Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2022 Preliminary Examination

PHYSICS **9749/02**
Higher 2

12 September 2022
Paper 2 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 in the spaces provided in this booklet.
You may use 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.

Answer **all** questions.

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

For Examiner's Use	
1	/ 9
2	/ 5
3	/ 8
4	/ 10
5	/ 7
6	/ 12
7	/ 7
8	/ 22
Deduction	
Total	/ 80

This document consists of **24** 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	=	$T / {}^\circ\text{C} + 273.15$
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\ln 2/t_{1/2}$

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

1 Particle A of mass $9m$ and particle B of mass m travel towards each other along a smooth horizontal surface in a straight line and collide head-on. The initial speed of particle A before the collision is u.

In Fig. 1.1, the variation with time t of momentum p is shown from $t = 0$ to $t = 3T$ for particle A and from $t = 0$ to $t = T$ for particle B.

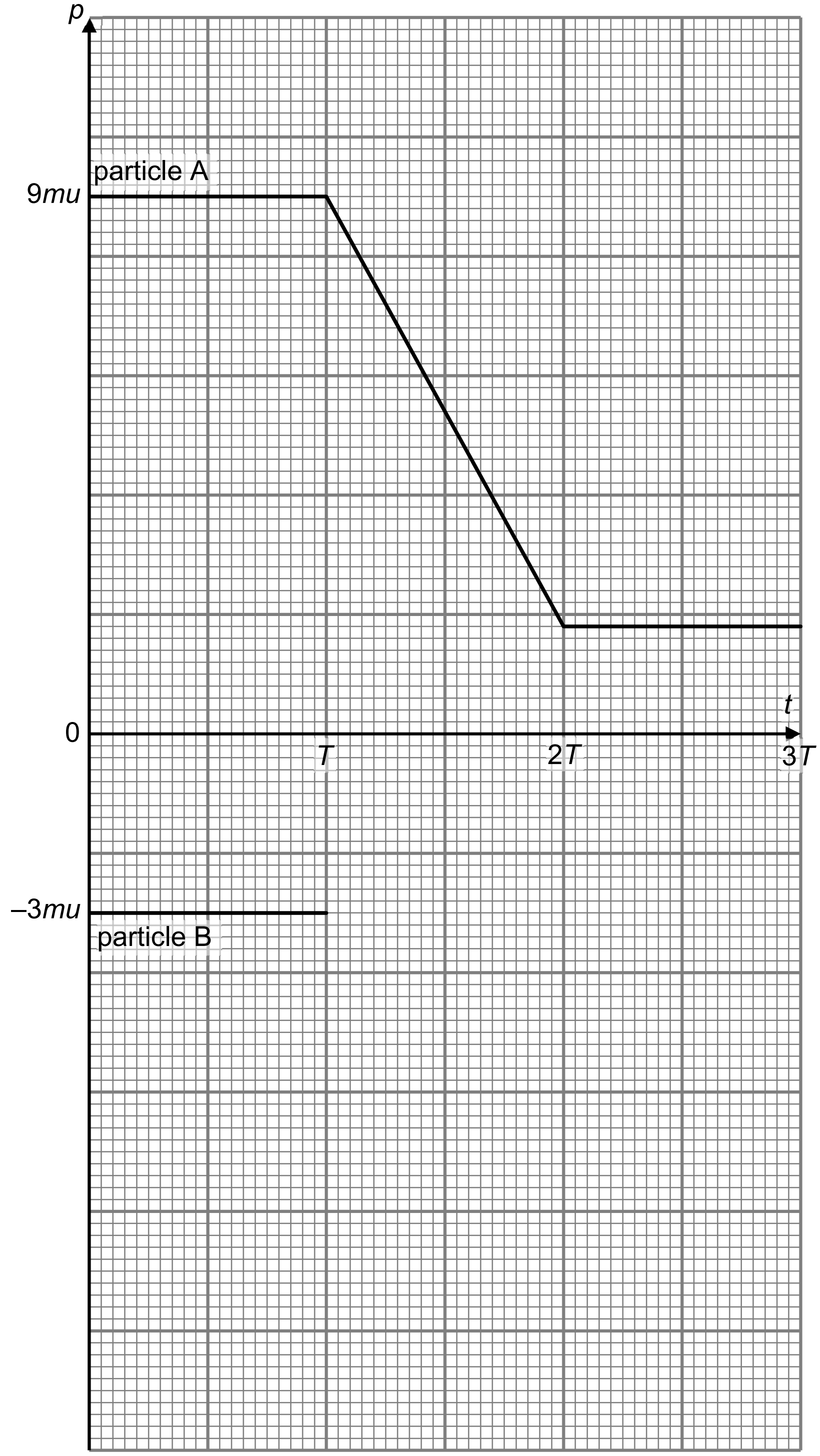

Fig. 1.1

(a) **(i)** On Fig. 1.1, draw the variation with t of p from $t = T$ to $t = 3T$ for particle B. [1]

(ii) Explain how the principle of conservation of momentum is used to complete the graph in **(a)(i)**.

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.... [2]

(b) Explain, with appropriate working, whether the collision between particles A and B is elastic.

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.... [3]

