LEC 18: MAGNETIC INTERACTIONS AND MAGNETIC FORCE
LEC 19: MAGNETIC FIELDS
LEC: 20: APPLICATIONS OF MAGNETIC FORCES AND FIELDS

CHAPTER 20:

20.1 : MAGNETIC INTERACTIONS
20.2 : MAGNETIC FIELDS
20.3: MAGNETIC FORCE ON A CURRENT-CARRYING WIRE
20.4: MAGNETIC FORCE EXERTED ON A SINGLE MOVING CHARGED PARTICLE
20.5 MAGNETIC FIELDS PRODUCED BY ELECTRIC CURRENTS
20.6: SKILLS OF ANALYZING MAGNETIC PROCESSES
20.7 MAGNETIC PROPERTIES OF MATERIALS

ERRATUM

When a charged particle enters magnetic field & $\vec{v} \perp \vec{B}$

$$F_B = ma_c = m\frac{v^2}{R}$$

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

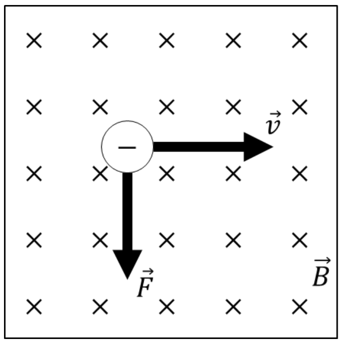
$$\boxed{R = \frac{mv}{qB}}$$

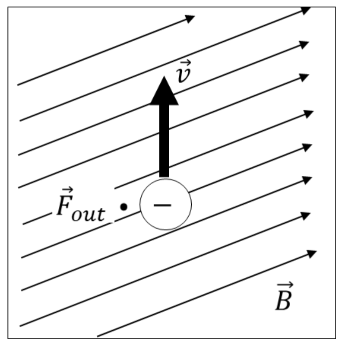
LEARNING CATALYTICS – QUICK CHECK

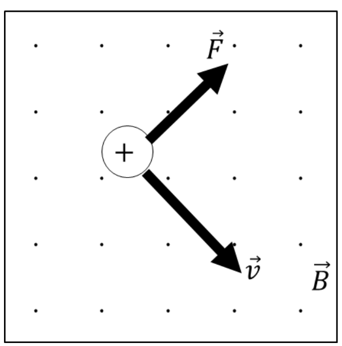
Which picture is correct?

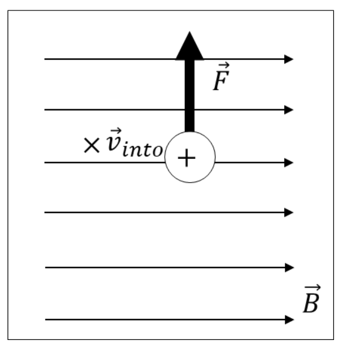
The pictures do not have labels as they may show up in different order on your LC.

Everyone – hand exercises!





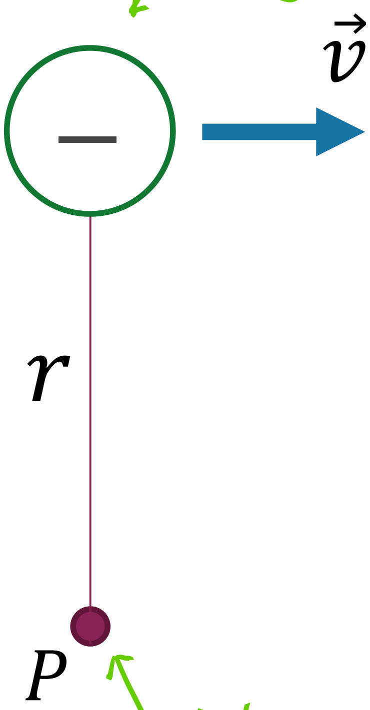




Learning Catalytics – Quick Check

If the negative particle moves to the right with velocity $\vec{v}$, which is true about magnetic and electric field created by it at point P?

negative charge



determine both fields here

A: **Electric field** is downwards,
the **magnetic field** is out of the page

B: **Electric field** is upwards,
the **magnetic field** is out of the page

C: **Electric field** is downwards,
the **magnetic field** is into the page

D: **Electric field** is upwards,
the **magnetic field** is into the page.

