JC 2 PRELIMINARY EXAMINATION
in preparation for General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME			
CLASS		INDEX NUMBER	

PHYSICS 9646/02

Paper 2 Structured Questions **19 August 2016**

1 hour 45 minutes

Candidates answer on the Question Paper

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in the brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	11
2	7
3	9
4	11
5	7
6	15
7	12
Significant Figures	
Total	72

Data

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

Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on/by a gas,	$W = p\Delta V$
mean kinetic energy of a molecule of an ideal gas	$E = \frac{3}{2}kT$
hydrostatic pressure,	$p = \rho gh$
gravitational potential,	$\Phi = -\frac{GM}{r}$
displacement of particle in s.h.m.	$x = x_o \sin \omega t$
velocity of particle in s.h.m.	$v = v_o \cos \omega t$
	$= \pm\omega\sqrt{(x_o^2 - x^2)}$
resistors in series,	$R = R_1 + R_2 + \ldots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = Q/4\pi\varepsilon_o r$
alternating current/voltage,	$x = x_o \sin\omega t$
transmission coefficient	$T = \exp(-2kd)$
	where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{½}}$

For Examiner's Use

1 One end of a spring is fixed to a support. A mass is attached to the other end of the spring. The arrangement is shown in Fig. 1.1.

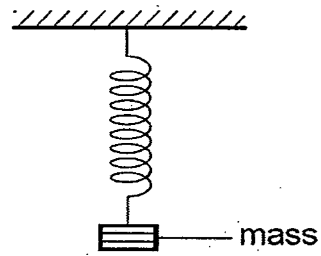


Fig. 1.1

(a) The mass is in translational equilibrium. Explain, with reference to the forces acting on the mass, what is meant by translational equilibrium.

....

....

.... [2]

(b) The mass is pulled down and then released at time $t = 0$. The mass oscillates up and down. The variation with t of the displacement of the mass d is shown in Fig. 1.2.

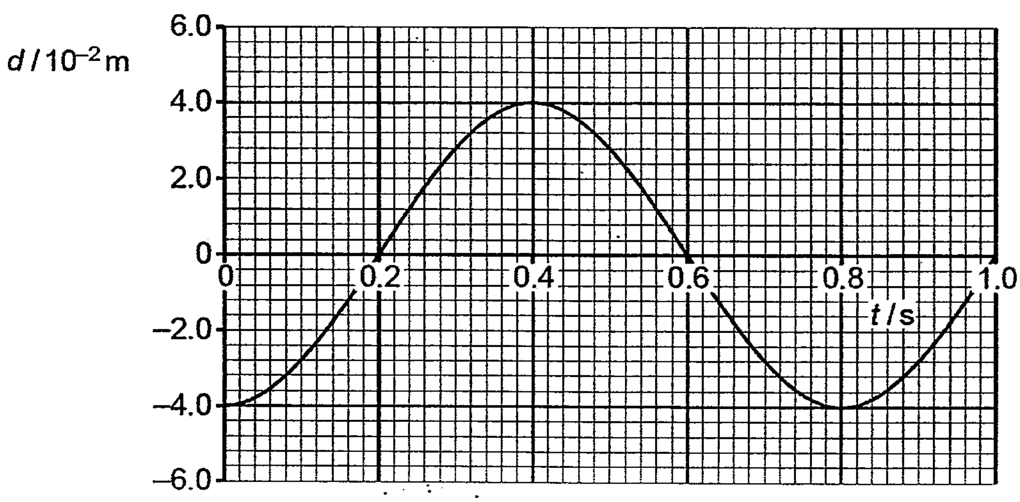


Fig. 1.2

Using Fig. 1.2, state an instant when

(i) the elastic potential energy stored in the spring is a maximum,

time = ... s [1]

(ii) the mass is in equilibrium.

time = ... s [1]

(c) The arrangement shown in Fig. 1.3 is used to determine the length l of a spring when different masses M are attached to it.

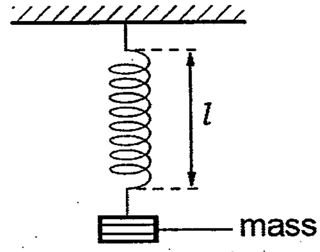


Fig. 1.3

The variation with mass M of l is shown in Fig. 1.4 below.

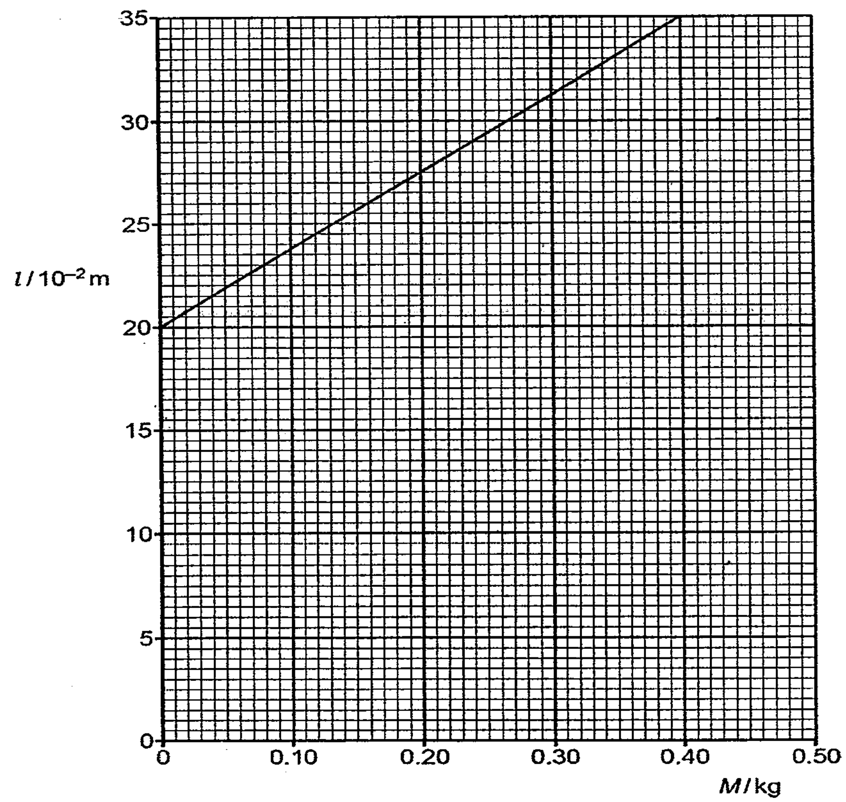


Fig. 1.4

(i) State and explain whether the spring obeys Hooke's law.

....

....

.... [2]

(ii) Show that the spring constant of the spring is 26 N m^{-1}. [2]

(iii) A mass of 0.40 kg is attached to the spring. Calculate the energy stored in the spring.

energy = ... J [3]

For Examiner's Use

2 **(a)** State the first law of thermodynamics.

....

....

.... [1]

(b) During the first part of the power stroke in a diesel engine, the pressure of the burning gas remains constant at 8.00×10^6 Pa, while the volume of the gas increases from 3.00×10^{-5} m^3 to 7.10×10^{-5} m^3.

(i) Calculate the work done on the gas during the first part of the power stroke.

work done on gas = ... J [2]

(ii) While this expansion is taking place, the temperature of the gas rises by 900 K. The mass of the gas is 1.27×10^{-3} kg and its specific heat capacity at constant pressure is 1.004×10^3 J kg^{-1} K^{-1}. The gas is diatomic.

Calculate the heat gained by the burning gas.

heat gained = ... J [1]

(iii) Hence find the increase in internal energy during the first part of the power stroke in the diesel engine.

increase in internal energy = ... J [1]

(iv) The gas subsequently undergoes the following processes:

1. second part of the power stroke being an adiabatic expansion from 7.10×10^{-5} m^3 to 9.00×10^{-5} m^3.

2. third part of the power stroke being an isothermal compression from 9.00×10^{-5} m^3 back to its original starting state at 3.00×10^{-5} m^3.

Sketch and label, in Fig. 2.1 below, all three parts of the power stroke in the diesel engine. The starting point of the power stroke, point A, has been drawn for you.

[2]

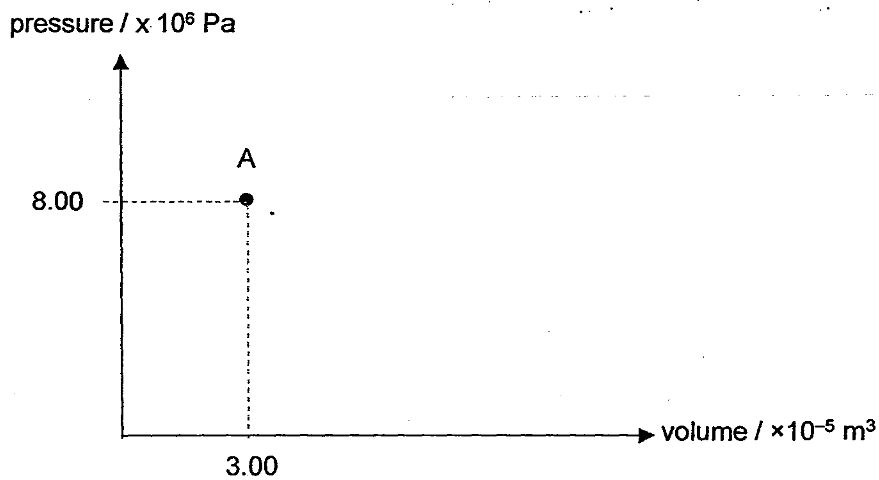


Fig. 2.1

3 (a) (i) Define the electromotive force of a cell.

....

....

.... [1]

(ii) Explain why the terminal potential difference of a cell is usually smaller than its electromotive force.

....

....

.... [1]

(b) Fig. 3.1 shows a circuit containing a cell and four resistors.

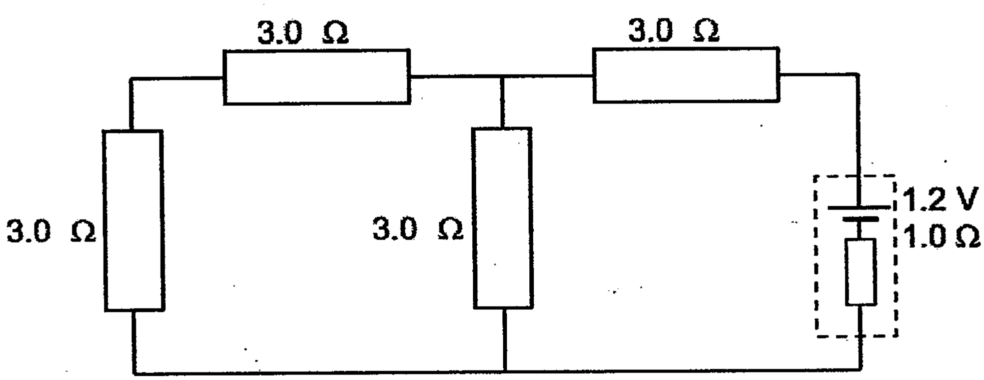


Fig. 3.1

Calculate

(i) the current through the 1.2 V cell,

current = ... A [2]

(ii) the terminal p.d. of the 1.2 V cell,

terminal p.d. = ... V [1]

(iii) the efficiency of the circuit.

efficiency = ... % [1]

(c) Fig. 3.2 below shows 2 coils X and Y wound on a soft iron core.

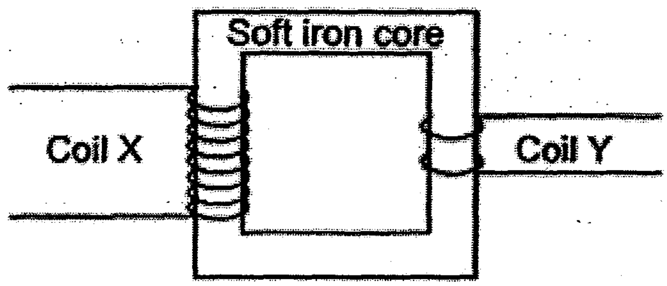


Fig. 3.2

The inputs of coil X is now connected to a 240 V mains supply, where the current changes directions 100 times per second. The output of coil Y is connected to a 12 V, 3.0 A light bulb, the bulb is working normally.

(i) Assuming that the efficiency of the transformer is 90%, make use of energy considerations to calculate the current in coil X.

current = ... A [2]

(ii) Suggest one reason why the transformer is not 100% efficient.

....

.... [1]

4 **(a)** State the laws of electromagnetic induction.

....

....

....

.... [2]

(b) **(i)** A solenoid is connected in series with a resistor, as shown in Fig. 4.1.

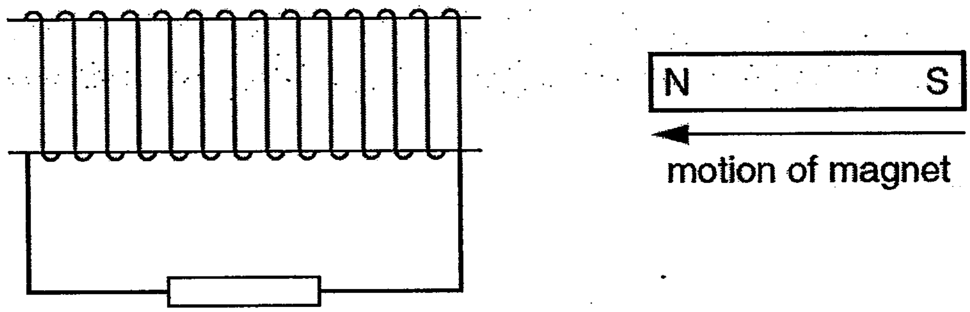


Fig. 4.1

As the magnet is being moved into the solenoid, thermal energy is generated in the resistor.

Use the laws of electromagnetic induction to explain the origin of this thermal energy.

....

....

....

....

....

....

....

....

....

....

....

.... [4]

(ii) Draw in Fig. 4.1. the direction of the induced current in the solenoid. [1]

(c) Explain why the alternating current in the primary coil of a transformer is not in phase with the alternating e.m.f. induced in the secondary coil.

....

....

....

....

....

....

....

.... [4]

For Examiner's Use

5 **(a)** Explain, using band theory, why the conductivity of an intrinsic semiconductor increases when temperature increases.

....

....

....

.... [2]

(b) Explain why the conductivity of a metal decreases when temperature increases.

....

....

....

.... [2]

(c) **(i)** Explain, using band theory, how the introduction of small amounts of Group 5 impurities to intrinsic semiconductors improves their conductivities.

....

....

....

.... [2]

(ii) However, when too many impurity atoms are introduced, as in the case of highly-doped semiconductors, the resistance of the semiconductor actually increases, rather than decrease, when temperature increases.

With reference to your answer to **(b)**, suggest a reason for this behavior of highly-doped semiconductors.

....

....

.... [1]

6 A scintillation counter is an instrument that detects and measures high energy charged particles. A scintillation counter comprises three main components i.e.

Component 1: Scintillator material
Component 2: Photocathode
Component 3: Photomultiplier tube

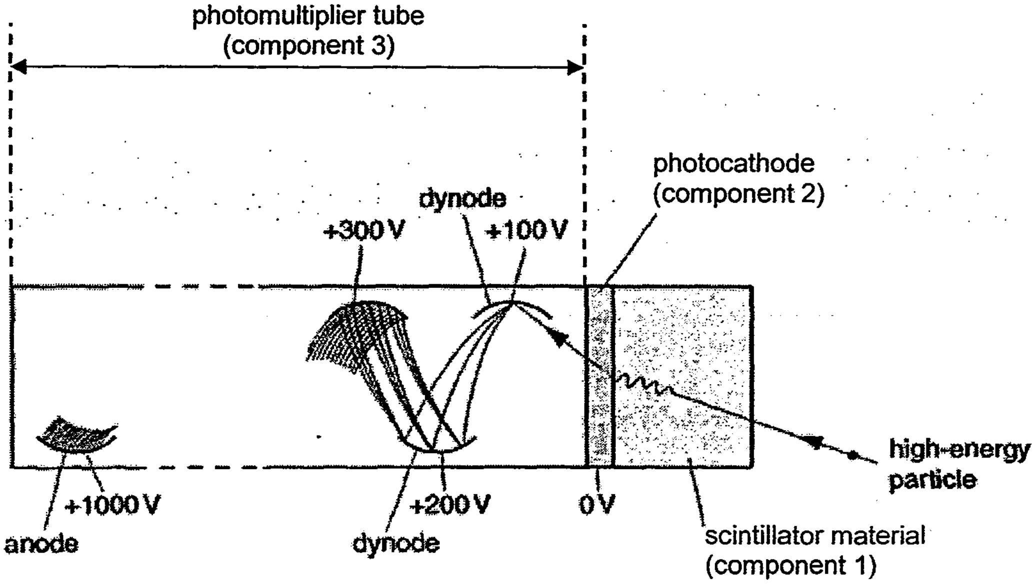


Fig 6.1

(a) In the scintillator material (component 1), high energy particles interact with the material to produce photons.

