CHAPTER 29:
Magnetic Fields and Sources

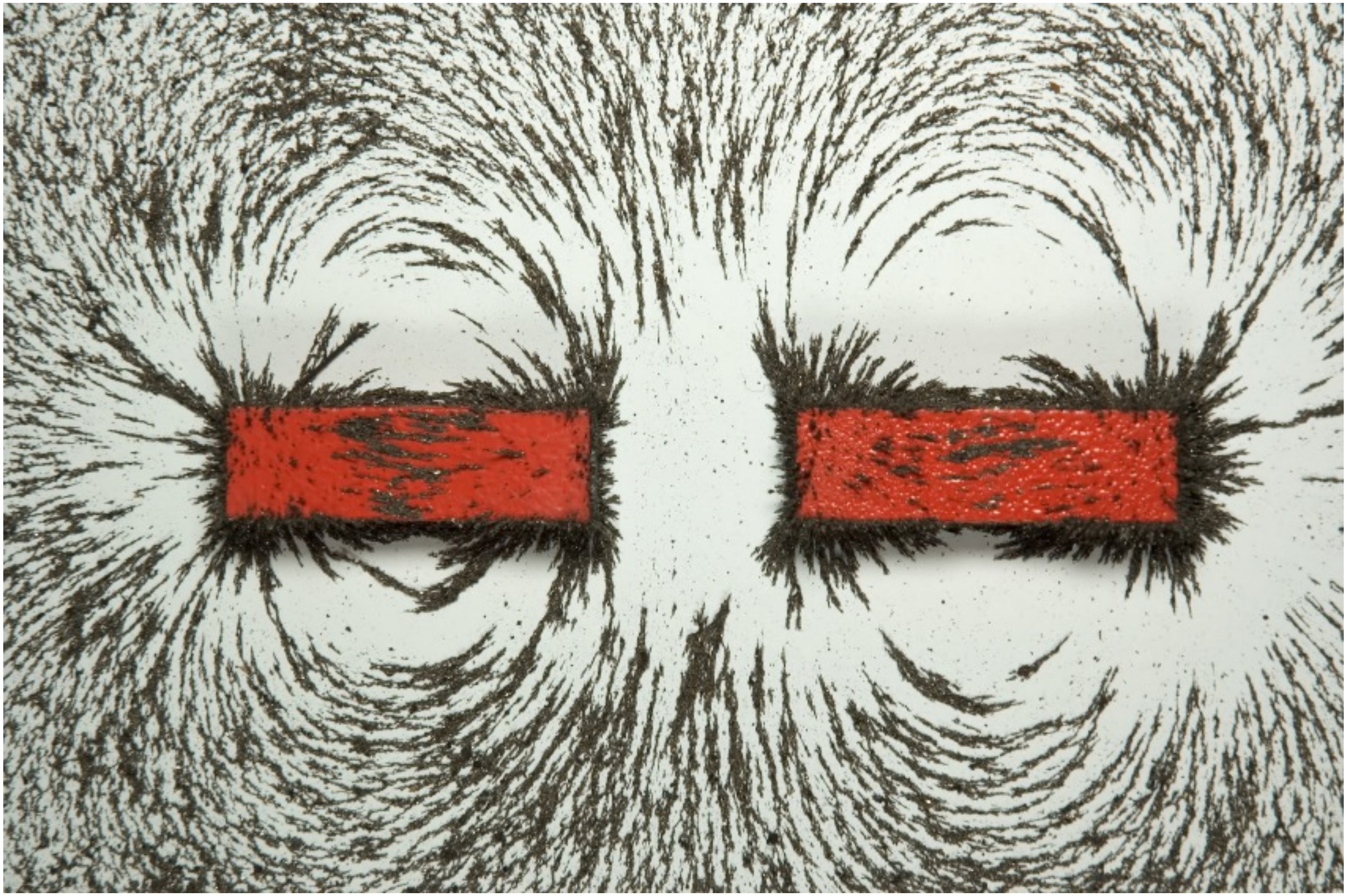


photo courtesy of
Mr. White

Relativity and Magnetism

--Newton's Classical Mechanics demands that the speed of light depend upon the relative motion between the *frame of reference* of the light source and the observer's frame (think of about a passing car's speed on the freeway—how fast it passes you depends upon how fast *you* are going).

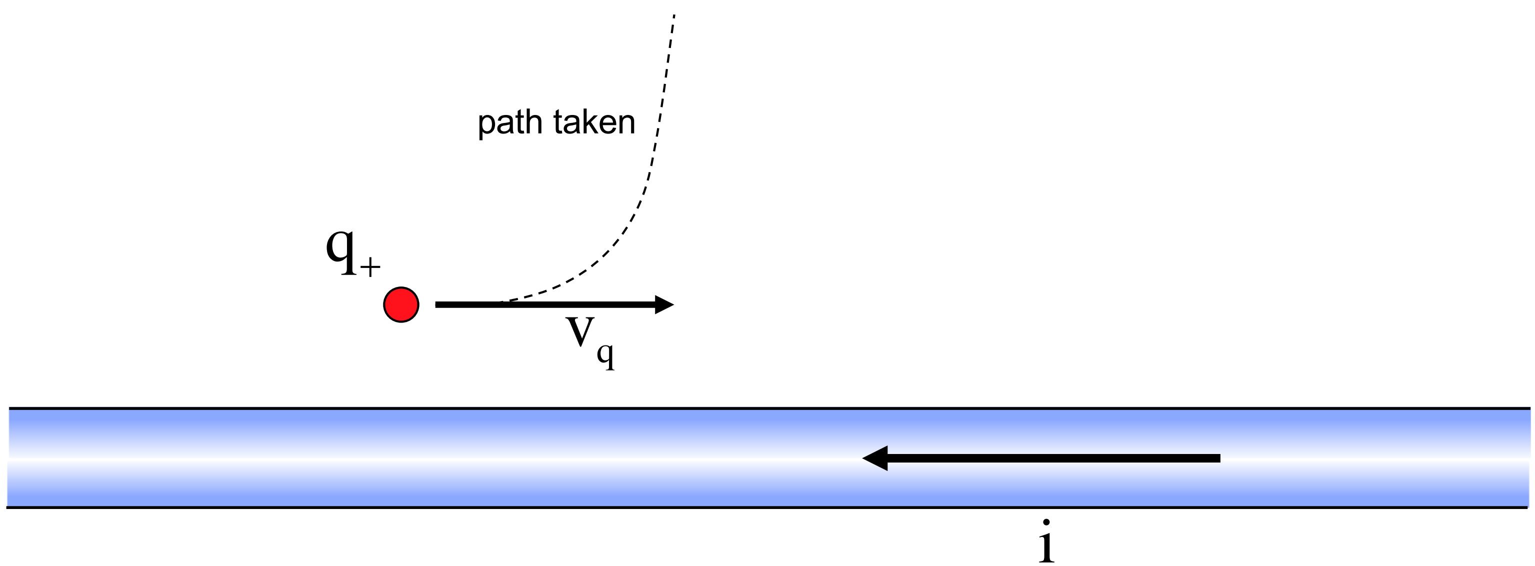
--Yet because alternating magnetic fields (B-flds) induce electric fields (E-flds), and alternating E-flds induce B-flds, the only way an alternating E-fld can coupled with an alternating B-fld to produce an electromagnetic wave (i.e., a wave in which the alternating E-fld feeds the B-fld and the alternating B-fld feeds the E-fld), is if, according to Maxwell's equations, the wave's velocity is 3×10^{8} m/s, *the speed of light*.

--You can't have it both ways. The *speed of light* is either frame-of-reference dependent alla Newton, or it's a fixed value independent of frame-of-reference alla Maxwell.

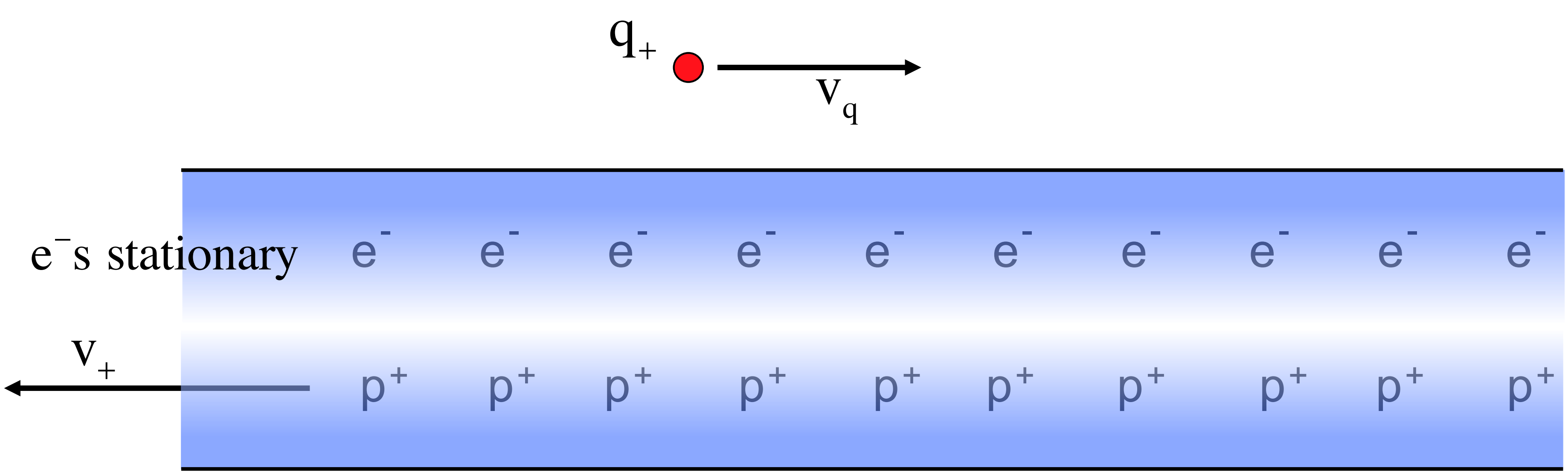
--This conundrum is what motivated Einstein to develop his Theory of Special Relativity, a form of Mechanics that assume that the speed of light is the same in all frames of reference.

--One of the stranger characteristics of *Special Relativity* is that if you have an object that is approaching at relativistic speeds, it will *length contract*. And, in fact, this length contraction phenomenon will occur even at classical speeds (though observing it at classical speeds is difficult).

--With this in mind, consider a wire with conventional current flowing through it (i.e., assume positive charge flow). If you fire a positive charge opposite the direction of current flow, an interesting thing is observed. The charge will feel a force that motivates it to veer away from the wire. So what's going on?

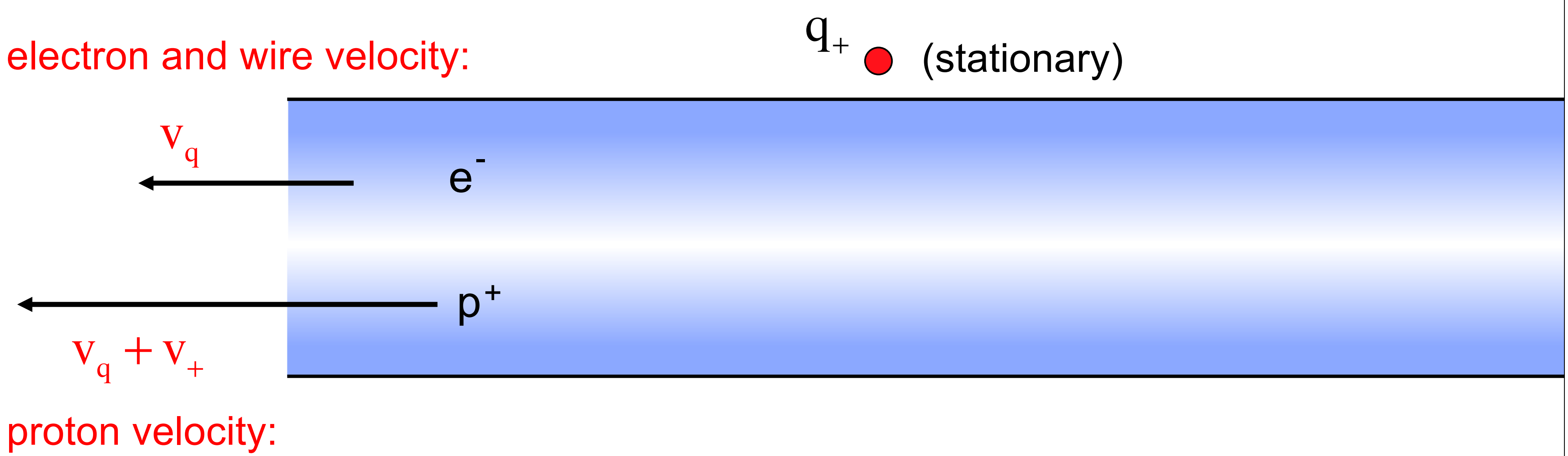


As positive charge carriers move onto the wire (with electrons assumed stationary), an equal number of positive charge carriers move off the wire. That means the number of positive and negative charge stays even throughout time, the wire stays electrically neutral, and there's no good reason for the moving test charge to feel a force. But it does. This led early theorists to conclude that there must be a force, a *magnetic* force, affecting the moving charge . . . except that isn't what's really happening here. To see this, we have to look at the situation through the perspective of the moving charge q_+.

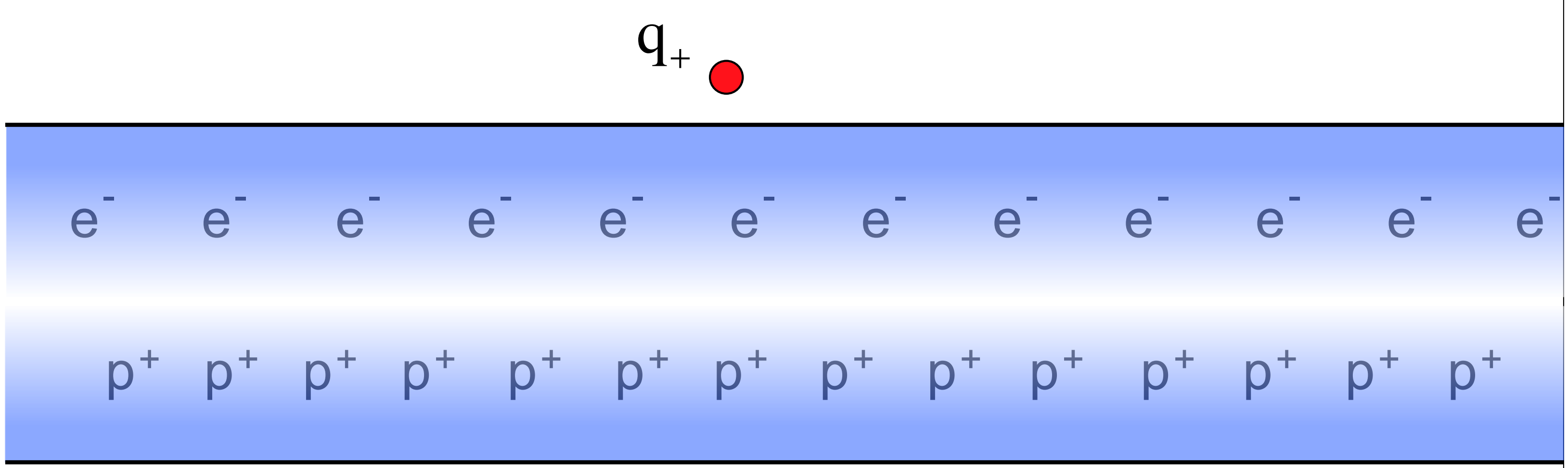


assume velocity of positive charge is v_+

In the frame of reference attached to q_+ , q_+ is not moving. What's more, as far as q_+ is concerned, both the electrons and the wire are seen to be moving to the left with velocity v_q , and the protons are seen to be moving to the left with velocity $v_q + v_+$. The sketch below show all of this.

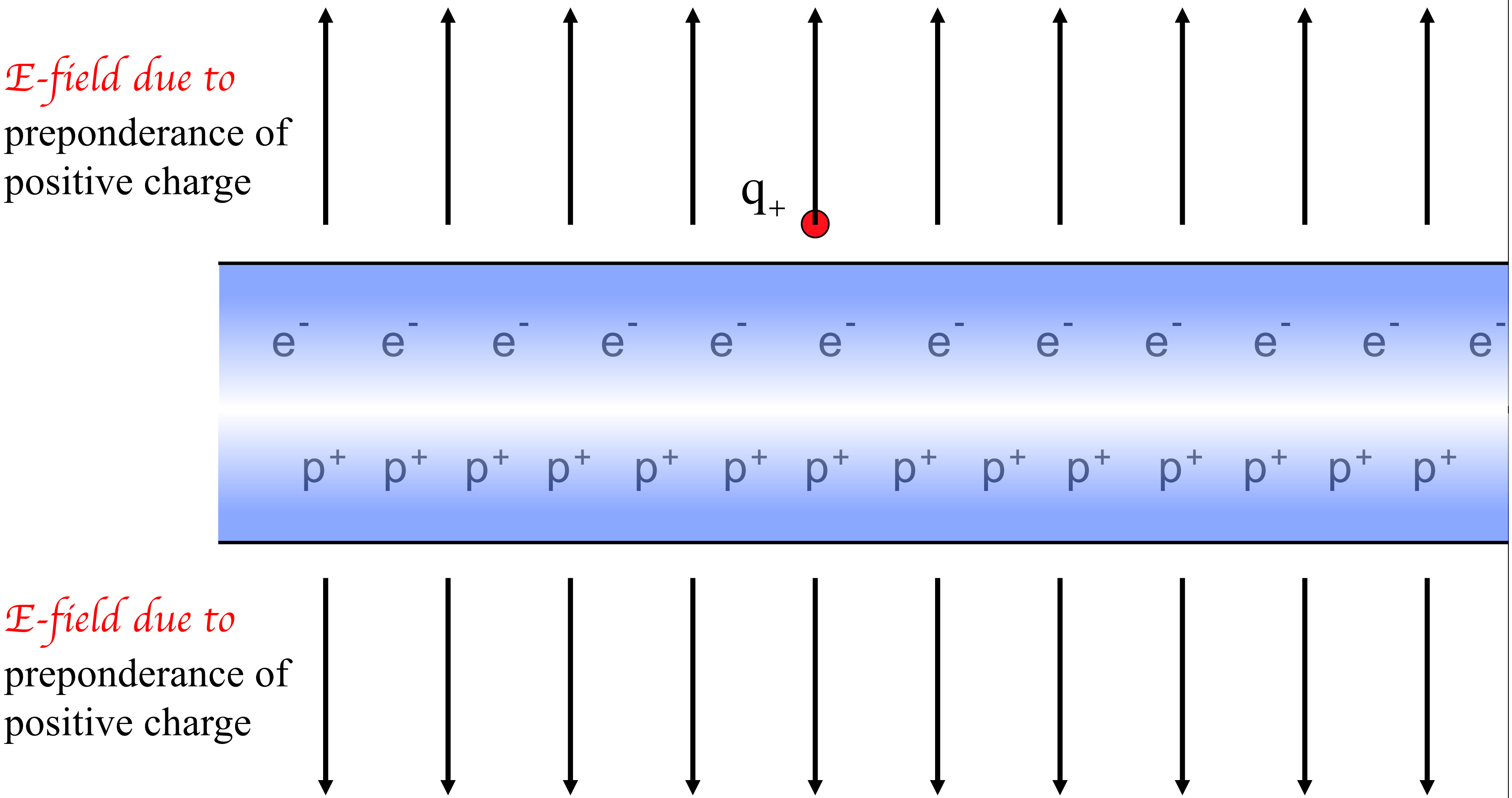


What's important to notice here is that because the *protons are moving faster than the electrons*, they will *length contract* more than will the electrons. When they do so, from the moving charge's perspective, there appears to be more protons on the wire than electrons.



