# ELECTROMAGNETISM

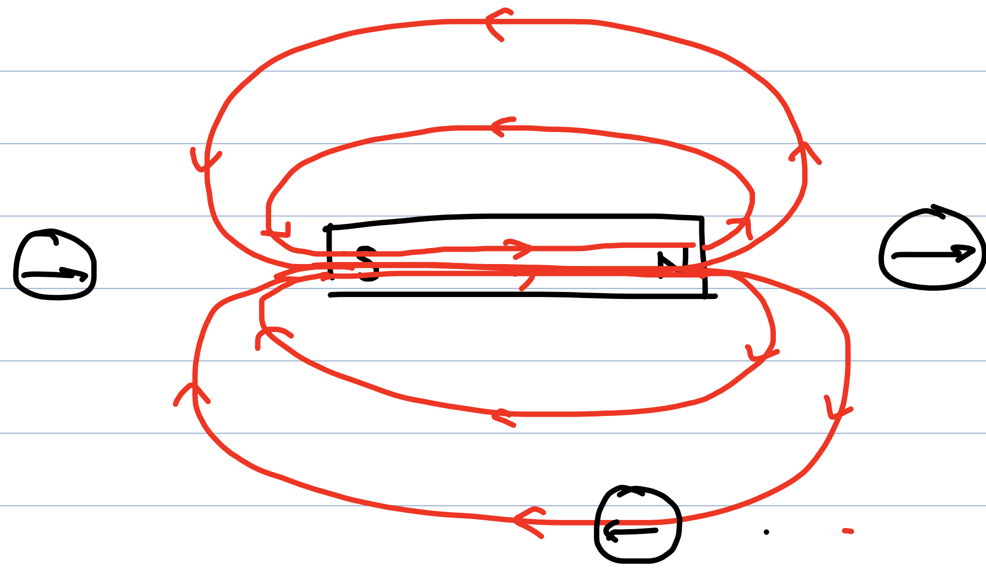
## BASIC CONCEPTS

1. MAGNETS HAVE TWO POLES: NORTH AND SOUTH
2. NORTH REPELS NORTH; SOUTH REPELS SOUTH
3. NORTH ATTRACTS SOUTH

## MAGNETIC FIELD

- MAGNETIC FIELD LINES <u>OUTSIDE</u> A MAGNET FLOW FROM NORTH TO SOUTH
- MAGNETIC FIELD LINES <u>INSIDE</u> A MAGNET FLOW FROM SOUTH TO NORTH
- THE DENSITY OF LINES AT A GIVEN POINT IS PROPORTIONAL TO THE MAGNETIC FIELD STRENGTH AT THAT POINT
- FIELD LINES FORM A VECTOR FIELD THAT SHOWS THE ORIENTATION OF A COMPASS