In one particular experiment, high energy particles produce 90 nW of light of wavelength 400 nm in the scintillator material.

(i) Calculate the energy, E_p, of a single photon of wavelength 400 nm.

E_p = ... J [1]

(ii) Show that the rate of photons produced in the scintillator, n_p, is 1.81×10^{11} s^{-1} .

[1]

(b) When the photons produced in the scintillator material (component 1) reaches the photocathode (component 2), the photons eject some of the surface electrons due to the photoelectric effect.

Radiant sensitivity, S, is defined as the photoelectric current generated by the photocathode divided by the incident radiant flux, ϕ of the incoming photons from the scintillator material.

S is expressed in units of amperes per watts (A W^{-1}).

(i) Starting from the definition of radiant sensitivity and/ or examining its units, show that radiant sensitivity, S, is given by:

$$S = \frac{n_e e \lambda}{n_p hc}$$

where n_e is the rate of emission of photoelectrons and n_p is the rate of photons produced in the scintillator material.

Show your working clearly.

[1]

(ii) Quantum efficiency, η, is defined as the number of photoelectrons emitted, N_e, from the photocathode divided by the number of incident photons, N_p.

$$\eta = \frac{N_e}{N_p}$$

Quantum efficiency can also be calculated from the radiant sensitivity, S, of the photocathode.

Using the expression for S in **b(i)** or otherwise, show that the quantum efficiency, η, can be expressed as:

$$\eta = 1.24 \times 10^{-6} \frac{S}{\lambda}$$

[2]

For Examiner's Use

(c) Fig. 6.2 shows the variation of the radiant sensitivity, S with the wavelength of the incident photons, for various types of photocathodes.

The graph uses a logarithmic scale.

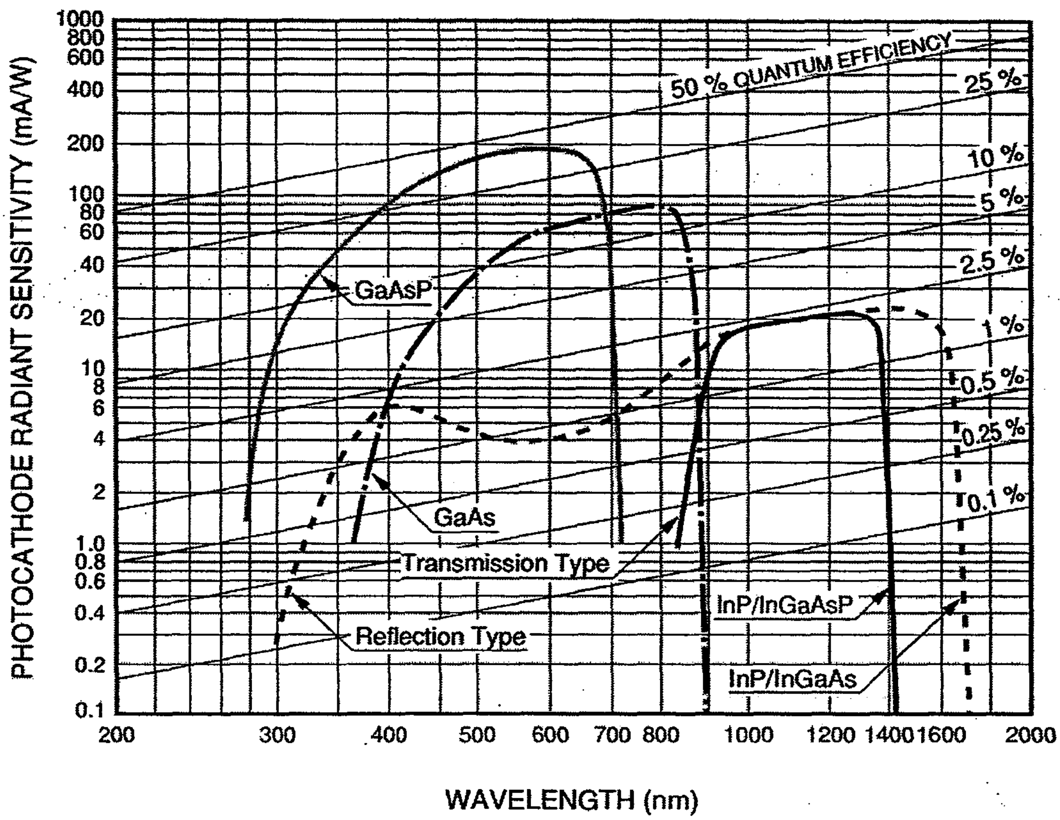


Fig. 6.2

In the experiment detailed in **(a)**, the Gallium Arsenide Phosphide (GaAsP) photocathode was used in the scintillation counter.

(i) Using Fig. 6.2, state and explain which photocathode would not have been suitable for use in the experiment.

....

....

....

.... [2]

(ii) Using values from Fig. 6.2, determine the rate of emission of photoelectrons, n_e from the GaAsP photocathode in the experiment detailed in **(a)**.

n_e = ... s^{-1} [3]

(d) In the photomultiplier tube (component 3), the photoelectrons emitted from the photocathode are accelerated towards the first positive dynode because of the 100 V potential difference between the dynode and the photocathode.

The kinetic energy of the electron is sufficient to eject, on average, 3 'secondary' electrons from the dynode. These electrons are then accelerated towards the next dynode and the whole process is repeated.

Eventually a tiny pulse of charge is detected at the anode in the photomultiplier tube and measured as the anode current.

(i) The work function energy of the photocathode material is 3.5×10^{-19} J .

Calculate the maximum kinetic energy of the photoelectrons just ejected from the photocathode due to the photoelectric effect.

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

(ii) For a photomultiplier with 10 dynodes, show that the number of electrons arriving at the anode for **each** photoelectron emitted from the cathode is 3^9.

Explain your working.

[1]

(iii) Determine the current detected by the photomultiplier tube's anode.

current = ... A [2]

For Examiner's Use

7 The efficiency η of a glowing filament may be expressed as

$$\eta = \frac{\text{light energy emitted in the visible range}}{\text{electrical energy input}}$$

As light energy emitted in the visible range can be difficult to measure, the efficiency could instead be determined by measuring the amount of wasted energy produced by the filament in the form of thermal energy. The efficiency is subsequently calculated using

$$\eta = 1 - \frac{\text{thermal energy}}{\text{electrical energy input}}$$

The efficiency is thought to depend on the temperature, T of the filament. The relationship between the efficiency and the temperature may be written in the form:

$$\eta = aT^b$$

where a and b are constants.

You are provided with a filament, a beaker with water that is to be used in the determination of the thermal energy produced by the glowing filament, and an infrared thermometer. You may also use any of the other equipment usually found in a physics laboratory.

Design an experiment to determine the relationship between η and T.

You should draw a labelled diagram to show the arrangement of your apparatus. In your account you should pay particular attention to:

(a) the identification and control of variables,
(b) the equipment you would use,
(c) the procedure to be followed,
(d) how the relationship between η and T is determined from your readings,
(e) any precautions that would be taken to improve the accuracy and safety of the experiment.

Diagram

For Examiner's Use

[12]

JC 2 PRELIMINARY EXAMINATION
in preparation for General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME	

CLASS		INDEX NUMBER	

PHYSICS **9646/02**

Paper 2 Structured Questions **19 August 2016**

1 hour 45 minutes

Candidates answer on the Question Paper

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in the brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 11
2	/ 7
3	/ 9
4	/ 11
5	/ 7
6	/ 15
7	/ 12
Significant Figures	
Total	/ 72

Data

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

Formulae

uniformly accelerated motion,	$s = ut + ½at^2$
	$v^2 = u^2 + 2as$
work done on/by a gas,	$W = p\Delta V$
mean kinetic energy of a molecule of an ideal gas	$E = \frac{3}{2}kT$
hydrostatic pressure,	$p = \rho gh$
gravitational potential,	$\Phi = -\frac{GM}{r}$
displacement of particle in s.h.m.	$x = x_o \sin \omega t$
velocity of particle in s.h.m.	$v = v_o \cos \omega t$
	$= \pm\omega\sqrt{(x_o^2 - x^2)}$
resistors in series,	$R = R_1 + R_2 + \ldots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = Q/4\pi\varepsilon_o r$
alternating current/voltage,	$x = x_o \sin \omega t$
transmission coefficient	$T = \exp(-2kd)$
	where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{½}}$

1 One end of a spring is fixed to a support. A mass is attached to the other end of the spring. The arrangement is shown in Fig. 1.1.

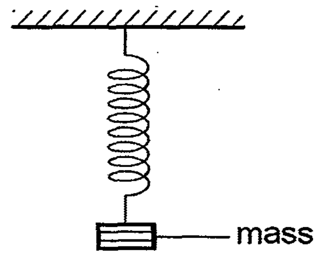


Fig. 1.1

(a) The mass is in translational equilibrium. Explain, with reference to the forces acting on the mass, what is meant by translational equilibrium.

There is no net resultant force in all directions. [B1]
The weight downwards is equal to the tension upwards. [B1]

.... [2]

(b) The mass is pulled down and then released at time t = 0. The mass oscillates up and down. The variation with t of the displacement of the mass d is shown in

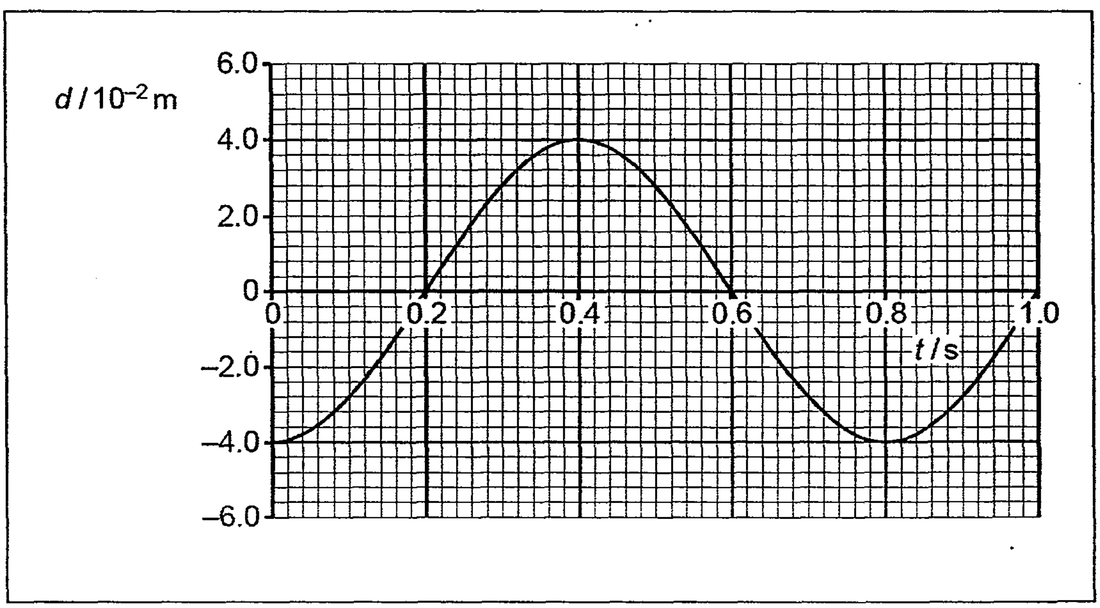


Fig. 1.2.

Fig. 1.2

Using Fig. 1.2, state an instant when

(i) the elastic potential energy stored in the spring is a maximum,

0, 0.8 s (any one of these values) [A1]

time = ... s [1]

(ii) the mass is in equilibrium.

0.2, 0.6, 1.0 s (any one of these values) [A1]

time = ... s [1]

(c) The arrangement shown in Fig. 1.3 is used to determine the length l of a spring when different masses M are attached to it.

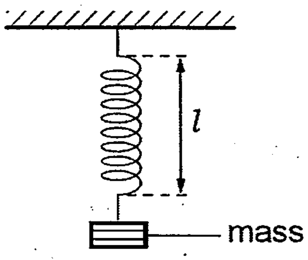


Fig. 1.3

The variation with mass M of l is shown in Fig. 1.4 below.

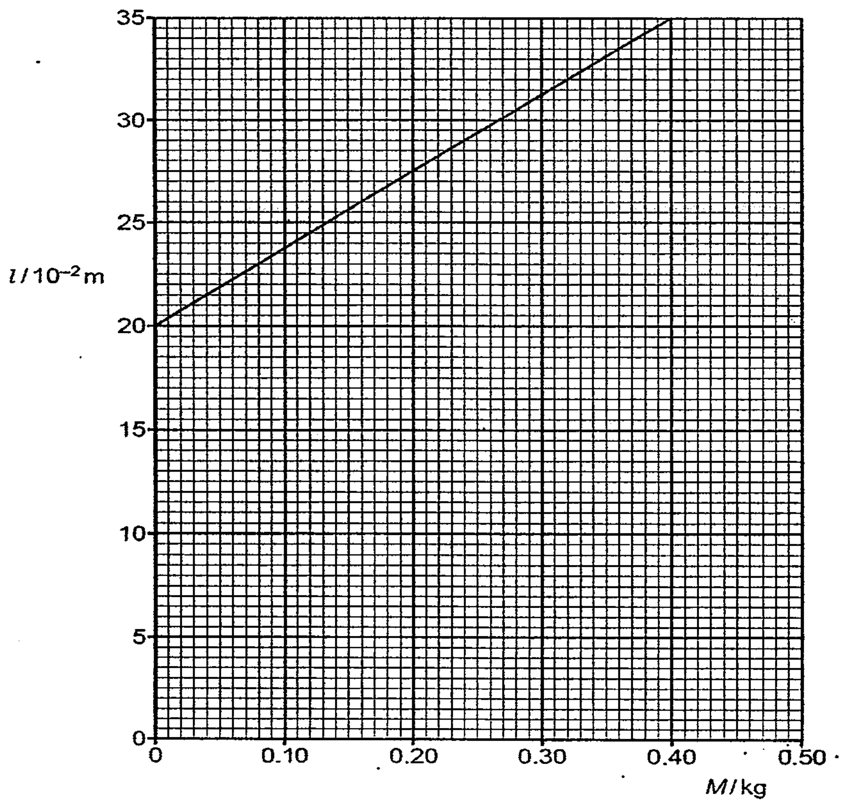


Fig. 1.4

(i) State and explain whether the spring obeys Hooke's law.

The spring obeys Hooke's Law. [B1]
From the linear/straight line graph, it suggests that the mass is proportional to the extension, hence the applied force (W=mg) is proportional to extension. [B1]

[2]

(ii) Show that the spring constant of the spring is 26 N m^{-1}. [2]

Solution

Use of the gradient of F-x graph (not $F = kx$) [C1]

$$k = \frac{(0.40 \times 9.81) - 0}{(35-20) \times 10^{-2}}$$ [M1]

$k = 26$ N m^{-1} [A0]

(iii) A mass of 0.40 kg is attached to the spring. Calculate the energy stored in the spring.

Solution

energy = area under the F-x graph or energy = ½ F x [M1]

= ½ (0.40 × 9.81) (15 × 10^{-2}) [M1]

= 0.294 J [A1]

energy = ... J [3]

For Examiner's Use

2 **(a)** State the first law of thermodynamics.

The increase in the internal energy of the system is the sum of the heat supplied to and work done on the system. [B1]
"Change in internal energy" is too vague and not accepted.

.... [1]

(b) During the first part of the power stroke in a diesel engine, the pressure of the burning gas remains constant at 8.00×10^6 Pa, while the volume of the gas increases from 3.00×10^{-5} m^3 to 7.10×10^{-5} m^3.

(i) Calculate the work done on the gas during the first part of the power stroke.

Solution
Work done on the gas = $- p \Delta V$
$= -(8.00 \times 10^6)(7.10 \times 10^{-5} - 3.00 \times 10^{-5})$ [M1]
$= -328$ J [A1]

If student indicate +328 J, or use $W = p\Delta V$ i.e. no negative sign, 1 mark will be awarded.

work done on gas = ... J [2]

(ii) While this expansion is taking place, the temperature of the gas rises by 900 K. The mass of the gas is 1.27×10^{-3} kg and its specific heat capacity at constant pressure is 1.004×10^3 J kg^{-1} K^{-1}. The gas is diatomic.

Calculate the heat gained by the burning gas.

Solution
Heat gained, $Q = m c \Delta\theta$
$= (1.27 \times 10^{-3})(1.004 \times 10^3)(900)$
$= +1150$ J [A1]

Note: values for specific heat capacity only exists for the isovolumetric and isobaric processes, none of adiabatic.

heat gained = ... J [1]

(iii) Hence find the increase in internal energy during the first part of the power stroke in the diesel engine.

