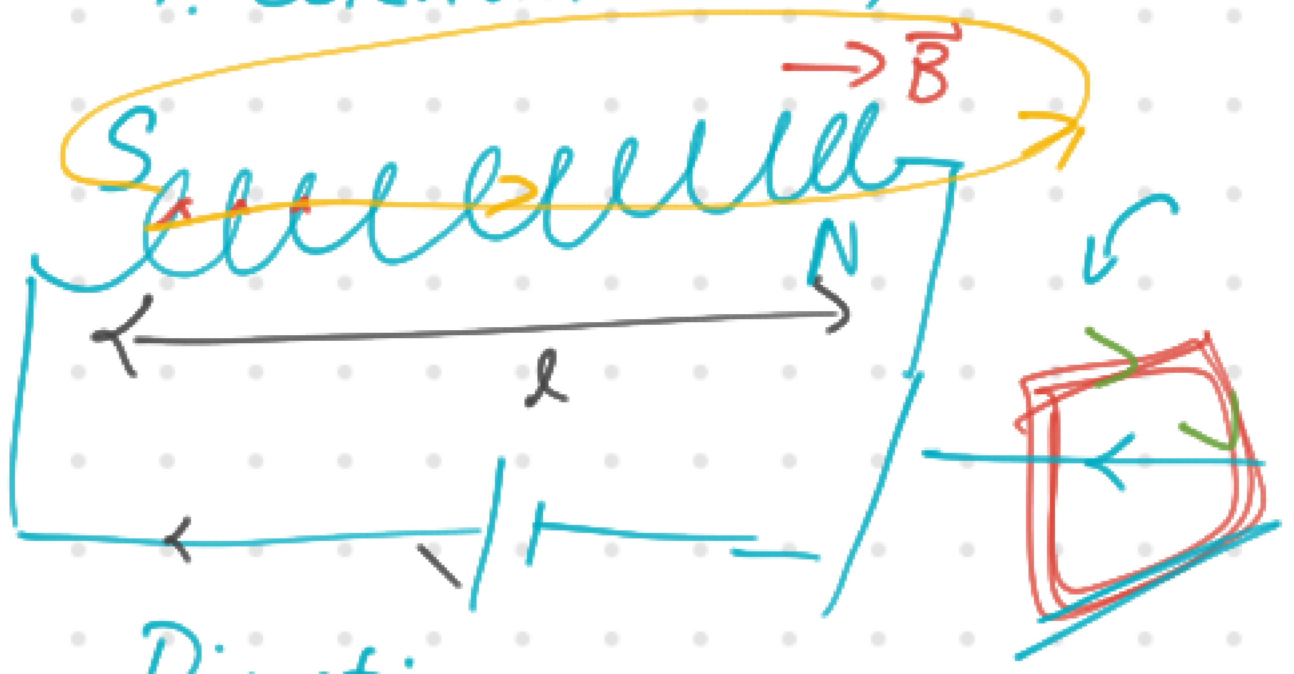
Typical sources for magnetic field ($\vec{B}$)

1. Solenoid (coil)

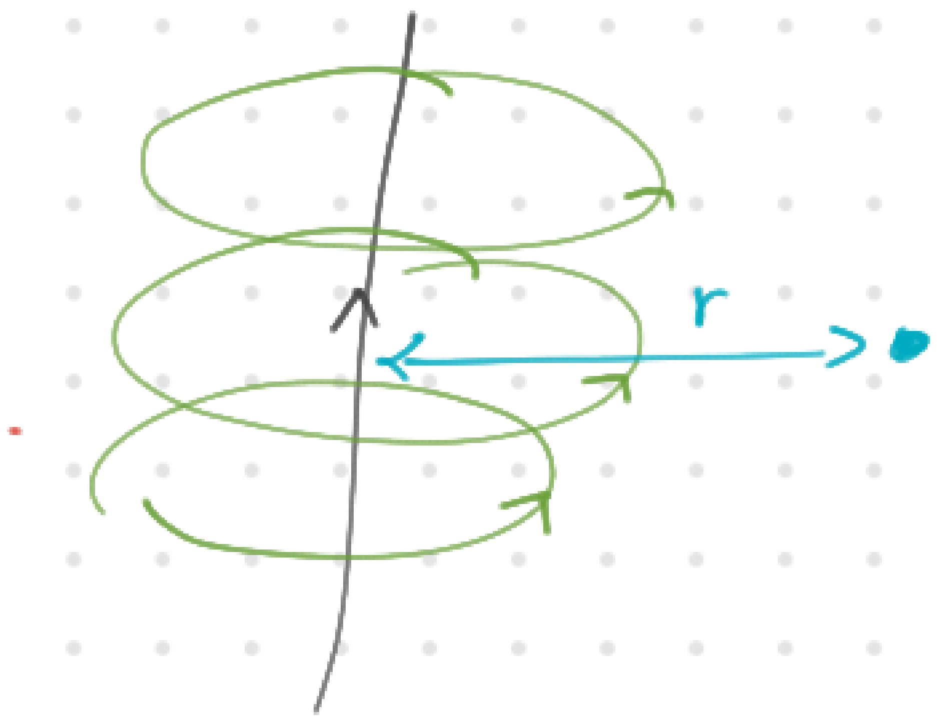


Direction:
Right hand grip rule

$|\vec{B}| = \mu_0 I \frac{N}{l}$

↳ where does this apply?

