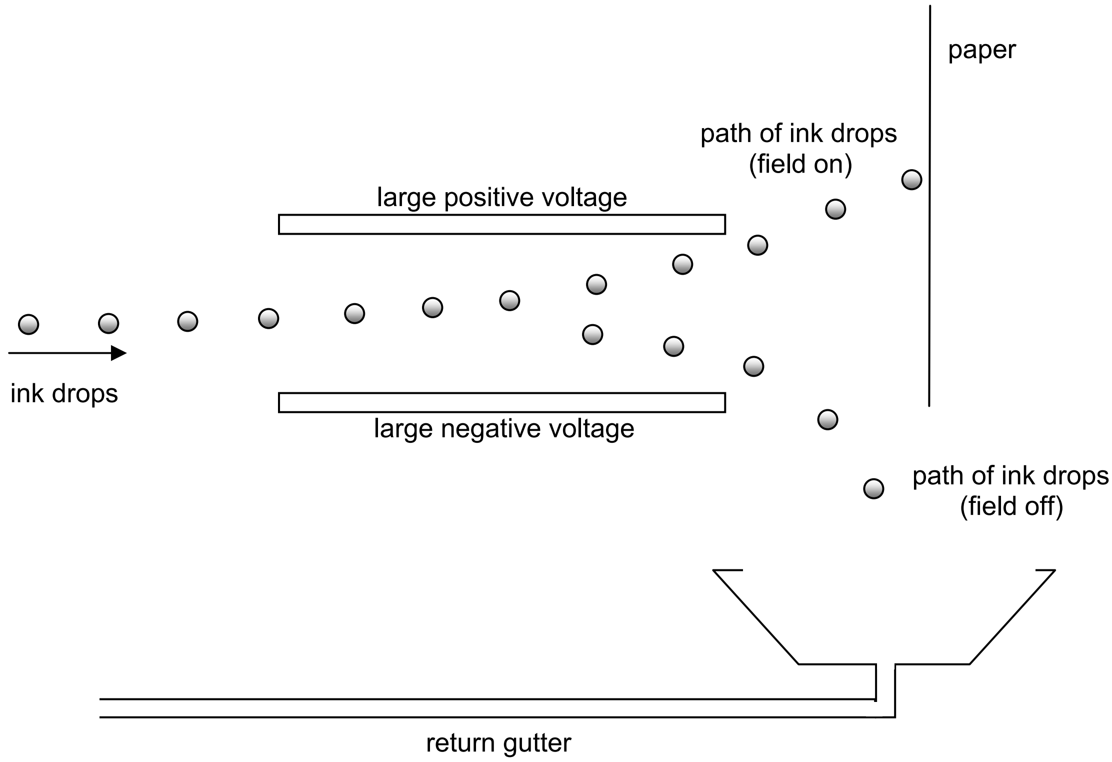
**Question 5** **(5 marks)**

The principle of inkjet printing depends on the physics of charged particles in electric fields. The diagram below shows charged ink drops entering an electric field. The field is caused by high voltage deflection plates. The field on the plates switches on and off to direct drops to the paper rather than the gutter. Drops that do not impact on the page are 'recycled' via the gutter.

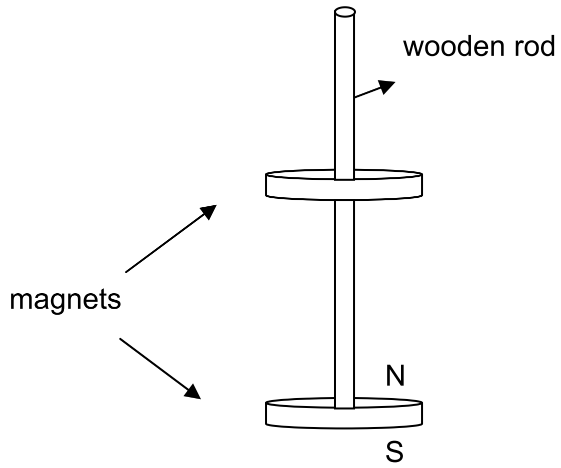



(a) The plates are separated by 0.025 m and the voltage difference between the plates is 1000 V. Calculate the electric field intensity. (2 marks)

(b) If the force required to cause a black spot on the paper is $1.00 \times 10^{-8}$ N, calculate the charge on each drop. (3 marks)

**Question 13** **(4 marks)**

Below is a diagram of a wooden rod on which there are two powerful magnets, one 'floating' above the other.




(a) Indicate the north pole of the floating magnet and draw the magnetic field lines between the magnets. (2 marks)

(b) Explain why the top magnet 'floats'. (2 marks)

