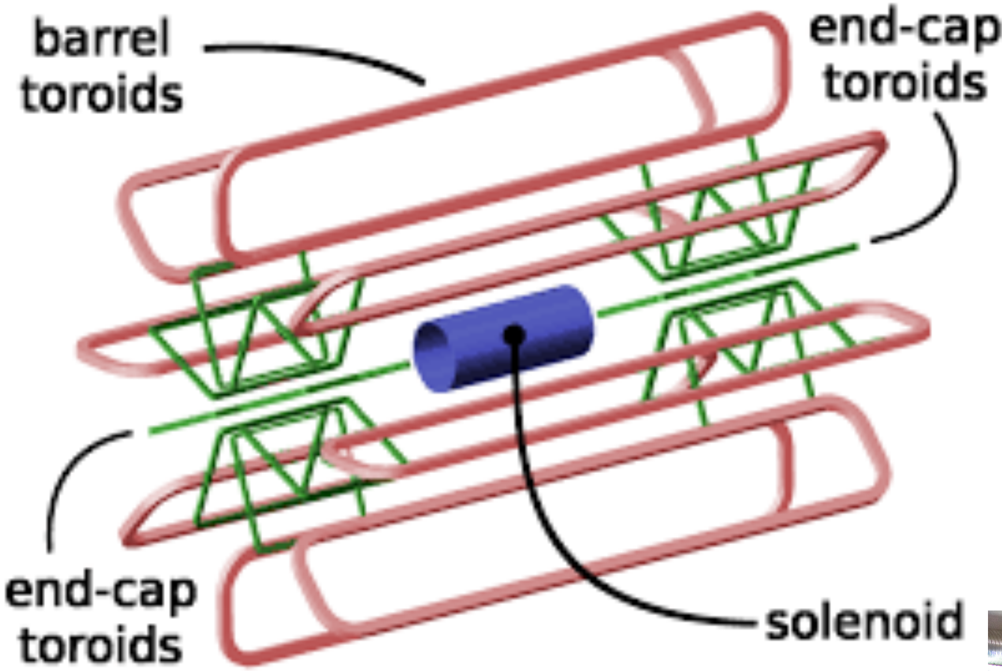
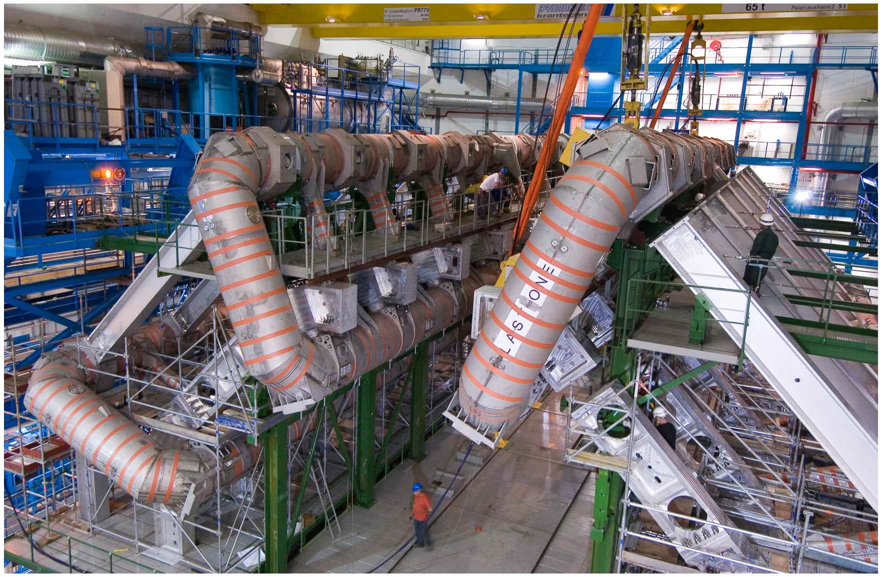
PHY294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: <u>12:40-2:40 Monday (note change)</u>; 3:00-4:00 PM Friday**
  - **hand-in problem for next Wed: 32.80**
- Quizzes by iclicker (sometimes hand-written)
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

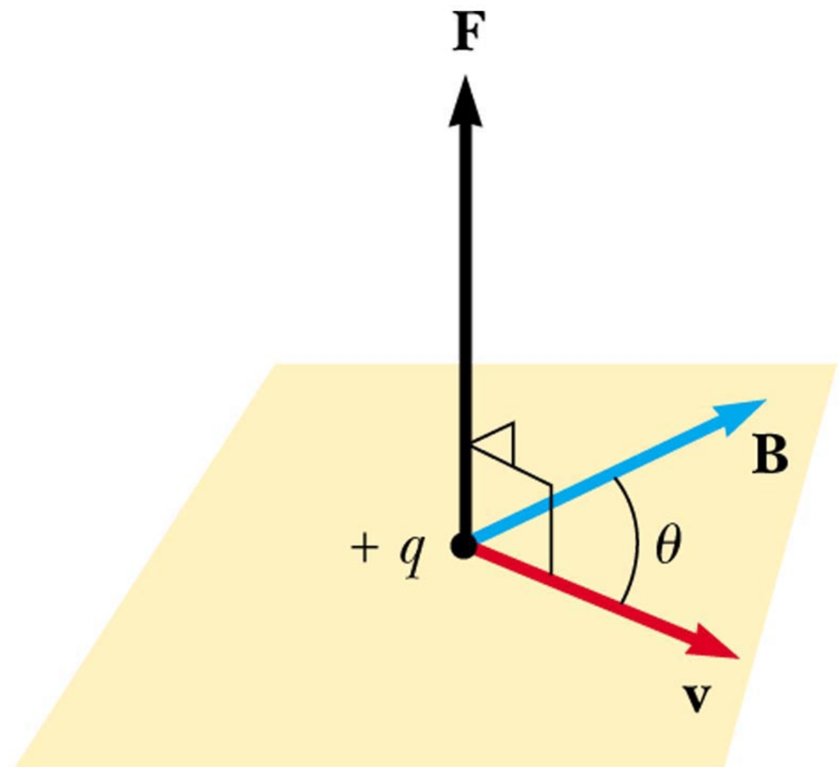
Magnets in ATLAS





Magnetic force

- $|F| = qvB \sin\theta$ gives the magnitude
- What about the direction?
- F is perpendicular to v and to B
- Which way?
    - right-hand rule