(c) Using Fig. 1.1, explain how the graphs are consistent with Newton's third law of motion during the collision.

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.... [3]

2 A uniform square box with sides 0.80 m and mass 2.0 kg is at rest on the ground. One end of a light rope is attached to the box and the other end is attached to the wheel of a motor. The motor applies a constant clockwise torque of 5.0 N m on the wheel of radius 0.20 m.

At the instant shown in Fig. 2.1, the rope is taut and it makes an angle of $\theta = 20°$ with the vertical side of the box. The system remains in equilibrium.

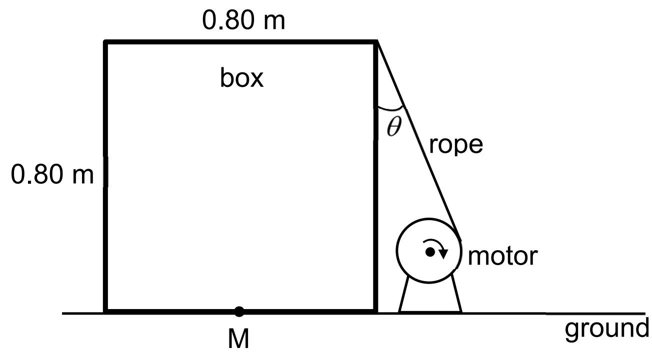

Fig. 2.1

(a) Calculate the tension in the rope.

tension = ... N [1]

(b) Point M is the mid-point at the base of the box as shown in Fig. 2.1.

By taking moments about point M, determine the horizontal distance *d* between M and the point at which the contact force by the ground acts on the box.

d = ... m [3]

(c) The motor is shifted to the right such that θ increases. The torque applied by the motor remains constant.

Without any further calculations, explain why there is a maximum value of θ for which equilibrium can be maintained.

....

....

.... [1]

3 A bob of mass 1.5 kg is attached to a string of negligible mass and of length 25.0 cm. The other end of the string is fixed to point X of an inverted "L" structure of arm length *d*. The structure is fixed to the centre of a rotating disc of radius 8.0 cm.

When the disc rotates with an angular velocity ω, the string makes at an angle θ to the vertical as shown in Fig. 3.1.