Solution
$\Delta U = Q + W = (+1150) + (-328) = +822$ J

increase in internal energy = ... J [1]

(iv) The gas subsequently undergoes the following processes:

1. second part of the power stroke being an adiabatic expansion from 7.10×10^{-5} m^3 to 9.00×10^{-5} m^3.
2. third part of the power stroke being an isothermal compression from 9.00×10^{-5} m^3 back to its original starting state at 3.00×10^{-5} m^3.

Sketch and label, in Fig. 2.1 below, all three parts of the power stroke in the diesel engine. The starting point of the power stroke, point A, has been drawn for you.

[2]

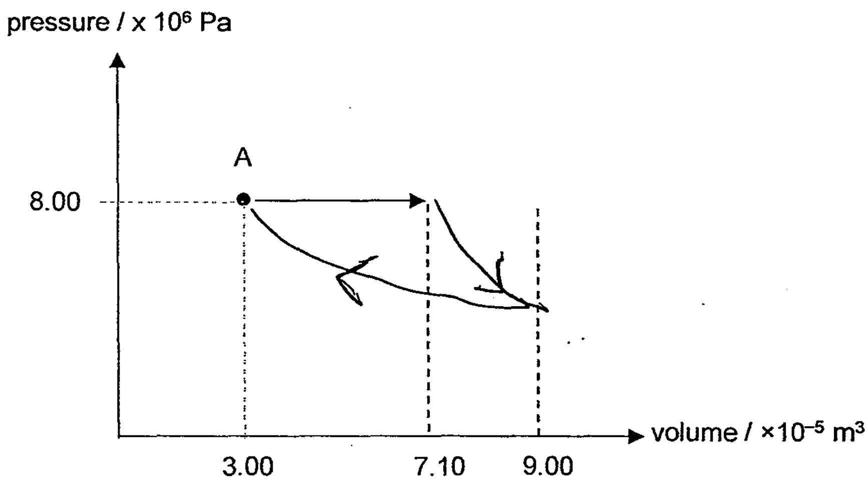


Fig. 2.1

Solution

The diagram consists of 3 arrows;

1. horizontal arrow direction to the right from A to B.
2. steep slope downwards from B to C.(adiabatic process)
3. less steep slope upwards from C to A. (isothermal process)

1 mark for correct values of 7.10×10^{-5} & 9.00×10^{-5} m^3.

1 marks for correct 3 arrows with directions.

For Examiner's Use

3 **(a)** **(i)** Define the electromotive force of a cell.

The electromotive force of a cell is defined as the energy converted from other forms to electrical energy per unit charge passing through the source. [B1]

[1]

(ii) Explain why the terminal potential difference of a cell is usually smaller than its electromotive force.

When current flows through the battery, there is a potential drop due to the internal resistance of the cell. Hence terminal p.d. is always smaller than e.m.f. [B1]

[1]

(b) Fig. 3.1 shows a circuit containing a cell and four resistors.

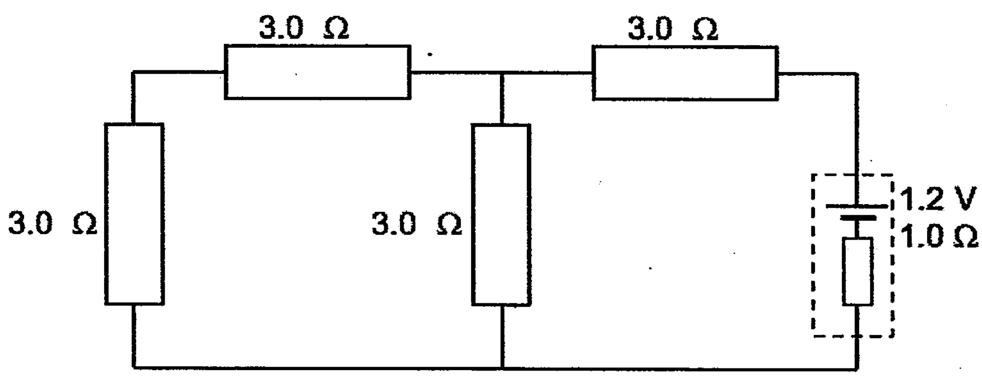


Fig. 3.1

Calculate

(i) the current through the 1.2 V cell,

Solution

$R_T = \left(\frac{1}{6.0}+\frac{1}{3.0}\right)^{-1} + 3.0 + 1.0$ M0

$R_T = 6.0\ \Omega$ M1

$I = \frac{E}{R_T} = \frac{1.2}{6.0} = 0.2\ \text{A}$ A1

current = ... A [2]

(ii) the terminal p.d. of the 1.2 V cell,

$V = E - Ir$

$V = 1.2 - 0.2(1.0)$ M0

$V = 1.0\ \text{V}$ A1

terminal p.d. = ... V [1]

(iii) the efficiency of the circuit.

$$\frac{P_V}{P_E} = \frac{IV}{IE}$$

$$\frac{P_V}{P_E} = \frac{1.0}{1.2} \qquad \text{M0}$$

$$\frac{P_V}{P_E} =$$ [redacted] 83% A1

efficiency = ... % [1]

(c) Fig. 3.2 below shows 2 coils X and Y wound on a soft iron core.

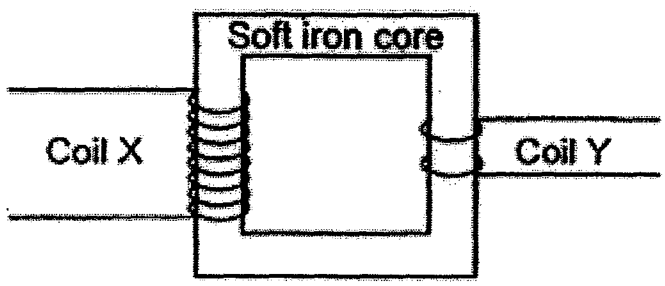


Fig. 3.2

The inputs of coil X is now connected to a 240 V mains supply, where the current changes directions 100 times per second. The output of coil Y is connected to a 12 V, 3.0 A light bulb, the bulb is working normally.

(i) Assuming that the efficiency of the transformer is 90%, make use of energy considerations to calculate the current in coil X.

$$P_{out} = VI = 12(3) = 36 \text{ W} \qquad \text{M0}$$

$$P_{in} = \frac{P_{out}}{0.90} = 40 \text{ W} \qquad \text{M1}$$

$$I_{in} = \frac{P_{in}}{V_{in}} = \frac{40}{240} = 0.167 \text{ A} \qquad \text{A1}$$

current = ... A [2]

(ii) Suggest one reason why the transformer is not 100% efficient.

Loss of energy through generation of eddy currents in the soft iron core.
Loss of energy through hysteresis effect
Loss of energy through heat generated by current flowing through the solenoids and wires.

..... [1]

4 (a) State the laws of electromagnetic induction.

Faraday's law of electromagnetic induction states that the **induced e.m.f.** ε is **directly proportional** to the **rate of change of magnetic flux linkage** Φ. [B1]
Lenz's law states that the **induced e.m.f. will be directed** such that the **current** which it causes to flow **opposes the change that is producing it**. [B1]

.... [2]

(b) (i) A solenoid is connected in series with a resistor, as shown in Fig. 4.1.

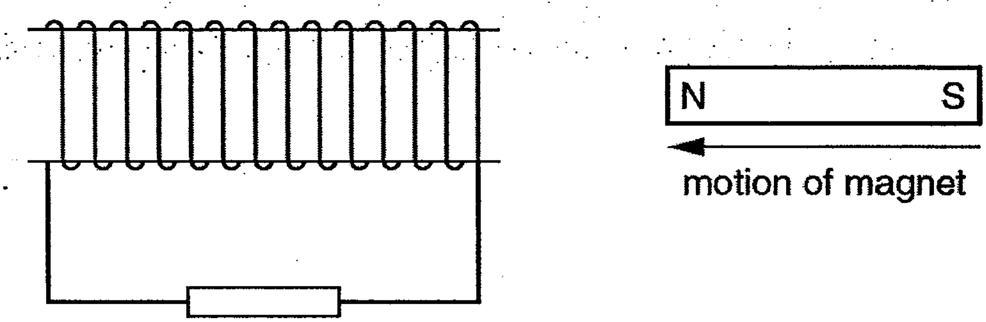


Fig. 4.1

As the magnet is being moved into the solenoid, thermal energy is generated in the resistor.

Use the laws of electromagnetic induction to explain the origin of this thermal energy.

1. As the magnet approaches the solenoid, the **magnetic field strength** in the region in the solenoid **increases**. Hence the **magnetic flux linkage** through the solenoid **increases.** [B1]
2. **By Faraday's law, an e.m.f. is induced** in the solenoid that is directly proportional to the rate of change of magnetic flux linkage. **An induced current thus flows through the circuit** causing the **resistor to heat up**. [B1]
3. By lenz's law, the induced current will flow in the clockwise direction in the circuit so as to produce **an induced north pole facing the approaching magnet**. **Work is done by an external force** to **overcome the repulsive force** and move the magnet towards the solenoid. [B1]
4. Hence, the **mechanical work done by the external force** is **converted into electrical energy** and **eventually thermal energy in the resistor.** [B1]

....

....

.... [4]

For Examiner's Use

(ii) Draw in Fig. 4.1. the direction of the induced current in the solenoid. [1]

(c) Explain why the alternating current in the primary coil of a transformer is not in phase with the alternating e.m.f. induced in the secondary coil.

The **alternating current in the primary coil** sets up **a changing magnetic field in the primary coil and hence the soft iron core.** [B1]

Thus the **primary current** is **in phase with the changing magnetic field and magnetic flux in the soft iron core, and also the magnetic flux linkage in the secondary coil.** [B1]

By Faraday's law, the **changing magnetic flux linkage** in the secondary coil **induces an emf** in the secondary coil. [B1]

This induced emf is in phase with the rate of change of magnetic flux linkage in the secondary coil, **and not the magnetic flux linkage per se.** Thus the **induced emf is not in phase with the primary current.** [B1]

[4]

5 (a) Explain, using band theory, why the conductivity of an intrinsic semiconductor increases when temperature increases.

When temperature increases, more electrons are able to gain sufficient energy to overcome the narrow forbidden band (or energy gap) to transit into the conduction band. [B1]
Thus, its conductivity increases due to the increase in the number of charge carriers with temperature. More electrons in the conduction band and more holes in the valence band. [B1]

[2]

(b) Explain why the conductivity of a metal decreases when temperature increases.

When temperature increases, the lattice ions vibration will also increase. [B1]
This causes the net flow of the charge carriers across the metal to be impeded due to the frequent collisions the charge carriers make with the lattice ions. Thus, its conductivity is reduced. [B1]

[2]

For Examiner's Use

(c) **(i)** Explain, using band theory, how the introduction of small amounts of Group 5 impurities to intrinsic semiconductors improves their conductivities.

In a n-type semiconductor, the donor atoms introduce an energy level (called **donor level)** that is just slightly below the conduction band.[B1]
As the **energy gap is smaller** now, more electrons are able to move from the donor level to the conduction band. The increased in the number of electrons increase the conductivity of the n-type semiconductor. [B1]

[2]

(ii) However, when too many impurity atoms are introduced, as in the case of highly-doped semiconductors, the resistance of the semiconductor actually increases, rather than decrease, when temperature increases.

With reference to your answer to **(b)**, suggest a reason for this behavior of highly-doped semiconductors.

A highly doped semiconductor will have relatively larger number of charge carriers causing it to **behave more like a conductor (metal).** Thus, when the temperature increases, with increased lattice ions and charge carriers interaction, the electron flow is hampered and so its resistance will increase. [B1]

[1]

For Examiner's Use

6 A scintillation counter is an instrument that detects and measures high energy charged particles. A scintillation counter comprises three main components i.e.

Component 1: Scintillator material
Component 2: Photocathode
Component 3: Photomultiplier tube

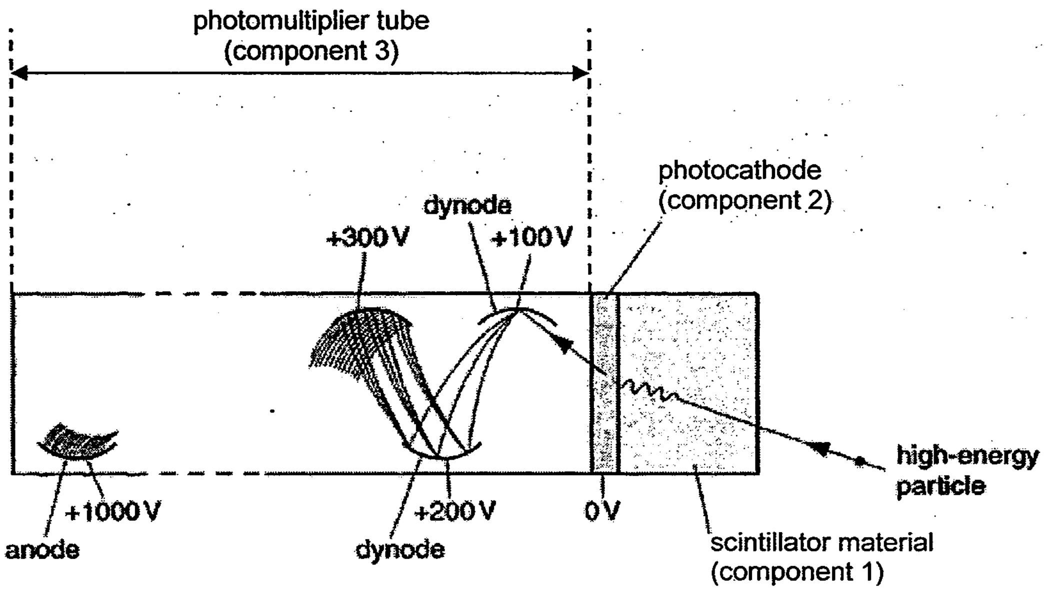


Fig 6.1

(a) In the scintillator material (component 1), high energy particles interact with the material to produce photons.

In one particular experiment, high energy particles produce 90 nW of light of wavelength 400 nm in the scintillator material.

(i) Calculate the energy, E_p, of a single photon of wavelength 400 nm.

Solution

$E_p = hf = h(c/\lambda) = (6.63\text{x}10^{-34})(3\text{x}10^{8}/(400\text{x}10^{-9}))= 4.97\text{x}10^{-19}$ J [A1]

E_p = ... J [1]

(ii) Show that the rate of photons produced in the scintillator, n_p, is 1.81×10^{11} s^{-1} .

[1]

Solution

power of em radiation

$P = N_pE_p/t$

$n_p = P/E_p$

$N_p/t = (90\text{x}10^{-9}) /(4.9725\text{x}10^{-19})$ [M1] = 1.8099x 10 $^{-11}$ = 1.8 x 10^{-11} s^{-1}

(b) When the photons produced in the scintillator material (component 1) reaches the photocathode (component 2), the photons eject some of the surface electrons due to the photoelectric effect.

Radiant sensitivity, S, is defined as the photoelectric current generated by the photocathode divided by the incident radiant flux, ϕ of the incoming photons from the scintillator material.

S is expressed in units of amperes per watts (A W^{-1}).

(i) Starting from the definition of radiant sensitivity and/ or examining its units, show that radiant sensitivity, S, is given by:

$$S = \frac{n_e e \lambda}{n_p h c}$$

where n_e is the rate of emission of photoelectrons and n_p is the rate of photons produced in the scintillator material.

Show your working clearly.

[1]

$S = \frac{I_P}{P} = \frac{n_e e}{n_p E_p} = \frac{n_e e}{n_p h \frac{c}{\lambda}}$ where n_p is the rate of photons incident on the photocathode, h is the Planck constant, c is speed of light in vacuum, λ is wavelength of incident radiation (in m)

(ii) Quantum efficiency, η, is defined as the number of photoelectrons emitted, N_e, from the photocathode divided by the number of incident photons, N_p.

$$\eta = \frac{N_e}{N_p}$$

Quantum efficiency can also be calculated from the radiant sensitivity, S, of the photocathode.

Using the expression for S in **b(i)** or otherwise, show that the quantum efficiency, η, can be expressed as:

$$\eta = 1.24 \times 10^{-6} \frac{S}{\lambda}$$

[2]

$$\eta = \frac{N_e}{N_p} = \frac{n_e t}{n_p t}$$

$$S = \frac{n_e e}{n_p h \frac{c}{\lambda}} = \frac{n_e t e}{n_p t h \frac{c}{\lambda}}$$

$$\eta = \frac{h \frac{c}{\lambda}}{e} S = \frac{6.63 \times 10^{-34} (3 \times 10^{8})}{1.6 \times 10^{-19}} \frac{S}{\lambda}$$

$$\eta = 1.24 \times 10^{-6} \frac{S}{\lambda}$$

(c) Fig. 6.2 shows the variation of the radiant sensitivity, S with the wavelength of the incident photons, for various types of photocathodes.

