Class	Index Number	Name
23S		

ST. ANDREW'S JUNIOR COLLEGE
JC 2 2024
Preliminary Examination

PHYSICS, Higher 2 **9749/03**

Paper 3 Longer Structured Questions **11th September 2024**
2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, index number and Civics Group 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.

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

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

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

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

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

For Examiner's Use	
Section A	
1	**/ 15**
2	**/ 6**
3	**/ 6**
4	**/ 8**
5	**/ 7**
6	**/ 10**
7	**/ 8**
Section B	
8	**/ 20**
9	**/ 20**
Total	**/ 80**

This document consists of **26** printed pages including this page.

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

Formulae

uniformly accelerated motion	$s = u t + \frac{1}{2} a t^2$
	$v^2 = u^2 + 2 a s$
work done on/by a gas	$W = p \Delta V$
hydrostatic pressure	$p = \rho g h$
gravitational potential	$\varphi = -\frac{Gm}{r}$
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.	$x = x_o \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$v = \pm \omega \sqrt{x_0^2 - x^2}$
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	$x = x_o \sin \omega t$
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	$B = \frac{\mu_0 N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 n I$
radioactive decay	$x = x_o \exp(-\lambda t)$

decay constant $\lambda = \frac{\ln 2}{t_{1/2}}$

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

1 **(a)** The Earth spins on its axis with a period of one day.

(i) Show that the angular velocity of a point on the Earth's surface is 7.27×10^{-5} rad s^{-1}.

[1]

(ii) Calculate the centripetal acceleration of a point on the Earth's equator. The radius of the Earth's equator is 6.38×10^{6} m.

centripetal acceleration = ………………… m s^{-2} [2]

(b) The acceleration of free fall *g* at the equator is not equal to the acceleration of free fall at the poles. Explain

(i) why they are different,

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

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

(ii) why the difference is small.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……….

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

(c) **(i)** State Newton's law of gravitation.

…..…………………………………………………………………………………

……………………………………………………………………………………….[1]

(ii) The mass M of the Earth may be considered to be concentrated at its centre. The radius of the Earth is R. Derive, in terms of M and R, the equation relating the Earth's gravitational field strength g to the gravitational constant G.

Explain your working.

[2]

(d) **(i)** Calculate how far a satellite needs to be from the centre of the Earth for its angular velocity to be equal to the angular velocity of the Earth.

distance =……………………….m [3]

(ii) State two circumstances under which a satellite at this distance will be a geostationary satellite.

1. …………………………………………………………………………………………

..…………………………………………………………………………………………

2. …..………………………………………………………………………………………

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

2 The first law of thermodynamics, when applied to a system, can be expressed as:

$$\Delta U = q + w$$

where ΔU is the increase in internal energy of the system,
q is the heat supplied to the system and
w is the work done on the system.

State and explain, in terms of the first law of thermodynamics, the change, if any, in the internal energy

(a) of the water in an ice cube when ice melts, at atmospheric pressure, to form a liquid without any change of temperature,

....

....

....

....[3]

(b) of the gas in a tyre when the tyre bursts so that the gas suddenly increases in volume. Assume that the gas is ideal.

....

....

....

....[3]

3 **(a)** Explain qualitatively how molecular movement causes the pressure exerted by a gas.

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

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

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

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

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

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

(b) A fixed mass of neon gas has a pressure of 1.02×10^5 Pa and density of 0.900 kg m^{-3}. Neon may be assumed to be an ideal gas.

Calculate the root-mean-square speed of neon atoms.

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

(c) The density of the neon gas in **(b)** is now varied, keeping its pressure constant.

On Fig. 3.1, sketch the variation with volume V of the internal energy U of the gas.