Review

Magnetic Field of a straight, wire

$$B_{wire} = \frac{\mu_0 I L}{2\pi d\sqrt{L^2 + d^2}}$$

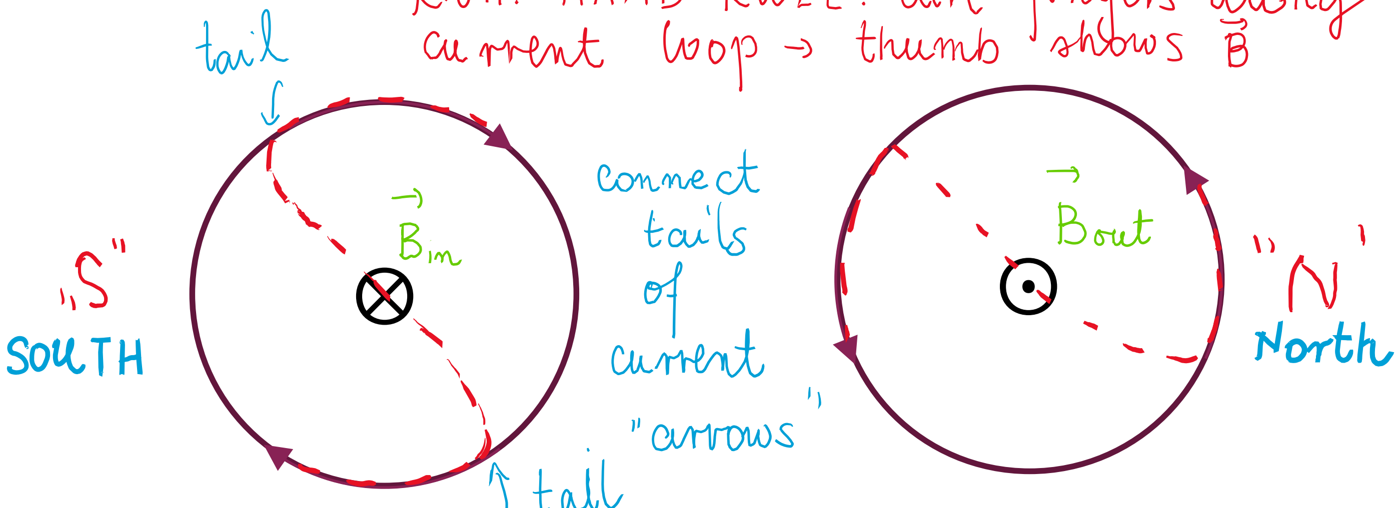
L – length of the wire
I – current
d – distance from the wire

$$B_{long\,wire} = \frac{\mu_0 I}{2\pi d}$$

Magnetic Field in the middle of a Loop of Wire

RIGHT HAND RULE: curl fingers along current loop → thumb shows $\vec{B}$

$$B_{loop} = \frac{\mu_0 I}{2d}$$



$$B_{loop\,fraction} = \frac{\mu_0 I}{2d} \cdot \frac{\theta}{2\pi}$$ where θ in the angle subtended by the arc (in radians)

LEARNING CATALYTICS

Two concentric circular loops of radii a and b, carry currents I_1 (clockwise) and I_2 (counter-clockwise), respectively as shown in the picture. What is the correct expression for the magnetic field in the center of the loops?

