Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2023 Preliminary Examination

PHYSICS **9749/03**

Higher 2 **September 2023**

Paper 3 Longer Structured Questions **2 hours**

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

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class 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 and **circle** the question number on the cover page.

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.

***This booklet only contains Section A.**

For Examiner's Use		
Section A	1	/ 9
	2	/ 10
	3	/ 8
	4	/ 10
	5	/ 7
	6	/ 8
	7	/ 8
Section B (circle question attempted)	8	/ 20
	9	/ 20
Deduction		
Total		/ 80

This document consists of **16** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
			$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on / by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T / K	=	T / °C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t = \pm \omega \sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{1/2}}$

Section A

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

1 **(a)** The angular velocity ω of a satellite in a circular orbit of radius r about the Earth is given by:

$$\omega = A r^k$$

where A and k are constants.

(i) Use Newton's law of gravitation to write an equation that relates the centripetal force on the satellite to the gravitational force acting on the satellite and determine the value of k.

k = ... [2]

(ii) A geostationary orbit has a radius of 42 000 km.

Determine the angular velocity of a satellite with an orbital radius of 6700 km.

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

(b) **(i)** By considering the potential energy and kinetic energy of the satellite, show that the total energy E_T of the satellite in a circular orbit of radius r about the Earth is given by:

$$E_T = -\frac{GMm}{2r}$$

where M and m are the masses of the Earth and the satellite respectively.

[2]

(ii) When a geostationary satellite is near the end of its useful life, it will be decommissioned and moved to a graveyard orbit. A graveyard orbit is an orbit that lies far away from common orbits used by satellites in service and its radius is at least 300 km more than that of the geostationary orbit.

The mass of the Earth is 6.0×10^{24} kg.

Determine the minimum energy needed to bring a geostationary satellite of mass 700 kg to a graveyard orbit from a geostationary orbit.

minimum energy = ... J [2]

(c) The Moon is the Earth's only natural satellite. Its orbital path is actually elliptical and not circular. Fig. 1.1 shows the orbit of the Moon about the Earth when viewed normal to the plane of the orbit of the Moon. There are points where the Moon is closer to the Earth and points when it is further from the Earth.

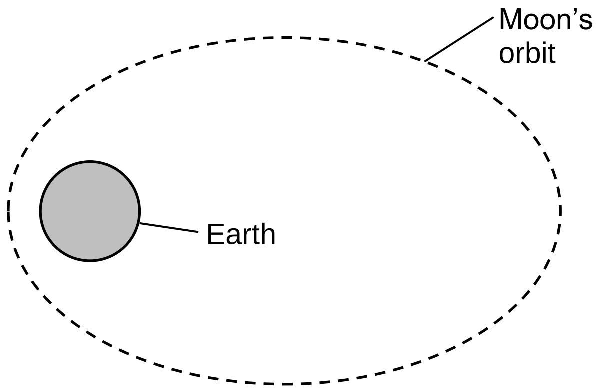

Fig. 1.1 (not to scale)

On Fig. 1.1, mark with a cross on the Moon's orbit where the Moon has the largest speed. Explain your answer.

....

.... [1]