Protons length contract more than electrons. More protons means the wire looks electrically positive and an electric field is set up pointing outward from the wire.

With more protons apparently on the wire, there is an electric field generated emanating outward from the wire. It is that electric field that the q_+ responds to.



In short, what was described by early researchers as a MAGNETIC EFFECT was (and is) really a RELATIVISTIC EFFECT.

Still, the Classical Theory of Magnetism is a good theory in the everyday world (just as is the case with Newtonian Mechanics), so that's what you will be spending the next several weeks learning.

General Information

Electric Fields

--electric fields (abbreviated as *E-flds*), with units of *newtons per coulomb* or *volt per meter*, are modified force fields (release a charge in an E-fld and it will accelerate);

--electric fields are generated with the presence of charge;

--an electric field's direction is defined as the *direction a positive charge will accelerate if released in the field*;

--electric field lines:

- *--go from* positive to negative charge;
- *--identify* the E-fld's direction in a region;
- *--are closer together* where E-flds are more intense;

Magnetic Fields

--magnetic fields (abbreviated as *B-flds*), with units of *teslas* in the *MKS system*, are NOT modified force fields (release a charge in a B-fld and it will just sit there);

--magnetic forces do exist when a charge moves through a B-fld—they are centripetal and are governed by the relationship: $\vec{F} = q\vec{v}x\vec{B}$

--B-fields are generated by charge in motion;

--a B-field's direction is defined as the *direction a compass points when placed in the field*;

--magnetic field lines:

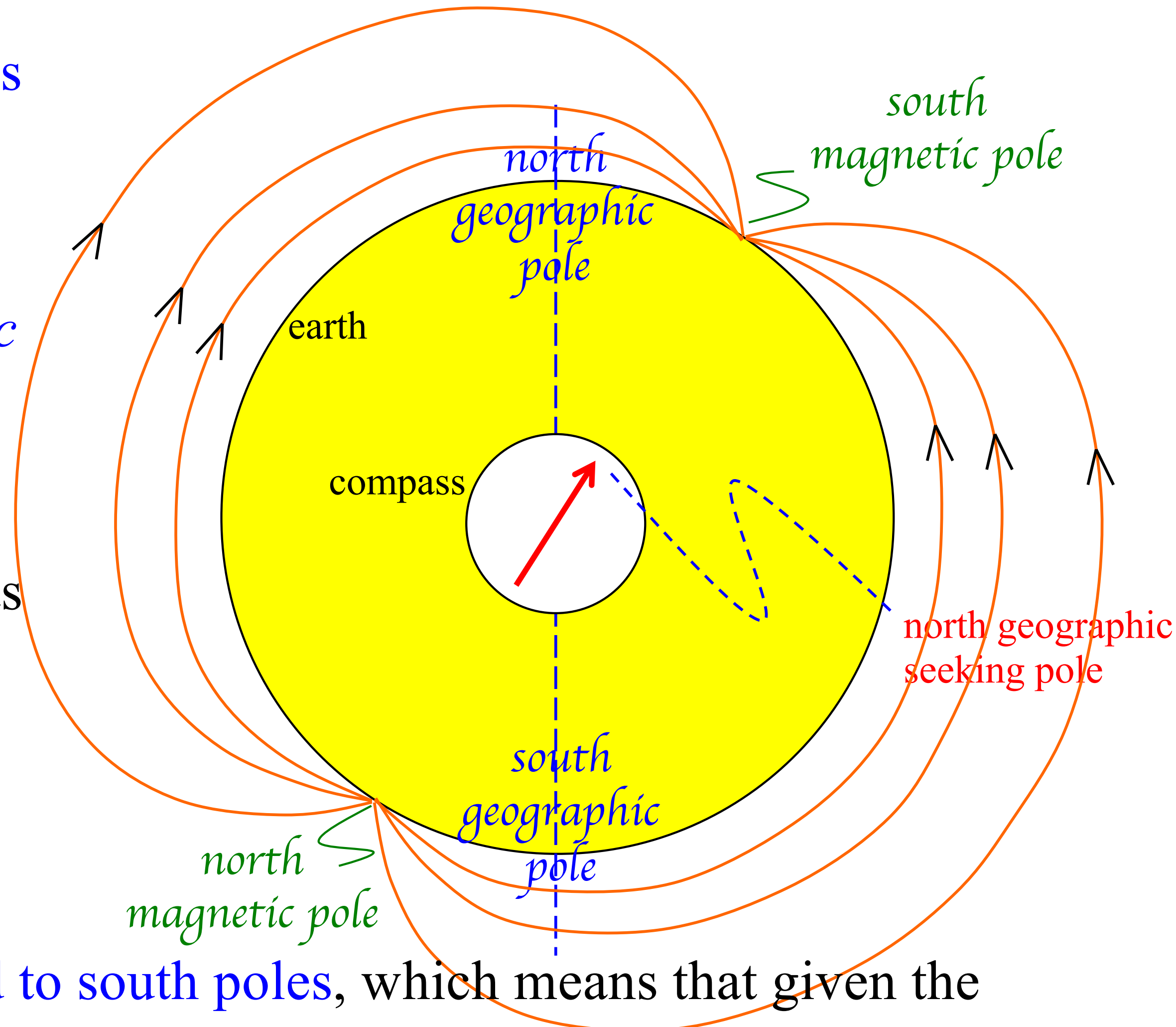
- *--go from* north to south pole, or circle around current carrying wire;
- *--identify* the B-fld's direction in a region;
- *--are closer together* where B-flds are more intense;

Terminology and the Compass

Place a compass in the earth's magnetic field.

The compass end that originally pointed toward the *north geographic hemisphere* was called *the north geographic seeking magnetic pole*.

With time, the word *geographic* was dropped leaving *the north seeking magnetic pole,* and with even more time, the *seeking and magnetic* was dropped leaving us with *north pole*.



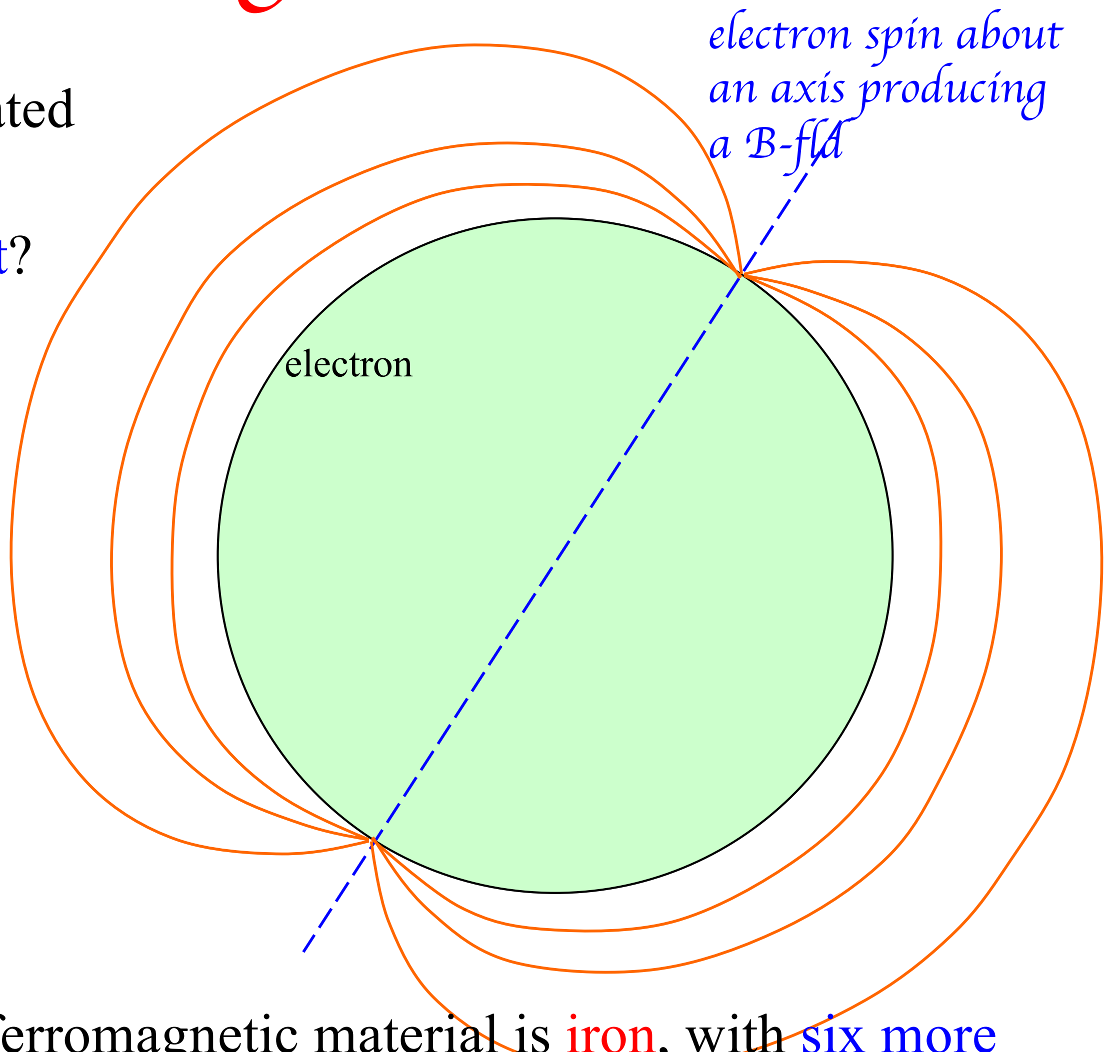
Problem is, north poles are attracted to south poles, which means that given the definition, there must be a south magnetic pole in the north geographic hemisphere. Not very esthetically pleasing, but that's life (and it'll switch directions in another 200,000 or so years due to slow oscillatory patterns in the earth's magma).

Bar Magnets

If magnetic fields are generated by *charge in motion*, where is the motion associated with a bar magnet?

An atom's spin quantum number highlights the fact that electrons spin up or down, depending.

In most atoms, approximately the same number of electrons spin in one direction as the other, but in certain atoms (the ferromagnetic ones), they spin considerably more in one direction than the other.



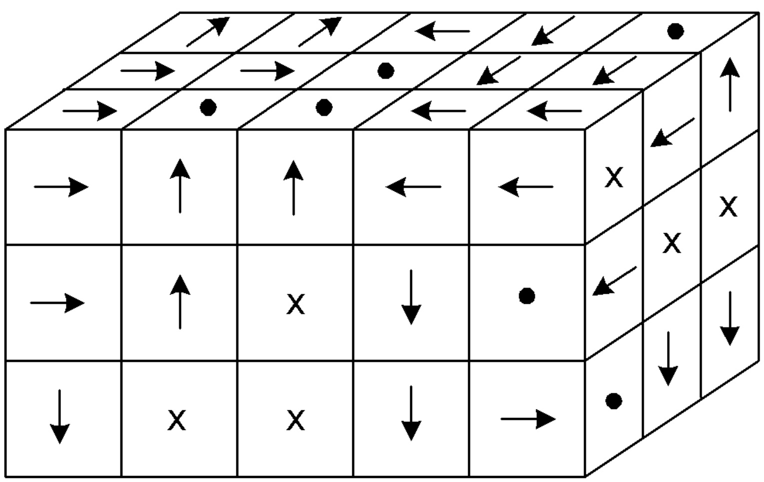
The most prominent example of a ferromagnetic material is iron, with six more electrons spinning in one direction than the other. As such, EACH *IRON* ATOM IS A MINI-MAGNET UNTO ITSELF.

So how can a piece of iron *be magnetic under some conditions* and not under other conditions (there are, after all, iron nails that do not exhibit magnetic characteristics at all). (The explanation is called *Ampere's Theory of Magnetism*.)

Enter the magnetic domain. What happens is this: Atoms within irregular, microscopic regions, called domains, align themselves so that all of their magnetic fields are in the same direction.

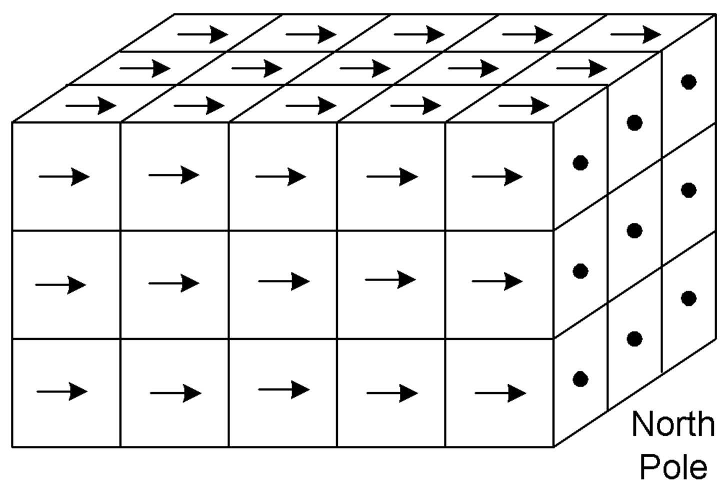
When the domains are themselves aligned, the material acts like a magnet. When the domains are NOT aligned, the *net magnetic effect is lost* (in some cases, all that is needed to de-magnetize a magnetic is to have thermal agitation shake the domains out of alignment). In any case, the first sketch below is without alignment, the second with alignment.

domains unaligned (not realistic rendering)



domains aligned

sketches courtesy of Mr. White



3 Types of Magnetism

Ferromagnetism - material has a permanent "magnetic moment," due to microscopic "domains" in which moments are aligned.

Paramagnetism - materials has a small magnetic susceptibility, that only becomes evident when placed in an external magnetic field.

Diamagnetism - material does not have permanent magnetic moments. In the presence of an external magnetic field, a weak magnetic moment is induced in a direction opposite to the external field.

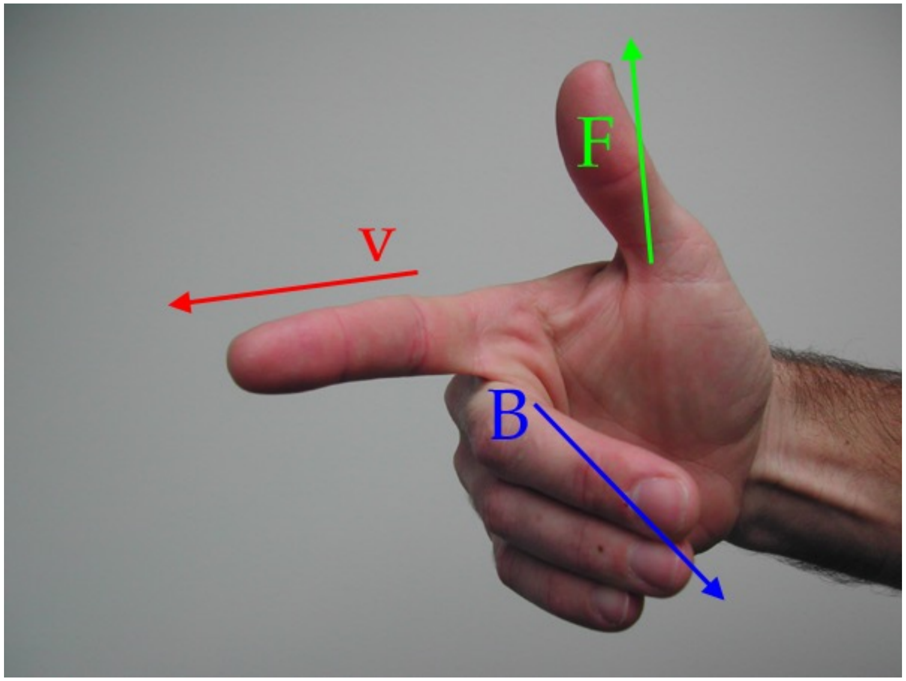
Magnetic Force

When charge moves through a magnetic field, it may or may not feel a force, depending upon its motion. If present, that force will be:

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

The magnitude is $|\vec{F}| = q|\vec{v}||\vec{B}| \sin\theta$, where *q* is the size of the charge, $|\vec{v}|$ is the magnitude of the velocity vector, $|\vec{B}|$ is the magnitude of the magnetic field and θ is the angle between the line of the two vectors.

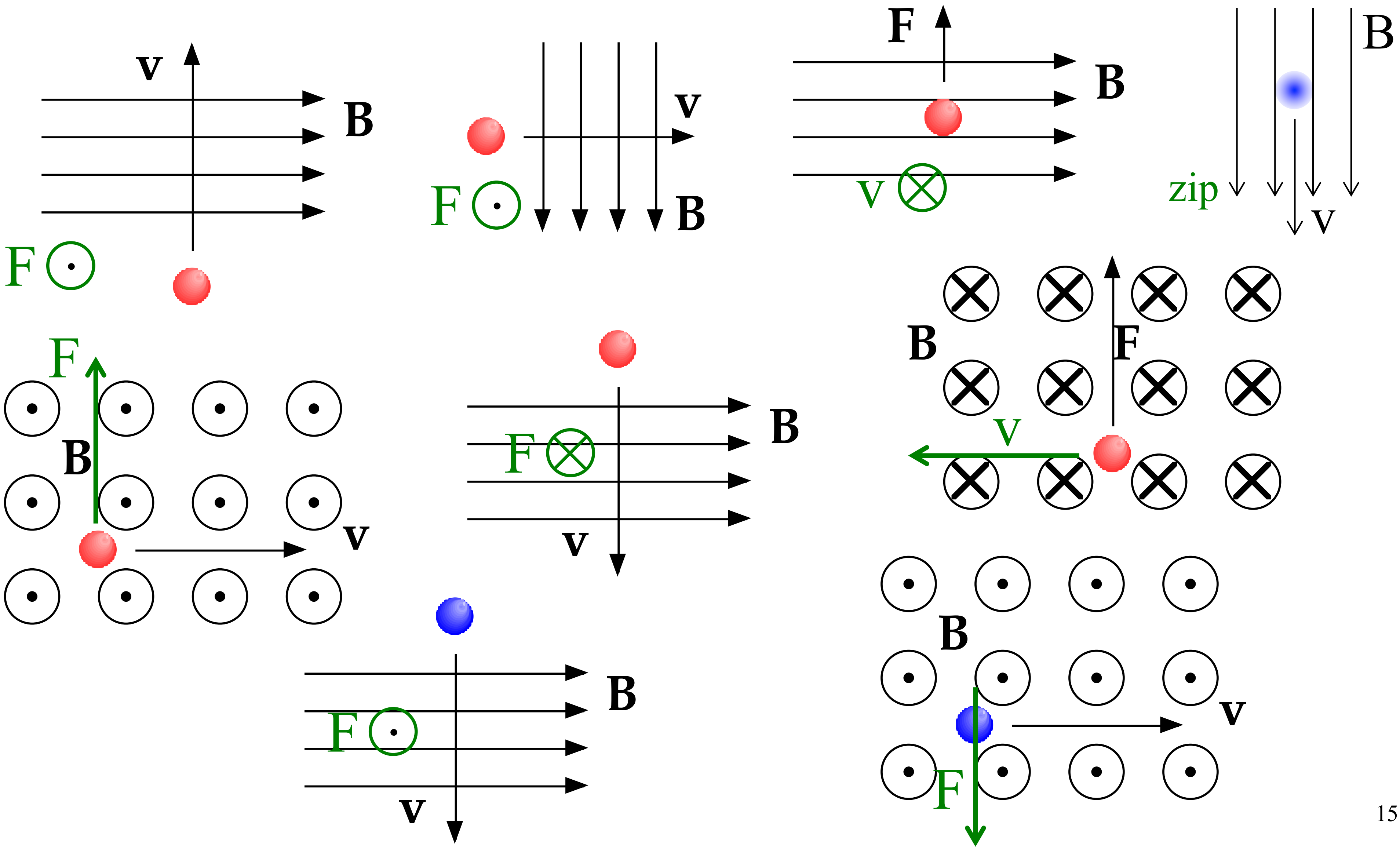
The direction is determined using the *right-hand rule*.



sketch courtesy of Mr. White

Example 1: (courtesy of Mr. White)

Identify the missing vector in these diagrams. Assume red signifies negative charges, blue positive charges. The responses are in green



Fine Print for $\vec{F} = q\vec{v}x\vec{B}$

The right-hand-rule determine the direction of force for a *positive charge*.