I_1 creates field ________ the page

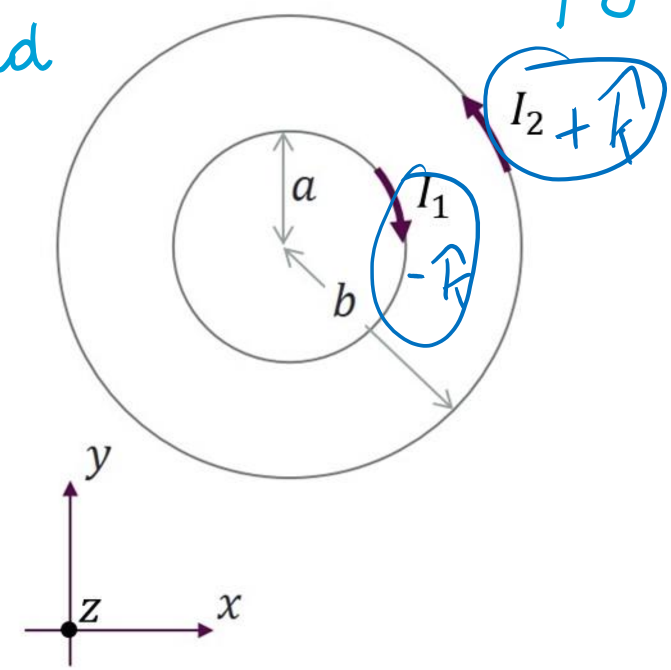
I_2 creates field ________ the page

$$a)\ \vec{B} = \frac{\mu_0}{2}\left(\frac{I_2}{b} - \frac{I_1}{a}\right)\hat{k}$$

$$b)\ \vec{B} = \frac{\mu_0}{2}\left(\frac{I_1}{a} - \frac{I_2}{b}\right)\hat{k}$$

$$c)\ \vec{B} = \frac{\mu_0}{2\pi}\left(\frac{I_2}{b} - \frac{I_1}{a}\right)\hat{k}$$

$$d)\ \vec{B} = \frac{\mu_0}{2\pi}\left(\frac{I_1}{a} - \frac{I_2}{b}\right)\hat{k}$$



unit vector in z direction

Note: the answers on LC may show up in different order!

EXAMPLE 20E

$\rightarrow m = m_p \qquad q = -e$

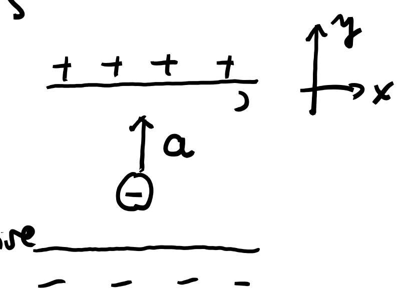
An **antiproton** is accelerated across the potential difference $\Delta V = 2500\ \mathrm{V}$ and it enters a uniform magnetic field $\vec{B} = -0.31\ \mathrm{T}\hat{k}$ while moving in the positive $+y$ direction. What is the radius of the antiproton's path?

outline

To find speed

assume $\rightarrow K_i = 0$ $\qquad \Delta U = q\Delta V$

$K_f = ?$



$$K_i + U_i = K_f + U_f$$

$$K_f - K_i = U_i - U_f = -\Delta U = -q\Delta V$$

has to be positive

negative (−e)

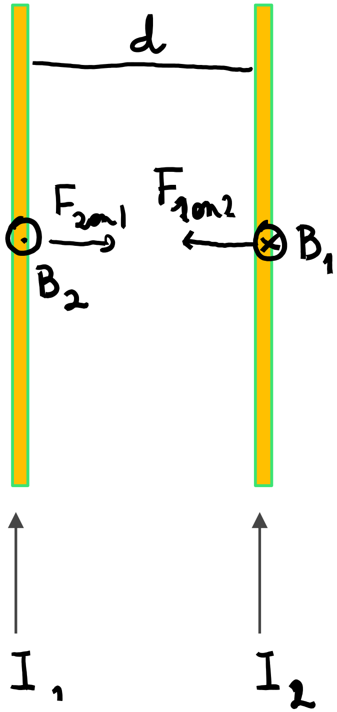
$$K_f = \frac{1}{2} m_p v^2 = -(-e)(2500) \rightarrow v$$

