Magnetic field lines lab

- Around the room are numbered stations. Your task is to go through each one and sketch the magnetic field lines for each situation. To help, you have:
  - A compass
    - This will be particularly helpful for the two stations involving circuits
  - Iron filings in a cup
    - ****DO NOT SPILL THESE
    - ****DO NOT PUT DIRECTLY ON THE MAGNETS
    - ****DO NOT DUMP THESE ON THE ACETATES - sprinkle lightly and see what it does!

Quick refreshers

What is the source of all magnetic fields?

Moving charges

Why are some materials magnetic and others not?

In most materials, the spins of the electrons in the domains are randomized; only in ferromagnetic materials are they aligned, creating an overall magnetic field.

Do magnetic field lines align with the direction of magnetic force? If not, what do they tell us?

No, magnetic fields show the way a compass needle would deflect at a particular point.

What is required for a particle to be affected by a magnetic field?

It must be charged, it must be moving, and it must have a component of its motion that is perpendicular to the magnetic field

When a particle is affected by a magnetic field, what happens to it and why?

Magnetic fields cause moving, charged particles to deflect, acting as a centripetal force

How do we determine the direction of a magnetic force on a particle traveling through a B-fld?

With the right hand rule, and considering whether the particle is positive or negative

What are the units for the magnetic field? How about magnetic force?

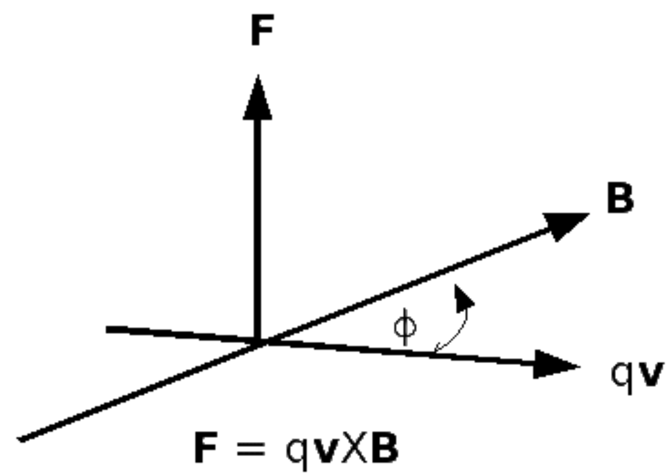
Magnetic fields (B) are measured in Teslas (T); magnetic force is measured in Newtons as always

Magnetic force on a charged particle

- Experimentally, we've seen that the magnetic force depends on three main things:
  - The charge on the particle (q) in coulombs
  - The strength of the magnetic field (B) in **Teslas** (T = N/Am)
  - The velocity component that is perpendicular to the magnetic field (vsin**θ**) in m/s
- In equation form: $\vec{F}_B = qvB\sin\theta = q\vec{v}\times\vec{B}$

Remember that a <u>cross product</u> produces a vector that is <u>perpendicular</u> to the two crossed vectors. In other words →

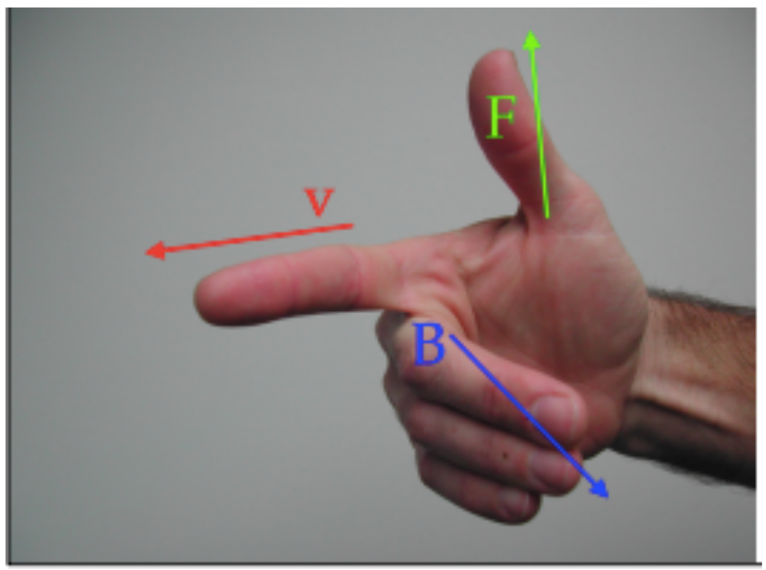
Hang on. If the force is perpendicular to the velocity, then what will that force cause the particle to do?