- MAGNETIC FIELD LINES ALWAYS FORM CLOSED LOOPS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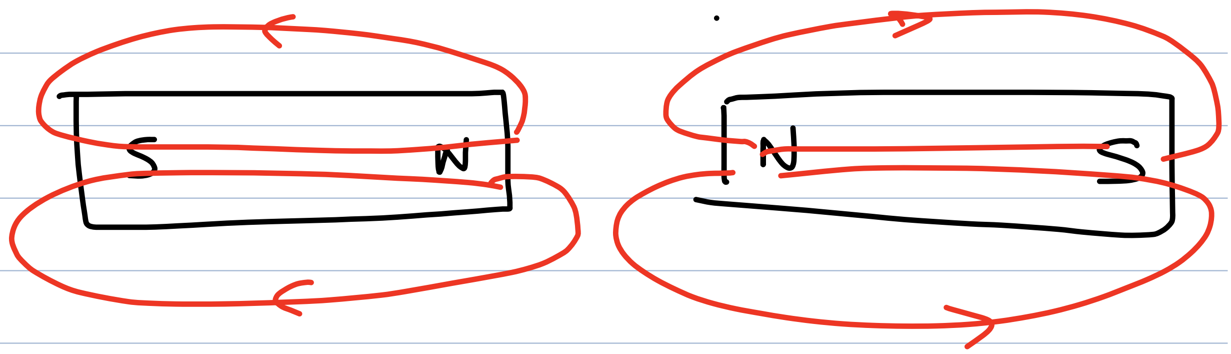
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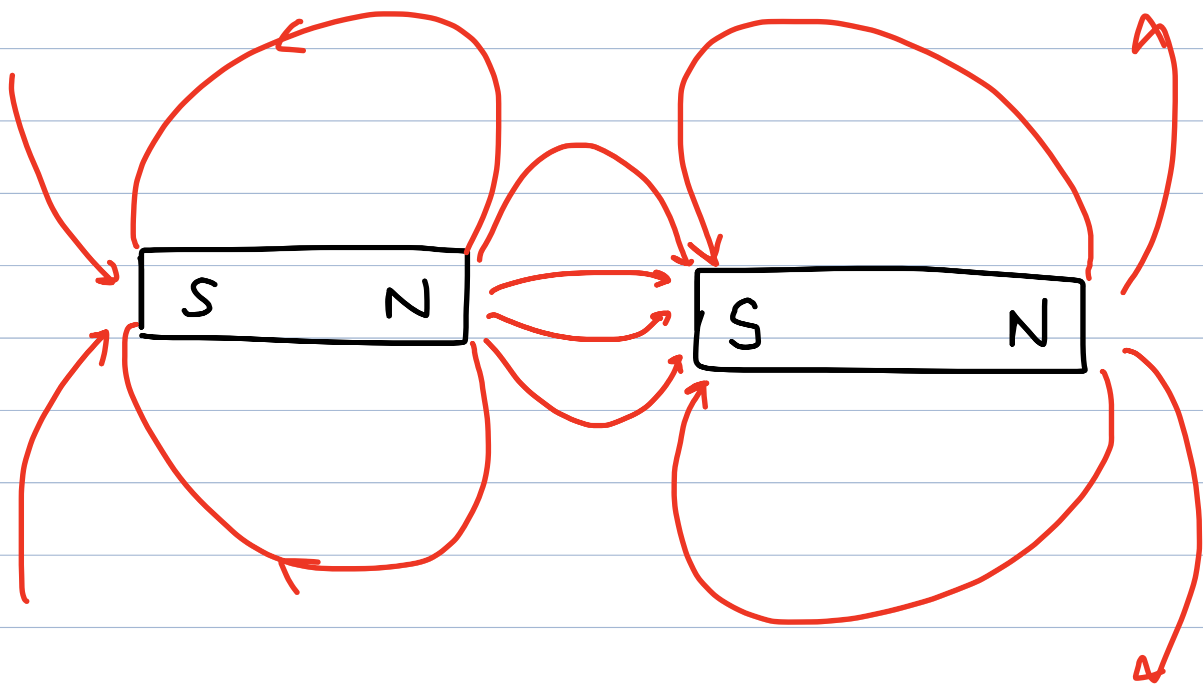
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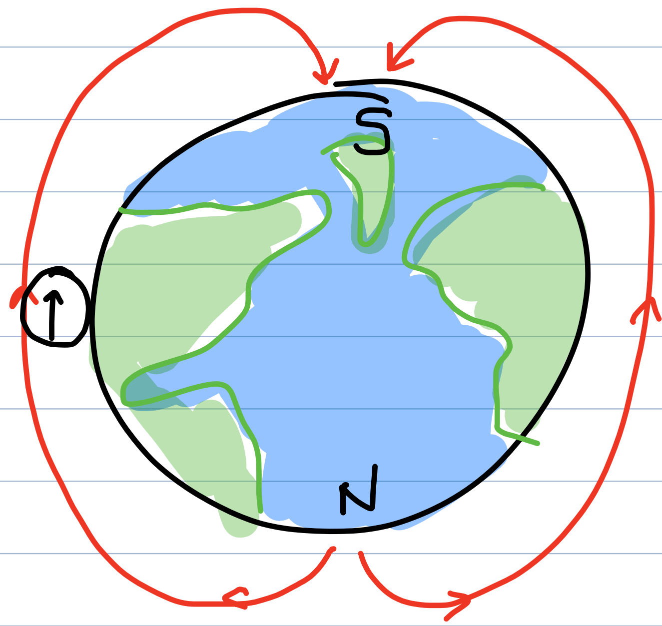
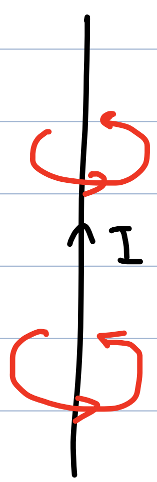
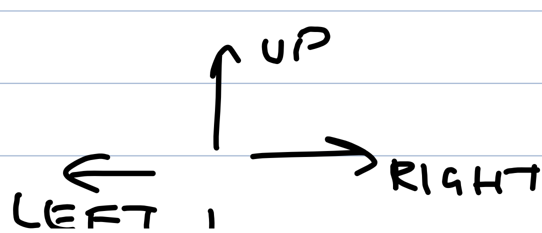
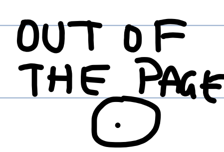