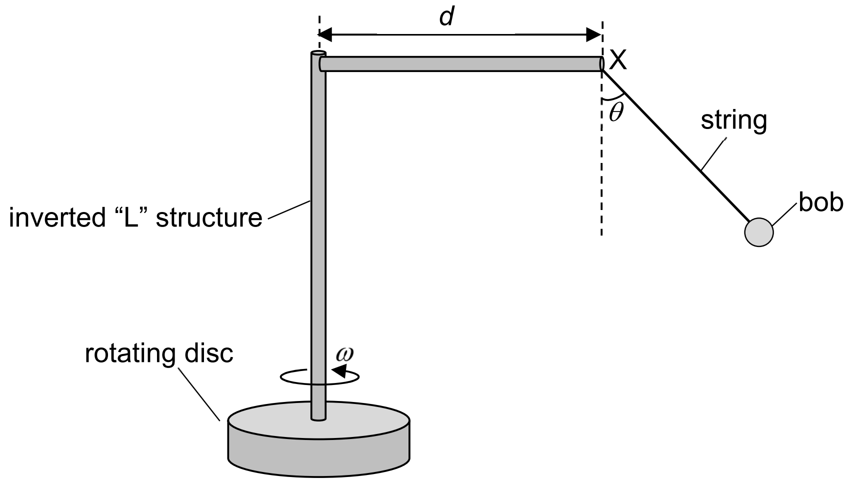

Fig. 3.1

(a) A point on the circumference of the rotating disc has a speed of 24.0 cm s^{-1}.

Determine ω.

ω = ... rad s^{-1} [1]

(b) (i) Determine the tension in the string for $\theta = 30°$.

tension = ... N [2]

(ii) Calculate *d*.

d = ... m [3]

(c) A student states that as the angular velocity of the disc increases, θ increases but θ will always be smaller than $90°$.

Comment on the validity of the statement made by the student.

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.... [2]

4 **(a)** Explain why gravitational potential is always negative whereas electric potential can have positive and negative values, given that both potentials are zero at infinity.

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.... [3]

(b) Fig. 4.1 shows how the gravitational potential ϕ from the surface of a planet varies with distance r from the centre of the planet.