2 In a particular combustion engine, a fixed amount of ideal gas undergoes a cycle of four stages as shown in Fig. 2.1.

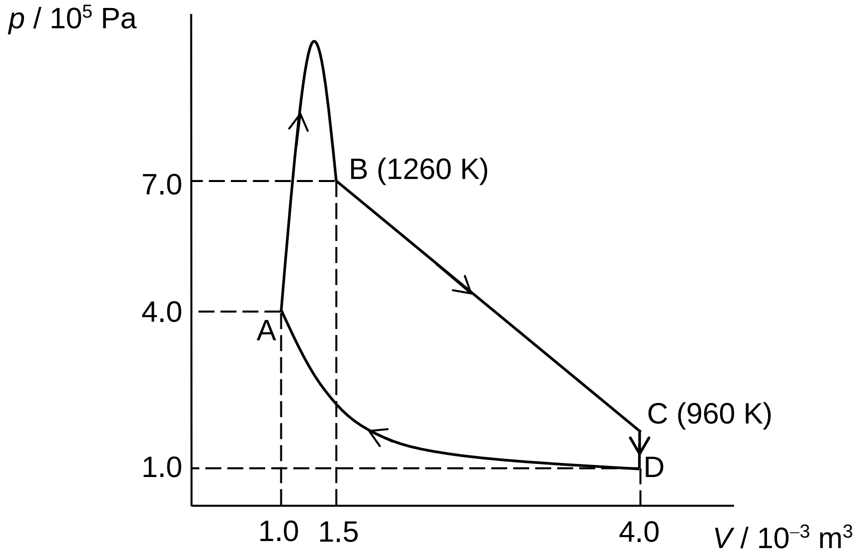

Fig. 2.1

Some values for the pressure p and volume V of the gas at the various states are labelled in the figure.

The four stages of the cycle are:

A → B: the gas gains 2625 J of heat through an explosion and the pressure rises rapidly before decreasing to 7.0×10^5 Pa at state B

B → C: the gas expands to state C

C → D: the gas cools to state D at constant volume

D → A: the gas is compressed at constant temperature to state A.

(a) The temperatures of the gas at states B and C are 1260 K and 960 K respectively.

(i) Determine the pressure of the gas at state C.

pressure = ... Pa [2]

(ii) Hence, determine the magnitude of the work done by the gas in the stage B → C.

work done = ... J [2]

(b) The stage D → A is compression at constant temperature.

State **two** conditions under which the process in the engine is carried out such that it may be considered to be a constant temperature process.

1. ....

....

2. ....

.... [2]

(c) Some energy changes during one cycle of the engine are shown in Fig. 2.2.

Complete Fig. 2.2.

stage	work done on gas / J	heat supplied to gas / J	increase in internal energy / J
A → B	–1000	2625	
B → C		500	
C → D			
D → A		–555	

Fig. 2.2

[3]

(d) In Fig. 2.1, the stage A → B is represented by a curve.

Explain why it may not be appropriate to represent the process with a curve on the graph.

....

.... [1]

3 Fig. 3.1 shows two slits S_1 and S_2, separated by distance a, illuminated by a point source of light producing coherent light of wavelength 750 nm. The light source is equidistant from both slits.

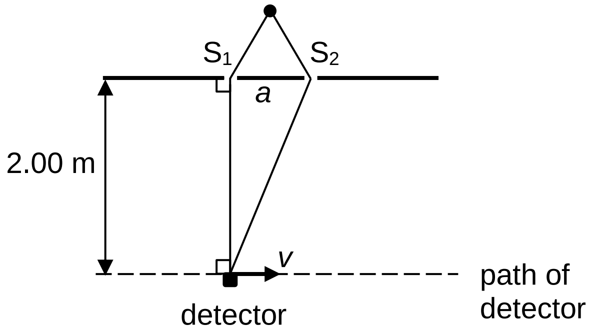

Fig. 3.1 (not to scale)

A light detector, 2.00 m below the slits, is moving to the right at a uniform speed v, in the direction shown.

(a) When the detector is directly below S_1, the detector records a minimum intensity reading.

Show that the minimum value for a is 1.22 mm.

[2]

(b) The slits are now fixed at 1.22 mm apart, with the light source still equidistant from both slits.

(i) The detector detects three maxima per second while moving to the right.

Determine the speed v at which the detector is moving.

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

(ii) The light detector now moves with the same speed v along a diagonal path as shown in Fig. 3.2.

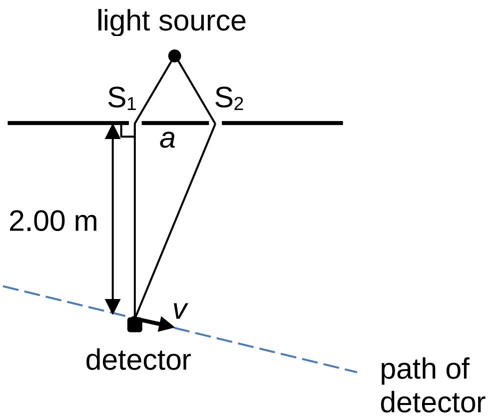

Fig. 3.2 (not to scale)

Describe and explain what happens to the frequency at which the detector detects maxima.