# ELECTROMAGNETISM

- A CURRENT-CARRYNG WIRE PRODUCES A MAGNETIC FIELD.
- THE DIRECTION OF THE MAGNETIC FIELD IS GIVEN BY THE RIGHT HAND RULE (#1)
  - → THUMB POINTS IN DIRECTION OF CURRENT, FINGERS WRAP AROUND IN DIRECTION OF MAGNETIC FIELD

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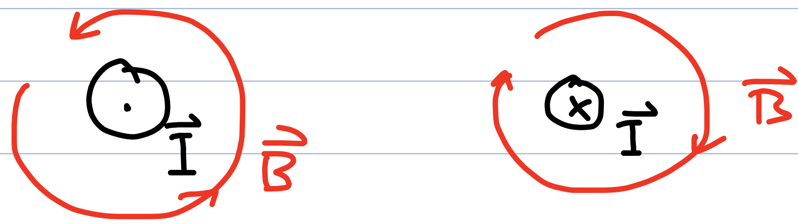




- THE BIOT-SAVART LAW DESCRIBES THE MAGNETIC FIELD STRENGTH NEAR A WIRE.

$$\boxed{B = \frac{\mu_0 I}{2\pi d}}$$

B: MAG. FIELD STRENGTH, T (TESLA)

$\mu_0$: PERMIABILITY OF FREE SPACE ($4\pi \times 10^{-7}$ T·m/A)

I: CURRENT, A

d: DISTANCE FROM WIRE, m

EXAMPLE

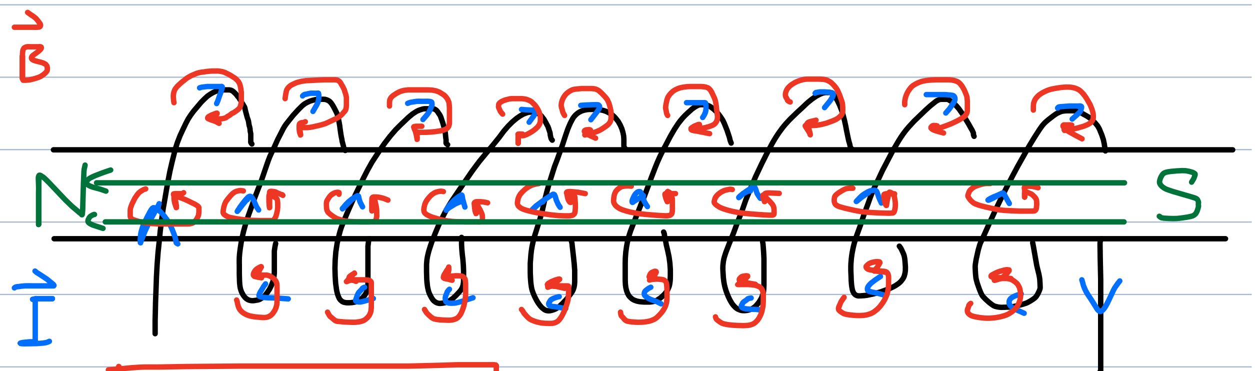
A TOASTER USES 10 A OF CURRENT. IF THE CURRENT IS CONSTANT, WHAT IS THE MAGNETIC FIELD STRENGTH AT A DISTANCE

OF 1.0 m?

$$B = \frac{\mu_0 I}{2\pi d} = \frac{(4\pi \times 10^{-7})(10)}{2\pi(1.0)} = 2 \times 10^{-6}\,T$$

# SOLENOIDS

- B-FIELDS AROUND SINGLE WIRES ARE RELATIVELY WEAK AT NORMAL CURRENT LEVELS
- SOLENOIDS GEOMETRICALLY CONCENTRATE THE FIELD BY WRAPPING THE WIRE INTO A COIL




$$\boxed{B = \mu_0 n I}$$

$$= \mu_0 \frac{N}{L} I$$

$$n = \frac{N}{L}$$

N: TOTAL WINDS

L: TOTAL LENGTH

B: MAG. FIELD, T

$\mu_0$: PERMEABILITY OF FREE SPACE ($4\pi \times 10^{-7}$ T·m/A)

n: # OF WINDS PER METRE ($m^{-1}$)

I: CURRENT (A)

- THE DIRECTION OF THE B-FIELD INSIDE THE SOLENOID IS GIVEN BY THE RIGHT HAND RULE (#2)
  - WRAP FINGERS IN DIRECTION OF CURRENT, THUMB POINTS NORTH

EXAMPLE

A SOLENOID 25 cm IN LENGTH HAS 500 WINDINGS. WHAT IS THE B-FIELD INSIDE THE SOLENOID WHEN IT HAS A CURRENT OF 2.0 A?