Directions…

- How can we tell the direction of the magnetic force if we know the directions of v and B? We use our handy **right hand rule**.

1. Point fingers in direction of velocity vector.



Thanks, Mr White!

3. Thumb will point in the direction a **positive** charge will be affected

2. Curl fingers in direction of magnetic field.

For a negative charge, the force will be opposite the thumb (in this picture, down instead of up)

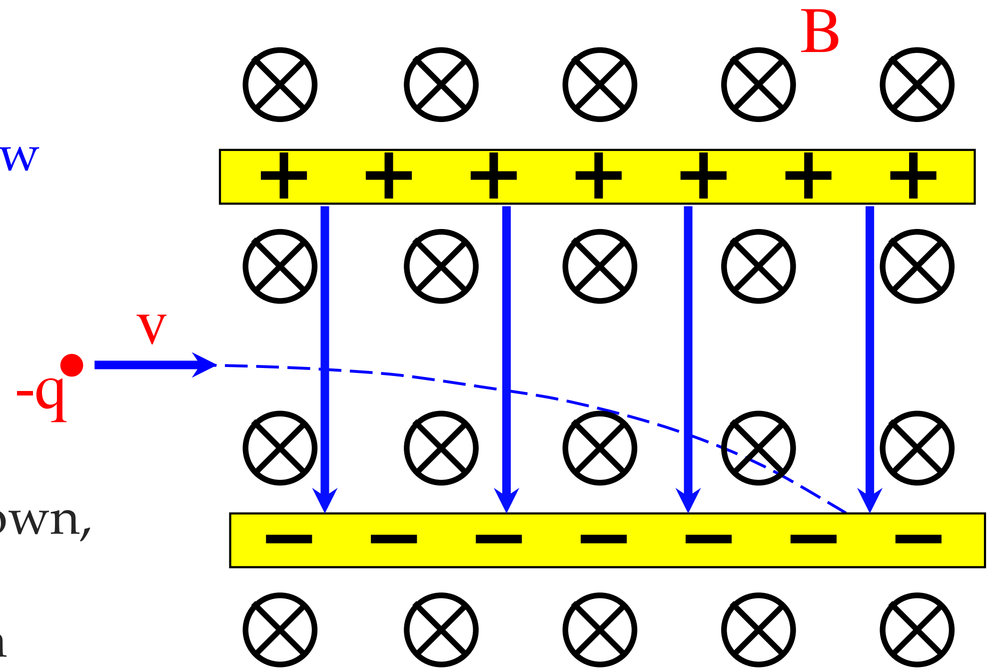
Calculation example (19.7)

- What velocity would a proton need to circle the Earth 1000 km above the magnetic equator, where Earth's magnetic field is directly horizontally northward with a magnitude of 4×10^{-8} T?
  - Hint: draw a picture and think N2L!

Solution on class Website

Velocity trap example

A velocity trap (or velocity selector) is an electric field and magnetic field at right angles to one another that selectively allow charged particles with *one velocity only* to proceed down its axis. It is made up of parallel plates bathed in a B-fld (see sketch).



Assuming the *B-fld* is into the page as shown, what path will a negative charge take if nothing additional is added to the system (i.e., no *E-fld* is present).

According to the right-hand-rule, a positive charge would feel a force *upward,* so a negative charge will feel a force *downward*.

Insert the *E-fld* required to make the charge travel along a straight line.

The force exerted by the *B-fld* is *downward*, so the force exerted by the *E-fld* must be *upward*. To create an *upward force* on a *negative charge,* you need an *E-fld* that is *downward.*