The graph uses a logarithmic scale.

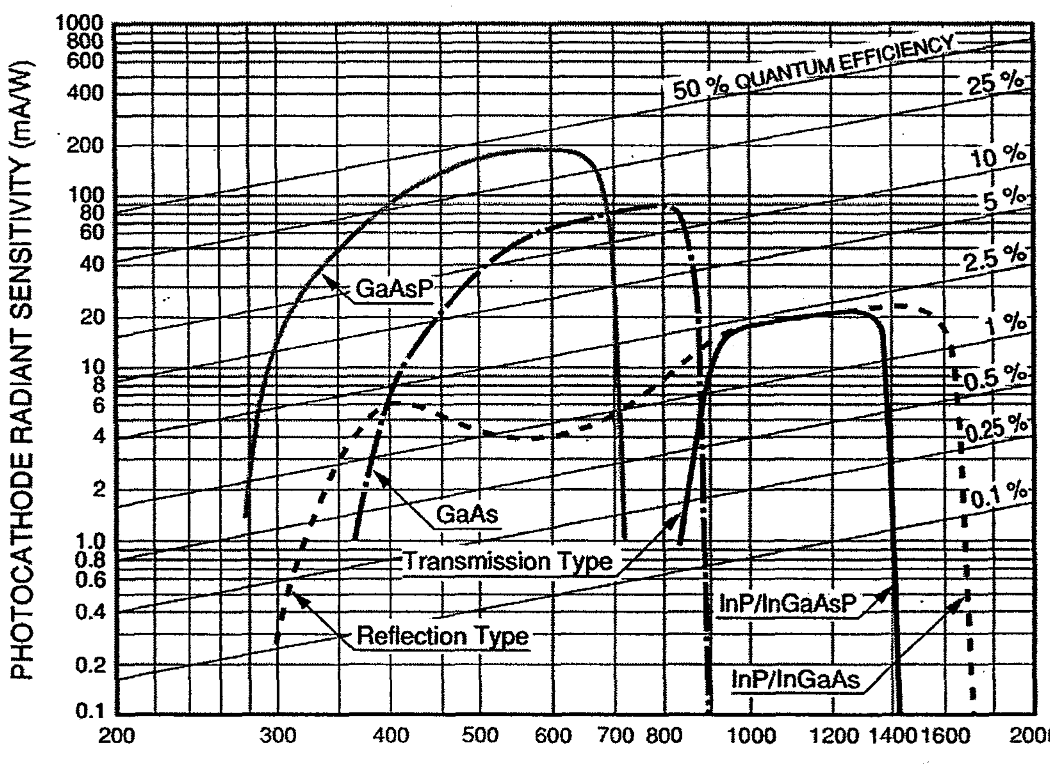


Fig. 6.2

In the experiment detailed in **(a)**, the Gallium Arsenide Phosphide (GaAsP) photocathode was used in the scintillation counter.

(i) Using Fig. 6.2, state and explain which photocathode would not have been suitable for use in the experiment.

InP/InGaAsP (or transmission type)[A1] is not suitable for use in this experiment because it can only detect radiation over a narrow range of between 850 and 1400 nm, which is in the infra-red region. [B1]

For Examiner's Use

....

.... [2]

(ii) Using values from Fig. 6.2, determine the rate of emission of photoelectrons, n_e from the GaAsP photocathode in the experiment detailed in **(a)**.

Solution
From the graph, when λ=400 nm, S=90 mA/W. [A1-graphical interpretation skill]

$$\eta = \frac{1.24\times10^{-6}}{\lambda}S = \frac{1.24\times10^{-6}}{400\times10^{-9}}(90\times10^{-3}) = 0.279$$

$$\eta = \frac{n_e}{n_p} = \frac{n_e}{1.8\times10^{11}} = 0.279$$

$$n_e = 5.02\times10^{10}$$

[M1- correct use of the formula in (b)(ii)]
[A1- correct final answer]

n_e = ... s^{-1} [3]

(d) In the photomultiplier tube (component 3), the photoelectrons emitted from the photocathode are accelerated towards the first positive dynode because of the 100 V potential difference between the dynode and the photocathode.

The kinetic energy of the electron is sufficient to eject, on average, 3 'secondary' electrons from the dynode. These electrons are then accelerated towards the next dynode and the whole process is repeated.

Eventually a tiny pulse of charge is detected at the anode in the photomultiplier tube and measured as the anode current.

(i) The work function energy of the photocathode material is 3.5×10^{-19} J .

Calculate the maximum kinetic energy of the photoelectrons just ejected from the photocathode due to the photoelectric effect.
Solution

$$E_P = \phi + E_{k\max}$$

$$4.97x10^{-19}\text{J} = 3.5\ x\ 10^{-19}\text{J} + E_{k\max}$$

$$E_{k\max} = 4.97x10^{-19} - 3.5\ x\ 10^{-19}[M1] = 1.47\ x\ 10^{-19}\text{J}\ [A1]$$

Allow ecf

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

(ii) For a photomultiplier with 10 dynodes, show that the number of electrons arriving at the anode for **each** photoelectron emitted from the cathode is 3^9

Explain your working.

[1]

Solution

No. of electrons arriving at the node for each photoelectron emitted from cathode:

For 1st dynode: 1 photoelectron arrives = 3^0

For 2nd dynode: 3 photoelectrons arrive = 3^1

For 3rd dynode: 9 photoelectrons arrive = 3^2

....

For 10th dynode: 3^9 = 19683 photoelectrons arrive

(iii) Determine the current detected by the photomultiplier tube's anode.

Solution

$I = An_e e$

$I = 19683(5.022 \times 10^{10})(1.6 \times 10^{-19})$[M1] [A1]

$I = 1.58 \times 10^{-4}$ A

Allow ecf

current = ... A [2]

7 The efficiency η of a glowing filament may be expressed as

$$\eta = \frac{\text{light energy emitted in the visible range}}{\text{electrical energy input}}$$

As light energy emitted in the visible range can be difficult to measure, the efficiency could instead be determined by measuring the amount of wasted energy produced by the filament in the form of thermal energy. The efficiency is subsequently calculated using

$$\eta = 1 - \frac{\text{thermal energy}}{\text{electrical energy input}}$$

The efficiency is thought to depend on the temperature, T of the filament. The relationship between the efficiency and the temperature may be written in the form:

$$\eta = aT^b$$

where a and b are constants.

You are provided with a filament, a beaker with water that is to be used in the determination of the thermal energy produced by the glowing filament, and an infrared thermometer. You may also use any of the other equipment usually found in a physics laboratory.

Design an experiment to determine the relationship between η and T.

You should draw a labelled diagram to show the arrangement of your apparatus. In your account you should pay particular attention to:

(a) the identification and control of variables,
(b) the equipment you would use,
(c) the procedure to be followed,
(d) how the relationship between η and T is determined from your readings,
(e) any precautions that would be taken to improve the accuracy and safety of the experiment.

Diagram

Q8 Thinking Process

Independent Variable: Temperature of the filament, measured using [illegible] thermometer. Temperature of the filament can be varied by varying the electrical power supplied to the filament.

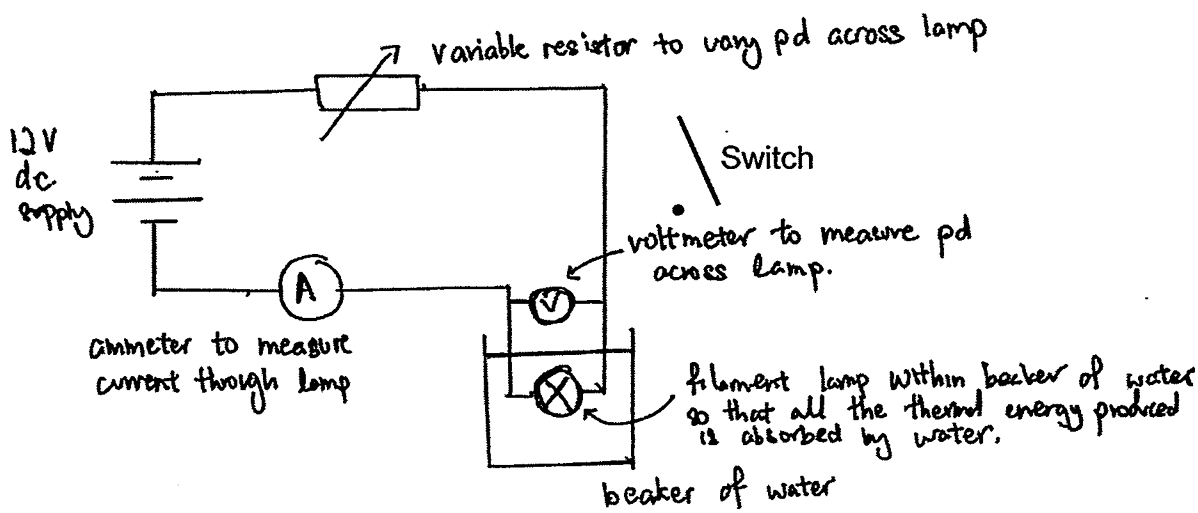
Dependent Variable: Efficiency

Requires the **thermal energy** supplied by lamp to water to be measured.
Possible equation to use would be $E = mc\Delta\theta$.
Specific heat capacity of water is known but mass of water and change in temperature needs to be measured.
Mass of water measured using mass balance while change in temperature can be measured using the infrared thermometer.

Electrical energy supplied to lamp also needs to be measured.
Possible equation to use would $E = P.t = I.V.t$
Current and p.d. would require ammeter connected in series, and voltmeter connected in parallel to measure. time can be measured using a stop watch.

Possible Control Variables: Mass of water, time in heating water.

Labelled Diagram (Max: 2 marks)
[D1 x 2]



Award one mark only if both are satisfied:

Filament bulb is connected to a **d.c. power supply**.

Circuit should have a **variable resistor**, **an ammeter** connected in series, and **a voltmeter** connected across the lamp.

[Variable resistor can be omitted if student specifies that the voltage input can be varied. If batteries are used than variable resistor is required.]

Award one mark if :

Filament lamp should be **immersed in a beaker of water**.

Control Variables (Max: 2 marks)
[C1x2]

- Keep the **mass of water** used to determine the thermal energy produced by the lamp **constant**.

  This is achieved by **reading the volume of the water in the beaker**, and **ensuring that it remains at the same fixed value before each measurement.**

- Keep the **duration over which the water is heated a constant.**

  We can use a **stopwatch** to ensure that the water is **heated for a fixed time** e.g. 5 mins before proceeding to record the readings.

Procedure and Measurement (Max: 3 marks)
[P1x3]

Award 1 mark for:

1. Measure the mass of water using a mass balance. Remember to tare the mass balance before adding water to the empty beaker so that only the mass of the water is recorded.
2. Measure the initial temperature T_i of the water using the infra-red thermometer.
3. Set the variable resistor to a low resistance value, close the switch, and start the stop watch.
4. Record the readings for current, I from the ammeter, readings for the p.d. across the lamp, V are read from the voltmeter, once the values have stabilised.
5. After 5 minutes, open the switch.
6. Remove the bulb from the water, measure and record the highest temperature reached on the infrared thermometer, T_f for the water.
7. Also, measure and record the highest temperature reached on the infrared thermometer, T for the filament.

Award 1 mark for:

8. The thermal energy supplied can be calculated by $E_{\text{thermal}} = m_{\text{water}} c \Delta\theta = m_{\text{water}} c (T_f - T_i)$, where c is the specific heat capacity of water which is a known constant.
9. The electrical energy input can be calculated using $E_{\text{input}} = I.V.t$ where t is the time taken to heat the water which is 5 min or 300 s.
10. The efficiency η can be calculated using $\eta = 1 - \dfrac{E_{\text{thermal}}}{E_{\text{input}}} = 1 - \dfrac{m_{\text{water}} c (T_f - T_i)}{I.V.t}$

Award 1 mark for:

11. Repeat steps 1 – 9 for another 9 different values of resistance across the variable resistor to obtain a total of 10 sets of readings for temperature of the filament lamp and efficiency i.e. (T, η)
12. Tabulate the values for temperature and efficiency.

For Examiner's Use

Analysis Mark (Max: 2 marks)
[A1x2]

Award 1 mark for:

Plot a graph of lg η against lg T.
The relationship of $\eta = aT^b$ is valid if the plotted points follow the trend of a straight line graph.

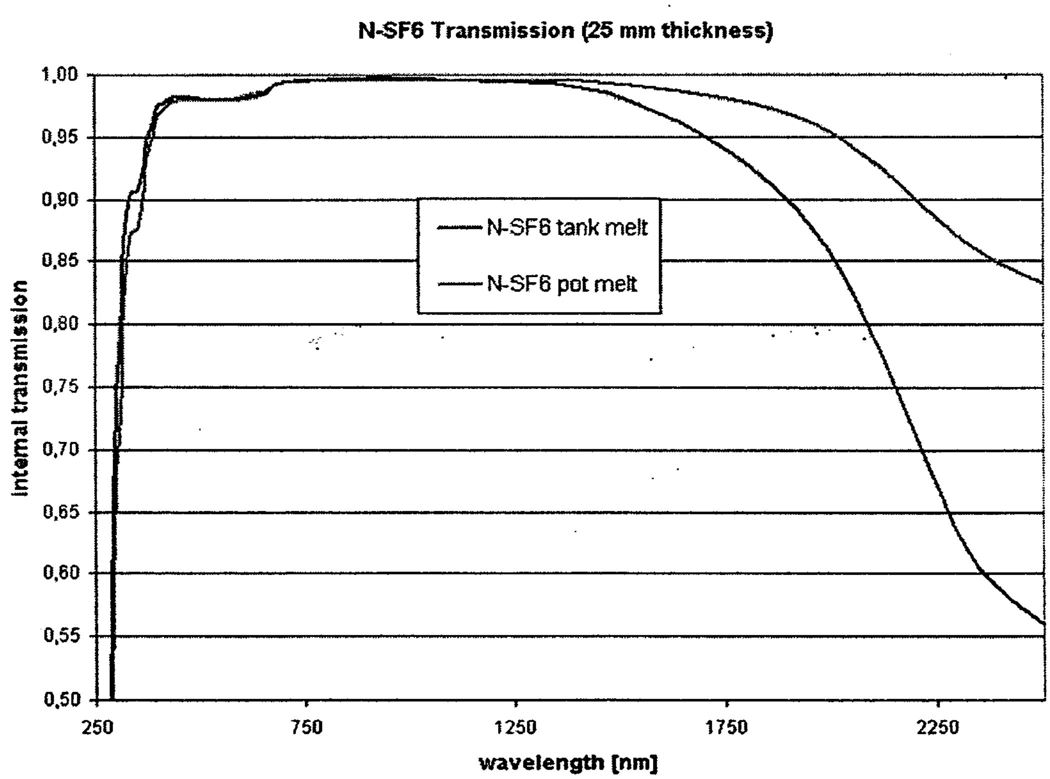
Award 1 mark for:

If the relationship is valid, then b can be determined from the gradient of the straight line graph, and
a can be calculated from the vertical intercept which is equal to *lg* a.

Reliability measures (Max: 2 marks)
[R1x2]

Any 2 of the following:

- Use a **stirrer to periodically stir** the water to ensure that the **water is of uniform temperature** before measuring the temperature.
- Place the **beaker of water in a styrofoam box** to **minimize heat loss to the surroundings.**
- *For stronger students*: the **wavelength used by the infra-red thermometer** must **not be absorbed by the glass bulb surrounding the filament**, this is ensured by **checking the IR wavelength used by the thermometer against the absorption or transmission spectrum of the glass bulb.**



The graph above is **an example of transmission spectrum for a type of glass** but made under two different conditions. If the filament is made using such a glass, the IR wavelength you would like to use on the IR thermometer would be from 800 nm – 100 nm where the transmission is almost 100%.

Safety Precautions [Max: 1 mark]

[S1]

- Use gloves when handling the hot beaker of water or adjusting the hot filament bulb to prevent being burned.

