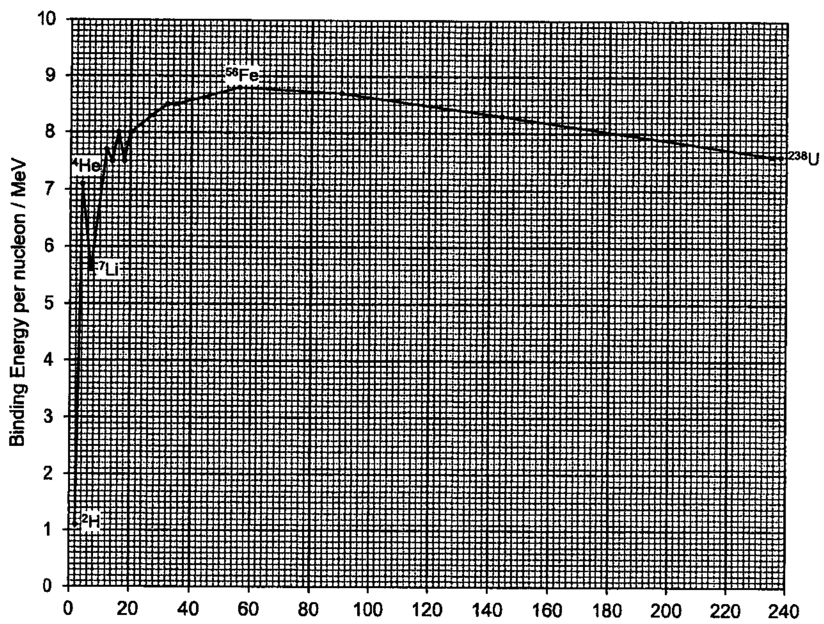


**Fig. 8.1**

**(i)** Explain why hydrogen-1 is not typically included in a binding energy graph.

H-1 is a proton which is a nucleon/constituent particle of the nucleus. Hence it has no binding energy or there is no meaning to binding energy of a proton. (Identify & reasoning) [1]

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





**(ii)** A nuclear power station uses uranium-235 as fuel in fission reactions. One possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + 2^{1}_{0}n.$$

**1.** Use data from Fig. 8.1 to show that energy released in the reaction is about 190 MeV.

Energy released
= total final BE – total initial BE
= (144 x 8.3) + (90 x 8.7) – (235 x 7.6) [1]
= 192.2 MeV [1]
= 190 MeV

[2]

**2.** Hence, calculate the energy released in the fission of 1 kg of uranium-235.

Energy released
= no of reactions x 190 MeV
= (1/235u) x 190 MeV [1]
= 4.9 x $10^{26}$ MeV [1]

energy released = .......................... MeV [2]

**(c)** A small sample of waste produced by the reactor in **(b)(ii)** contains strontium-90 ($^{90}_{38}Sr$). Strontium-90 is radioactive and undergoes beta decay into a daughter nuclide Yttrium-90 (Y).

**(i)** In beta decay, it was discovered that an antineutrino ($\bar{\nu}$) must be emitted in order that two conservation laws are not violated. State the two conservation laws.

Conservation of momentum and Conservation of energy/mass-energy.

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

**(ii)** Complete the beta decay equation, including all the decay products.

$^{90}_{38}Sr \rightarrow$ $^{90}_{39}Y + ^{0}_{-1}\beta + \bar{\nu}$ [1]

(Optional to include antineutrino)



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(iii) A radiation detector is placed close to the sample to measure the count rate for strontium-90 found in the sample. Fig. 8.2 below shows the variation with time $t$ of the count rate.

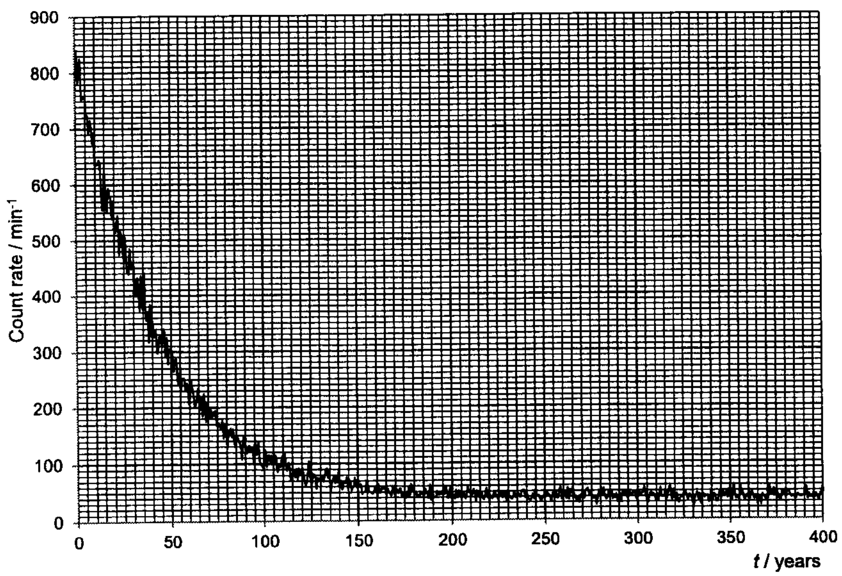


Fig. 8.2

1. State the feature of Fig. 8.2 that indicates the random nature of radioactive decay.

Fluctuations on the curve / curve is not smooth ..........[1]