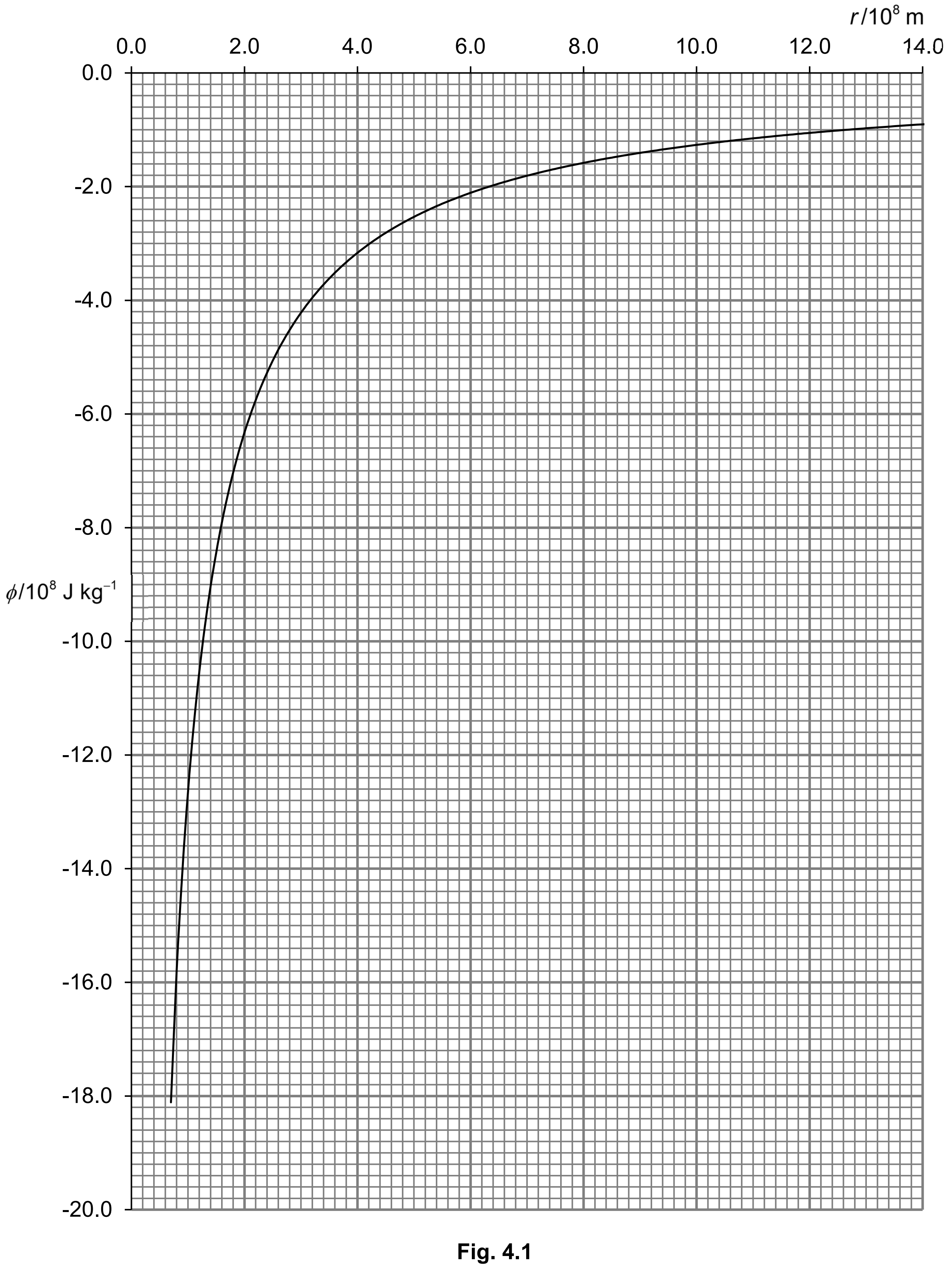

Fig. 4.1

(i) A moon orbits the planet. The mass of the moon is 1.48×10^{23} kg and its orbital radius is 1.07×10^{6} km.

Using Fig 4.1, calculate

1. the orbital speed of the moon,

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

2. the total energy of the moon.

total energy = ... J [2]

(ii) A rock is projected vertically upwards with a speed of 45 km s^{-1} from the surface of the planet. The resistive forces on the rock by the planet's atmosphere are negligible.

Using Fig 4.1,

1. show, with clear working, that the rock will not escape the planet,

[2]

2. determine the maximum distance of the rock from the surface of the planet.

distance = ... m [1]

5 A transverse wave on a rope is travelling to the right. Fig. 5.1 shows the waveform at a particular time. Particles Q, R, S, T, U and V are labelled.

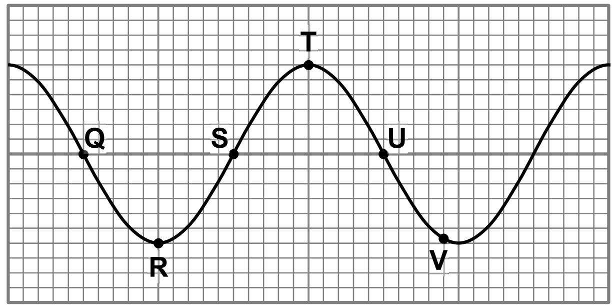

Fig. 5.1

(a) On Fig. 5.1, indicate using arrows the directions in which the particles Q, S and U are moving.

[2]

(b) State the motion of particles R and T at this instant shown.

.... [1]

(c) On Fig. 5.1, mark two particles on the waveform, other than Q, R, S, T and U, that are

(i) in phase with each other (mark with ‘X’),

(ii) in antiphase with each other (mark with ‘+’). [2]

(d) Particle V leads particle U by a phase of ϕ .

Calculate ϕ . Explain your working.

ϕ = ... rad [2]

6 Fig 6.1 shows a miniature E10 filament light bulb with a rating of 6.0 V, 3.0 W.

Fig. 6.1

(a) **(i)** Calculate the resistance of the bulb.

resistance = ... Ω [1]

(ii) The filament of the bulb is made of tungsten wire of length 2.0 cm and diameter 78 μm.

Calculate the resistivity of the tungsten filament.

resistivity = ... Ω m [2]

(iii) The resistivity of tungsten from a table of constants is stated to be 5.6×10^{-8} Ω m.

Explain, in microscopic terms, the difference between this value and your answer in **(a)(ii)**.

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.... [2]

(b) Six identical E10 light bulbs are connected to a 6.0 V d.c. supply of negligible internal resistance in the arrangement shown in Fig. 6.2.