[1]

Fig. 3.1

4 A tube, closed at one end, has a uniform area of cross-section. The tube contains some sand so that the tube floats upright in a liquid, as shown in Fig. 4.1

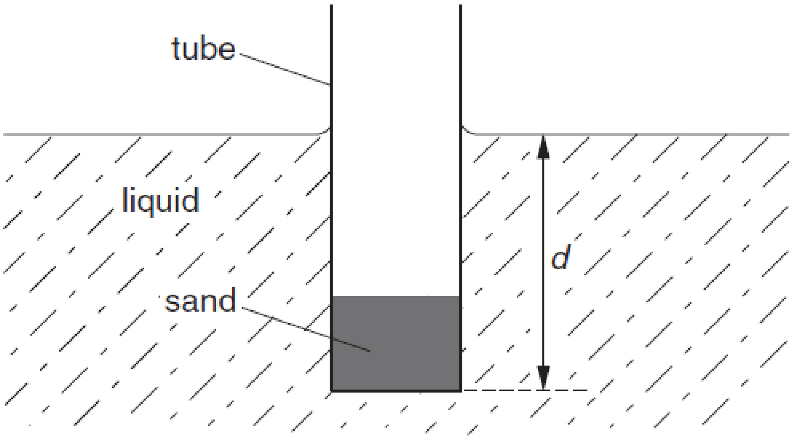


Fig. 4.1

When the tube is at rest, the depth *d* of immersion of the base of the tube is 16 cm. The tube is displaced vertically and then released.

The variation with time *t* of the depth *d* of the base of the tube is shown in Fig. 4.2.

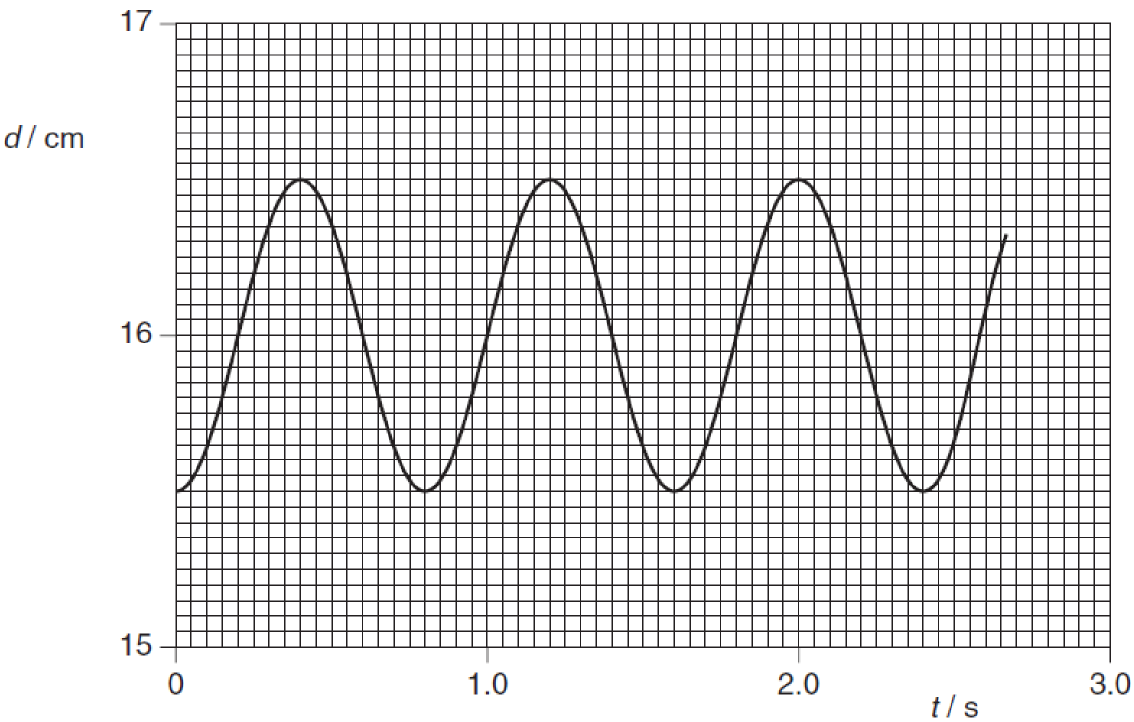


Fig. 4.2

(a) Use Fig. 4.2 to determine, for the oscillations of the tube, the amplitude.

amplitude = ... cm [1]

(b) **(i)** Calculate the vertical speed of the tube at a point where the depth *d* is 16.2 cm.

speed = ... cm s^{-1} [3]

(ii) State **one** other depth *d* where the speed will be equal to that calculated in **(i)**.

d = ... cm [1]

(c) The liquid in **(b)** is now cooled so that, although the density is unchanged, there is friction between the liquid and the tube as it oscillates. Having been displaced, the tube completes approximately 10 oscillations before coming to rest.