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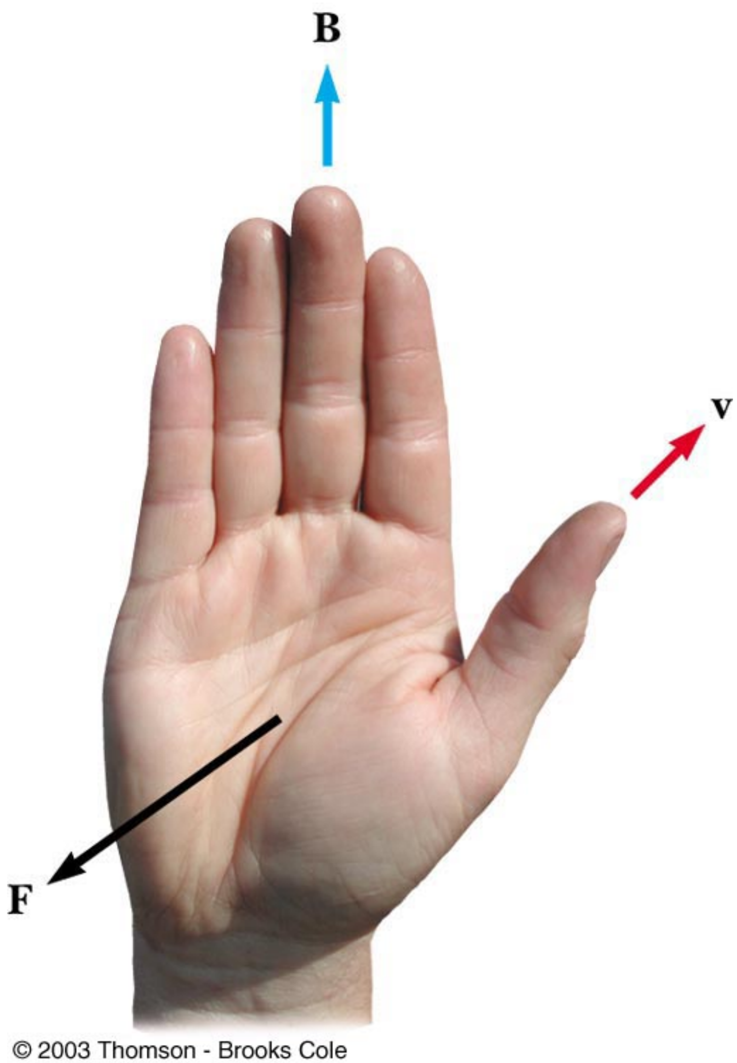
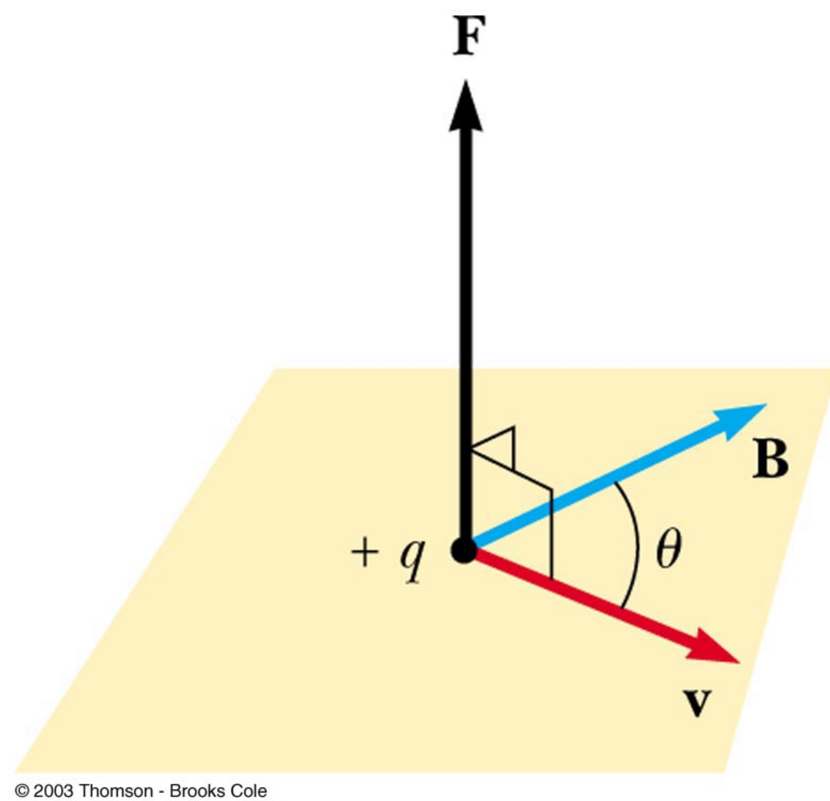
Talk to the hand

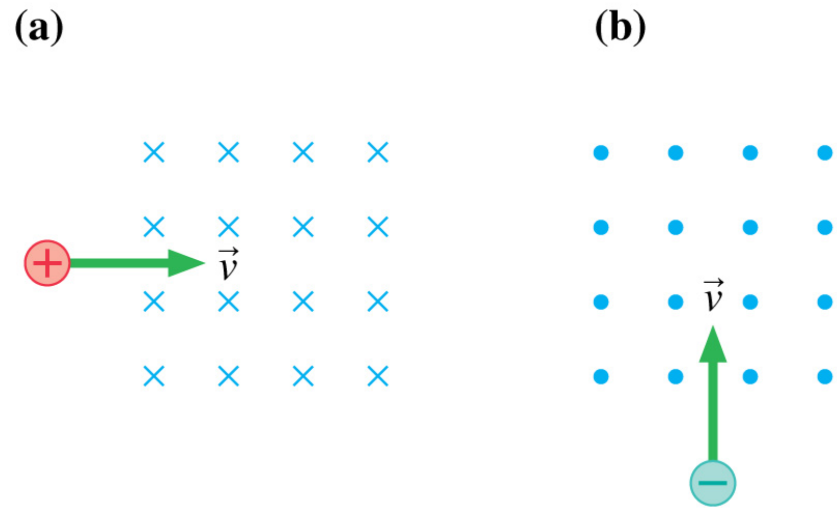


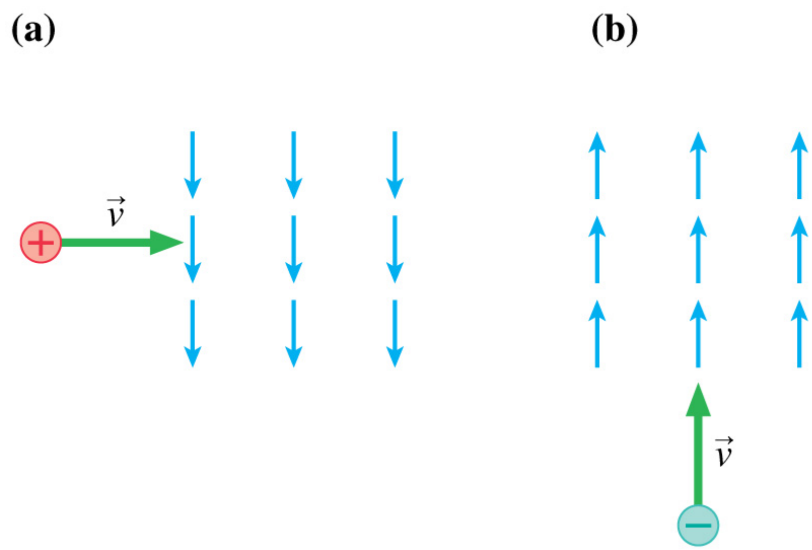


$$\vec{F} = q\vec{v}x\vec{B}$$

Examples

- What is the initial direction of deflection for the charged particles entering the magnetic fields shown to the right?