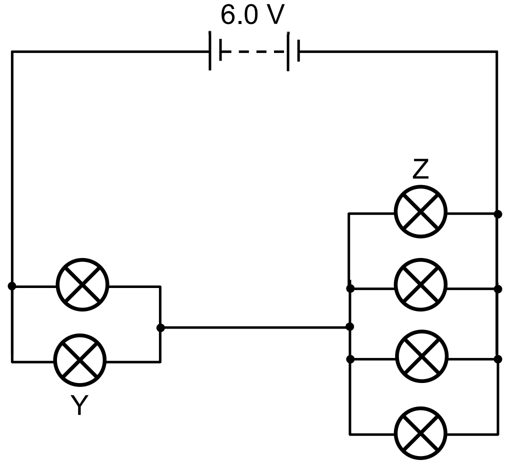

Fig. 6.2

Assume that the resistance of each bulb is as calculated in **(a)(i)**.

(i) Determine the amount of charge that passes through bulb Y in 2 minutes.

charge = ... C [2]

(ii) Explain how the mean drift velocity of the electrons in the filament of bulb Y compare with that of the electrons in the filament of bulb Z.

....

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....

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.... [2]

(c) The six E10 light bulbs are now connected to an alternating power supply with frequency 50 Hz and r.m.s. voltage 6.0 V. An ideal diode is connected in parallel to bulb Z as shown in Fig. 6.3.

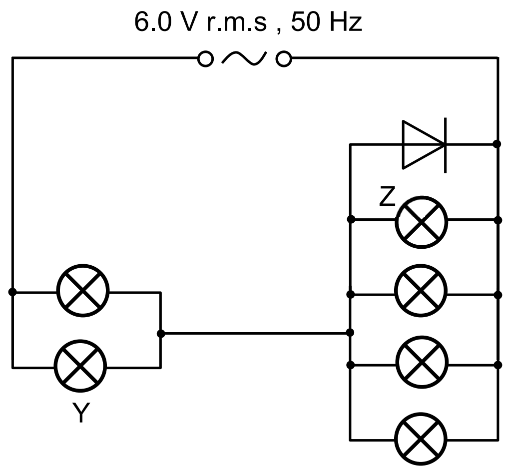

Fig. 6.3

On Fig. 6.4, sketch the variation with time t of the power P dissipated in bulb Y from $t = 0$ s to $t = 0.04$ s.

Include appropriate values for power on the vertical axis.

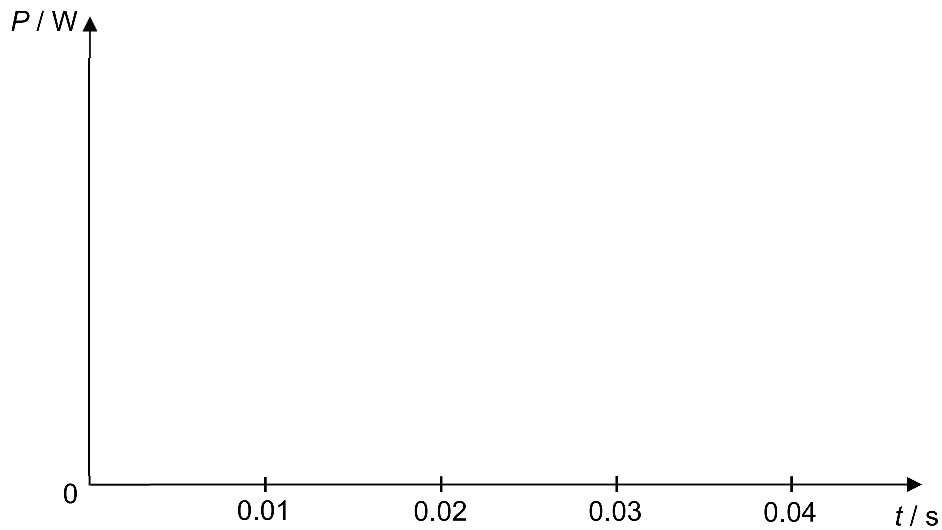

Fig. 6.4

[3]

7 A medical treatment makes use of a sample of americium-240 that emits alpha particles to kill cancer cells. In one such treatment, a total energy of 1140 J is applied to a tumour of mass 0.500 kg. At the start of the treatment, the mass of the americium-240 sample is 2.00×10^{-9} kg.