Lorentz relationship

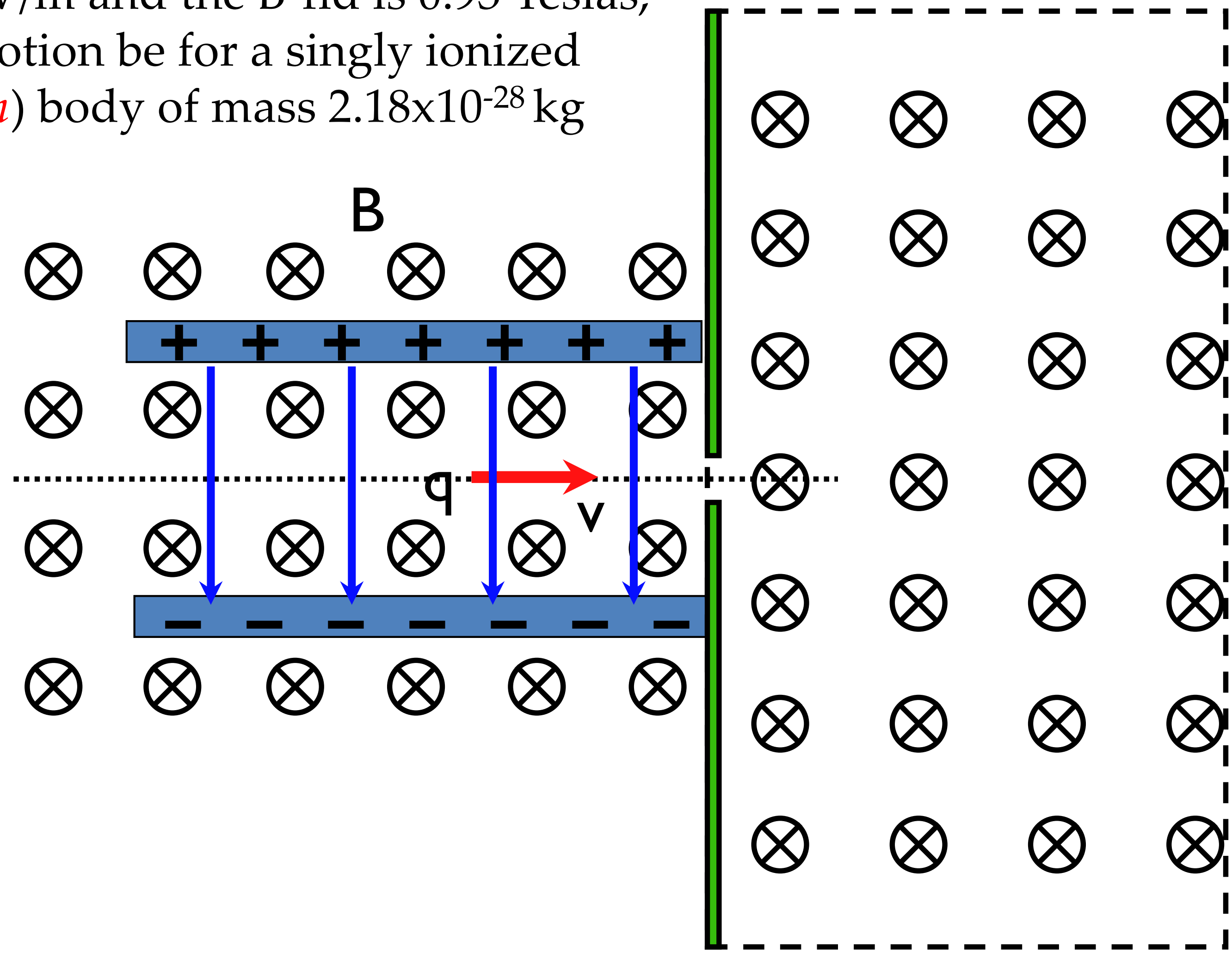
- The principle we used in that last part is more formally known as the **Lorentz relationship**. Simply put, it says that when both electric and magnetic forces act, we see:

$$\vec{F}_{net} = F_E + F_B$$
$$= q\vec{E} + q\vec{v}x\vec{B}$$

- Thus, if the net force on a particle is 0, we can see that F_E and F_b are equal in magnitude and opposite in direction. This can simplify lots of problems if you use your head!