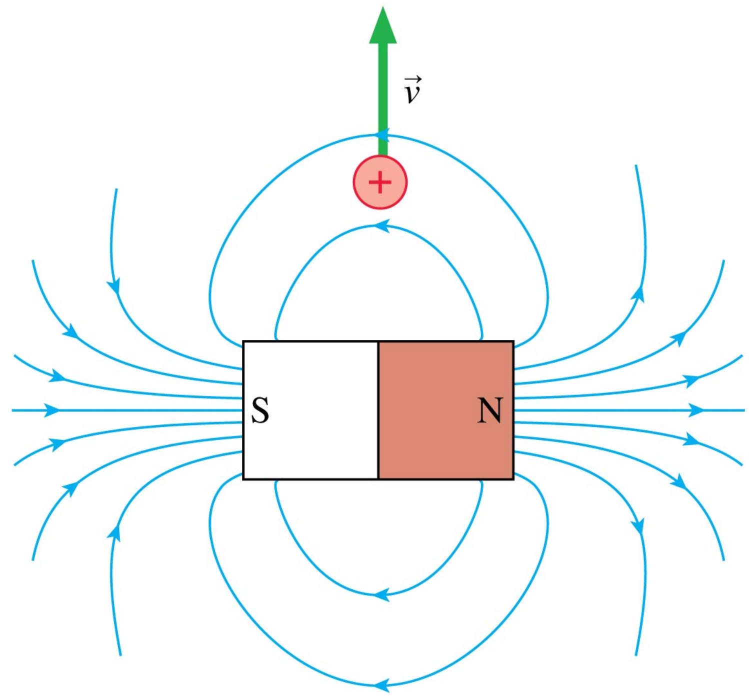




iclicker question

The direction of the magnetic force on the proton is

A. To the right.
B. To the left.
C. Into the screen.
D. Out of the screen.
E. The magnetic force is zero.



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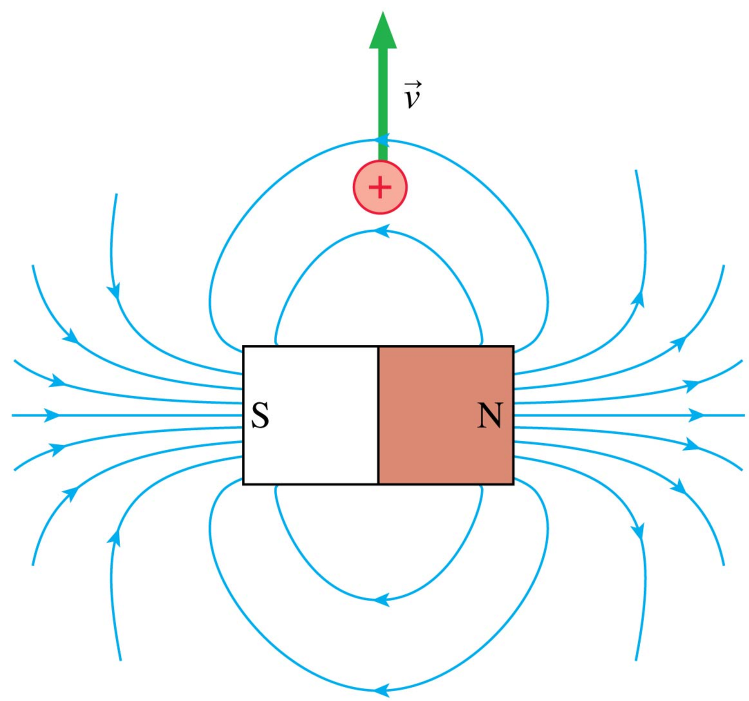
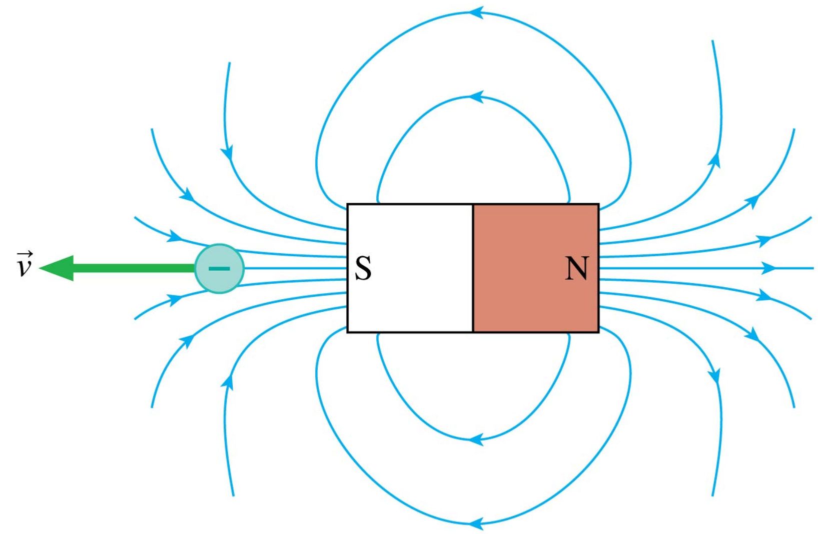


iclicker question

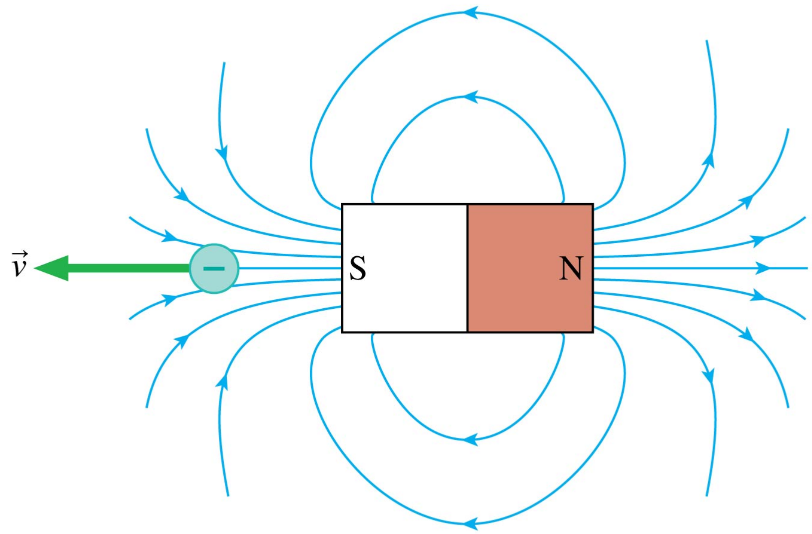
The direction of the magnetic force on the electron is

