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MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

CENTRE NUMBER S

INDEX NUMBER

* 3 9 8 6 1 8 7 9 4 2 *

PHYSICS

9749/02

Paper 2 Structured Questions

October/November 2023

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and 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 an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE ON ANY BARCODES.

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.

PIVOT
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This document consists of **22** printed pages and **2** blank pages.

Singapore Examinations and Assessment Board

Cambridge Assessment International Education

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Data

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

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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	$\phi = -\frac{Gm}{r}$
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 gas 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	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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

1 A block is attached to a uniform beam using a light string. The beam is horizontal and in equilibrium on a pivot, as shown in Fig. 1.1.

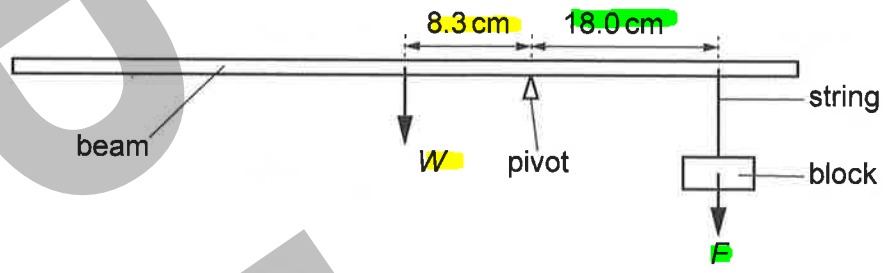


Fig. 1.1 (not to scale)

The weight W of the beam acts at a distance of 8.3 cm from the pivot.
The weight F of the block acts at a distance of 18.0 cm from the pivot.

The block is then submerged in water of density 1.0×10^3 kg m^{-3}. The pivot and the block are both moved so that the beam is once more in equilibrium, as shown in Fig. 1.2.

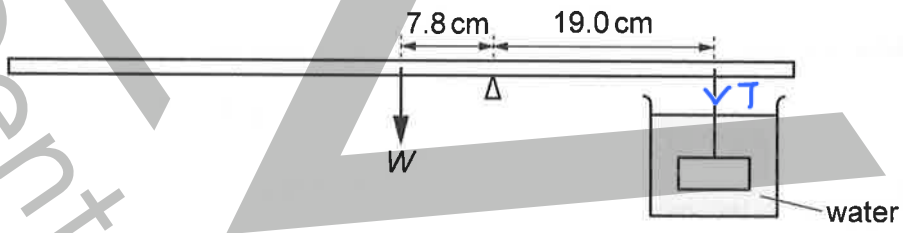


Fig. 1.2 (not to scale)

The weight W of the beam acts at a distance of 7.8 cm from the pivot.
The string supporting the block is at a distance of 19.0 cm from the pivot.

(a) Explain the origin of the force of upthrust acting on the block when it is submerged in the water.

It arises due to the pressure difference of the water between the top (smaller pressure) and bottom (larger pressure) of the block, resulting in a net upward force, which is the upthrust.

[2]

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(b) The block has a volume of $27.8\,cm^3$.

(i) Show that the upthrust acting on the block is 0.27 N. Explain your working.

$U = \rho_w V_b g = (1000)(27.8 \times 10^{-6})(9.81)$

$= 0.2727$

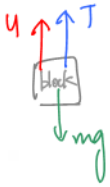
$= 0.27\,N$ # (shown)

[2]

(ii) Determine *F*.

① By P.O.M : $W(8.3) = F(18)$ $\therefore$ $W = \frac{18F}{8.3}$

② By POM : $W(7.8) = T(19)$



③ Since block is in equilibrium, $U + T = mg = F$

$\therefore T = F - U = F - 0.2727$

Sub ① & ③ into ②

$\therefore \left(\frac{18F}{8.3}\right)(7.8) = (F - 0.2727)(19)$

$16.91566F = 19F - 5.1813$

$\therefore F = 2.4858$

$= 2.49\,N$ # (3sf)

$F =$ 2.49 N [3]

[Total: 7]

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2 An object of mass 0.55 kg is launched with velocity v from horizontal ground. It is launched at an angle of 42° above the horizontal. It follows the path shown in Fig. 2.1.

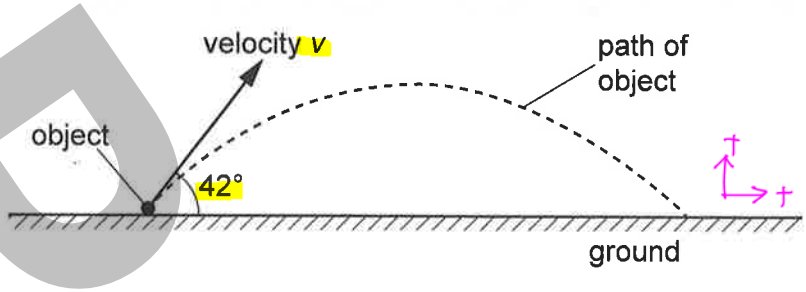


Fig. 2.1 (not to scale)

When moving along the path, the minimum kinetic energy of the object is 65 J. Assume that air resistance is negligible.

