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.

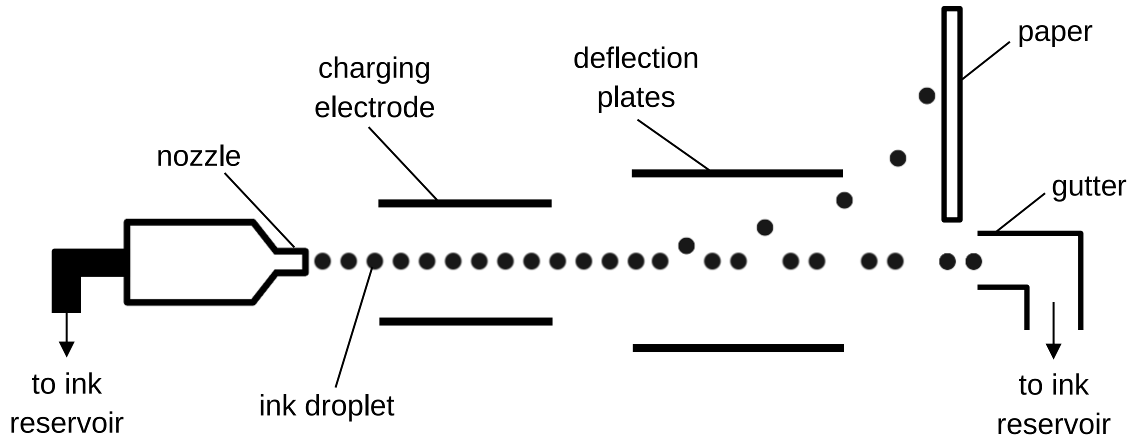

Fig. 8.1

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.

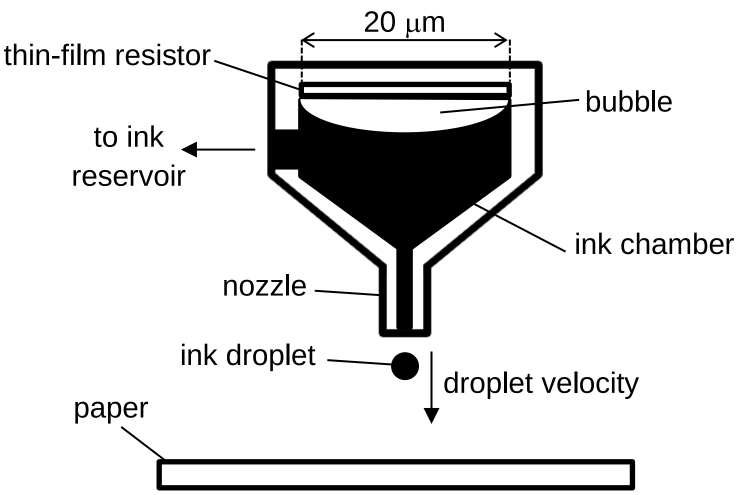

Fig. 8.2

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.

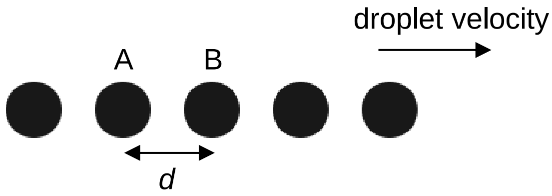

Fig. 8.3

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.

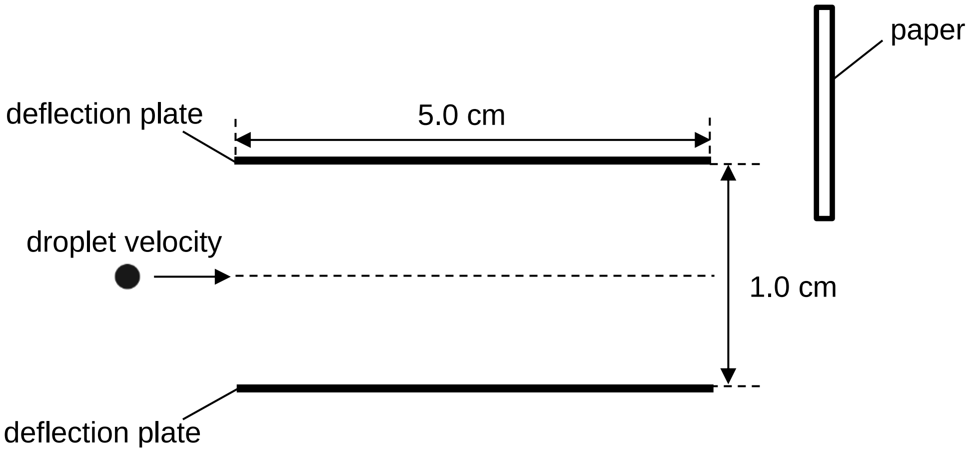

Fig. 8.4 (not to scale)

(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.

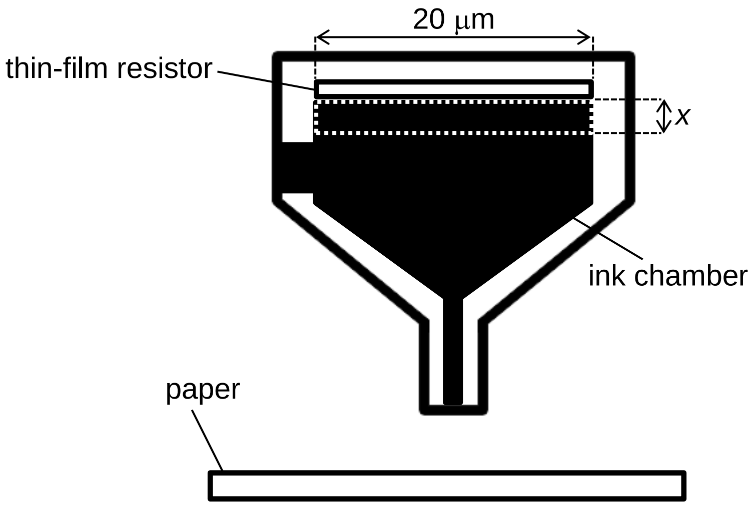

Fig. 8.5

(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