A. Upward.
B. Downward.
C. Into the screen.
D. Out of the screen.
E. The magnetic force is zero.



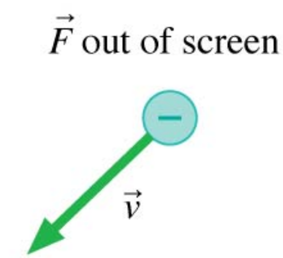
The direction of the magnetic force on the electron is

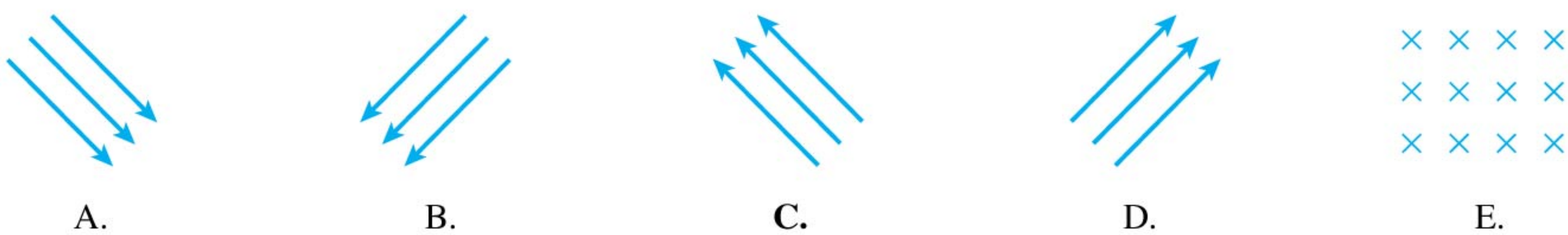
A. Upward.
B. Downward.
C. Into the screen.
D. Out of the screen.
E. The magnetic force is zero.



iclicker question

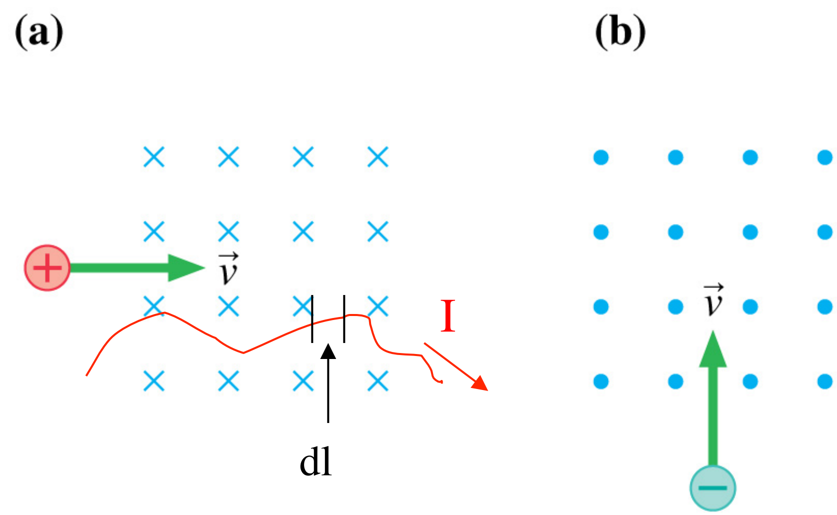
Which magnetic field causes the observed force?





Forces on currents

- An electric current is just a bunch of moving electric charges
- So there should be a force acting on an electric current moving in a magnetic field
- What direction?
- The direction that the magnetic force would be on a moving positive charge
- Consider the force on an element dl of a current-carrying wire
  - q=Idl



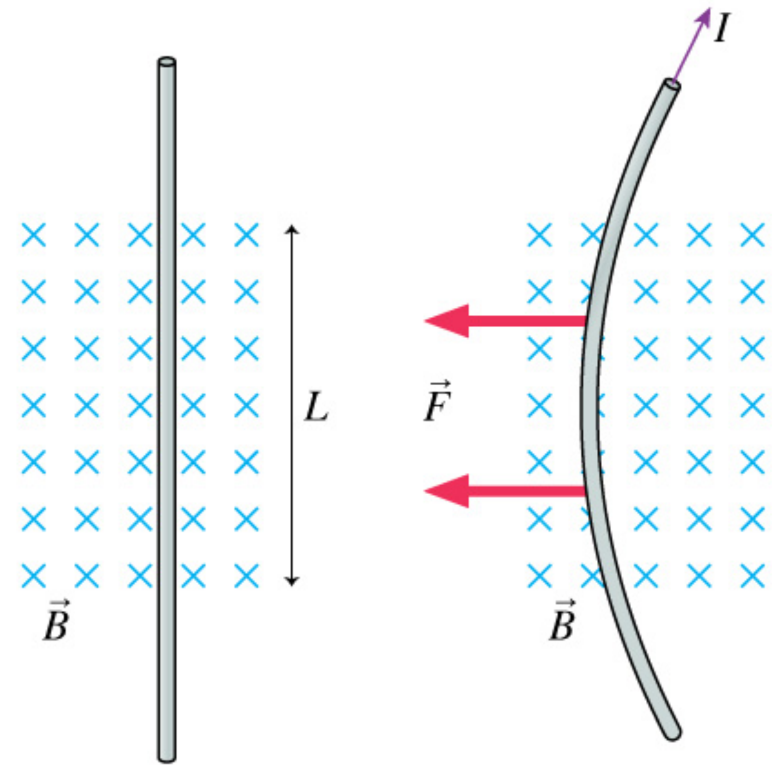
$$\vec{F} = q\vec{v}X\vec{B}$$

$$\vec{F} = Id\vec{l}X\vec{B}$$

…where $d\vec{l}$ has the direction of the current I

Force on a current

- Same direction as force on a positive charge moving in the direction of the current
- What if we realize that it's actually a current of electrons moving in the opposite direction?