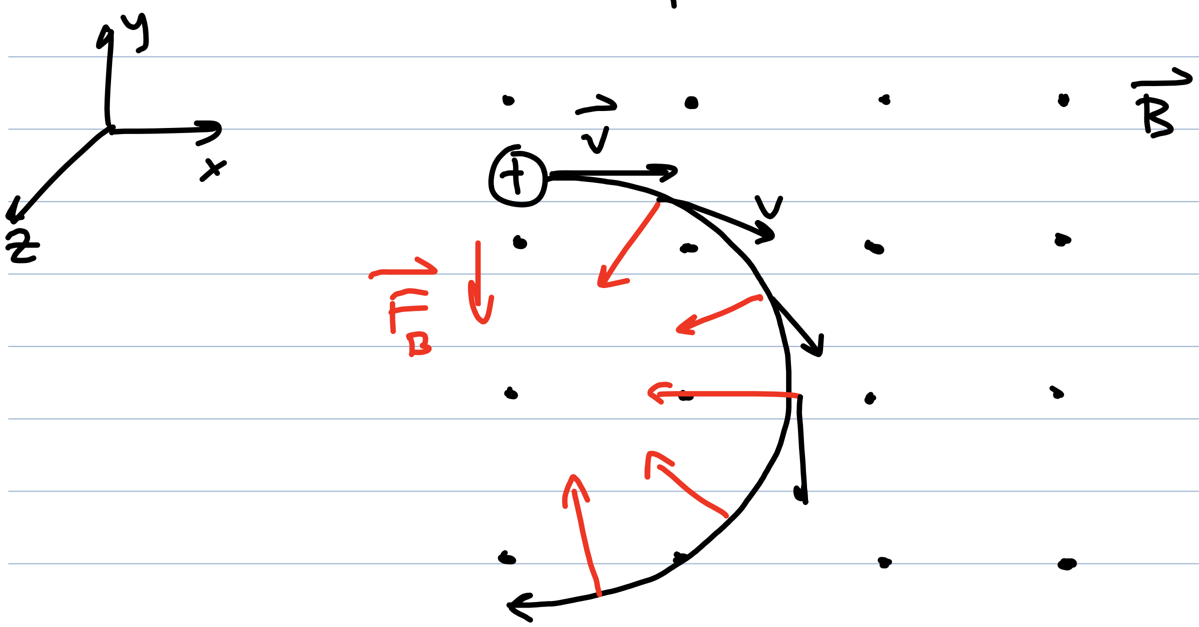
$$B = \mu_0 n I \qquad \frac{N}{L} = n$$

$$= (4\pi \times 10^{-7})\left(\frac{500}{0.25}\right)(2.0)$$

$$= \boxed{0.005\ T}$$

# MAGNETIC FORCE ON A CHARGE

- A CHARGE IN MOTION PRODUCES A MAGNETIC FIELD WHICH CAN INTERACT WITH AN EXTERNAL MAGNETIC FIELD




$$\boxed{\vec{F}_B = q\,\vec{v} \times \vec{B}}$$

VECTOR PRODUCT

$\vec{F}_B$ : MAGNETIC FORCE, N
$q$ : CHARGE, C
$\vec{v}$ : VELOCITY, $\frac{m}{s}$
$\vec{B}$ : MAGNETIC FIELD, T

- V AND B MUST BE PERPENDICULAR
  - IF NOT PERPENDICULAR, USE THE PERPENDICULAR COMPONENT

$$F_B = qvB\sin\theta$$

  - IF V AND B ARE PARALLEL, THERE IS NO MAGNETIC FORCE

- THE DIRECTION OF THE MAGNETIC FORCE IS GIVEN BY THE RIGHT HAND RULE (#3) (AKA FBI RULE)
  - F: MAGNETIC FORCE — MIDDLE F.
  - B: MAGNETIC FIELD — INDEX
  - I: CURRENT / VELOCITY OF POSITIVE CHARGE — THUMB.

- BECAUSE MAGNETIC FORCE IS $\perp$ TO THE VELOCITY, ALL CHARGED PARTICLES THAT ENTER A MAGNETIC FIELD WILL EXPERIENCE CIRCULAR MOTION.