JC 2 PRELIMINARY EXAMINATION
in preparation for General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME			
CLASS		INDEX NUMBER	

PHYSICS 9646/03

Paper 3 Longer Structured Questions

25 August 2016

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams or 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 any **two** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in the brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	7
2	9
3	7
4	7
5	10
6	20
7	20
8	20
Significant Figures	
Total	**80**

Data

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

Formulae

uniformly accelerated motion,	s	$= ut + \frac{1}{2}at^2$
	v^2	$= u^2 + 2as$
work done on/by a gas,	W	$= p\Delta V$
mean kinetic energy of a molecule of an ideal gas	E	$= \frac{3}{2}kT$
hydrostatic pressure,	p	$= \rho gh$
gravitational potential,	Φ	$= -\frac{GM}{r}$
displacement of particle in s.h.m.	x	$= x_o \sin \omega t$
velocity of particle in s.h.m.	v	$= v_o \cos \omega t$
		$= \pm\omega\sqrt{\left(x_o^{\ 2} - x^2\right)}$
resistors in series,	R	$= R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	$= 1/R_1 + 1/R_2 + \ldots$
electric potential	V	$= Q/4\pi\varepsilon_o r$
alternating current/voltage,	x	$= x_o \sin \omega t$
transmission coefficient	T	$\propto \exp(-2kd)$
		where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	x	$= x_o \exp(-\lambda t)$
decay constant,	λ	$= \frac{0.693}{t_{1/2}}$

For Examiner's Use

Section A

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

1 An Olympic ski jumper skis down a slope and launches off a cliff, landing on the ground a short time later. The mass of the ski jumper and his equipment is 80 kg.

Fig. 1.1 below shows the ski jumper just before he leaves the slope with a velocity of 20 m s^{-1} in the horizontal direction.

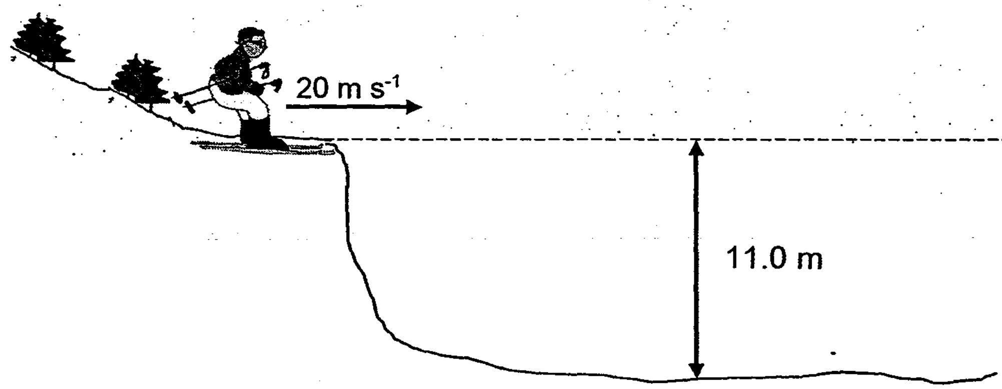


Fig 1.1

The ski jumper falls through a vertical distance of 11.0 m before landing on the ground.

(a) Calculate

(i) the time of flight of the ski jumper,

time of flight = ... s [1]

(ii) the horizontal distance travelled by the ski jumper during this time,

horizontal distance = ... m [1]

For Examiner's Use

(iii) the velocity of the ski jumper just before he lands.

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

direction: .... ° below the horizontal [1]

(b) By considering Newton's 2nd Law, explain how the snow covering the ground enables the ski jumper to land safely despite the high landing speed.

....

....

....

.... [2]

2 **(a)** State Newton's law of gravitation.

....

....

.... [1]

(b) The Earth and the Moon may be considered to be isolated in space with their masses concentrated at their centres.

The orbit of the Moon around the Earth is circular, with a radius of 3.84×10^5 km. The period of the orbit is 27.3 days.

Show that

(i) the angular speed of the Moon in its orbit around the Earth is 2.66×10^{-6} rad s^{-1}.

[1]

(ii) the mass of the Earth is 6.0×10^{24} kg.

[2]

(c) The mass of the Moon is 7.4×10^{22} kg.

(i) Using data from **(b)**, determine the gravitational force between the Earth and the Moon.

force = ... N [2]

For Examiner's Use

(ii) Tidal action on the Earth's surface causes the radius of the Moon's orbit to increase by 4.0 cm each year.

Using your answer to **(c)(i)**, determine the change of the Moon's gravitational potential energy in one year.

Explain your working.

change in Moon's gravitational potential energy = ... J [3]

3 **(a)** A simple pendulum is given a small displacement from its equilibrium position and performs *simple harmonic motion.*

State what is meant by *simple harmonic motion.*

....

....

.... [2]

(b) The length of a pendulum l is measured to be 30.0 cm. The angular frequency of the simple pendulum is given by $\sqrt{\frac{g}{l}}$, where g is the acceleration of free fall. Determine the period of this simple pendulum.

period = ... s [2]

(c) A simple pendulum of period 1.90 s is set up alongside another pendulum of period 2.00 s. Both pendulums are displaced in the same direction and released at the same time.

Calculate the time interval until they next move in phase.

time interval = ... s [3]

4 A long rope is held under tension between two points A and B. Point A is made to oscillate vertically and a wave is sent down the rope towards B as shown in Fig. 4.1.

For Examiner's Use

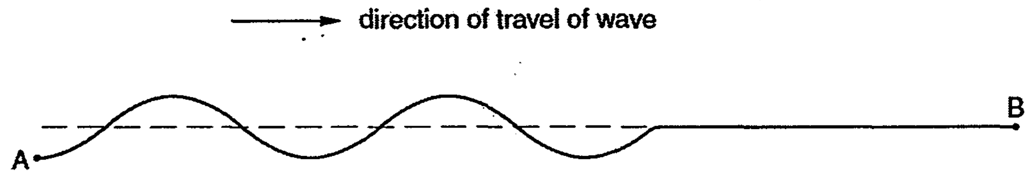


Fig. 4.1

The time for one oscillation of point A on the rope is 0.20 s. The point A moves a total distance of 80 mm during one oscillation. The wave on the rope has a wavelength of 1.5 m.

(a) **(i)** Explain the term *displacement* for a particle in the wave, on the rope.

....

.... [1]

(ii) Calculate, for the wave on the rope,

1. the amplitude,

amplitude = ... mm [1]

2. the speed.

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

(b) Draw on Fig.4.1, the wave pattern on the rope at a time 0.050 s later than that shown.

[1]

For Examiner's Use

(c) State and explain, whether the wave on the rope is

(i) progressive or stationary,

....

.... **[1]**

(ii) longitudinal or transverse.

....

.... **[1]**

For Examiner's Use

5 **(a)** Fig. 5.1 below shows a filament lamp emitting white light, and is surrounded by a region of cooler helium gas.

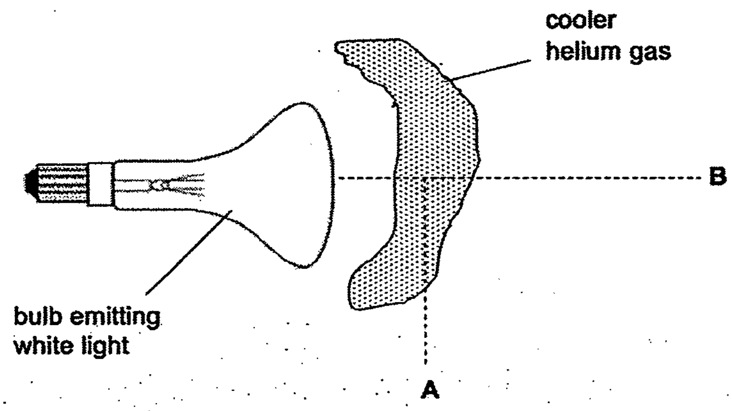


Fig. 5.1

(i) State if a helium *absorption* or *emission* spectrum is observed from

1. point A,

.... [1]

2. point B.

.... [1]

(ii) Explain the formation of the helium spectrum observed from point A.

....

....

....

....

.... [2]

(b) Fig. 5.2 shows some of the energy levels of an isolated helium atom.

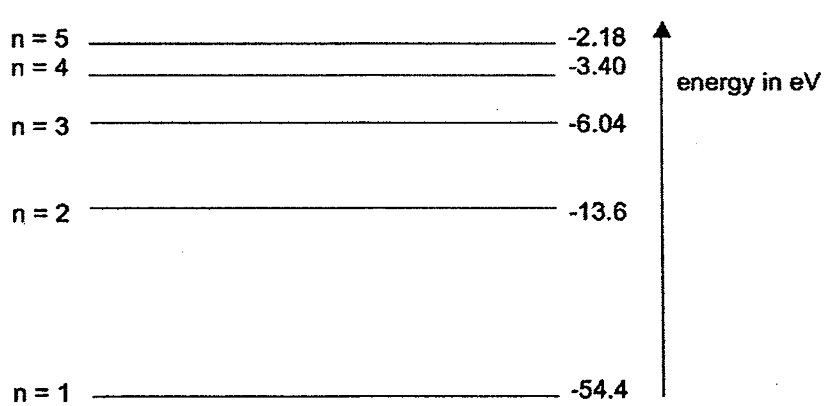


Fig. 5.2

An electron with a kinetic energy of 50 eV collides inelastically with a helium atom in the ground state.

(i) Draw, in Fig. 5.2, the possible downward transitions of the excited helium atom following this collision.

[2]

(ii) Calculate the shortest wavelength of the radiation that is emitted from the transitions in **(b)(i)**.

wavelength = ... m [1]

(iii) Hence state the type of radiation for the wavelength calculated in **(b)(ii)**.

.... [1]

(iv) Explain what happens if UV photons of energy of 50 eV had been used to excite the ground state helium atoms instead 50 eV electrons.

....

....

....

.... [2]

Section B

For Examiner's Use

Answer **two** questions in this section.

6 **(a)** State Coulomb's law in electrostatics.

....

....

.... [1]

(b) Fig. 6.1 shows two identical conducting spheres A and B, each carrying a charge of +Q. They are placed in a vacuum with their centres separated by a distance d, where d is of the same order of magnitude as the radii of the two spheres.

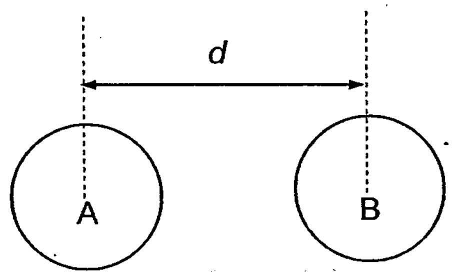


Fig. 6.1

Explain why the electric force, F between the two spheres is not given by the expression:

$$F = \frac{Q^2}{4\pi\varepsilon_0 d^2}$$

....

....

....

.... [2]

(c) An isolated conducting sphere R has a radius of 40.0 cm, and the charge on the sphere is +6.67 nC.

(i) Show that the potential on the surface of sphere R is 150 V.

[2]

(ii) A second conducting sphere S which is electrically neutral is now brought close to R. S has a radius 20.0 cm.

A wire is used to connect the surface of sphere S to that of sphere R. After connecting, the charges will redistribute themselves between the surfaces of the two spheres until the potential on the surfaces of both spheres are the same.

Show that $\dfrac{\text{final charge on S}}{\text{final charge on R}} = \dfrac{1}{2}$.

[2]

(iii) Hence, determine the final electric potential on the surface of the two spheres.

potential = ... V [3]

(d) Fig. 6.2 shows two parallel metal plates P and Q situated 8.0 cm apart in air.

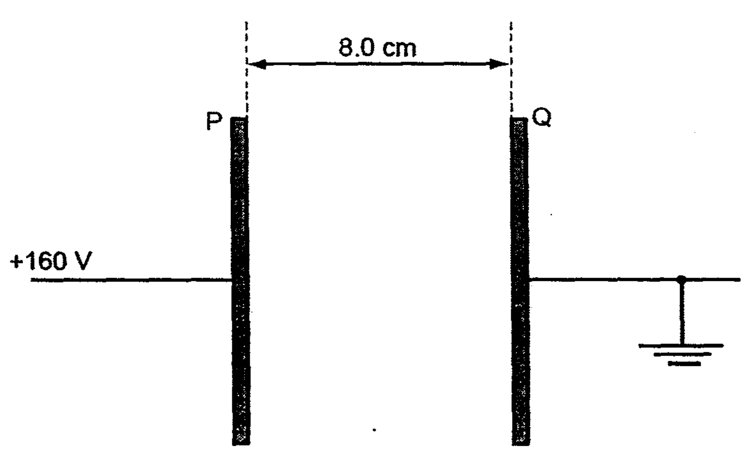


Fig. 6.2

Plate Q is earthed while plate P is maintained at a potential of +160 V.

(i) On Fig.6.2, draw lines to represent the electric field in the region between the plates.

[2]

(ii) Show that the magnitude of the electric field strength between the plates is 2000 V m^{-1}.

[1]

(iii) A dust particle is suspended in the air between the plates. The particle has charges of $+1.2\times10^{-15}$ C and -1.2×10^{-15} C near its ends.

The charges may be considered to be point charges separated by a distance of 2.5 mm, as shown in Fig. 6.3.

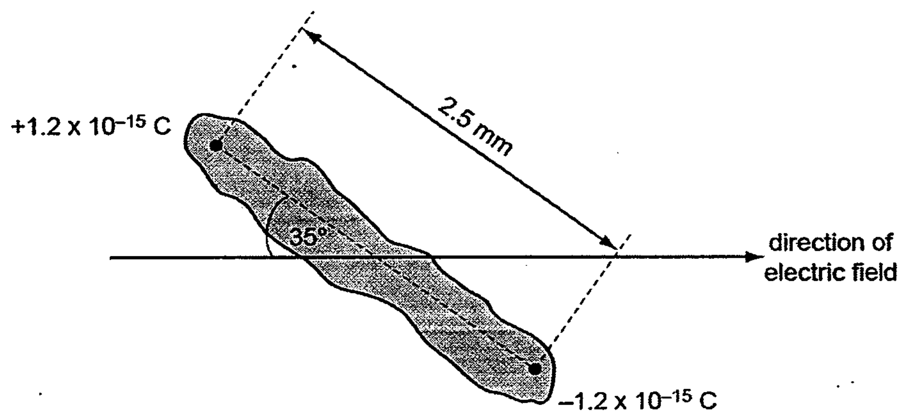


Fig. 6.3

The particle makes an angle of 35° with the direction of the electric field.

1. Draw on Fig.6.3, arrows to show the direction of the electric force on each charge due to the electric field.

[1]

2. Calculate the magnitude of the electric force on each charge due to the electric field.

force = ... N [2]

3. Determine the magnitude of the couple acting on the particle at this instant.

couple = ... N m [2]

4. Suggest the subsequent motion of the particle in the electric field.

....

....

....

.... [2]

For Examiner's Use

For Examiner's Use

7 (a) State what is meant by

(i) *nuclear binding energy,*

....

.... [1]

(ii) *nuclear fusion.*

....

.... [1]

(b) A possible reaction for use in a nuclear fusion reactor is one in which the deuterium and tritium nuclei fuse together to produce a helium nucleus.

Fig. 7.1 below shows the nuclear binding energies (BE) per nucleon for some particles.

particle	BE per nucleon / MeV
neutron, $^{1}_{0}n$	0
deuterium, $^{2}_{1}H$	1.11
tritium, $^{3}_{1}H$	2.83
helium, $^{4}_{2}He$	7.07

Fig. 7.1

(i) Complete the following nuclear equation to represent the fusion of the deuterium and tritium nuclei.

$^{2}_{1}H + ^{3}_{1}H \rightarrow$ .... + ... + energy released

[1]

(ii) Using values from Fig. 7.1, determine the energy released in the process in **b(i).**

energy released = ... MeV [2]

(iii) Fig. 7.2 below shows the masses for the neutron and various nuclei.

particle	mass / u
neutron, ${}^{1}_{0}n$	1.00867
deuterium, ${}^{2}_{1}H$	2.01356
tritium, ${}^{3}_{1}H$	3.01551
helium, ${}^{4}_{2}He$	4.00151

Fig. 7.2

By considering the change in mass during the nuclear fusion reaction, determine the energy released in the process in **(b)(i)**.

energy released = ... MeV [2]

(iv) Suggest why for nuclear fusion reactions to take place, high temperatures are required.

....

....

....

....

.... [3]

(v) In the doughnut-shaped Tokamak Fusion Test Reactor, the deuterium-tritium fuel can reach temperatures of up to 5.1×10^{8} K, more than thirty times the core temperature of the sun.

No material can withstand the extreme temperature of the deuterium-tritium fuel.

Suggest one way of confining the deuterium-tritium fuel in the fusion reactor, without the walls of the reactor coming into contact with it.

....

....

.... [2]

(vi) Suggest one advantage of nuclear fusion over nuclear fission as a means of energy production.

....

.... [1]

(c) The mass of a sample of Tritium is 1.0 g. The nuclide Tritium has a *half life* of 12.3 years.

(i) Define *half life* of a radioactive substance.

....

.... [1]

(ii) Find the number of Tritium atoms in the sample.

number of Tritium atoms = ... atoms [1]

(iii) Determine the decay constant for Tritium.

decay constant = ... s^{-1} [2]

(iv) Calculate the fraction of Tritium atoms which remained after 20 years.

fraction = ... [3]

8 **(a)** Define the *tesla*.