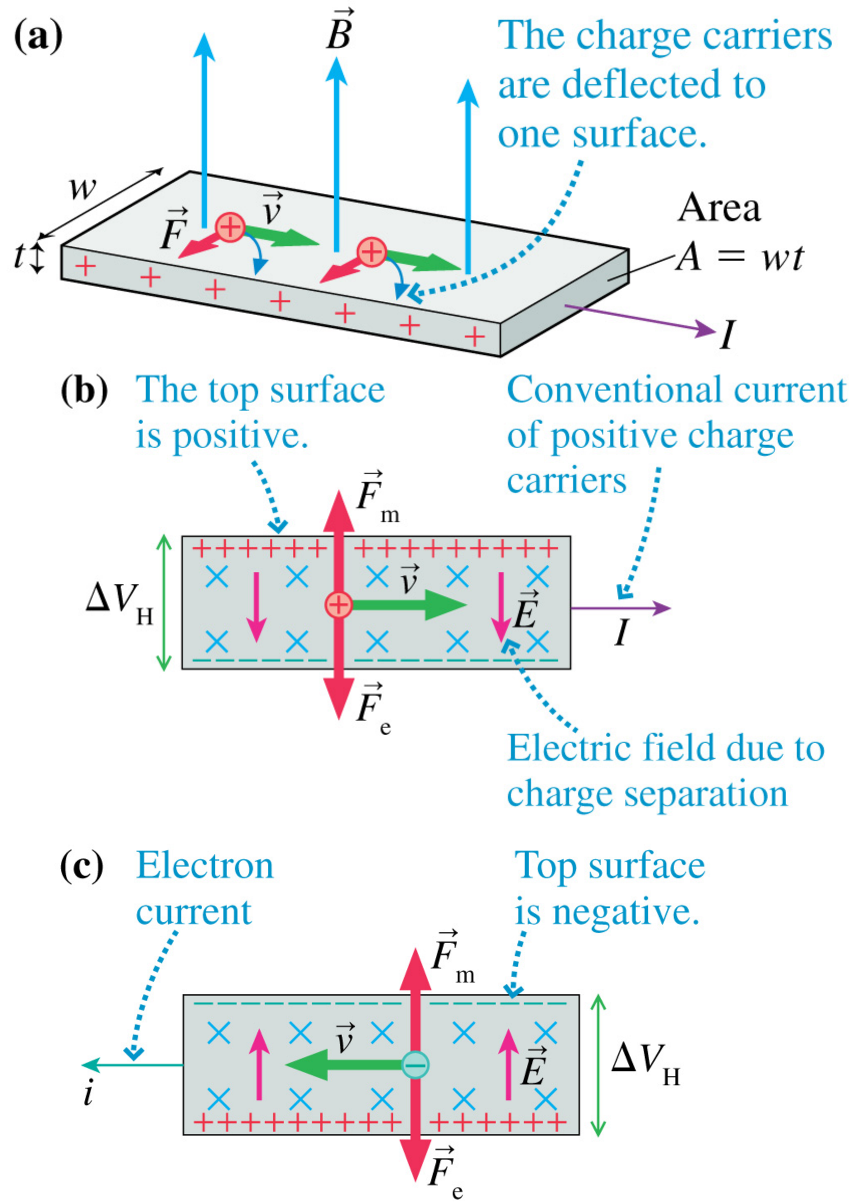


A wire is perpendicular to an externally created magnetic field.

A current through a wire that is fixed at the ends causes the wire to be bent sideways.

Hall effect

- Remember when I said it didn't matter that we assume that an electric current is the movement of positive charges (rather than the negatively charged electrons)
- Only a few ways you can tell the difference
- One way is the Hall effect
- Consider a current I in the direction indicated moving through a thin conductor
- Each charge in the current experiences a force equal to ev_dB, perpendicular to v and B
- This magnetic force causes a separation of charges so that one side of the conductor will be positive and one side negative
- Now it makes a difference whether the current is a flow of + charges to the right or - charges to the left



Hall effect

- The separation of charges creates an electric field that continues to build until the electric force cancels out the magnetic force (F_e=F_m)
- This creates a potential difference ΔV_H which can be measured (although it's small)
- When F_e=F_m

$$F_m = ev_d B = F_e = eE = e\frac{\Delta V}{w}$$

- The Hall voltage is

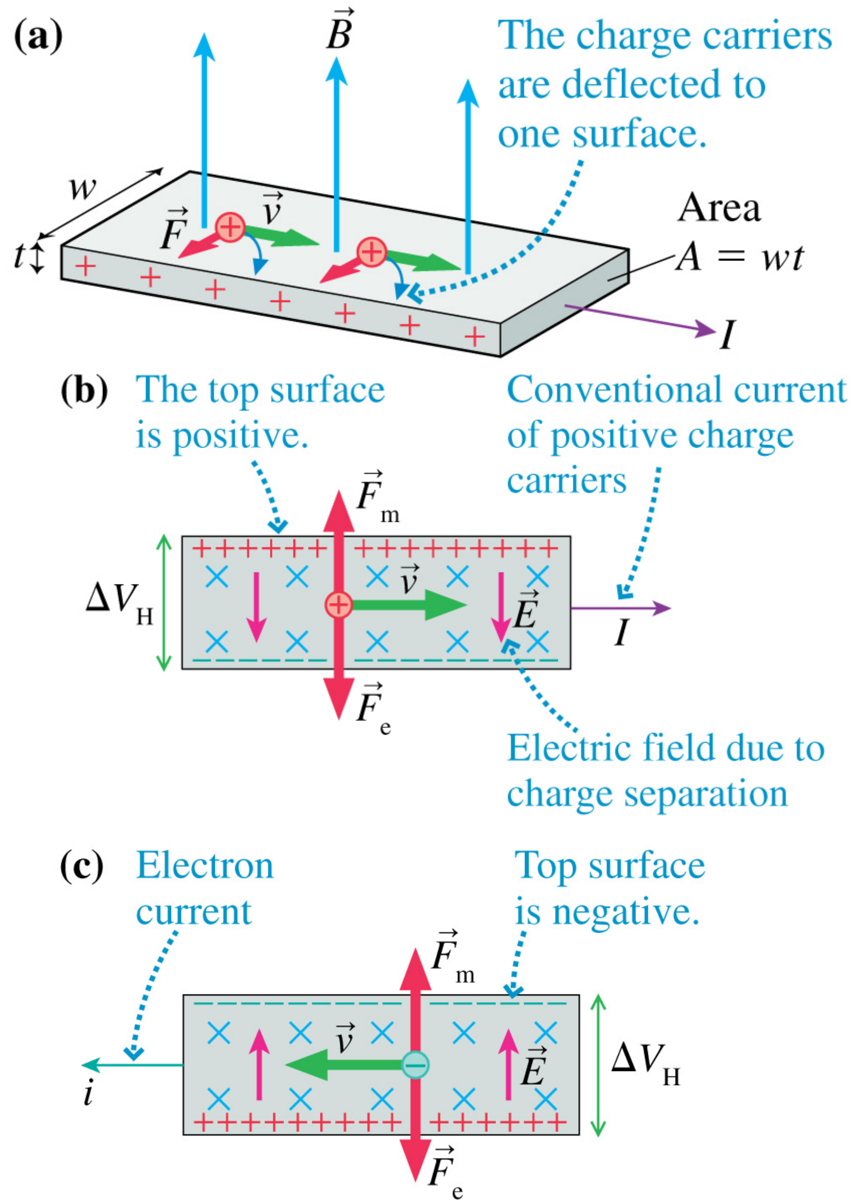
$$\Delta V_H = wv_d B$$

- Using the formula for v_d

$$v_d = \frac{I}{wtne}$$

- ΔV_H is

$$\Delta V_H = \frac{IB}{tne}$$



Forces between currents

- Now consider 2 current carrying wires separated by a distance r and carrying currents I_1 and I_2
- Current I_1 produces a magnetic field at the position of I_2 equal to