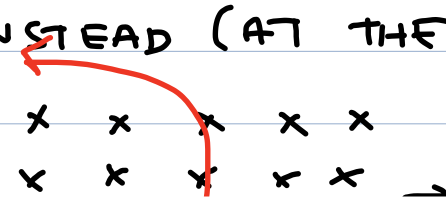
## EXAMPLE

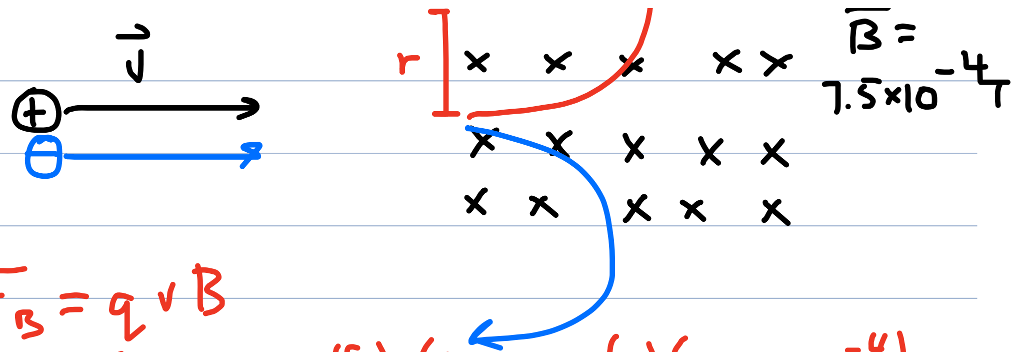
A PROTON BEAM ENTERS A MAGNETIC FIELD AS SHOWN WITH A SPEED OF $6.0 \times 10^6 \frac{m}{s}$.

a) DETERMINE THE MAGNITUDE OF $F_B$.

b) DESCRIBE THE PATH OF THE PROTON.

c) HOW WOULD THE PATH CHANGE IF AN ELECTRON BEAM ENTERED THE B-FIELD INSTEAD (AT THE SAME SPEED)?






a) $F_B = qvB$

$= (1.60\times10^{-19})(6.0\times10^{6})(7.5\times10^{-4})$

$= \boxed{7.2\times10^{-16}\ \text{N}}$

b) $F_B = F_c$

$qvB = ma_c$

$qvB = m\frac{v^2}{R}$

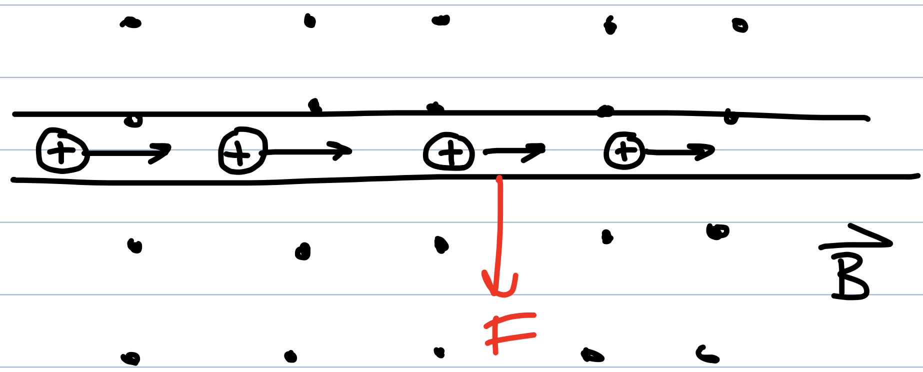
$R = \frac{mv}{qB} = \frac{(1.67\times10^{-27})(6.0\times10^{6})}{(1.60\times10^{-19})(7.5\times10^{-4})}$

$= \boxed{83.5\ \text{m}}$

c) See DIAGRAM

- radius is smaller
  (same Force, less mass)

# MAGNETIC FORCE ON A CURRENT-CARRYING WIRE




- A CURRENT-CARRYING WIRE IN A B-FIELD WILL EXPERIENCE A FORCE BECAUSE OF THE MOVING CHARGES CONTAINED IN IT.