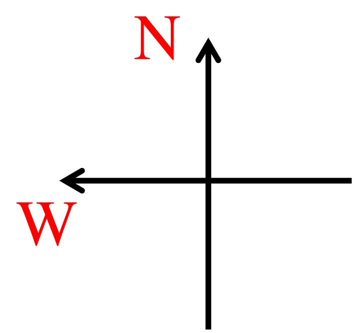
Magnetic forces are *centripetal forces* acting *perpendicular* to magnetic fields (whereas electric forces act along electric fields). That means magnetic forces DO NO WORK on charges that feel their effect.

Magnetic forces are experience only by charges in motion.

Example 2: *A proton* moving upward with speed $5x10^6$ m/s in a magnetic field feels a force of $8x10^{-14}$ N to the west. When moving horizontally to the north, it feels no force. Find the magnitude and direction of the magnetic field in this region. (courtesy of Mr. White)

Because no force is felt when the proton is moving *northward,* the magnetic field must either be toward the north or the south.

Reverse engineering the *right-hand-rule* suggests if the field is to the north*, the velocity vector would have to be *out of the page* to generate a force to the *west,* with a magnitude of:



$$F = qv\vec{B}\sin 90^\circ$$

$$\Rightarrow \quad B = \frac{F}{qv}$$

$$= \frac{\left(8x10^{-14}\,N\right)}{\left(1.6x10^{-19}\,C\right)\left(5x10^{6}\,m/s\right)}$$

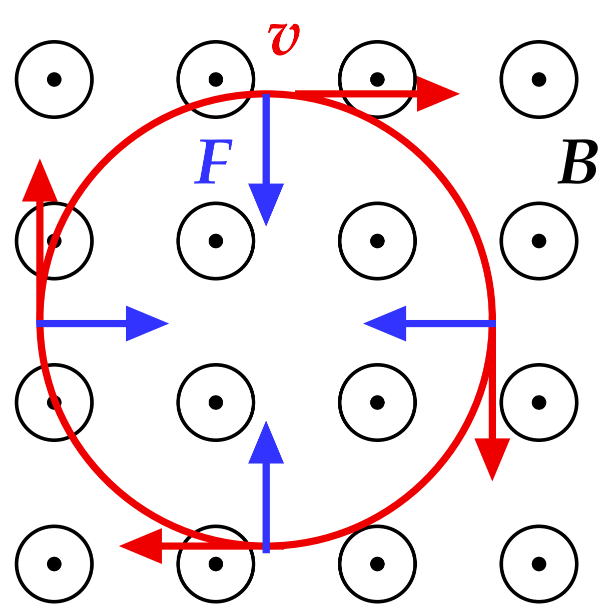
$$\Rightarrow \quad = 10^{-1}\ T$$

**Note that if* the field was to the south, the velocity vector would be *into the page*.

Example 3: A charge q of mass *m* is moving with constant velocity *v* at right angles to a magnetic field *B*. (idea courtesy of Mr. White)

a.) What kind of motion will it execute?

Because magnetic forces are centripetal, the mass will follow a circular path.



b.) What is the radius of the motion's path?

$$\sum F_{cent}:$$

$$q\vec{v}x\vec{B} = m\vec{a}_{cent}$$

$$\Rightarrow \quad qvB\sin 90^{o} = m\frac{v^2}{R}$$

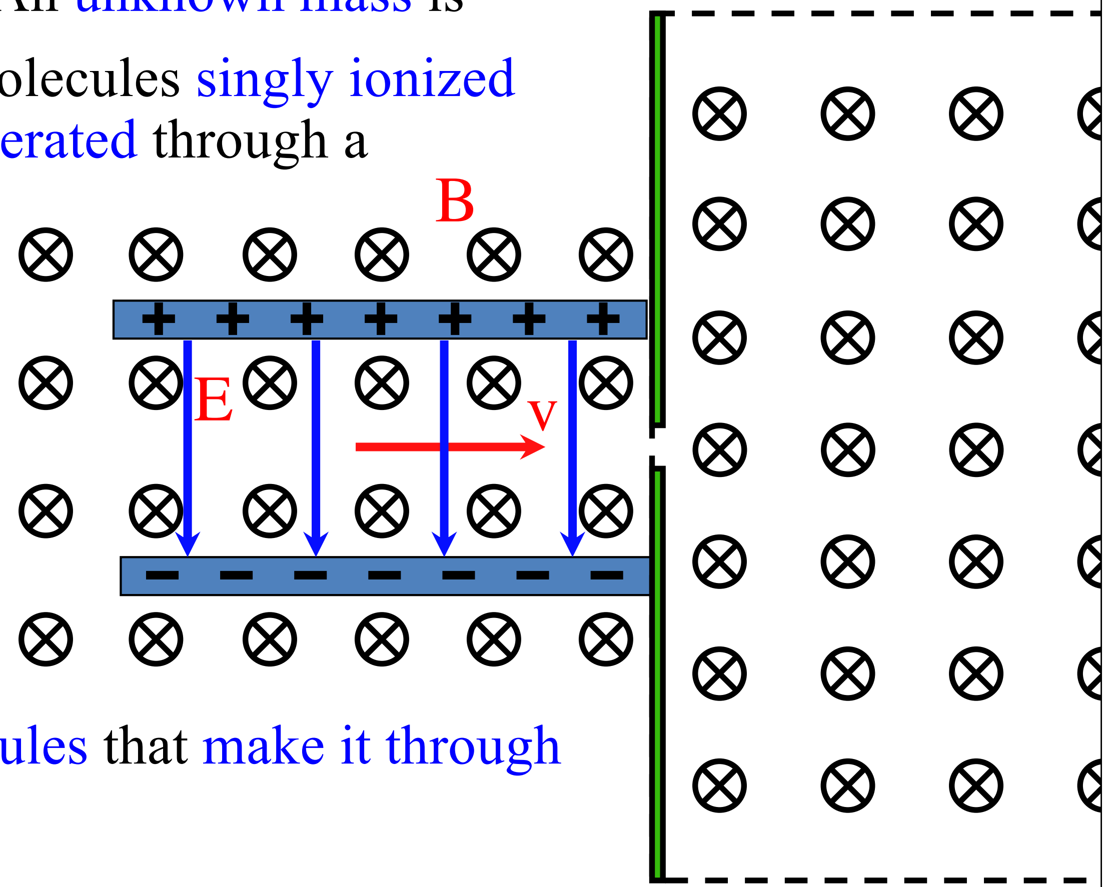
$$\Rightarrow \quad R = \frac{mv}{qB}$$

Lorentz Relationship

When both magnetic and electric forces act, the relationship looks like:

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

Example 5 (mass spectrometer): An unknown mass is volatalizes (made into a gas), had its molecules singly ionized (had one electron stripped away), accelerated through a potential difference to give them velocity, and sent through a velocity trap made up of a 95,000 V/m *E-fld* and a .93 teslas *B-fld*. The molecules that make it through the trap move into a region in which there is only the *B-fld*.



a.) What is the *velocity* of the molecules that make it through the trap?

$$qE = qvB$$

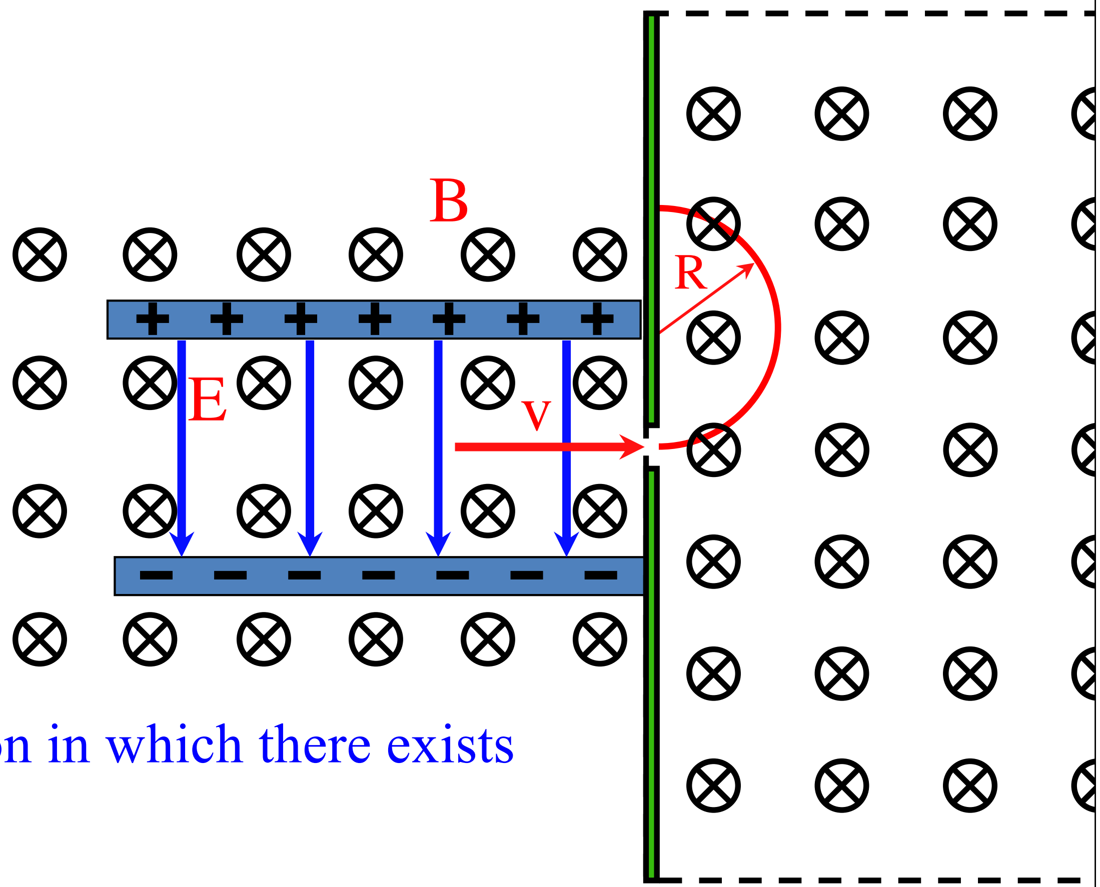
$$\Rightarrow \quad v = \frac{E}{B} = \frac{9.5\text{x}10^4 \ \text{V}/\text{m}}{.93 \text{ T}}$$

$$= 1.02\text{x}10^5 \text{ m/s}$$

b.) Draw in the path of the molecules in the far right chamber.

They will circle upward.

c.) If the radius of the arc is observed to be .0667 meters, what was the mass of the particle (that's what these devices are designed to do—determine the mass of an unknown material from which the identification of the material can be had). In the region in which there exists only a B-fld:



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

$$\Rightarrow \quad m = \frac{qBR}{v} = \frac{(1.6x10^{-19}\,C)(.93\ T)(6.67x10^{-2}\ m)}{(1.02x10^{5}\ m/s)}$$

$$= 9.7x10^{-26}\ kg$$

(This is the molecular weight of table salt.)

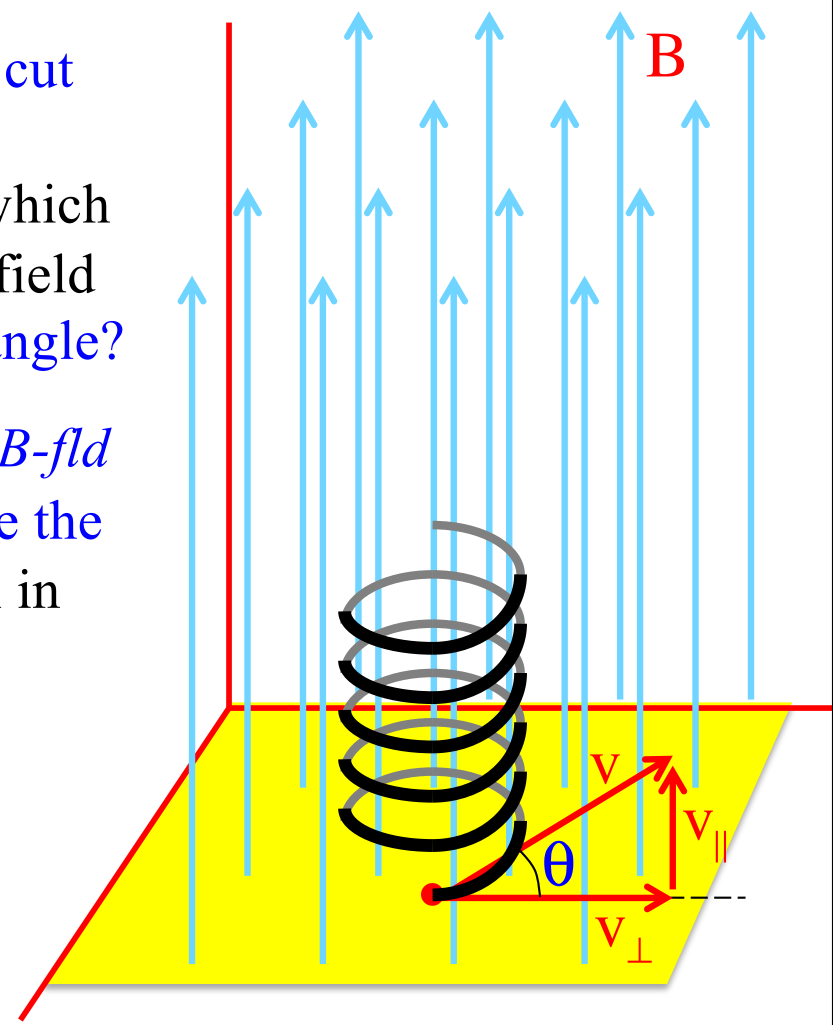
Point of Order

Magnetic forces exist on charges moving through magnetic fields ONLY when the charges cut across magnetic field lines. Until now, the only examples we've viewed have been situations in which the charges have cut across at right-angles to the field lines. What happens when they cut across at an angle?

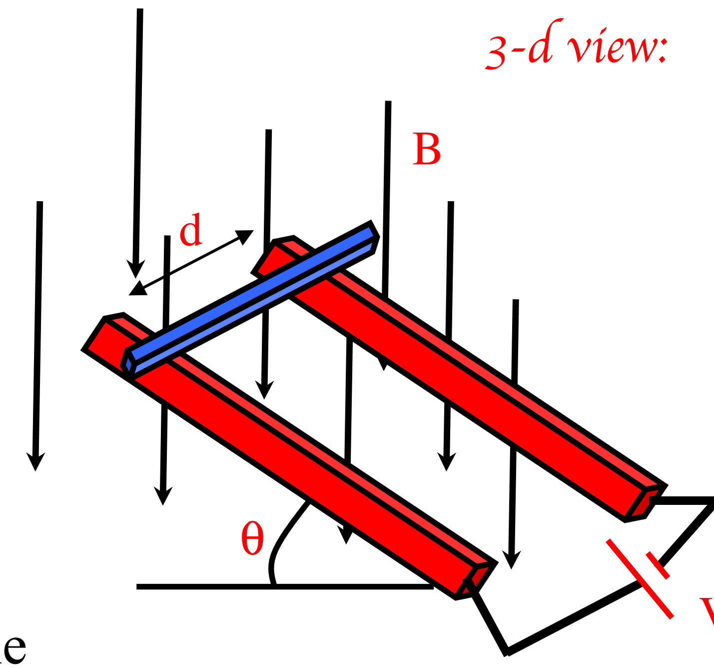
--*The velocity component* perpendicular to the *B-fld* will generate a magnetic force that will motivate the charge to circle (magnetic forces *are* centripetal in nature);

--*The parallel component* will simply provide momentum for the charge to continue to move in that *parallel* direction.

--*The net effect* is that the charge will helix along the *B-fld* lines.

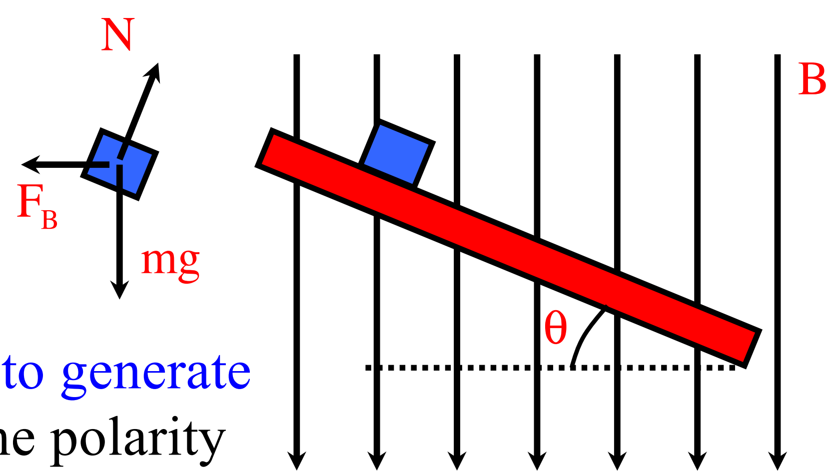


Example 8: Two metal ramps (in red) at an angle θ are *d* units apart and are bathed in a downward *B-fld*. A battery wire is connected to each ramp making a circuit. A metal rod would slide frictionless down the ramp if it were not for the magnetic force provided by the *B-fld*. In fact, in this case the rod is motionless. Assuming the net resistance of the system is *R*:



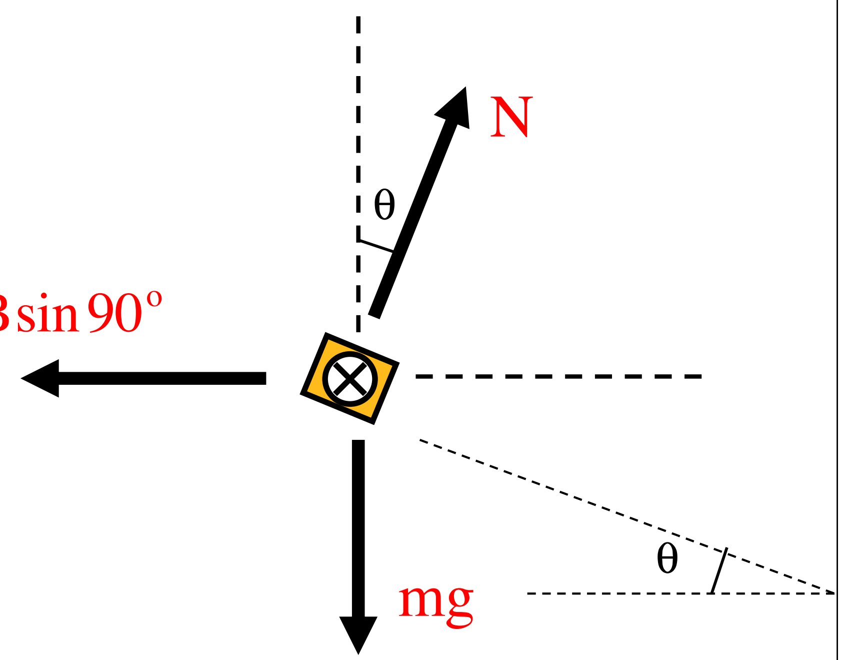
a.) What must the polarity of the battery be if the rod is to stay stationary on the ramp (again, assume the rod is frictionless).