Example 19.36 - mass spectrometer

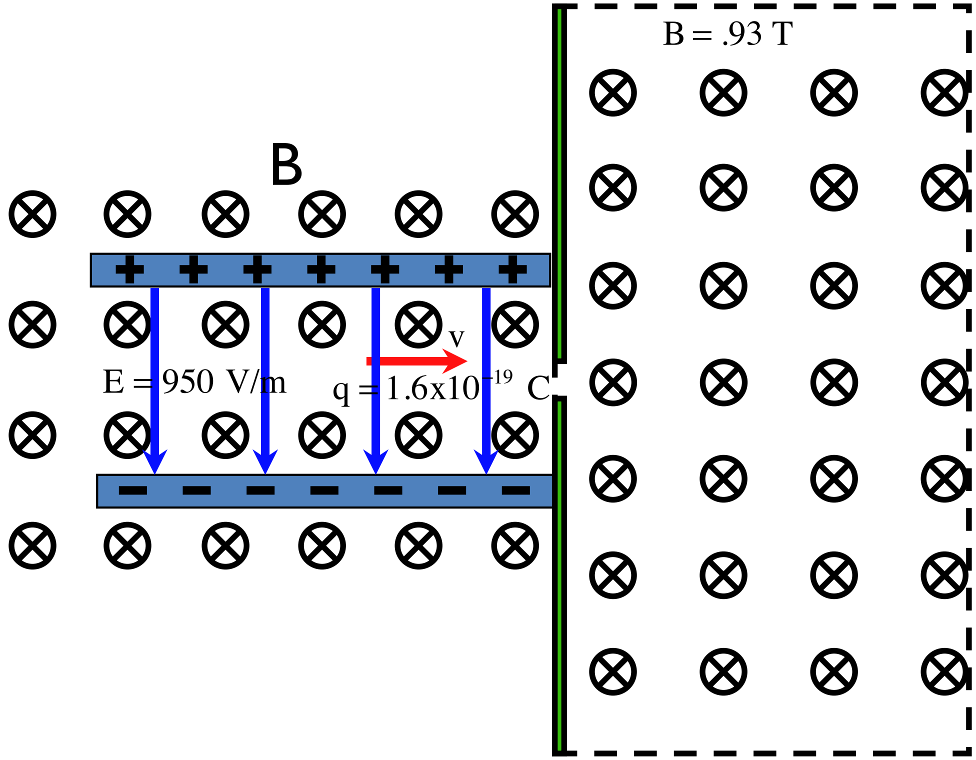
If the electric field is 950 V/m and the B-fld is 0.93 Teslas, what will the radius of motion be for a singly ionized (i.e., charge of one *electron*) body of mass 2.18×10^{-28} kg be?



$m = 2.18x10^{-28}\ kg$ $\quad E = 950\ V/m$

$q = 1.6x10^{-19}\ C$ $\quad B = .93\ T$

The radius of the motion when the charge gets into the area where there is only a magnetic field?



Using N.2.L., we can write:

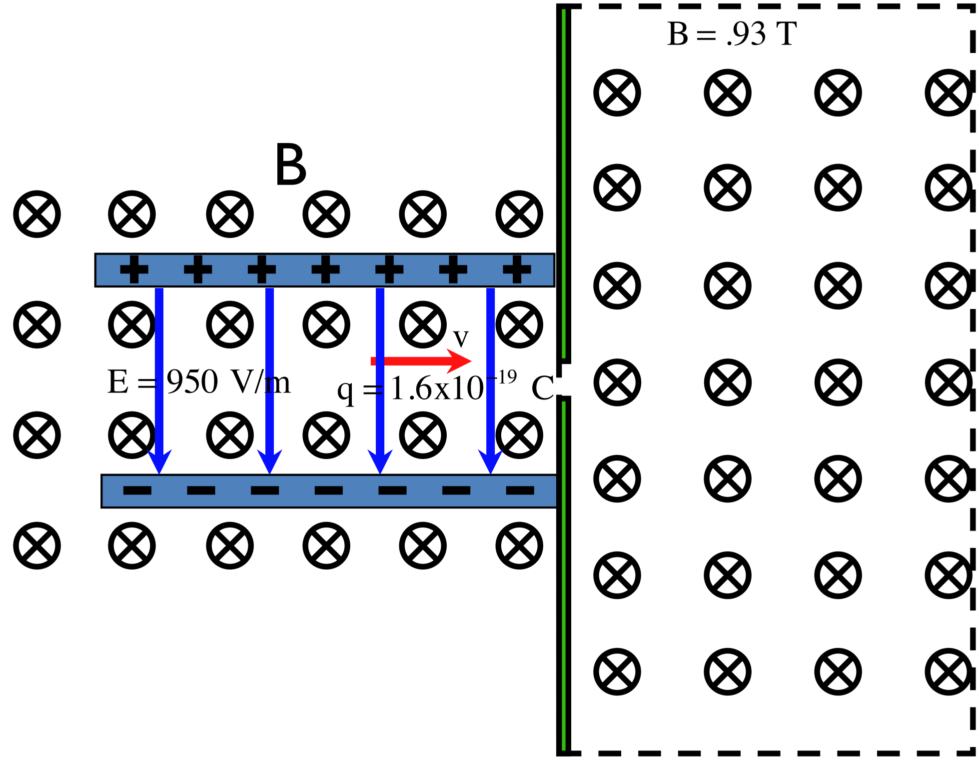
$$\sum F_{centripetal}$$

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

$$\Rightarrow \quad R = m\frac{v}{qB}$$

$$\Rightarrow \quad R = \left(2.18x10^{-28}\ kg\right)\frac{v}{\left(1.6x10^{-19}\ C\right)\left(.93\ T\right)}$$

$$m = 2.18 \times 10^{-28} \text{ kg}$$
$$E = 950 \text{ V/m}$$
$$q = 1.6 \times 10^{-19} \text{ C}$$
$$B = .93 \text{ T}$$



To do this, we need a relationship for "v" knowing the magnitudes of the E-fld and the B-fld. We can get that by noting **that for the charge to pass through the left chamber following a straight-line path, the magnetic and electric forces must be balanced**. In other words:

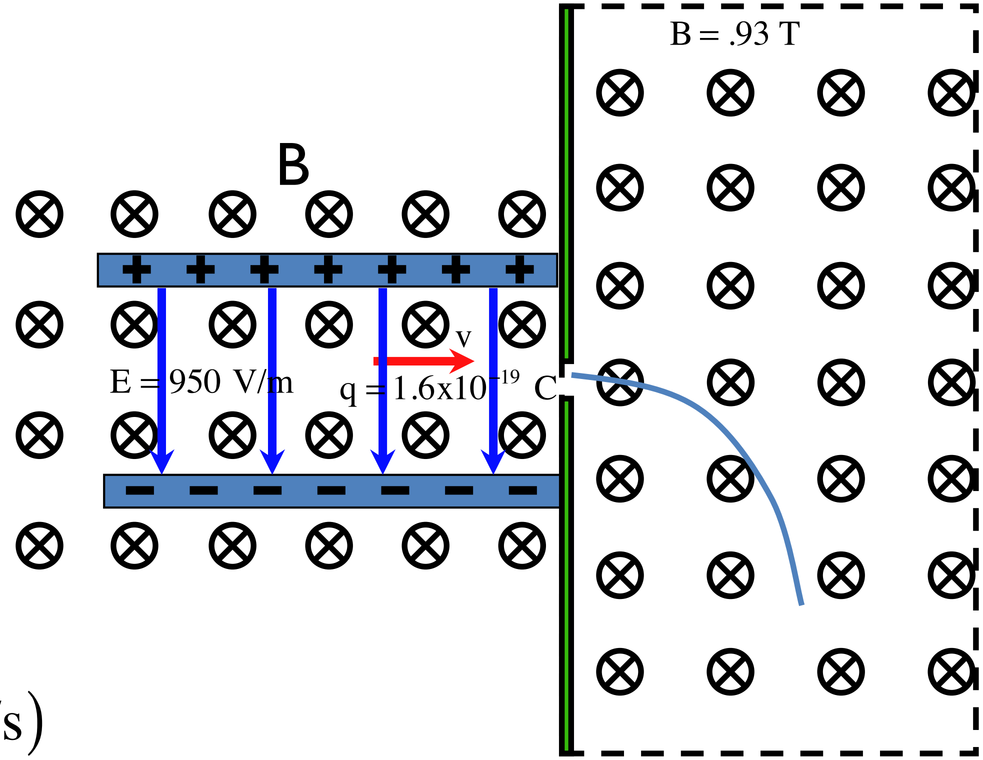
$$qE = qvB$$

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

$$\Rightarrow \quad v = \frac{(950 \text{ V/m})}{(.93 \text{ T})}$$

$$\Rightarrow \quad v = 1021.5 \text{ m/s}$$

With the velocity, we end up with:



$$R = \left(2.18\text{x}10^{-28}\ \text{kg}\right)\frac{\left(1021.5\ \text{m/s}\right)}{\left(1.6\text{x}10^{-19}\ \text{C}\right)\left(.93\ \text{T}\right)}$$

$$= 1.5\text{x}10^{-6}\ \text{m}$$

Based on the sketch above, is the particle positive or negative? How do you know?