- CONSIDER THE MAGNETIC FORCE ON A CHARGE:

$$F_B = q v B$$
$$= q \frac{d}{t} B$$
$$= d \frac{q}{t} B$$
$$= \ell I B$$

$$\boxed{\vec{F}_B = \ell \vec{I} \times \vec{B}}$$

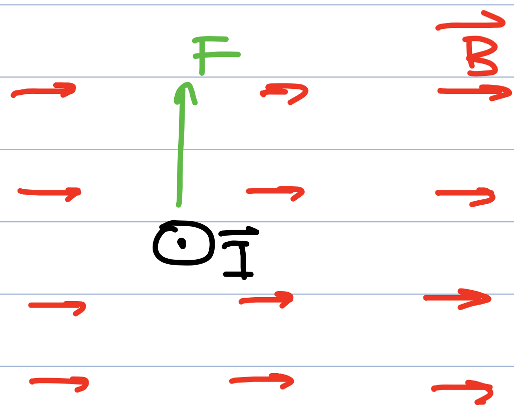
$F_B$: MAGNETIC FORCE, N
$\ell$: length OF WIRE IN B-FIELD, m

VECTOR PRODUCT

$I$ : CURRENT, A

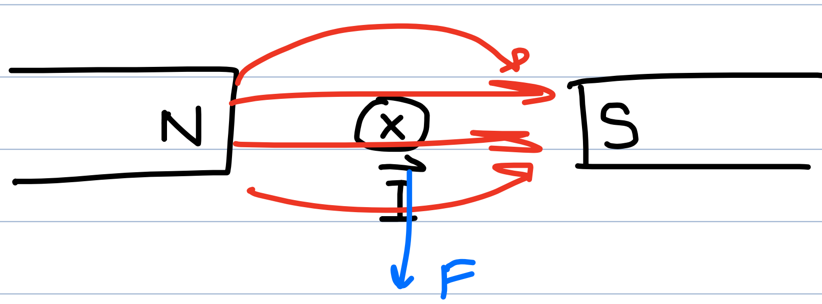
$B$ : MAGNETIC FIELD, T

- DIRECTION IS DETERMINED BY THE RIGHT HAND RULE (#3)
  - FBI RULE




# EXAMPLE

A WIRE CARRYING 10 A OF CURRENT PASSES THROUGH A 1.5 mT B-FIELD SO THAT 2.0 cm OF THE WIRE IS PERPENDICULAR AS SHOWN. WHAT FORCE IS EXERTED ON THE WIRE?



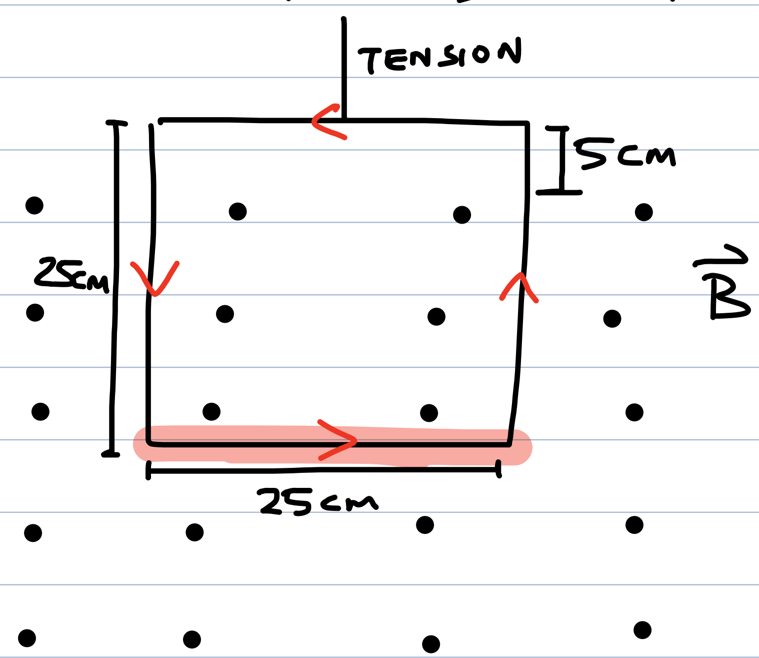

$F_B = lIB$

$= (0.020)(10)(1.5\times10^{-3})$

$= \boxed{3.0 \times 10^{-4}\ N \quad \text{DOWN}}$

EXAMPLE

A WIRE LOOP IS SUSPENDED IN A UNIFORM 0.050T FIELD AS SHOWN. WHAT CURRENT WILL INCREASE THE TENSION BY 0.30 N?