2. Current passing through wire



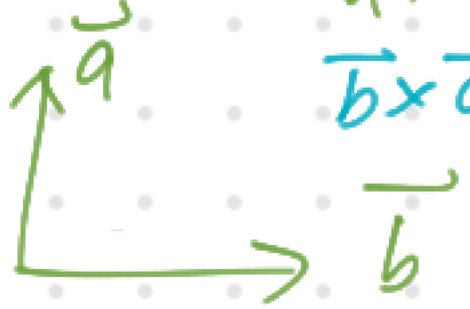
Direction: Right hand grip rule

$$|\vec{B}| = \frac{\mu_0 I}{2\pi r}$$

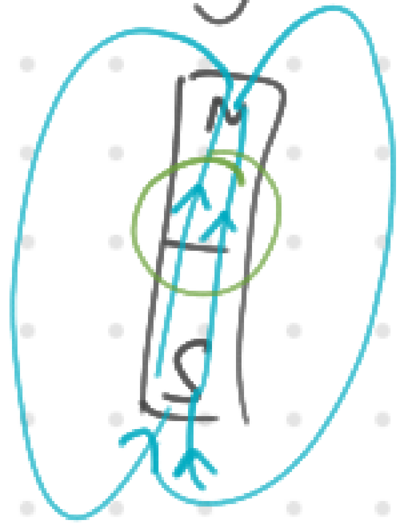
$\frac{\mu_0}{4\pi} = 10^{-7}$

$\vec{a} \times \vec{b}$

$\vec{b} \times \vec{a}$

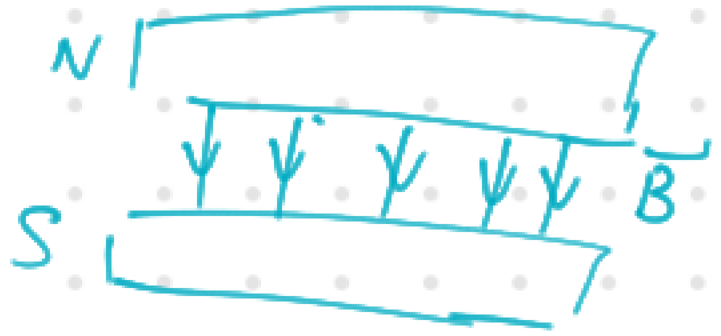


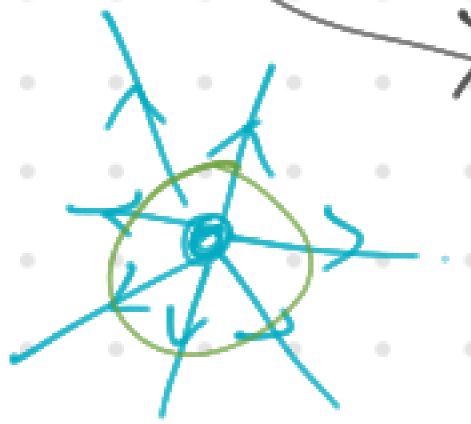
3. Magnet



$|\vec{B}| = ?$

No need to know





Magnetic forces

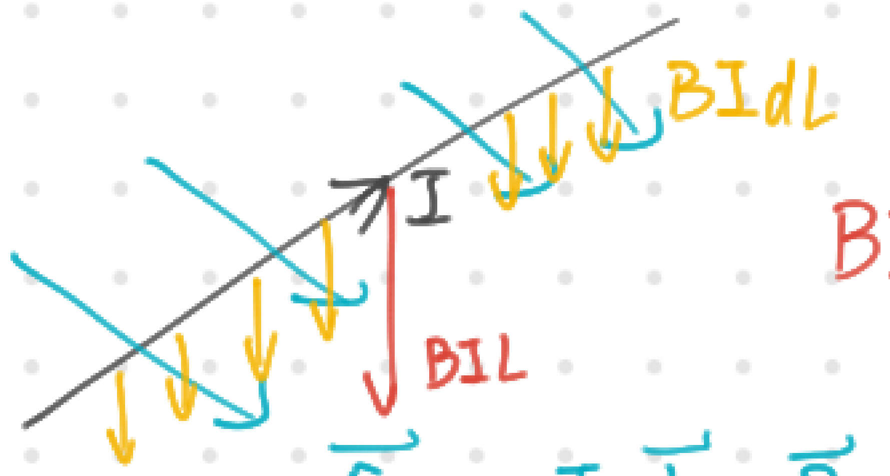
① force on a moving charge

$$\vec{F} = q\vec{v}\times\vec{B} \rightsquigarrow |\vec{F}| = q|\vec{v}||\vec{B}|\sin\theta$$

or in AL formula sht.

$$F = qvB$$

② force ~~in~~ on current carrying wire in $\vec{B}$.



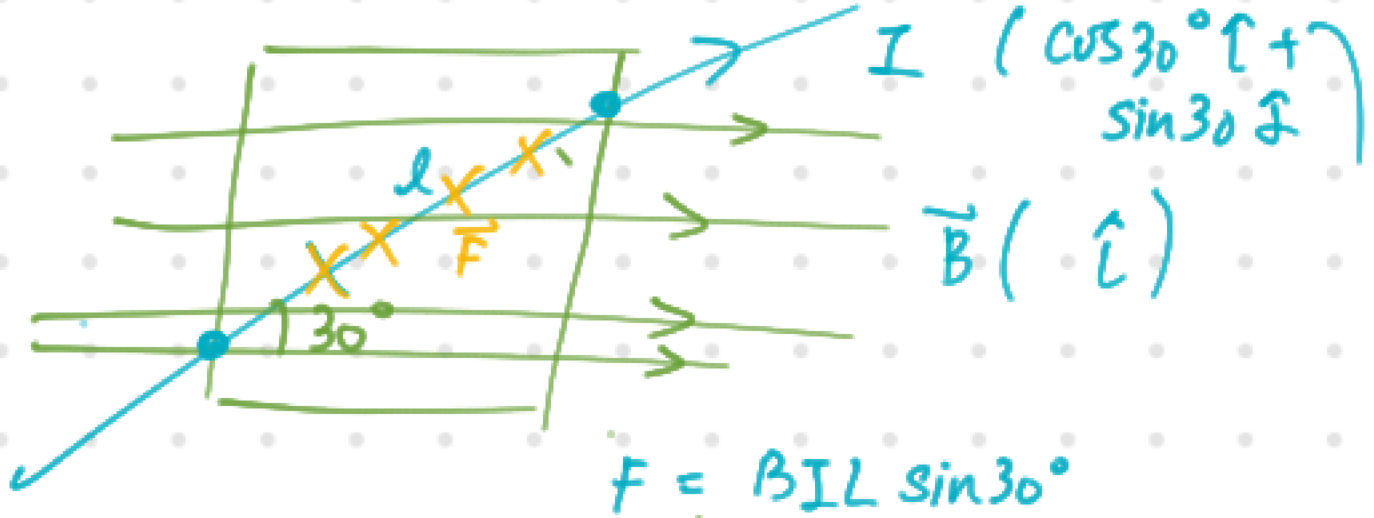
$BIL = \sum BIdL$

- - - -> Actually the same

$$\vec{F} = I\vec{L}\times\vec{B}$$

in formula sht:

$$F = BIL$$



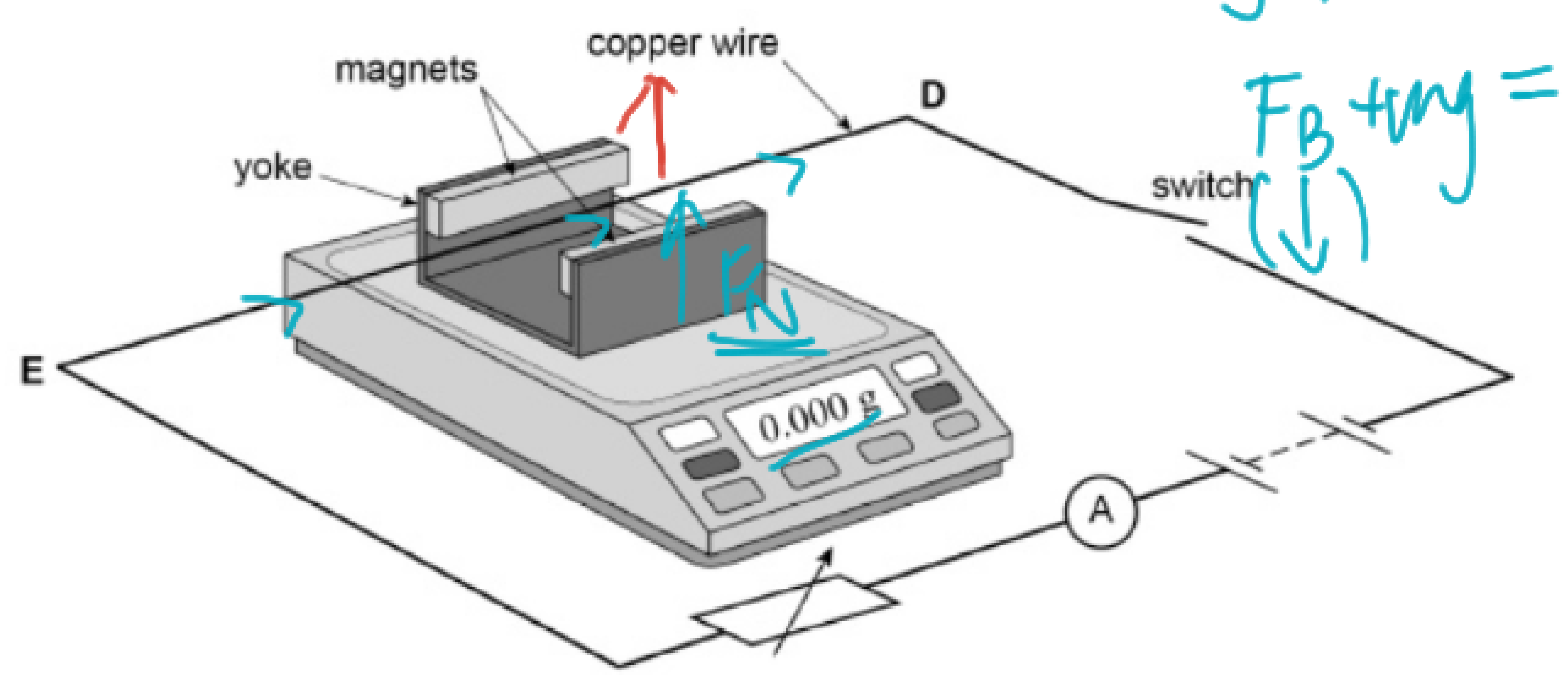
$$F = BIL\sin 30^\circ$$
$$= \tfrac{1}{2} BIl$$

33. **Figure 1** shows two magnets, supported on a yoke, placed on an electronic balance.

Figure 1

yoke 3

$F_B + mg = F_N$
(↓)



The magnets produce a uniform horizontal magnetic field in the region between them. A copper wire **DE** is connected in the circuit shown in **Figure 1** and is clamped horizontally at right angles to the magnetic field.

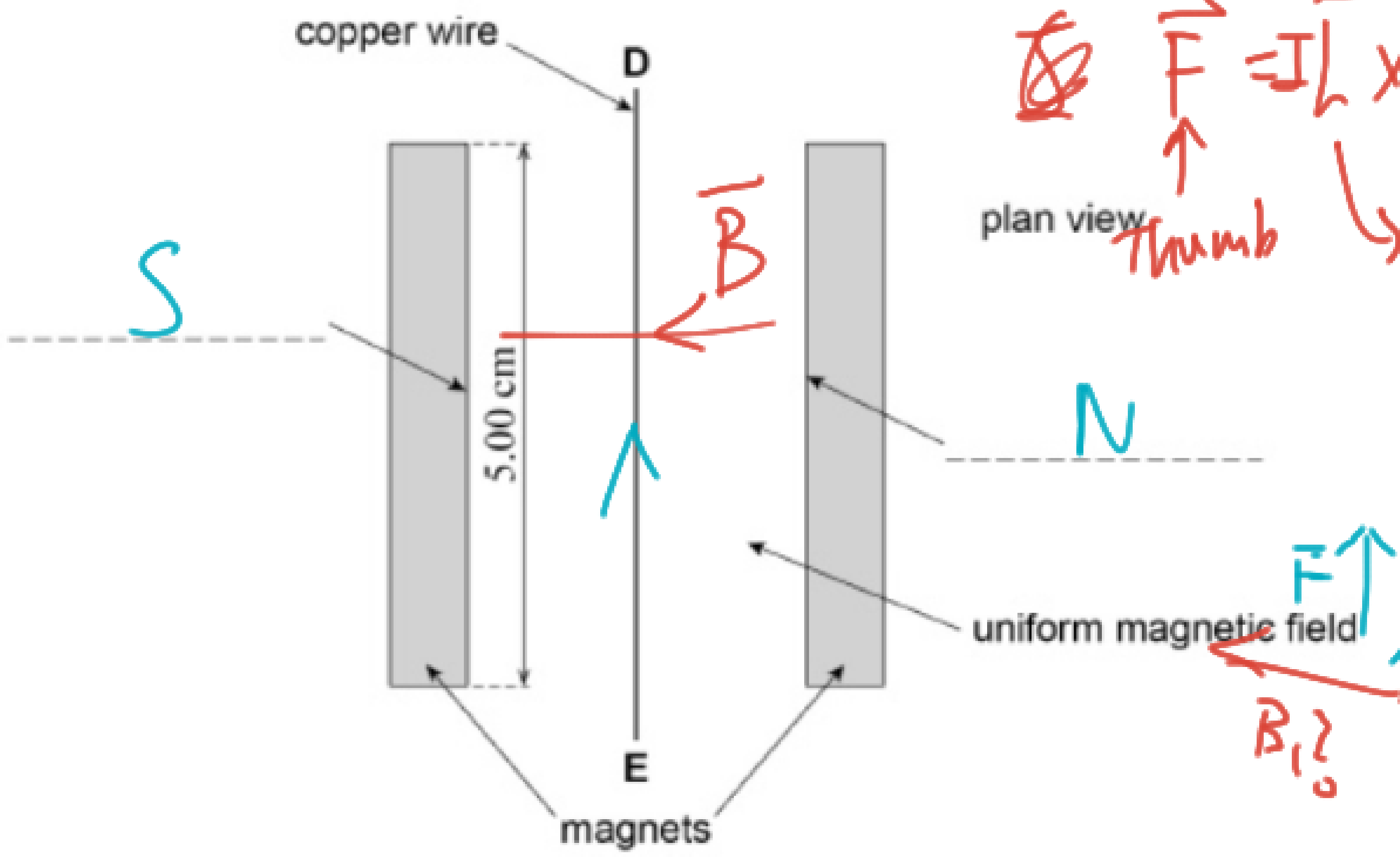
curl direction

Figure 2 shows a simplified plan view of the copper wire and magnets.