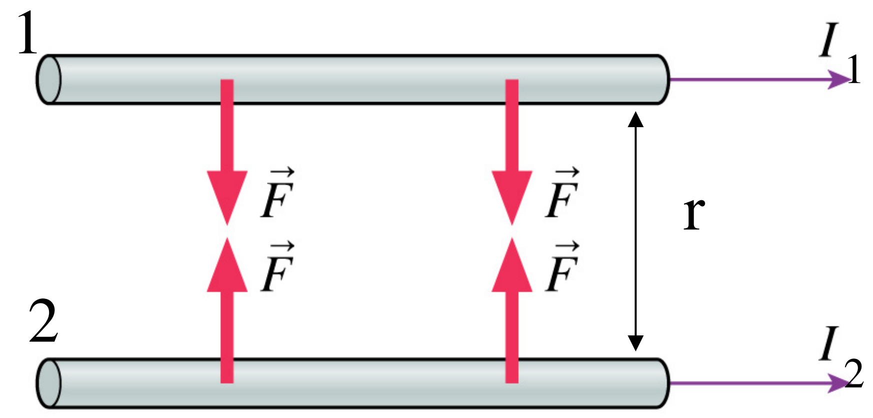
$$B_1 = \frac{\mu_o I_1}{2\pi r}$$

- A length l of current I_2 experiences a force given by

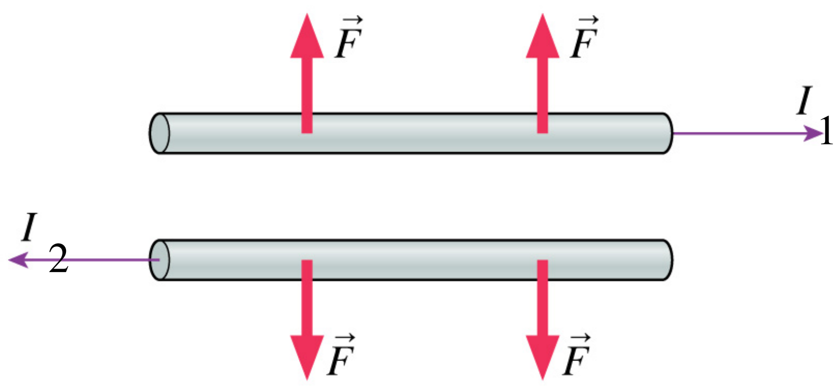
$$|\vec{F}_2| = I_2 l B_1 \sin\theta = I_2 l \frac{\mu_o I_1}{2\pi r}\sin\theta$$

$$|\vec{F}_2| = \frac{\mu_o}{2\pi}\frac{I_1 I_2 \sin\theta\, l}{2\pi r}$$

- What's the direction of the force?
  - given by RHR



"Like" currents attract.



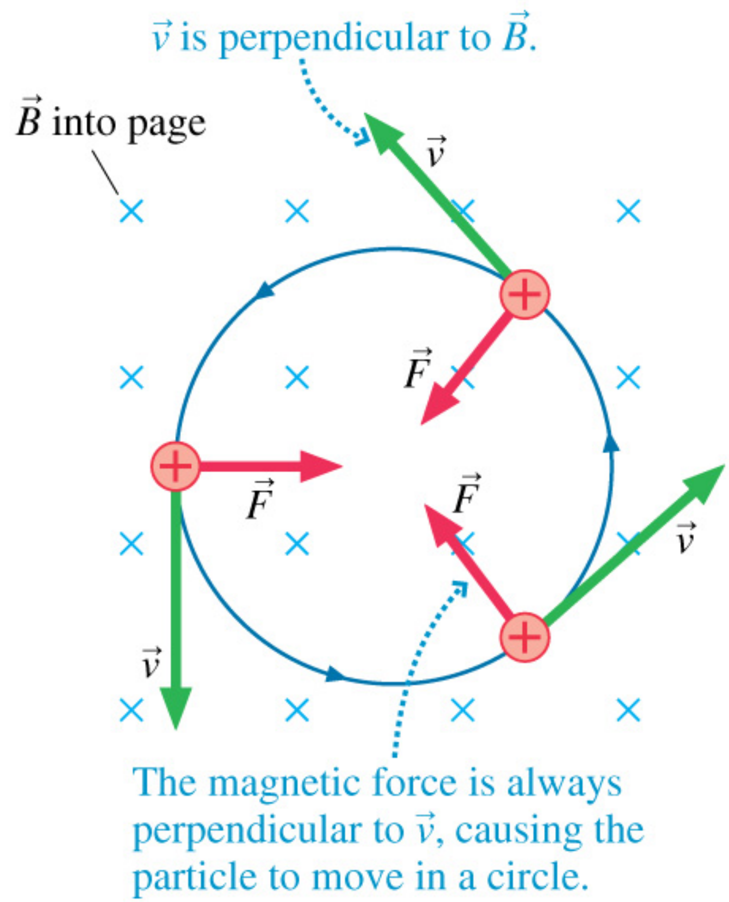
"Opposite" currents repel.

Force on a moving charge

- We' ve seen that the magnetic force acting on a moving electric charge is always perpendicular to the direction of motion
- A force that is always perpendicular to the motion changes the direction of motion but not the speed
- If I have a particle moving perpendicular to a uniform magnetic field, that particle will undergo uniform circular motion