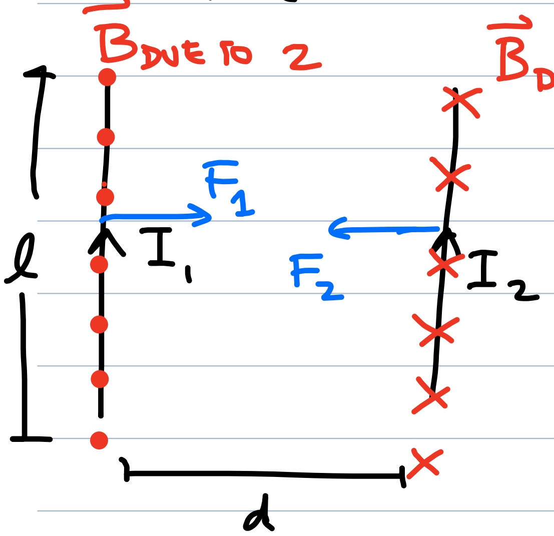



$F_B = \ell I B$

$I = \frac{F_B}{\ell B}$

$= \frac{0.30}{(0.25)(0.050)} = \boxed{24\ A}$

- PARALLEL WIRES WILL EXERT A FORCE ON EACH OTHER



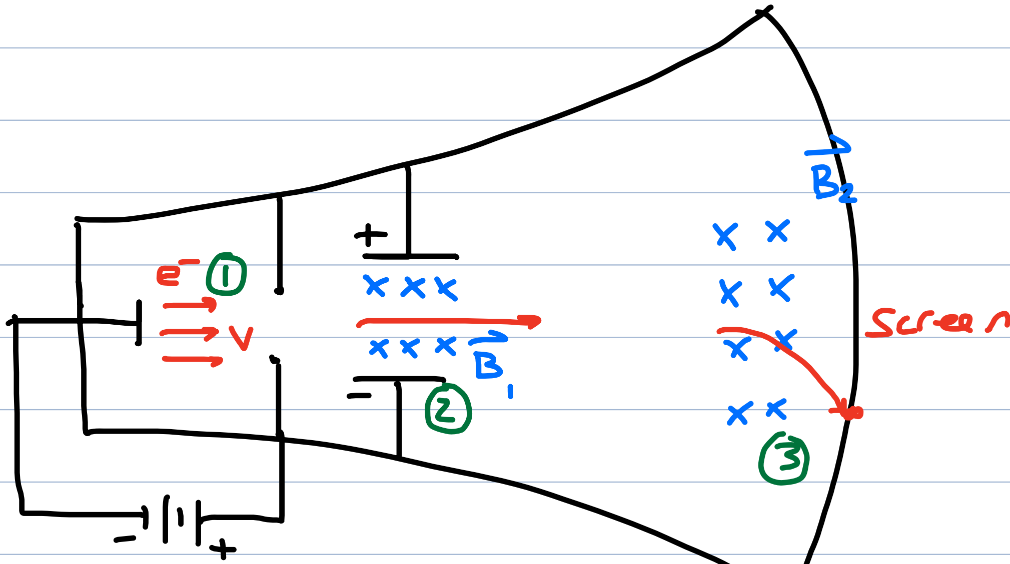

$$F_1 = \ell I_1 B_2$$
$$= \ell I_1 \frac{\mu_0 I_2}{2\pi d}$$
$$\frac{F}{\ell} = \mu_0 \frac{I_1 I_2}{2\pi d}$$

- IF THE CURRENTS ARE IN THE SAME DIRECTION, THE MAGNETIC FORCES ON THE WIRES ARE TOWARDS EACH OTHER; THEREFORE, THE WIRES ATTRACT EACH OTHER
- IF THE CURRENTS ARE IN THE OPPOSITE DIRECTION, THE WIRES WILL REPEL EACH OTHER.

# MAGNETIC APPLICATIONS

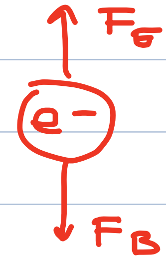
electron charge

$\frac{e}{m}$ RATIO – J.J THOMSON




① CATHODE RAY TUBE OR ELECTRON GUN
- ELECTRONS ARE ACCELERATED BY A POTENTIAL DIFFERENCE V

② VELOCITY SELECTOR
- ELECTRONS ENTER A MAGNETIC FIELD* COMBINED WITH AN ELECTRIC FIELD**




* MAGNETIC FIELD CAN BE MEASURED BY KNOWING THE LENGTH OF THE COIL, COUNTING THE # OF WINDINGS AND KNOWING THE CURRENT THROUGH THE COIL $B = \mu_0 n I$

** ELECTRIC FIELD CAN BE MEASURED USING

$$F_E = F_B$$

$$qE = qvB$$

$$\boxed{v = \frac{E}{B_1}}$$

THE VOLTAGE OF THE PLATES AND THE DISTANCE BETWEEN THE PLATES. $E = \frac{V}{d}$

(3) SELECTED ELECTRONS ENTER A SECOND MAGNETIC FIELD.