Figure 2

$\vec{F} = I\vec{L} \times \vec{B}$

thumb 4 finger



When the apparatus is assembled with the switch open, the reading on the electronic balance is set to 0.000 g. This reading changes to a positive value when the switch is closed.

(a) Which of the following correctly describes the direction of the force acting on the wire **DE** due to the magnetic field when the switch is closed?

Tick (✓) the correct box.

towards the left magnet in **Figure 2**	☐
towards the right magnet in **Figure 2**	☐
vertically up	✓
vertically down	☐

(b) Label the poles of the magnets by putting **N** or **S** on each of the two dashed lines in **Figure 2**.

(c) Define the tesla.

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(1)

(d) The magnets are 5.00 cm long. When the current in the wire is 3.43 A the reading on the electronic balance is 0.620 g.

$F_B = BIL = \frac{0.62}{1000} g$

Assume the field is uniform and is zero beyond the length of the magnets.

= magnetic field strength

Calculate the magnetic flux density between the magnets.

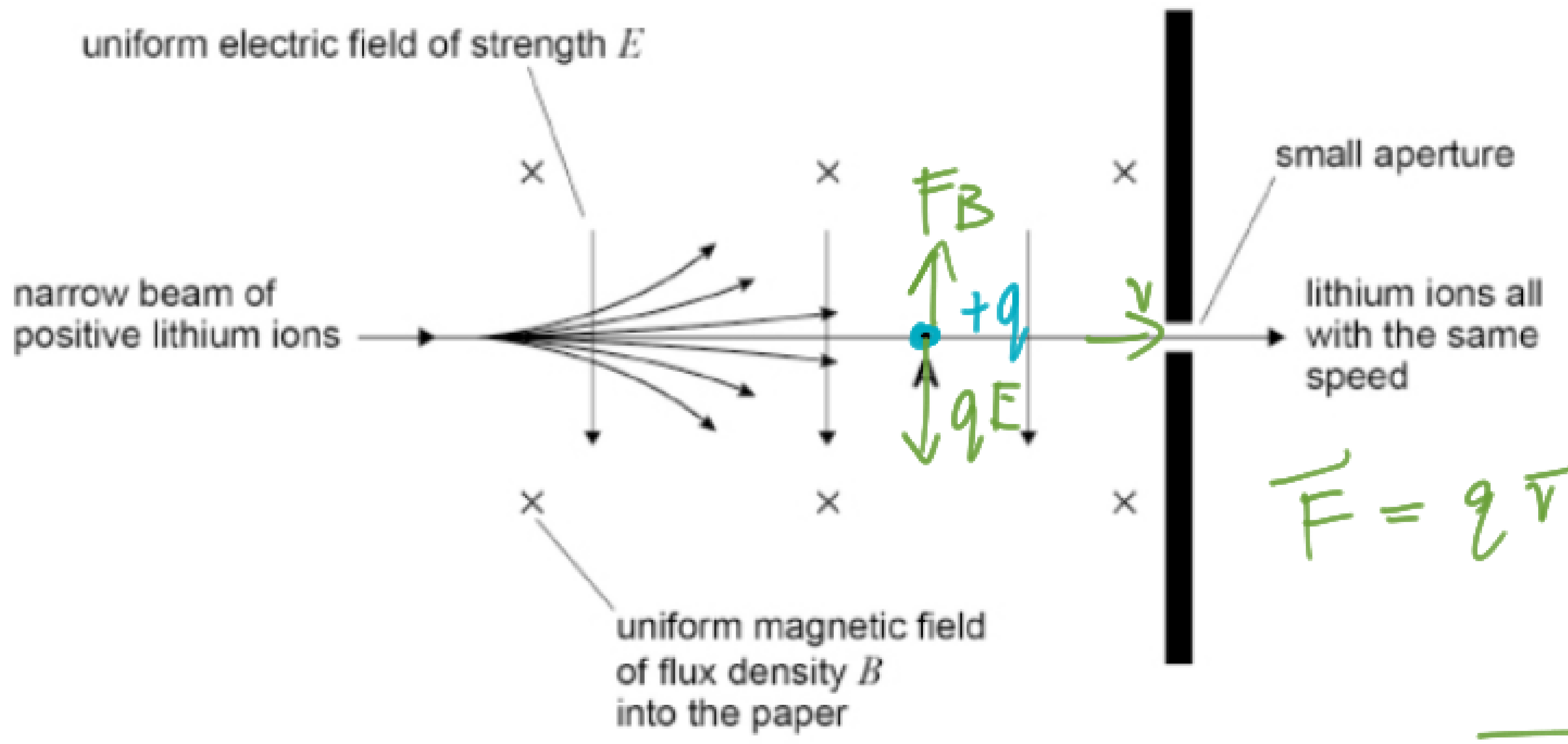
$B \approx 0.0355$ T

F mg

8. Mass spectrometers are used to measure the masses of ions.

Figure 1 shows one part of a mass spectrometer.

Figure 1



A narrow beam consists of positive lithium ions travelling at different speeds.
The beam enters a region where there is an electric field and a magnetic field.
The directions of the uniform electric field of strength E and the uniform magnetic field of flux density B are shown on **Figure 1**.

Most ions are deflected from their original path.
Lithium ions that travel at one particular speed are not deflected, and pass through the small aperture.

(a) The positive lithium ion **A** in **Figure 1** moves at a speed v.

Draw **two** labelled arrows on **Figure 1** to show the directions of the electric force F_E and the magnetic force F_M acting on **A**.

(1)

$\vec{F} = q\vec{v}\times\vec{B}$

$\hat{k}$, $\hat{j}$, $\hat{i}$

$v = \hat{i}$

$B = -\hat{k}$

$F = q\vec{v}\times\vec{B}$

$\rightarrow v$

B curl direction

$\vec{v}$

(b) Lithium ions travelling at 1.5×10^5 m s^{-1} pass through the small aperture.

Calculate E.