On Fig. 4.2, draw a line to show the variation with time *t* of depth *d* for the first 2.5 s of the motion.

[3]

5 **(a)** A beam of vertically polarised light is incident normally on a polarising filter, as shown in Fig. 5.1.

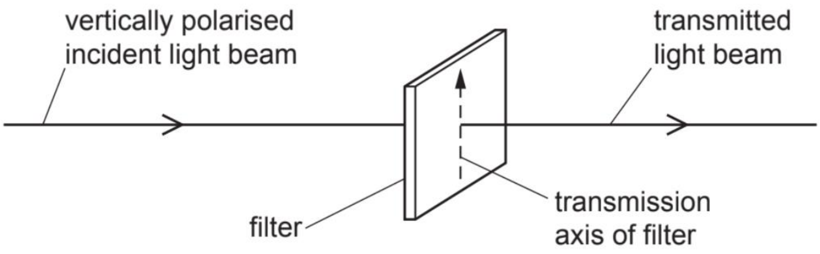
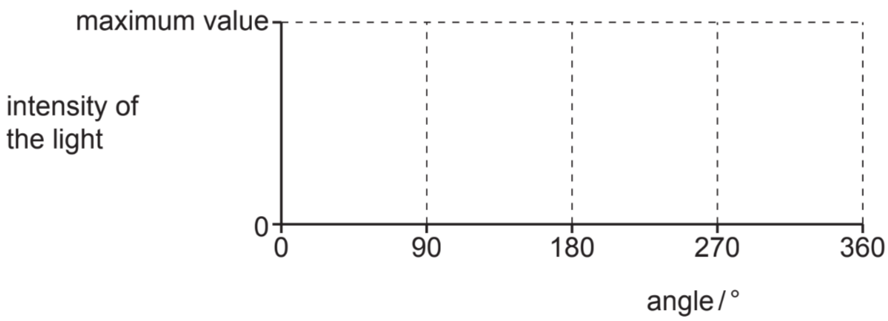


Fig. 5.1

(i) The transmission axis of the filter is initially vertical. The filter is then rotated through an angle of 360° while the plane of the filter remains perpendicular to the beam.

On Fig. 5.2, sketch a graph to show the variation of the intensity of the light in the transmitted beam with the angle through which the transmission axis is rotated.



[2]

Fig. 5.2

(ii) The intensity of the light in the incident beam is 7.6 W m^{-2}. When the transmission axis of the filter is at angle θ to the vertical, the light intensity of the transmitted beam is 4.2 W m^{-2}.

Calculate angle θ.

θ = ...° [1]

(b) State what is meant by the diffraction of a wave.

....

....

.... [1]

(c) A beam of light of wavelength 4.3×10^{-7} m is incident normally on a diffraction grating in air, as shown in Fig. 5.3.

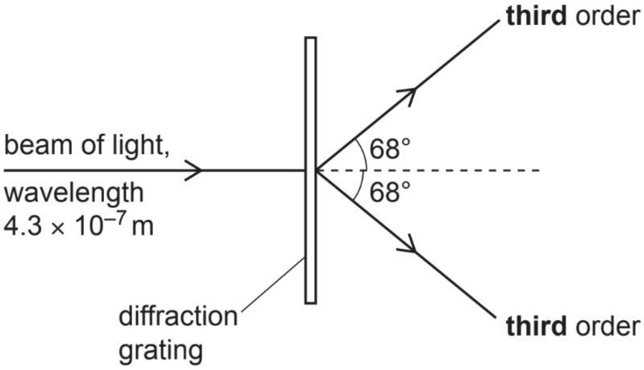


Fig. 5.3 (not to scale)

The **third**-order diffraction maximum of the light is at an angle of 68° to the direction of the incident light beam.

Determine a different wavelength of visible light that will also produce a diffraction maximum at an angle of 68°.

wavelength = ...m [3]

6 **(a)** The graphs on Fig. 6.1 show how the resistance of a metal resistor **R** and a thermistor **T** varies when the temperature changes.