....

....

....

.... [2]

(c) The detector is now replaced with a camera. The camera lens is at a distance R below the two slits and is equidistant from both slits.

The camera lens has an aperture diameter of 4.0 mm.

Determine the value of R where the images of both slits are just resolved.

R = ... m [2]

4 **(a)** Define *electric potential* at a point.

....

....

....

.... [2]

(b) A solid metal sphere A of radius 27 cm is fixed in a vacuum and carries a charge of +0.060 μC. The charge on the metal sphere may be considered as a point charge at its centre.

(i) Determine the electric potential V_R at the surface of the sphere.

V_R = ... V [1]

(ii) On the axes of Fig. 4.1, draw a graph to show the variation with distance x from the centre of sphere A of the electric potential V for x = 0 to x = 120 cm.

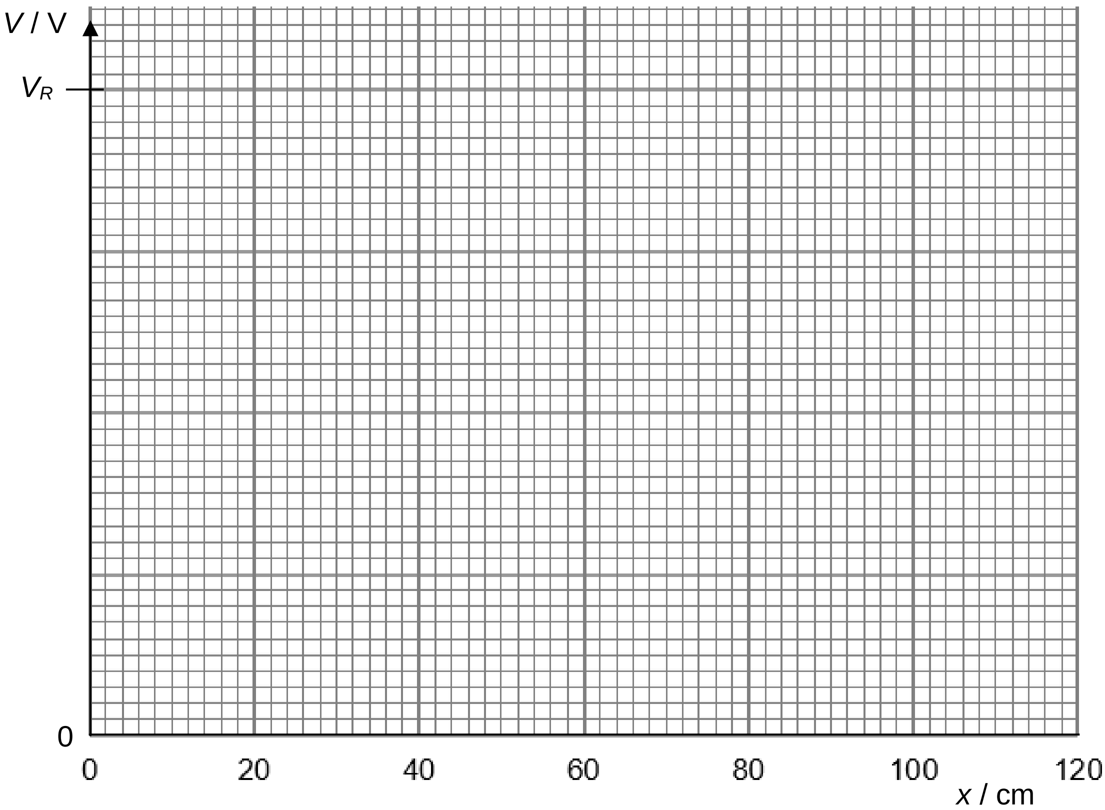

Fig. 4.1

[3]

(iii) A charged particle B is placed at a distance 1.4 m from the centre of sphere A as shown in Fig. 4.2.