$B = 0.12$ T

F_B

F_e

$a_y = 0$

$F_{net} = 0$

$\cancel{q}|\vec{v}||\vec{B}| - \cancel{q}|\vec{E}| = 0$

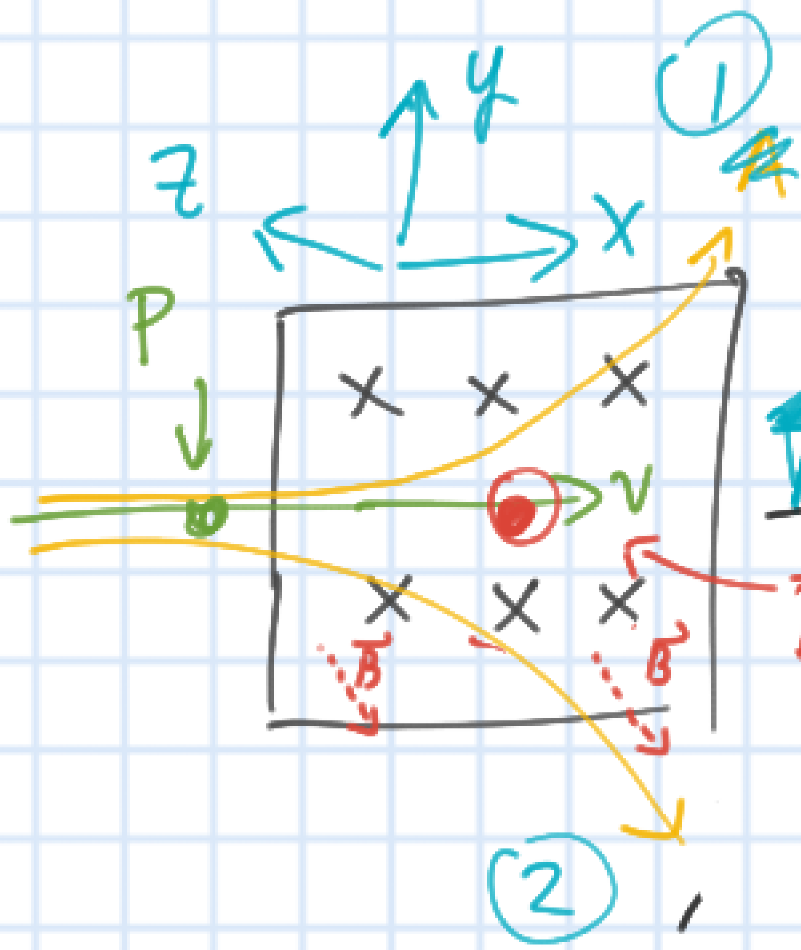
$|\vec{v}||\vec{B}| = |\vec{E}|$

$|\vec{E}| = 1.8\cdot 10^4\ NC^{-1}$

$v = \frac{E}{B}$

selected velocity

$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$



for proton

$$\vec{F} \quad \vec{F} = q\underbrace{\boxed{(\vec{v}\times\vec{B})}}_{\text{right hand grip rule}} + q$$

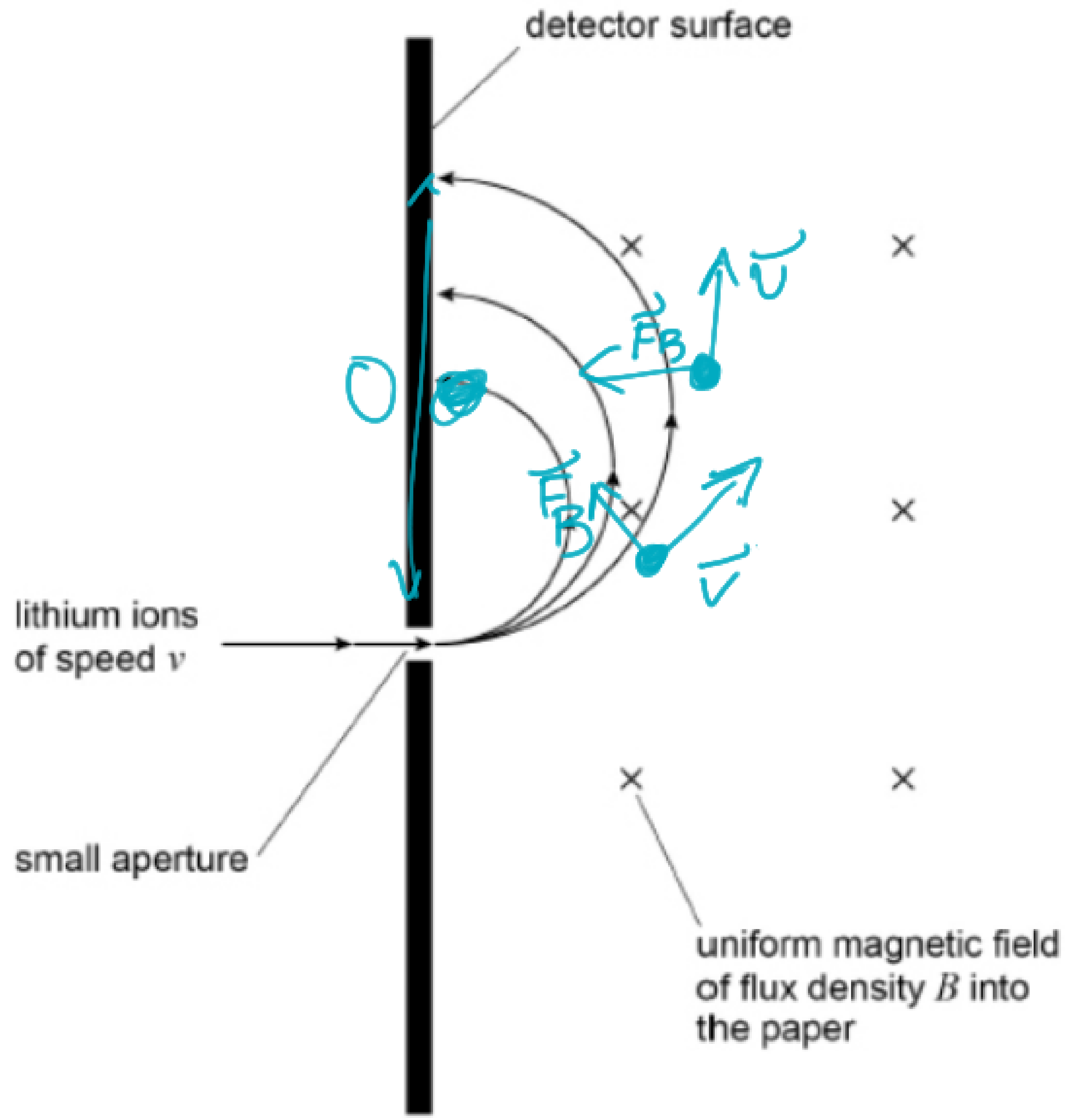
$\vec{B} = -\hat{k}$

to determine direction

$$\vec{F} = I(\vec{L}\times\vec{B})$$

(c) Ions that pass through the small aperture enter a second uniform magnetic field of flux density B.
Ions of different mass are separated because they follow different paths as shown in **Figure 2**.

Figure 2



Ions of mass m and charge q travelling at speed v follow a circular path in the uniform magnetic field.

Show that the radius r of the circular path is given by

$$r = \frac{mv}{Bq}$$

(1)

$$F_{cent} = \frac{mv^2}{r} = Bqv$$

$$r = \frac{mv}{Bq} = \frac{v}{B}\left(\frac{m}{q}\right)$$

(d) The ions of different mass are deflected and strike the detector surface at different distances from the small aperture as shown in **Figure 2**.

A singly-charged lithium ion ($^6_3Li^+$) passes through the small aperture.

Calculate the distance between the small aperture and the point where this ion strikes the detector surface.