(a) Show that the vertical component of v is 14 m s^{-1}.

① KE_{min} is at top of motion

② $KE_{min} = \frac{1}{2}m(v\cos 42)^2 = \frac{1}{2}(0.55)(\cos 42)^2(v^2) = 65$

$\therefore v = 20.6879$

③ Hence, $v_y = v\sin 42 = 20.6879\sin 42 = 13.84 = 14 \text{ m/s}$ (shown)

[3]

(b) Determine the horizontal displacement of the object from its launch position to the point where it lands.

① Using vert. components:

$v = u + at$

$\therefore -13.84 = 13.84 + (-9.81)(t)$

$\therefore t = 2.82168$ (time for entire journey)

② Using horz. components:

$s = ut + \frac{1}{2}at^2$

$= (20.6879\cos 42)(2.8216) + 0$

$= 43.37397$

$= 43.4 \text{ m}$ (3sf)

displacement = ... 43.4 ..... m [3]

(c) In practice, air resistance is not negligible.

Suggest, with a reason, how the time taken for the object to reach its maximum height compares with the time taken for the object to return to the ground from its maximum height.

Time to reach maximum height is shorter than time to return to ground from maximum height, because net force when ball is travelling upwards is larger than that when the ball is travelling downwards at any given speed. [1]

[Total: 7]

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3 (a) A satellite of mass 6800 kg is in geostationary orbit at a height of 36 000 km above the Earth's surface.

(i) Calculate the magnitude of the force keeping the satellite in orbit.

The radius of the Earth is 6400 km and the mass of the Earth is 6.0×10^{24} kg.

$$|F_G| = \frac{GMm}{r^2} = \frac{(6.67\times10^{-11})(6\times10^{24})(6800)}{[(36+6.4)\times10^6]^2} = 1.5137\times10^3\ N = 1.51\ kN\ (3sf)$$

force = 1.51K N [2]

(ii) Explain whether all satellites in geostationary orbit must have a mass of 6800 kg.

Use relevant equations to support your answer.

$T^2 \propto R^3$

No. From Kepler's 3rd law, the orbital period squared is directly proportional to the orbital radius cube and hence its independent of the satellites' mass. [1]

(b) An ion of chlorine has a charge of −1e, where e is the elementary charge. The ion is moving in a vacuum with a momentum of 3.4×10^{-23} Ns. It enters a uniform magnetic field of magnetic flux density 1.8 mT at 90° to the field lines.

(i) Calculate the radius of the circular path followed by the ion.

$F_B = F_C$

$Bqv = \frac{mv^2}{r}$

$\therefore r = \frac{mv}{Bq} = \frac{p}{Bq} = \frac{(3.4\times10^{-23})}{(1.8\times10^{-3})(1.6\times10^{-19})} = 0.11805 = 0.118\ m\ (3sf)$

radius = 0.118 m [2]

(ii) Explain whether all ions with a charge of −1e must have the same radius of circular path in this magnetic field.

No. Because radius is directly proportional to the momentum. [1]

[Total: 6]

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4 **(a)** A signal generator, loudspeaker, microphone, oscilloscope and metal plate are used to investigate stationary waves, as shown in Fig. 4.1.

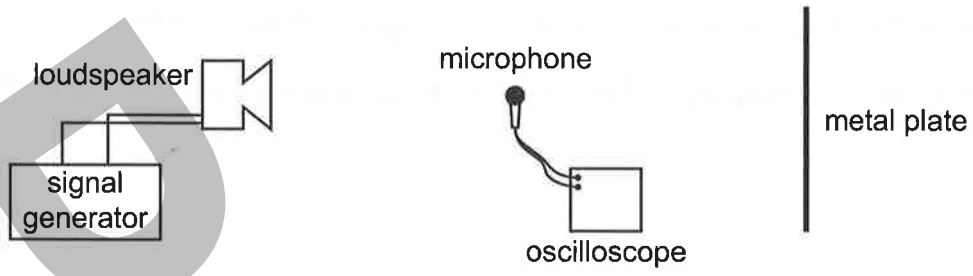


Fig. 4.1

The loudspeaker emits sound of a single frequency. The microphone is connected to the oscilloscope.

(i) Describe how a stationary wave is formed between the loudspeaker and the metal plate.

Incident sound waves gets reflected from the metal plate. The incident and reflected sound waves have the same frequency, wavelength, speed, amplitudes and period but are in anti-phase. They meet and superpose to form a stationary wave due to destructive interference, with displacement nodes and anti-nodes between the loudspeaker and the plate. [2]

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(ii) The waveform obtained on the oscilloscope is shown in Fig. 4.2.