For equilibrium, you can see from observation that you need a component of the magnetic force *to the left* to counter the component of gravity *to the right*. Reverse engineering $\vec{F} = i\vec{L}x\vec{B}$ yields the need for a current *into the page* to generate a magnetic force in that direction . . . So the polarity of the battery must be high-side on left.



b.) How big must the battery voltage be to effect this situation?

Doing a f.d.b. and breaking the forces into components, we can determine *i*:



$$\sum F_y :$$

$$-mg + N\cos\theta = 0$$

$$\Rightarrow \quad N = \frac{mg}{\cos\theta}$$

$$\sum F_x :$$

$$-i\,d\,B + N\sin\theta = 0$$

$$\Rightarrow \quad i = \frac{N\sin\theta}{dB}$$

$$\Rightarrow \quad i = \frac{\left(mg/\cos\theta\right)\sin\theta}{dB}$$

$$\Rightarrow \quad i = \frac{mg\tan\theta}{dB}$$

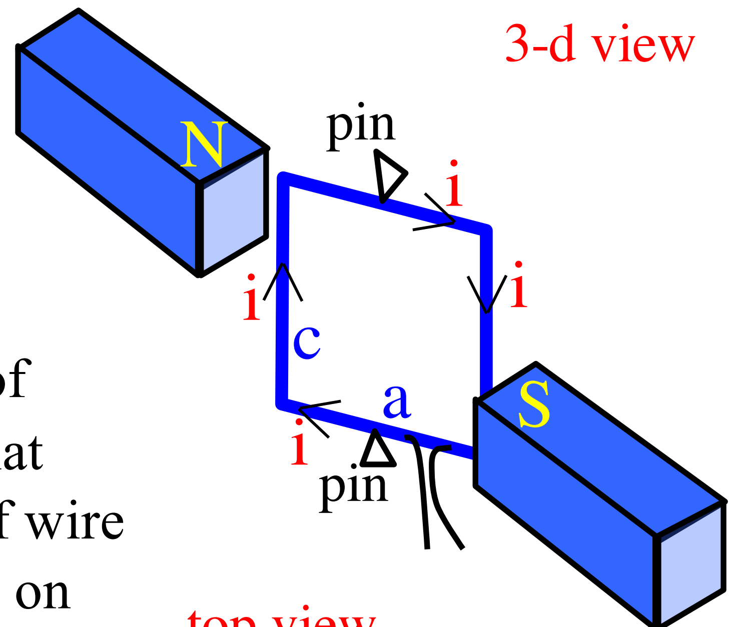
From Ohm's Law:

$$V = iR$$

$$= \left(\frac{mg\tan\theta}{dB}\right)R$$

Show and Tell—the Galvanometer

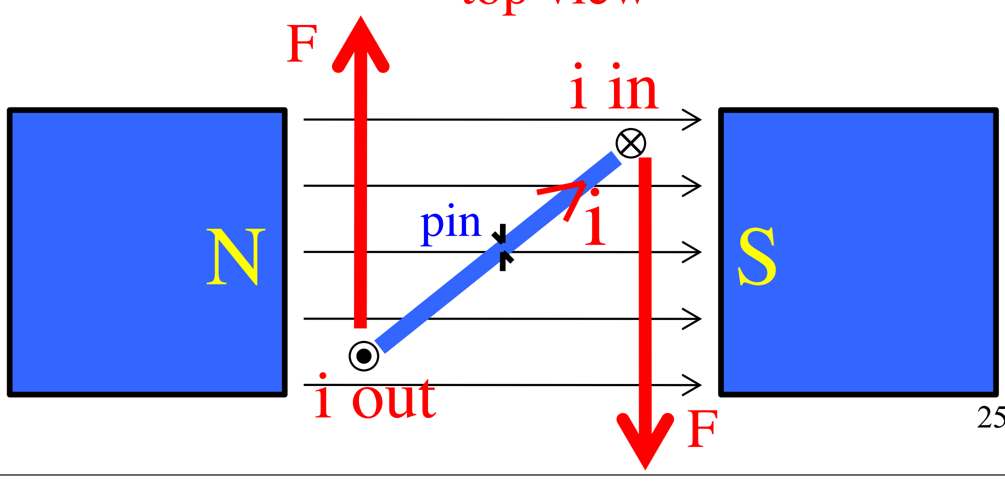
Consider a *current-carrying loop* of width *a* and height *c,* pinned at the top and bottom, bathed in a magnetic field.



How will the current *i* respond to the *B-fld?*

Look down from the top and ignore the billowing of magnetic field generated by the bar magnets. In that view, the current moves across the upper section of wire as shown, moves down into the page in the section on the right, and moves out of the page in the section on the lower left.

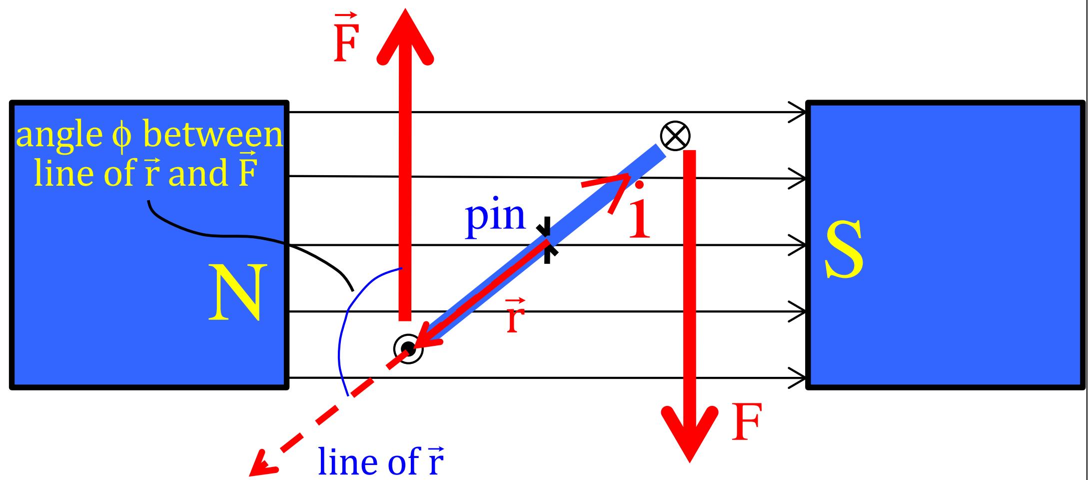
The *r.h.r.* suggests the direction of the magnetic forces on those sections are as shown.



The magnitude of the *magnetic force* will be:

$$\vec{F} = i\vec{L}x\vec{B}$$
$$\Rightarrow \quad F = iLB\sin 90^{o}$$
$$= icB$$

The total torque due to the current in the wires into and out of the page is:



$$\left|\vec{\tau}\right| = 2\left|\vec{r}x\vec{F}\right|$$
$$= 2\left|\vec{r}\right|\left|\vec{F}\right|\sin\phi$$
$$= 2\left(\frac{a}{2}\right)\left(icB\right)\sin\phi$$
$$= i\left(ac\right)B\sin\phi$$

where ϕ is the angle between the *line of the force* $\vec{F}$ and the *line of the position vector* $\vec{r}$.

Two observations:

1.) There could be *N* loops in our coil, so the most general torque expression should be the torque expression we've already derived multiplied by *N*.

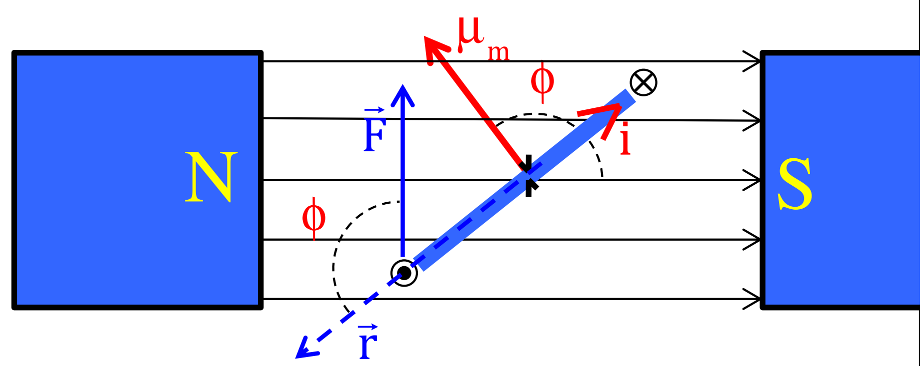
2.) Notice that *ac* is the area *A* of the loop.

With this, we can write the torque calculation as:

$$\left|\vec{\tau}\right| = N\left[i\left(ac\right)B\sin\phi\right]$$
$$= N\left[iAB\sin\phi\right]$$

--Although this is not something I think the AP folks are likely to ever test on, consider:

Lay your right-hand on the loop in the *direction of the current.* The *direction your outstretched thumb points* will define a direction perpendicular to the face of the coil.

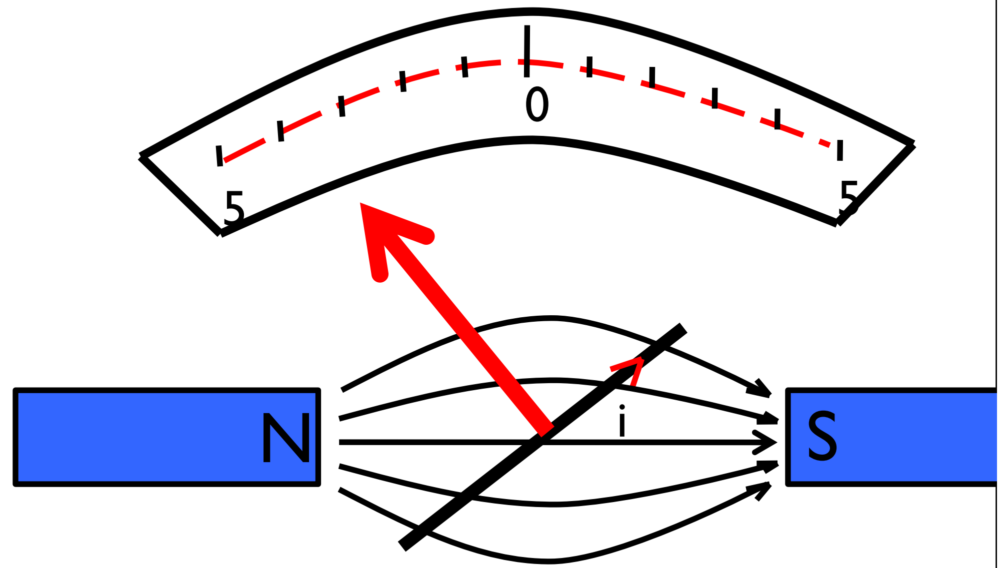


Define a vector, called the *magnetic moment* $\vec{\mu}_M$, whose direction is in that perpendicular direction and whose magnitude is equal to NiA. Crossing that magnetic moment vector into the B-fld yields a magnitude:

$$\left|\vec{\mu}\mathrm{x}\vec{B}\right| = \left(NiA\right)B\sin\phi$$ which is the torque on the coil . . .

Aside from giving physics teachers an excuse for having students do torque calculations in an E&M section, the real usefulness of all of this quite cool.

If you put a pinned coil in a magnetic field, attach a spring to it to provide a restoring torque, then attach a pointer hung over a scale, you have the makings of a meter.



And, in fact, that is exactly how a GALVANOMETER is made—it's a coil suspended in a magnetic field with a spring attached to it to provide a restoring torque, so that when you put $5\text{x}10^{-4}$ amps through it, the torque provided by the moving current in the *B-fld* coupled with the restoring torque sees the pointer swing "full deflection" over the scale . . . and that is very cool . . .

Sources of Magnetic Fields

Cern's single-walled coil operates at 7600 amps and produces a 2.0 Tesla B-fld.
http://atlas-magnet.web.cern.ch/atlas-magnet/info/project/ATLAS_Magnet_Leaflet-ds.pdf

Photo and info courtesy of Mr. White

B-flds Produced by Charge in Motion

In 1820, Hans Christian Oersted, observed that a compass near a current-carrying wire will react. Conclusions: *B-flds* are produced by *charge in motion*, and *B-flds circle around current carrying wires*.

The sense of circulation can be deduced using what I call *the right-thumb rule:*

> *Grasp the wire* with the *right hand* with the *thumb in the direction of current*. Your fingers will curl in the direction of the *B-fld*.

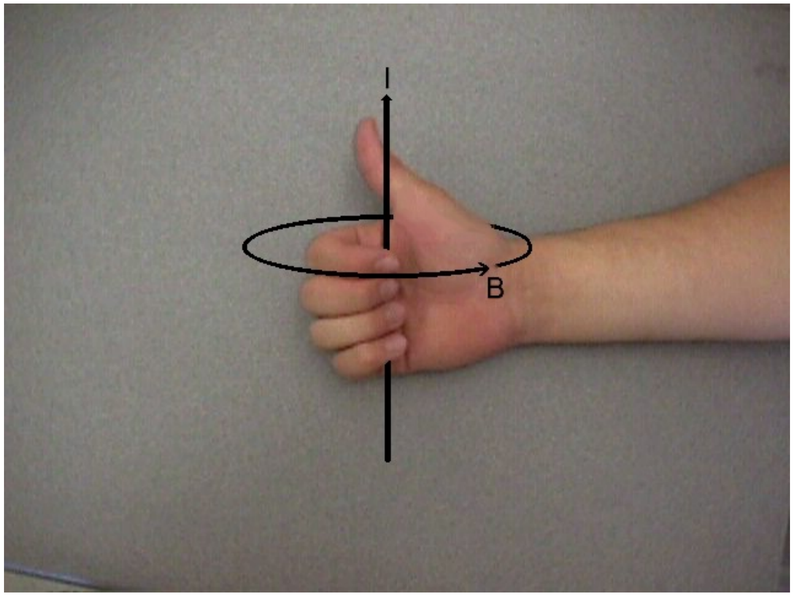
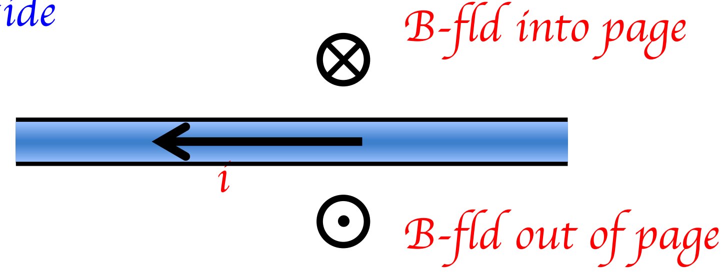
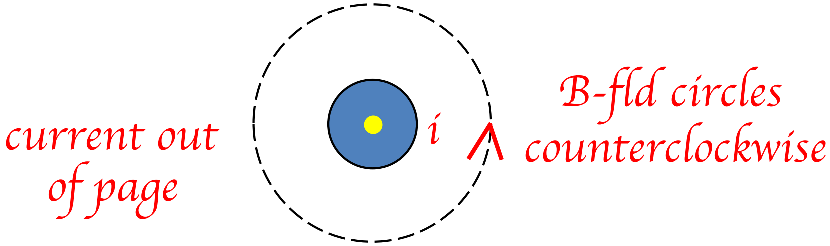


photo courtesy of Mr. White

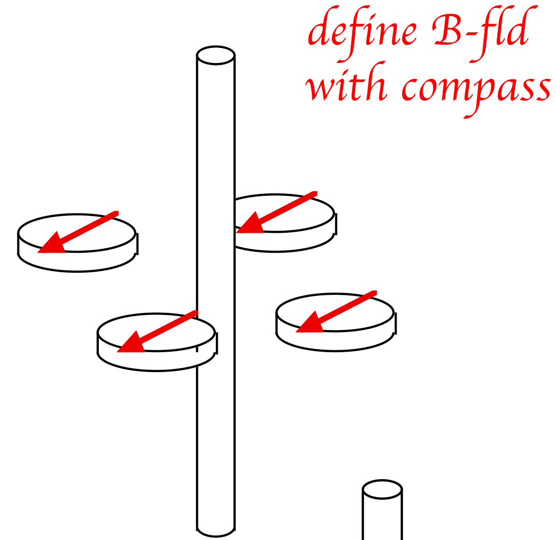
from side



from above

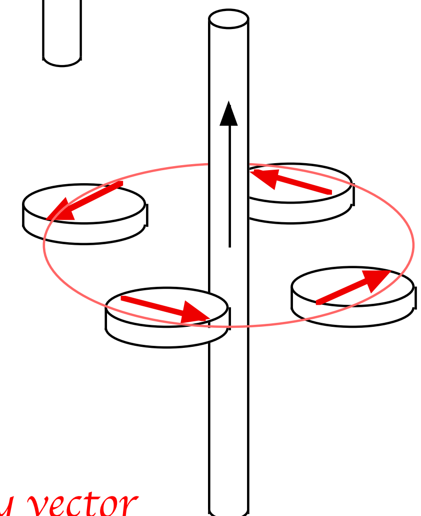


Oersted (1820) (courtesy of Mr. White)



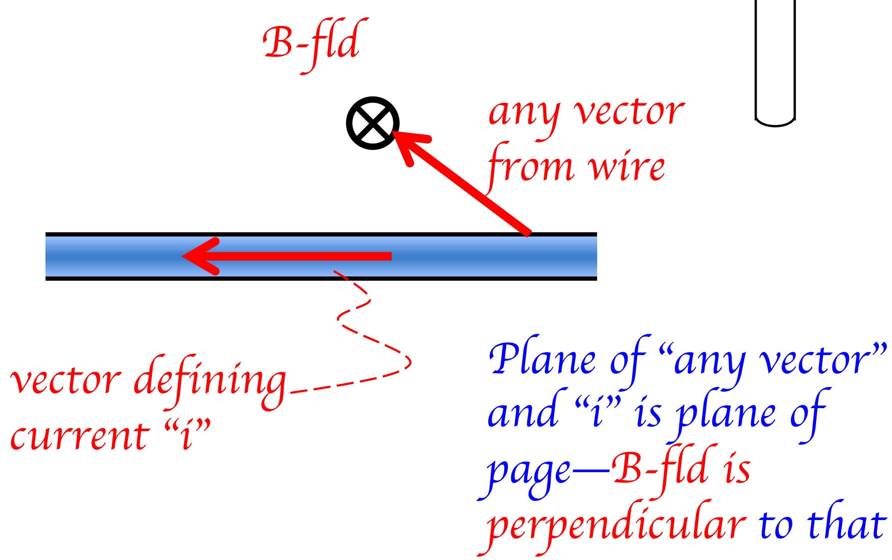
If the wire is grasped with the right hand, with the thumb in the direction of current flow, the fingers curl around the wire in the direction of the magnetic field.