$q = +e$

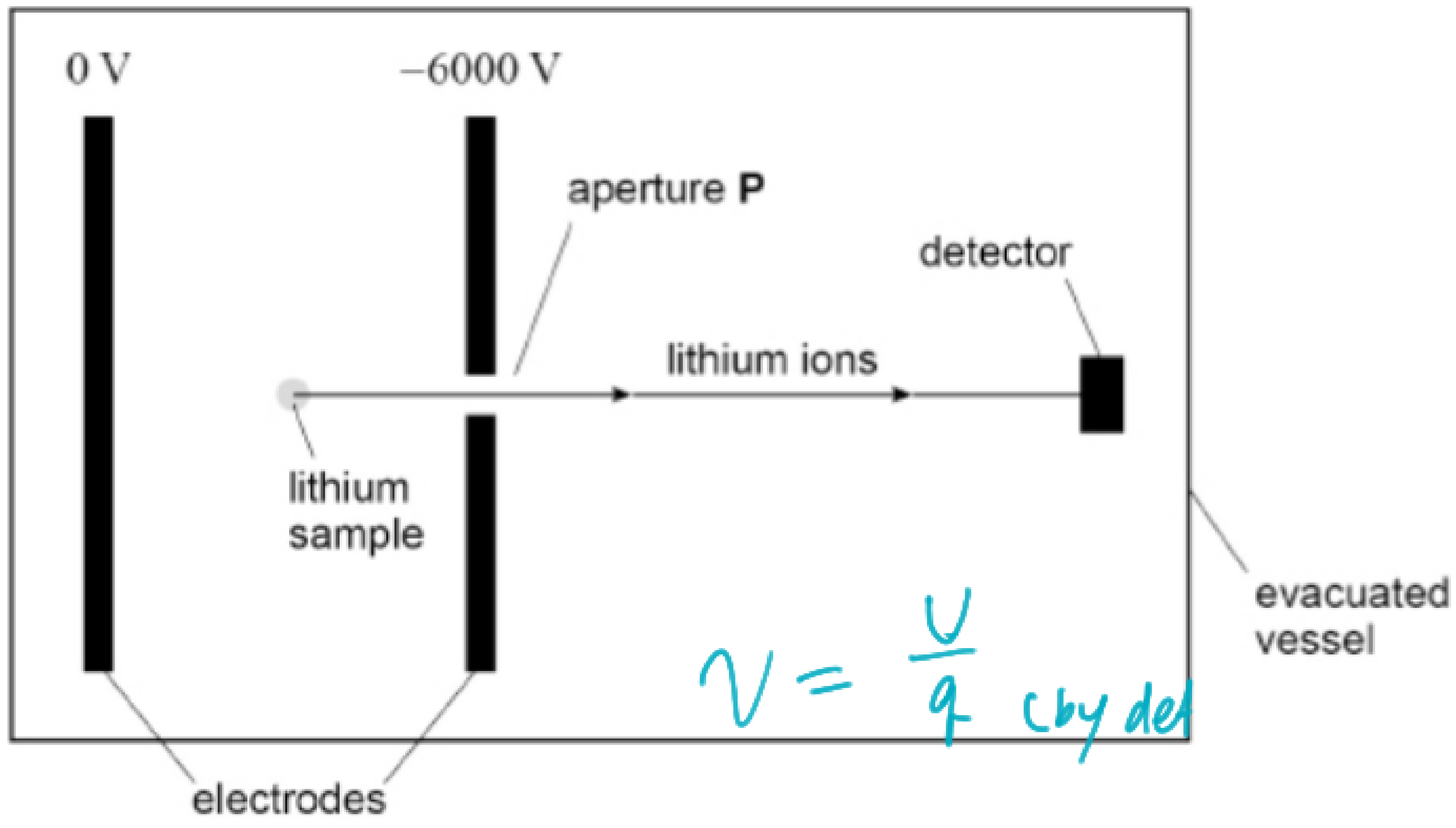
$v = 1.5 \times 10^5$ m s^{-1}
$B = 0.12$ T
mass of $^6_3Li^+$ ion $= 1.0 \times 10^{-26}$ kg

$$r = \frac{mv}{Bq}$$

$$d = 2r = 0.156\text{ m}$$
$$= 15.6\text{ cm}$$

(e) **Figure 3** shows a different type of mass spectrometer working with lithium ions.

Figure 3



$V = \frac{U}{q}$ (by def

A stationary $^{7}_{3}Li^{+}$ ion in the lithium sample is at the mid-point between the parallel electrodes. The $^{7}_{3}Li^{+}$ ion accelerates towards aperture **P**.

Determine the speed of the ion when it emerges through aperture **P**.

mass of $^{7}_{3}Li^{+}$ ion $= 1.2 \times 10^{-26}$ kg

EPE $\rightarrow$ KE

$-q\Delta V = \frac{1}{2}mv^2$ $\quad -\Delta V = \Delta KE$

$v^2 = \frac{-2q\Delta V}{m}$

$v \approx 2.83 \cdot 10^5\ ms^{-1}$

(f) $^{6}_{3}Li^{+}$ and $^{7}_{3}Li^{+}$ ions are produced in the sample simultaneously and travel a distance L from aperture **P** to the detector.
For each type of ion, the time interval between production and detection is measured.

Discuss how the masses of the ions can be deduced from the measurement of these time intervals.