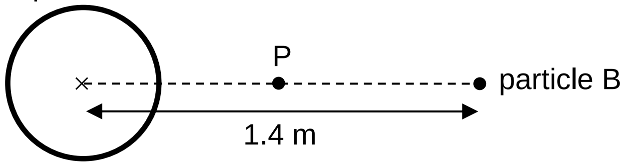

Fig. 4.2

Particle B carries a charge of –0.035 μC. Sphere A and particle B are fixed in position. Point P is the midpoint of the line joining the centre of the sphere and particle B.

Determine the magnitude of electric field strength at point P.

magnitude of electric field strength = ... N C^{-1} [2]

(iv) State and explain, in practice, whether the magnitude of the electric field strength at point P is greater than, smaller than or the same as your answer to **(b)(iii)**.

....

....

....

.... [2]

5 A cell of electromotive force (e.m.f.) 6.0 V and negligible internal resistance is connected to a resistor of 12 Ω, a resistor of 33 Ω, a resistor R and an ammeter as shown in Fig. 5.1.

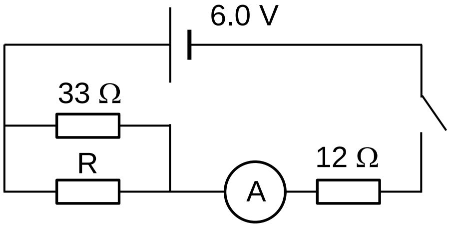

Fig. 5.1

When the switch is closed, the reading on the ammeter is 150 mA.

(a) Determine the charge *Q* that passes through the 12 Ω resistor in a time of 20 minutes.

Q = ... C [1]

(b) Calculate the potential difference across the 12 Ω resistor.

potential difference = ... V [1]

(c) Hence, determine the resistance of the resistor R.

resistance = ... Ω [3]

(d) Resistor R is replaced by an NTC thermistor. Initially the resistance of the thermistor is 200 Ω. The switch is closed.

State and explain the change, if any, to the ammeter reading when the temperature of the thermistor increases.

....

....

....

.... [2]

6 A plane circular coil of radius 0.17 m has 30 turns and is placed with its plane horizontal in a vertical magnetic field of flux density B as shown in Fig. 6.1.

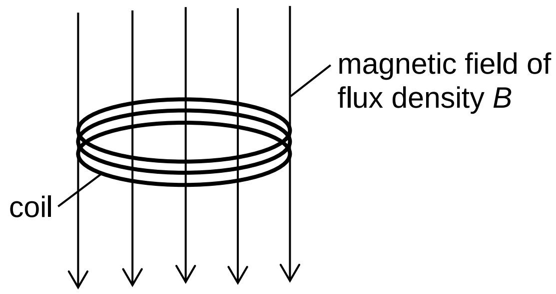

Fig. 6.1

Fig. 6.2 shows the variation with time t of the magnetic flux density B.