The magnitude of B is the same everywhere on a circular path perpendicular to the wire and centered on it. Experiments reveal that B is proportional to I, and inversely proportional to the distance from the wire.



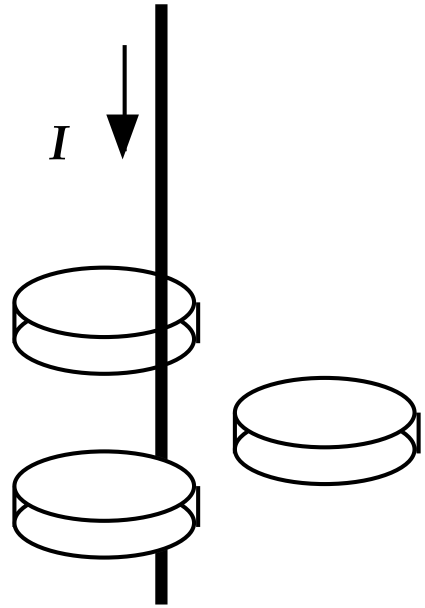
Obscure observation from Fletch:

Notice that if the *current-carrying wire* is straight and you draw a vector from any point on the wire to a point of interest, the direction of the magnetic field at that point will be perpendicular to the plane defined by that vector and the direction of the current (treated like a vector).



Example 1 (courtesy of Mr. White)

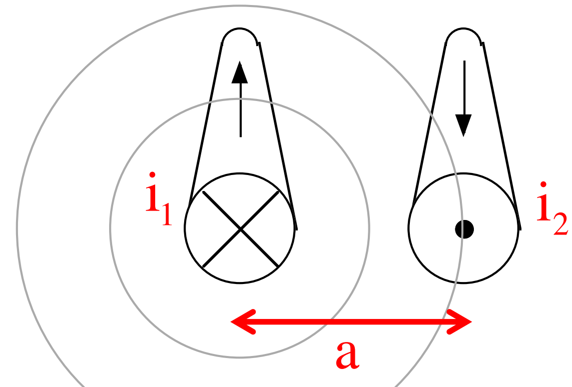
Predict the orientation of the compass needles.



Magnetic Forces Between Wires

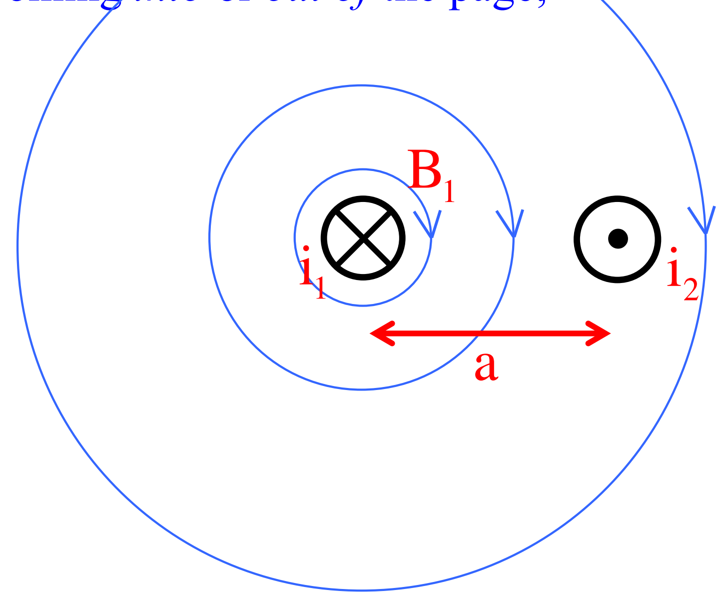
Example 4: Derive an expression for the magnitude and direction of force on a current-carrying wire bathed in the *B-fld* generated by a second current carrying wire *a* units away.

There is only one way to get the magnitude of the force, but there are TWO ways to get the direction. We'll do it all.



graphic courtesy of Mr. White with slight modification

A more standard way to present a current coming *into* or *out of* the page;



For the magnitude: The direction of the magnetic field due to the left-side wire can be determined using the *right-thumb rule* and is as shown. The magnitude of it's *B-fld* is:

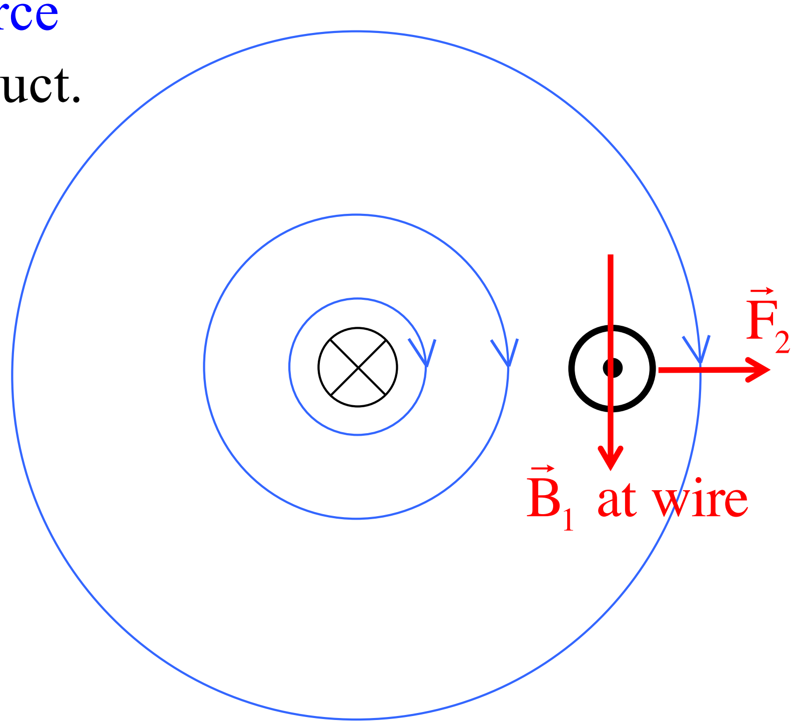
$$B_1 = \left(\frac{\mu_o}{2\pi}\right)\frac{i_1}{a}$$

Because the force relationship between a current-carrying wire and the *B-fld* the wire is bathed in is known, we can write:

$$\left|\vec{F}_2\right| = i_2\left|\vec{L}x\vec{B}_1\right|$$
$$= i_2L\left(\frac{\mu_o i_1}{2\pi a}\right)$$

Now for the fun—finding the direction of the force on the right-hand wire: Start with the cross product.

$$\vec{F}_2 = i_2\vec{L}x\vec{B}_1$$

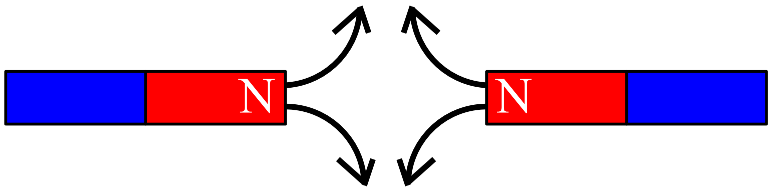


$\vec{L}$ is out of the page (in the direction of the right-hand wire's current), and we've already determined the direction of the *B-fld* due to the left-hand wire in that region (it's downward at the right-hand wire).

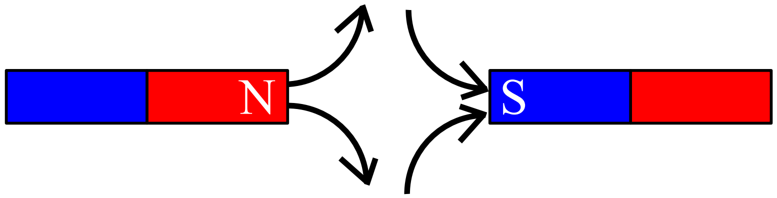
Executing $\vec{L}x\vec{B}_1$ yields a vector direction to the *right,* AWAY from the *left wire.*

But there's a cooler way to do this which requires an interesting observation.

Consider two north poles juxtaposed against one another. You know from experience that these two magnets will repulse one another. Notice that the direction of the magnetic field lines generated by the two in this case are *parallel*ish.



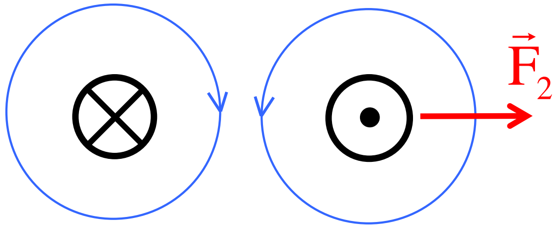
If, on the other hand, the poles are *opposites*, their magnetic field lines will be *anti-parallel*ish and the two magnets will attract one another.



The rule: If the *magnetic field lines* between two field-producing objects are *parallel* to one another, the two objects will magnetically repulse one another. If they are *anti-parallel*, they will magnetically attract one another.

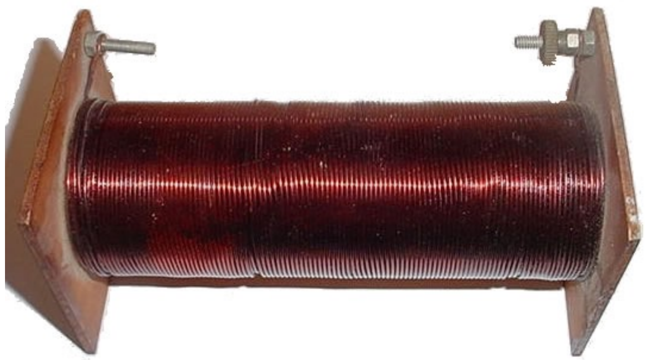
So going back to the direction of the force on the right-hand wire:

A quick determination (using the right-thumb rule) of the direction of the *B-flds* set up by the two wires in the region between the two wire shows that their field lines are *parallel* between one another . . . which means the two wires will *repulse one another*. That means the force on the right-hand wire should be *away from* the left-hand wire, as determined using the mathy approach.



B-flds suggest repulsion

Solenoids



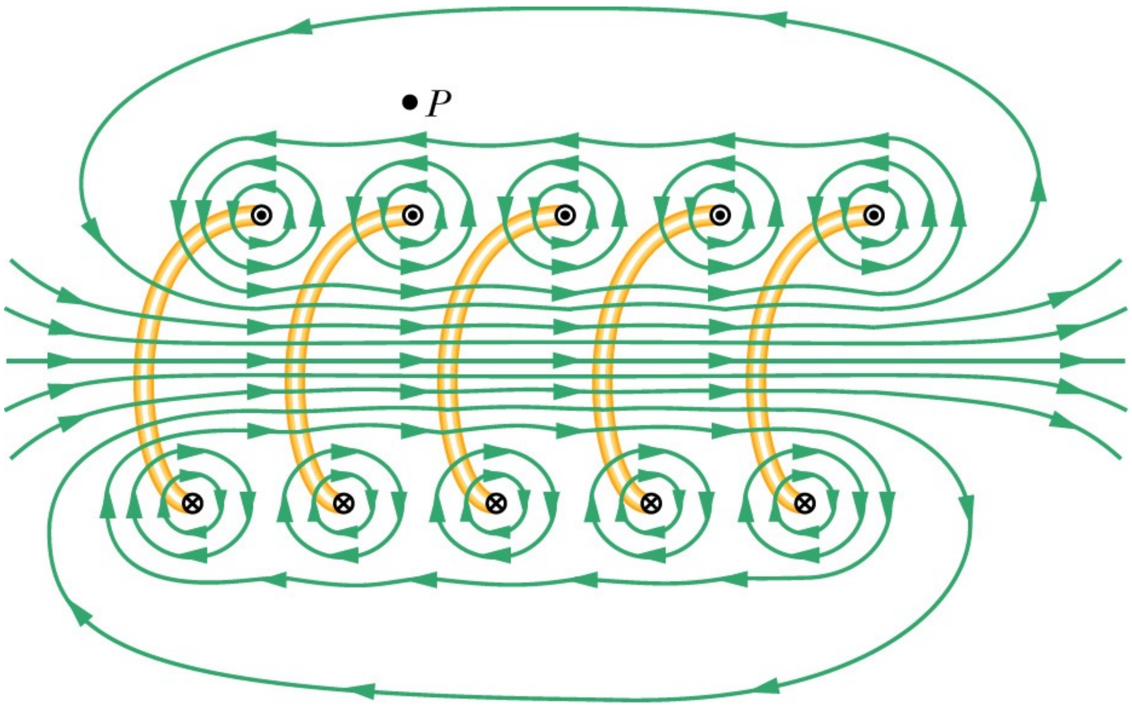
A solenoid, also referred to as a *coil*, is exactly that. A long wire tightly coiled helically. They are typically characterized by the number of winds per unit length n.

--Solenoids are typically tightly wound, but an spread out version (courtesy of Mr. White) allows us to see their microstructure.

--Between the winds the fields add to zero;

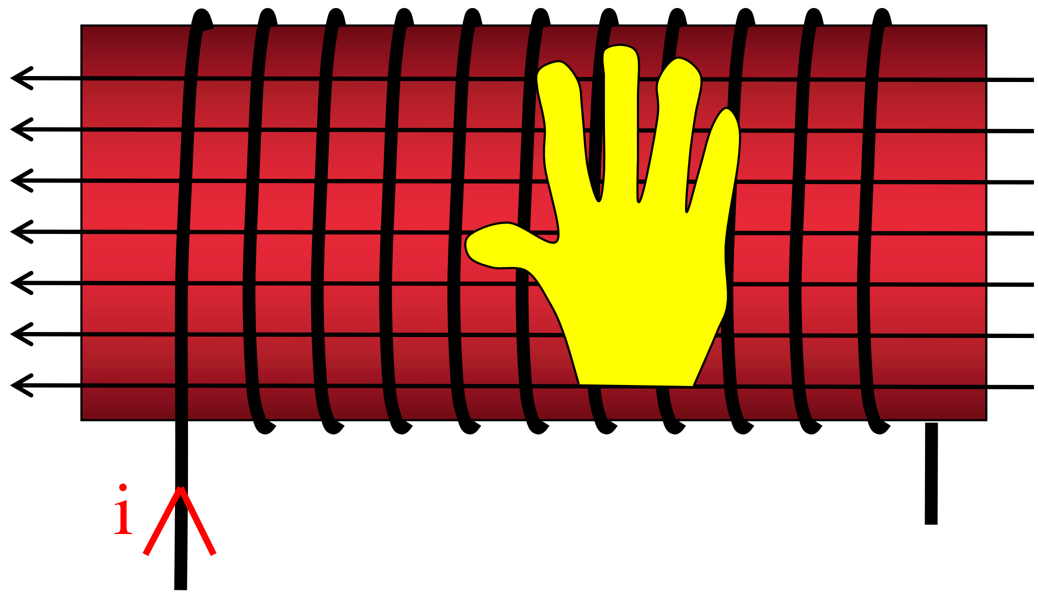
--Outside the winds the field is weak and drops to zero fairly quickly;

--Down the axis, the field is intense;



Trickery

There is still another right-hand rule that can be used to determine the direction of the magnetic field due to current through a coil. It's easy (and fun!).

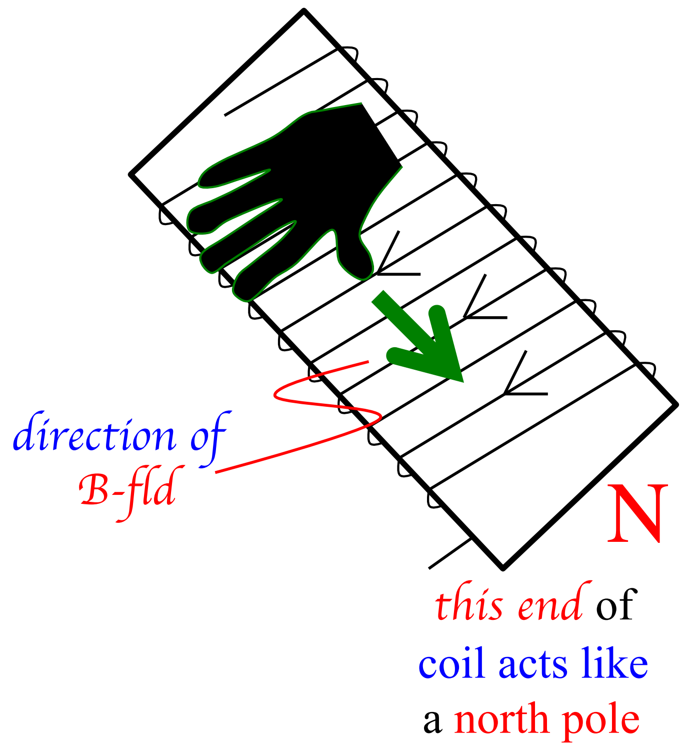


Lay your right-hand on the coil with your fingers pointing in the direction of the current.
The direction your thumb points is the direction of the *B-fld* down the axis of the coil.

Other Devices

A little more sophisticated version of a motor required one bit of information that would normally not be covered until next chapter.

It is charge in motion that generates magnetic fields. With current carrying coils, the generated magnetic fields are *down the axis* and *through the face of the coil*.



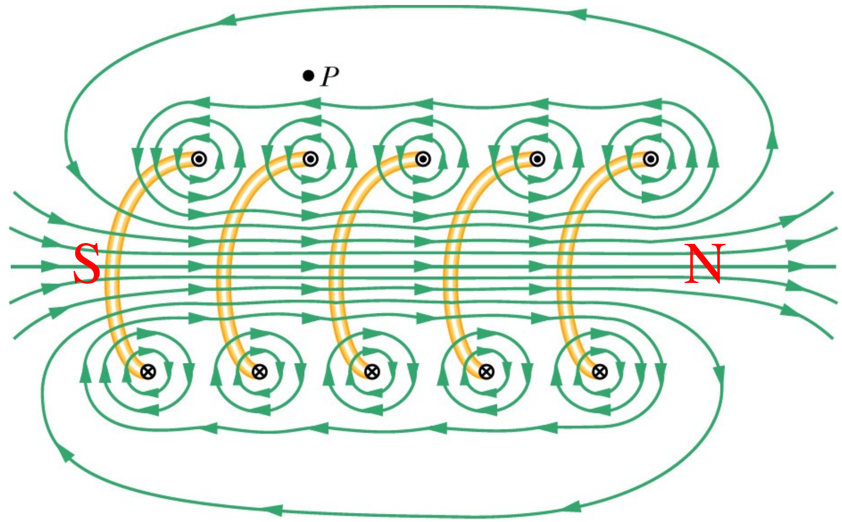
A handy trick to determine the direction of a current carrying wire's *B-fld* is to lay your right hand on the coil with your fingers following the direction of current in the coil. The direction in which your extended right-thumb points identifies the direction of the coil's B-fld.

Note that with the *B-fld* extending along the axis as it does, the coil's ends look like north and south poles.