One you have v,

$\uparrow v$, $\otimes \vec{B} \rightarrow \vec{F}$ (negative charge)

$$F = qvB = \frac{mv^2}{R} \rightarrow R = \frac{mv}{qB}$$

Force Between Two Parallel Wires



$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

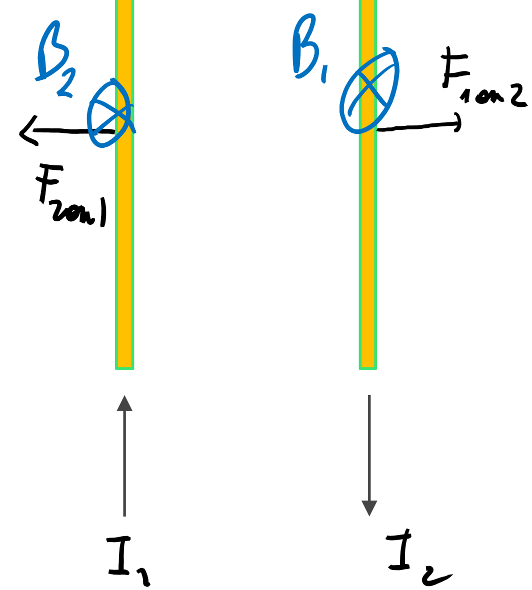
$$F_{1 on 2} = I_2 L B_1$$

$$= I_2 L \frac{\mu_0 I_1}{2\pi d}$$

$$B_2 = \frac{\mu_0 I_2}{2\pi d}$$

$$F_{2 on 1} = I_1 L B_2$$

$$= I_1 L \frac{\mu_0 I_2}{2\pi d}$$



L_1

L_2

smaller L_1 or L_2

$$\boxed{F_{parallel\,wires} = \frac{\mu_0 L I_1 I_2}{2\pi d}}$$ → next page

EXAMPLE 20F – LEARNING CATALYTICS

Determine magnetic $\boxed{\text{force per unit length}}$ between two wires each carrying current $I = 1.5\ A$ separated by distance $d = 0.030\ m$.

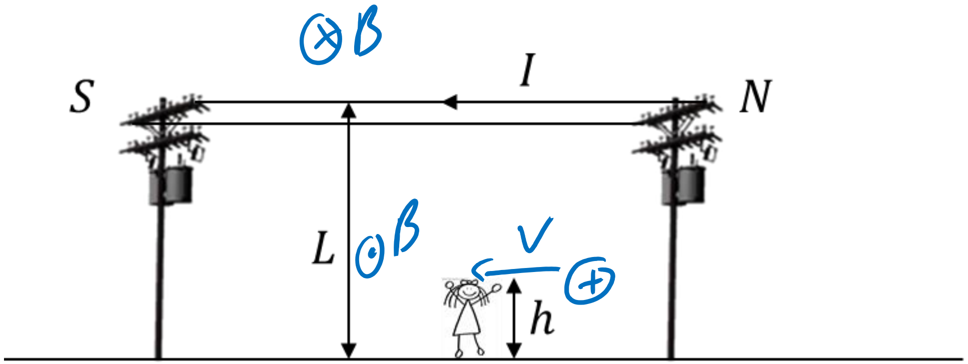
$$F = \frac{\mu_0 I_1 I_2 L}{2\pi d}$$

$$\frac{F}{L} = \frac{\mu_0 I^2}{2\pi d}$$

AN OLD EXAM QUESTION

EXAMPLE 20G – COMBINE VARIOUS CONCEPTS

A distribution line (power line), located $L = 5.5\ \mathrm{m}$ above ground carries current $I = 55\ \mathrm{A}$, going from North to South. Dr. Harlick ($h = 1.55\ \mathrm{m}$) stands directly underneath it. What is the magnitude of the magnetic force experienced by a charged particle of charge $q = +4e$ and mass $m = 1.59 \times 10^{-25}\ \mathrm{kg}$ that moves with a velocity $v = 2.0 \times 10^{5}\ \mathrm{m/s}$ directly over Dr. Harlick's head, in the same direction as the current in the wire