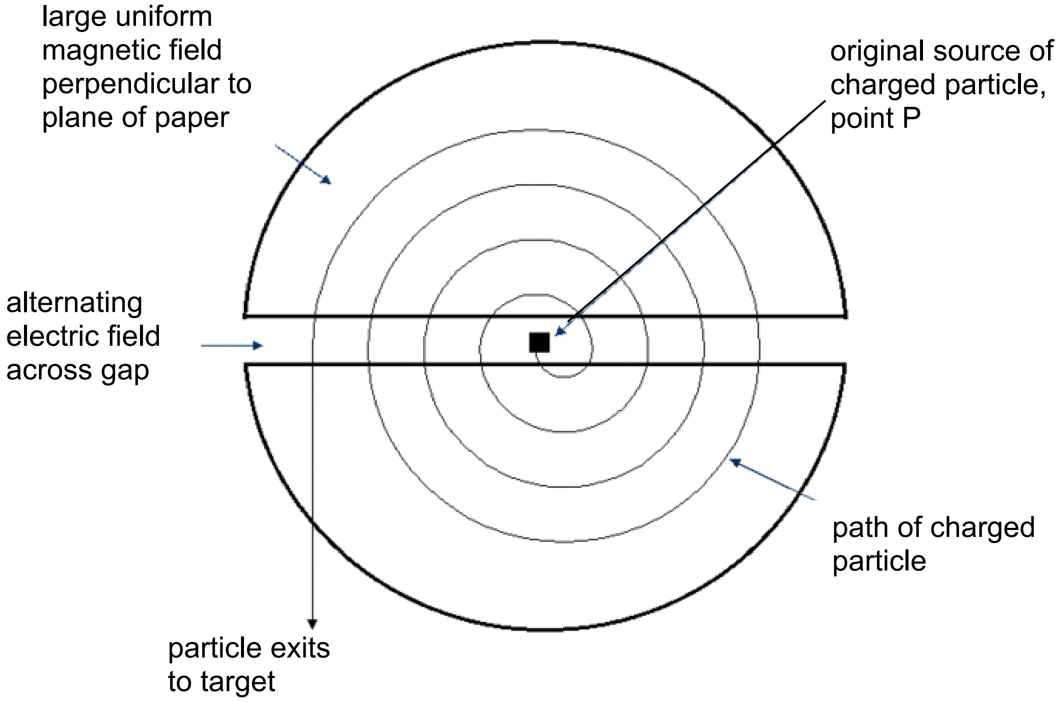
**End of Section One**

**Question 23** **(23 marks)**

**Introduction**

A cyclotron is a device in which heavy charged particles such as protons, deuterons (deuterium nuclei, $^{2}_{1}H$) and alpha particles can be accelerated to high energies. The high energy charged particle beam can then be used to study nuclear reactions and can also be used in hospitals to produce short-lived radioisotopes for diagnostic purposes. One such medical cyclotron is located at Sir Charles Gairdner Hospital in Perth. It can accelerate protons and deuterons to very high energies.

**Cyclotron**




**How a cyclotron works**

A cyclotron consists of two hollow D-shaped semicircular metal electrodes (called 'dees'), an ion source, an electromagnet and an alternating power supply.

The dees are mounted inside a vacuum chamber that fits between the two flat pole pieces of an electromagnet. The dees are connected to a high frequency alternating voltage supply that provides an alternating electric field across the gap between the dees.

When charged particles are injected at the centre of the dees (point P), they are accelerated by the electric field and then move into a semicircular path inside the hollow space of the dee under the influence of the uniform magnetic field that acts perpendicular to the path of the charged particles. Once inside the dee they are shielded from the electric field and thus do not gain any further energy.

Because the dees are connected to an alternating voltage supply, the charged particles are accelerated by the electric field each time they cross the gap, increasing their energy by a small amount qV. Therefore their speed increases and they move into larger and larger path radii. If the charged particles do not arrive at the gap when the polarity is correct, they will fall out of synchronisation and the beam will be lost. So for the satisfactory operation of the cyclotron, the frequency of the alternating voltage must be equal to the orbital or cyclotron frequency of the charged particles. This condition is valid only when the speed of the charged particles is much less than the speed of light. At higher particle speeds (above about 10% of the speed of light) the frequency of the circulating particle decreases steadily due to relativistic effects. Thus the particle goes out of step with the frequency of the oscillator and its energy stops increasing.

In the normal operation of the cyclotron, when the charged particles reach the outside perimeters of the dees, they are deflected by the electric field of an ejector plate and strike the outside target.

**Charged particle data**

| **Type of charged particle** | **Mass of charged particle (kg)** | **Charge of the particle (coulombs)** | $\frac{q}{m}$ |
|---|---|---|---|
| electron | $9.11 \times 10^{-31}$ | $1.60 \times 10^{-19}$ | |
| proton | $1.67 \times 10^{-27}$ | $1.60 \times 10^{-19}$ | |
| deuteron | $3.34 \times 10^{-27}$ | $1.60 \times 10^{-19}$ | |

(a) What provides the centripetal force that acts on the charged particle? (1 mark)

(b) The operation of the cyclotron is based on the principle that frequency of revolution is independent of the speed of charged particles and the radius of the circular path. Use the equations given in the Formulae and Constants Sheet to show that frequency, f is given by $f = \frac{qB}{2\pi m}$. (4 marks)

(c) Suppose a cyclotron with a dee radius of 53.0 cm is tuned to accelerate protons at an oscillator frequency of 12.0 MHz. Calculate the strength of the magnetic field needed to accelerate deuterons with the same frequency. (3 marks)

(d) A conventional cyclotron begins to fail beyond a proton energy of 50 MeV.

(i) Explain why is this so. (2 marks)

(ii) At what electron energy will the same cyclotron begin to fail? (2 marks)

(e) An unknown particle was tested and gave the following values of high voltage oscillator frequency and the corresponding magnetic field:

| **Frequency of high voltage oscillator × $10^6$ hertz** | **Magnetic field B (tesla)** |
|---|---|
| 1.0 | 0.10 |
| 3.2 | 0.42 |
| 6.0 | 0.78 |
| 9.0 | 1.20 |
| 12.0 | 1.62 |
| 15.0 | 1.95 |

(i) Using the graph paper on the next page, plot a straight line graph with magnetic field on the *x*-axis and frequency on the *y*-axis. (3 marks)

(ii) Calculate the gradient of this graph. (3 marks)

(iii) Use the gradient to find the ratio $\frac{\text{charge on the particle}}{\text{mass of particle}}$ for the unknown particle.(3 marks)

(If you could not complete (ii), use a gradient of magnitude $2.9 \times 10^{10}$.)

(iv) Circle the unknown particle involved and justify your selection. (2 marks)

(I) electron (II) proton (III) neutron (IV) deuteron

Justification: ______________________________

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**End of questions**