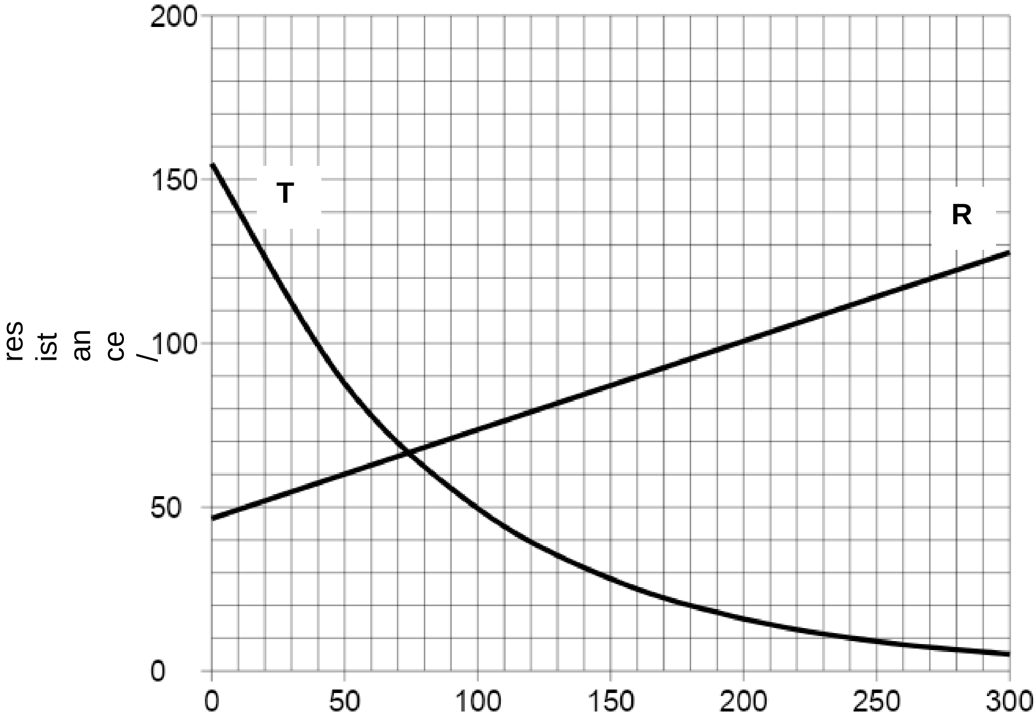


Fig. 6.1

The metal resistor **R** and the thermistor **T** are connected in series as shown in Fig. 6.2 together with a battery of negligible internal resistance. **R** and **T** are kept at the same temperature as each other.

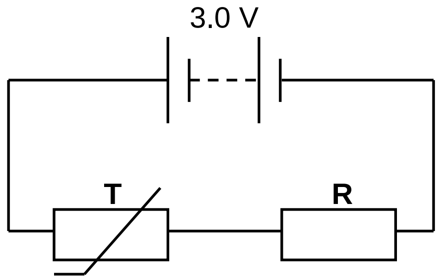


Fig. 6.2

(i) Determine the current in the circuit shown in Fig 6.2 when the resistance of **R** is twice that of **T**.

current = ………………………….. A [2]

(ii) Describe how the effective resistance of the circuit in Fig 6.2 changes as temperature increases from 0 °C to 75 °C.

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

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

(iii) Determine the potential difference across **T** when the temperature is at 30 °C.

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

(b) Fig. 6.3 shows a circuit containing five identical lamps A, B, C, D and E. The circuit also contains three switches S_1, S_2 and S_3.

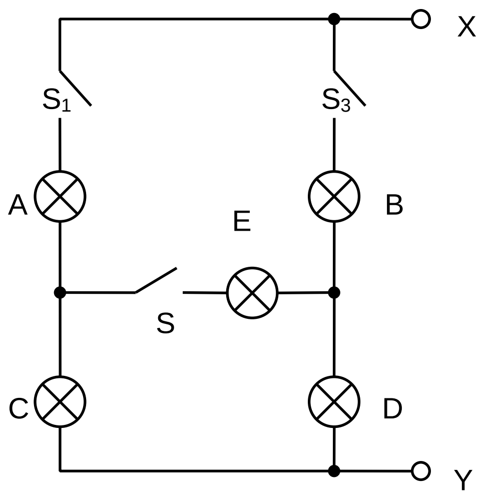


Fig. 6.3

One of the lamps is faulty. In order to detect the fault, an ohm-meter (a meter that measures resistance) is connected between terminals X and Y. When measuring resistance, the ohm-meter causes negligible current in the circuit.