2. Use Fig. 8.2 to determine the half-life of strontium-90.

Background count rate = 40 $min^{-1}$ considered backgrd in calculation of $t_{1/2}$ (allow 30-50) [1]

$t_{1/2,1}$
Actual count rate at t=0 = 840 – 40 = 800 $min^{-1}$
After 1 $t_{1/2}$, actual count rate = 400 $min^{-1}$
measured count rate = 400 + 40 = 440 $min^{-1}$
From graph, $t_{1/2}$ = 35 – 0 = 35 yrs method to determine $t_{1/2}$ [1]

$t_{1/2,2}$
Actual count rate at t=50 yr = 300 – 40 = 260 $min^{-1}$
After 1 $t_{1/2}$, actual count rate = 130 $min^{-1}$
measured count rate = 130 +40 = 170 $min^{-1}$
From graph, $t_{1/2}$ = 75 – 50 = 25 yrs

Average $t_{1/2}$ = (35 + 25)/2 = 30 years
determined half-life at least twice and find <$t_{1/2}$>, range within 26 – 32 yrs [1]

half-life = .......................... years [4]





3. Hence, determine the probability that a nuclide of strontium-90 will undergo decay in 1 year.

Probability of decay in 1 yr = Probability of decay per unit time × 1 yr
= λ × 1 yr
= (ln 2 / $t_{1/2}$) × 1 yr
= (ln 2) / (30 yr) × 1 yr [1]
= 0.023 or 2.3%

probability = ..........................[1]

(d) Nuclear fusion occurs in the core of stars composed of ionised gas. A possible fusion reaction is

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e\ .$$

Each ${}^{1}_{1}H$ nuclide can be considered to be a sphere of radius 0.0010 pm. Fusion occurs when the two nuclides are able to overcome the force of repulsion between them and collide.

(i) Show that the minimum total kinetic energy required of the two ${}^{1}_{1}H$ nuclides for fusion to occur is $1.2 \times 10^{-13}$ J.

By cons. of energy,
Total initial KE = Total final EPE
= (+e)(+e) / ($4\pi\varepsilon_o$ d)
= $(1.6 \times 10^{-19})^2$ / ($4\pi\varepsilon_o$ x 2 x 0.0010 x $10^{-12}$) [1]
= $1.15 \times 10^{-13}$ J [1]
= $1.2 \times 10^{-13}$ J

[2]

(ii) If the ionised gas is assumed to be ideal, determine the temperature of the gas required for fusion to occur.

Average KE of nuclide = 3/2 kT
($1.2 \times 10^{-13}$) / 2 = 3/2 kT [1]
T = $2.9 \times 10^{9}$ K [1] (if used intermediate K, T = $2.8 \times 10^{9}$ K)

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

(iii) The temperature of the core of the Sun is known to be about $1.5 \times 10^{7}$ K. With reference to **(d)(i)** and **(d)(ii)**, comment on the actual kinetic energy of the nuclei in the Sun's core.

Actual temperature of Sun is much cooler than temp calculated in (ii)
So Sun's core must involve nuclei with actual KE far above the average KE calculated in (i) (since fusion must occur). [1] ..........[1]

[Total: 20]

**9 (a)** State what is meant by a *field of force.*

A field of force (or force field) is a region of space in which a particle experiences a force due to a physical property that it possesses. [1]

**(b)** Two parallel metal plates are separated by a distance of 6.0 cm in a vacuum, as shown in Fig. 9.1. The plates have length 16 cm and potential difference of 2400 V.

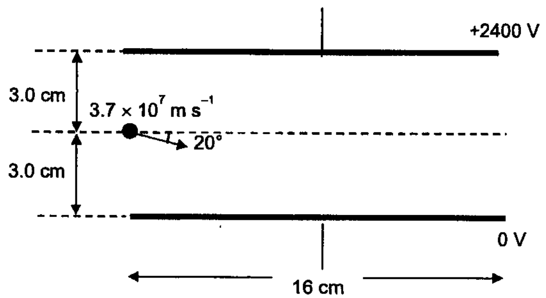


**Fig. 9.1**

An electron with speed $3.7 \times 10^7$ m s$^{-1}$ enters the region between the plates. The initial direction of the electron is 20° below the midline between the plates.

**(i)** Calculate the acceleration of the electron and state its direction.

$F = qE = q\dfrac{\Delta V}{d}$

$= (1.60 \times 10^{-19})\dfrac{2400}{0.06}$

$= 6.40 \times 10^{-15}$ [1]

$a = \dfrac{F}{m}$

$= \dfrac{6.40 \times 10^{-15}}{9.11 \times 10^{-31}}$

$= 7.0252 \times 10^{15}$ upwards [2]

acceleration = .......................................... m s$^{-2}$

direction = ..............................................