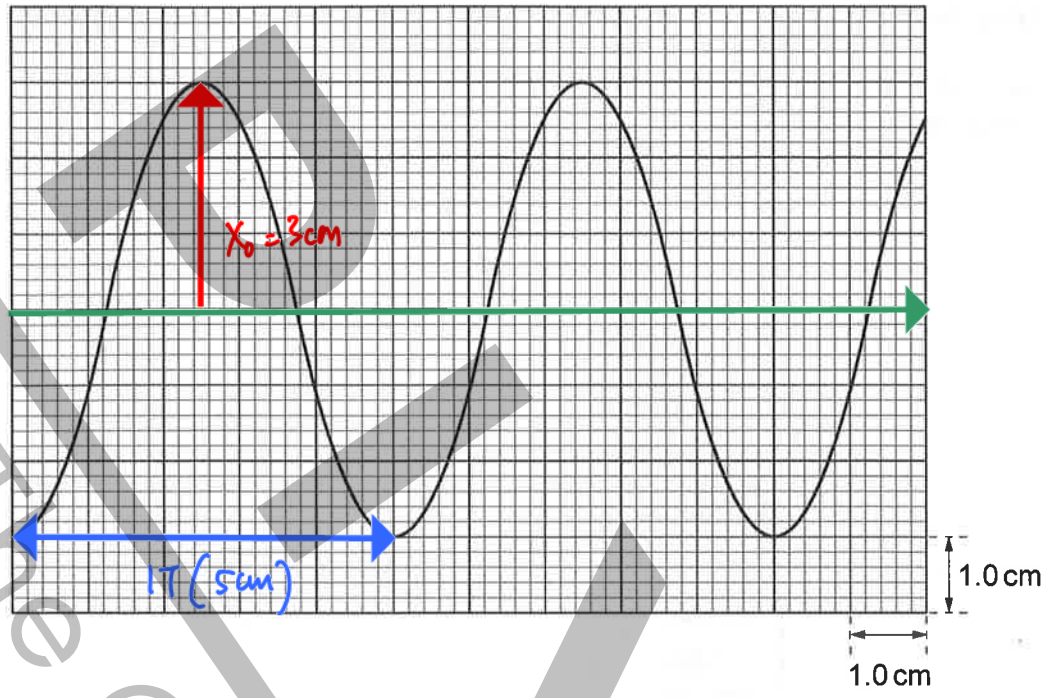


Fig. 4.2

The time base setting on the oscilloscope is 0.50 ms cm^{-1}.

Use Fig. 4.2 to show that the frequency of the sound wave is 400 Hz.

① $T = (0.50 \times 10^{-3})(5) = 2.5$ ms

② $f = \frac{1}{T} = \frac{1}{2.5 \times 10^{-3}} = 400$ Hz shown.

[2]

(iii) The speed of sound is 340 m s^{-1}.

Calculate the distance between adjacent nodes of the stationary wave.

① $v = f\lambda$

$\therefore \lambda = \frac{v}{f} = \frac{340}{400} = 0.85$ m

② $D_{N-N} = \frac{\lambda}{2} = \frac{0.85}{2} = 0.425$ m (3sf)

distance = ... 0.425 ..... m [2]

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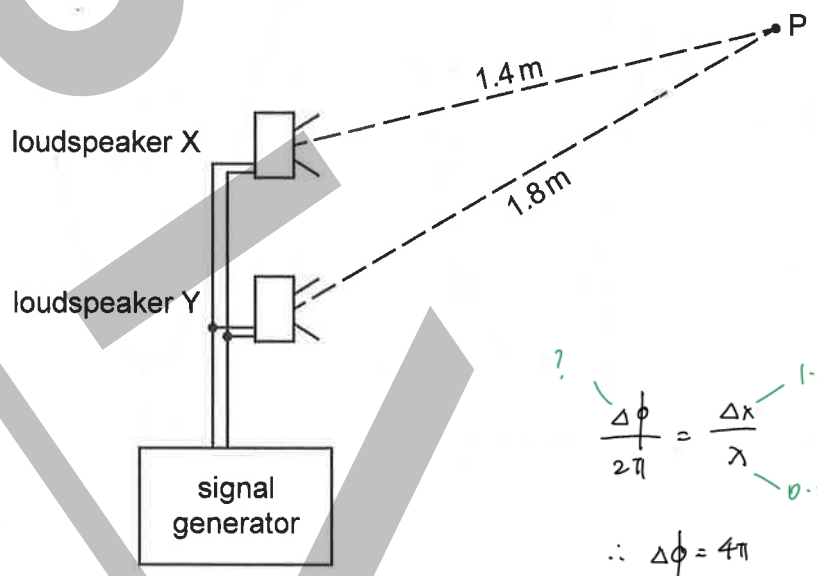
(b) Two loudspeakers X and Y are connected to a signal generator and used to investigate interference. The loudspeakers emit sound waves of wavelength 0.20 m. The sound waves emitted from the two loudspeakers are in phase and have equal intensities.

The sound at point P is detected. Point P is 1.4 m from loudspeaker X and 1.8 m from loudspeaker Y, as shown in Fig. 4.3.

① $I_x = I_y$

$\therefore A_x = A_y$

② $\lambda = 0.2\,m$



? $\frac{\Delta\phi}{2\pi} = \frac{\Delta x}{\lambda}$ ($\Delta x = 1.8 - 1.4$, $\lambda = 0.2$)

$\therefore \Delta\phi = 4\pi$

$\therefore$ const. int.