Table 6.1 shows the readings of the ohm-meter for different switch positions. The resistance of the non-faulty lamps can be assumed to be constant.

switch			ohm-meter reading / Ω
S_1	S_2	S_3	
open	open	open	∞
closed	open	open	30.0
closed	closed	open	30.0
closed	closed	closed	15.0

Table 6.1

(i) Identify the faulty lamp, and the nature of the fault.

faulty lamp = ……………………………[1]

nature of fault = ……………………………[1]

(ii) State the resistance of one of the non-faulty lamps, as measured using the ohm-meter.

resistance = ………………….Ω [1]

(iii) After replacing the faulty lamp in the circuit in Fig. 6.3 with a similar working lamp, the ohm-meter is connected between terminals X and Y.

On Table 6.2, complete the readings of the ohm-meter for different switch positions.

switch			ohm-meter reading / Ω
S_1	S_2	S_3	
open	open	open	∞
closed	open	open	
closed	closed	open	
closed	closed	closed	

Table 6.2

[2]

7 Two small spherical charged particles P and Q may be assumed to be point charges located at their centres. The particles are in vacuum.

Particle P is fixed in position. Particle Q is moved along the line joining the two charges, as shown in Fig. 7.1.

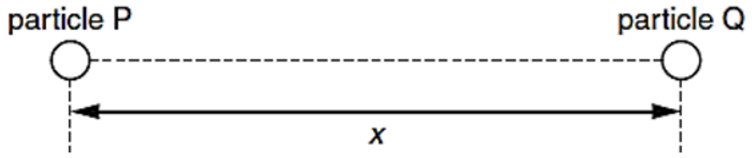


Fig. 7.1

The variation with separation *x* of the electric potential energy *E*p of particle Q is shown in Fig. 7.2.

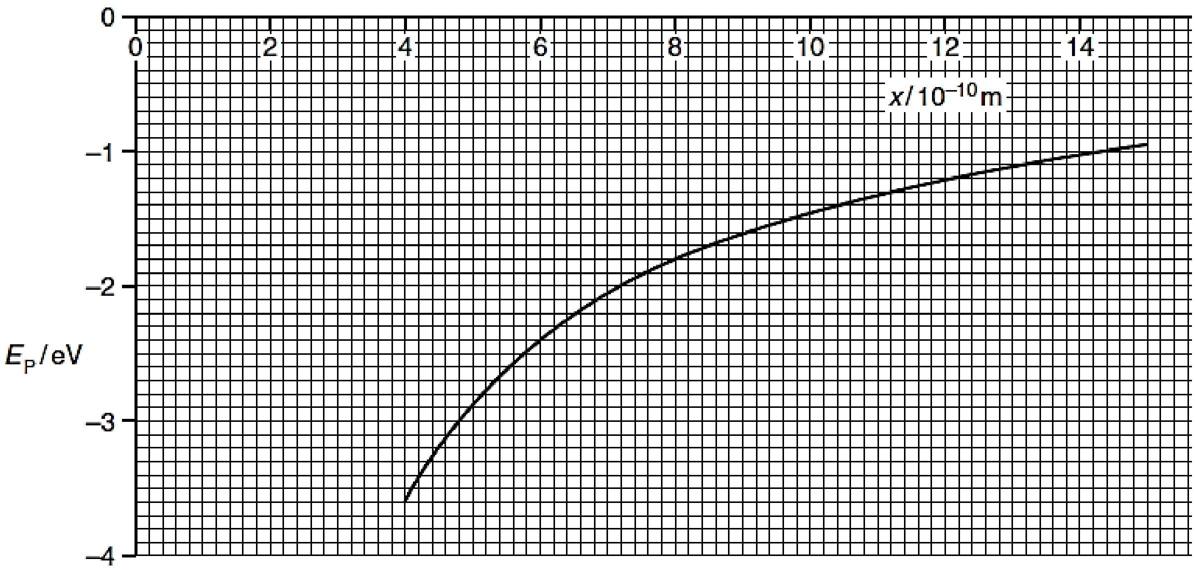


Fig. 7.2

(a) Deduce that the force on particle Q is proportional to the gradient of the curve of Fig. 7.2.