....

....

.... [3]

(b) An electron is travelling with momentum p in a vacuum. It enters a region of uniform magnetic field of flux density 0.24 T, as shown in Fig. 8.1.

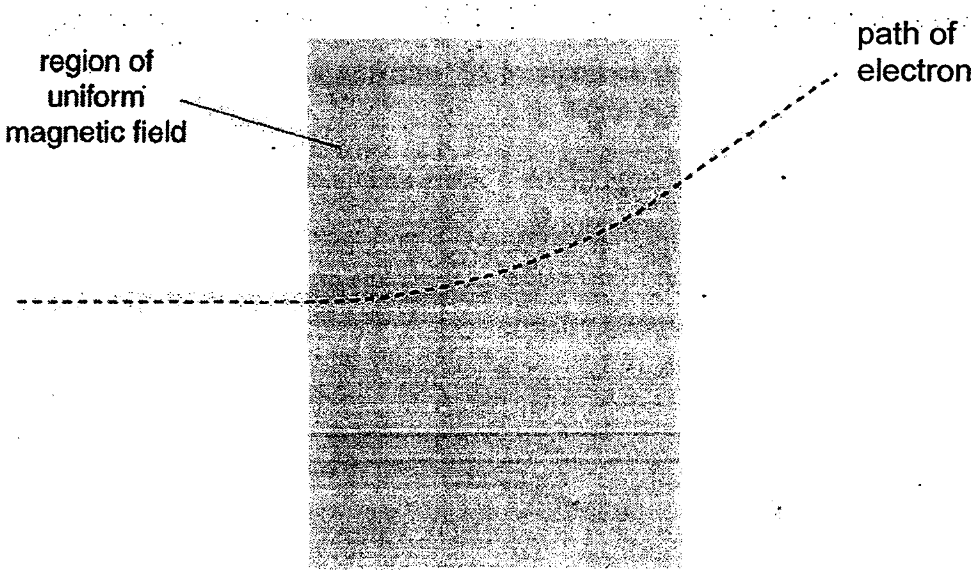


Fig. 8.1.

When the electron is in the magnetic field, it is travelling at right-angles to the direction of the field.

(i) Explain why the path of the electron in the magnetic field is an arc of a circle.

....

....

....

....

....

.... [3]

(ii) Draw in Fig. 8.1. the direction of the magnetic field. [1]

For Examiner's Use

(iii) The radius of the circular path of the electron in the magnetic field is 6.2 cm.

For Examiner's Use

Calculate the momentum p of the electron.

p = ... N s [3]

(c) Electrons are produced in beta decay. One example would be the beta decay of the Bismuth-210 nucleus to produce an electron and a Polonium-210 nucleus.

Fig. 8.2 below shows the tracks formed by the electron and the Polonium-210 nucleus, following the decay of an initially stationary Bismuth-210 nucleus, in a cloud chamber.

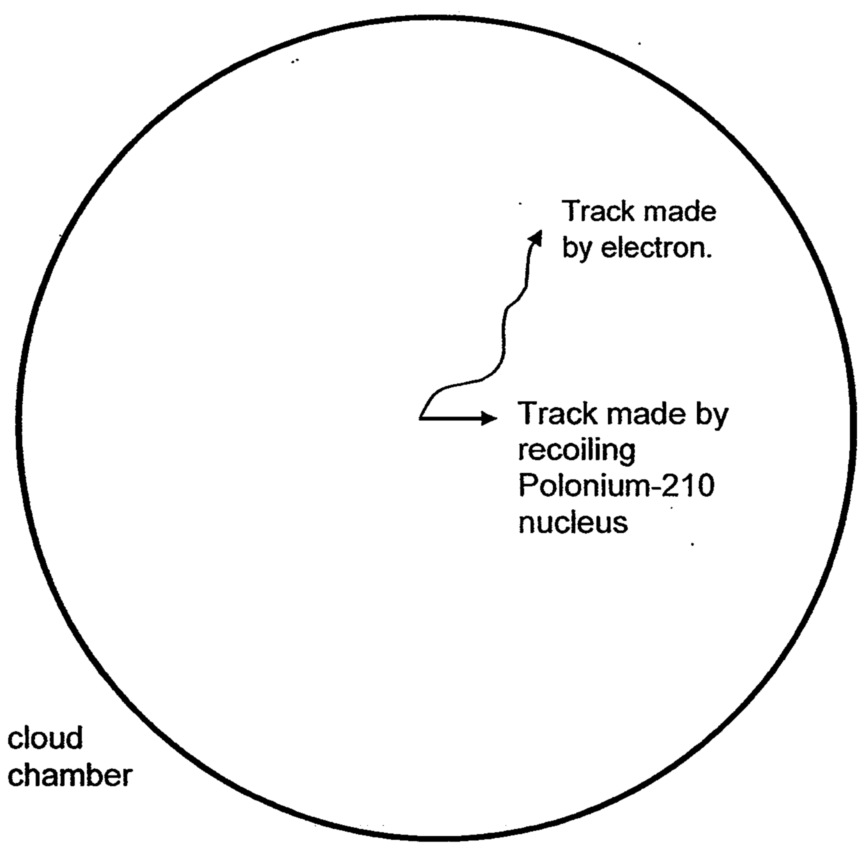


Fig. 8.2

(i) With reference to the directions of the cloud chamber tracks, and the principle of conservation of momentum, explain how a third particle (now known as the anti-neutrino) must have been formed despite not being seen in the cloud chamber.

....

....

....

....

.... [3]

(ii) Draw in Fig. 8.2. an arrow showing the path of the anti-neutrino. [1]

(d) An X-ray photon of wavelength 965.0×10^{-12} m collides elastically with a stationary electron, as illustrated in Fig. 8.3.

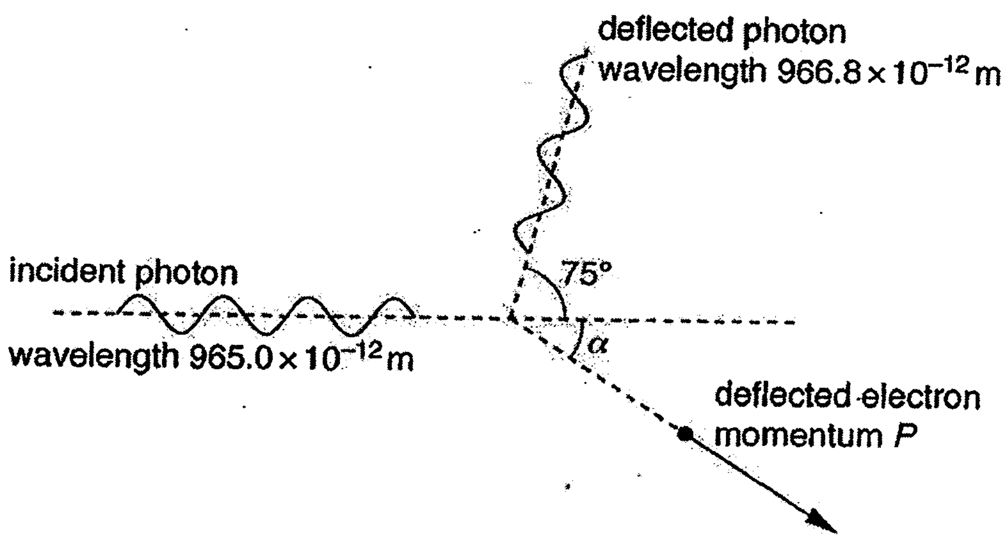


Fig. 8.3.

The photon is deflected through an angle of 75° and has a wavelength of 965.0×10^{-12} m . The electron is deflected through an angle α and has a momentum of 8.36×10^{-25} N s.

(i) Calculate the kinetic energy of the deflected electron.

kinetic energy = ... J [2]

(ii) By considering the conservation of momentum or otherwise, calculate the angle of deflection, α of the electron in Fig. 8.3.

Explain your working.

angle α = ... ° [4]

JC 2 PRELIMINARY EXAMINATION
in preparation for General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME			
CLASS		INDEX NUMBER	

PHYSICS 9646/03

Paper 3 Longer Structured Questions **25 August 2016**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams or 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 any **two** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in the brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	7
2	9
3	7
4	7
5	10
6	20
7	20
8	20
Significant Figures	
Total	80

Data

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

Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on/by a gas,	$W = p\Delta V$
mean kinetic energy of a molecule of an ideal gas	$E = \frac{3}{2}kT$
hydrostatic pressure,	$p = \rho gh$
gravitational potential,	$\Phi = -\frac{GM}{r}$
displacement of particle in s.h.m.	$x = x_o \sin \omega t$
velocity of particle in s.h.m.	$v = v_o \cos \omega t$
	$= \pm\omega\sqrt{\left(x_o^2 - x^2\right)}$
resistors in series,	$R = R_1 + R_2 + \ldots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = Q/4\pi\varepsilon_o r$
alternating current/voltage,	$x = x_o \sin \omega t$
transmission coefficient	$T \propto \exp(-2kd)$
	where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{1/2}}$

Section A

For Examiner's Use

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

1 An Olympic ski jumper skis down a slope and launches off a cliff, landing on the ground a short time later. The mass of the ski jumper and his equipment is 80 kg.

Fig. 1.1 below shows the ski jumper just before he leaves the slope with a velocity of 20 m s^{-1} in the horizontal direction.

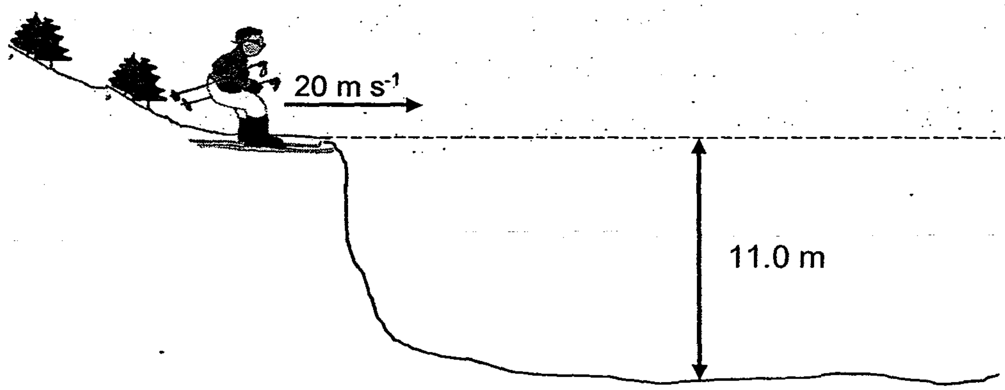


Fig 1.1

The ski jumper falls through a vertical distance of 11.0 m before landing on the ground.

(a) Calculate

(i) the time of flight of the ski jumper,

Taking downwards to be positive,
$s_y=u_yt + 0.5a_yt^2$
$11=0+0.5(9.81)t^2$
t = 1.5 s [A1]

time of flight = ... s [1]

(ii) the horizontal distance travelled by the ski jumper during this time,

Assuming no resistance,
$s_x=u_xt$ = (20)(1.4975) [M1]= 30 m
allow e.c.f

horizontal distance = ... m [1]

(iii) the velocity of the ski jumper just before he lands.

$v_y=u_y+a_yt$
v_y=0+(9.81)(1.4975)
v_y=14.69
v = sqrt(14.69 2+202)[M1]=24.8 m s-1 [A1]
tan(θ)= 14.69/20,
θ=36.3° [A1] (below horizontal)

For Examiner's Use

			velocity = ... m s^{-1}	[2]
			direction: .... ° below the horizontal	[1]
	(b)	By considering Newton's 2nd Law, explain how the snow covering the ground enables the ski jumper to land safely despite the high landing speed.		
		On landing, the snow gets compressed and this lengthens the time interval [B1]of the impact. By N2L, the average force experienced by the body is given by the rate of change in momentum i.e. F = dp/dt, hence the average impact force is lower allowing the ski jumper to land safely [B1]		
		....		
		....		
		....		[2]

2	(a)	State Newton's law of gravitation.		For Examiner's Use
		1 (a) The gravitation force between 2 point masses is directly proportional to product of masses and inversely proportional to square of their separation. [A1]		
		....	[1]	
	(b)	The Earth and the Moon may be considered to be isolated in space with their masses concentrated at their centres. The orbit of the Moon around the Earth is circular, with a radius of 3.84×10^5 km. The period of the orbit is 27.3 days. Show that .		
		(i) the angular speed of the Moon in its orbit around the Earth is 2.66×10^{-6} rad s^{-1}.		
		ω=2π/T ω=2π/(27.3 × 24 × 3600) [M1] ω= 2.66 × 10-6 rad s-1 (shown) [A0]	[1]	
		(ii) the mass of the Earth is 6.0×10^{24} kg.		
		The gravitational force provides the centripetal force for the Moon. [M1] $F_C = F_G$ $mr\omega^2 = \frac{GMm}{r^2}$ $r^3\omega^2 = GM$ $(3.84 \times 10^8)^3\omega^2 = G(M)$ [M1] $M = 6.0 \times 10^{24}$ kg [A0]	[2]	
	(c)	The mass of the Moon is 7.4×10^{22} kg.		
		(i) Using data from **(b)**, determine the gravitational force between the Earth and the Moon.		
		$F_G = \frac{GMm}{r^2}$ $= (6.67 \times 10^{-11})(6.0 \times 10^{24})(7.4 \times 10^{22}) / (3.84 \times 10^8)^2$ [M1] $= 2.0 \times 10^{20}$ N [A1] force = ... N	[2]	

		(ii)	Tidal action on the Earth's surface causes the radius of the Moon's orbit to increase by 4.0 cm each year. Using your answer to **(c)(i)**, determine the change of the Moon's gravitational potential energy in one year. Explain your working.	*For Examiner's Use*
			ΔU = work done Since the question requires the use of answer in (i), we can assume that the gravitational force on Moon is constant during its small displacement of 4.0 cm. [M1] work done = F x = $(2.0 \times 10^{20})(0.04)$ [M1] = 8.0×10^{18} J [A1] [Note: The other assumption is that the change in KE is zero.]	
			change in Moon's gravitational potential energy = ... J	[3]

3 (a) A simple pendulum is given a small displacement from its equilibrium position and performs *simple harmonic motion*.

State what is meant by *simple harmonic motion*.

Acceleration proportional to displacement [C1]
Acceleration is in the opposite direction to its displacement [C1]

.... [2]

(b) The length of a pendulum l is measured to be 30.0 cm. The angular frequency of the simple pendulum is given by $\sqrt{\frac{g}{l}}$, where g is the acceleration of free fall. Determine the period of this simple pendulum.

Solution

Period, $T = 2\pi\sqrt{\frac{l}{g}}$

$$= 2\pi\sqrt{\frac{0.30}{9.81}} = 1.10s$$

[M1 for substitution, A1 for correct answer]

period = ... s [2]

(c) A simple pendulum of period 1.90 s is set up alongside another pendulum of period 2.00 s. Both pendulums are displaced in the same direction and released at the same time.

Calculate the time interval until they next move in phase.

Solution
Let n be the number of oscillations for pendulum of 2.00 s
Hence, for period of 1.90s will be (n + 1) number of oscillations. [C1]
When the two pendulum bobs are next in phase, they will be at the same stage of their oscillation. Each would have cover an integer no. of oscillations. although not the same no. of oscillations.
(n + 1) × 1.90 = n × 2.00 □ {M1}
gives n = 19 (oscillations of longer pendulum) □
minimum time between in phase condition = 19 × 2.00 = 38 (s) [A1]

Or
Alternatively: In exam, MCQ, use LCM.
1.9 = (19/10) = (19)/10
2.0 = (20/10) = (20)/10
LCM of 1.9 & 2.0 = (20 x 19)/100 = 3.8 s.
Since the number of oscillations has to be an integer number, the number of oscillation has to be multiplied by 10 to 19 instead of 1.9. Hence time interval is 38.0 s

Or

For Examiner's Use

Let x be the time lapse before the 2 periods are in phase.
The difference between the number of oscillations must be 1.
$(x/1.9) - (x/2.0) = 1 \rightarrow x = 38$ s

Or

The phase difference of the 2 periods when they are next in phase is 2π rad.
Angular frequency of 2.0 s pendulum, $\omega = \pi$ rad s^{-1}.
Angular frequency of 1.9 s pendulum, $\omega = 1.0526\,\pi$ rad s^{-1}.
Difference of 2 angular frequencies of the pendulums is 0.0526π rad s^{-1}.
Hence, time lapse, $t = 2\pi / (0.0526\pi) = 38$ s

time interval = ... s [3]

4 A long rope is held under tension between two points A and B. Point A is made to oscillate vertically and a wave is sent down the rope towards B as shown in Fig. 4.1.