Fig. 4.3 (not to scale)

(i) State and explain whether the intensity of the sound at P is a maximum or a minimum.

Maximum. The 2 sources are in phase. The path difference between the 2 sources is 0.4 m, which is an integer multiple of the wavelength. When the 2 waves from X & Y meet at P, there is hence constructive interference, yielding a maximum. [2]

(ii) The loudspeakers can be treated as point sources. The intensity at P of the sound from loudspeaker X is $4.5 \times 10^{-6}\,W\,m^{-2}$.

Calculate the intensity at P of the sound from loudspeaker Y.

① $I \propto \frac{1}{r^2}$

② $\therefore \frac{I_x}{I_y} = \frac{\frac{1}{r_x^2}}{\frac{1}{r_y^2}}$

$\therefore \frac{4.5 \times 10^{-6}}{I_y} = \frac{\frac{1}{1.4^2}}{\frac{1}{1.8^2}}$

$\therefore I_y = 2.722 \times 10^{-6} = 2.72\mu\,W\,m^{-2}$ (3sf) #

intensity = 2.72μ $W\,m^{-2}$ [2]

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(iii) For the sound waves at P, calculate the ratio:

$$\frac{\text{amplitude of wave from loudspeaker X}}{\text{amplitude of wave from loudspeaker Y}}.$$

$$\frac{A_x}{A_y} = \sqrt{\frac{I_x}{I_y}} = \sqrt{\frac{4.5\mu}{2.72\mu}} = 1.2862 = 1.29 \text{ (3sf)}$$

ratio = ... 1.29 ..... [2]

[Total: 12]

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5 **(a)** The *I-V* characteristic graph for a thermistor is shown in Fig. 5.1.

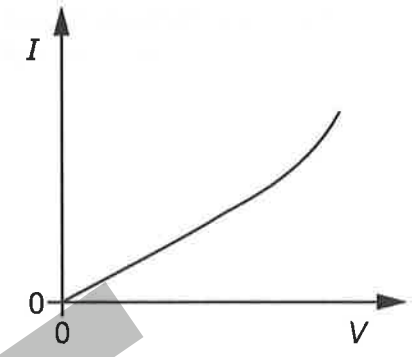


Fig. 5.1

Describe and explain what this graph shows about the resistance of the thermistor as the potential difference (p.d.) across it is increased from zero.

Resistance is the ratio of the voltage, V to the current, I at any point on the I-V graph. When p.d. is 0, the resistance is 0. When the p.d. increases, the resistance decreases. [2]

(b) Two resistors are connected to a d.c. power supply with negligible internal resistance. One resistor has a resistance of 220 Ω and the other has a resistance of 640 Ω. They can be connected in series, as shown in Fig. 5.2, or in parallel, as shown in Fig. 5.3.

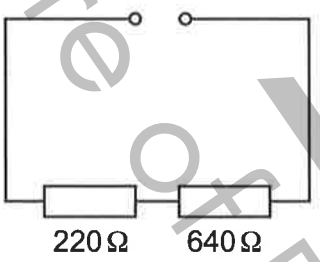


Fig. 5.2

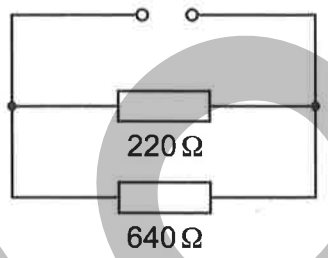


Fig. 5.3

(i) For the two resistors connected in series, show that the ratio:

$$\frac{\text{power dissipated in 220 Ω resistor}}{\text{power dissipated in 640 Ω resistor}} = 0.34.$$

Explain your working.

$\frac{P_{220}}{P_{640}} = \frac{I^2 R_{220}}{I^2 R_{640}}$, where I passing through both 220Ω & 640Ω resistor is the same in series circuit

$= \frac{220}{640} = 0.34375 = 0.34$ (shown) [2]

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(ii) The power supply is replaced with another supply that has an internal resistance.

State and explain the effect on the ratio of the powers in **(b)(i)**.

Ratio is the same. The new current in the circuit decreases. This new current passes through both resistors. Ratio only depends on both resistors, which are unchanged. [1]

(iii) For the original power supply with negligible internal resistance, calculate the ratio:

$$\frac{\text{current from supply in series circuit}}{\text{current from supply in parallel circuit}}.$$

Show your working.

Let DC supply be $\mathcal{E}$.

① $R_{eff-series} = 220 + 640 = 860\ \Omega$

② $R_{eff-||} = 220 \,||\, 640 = \left(\frac{1}{220} + \frac{1}{640}\right)^{-1} = 163.7209$

③ $\text{Ratio} = \frac{I_{series}}{I_{||}} = \frac{\frac{\mathcal{E}}{R_{eff-series}}}{\frac{\mathcal{E}}{R_{eff-||}}} = \frac{163.7209}{860} = 0.1903 = 0.190\ (3sf)$ ✓

ratio = 0.190 [3]

(iv) The power supply is now replaced with an a.c. power supply that has negligible internal resistance. Its peak voltage is equal to the value of the output voltage from the d.c. power supply.