$$F_c = F_B$$

$$m\frac{v^2}{r} = qvB_2$$

$$\frac{q}{m} = \frac{v}{B_2 r}$$

$$v = \frac{E}{B_1}$$

charge of $e^-$ ($e$)

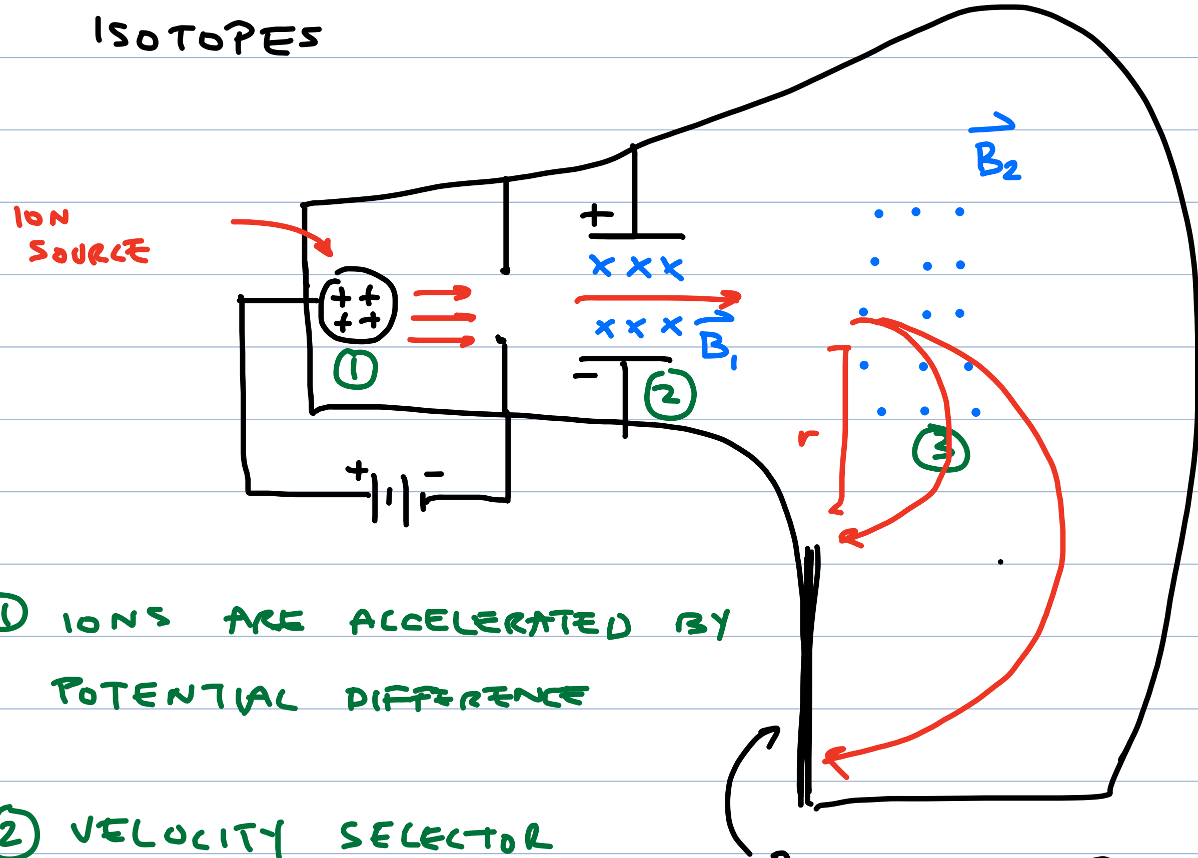
$$\boxed{\frac{q}{m} = \frac{E}{B_1 B_2 r}}$$

· THE $\frac{e}{m}$ RATIO WAS CALCULATED TO BE

$$\boxed{1.76 \times 10^{11} \frac{C}{kg}}$$

# MASS SPECTROMETER

· MEASURES THE MASS OF DIFFERENT ISOTOPES




① IONS ARE ACCELERATED BY POTENTIAL DIFFERENCE

② VELOCITY SELECTOR

$$v = \frac{E}{B_1}$$

③ DIFFERENT MASSES ARE SEPARATED ACCORDING TO r

$$F_c = F_B$$

$$m\frac{v^2}{r} = qvB_2$$

$$m = \frac{qB_2 r}{v} \qquad v = \frac{E}{B_1}$$

$$m = \left(\frac{qB_1B_2}{E}\right)r$$