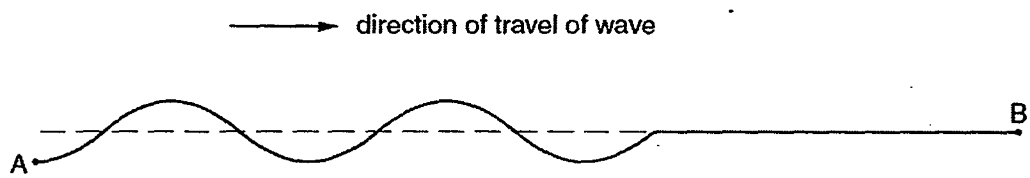


Fig. 4.1

The time for one oscillation of point A on the rope is 0.20 s. The point A moves a total distance of 80 mm during one oscillation. The wave on the rope has a wavelength of 1.5 m.

() **(a)** **(i)** Explain the term *displacement* for a particle in the wave, on the rope.

With reference to the wave on the rope, displacement is the **position** of a particle on the rope **with respect to the equilibrium point** during the course of the oscillation. [B1]

Accept: distance of a particle on the rope from the equilibrium / mean point during the oscillation.

Reject: distance travelled by a particle of the rope from the equilibrium / mean point during the oscillation.

[1]

(ii) Calculate, for the wave on the rope,

1. the amplitude,

Total distance travelled by A after one oscillation = 80 mm.
Amplitude = 80 mm / 4 = 20 mm

amplitude = ... mm [1]

2. the speed.

frequency, f = 1/period, T

f = 1/0.20 = 5.0 Hz

$v = f\lambda = (5.0)(1.5)$ [M1]
$= 7.5\ m\ s^{-1}$ [A1]

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

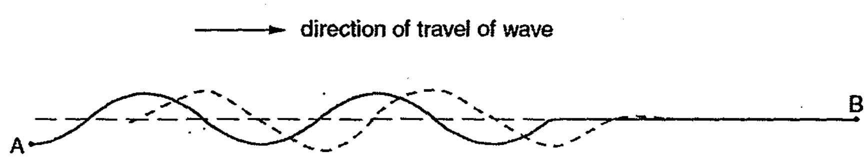
(b) Draw on Fig.4.1, the wave pattern on the rope at a time 0.050 s later than that shown.

[1]

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta t}{T}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{0.050}{0.20} = \frac{1}{4} \qquad \Delta\lambda = \frac{1}{4}\lambda$$

Thus, the waveform shifts to the right by a quarter of a wavelength. [B1]



(c) State and explain, whether the wave on the rope is

(i) progressive or stationary,

The wave is progressive because
- the wave profile (wave peak/trough) shifts to the right
- the energy of the wave is moving to the right

Any one of the above points [B1] [1]

(ii) longitudinal or transverse.

The wave is transverse because the plane of oscillation of the particles on the rope are <u>perpendicular</u> to the wave velocity. [B1] [1]

For Examiner's Use

5 (a) Fig. 5.1 below shows a filament lamp emitting white light, and is surrounded by a region of cooler helium gas.

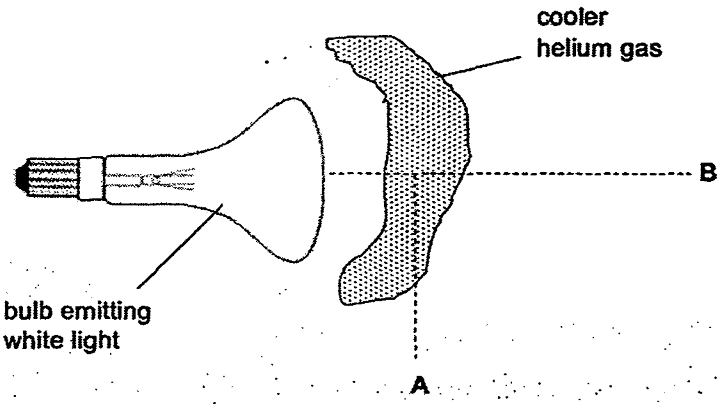


Fig. 5.1

(i) State if a helium *absorption* or *emission* spectrum is observed from

1. point A,

Emission [B1] [1]

2. point B.

Absorption [B1] [1]

(ii) Explain the formation of the helium spectrum observed from point A.

Bound helium electrons can only accept <u>photons which have the same energy as the difference in the helium's energy levels</u> [B1]

The excited electrons subsequently de-excite by <u>re-emitting photons of the same wavelengths as those that were previously absorbed.</u> However the <u>re-emission is in all directions</u> [hence the intensity of these photons on the screen at B is relatively lower resulting in a absorption spectrum]

When the detector is placed at A, it will detect the emitted photons from the excited He gas as it deexcites. Thus the spectrum at A is an emission spectrum i.e. Bright lines against a dark background. [B1]

.... [2]

(b) Fig. 5.2 shows some of the energy levels of an isolated helium atom.

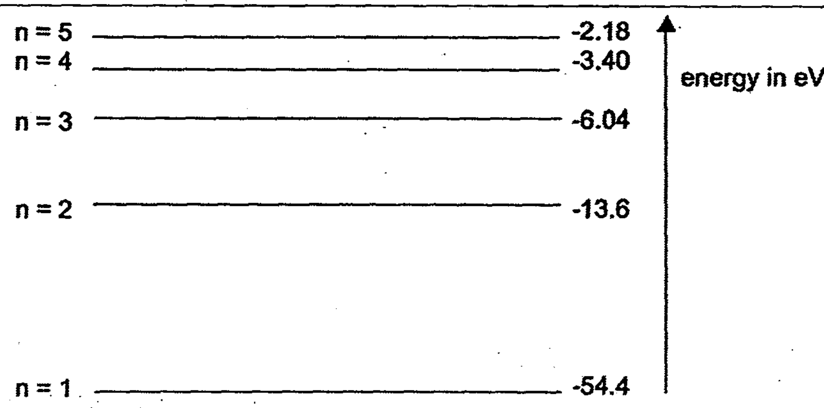


Fig. 5.2

An electron with a kinetic energy of 50 eV collides inelastically with
in the ground state.

(i) Draw, in Fig. 5.2, the possible downward transitions of the excited helium atom following this collision.

[2]

Highest possible level is -6.04 eV

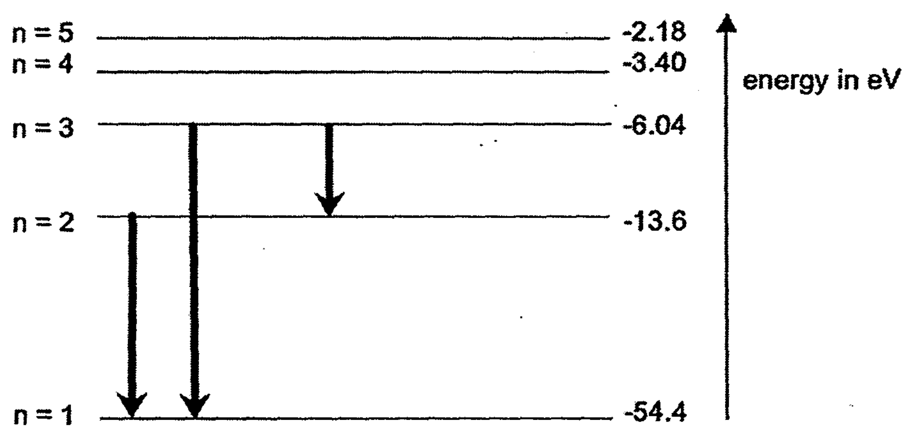


Fig. 4.2

All 3 transitions: B2
2 transitions: B1
0 or 1 transition: 0

(ii) Calculate the shortest wavelength of the radiation that is emitted from the transitions in **(b)(i)**.

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

$$\left[-6.04-(-54.4)\right]\left(1.6\times10^{-19}\right)=\frac{6.63\times10^{-34}\left(3.0\times10^{8}\right)}{\lambda} \quad \text{M0}$$

$$\lambda = 2.57\times10^{-8}\ \text{m} \quad \text{A1}$$

					For Examiner's Use
			wavelength = ... m	[1]	
		(iii)	Hence state the type of radiation for the wavelength calculated in **(b)(ii)**.		
			Ultraviolet or UV [B1]	[1]	
		(iv)	Explain what happens if UV photons of energy of 50 eV had been used to excite the ground state helium atoms instead 50 eV electrons.		
			A photon can only be absorbed completely or not at all. [M1] Since photon energy of 50 eV does not correspond to the difference of any of the energy levels, The photon is not absorbed and no upward emission subsequently [M1]		
				[2]	

Section B

For Examiner's Use

Answer **two** questions in this section.

6 (a) State Coulomb's law in electrostatics.

Coulomb's law states that the electrostatic force of interaction (attraction or repulsion) between two <u>point</u> electric charges is *directly proportional* to the <u>product</u> of the charges and *inversely proportional* to the <u>square</u> of the distance between them.

[1]

(b) Fig. 6.1 shows two identical conducting spheres A and B, each carrying a charge of $+Q$. They are placed in a vacuum with their centres separated by a distance d, where d is of the same order of magnitude as the radii of the two spheres.

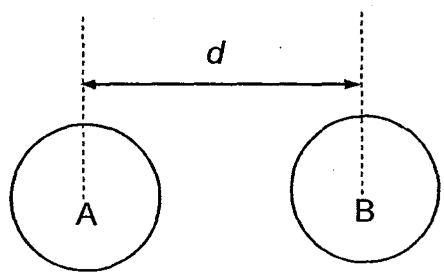


Fig. 6.1

Explain why the electric force, F between the two spheres is not given by the expression:

$$F = \frac{Q^2}{4\pi\varepsilon_0 d^2}$$

The conducting spheres are not regarded as <u>point charges</u>. [B1]

The expression does not apply as the radii of the spheres are not very small compared to the separation d between the centres of the spheres. [B1]

[2]

(c) An isolated conducting sphere R has a radius of 40.0 cm, and the charge on the sphere is +6.67 nC.

(i) Show that the potential on the surface of sphere R is 150 V.

$V = Q/(4\pi\varepsilon_o\, r)$ [C1]

$V = (9\times10^{9})(6.65\times10^{-9})/0.400$ [M1]

$V = 150$ V [A0]

For Examiner's Use

[2]

(ii) A second conducting sphere S which is electrically neutral is now brought close to R. S has a radius 20.0 cm.

A wire is used to connect the surface of sphere S to that of sphere R. After connecting, the charges will redistribute themselves between the surfaces of the two spheres until the potential on the surfaces of both spheres are the same.

Show that $\frac{\text{final charge on S}}{\text{final charge on R}} = \frac{1}{2}$.

After the wire is connected to the spheres, the charges will flow and quickly reach a state of equilibrium whereby the potential is constant.

Let the final constant potential = V_f

Since the spheres share the same final potential

$V_R = V_S = V_f$ [C1]

$\frac{Q'_R}{4\pi\varepsilon_0 r_R} = \frac{Q'_S}{4\pi\varepsilon_0 r_S}$ [M1]

$\frac{Q'_S}{Q'_R} = \frac{r_S}{r_R} = \frac{0.200}{0.400} = \frac{1}{2}$ [A0]

[2]

(iii) Hence, determine the final electric potential on the surface of the two spheres.

Based on the principle of conservation of charges,

$(Q_R + Q_S)$ initial = $(Q'_R + Q'_S)$ final

$6.65\times10^{-9} + 0 = (Q'_R + Q'_S)$ ...... Eqn (1) [B1]

Substituting $Q'_R = 2\,Q'_S$ into Eqn(1)

$3\,Q'_S = 6.65\times10^{-9}$

$Q'_S = 2.217\times10^{-9}$ C

$V_f = \frac{Q'_S}{4\pi\varepsilon_0 r_S}$

$= (9\times10^9)\frac{2.217\times10^{-9}}{(0.200)}$ [M1]

$= 99.8$ V [A1]

Accept 100 V as answer provided working is shown.

potential = ... V [3]

For Examiner's Use

(d) Fig. 6.2 shows two parallel metal plates P and Q situated 8.0 cm apart in air.

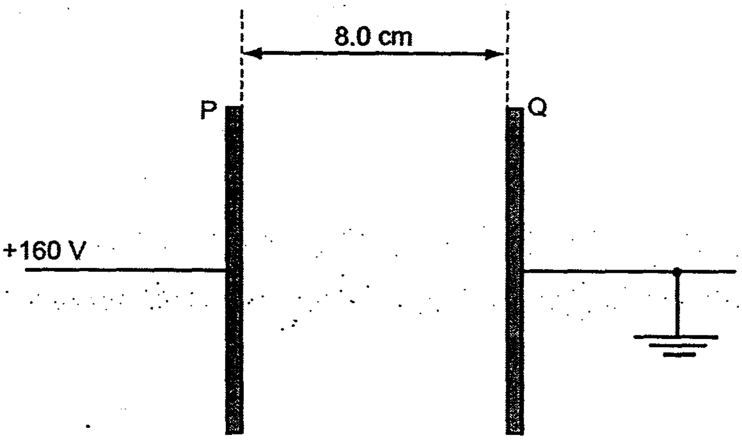


Fig. 6.2

Plate Q is earthed while plate P is maintained at a potential of +160 V.

(i) On Fig.6.2, draw lines to represent the electric field in the region between the plates.

[2]

Field lines perpendicular (normal) to the plates and equally spaced (at least 5 lines) [B1]
Direction is from P to Q.
[B1]

(ii) Show that the magnitude of the electric field strength between the plates is 2000 V m^{-1}.

$E = \frac{\Delta V}{d} = \frac{160-0}{0.080}$ [M1]

= 2 000 V m^{-1} [A0]

[1]

(iii) A dust particle is suspended in the air between the plates. The particle has charges of $+1.2\times10^{-15}$ C and -1.2×10^{-15} C near its ends.

The charges may be considered to be point charges separated by a distance of 2.5 mm, as shown in Fig. 6.3.

For Examiner's Use

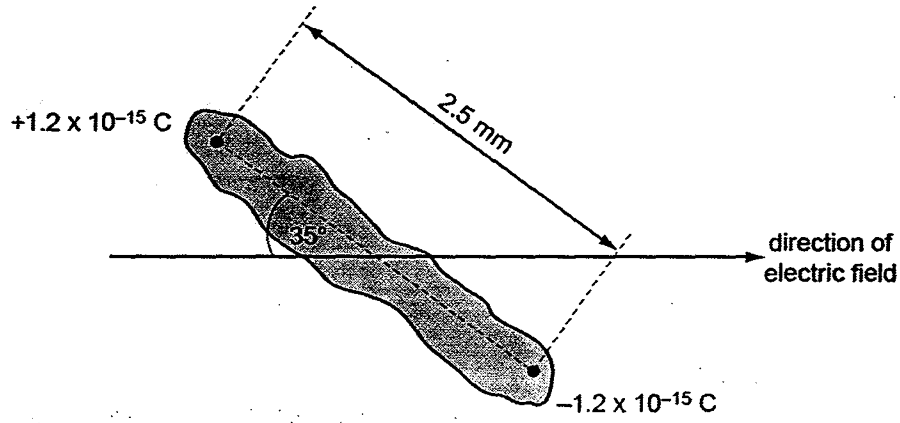
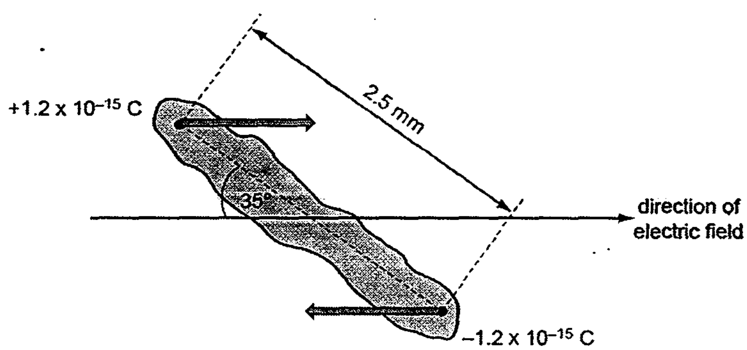


Fig. 6.3

The particle makes an angle of 35° with the direction of the electric field.

1. Draw on Fig.6.3, arrows to show the direction of the electric force on each charge due to the electric field.



For the positive charge, the direction of the force is horizontally to the right.
For the negative charge, the direction of the force is horizontally to the left.

The arrows should pass through the charges and the lengths should be approximately the same.