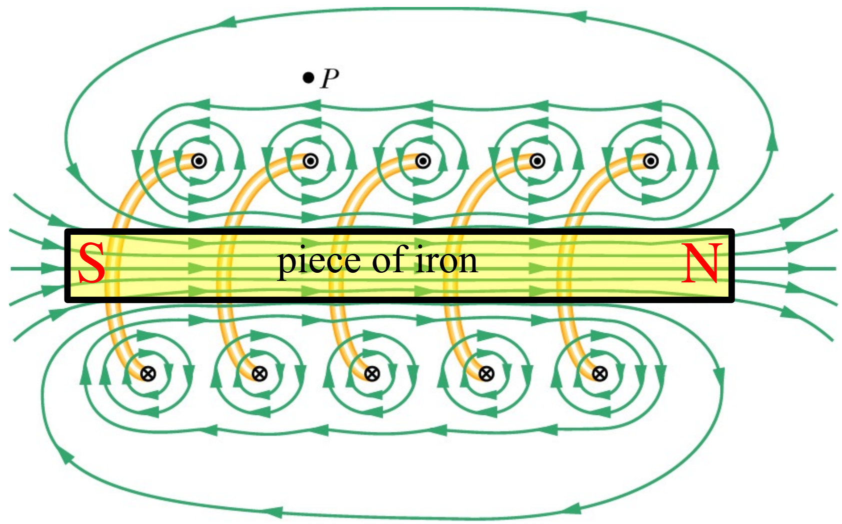
With that, consider the following:

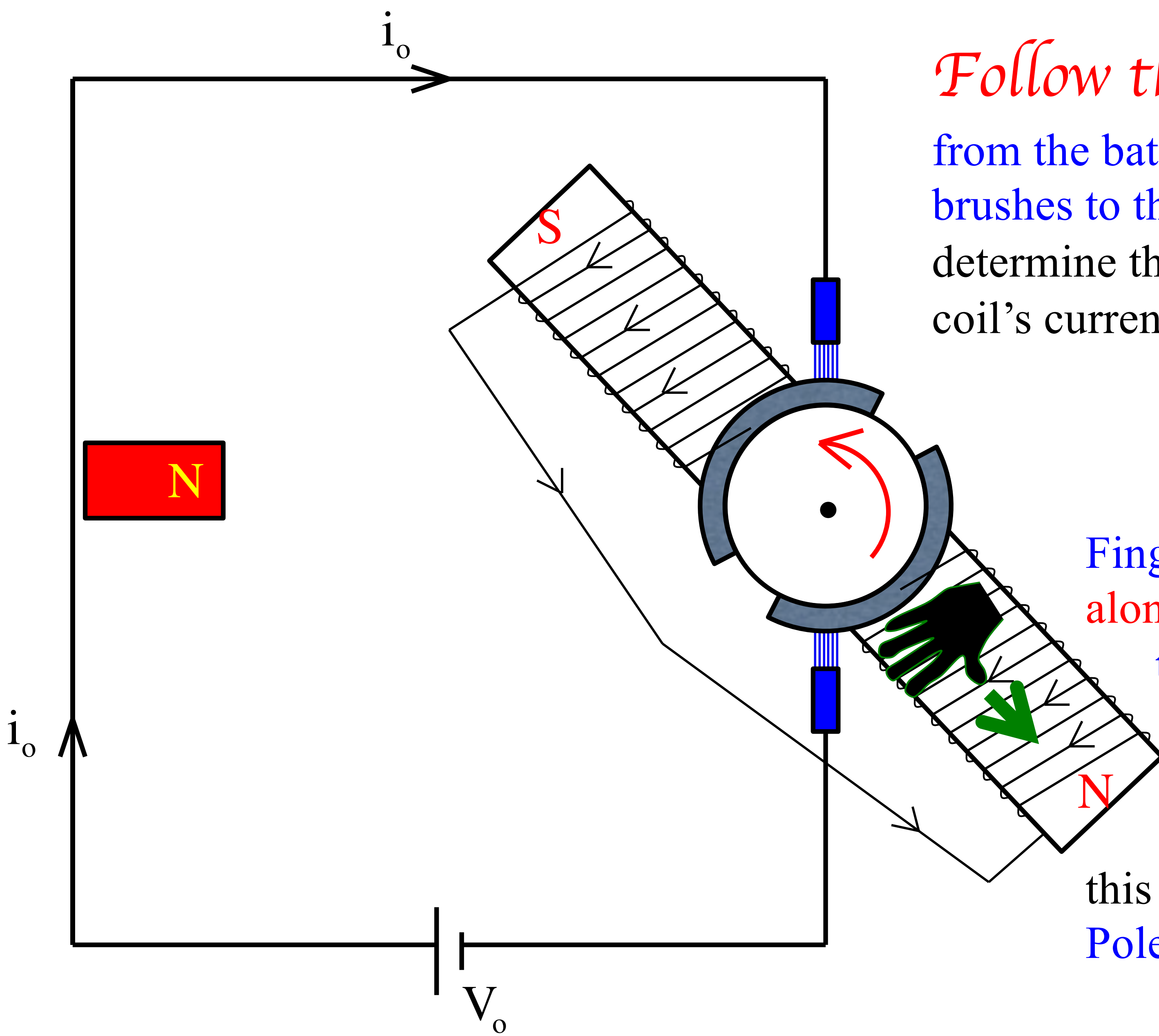
Electromagnetics

Because a coil sets up a magnetic field down its axis, as shown in the sketch, a tightly wound coil will act like a bar magnet in the sense that it will have one end that acts like a north pole and one end that acts like a south pole.



And because a ferromagnetic material (iron, steel, etc.) has within it magnetic domains that can align themselves to an external magnetic field, it is possible to make a very strong *electromagnet* by slipping a piece of iron (for instance) down the axis of a coil, then sending a current through the coil. That, in fact, is how electromagnets are made.



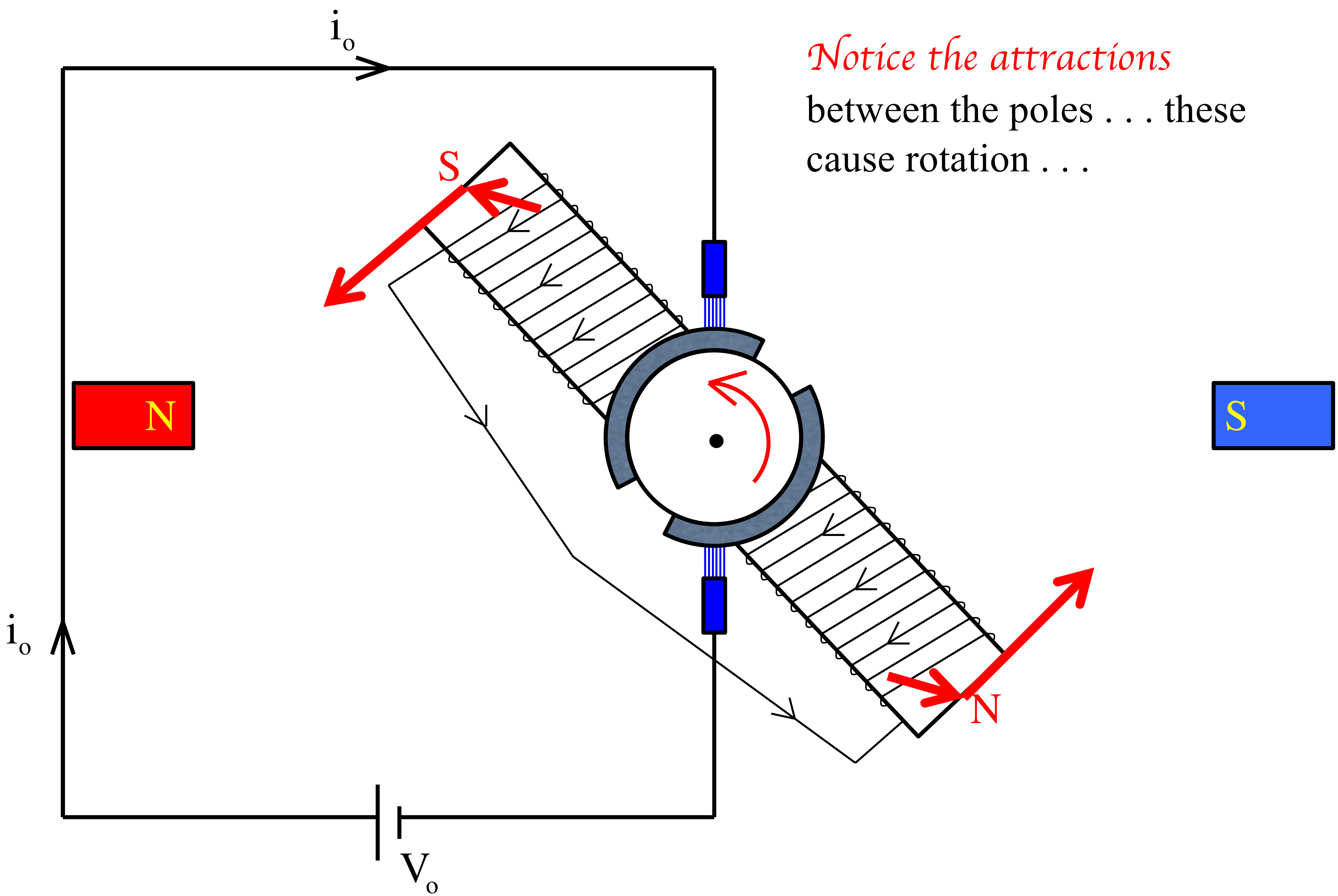


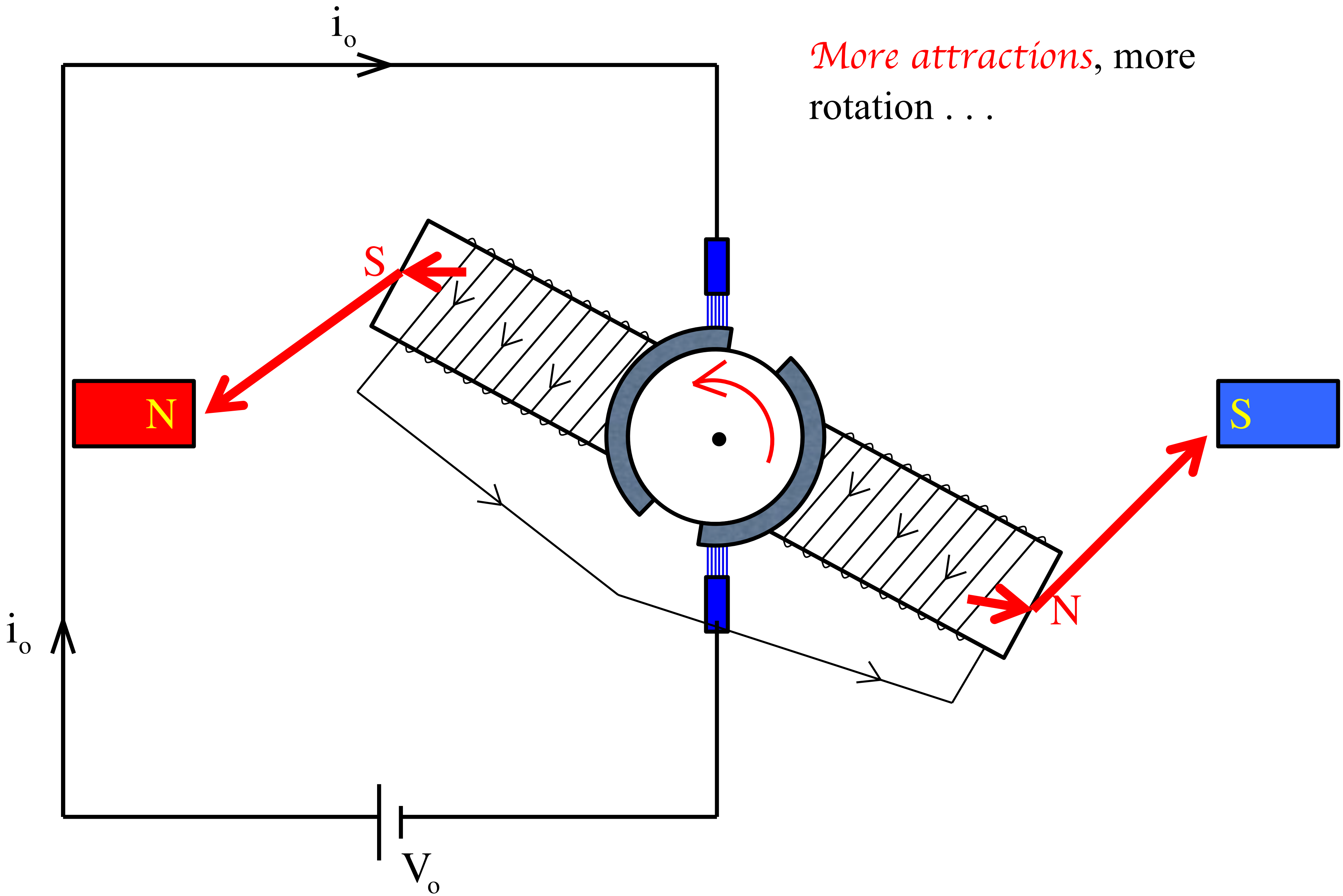
Follow the current

from the battery, through the brushes to the coil, then determine the *B-fld* due to the coil's current (see below).

Fingers of right hand curl along <u>*line of current*</u>; thumb identifies direction of B-field (with B-field lines exiting this end, so it's a North Pole)

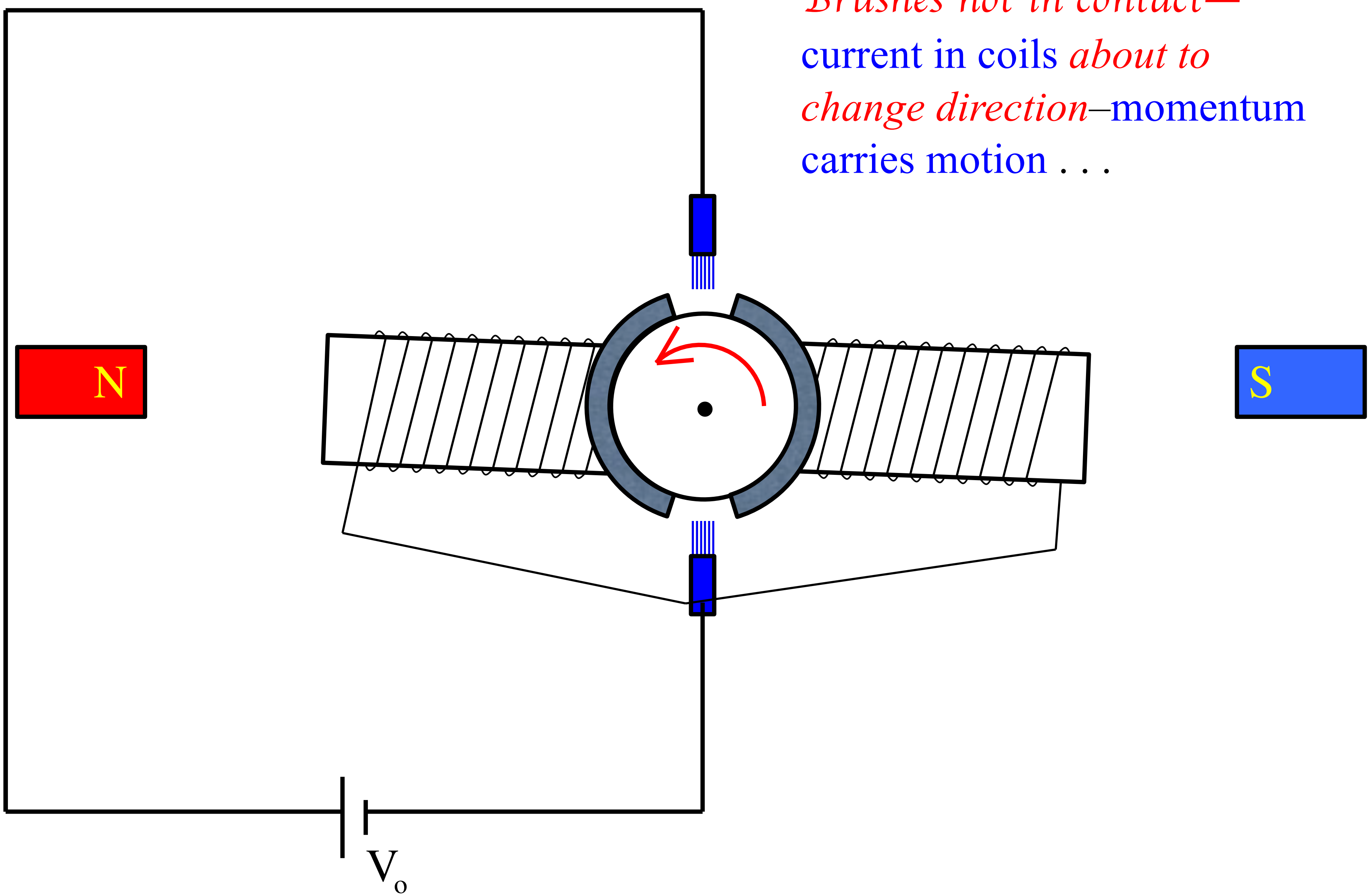
Notice the attractions
between the poles . . . these
cause rotation . . .



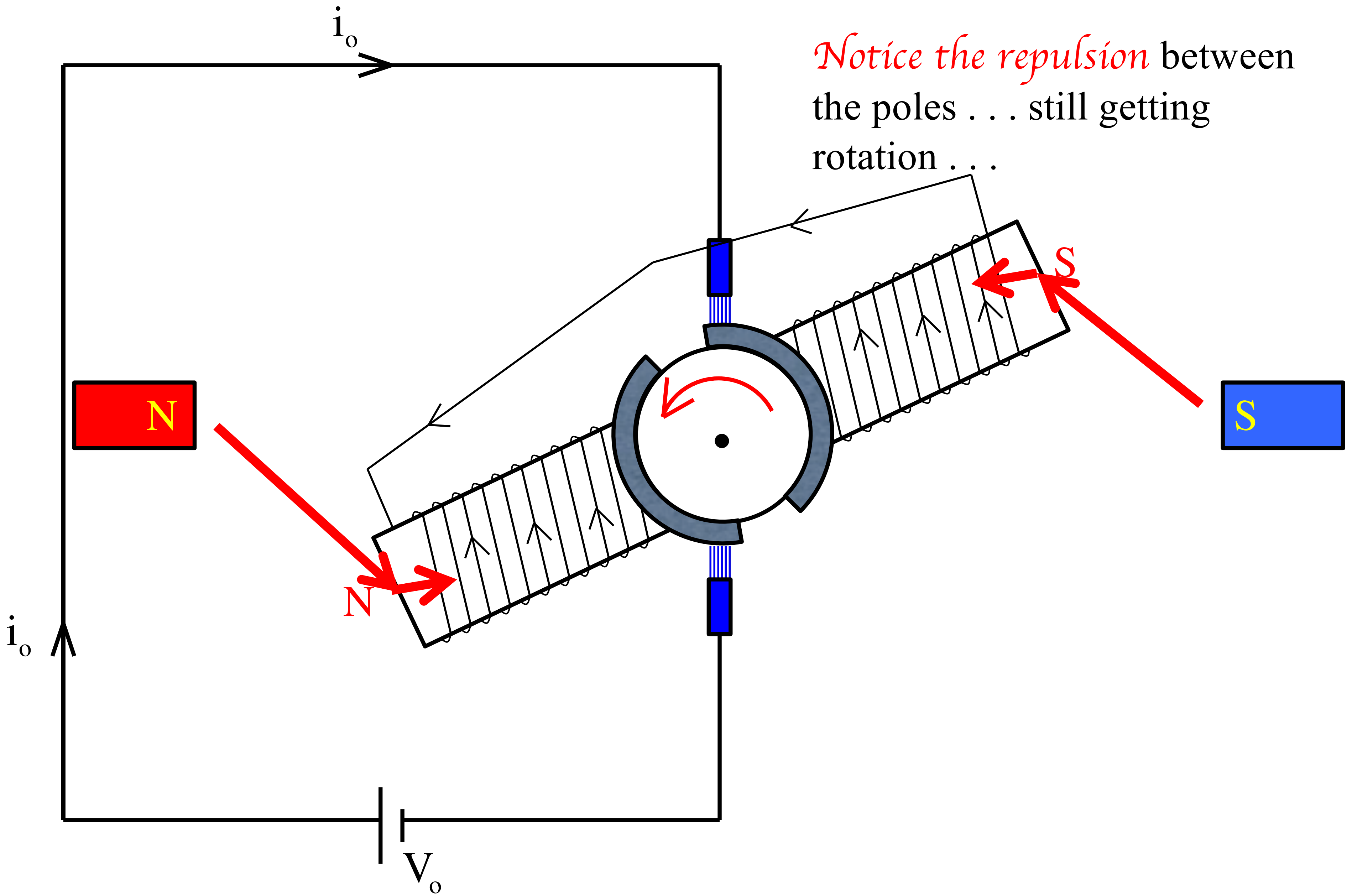


More attractions, more rotation . . .