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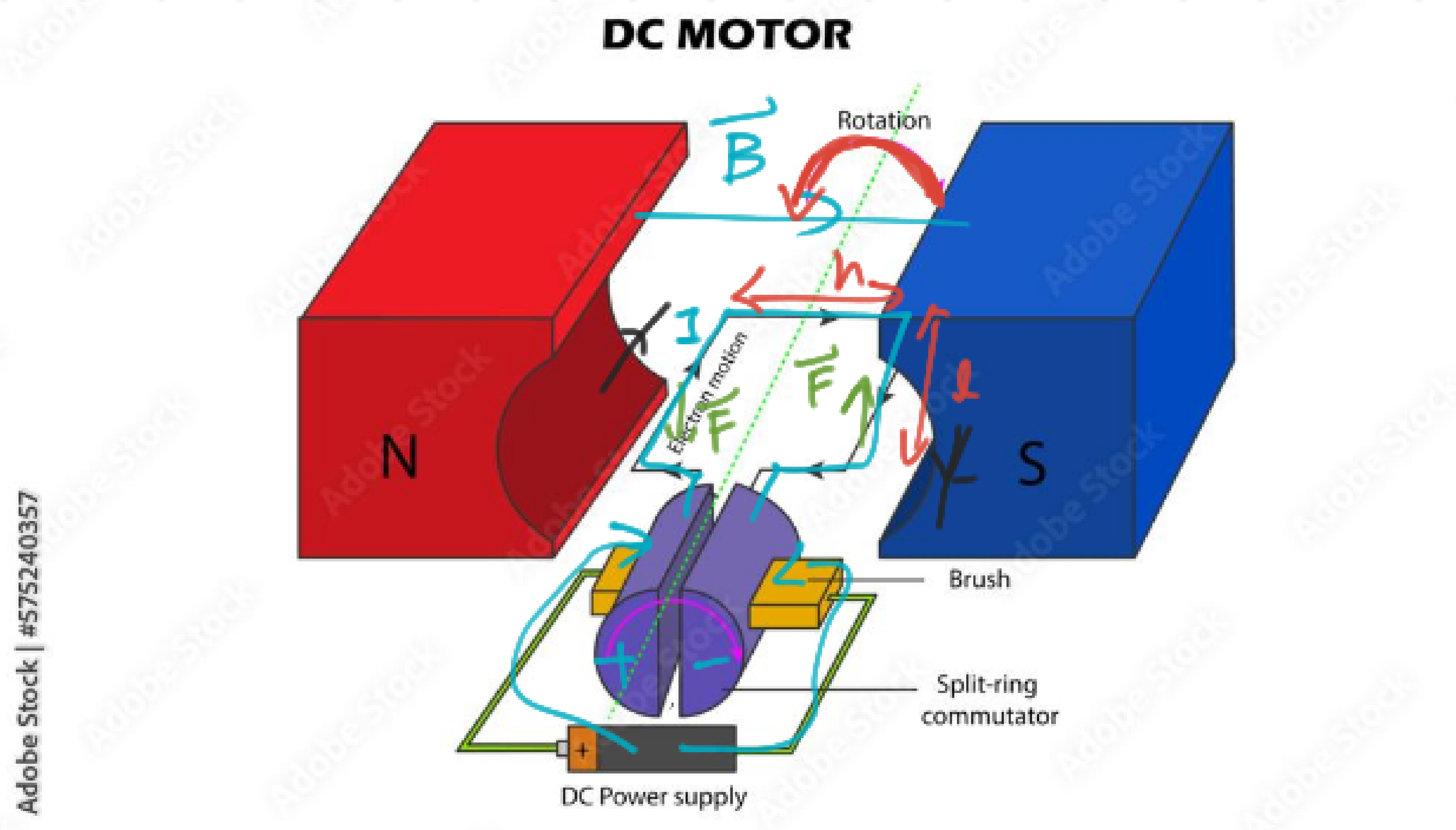
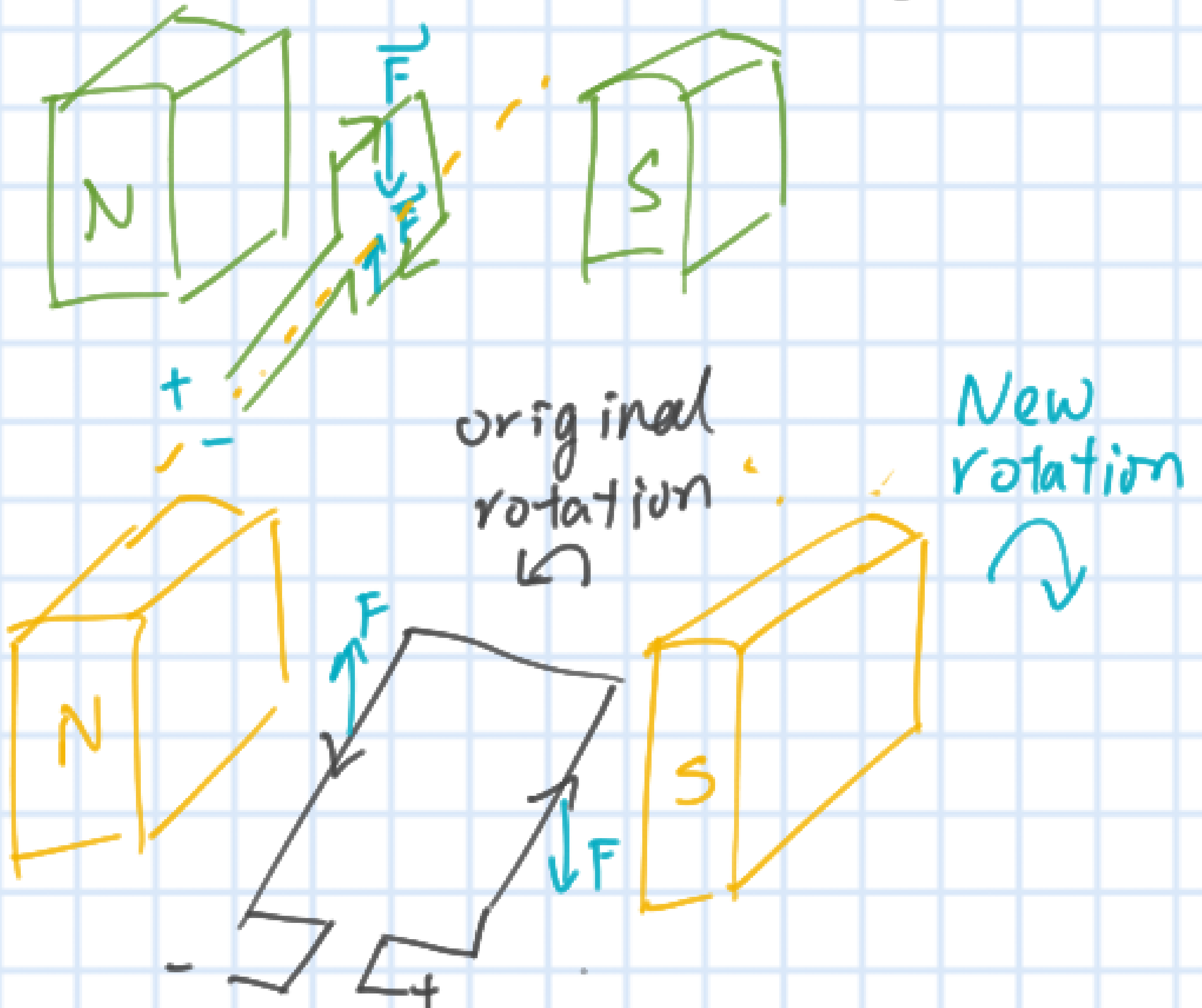
(2)

(Total 11 marks)

Motor



Function of (Split ring) commutator?