[1]

2. Calculate the magnitude of the electric force on each charge due to the electric field.

$F = E\,q$
$= (2000)(1.2\times10^{-15})$ [M1]
$= 2.4\times10^{-12}$ N [A1]

force = ... N [2]

3. Determine the magnitude of the couple acting on the particle at this instant.

For Examiner's Use

				Couple = force × perpendicular separation $= (2.4 \times 10^{-12})(2.5\times10^{-3} \sin35^{o})$ [M1] $= 3.44 \times10^{-15}$ N m [A1]	
				couple = ... N m	[2]
			4.	Suggest the subsequent motion of the particle in the electric field.	
				The particle will rotate clockwise (or oscillate about the equilibrium horizontal position) until it is aligned with the electric field. [B1] The positive end should be pointing towards the earthed plate. [B1]	[2]

7 (a) State what is meant by

(i) *nuclear binding energy,*

(a)(i) Accept either of the following from the lecture notes:

1. The ***binding energy*** of a *nucleus* is the energy required to **separate** to infinity all the nucleons of the nucleus (i.e. to become free **unbound** protons and neutrons). {A1}

2. The amount of energy that would be released if a nucleus were formed from separate protons and neutrons. [A1]

[1]

(ii) *nuclear fusion.*

From lecture notes: **Nuclear fusion** is a nuclear reaction in which two or more energetic light nuclei **combine** to produce a new heavier nucleus, with a release of energy. [A1]
'light' nuclei combine to form 'heavier' nuclei [A1]

[1]

(b) A possible reaction for use in a nuclear fusion reactor is one in which the deuterium and tritium nuclei fuse together to produce a helium nucleus.

Fig. 7.1 below shows the nuclear binding energies (BE) per nucleon for some particles.

particle	BE per nucleon / MeV
neutron, ${}^{1}_{0}n$	0
deuterium, ${}^{2}_{1}H$	1.11
tritium, ${}^{3}_{1}H$	2.83
helium, ${}^{4}_{2}He$	7.07

Fig. 7.1

(i) Complete the following nuclear equation to represent the fusion of the deuterium and tritium nuclei.

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow \ldots\ldots\ldots\ldots + \ldots\ldots\ldots\ldots + \text{energy released}$$

Answer is Helium-4 & neutron [1]

(ii) Using values from Fig. 7.1, determine the energy released in the process in **b(i)**.

$$\Delta E = BE_{products} - BE_{reactants}$$
$$= (7.07\times4) - [(1.11\times2)+(2.83\times3)] \quad [M1]$$
$$= 28.28 - 10.71$$
$$= 17.57$$
$$\approx 17.6 \text{ MeV} \quad [A1]$$

energy released = ... MeV [2]

(iii) Fig. 7.2 below shows the masses for the neutron and various

particle	mass / u
neutron, ${}^{1}_{0}n$	1.00867
deuterium, ${}^{2}_{1}H$	2.01356
tritium, ${}^{3}_{1}H$	3.01551
helium, ${}^{4}_{2}He$	4.00151

Fig. 7.2

By considering the change in mass during the nuclear fusion reaction, determine the energy released in the process in **(b)(i)**.

<u>Solution</u>
Mass defect = (2.01356 + 3.01551)u – (1.00867 + 4.00151)u
= 0.01889 u [M1]
Energy released = 0.01889 u x 931 MeV/u
= 17.6 MeV [A1]

Or
Energy released, $\Delta E = \Delta m\, c^2$
= 0.01889 u x $(3.0 \times 10^8)^2$
= 2.822×10^{-12} J
= 17.6 MeV [A1]

energy released = ... MeV [2]

(iv) Suggest why for nuclear fusion reactions to take place, high temperatures are required.

The deuterium and tritium nuclei are both positively charged and experiences electric repulsion. [1]

In order for fusion to occur, both nuclei must approach each other sufficiently close to tunnel through the coulomb barrier to fuse. [1]

Hence a higher temperature is needed, so that the nuclei would have a higher KE and would be able to approach each other close enough for fusion to take place. [1]

[3]

For Examiner's Use

(v) In the doughnut-shaped Tokamak Fusion Test Reactor, the deuterium-tritium fuel can reach temperatures of up to 5.1×10^8 K, more than thirty times the core temperature of the sun.

No material can withstand the extreme temperature of the deuterium-tritium fuel.

Suggest one way of confining the deuterium-tritium fuel in the fusion reactor, without the walls of the reactor coming into contact with it.

Using a magnetic field [B1] the moving charged particles can be confined to a circular path [B1], without touching the walls of the reactor.

[2]

(vi) Suggest one advantage of nuclear fusion over nuclear fission as a means of energy production.

No risk of meltdown [B1] It is difficult enough to reach and maintain the precise conditions necessary for fusion—if any disturbance occurs, the plasma cools within seconds and the reaction stops. The quantity of fuel present in the vessel at any one time is enough for a few seconds only and there is no risk of a chain reaction.

Or

The **same quantity of fuel for nuclear fusion produces more energy** compared to the same mass of fuel for nuclear fission. [B1]

Or

Unlike nuclear fission, nuclear fusion reactors **produce no high activity, long-lived nuclear waste.** [B1]

.... [1]

(c) The mass of a sample of Tritium is 1.0 g. The nuclide Tritium has a *half life* of 12.3 years.

(i) Define *half life* of a radioactive substance.

Half life is the average time taken for the activity of the substance to be halved.

[1]

(ii) Find the number of Tritium atoms in the sample.

Solution

Method 1

Number of atoms = $(1.0 \text{ g} \div 3.0 \text{ g}) \times 6.02 \times 10^{23}$

$= 2.0 \times 10^{23}$. [A1]

For Examiner's Use

			<u>Method 2</u> Mass of one atom = 3u = 3 x 1.67 x 10^{-27} Number of atoms = 1.0 x 10^{-3} ÷ (3 x 1.67 x 10^{-27}) = 2.0 x 10^{23} [A1]	
			number of Tritium atoms = ... atoms	[1]
		(iii)	Determine the decay constant for Tritium.	
			Solution Decay constant, λ = (0.693) ÷ (12.3 x 365 x 24 x 3600) [M1] = 1.79 x 10^{-9} [A1]	
			decay constant = ... s^{-1}	[2]
		(iv)	Calculate the fraction of Tritium atoms which remained after 20 years.	
			<u>Solution</u> $\frac{A}{Ao} = e^{-\lambda t}$ $\frac{A}{Ao} = e^{-\left(\frac{0.693}{12.3}\right)(20)}$ [M1 for formula] + [M1 for substitution] = 0.324 [A1]	
			fraction = ...	[3]

8 (a) Define the *tesla*.

One tesla is defined as the magnetic flux density of a **uniform** magnetic field [B1], when a magnetic force per unit current per unit length of 1 newton per ampere per metre [B1] acts on a long, straight wire placed perpendicular to the magnetic field [B1]. [3]

(b) An electron is travelling with momentum p in a vacuum. It enters a region of uniform magnetic field of flux density 0.24 T, as shown in Fig. 8.1.

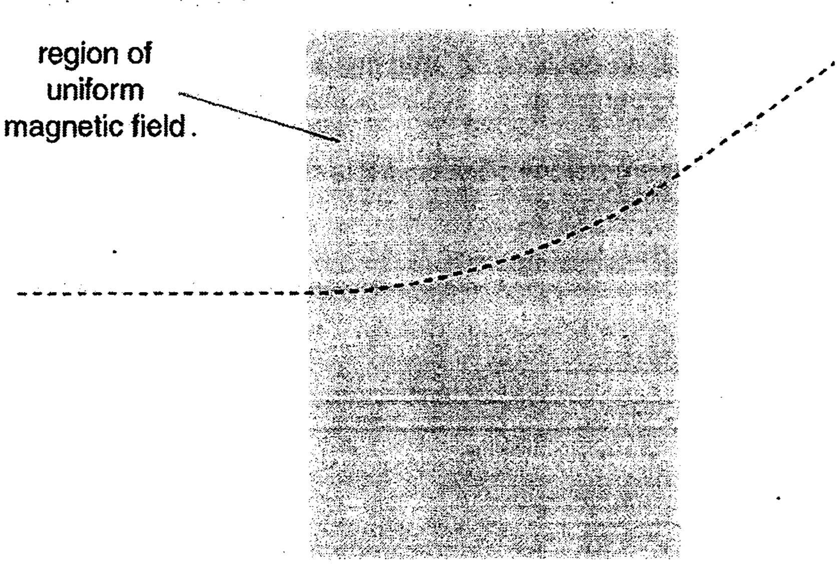


Fig. 8.1.

When the electron is in the magnetic field, it is travelling at right-angles to the direction of the field.

(i) Explain why the path of the electron in the magnetic field is an arc of a circle.

1. The electron will **experience a magnetic force** when it enters the uniform magnetic field since it is **a moving charge in a magnetic field**. [B1]
2. The magnetic force will **act in the direction** that is **always perpendicular to the velocity of the charged particle [B1]**,
3. thus providing a **centripetal force [B1]** causing the particle to **travel in an arc of a circle**.

[3]

(ii) Draw in Fig. 8.1. the direction of the magnetic field. [1]

			Magnetic field directed out of the page. [B1]	
		(iii)	The radius of the circular path of the electron in the magnetic field is 6.2 cm. Calculate the momentum p of the electron.	
			The magnetic force experienced by the charged particle provides for the centripetal force, thus $\lvert F_B \rvert = \lvert F_C \rvert$ [M1, statement explaining $\lvert F_B \rvert$ to $\lvert F_C \rvert$ must be included] $Bqv = \frac{mv^2}{r}$ $rBq = mv$ $p = rBq$ $= (0.062)(0.24)(1.6 \times 10^{-19})$ [M1] $= 2.38 \times 10^{-21}$ N s [A1]	
			$p =$ .... N s	[3]
	(c)		Electrons are produced in beta decay. One example would be the beta decay of the Bismuth-210 nucleus to produce an electron and a Polonium-210 nucleus. Fig. 8.2 below shows the tracks formed by the electron and the Polonium-210 nucleus, following the decay of an initially stationary Bismuth-210 nucleus, in a cloud chamber.	

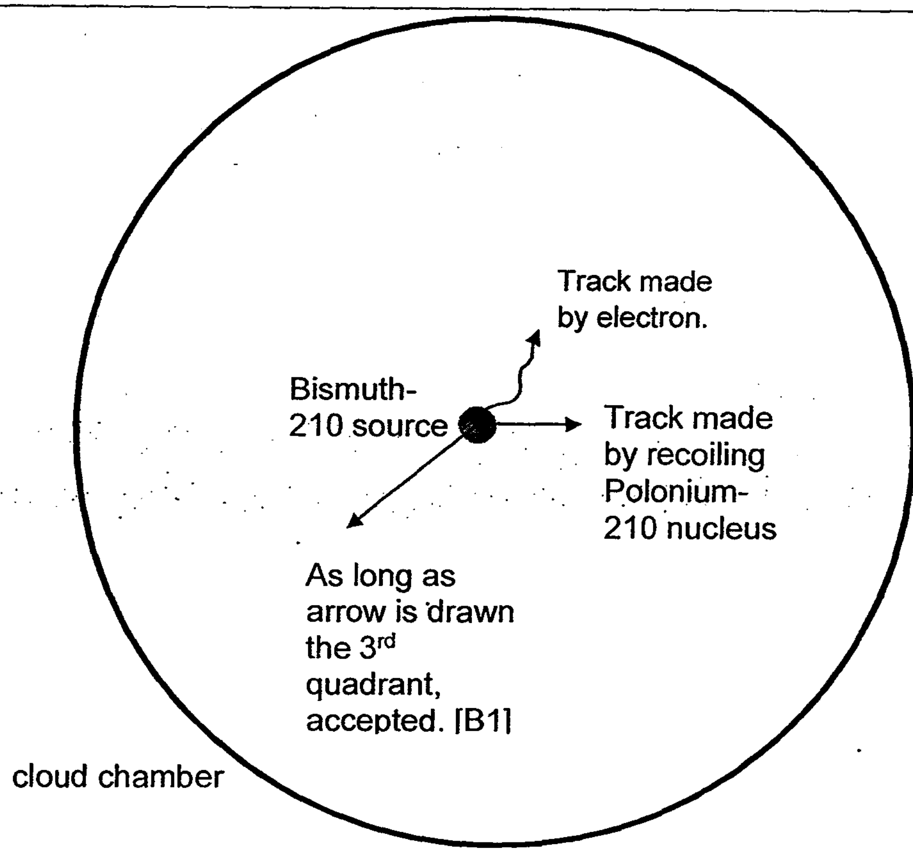


Fig. 8.2

(i) With reference to the directions of the cloud chamber tracks, and the principle of conservation of momentum, explain how a third particle (now known as the anti-neutrino) must have been formed despite not being seen in the cloud chamber.

1. The **initial momentum of the Bismuth 210 nucleus is 0** and by the **conservation of momentum**, we **expect the total momentum of the products to be zero** as well. [B1]

2. The **cloud chamber tracks show** the **direction** of the electron's and Polonium-210 nucleus's **velocities and hence, their momenta**. The **momenta** of the electron and the Polonium-210 nucleus are **not anti-parallel and thus will not add up to zero**. [B1]

3. Hence, **a third particle must have been produced** in **order for momentum to be conserved.** [B1]

[3]

(ii) Draw in Fig. 8.2. an arrow showing the path of the anti-neutrino. [1]

(d) An X-ray photon of wavelength 965.0×10^{-12} m collides elastically with a stationary electron, as illustrated in Fig. 8.3.

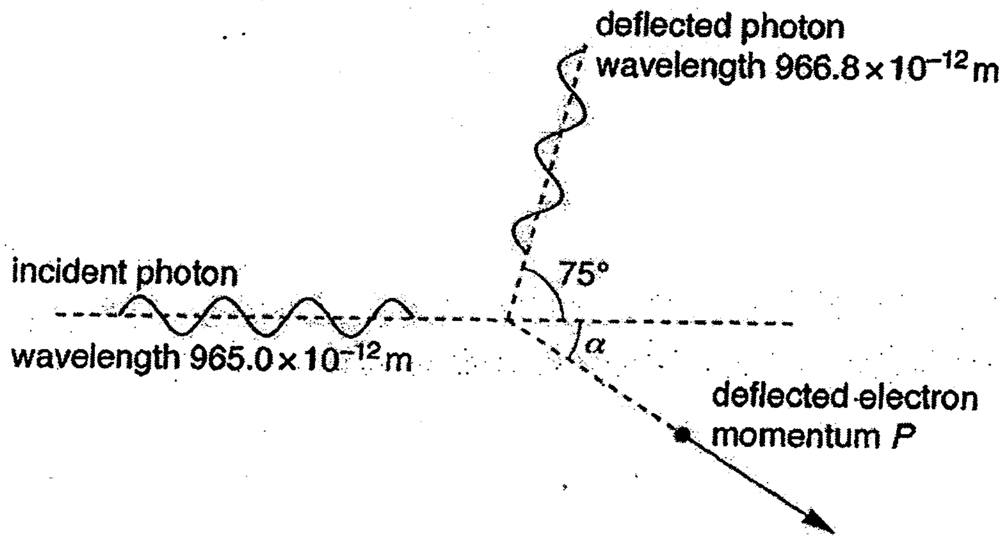


Fig. 8.3.

The photon is deflected through an angle of 75° and has a wavelength of 965.0×10^{-12} m. The electron is deflected through an angle α and has a momentum of 8.36×10^{-25} N s.

(i) Calculate the kinetic energy of the deflected electron.

Energy of deflected electron

$= E_{\text{incident photon}} - E_{\text{scattered photon}}$

$= \frac{hc}{\lambda_i} - \frac{hc}{\lambda_f}$

$= (6.63 \times 10^{-34})(3.0 \times 10^{8})\left(\frac{1}{965.0 \times 10^{-12}} - \frac{1}{966.8 \times 10^{-12}}\right)$ [M1]

$= 3.83 \times 10^{-19}$ J [A1]

kinetic energy = ... J [2]

(ii) By considering the conservation of momentum or otherwise, calculate the angle of deflection, α of the electron in Fig. 8.3.

Explain your working.

For Examiner's Use

By the conservation of momentum along the vertical direction:

$\vec{P}_{\text{y, incident photon}} = \vec{P}_{\text{y, deflected photon}} + \vec{P}_{\text{y, deflected electron}}$ [M1, including explanation]

The total initial momentum along the vertical direction is 0 i.e.

$0 = \vec{P}_{\text{deflected photon}}(\sin 75°) + \vec{P}_{\text{deflected electron}}(\sin\alpha)$

$0 = \left(+\frac{h}{966.8 \times 10^{-12}}\right)(\sin 75°) + (-8.36 \times 10^{-25})(\sin\alpha)$ [M1]

$\left(\frac{h}{966.8 \times 10^{-12}}\right)(\sin 75°) = (8.36 \times 10^{-25})(\sin\alpha)$

$\sin\alpha = 0.7923$ [M1]

$\alpha = 52.4°$ or $127.5°$

$\alpha = 52.4°$

since α is less than 90° and momentum has to be conserved in the horizontal direction as well [M1]

angle α = ... ° [4]