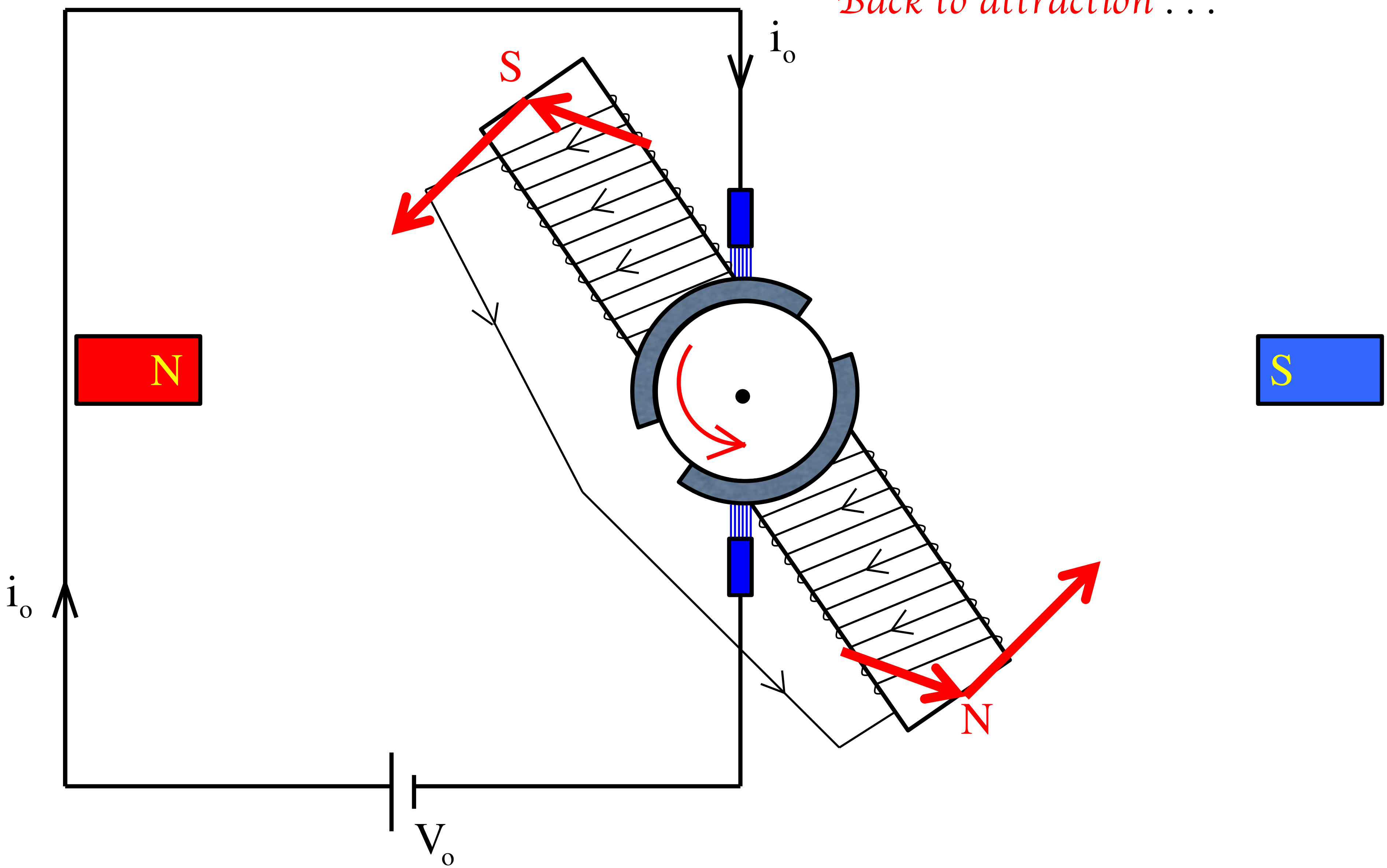
Brushes not in contact—
current in coils *about to*
change direction–momentum
carries motion . . .



Notice the repulsion between the poles . . . still getting rotation . . .



Back to attraction . . .

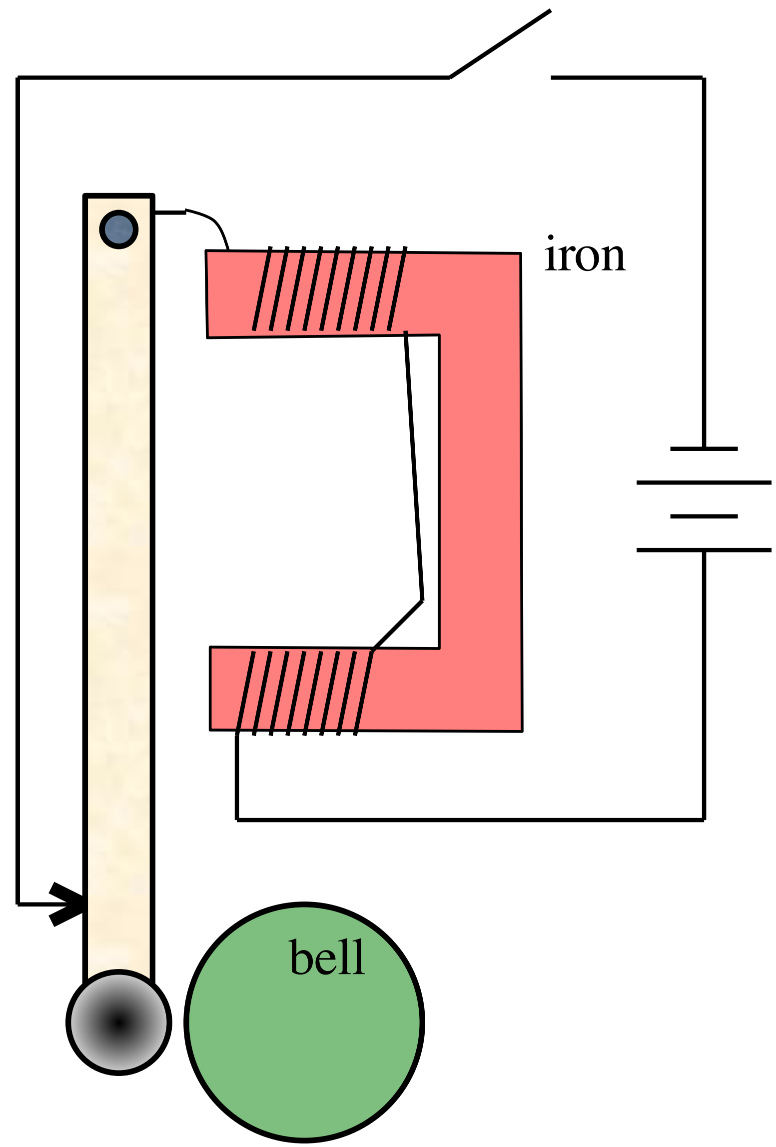


This is a DC motor. . .

.

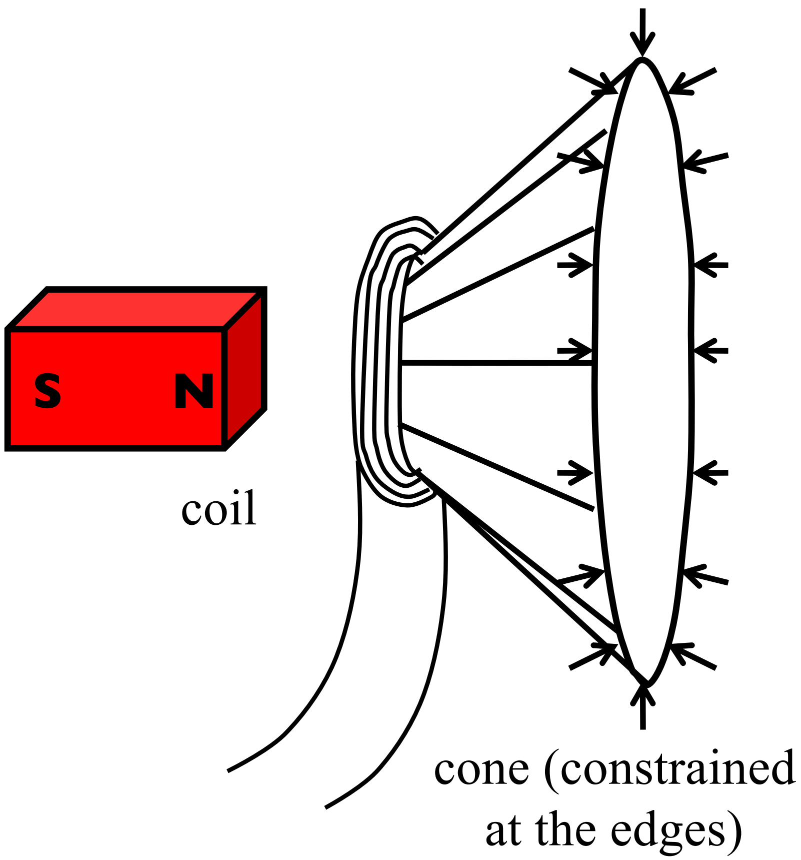
What is it?

What you are looking at here is the circuit for an old-fashioned door bell. See if you can follow through to see how the mechanism works (note the direction of the magnetic field in the green horseshoe electromagnet, and the direction of the induced magnetic field in the blue bar opposite the poles of the horseshoe magnetic, when the current flows).

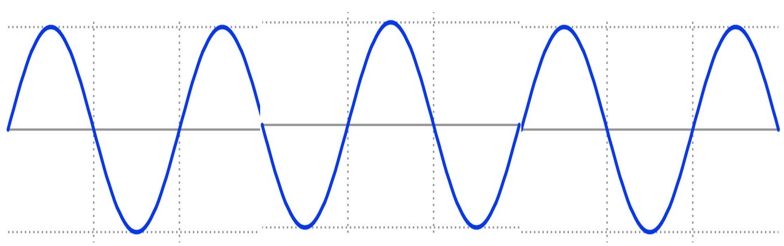


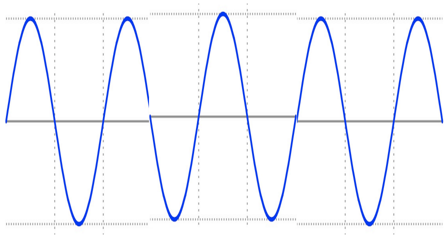
What is it?

This is the design for a loud speaker (actually, the coil and magnet are usually switched in real line). This is how it works:



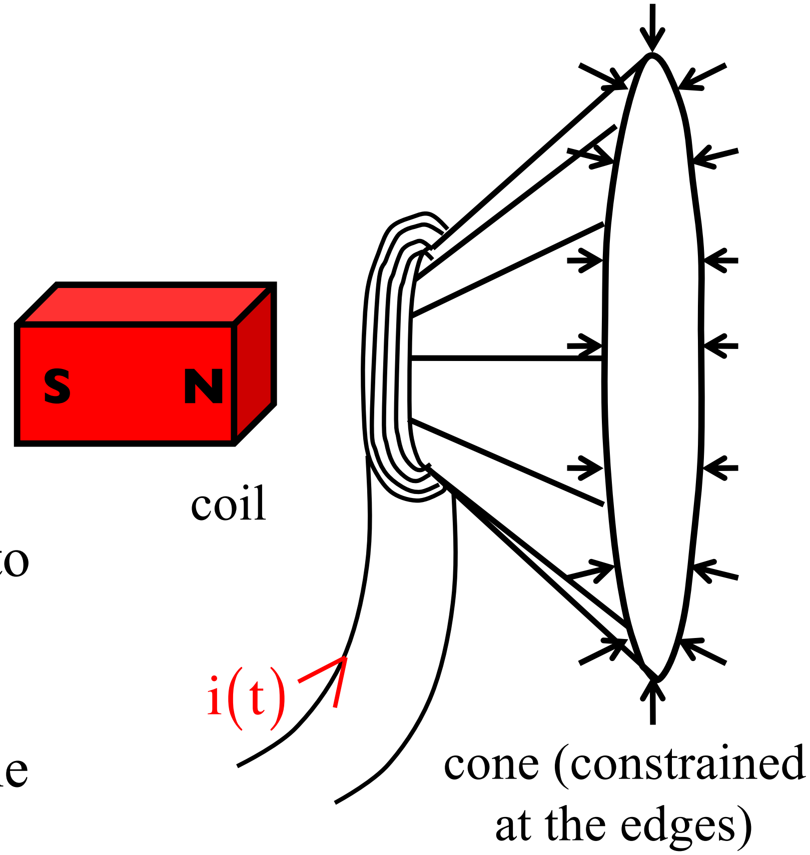
a.) *Let's assume* we want to project a 256 Hz (middle C) sound wave into the room. The signal would look like the sine wave shown below.





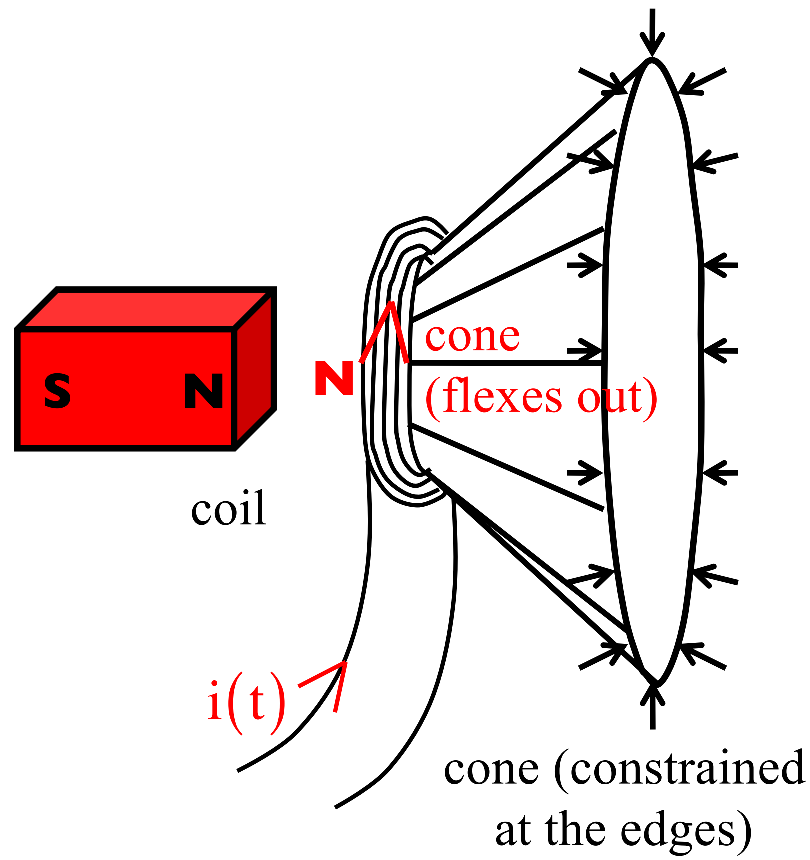
b.) During the first half of the cycle, let's assume the direction of the time-varying current through the coil is directed as shown on the sketch. There are two things to note:

i.) Being sinusoidal, the current will increase to a maximum, then will drop back down to zero whereupon the direction will change and the current will again increase to a maximum in the opposite direction, then proceed back to zero. This pattern will continue through time.



ii.) With the current moving in the direction noted, the direction of the induced magnetic field in the coil (alternate right-hand rule) will leave the side of the coil closest to the permanent magnet a North Pole (see sketch).

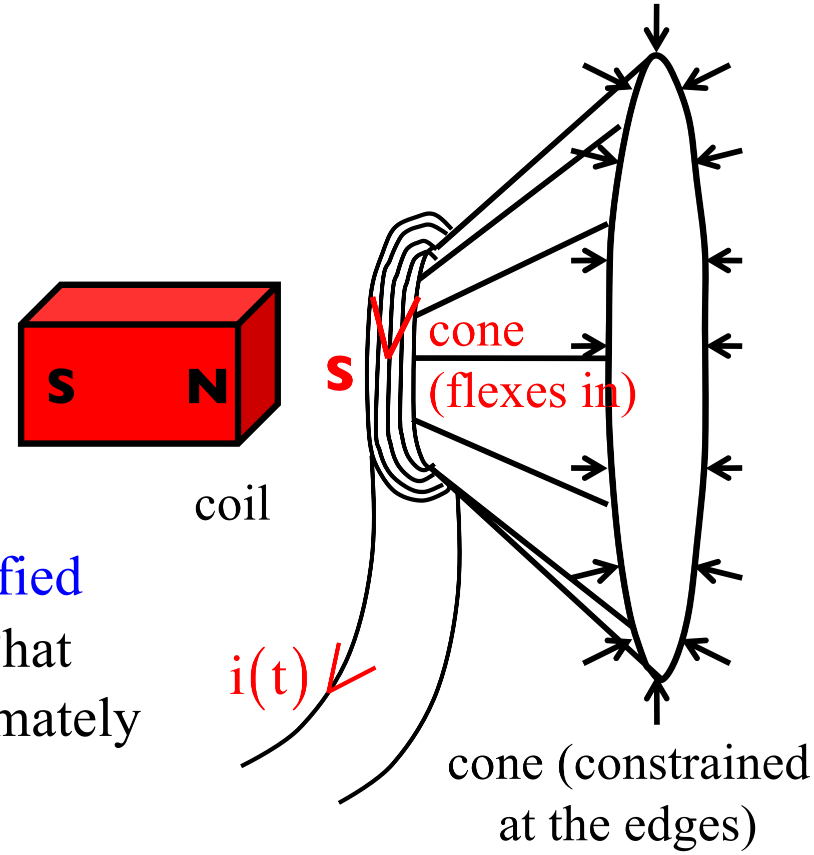
c.) The north pole of the *permanent magnet* will interact with the induced north pole of the current carrying coil, and the net effect will be a repulsion experienced by both the coil AND the cone. As the cone is fixed at it's outside edge, this will flex the cone outward with the amount of flex being dependent upon the size of the current at the given instant.



d.) As the cone flexes outward, it will compress air into a high pressure region. That pressure ridge will travel away from the cone at approximately 330 m/s, or the speed of sound in air.

e.) As the current proceeds down toward zero, the cone will relax, pulling back.

f.) When the current direction changes, the direction of the induced magnetic field in the coil will change and the "pulling back" will proceed through equilibrium and into a flexing inward. The degree of flexing will, again, depend upon how much current to moving through the coil at a given instant.