....

....

....

....

.... [2]

(b) By reference to Fig. 7.2, state and explain

(i) whether the two charges have the same, or opposite sign,

....

....

.... [2]

(ii) the effect, if any, on the shape of the graph of doubling the charge on particle P.

....

....

.... [2]

(c) Using Fig. 7.2, determine the separation of the particles at the point where particle Q has electric potential energy equal to -5.1 eV.

separation = ………………………….. m [2]

Section B

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

8 **(a)** Explain how an electric field and a magnetic field may be used for the velocity selection of charged particles. You may draw a diagram if you wish.

....

....

....

....

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....

....

....[4]

(b) A simple generator consists of a coil with a large number of turns that rotates at a constant rate in a uniform magnetic field, as shown in Fig. 8.1.

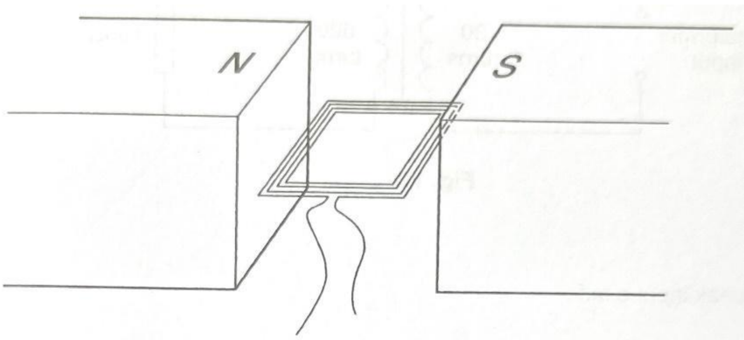


Fig. 8.1

(i) Explain why an e.m.f. is generated when the coil rotates.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

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

(ii) State two factors that affect the magnitude of the maximum e.m.f.

1. ……………………………………………………………………………………..

2. ……………………………………………………………………………………..

[2]

(iii) Explain briefly, in words, why the e.m.f. is sinusoidal.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

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

(c) A rectangular coil of dimensions 30 cm by 24 cm has 15 turns. A uniform magnetic field of flux density 0.018 T is at right-angles to the plane of the coil.

The magnetic field is kept constant for 2.0 s and then reduced to zero over a time of 4.0 s, as shown in Fig. 8.2.

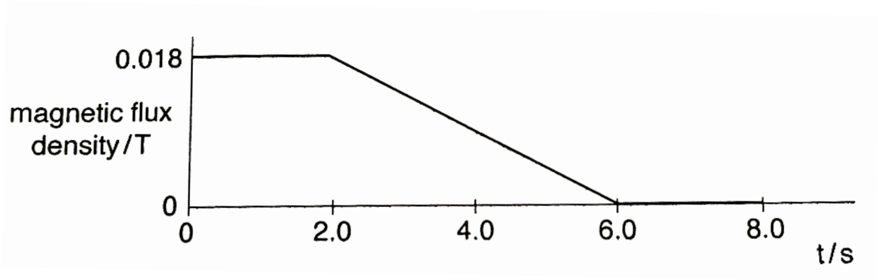
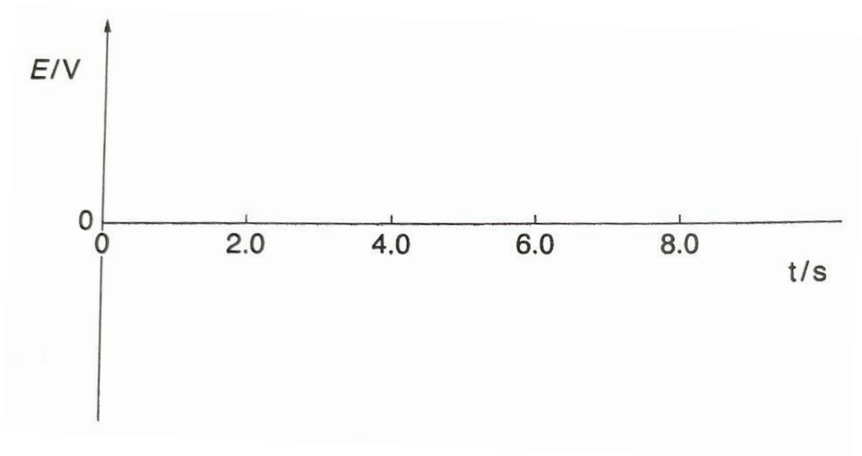