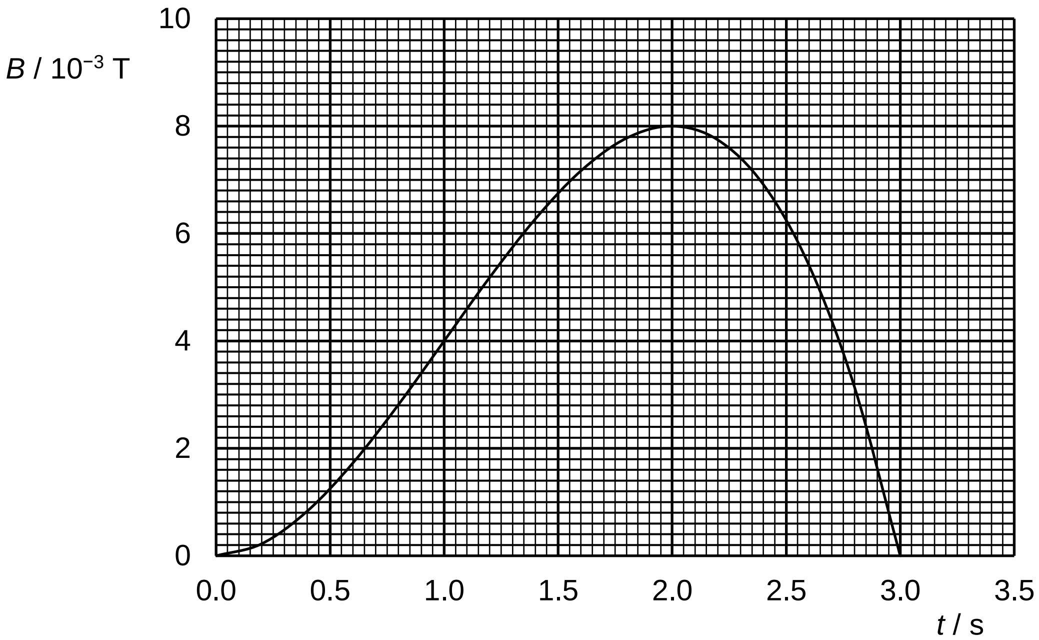

Fig. 6.2

(a) Calculate the maximum magnetic flux linkage of the coil.

maximum magnetic flux linkage = ... Wb [2]

(b) Determine the maximum induced e.m.f. in the coil during the time interval $t = 0$ to $t = 2.0$ s.

maximum induced e.m.f. = ... V [2]

(c) State and explain the direction of the induced current in the coil as viewed from the top for $t = 0$ to $t = 2.0$ s.

....

....

....

.... [2]

(d) On the axes of Fig. 6.3, sketch the variation with time t of the induced e.m.f. in the coil from $t = 0$ to $t = 3.0$ s.

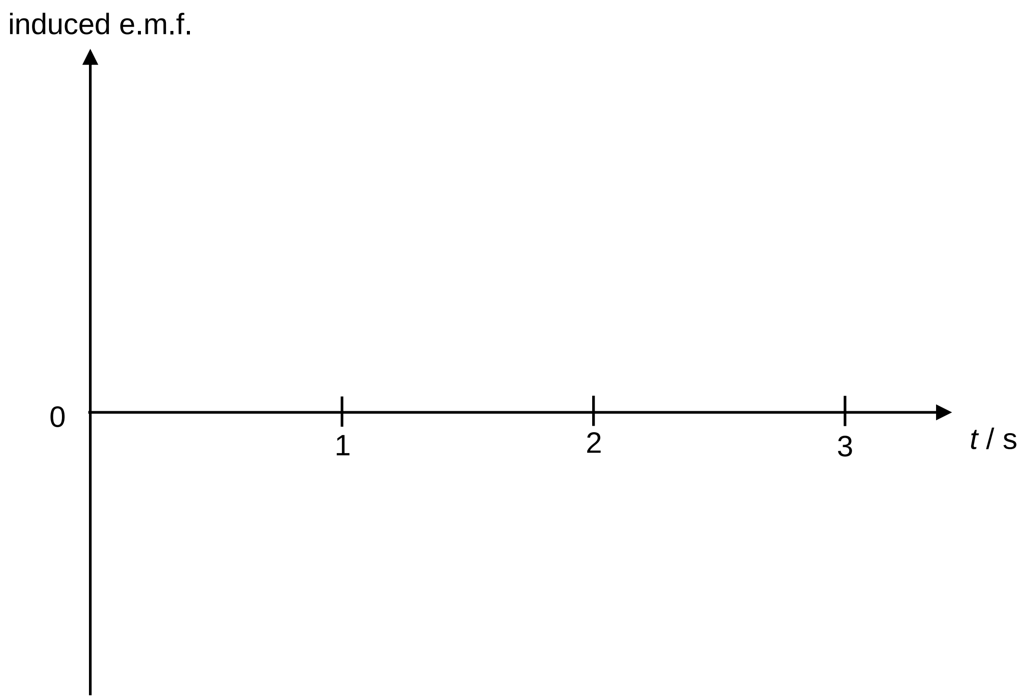

Fig. 6.3

[2]

7 A circuit used to investigate the photoelectric effect is shown in Fig. 7.1.

Electromagnetic radiation of wavelength 450 nm is incident on metal plate A and the stopping potential is 1.1 V.