Americium-240 has a half-life of 50.2 hours, and it decays by emitting an alpha particle of kinetic energy 5.71 MeV.

(a) Determine

(i) the initial activity of the americium-240 sample,

activity = ... Bq [2]

(ii) the number of decays required for the treatment,

number of decays = ... [2]

(iii) the duration of the treatment.

duration = ... h [2]

(b) A student states that "radioactive materials with a long half-life have low activity".

Explain whether the statement is correct.

....

.... [1]

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

Despite the increasing popularity of laser printers, inkjet printers remain a common choice for many people who are looking to print documents and photos from their computers due to their relatively low cost, smaller size and ability to print photos with better quality than laser printers.

In inkjet printers, tiny droplets of ink are ejected and directly applied onto the paper, which then form the text or image. Traditionally, there are two main technologies used for droplet ejection in inkjet printers: continuous inkjet (CIJ) and drop-on-demand (DOD).

In CIJ printers, a vibrating nozzle ejects a stream of regularly spaced ink droplets at a high velocity towards a pair of charging electrodes that deposits electrons on the droplets, giving the appropriate amount of charge to each droplet. The charged droplets then enter a region of uniform electric field between two deflection plates, which causes the droplets to deflect by different amounts corresponding to the amount of charge deposited on them. These droplets finally land on the piece of paper to form the desired image. This process in a CIJ printer is shown in Fig. 8.1.

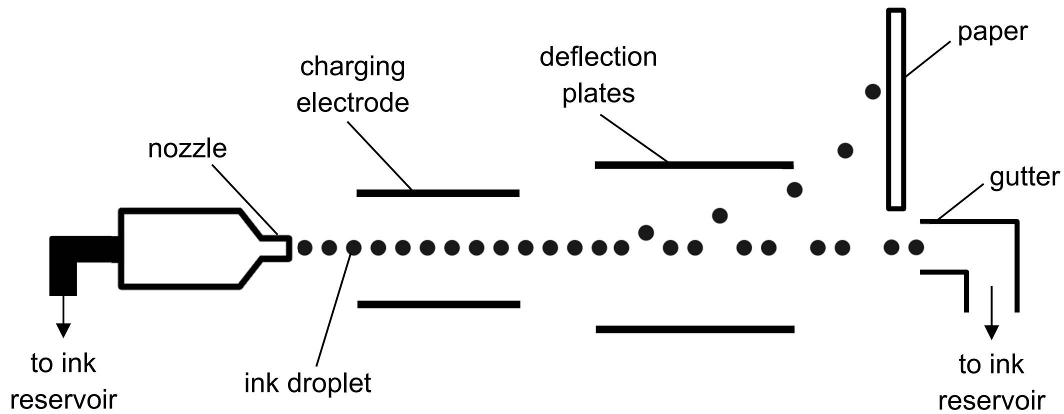

Fig. 8.1

Not every ink droplet that passes through the charging electrodes will get charged – instead, charged droplets will usually be separated by one or more uncharged “guard droplets”. These uncharged droplets, which will not be deflected by the electric field, will enter a gutter that will divert these unused droplets back into the ink reservoir to be reused.

Typical data for a commercial CIJ printer are given in Table 8.1.

Table 8.1

velocity of ink droplets / m s^{-1}	20
frequency of droplet ejection / kHz	110
average diameter of ink droplet / μm	80
density of ink / g cm^{-3}	0.84
p.d. across deflection plates / V	10000

In DOD inkjet printers, ink droplets are ejected from a nozzle one drop at a time. While there are a number of different methods by which the droplets are ejected out individually, a common method used is called the thermal inkjet, or sometimes known as the “bubble jet”.