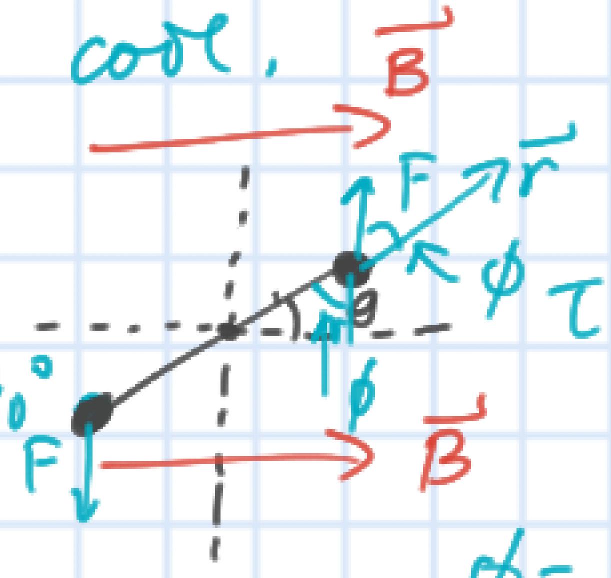
b. Consider, at some moment that the coil of wire is at angle θ to ~~normal~~ horizontal

Show that, τ, torque on coil,

$$\tau = BAI\cos\theta$$

$$|\vec{F}| = I(\vec{L} \times \vec{B}) = I|\vec{L}||\vec{B}|\sin 90^\circ = BIl$$

$$\tau = |\vec{F}|\cos\theta\left(\frac{h}{2}\right)\cdot 2 = BIL\cos\theta\, h = BAI\cos\theta$$



$$\tau = |\vec{F}||\vec{r}|\sin\phi$$

$$\phi = 90^\circ - \theta$$

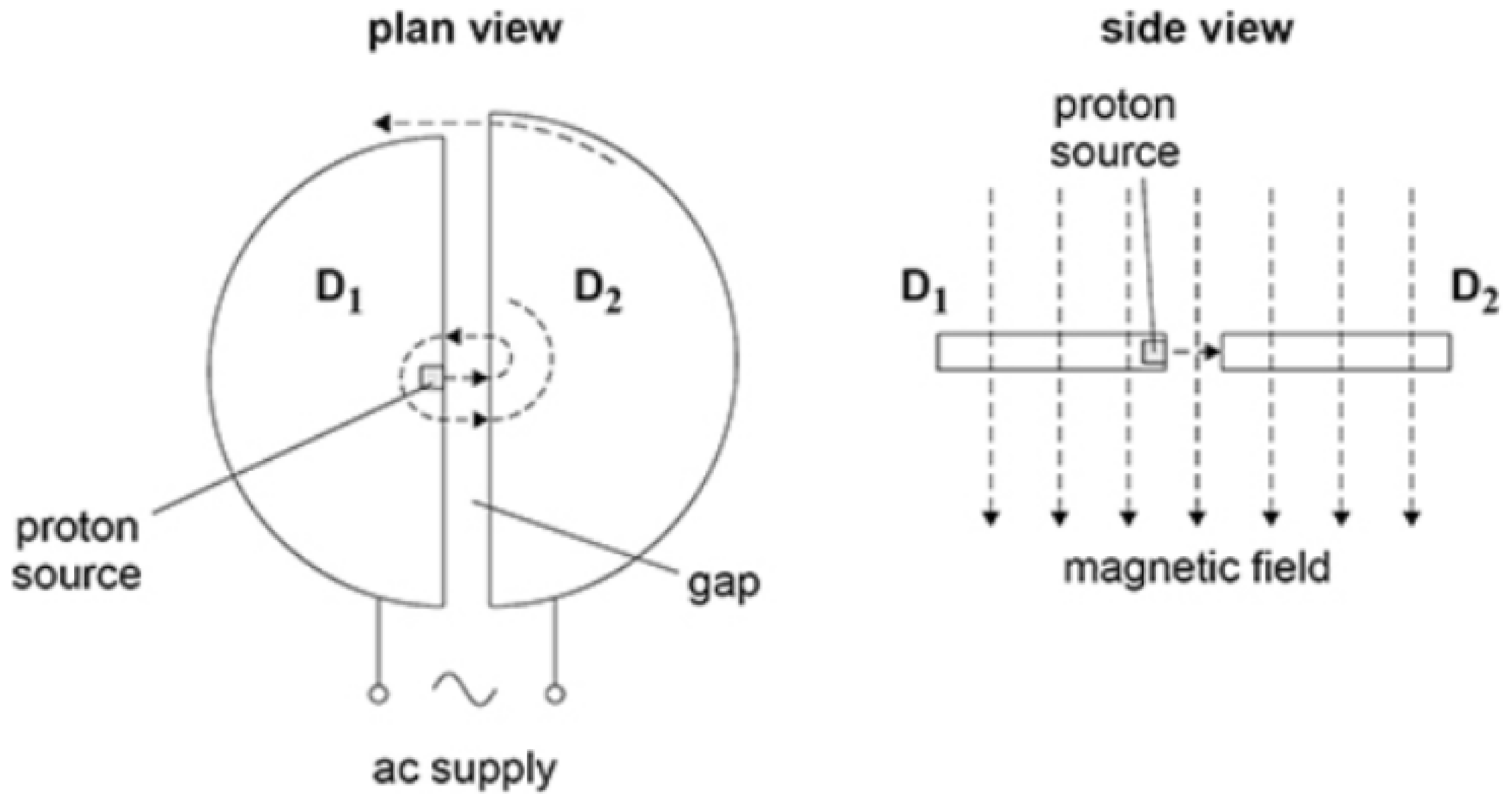
What if there were more rings on the coil?

$$\tau = NBAI\cos\theta$$

$$\varepsilon = NBA\omega\sin(\omega t)$$

The figure below shows a cyclotron. A proton is released from rest and is accelerated each time it reaches the gap between two horizontal 'dees' **D_1** and **D_2**. Between these accelerations the proton moves at constant speed. A vertical magnetic field of flux density B acts over the dees so that the proton follows a semicircular path in each dee.

The dees are connected to an alternating potential difference (pd).
This pd is adjusted so that the proton is always accelerated by the peak electric field as it crosses the gap between the dees.



(a) Explain why the proton travels in a semicircular path in a dee.

(b) The peak pd of the alternating supply is 10.0 kV. The proton leaves the cyclotron with kinetic energy of 14 MeV.

Determine the number of times the proton moves across the gap before it leaves the cyclotron.

The radius of the outermost semicircular path of the proton is R and the proton leaves with a maximum kinetic energy E_k.

(c) Show that E_k is given by

$$E_k = \frac{e^2 B^2 R^2}{2m_p}$$

(d) A hospital decides to purchase a cyclotron in order to manufacture its own radioactive isotopes using high-speed protons.
The required minimum kinetic energy of the emerging protons is 11 MeV.
The cost of a cyclotron is approximately proportional to $E_k^{1.5}$.
The cost of a 10 MeV cyclotron is about £2.3 million.
The table below gives information for three cyclotrons **X**, **Y** and **Z**.

Cyclotron	B / T	R / m
X	1.3	0.38
Y	1.1	0.50
Z	0.5	0.60

Deduce which cyclotron **X**, **Y** or **Z** will satisfy the energy requirement for the lowest cost.
Go on to determine the approximate cost of this cyclotron.

cyclotron = _______________

cost = _______________

(4)