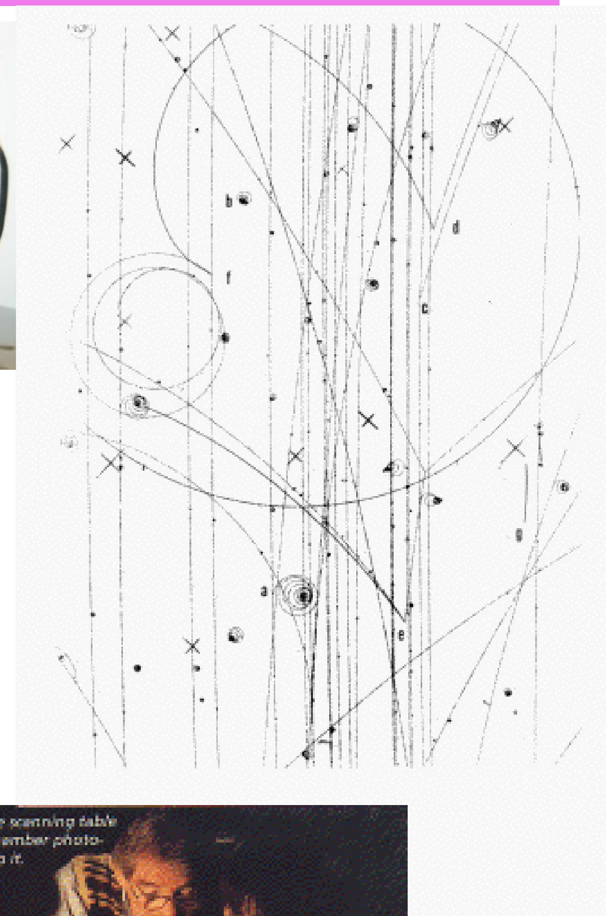
$$F_c = qvB = ma_r = \frac{mv^2}{r}$$

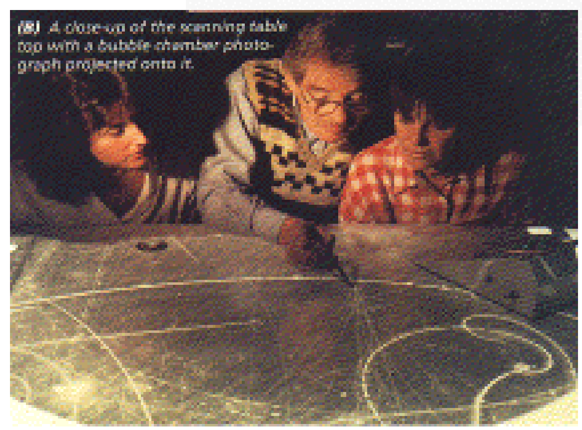
$$r = \frac{mv}{qB}$$

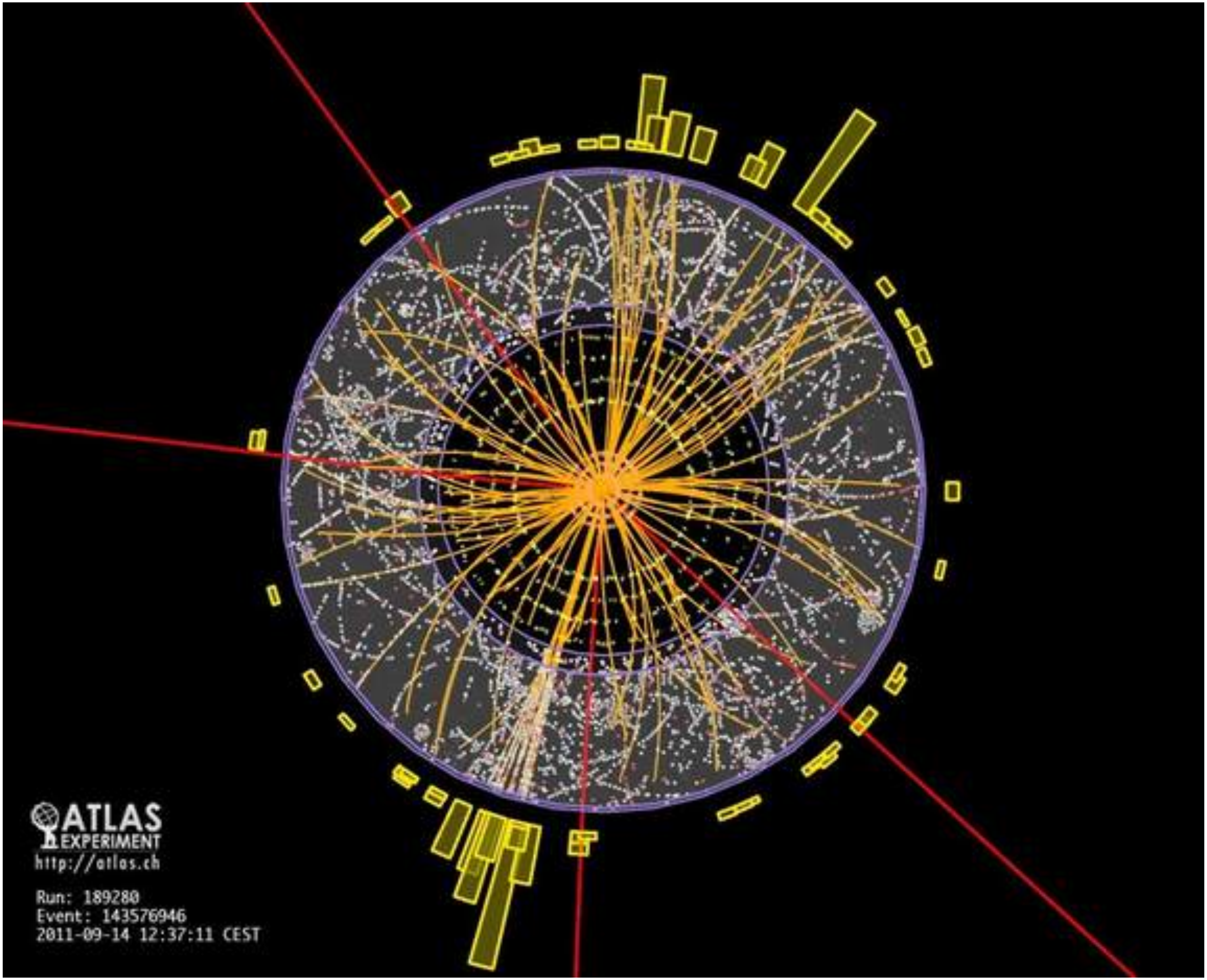


Bubble chambers

- Device formerly used in high energy physics experiments
  - invented by Donald Glaser who got the idea by staring at the bubbles in his glass of beer
- Charged particles interact in a boiling liquid (usually H_2) and leave tracks of bubbles
- Curvature in a magnetic field allows the determination of the particle momenta



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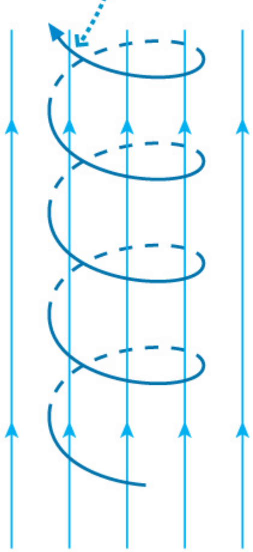
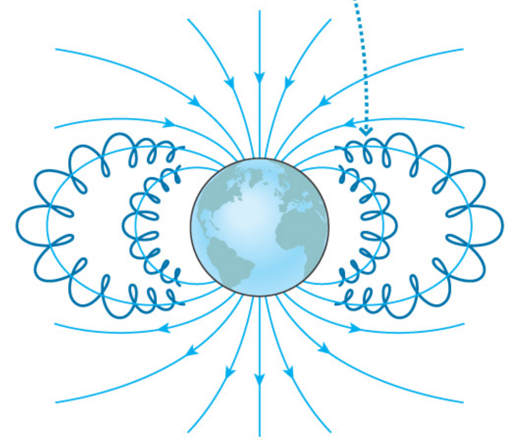
Force on a moving charge