$$\boxed{B_{long\,wire} = \frac{\mu_0 I}{2\pi d}} = \frac{\mu_0 I}{2\pi(L-h)}$$

assume long wire

S E

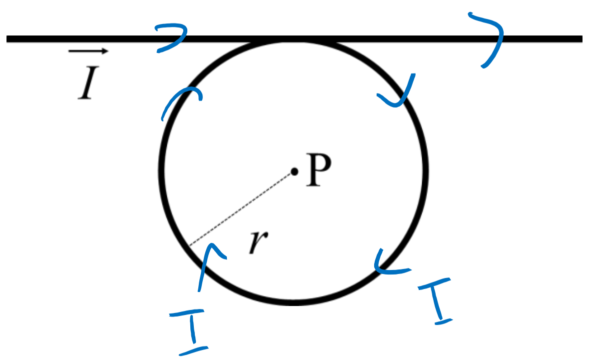
$$F = qvB = (+4e)(v)\left(\frac{\mu_0 I}{2\pi(L-h)}\right)$$

$$F = 3.56 \times 10^{-19}\ \mathrm{N}$$

$$a = \frac{F}{m} \sim \frac{10^{-19}\ N}{10^{-25}\ kg} \sim 10^{6}\ m/s^2$$

EXAMPLE 20H – TWO PIECES OF WIRE

Infinite wire, shaped as shown in the picture, carries current $I = 3.0\ A$. What is the magnitude of the net magnetic field at point *P* (in the middle of the loop) if radius is $r = 2.0\ \mathrm{cm}$?



$$B_{inside} = B_{long\,wire} + B_{loop} = \frac{\mu_0 I}{2\pi r} + \frac{\mu_0 I}{2r}$$