State and explain the effect on the ratio of the currents in **(b)(iii)**.

Ratio is the same. The RMS voltage for both circuits are the same. Ratio only depends on both resistors, which are unchanged. [1]

[Total: 9]

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6 (a) State Faraday's law of electromagnetic induction.

A change in the magnetic flux linkage causes an induced emf in a conductor and the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux linkage. [2]

(b) A horizontal wire is stretched between two fixed points A and B. The wire is between two magnetic poles, as shown in Fig. 6.1.

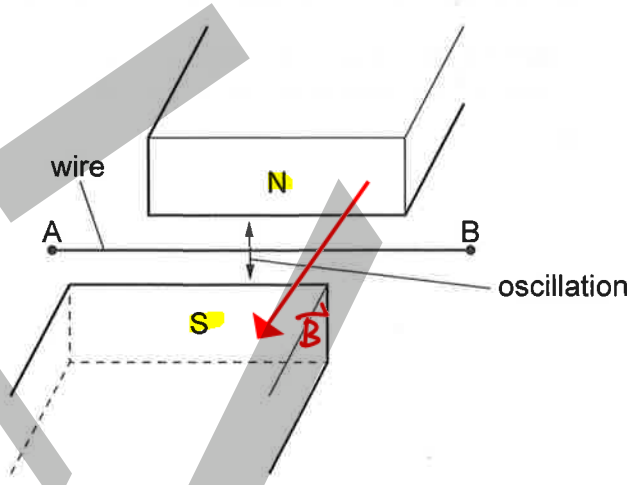


Fig. 6.1

The middle of the wire is displaced vertically and released so that it oscillates.

Explain why an alternating electromotive force (e.m.f.) is induced across the ends of the wire.

As the wire moves upwards, it cuts the magnetic flux. According to Faraday's law, emf is induced. By Fleming's right hand rule, emf is induced in the direction BA. As the wire moves down, emf is induced in the direction AB, from Fleming's right hand rule. Since wire is oscillating, the emf direction constantly alternates.

[2]

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(c) A second wire is moved at a speed of $0.80\,m\,s^{-1}$ between two magnetic poles, as shown in Fig. 6.2.

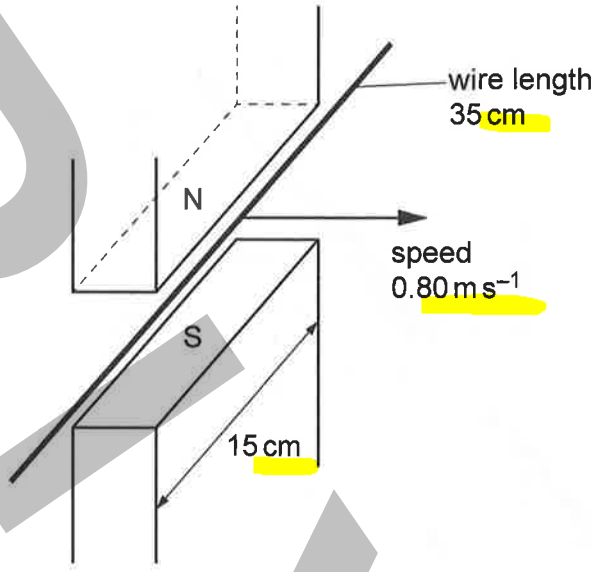


Fig. 6.2

The magnetic field between the two magnetic poles is perpendicular to the wire and to the direction of motion of the wire.
The magnetic flux density is 250 mT between the two magnetic poles and zero elsewhere.
The width of each magnetic pole is 15 cm and the length of the wire is 35 cm.

Calculate the e.m.f. induced across the ends of the wire.

$E_{sf} = BLv = (250\times10^{-3})(15\times10^{-2})(0.8)$

$= 0.0300\,V$ (3sf)

e.m.f. = 0.0300 V [2]

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(d) A third wire XY of twice the length of the wire in **(c)** is folded in half so that X is close to and vertically above Y. It is moved at the same speed of $0.80\,m\,s^{-1}$ between the same two magnetic poles in **(c)**, as shown in Fig. 6.3.