[3]





**(ii)** Calculate the time taken for the electron to reach the other end of the plate.

$t = \dfrac{s_x}{u_x}$

$= \dfrac{0.16}{3.7 \times 10^7 \cos 20°}$

$= 4.6018 \times 10^{-9}$ s

$= 4.60 \times 10^{-9}$ s

time = .......................................... s [1]

**(iii)** Use your answers in **(b)(i)** and **(ii)** to determine whether the electron will collide with any metal plate as it passes through the region between the plates.

Considering whether electron collides with top plate:

$s_y = u_y t + \frac{1}{2}a_y t^2$

$= (3.7 \times 10^7 \sin 20°)(4.6018 \times 10^{-9}) + \frac{1}{2}(-7.0252 \times 10^{15})(4.6018 \times 10^{-9})^2$

$= -0.0162$ m [1] which is less than $-0.030$ m

Considering whether electron collides with bottom plate:
when $v_y = 0$:

$0 = u_y + a_y t$

$t = \dfrac{-(3.7 \times 10^7 \sin 20°)}{-7.0252 \times 10^{15}}$

$= 1.8013 \times 10^{-9}$ [1]

$s_y = u_y t + \frac{1}{2}a_y t^2$

$= (3.7 \times 10^7 \sin 20°)(1.8013 \times 10^{-9}) + \frac{1}{2}(-7.0252 \times 10^{15})(1.8013 \times 10^{-9})^2$

$= 0.0114$ m [1] which is less than 0.030 m

Therefore, the electron will not collide with neither the top nor bottom plate. [1]

[3]

**(iv)** Hence, sketch, on Fig. 9.1, the path of the electron. [1]

**(iv)** Describe the path of the electron in the field.

For an electron in a uniform electric field, it is a parabolic path. [1]



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**(c)** Another electron of the same speed now enters a region of uniform magnetic field of flux density 4.5 mT as shown in Fig. 9.2.

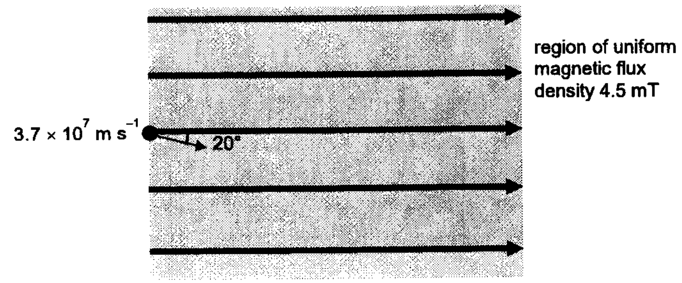



**Fig. 9.2**

The initial direction of the electron is at an angle of 20° to the direction of magnetic field.

**(i)** When the electron enters the magnetic field, the component of its velocity $v_\perp$ normal to the direction of the magnetic field causes the electron to begin to follow a circular path. Explain why.

When the velocity of the electron is perpendicular to the magnetic field, it gives rise to a magnetic force which is always perpendicular to its velocity [1]. This magnetic force on the moving charge provides a centripetal force [1] for it to move in a uniform circular motion. [2]

**(ii)** Calculate the radius of this circular path.

By Newton's Second Law, $\sum F = ma_c$

$$Bqv_\perp = \frac{mv_\perp^2}{r} \quad [1]$$

$$(4.5\times10^{-3})(1.60\times10^{-19}) = \frac{(9.11\times10^{-31})(3.7\times10^{7}\sin 20°)}{r}$$

$$r = 0.0160 \text{ m} \quad [1]$$

Correct component of velocity [1]

radius = .......................................... m [3]

**(iii)** State the magnitude of the force on the electron due to the component of its velocity along the direction of the field.

Zero. [1]

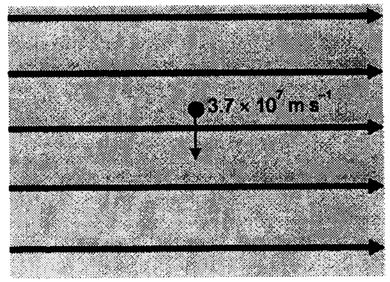
**(iv)** Use your answers in **(c)(ii)** and **(iii)** to describe the resultant path of the electron in the field.

For an electron moving at an angle to a uniform magnetic field, it is a helical path. [1]





**(d)** Another electron of the same speed is projected downwards in the magnetic field as shown in Fig. 9.3. A uniform electric field is now switched on in the same region as the magnetic field. The magnitude of the electric field is adjusted so that the electron moves undeviated through the two fields.




Magnetic force is into the page, so electric force on the electron must be out of the page. Therefore electric field must be into the page. Draw crosses [1]

**Fig. 9.3**

**(i)** On Fig. 9.3, draw the direction of the electric field. [1]

**(ii)** Determine the magnitude $E$ of the electric field strength.

By Newton's First Law, $\sum F = 0$

$$Bqv = qE \quad [1]$$

$$(4.5\times10^{-3})(3.7\times10^{7}) = E$$

$$E = 1.67\times10^{5} \text{ V/m} \quad [1]$$

$E$ = .......................................... V m$^{-1}$ [2]

**[Total: 20]**