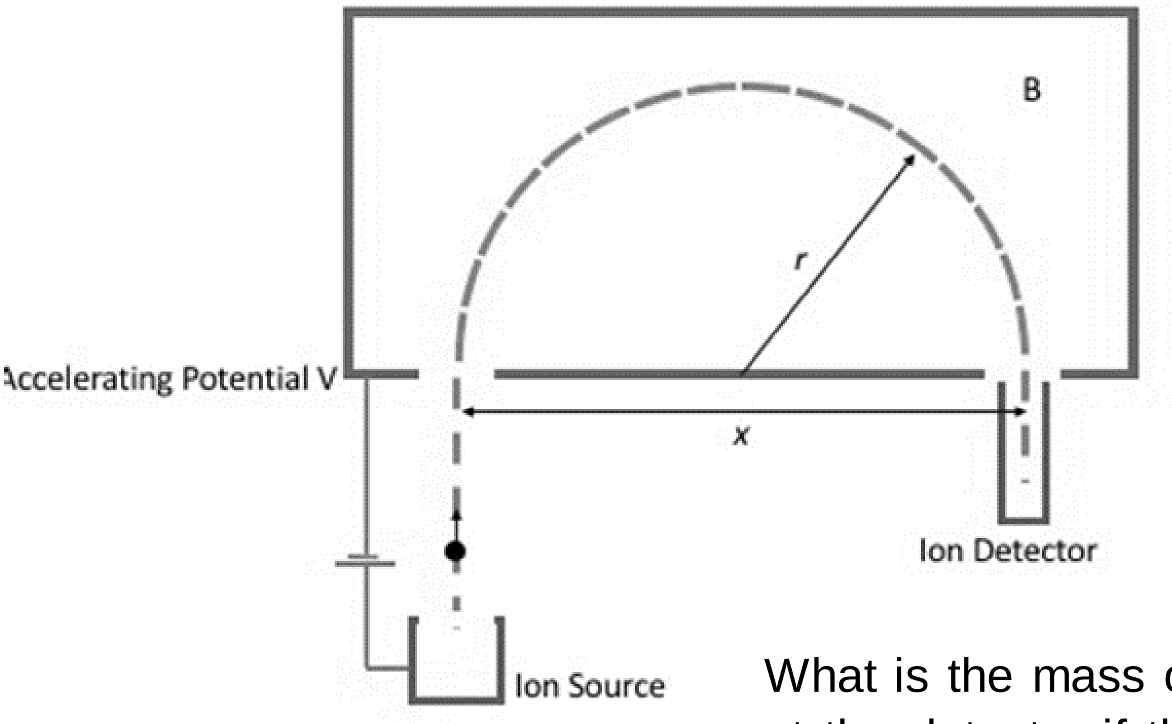
$$B_{inside} = 124\ \mu\mathrm{T}$$

There is a similar question on Learning Catalytics – you can try it!

EXAMPLE 20I – MASS SPECTROMETER

An ion source produces particles of charge $|e|$ **of unknown sign**.

A potential difference of 10 000 V between the ion source and the entrance to a uniform magnetic field accelerates the ions. The moving ions enter a region with a uniform magnetic field **pointing into the page** where a magnetic force causes the ions to move along an arc of radius *r*. An ion detector is mounted a distance of x = 0.500 m from the entrance to the magnetic field region.



What is the mass of the charges (in kg) incident at the detector if the magnitude of the magnetic field is 0.8000 T?

LEARNING CATALYTICS

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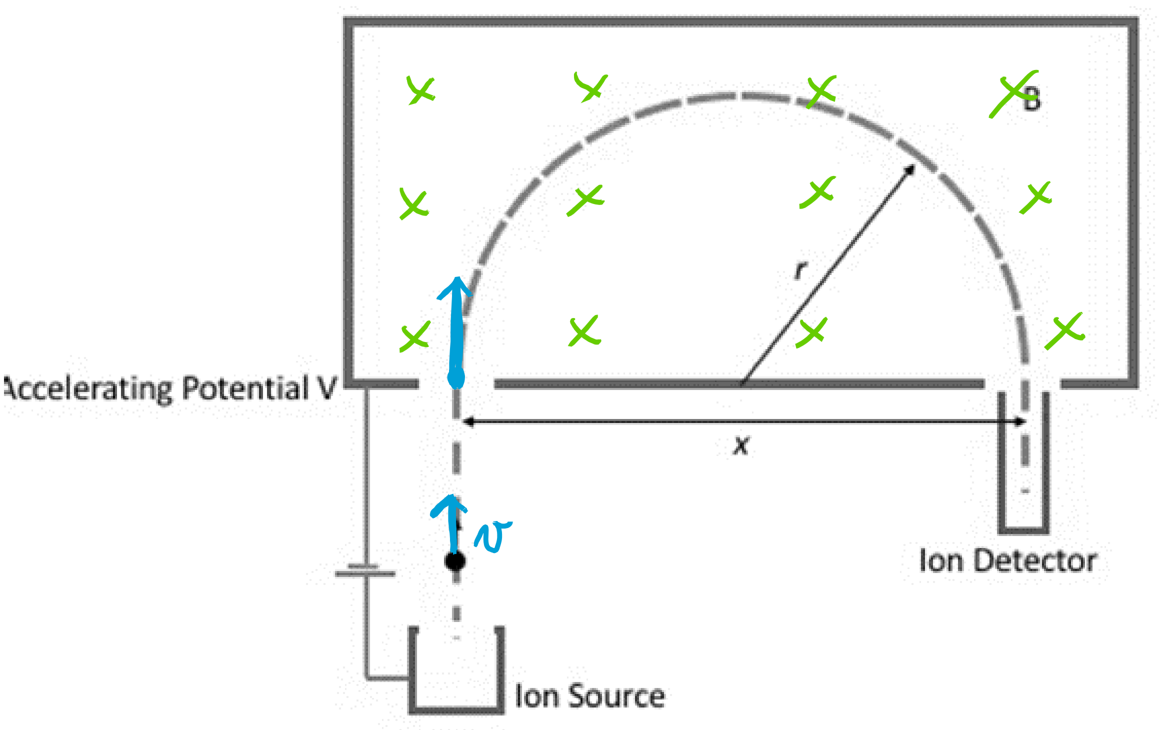

