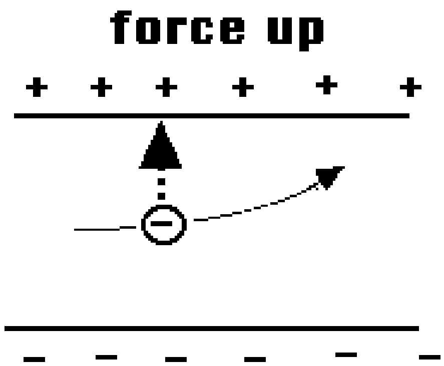
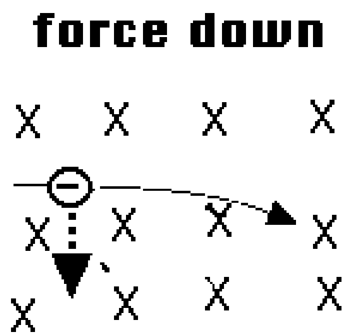
Applications of Charged Particles in Magnetic Fields

Crossing Electric and Magnetic Fields

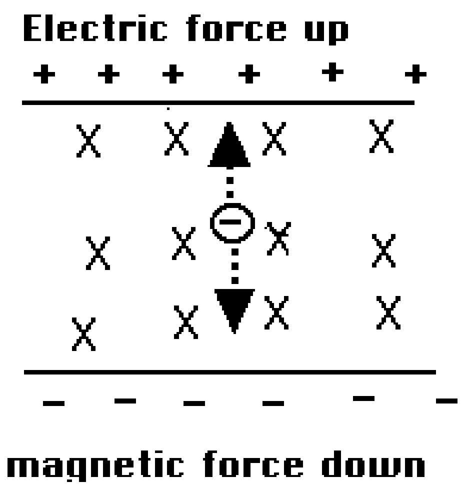
We now know that cathode rays (electron particles) can be deflected by an *electric* field **E** or by a *magnetic* field **B**, as shown below:

(a) an electric field (b) a magnetic field





Note that when combined, the forces are in opposite directions:



It is possible to cross electric and magnetic fields so that the deflecting effect of the electric field is just cancelled by the deflecting effect of the magnetic field. This can be achieved by placing a solenoid, with a constant **B** inside its coils, between charged electric plates that produce a constant **E**. If both fields produce equal and opposing forces on a moving charge, and if the length of the fields is the same, then the charged particle should experience **no deflection**.

If all of the aforementioned conditions exist, the velocity of the moving charge can be determined.

Here: **force from electric field = force from magnetic field**

That is: $\mathbf{qvB = qE}$ → cancel **q** to obtain $\mathbf{vB = E}$ and $\mathbf{v = \frac{E}{B}}$

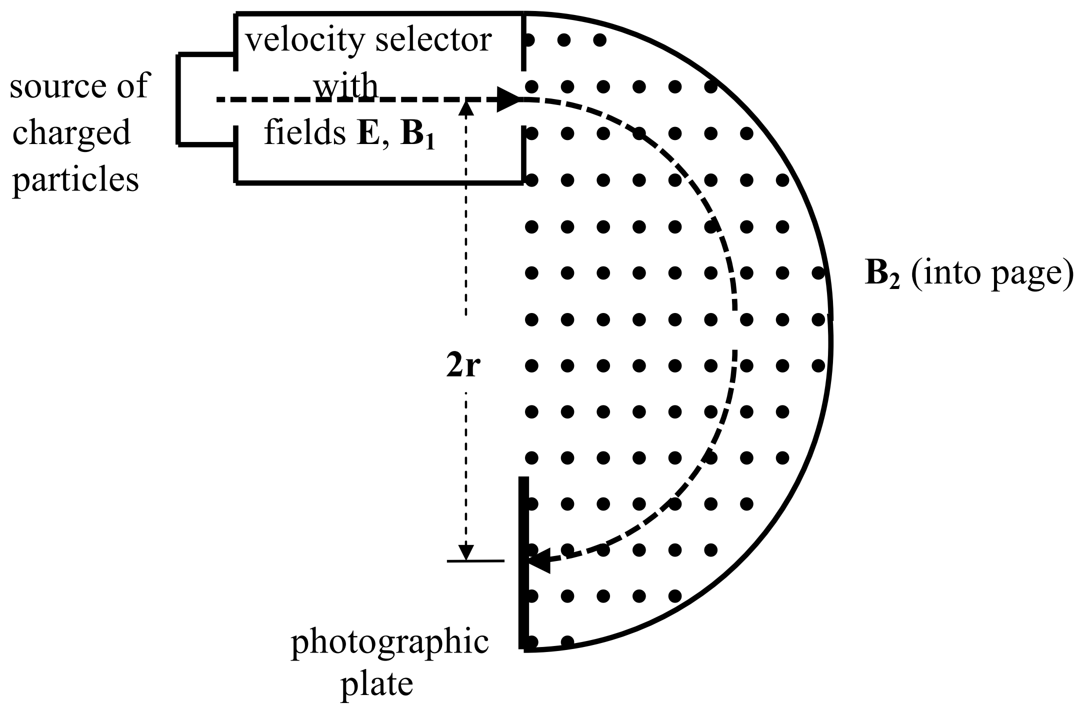
Learn to derive this formula.

Example # 6: A proton travels undeflected at 1.1 x 10^5 m/s through crossed electric and magnetic fields. If B = 0.50 T, determine the electric field strength E.

(see Electromagnetism Ex 6 for answer)

The Mass Spectrometer

The mass spectrometer was developed in the early part of the 20th century to measure the mass of atoms. Its basic function is to use a magnetic field to bend charged atoms, or *ions*, into a circular path of known radius from which the mass could be determined. Examine the diagram below:



This is how the mass spectrometer works:

- charged ions are produced by heating or an electric current at a source
- some ions pass through an opening into a region of crossed electric and magnetic fields **E** and $\mathbf{B_1}$
- only those ions with a speed equal to $\mathbf{v = \frac{E}{B}}$ will pass through un-deflected; such a set-up of crossed fields is often referred to as a *velocity selector*

- the un-deflected ions pass through another opening, entering a second region with another magnetic field $\mathbf{B_2}$ (no **E** field here)
- this field $\mathbf{B_2}$ will cause deflection into a circular path
- deflected ions will finally collide with a photographic plate, marking their positions so that the radius **r** of their circular path can be measured; note that different masses strike at different positions, due to their momentums
- in the magnetic field $\mathbf{B_2}$:

$$\mathbf{F = qvB_2 = m\frac{v^2}{r}} \quad \rightarrow \quad \mathbf{mv = qB_2r}$$

For the nucleus of any atom of a particular element placed in the mass spectrometer, all of the values listed in the above formulas are constant *except* mass and radius (recall that the nuclei of atoms of a n element must have the same # of protons, but not necessarily the same # of neutrons; i.e., same charge, but different mass).

In essence, $\mathbf{m \propto r}$, so once again, ratios can be used to determine the mass of a particular nucleus or ion, knowing its radial path as well as information from another ion.

Example #7: Carbon atoms of atomic mass 12.0 a.m.u. are mixed with atoms of another unknown material. In a mass spectrometer, the C-12 atoms follow a path of radius 22.4 cm, while the unknown atoms produce a 26.2-cm radius path. Assuming <u>identical</u> charges, what is the atomic mass of the unknown material?

(see Electromagnetism Ex 7 for answer)