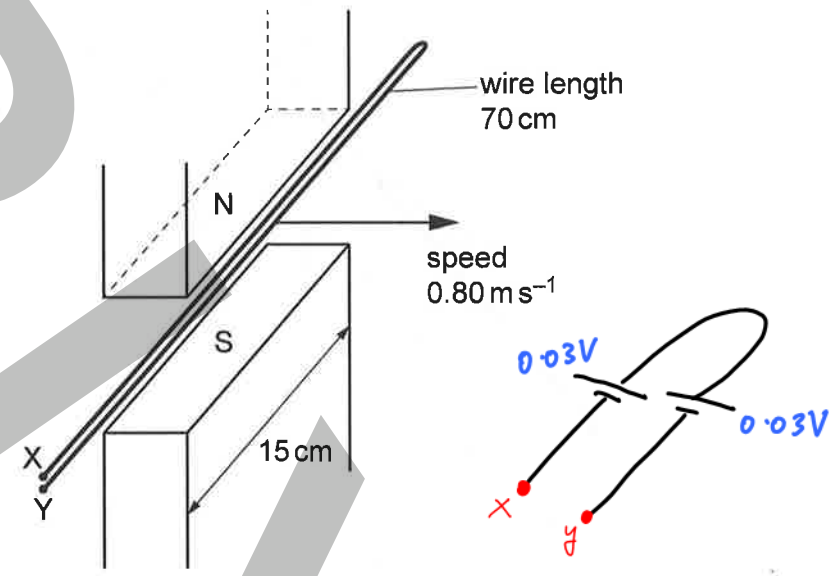


Fig. 6.3

State and explain the value of the e.m.f. induced across the ends X and Y of this wire.

0V. There will be now two of 0·03V induced in opposite directions across XY. Hence, the net emf across XY is 0V, by KVL.

[2]

[Total: 8]

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7 (a) (i) State the name of a phenomenon that gives evidence for the particulate nature of electromagnetic radiation.

Photo-electric effect ..... [1]

(ii) State the name of a phenomenon that gives evidence for the wave nature of electromagnetic radiation.

Diffraction / Interference ..... [1]

(b) A photocell consists of two electrodes and their connecting wires enclosed in a small glass bulb. There is a vacuum inside the glass bulb. Electromagnetic radiation is incident on the metal electrode, and emitted photoelectrons travel towards the collector electrode. The photocell is connected to a variable power supply and an ammeter as shown in Fig. 7.1.

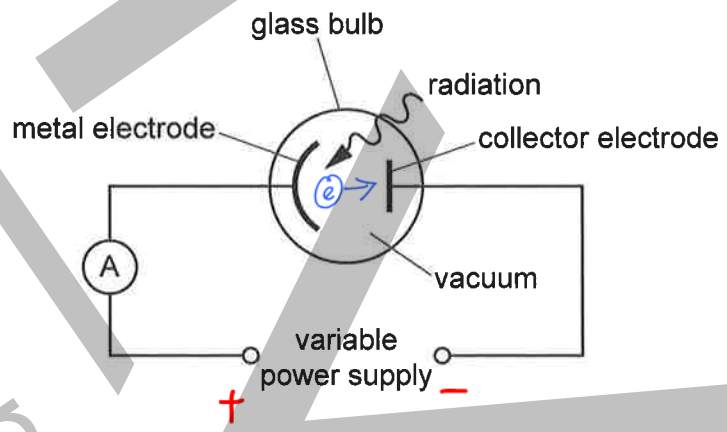


Fig. 7.1

$|-V_s|$

The magnitude of the output of the variable power supply is increased until the ammeter reading just decreases to zero.

(i) On Fig. 7.1, draw a plus sign (+) and a minus sign (–) to indicate the polarity of the power supply. [1]

(ii) The photon energy is 12.4 eV and the work function of the metal surface is 4.2 eV.

Calculate the stopping potential.

$hf = \phi + |eV_s|$

$\therefore 12.4eV = 4.2eV + |eV_s|$

$\therefore |V_s| = 8.2$

So, $V_s = -8.20V$ (3sf)

stopping potential = −8.20 V [2]

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(iii) Explain why the stopping potential is independent of the intensity of the electromagnetic radiation.

The stopping potential is the negative p.d. between the collector electrode and the metal electrode that turns away the fastest electron from the metal electrode (electrons ejected from surface of metal electrode have the largest kinetic energy, KE_{max}). KE_{max} only depends on the frequency of the incoming EM radiation, and is independent of the intensity, according to Einstein's photoelectric equation. [3]

(c) For the apparatus in Fig. 7.1, the variation of the ammeter reading I with the potential V of the collector electrode relative to the metal electrode is shown in Fig. 7.2.

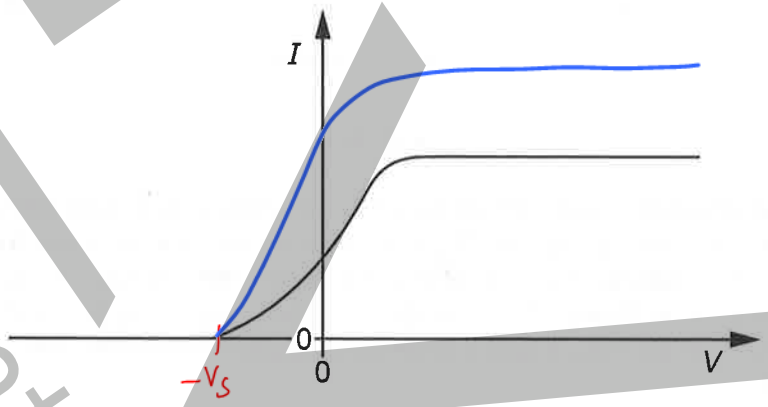


Fig. 7.2

(i) On Fig. 7.2, label the stopping potential V_S. [1]

(ii) The intensity of the electromagnetic radiation incident on the metal electrode is increased.