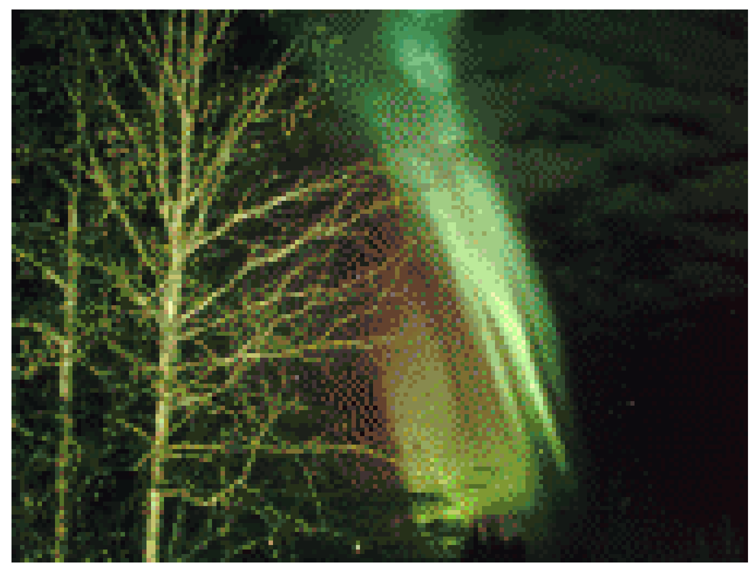
- What if the particle velocity is not exactly perpendicular to the direction of the magnetic field?
- It moves in a spiral

(a) Charged particles spiral around the magnetic field lines.



(b) The earth's magnetic field leads particles into the atmosphere near the poles, causing the aurora.



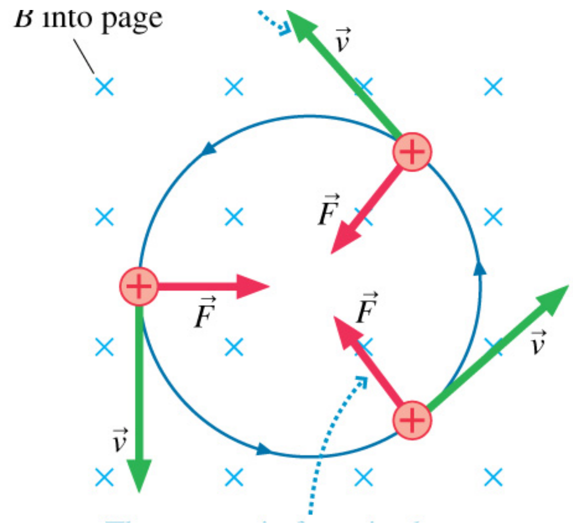


First cyclotron

- Consider the frequency with which a charged particle travels in a circle in a uniform magnetic field

$$f_{cyc} = \frac{v}{2\pi r} = \frac{qB\cancel{r}}{2\pi m\cancel{r}} = \frac{qB}{2\pi m}$$

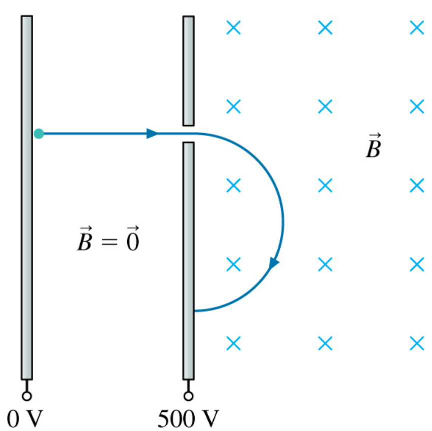
- Note that the r’s cancel out
- This first occurred to Ernest Lawrence in the late 20’s/early 30’s (in a bar) and he realized that it would make a cyclotron possible



first cyclotron

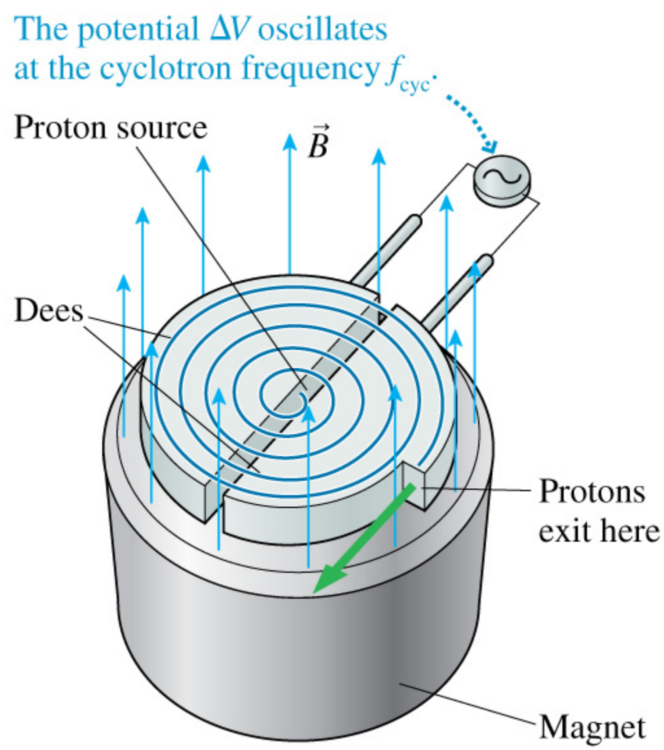
How a cyclotron works

- Suppose I accelerate a charged particle (a proton) through a potential difference of 500 V
- It then acquires a kinetic energy of $KE=\Delta U=qV=(1.6X10^{-19}C)(500V)=8X10^{-17}$ J
  - often easier to quote the energy gained as 500 eV (electron-volts)
- If it travels into a region of uniform magnetic field, it will travel a circular path of radius r



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

In a cyclotron, the potential oscillates in sign, so that when the protons emerge from the hollow conductors ("Dees"), they are accelerated towards the Dee on the opposite side. As p(=mv) increases, the radius r also increases (B is constant)



How a cyclotron works

- Suppose I have a 0.65 m cyclotron that uses a 500 V oscillating potential difference between the dees.
  - what is the maximum kinetic energy of a proton if the magnetic field strength is 0.75 T?
  - how many revolutions does the proton make before leaving the cyclotron?

In a cyclotron, the potential oscillates in sign, so that when the protons emerge from the hollow conductors ("Dees"), they are accelerated towards the Dee on the opposite side. As p(=mv) increases, the radius r also increases (B is constant)