Fig. 8.2

(i) Calculate the magnitude of the induced e.m.f. between 2.0 and 6.0 s.

e.m.f. ……………………………… V [2]

(ii) On Fig. 8.3, sketch a graph to show the variation with time of the e.m.f. *E* induced in the coil.



[2]

Fig. 8.3

(d) Fig. 8.4 shows the top view of a train, travelling on a flat ground heading due east at 30.0 m s^{-1}. **CD** is a horizontal metal axle of the train which is 1.5 m long. Assume the resistance of the axle is 0.400 Ω and resistance of the other parts of the train is negligible.

Fig. 8.4

The Earth's magnetic field strength is 6.0 x 10^{-5} T and acts downwards at 65^0 to the horizontal.

(i) Calculate the rate at which thermal energy is being generated in the axle.

rate = ………………………. W [4]

(ii) State and explain which end of the axle **CD** is at a higher potential.

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

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

9 **(a)** A beam of light of intensity 160 W m^{-2} is incident normally on a plane mirror, as shown in Fig. 9.1. The momentum of each photon in the beam is 9.5×10^{-28} N s.

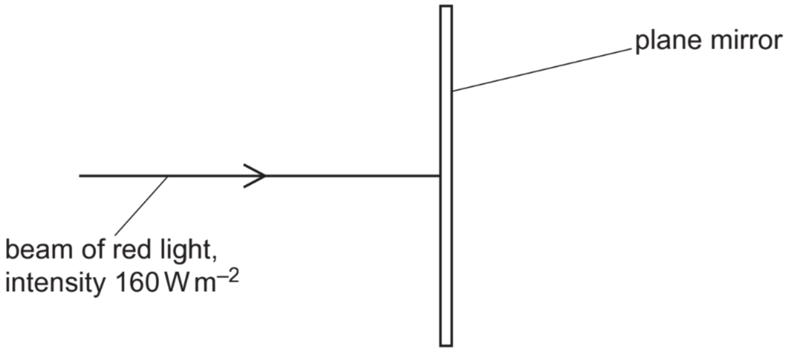


Fig. 9.1

All the light is reflected in the opposite direction to its original path by the mirror of cross-sectional area 2.5×10^{-2} cm^2. The number of photons incident on the mirror per unit time is 1.4×10^{15} s^{-1}.

(i) State what is meant by a photon.

....
.

....
[2]

(ii) Calculate the photon's de Broglie wavelength and determine its colour in the visible light spectrum.

wavelength = ... nm [1]

colour = ... [1]

(iii) Determine the pressure exerted by the light beam on the mirror.

pressure = ... Pa [2]

(b) Ultraviolet radiation of constant power is incident, in a vacuum, on a metal surface. Photoelectrons are observed to be emitted in the process.

The frequency of ultraviolet radiation is now increased.

State and explain the effect of this change on:

(i) the maximum kinetic energy of the photoelectrons

....
.

....
.

.... [2]

(ii) the rate of emission of photoelectrons.

....
.

....
.

.... [2]

(c) Fig. 9.2 shows a glass tube in which electrons are accelerated through a high p.d. to form a beam that is incident on a thin graphite crystal.