What is the sign of the charge?

a) Positive

b) Negative

c) Neutral ← not that!

d) The particle is either positive or negative.

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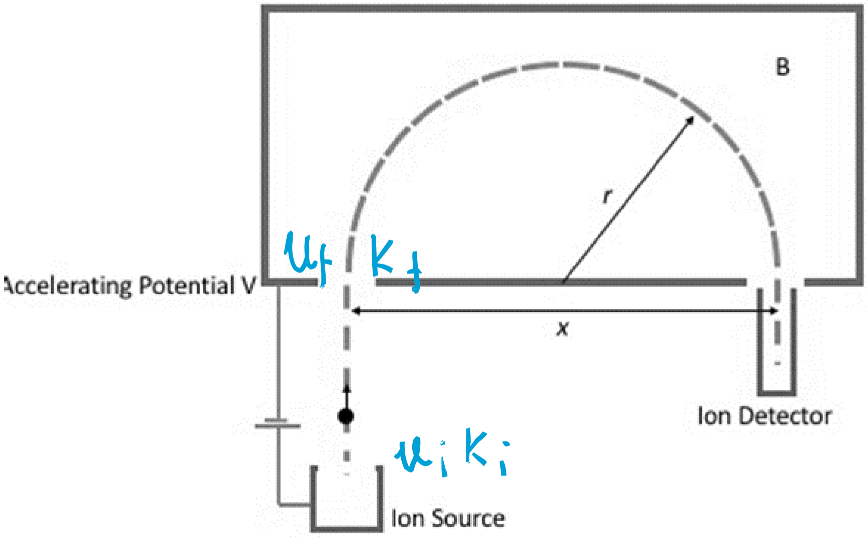
Figure out mass.

Two-steps need to be combined



In the spectrometer

$$\frac{mv^2}{r} = qvB \rightarrow m = \frac{qBr}{v}$$

??

From energy conservation in the accelerator

$$K_i + U_i = K_f + U_f$$

$$\frac{1}{2}mv_i^2 + U_i - U_f = \frac{1}{2}mv^2$$

$\Delta U = q\Delta V$ we know that the particle is sped up so $-\Delta U$ needs to be positive

$$K_i \underbrace{- \Delta U}_{\text{positive}} = \frac{1}{2} m v^2$$

zero

$$\rightarrow \frac{1}{2} m v^2 = e|\Delta V|$$

$$v^2 = \frac{2e|\Delta V|}{m}$$

$$m = \frac{qBr}{v} \rightarrow m^2 = \frac{q^2 B^2 r^2}{v^2} = \frac{e^2 B^2 \left(\frac{x}{2}\right)^2}{\frac{2e|\Delta V|}{m}}$$

$$m^{\cancel{2}} = \frac{e^{\cancel{2}} B^2 \left(\frac{x}{2}\right)^2 \cancel{m}}{2\cancel{e}|\Delta V|}$$

$$m = \frac{e B^2 x^2}{8|\Delta V|}$$

$$m = \frac{1.6 \times 10^{-19} \cdot (0.8)^2 \cdot 0.5^2}{8 \times 10000}$$

$$m = 3.2 \times 10^{-25} \text{ kg}$$