In thermal inkjet printers, the printhead consists of an ink chamber connected to a nozzle from which the ink will be ejected. There is a square-shaped thin-film resistor of sides length 20 μm that acts as a heating element on top of the ink chamber.

A small pulse of current is passed through the thin-film resistor, which quickly heats up and vapourises a thin layer of ink just below the thin-film resistor. This creates a bubble which expands rapidly. The pressure within the ink chamber increases and pushes a tiny drop of ink out of the nozzle onto the paper underneath to form the desired image. This process in a thermal inkjet printer is shown in Fig. 8.2.

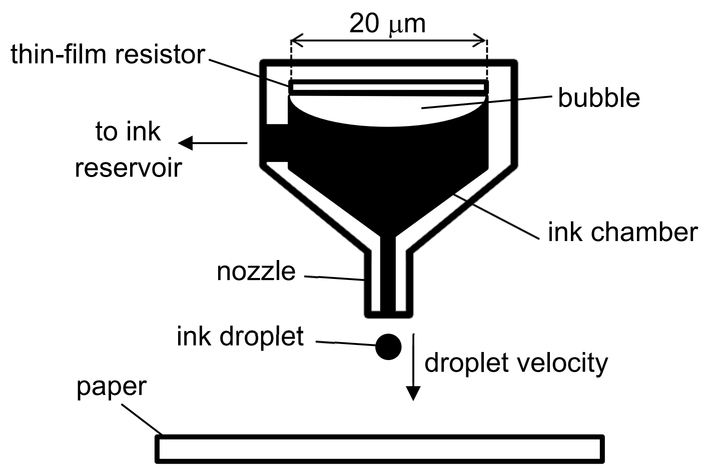

Fig. 8.2

Typical data for a commercial thermal inkjet printer are given in Table 8.2.

Table 8.2

velocity of ink droplets / m s^{-1}	4.5
frequency of droplet ejection / kHz	18
average diameter of ink droplet / μm	10
density of ink / g cm^{-3}	1.17
specific heat capacity of ink / J kg^{-1} K^{-1}	2090
specific latent heat of vaporisation of ink / kJ kg^{-1}	444
boiling point of ink / °C	80
resistance of thin-film resistor / Ω	30

(a) Fig. 8.3 shows a close-up of a series of spherical ink droplets travelling between the charging electrodes in a CIJ printer. Droplets A and B are two adjacent droplets.

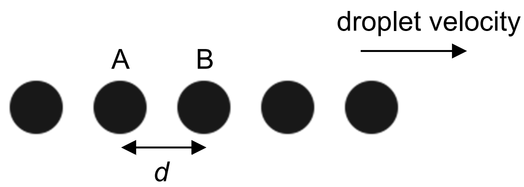

Fig. 8.3

Assume that the velocity of the droplets remains constant over its time of flight through the charging electrodes.

(i) Using the data given, determine

1. the distance *d* between droplets A and B,

d = ... μm [2]

2. the mass of each droplet.

mass = ... kg [2]

(ii) If droplets A and B are each charged uniformly with -1.0×10^{-13} C,

1. show that the electrostatic force between the droplets is 2.7 nN,

[1]

2. calculate the acceleration experienced by either droplet due to the electrostatic force in **(a)(ii)1.**

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

(iii) Suggest why "guard droplets" are necessary between two charged particles in the stream of ink droplets in a CIJ printer.

....

....

....

.... [2]

(b) Fig. 8.4 shows the deflection plates of the CIJ printer. Droplet A, with a charge of -1.0×10^{-13} C, enters at the midpoint between the plates at 20 $m\ s^{-1}$ and is to be deflected upwards towards the piece of paper.