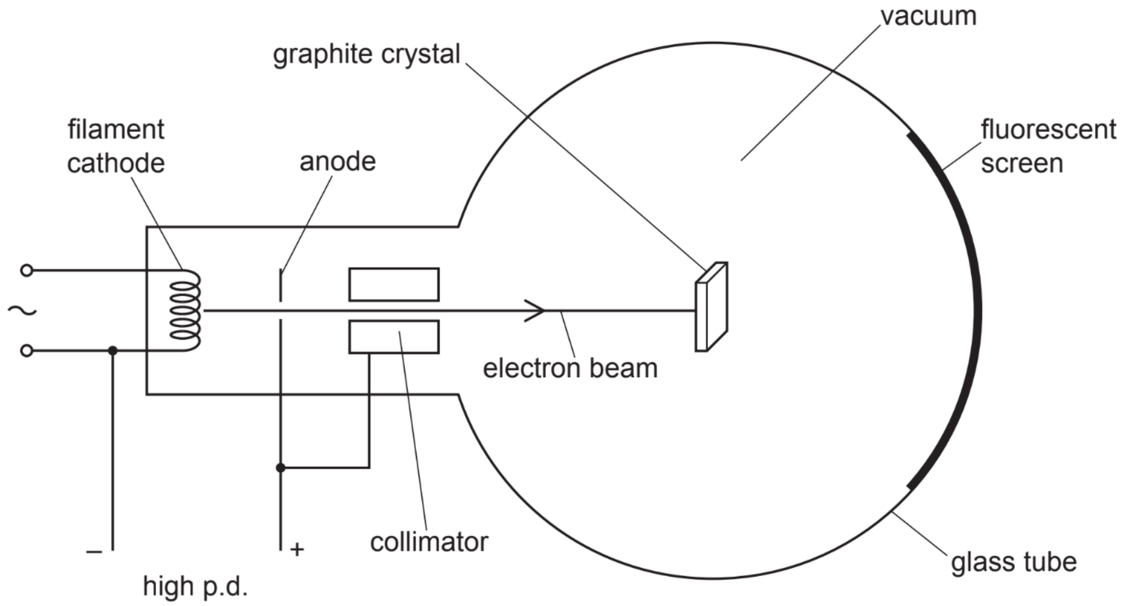


Fig. 9.2

After passing through the graphite crystal, the electrons reach the fluorescent screen. The screen glows where the electrons strike it.

Fig. 9.3 shows the fluorescent screen viewed end-on, from the right-hand side of Fig. 9.2.

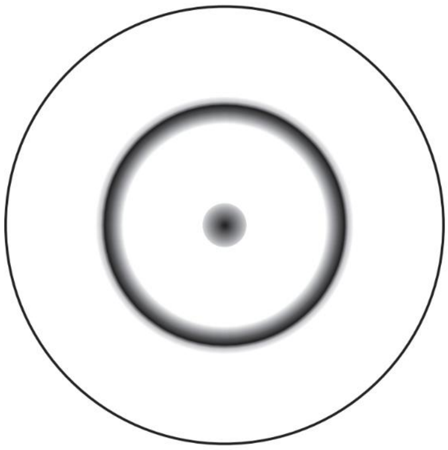


Fig. 9.3

(i) State the name of the phenomenon demonstrated by the pattern shown in Fig. 9.3.

.... [1]

(ii) Explain what can be concluded from the pattern in Fig. 9.3 about the nature of electrons.

....
.

....
.

.... [2]

(d) A beam of white light passes through a cloud of cool gas. The spectrum of the transmitted light is viewed and contains several dark lines.

Explain why these dark lines occur.

....

....

....

....

....

....

....

....

.... [4]

(e) Some energy levels for the electron in an isolated hydrogen atom are illustrated in Fig. 9.4.

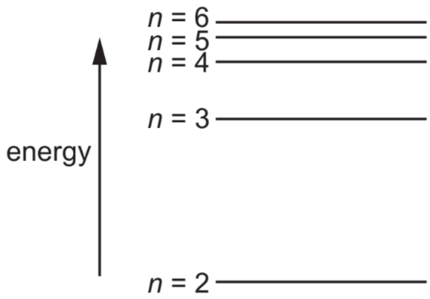


Fig. 9.4

Table 9.1 shows the wavelengths of photons that are emitted in the transitions to n = 2 from the other energy levels shown in Fig. 9.4.

wavelength / nm
412
435
488
658

Table 9.1

The energy associated with the energy level n = 2 is -3.40 eV.

Calculate the energy, in J, of energy level n = 3.

energy = ... J [3]

[End of Paper]