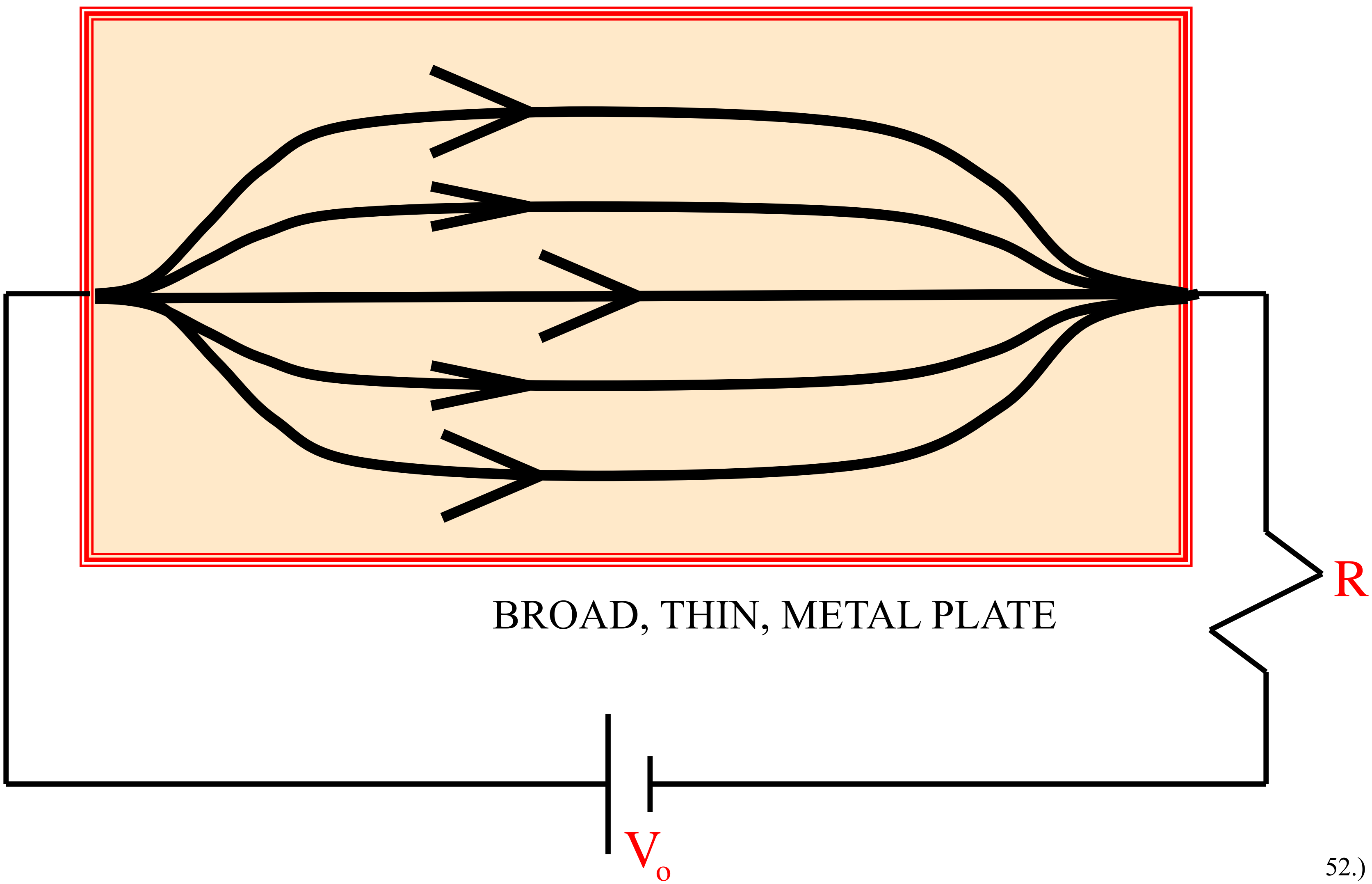
g.) As the cone flexes inward, it will create a rarified region of air generating a low pressure region. That region will travel away from the cone at approximately 330 m/s, or the speed of sound in air.

h.) This flexing outward, then inward, then outward will occur at the current frequency, or 256 Hz in our example, and the pressure variations will pass by your ear at a frequency of 256 Hz. That, in turn, will wiggle the little hairs in your ears creating electrical impulses that your brain will interpret as sound. Clever of nature, eh?

HALL EFFECT

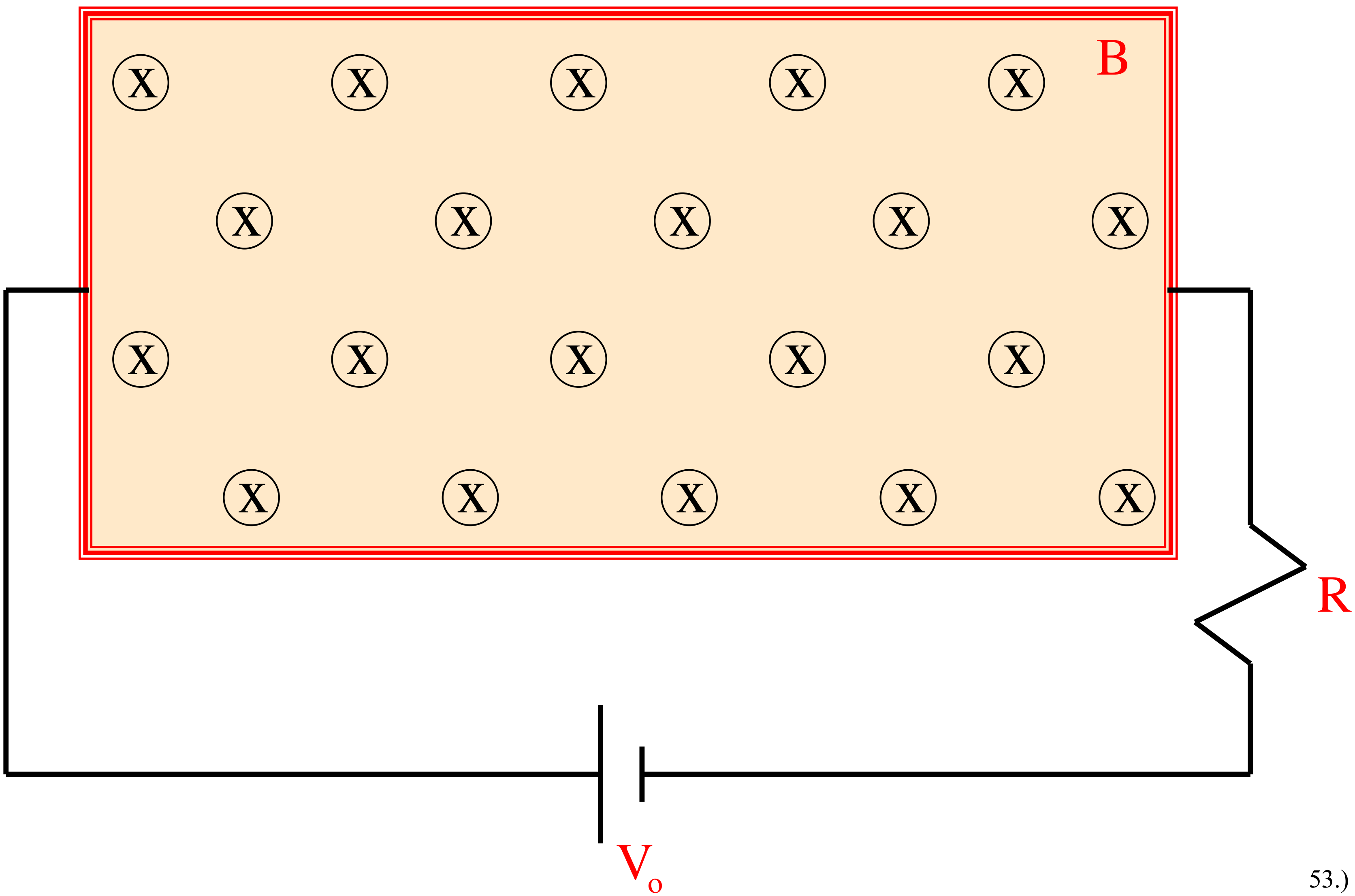
An experiment to prove that *negative charges* moves through electrical circuits when current flows.

How normal current flows through the plate.



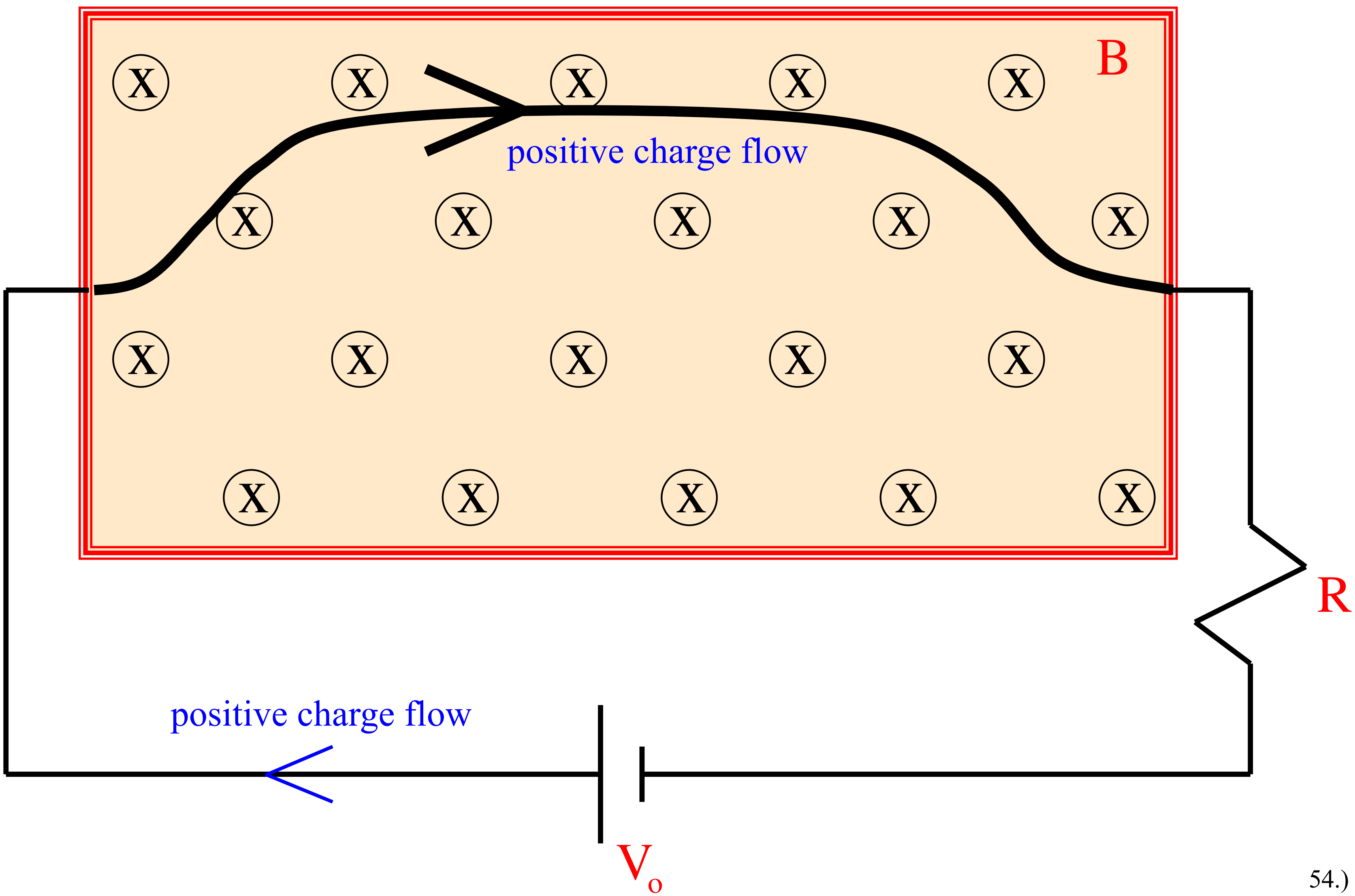
What happens when the plate is permeated by *B-fld*.

plate permeated by *B-fld*



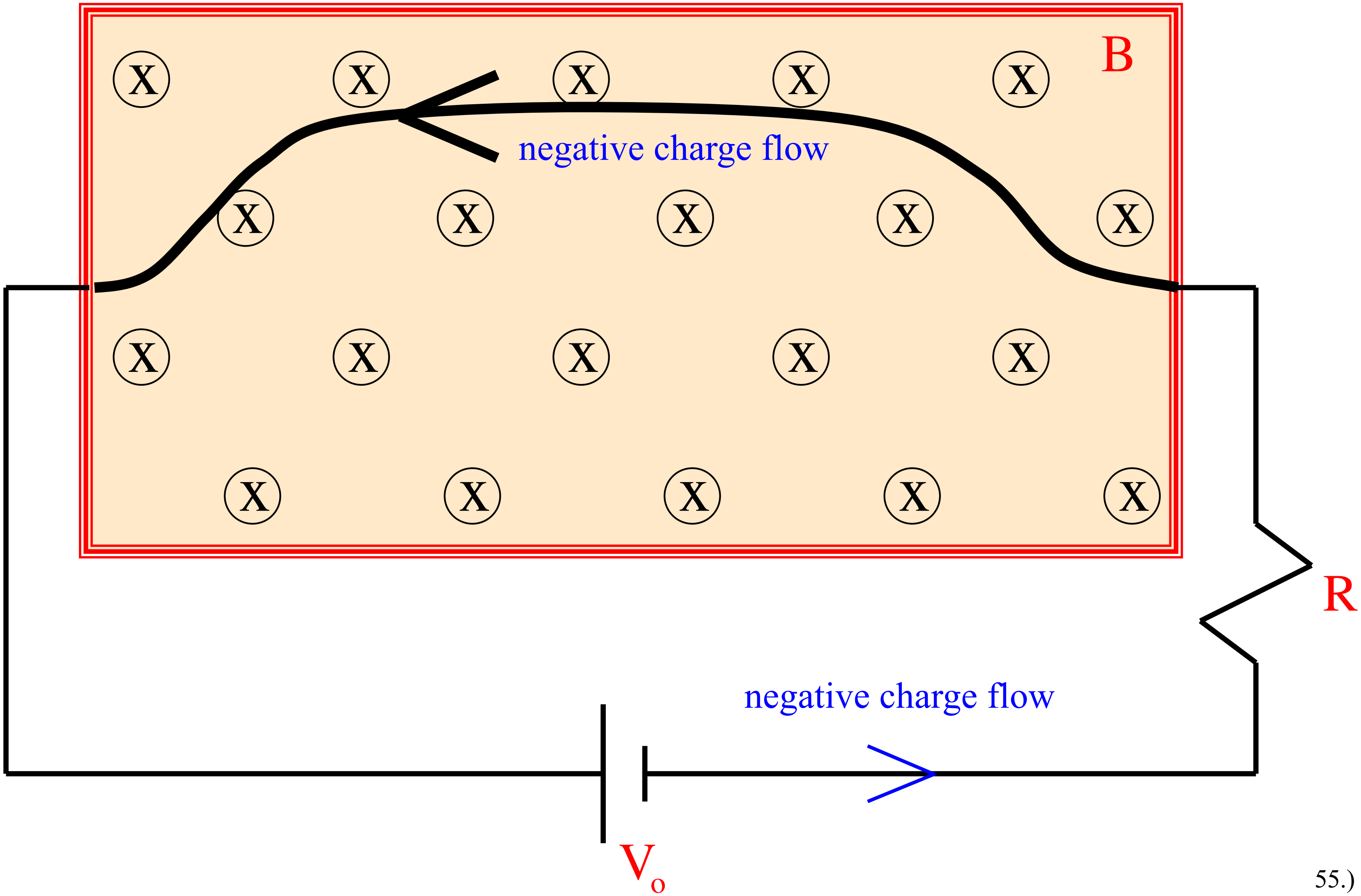
. . . *if POSITIVE charge* is assumed to flow through circuit?

positive charge flow suggests upper side of plate will be high voltage side



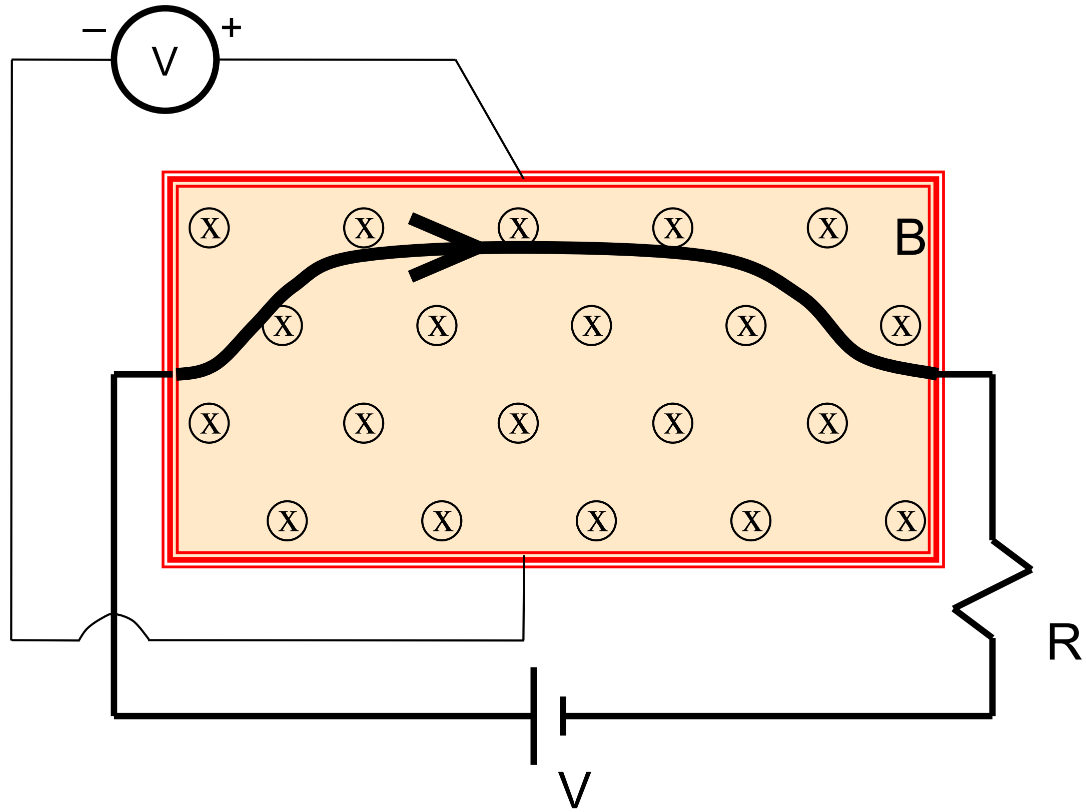
. . . *if NEGATIVE charge* is assumed to flow through circuit?

negative charge flow suggests upper side of plate will be low voltage side



So back to the positive charge-flow assumption:

If there exists a predominance of positive charge on the upper side of the plate making that side of the plate higher voltage than the bottom side, then placing a voltmeter with its + and – terminals as positioned would produce a meter reading *that was sensible* (that is, the needle would swing in the appropriate direction).



In fact, if this experiment was done, the needle would swing in the *wrong direction*. In other words, the the meter is hooked up wrong. What are accumulating on the upper side of the plate are not positive charges, they are NEGATIVE charges.

In short, it is *negative charge* that flows through circuits.