On Fig. 7.2, sketch a line to show how I now varies with V. [2]

[Total: 11]

① $hf = \phi + |eV_S|$ — const.

② ↑$I = \frac{P}{A} = \frac{E}{tA} = \frac{\uparrow n hf}{tA}$

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8 Read the passage below and answer the questions that follow.

In 1967, the first pulsar was discovered. A regular, repeating radio wave signal was found on a trace from a radio telescope near Cambridge, as shown in Fig. 8.1.

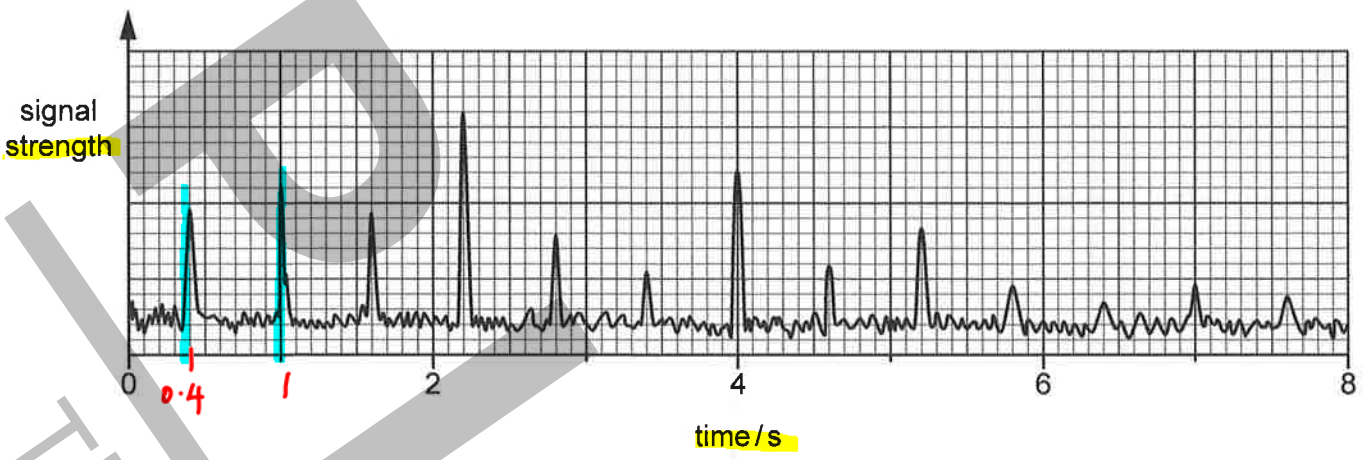


Fig. 8.1

A pulsar is a type of neutron star, formed after a supernova explosion when a star more massive than the Sun nears the end of its life. The nuclei inside the star undergo fusion to form the nuclei of heavier elements. Towards the end of the life of the star, heavier nuclei fuse together to form even heavier nuclei. Eventually, fusion stops and the core collapses under gravitational forces. The density of the core increases and a supernova explosion occurs. The pulsar that remains has an iron-rich crust.

The first pulsar discovered had a mass of approximately 1.4 solar masses, where one solar mass is the mass of the Sun, and a radius of approximately 10 km.

A pulsar spins much faster and has a much smaller period of rotation than the star from which it was formed.

Pulsars have very strong magnetic fields in the region of 10^8 T and very strong electric fields in the region of 10^9 V m^{-1}. A radio signal is emitted from each of the magnetic poles of the pulsar. The two radio signals travel in opposite directions. As the pulsar rotates, radio signals are swept across space because the magnetic poles do not coincide with the rotational poles of the pulsar. It was a radio signal from one of the poles of a pulsar that was first detected on Earth.

Pulsars can rotate many times every second. However, there are limits to the rate of rotation. One limit is that the speed of the surface cannot exceed the speed of light. A second limit is that the speed of the surface cannot be so high that the pulsar disintegrates. This would happen if, at a point on the surface of the pulsar, the centripetal acceleration exceeded the acceleration due to gravity.

A total of around 2500 pulsars have now been discovered. The Crab Pulsar, which is in the Crab Nebula, was detected in 1968. This pulsar emits photons with a maximum energy of 400 TeV. The Crab Pulsar has a period of rotation of 33.5 ms, and this period increases by 38 ns per day.

The Parkes Telescope in Australia has a diameter of 64 m and has led to the discovery of around 700 pulsars. A new telescope called the Square Kilometre Array (SKA) is to be built. The total effective collecting area of this telescope will be 1.0 km^2, and it is hoped that this telescope will lead to the discovery of many more pulsars.

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(a) Using Fig. 8.1, determine the angular velocity of the first pulsar discovered.

① $T = 0.6\,s$

② $\omega = \frac{2\pi}{T} = \frac{2\pi}{0.6} = 10.47 = 10.5\ rad/s$ (3sf)

angular velocity = 10.5 $rad\,s^{-1}$ [2]

(b) A spinning body has a quantity called angular momentum. Similar to linear momentum, the angular momentum of a closed system is conserved.