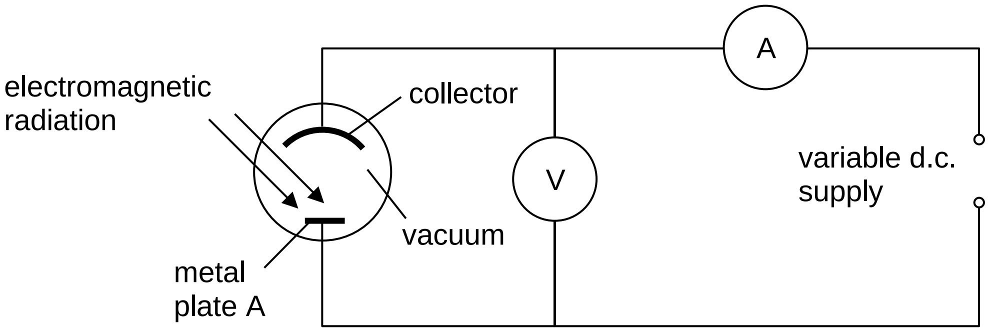

Fig. 7.1

(a) Calculate the maximum kinetic energy of the photoelectrons emitted from metal plate A.

maximum kinetic energy = ... J [2]

(b) Determine the threshold frequency of metal plate A.

threshold frequency = ... Hz [3]

(c) Explain whether maximum kinetic energy of the photoelectrons emitted from metal plate A is affected by the intensity of the electromagnetic radiation incident on the surface at constant frequency.

....

.... [1]

(d) The collector in Fig. 7.1 is replaced by metal plate B as shown in Fig. 7.2.

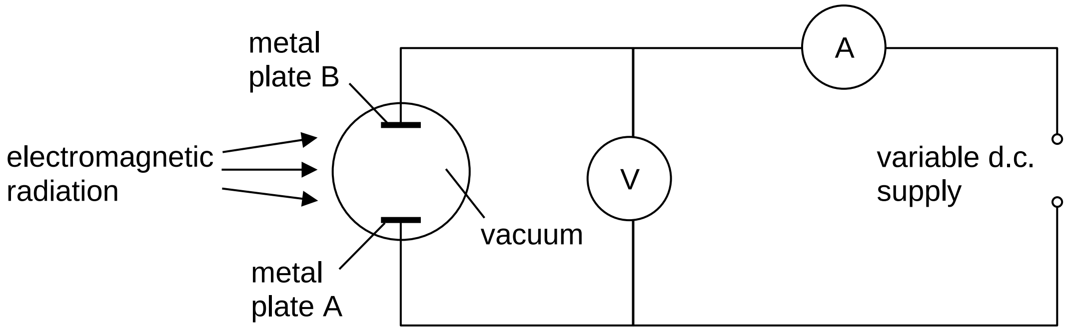

Fig. 7.2

Metal plate B has a higher threshold frequency than metal plate A.

The current-voltage (I – V) characteristic is obtained when both plates are illuminated with monochromatic electromagnetic radiation of frequency higher than the threshold frequencies of both plates.

On Fig. 7.3, sketch the I – V characteristic.

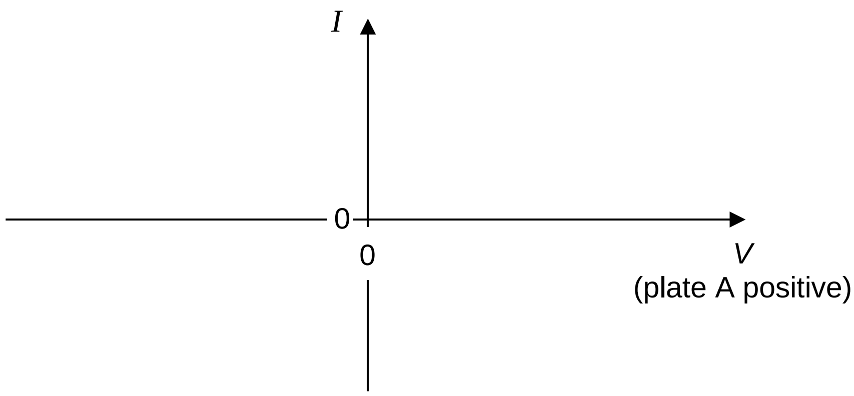

Fig. 7.3

[2]