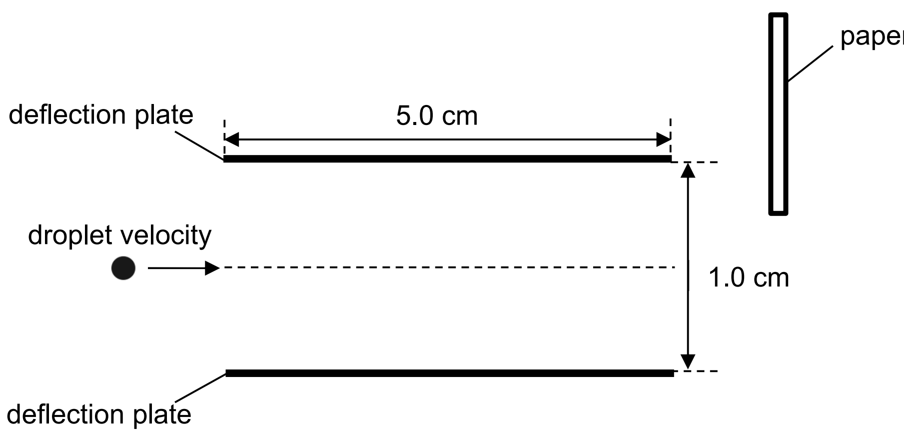

Fig. 8.4 (not to scale)

(i) Draw the electric field lines between the deflection plates on Fig. 8.4. [1]

(ii) Determine the electric field strength between the deflection plates.

electric field strength = ... $N\ C^{-1}$ [1]

(iii) An engineer suggests using a magnetic field instead of an electric field to deflect droplet A.

1. Describe the direction of the magnetic flux density that is required to deflect droplet A upwards.

.... [1]

2. To deflect droplet A onto the paper, a reasonable radius of curvature for droplet A to undergo in the magnetic field would be 26.0 cm.

By determining the magnitude of the magnetic flux density B required to achieve a radius of curvature of 26.0 cm, comment on the feasibility of using a magnetic field in a commercial CIJ printer. Explain your working clearly.

....

....

.... [2]

(c) In a thermal inkjet printer, a constant current of 0.50 A is passed through the thin-film resistor for a short time interval of 0.010 μs. This causes a square layer of ink below the thin-film resistor of thickness x to heat up and vaporise. This is shown in Fig. 8.5.

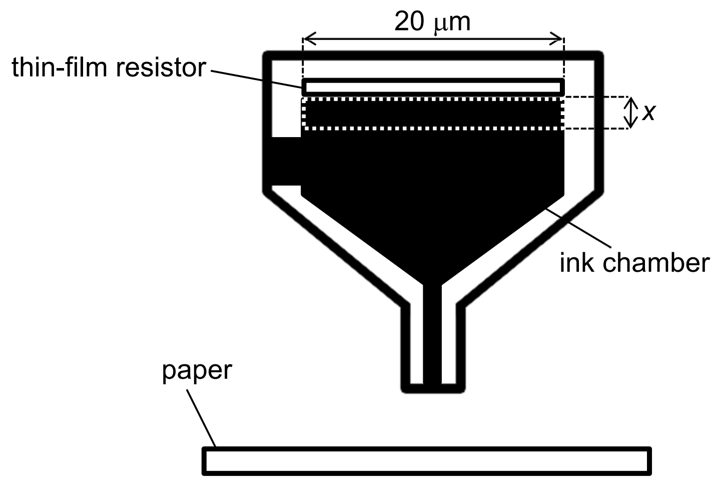

Fig. 8.5

(i) Determine the thermal energy produced by the current passing through the thin-film resistor.

thermal energy = ... J [2]

(ii) The ink in the ink chamber is initially at room temperature of 25°C.

Determine the maximum mass of ink that can be vaporised by the amount of thermal energy in **(c)(i)**.

mass = ... kg [2]

(iii) Hence, determine the maximum thickness x of the layer of ink that can be vaporised.

x = ... μm [2]

(iv) Suggest a possible reason why the actual thickness of the vaporised layer in real thermal inkjet printers is much smaller than that calculated in **(c)(iii)**.

....

.... [1]

(d) State, with reference to the information given, an advantage and a disadvantage of thermal inkjet printing as compared to CIJ printing.

Advantage: ....

....

....

Disadvantage: ....

....

.... [2]

End of Paper 2