The angular momentum L of a sphere spinning on its axis is given by:

$$L = \frac{2}{5} mr^2\omega$$

where m is the mass of the sphere, r is the radius of the sphere and ω is the angular velocity of the sphere.

Suggest why a pulsar spins much faster than the star from which it was formed.

A pulsar has a smaller mass and radius compared to the original star from which it was formed. Since angular momentum is conserved (constant), the angular velocity, ω, must increase, which means that it must spin faster. [1]

(c) Explain why the iron in the iron-rich crust of the pulsar did not undergo fusion.

Iron is the most stable nuclide. It cannot undergo nuclear fusion because the Binding Energy (BE) released in this process is smaller than the BE absorbed for this process to occur. Moreover, the temperature required for fusion of iron is much larger than the temperature of the environment. [2]

(d) **(i)** The mass of the Sun is 2.0×10^{30} kg.

Calculate the gravitational field strength g at the surface of the first pulsar discovered.

$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(1.4 \times 2 \times 10^{30})}{(10 \times 10^3)^2} = 1.8676 \times 10^{12} = 1.87\,T\ N/kg^{-1}$ (3sf)

g = 1.87T $N\,kg^{-1}$ [2]

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(ii) Determine the difference Δg in the gravitational field strength between a point at the surface of the pulsar and a second point 1.0 m vertically above the surface.

① $r_{pulsar} \gg 1m$

② $\therefore g_{surface} \simeq g_{1m}$

③ $\therefore \Delta g = 0$ #

$\Delta g =$ ..... 0 ..... $N kg^{-1}$ [1]

(iii) A steel rod of length 1.0 m is released and falls vertically from a height of 3.0 m above the surface of the pulsar.

Suggest what happens to the length of the rod as it accelerates towards the surface of the pulsar. Give a reason for your answer.

Unchanged. Since the rod is near the pulsar surface, the gravitational field strength experienced by both ends of the rod is constant, which implies that both ends of the rod will accelerate with the same magnitude according to Newton's 2nd Law. [1]

(e) (i) A pulsar has a radius of 100 km.

Explain why this pulsar cannot have a period of 2.0 ms. Support your answer with a calculation.

$v = r\omega = (100 \times 10^3)\left(\frac{2\pi}{2 \times 10^{-3}}\right) = 3.145 \times 10^8 > c$

The speed of the surface of the pulsar exceeds the speed of light, which is not possible. [2]

(ii) Show that the minimum average density ρ of a spherical pulsar that does not disintegrate is given by:

$$\rho = \frac{3\pi}{GT^2}$$

where G is the gravitational constant and T is the period of rotation of the pulsar.

① $a_c = g$, for non-disintegrating pulsar.

$\therefore r\omega^2 = \frac{GM}{r^2}$

So $M = \frac{r^3\omega^2}{G}$

② $\rho = \frac{M}{V} = \frac{\frac{r^3\omega^2}{G}}{\frac{4}{3}\pi r^3} = \frac{r^3\omega^2}{\frac{4}{3}G\pi r^3} = \frac{3\left(\frac{2\pi}{T}\right)^2}{4G\pi} = \frac{3(4\pi^2)}{4G\pi T^2} = \frac{3\pi}{GT^2}$ # shown.

[4]

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(iii) Use the expression in **(e)(ii)** to calculate ρ for the first pulsar discovered.

$$\rho = \frac{3\pi}{GT^2} = \frac{3\pi}{(6.67\times10^{-11})(0.6)^2} = 3.925\times10^{11} = 3.93\times10^{11}\ \text{kg m}^{-3}$$ #

ρ = 3.93 x10^11 kg m^{-3} [1]

(f) The age of a pulsar, in seconds, can be found using the expression:

$$\text{age} = \frac{\text{period}}{2 \times \text{rate of change of period}}.$$

Use this expression to determine the age, in years, of the Crab Pulsar.

① $\text{Age} = \dfrac{33.5\times10^{-3}}{2\times\dfrac{38\times10^{-9}}{24\times3600}} = 3.80842\times10^{10}\ \text{s}$

② $\therefore$ Age in years $= \dfrac{3.80842\times10^{10}\ \text{s}}{365\times24\times3600} = 1207.64 = 1210$ years (3sf) #

age = 1210 years [1]

(g) Determine the wavelength of the highest energy photons emitted from the Crab Pulsar.

$E = \dfrac{hc}{\lambda}$

$\therefore \lambda = \dfrac{hc}{E} = \dfrac{1.989\times10^{-25}}{400\times10^{12}\times1.6\times10^{-19}} = 3.1078\times10^{-21} = 3.11\times10^{-21}\ \text{m}$ (3sf) #

wavelength = 3.11x10^-21 m [2]

(h) Suggest why the greater effective collecting area of the SKA will enable it to detect pulsars that cannot be detected by the Parkes Telescope.

According to Rayleigh's Criterion, a larger telescope diameter increases the resolution of the telescope by decreasing its minimum resolvable angle.

[1]

[Total: 20]

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