

# Announcements

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- Help room hours (1248 BPS)
  - ◆ Ian La Valley(TA)
  - ◆ Mon 4-6 PM
  - ◆ Tues 12-3 PM
  - ◆ Wed 6-9 PM
  - ◆ Fri 10 AM-noon
- LON-CAPA #7 due Oct. 25
- Final Exam Tuesday Dec 11 7:45-9:45 AM

# What do we expect at $t=32s$ ?

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- How fast should be going at that point?
- How far has he fallen?

$$v = gt = (9.83m / s^2)(32s) = 315m / s$$

$$y - y_0 = -\frac{1}{2}gt^2 = -\frac{1}{2}(9.83m / s^2)(32s)^2 = 5033m$$

- Why are the numbers on the video somewhat smaller?

# Connection with electric currents

- The connection between electric currents and magnetic fields was discovered by Hans Christian Oersted in 1819 while doing a classroom demonstration

→ demo

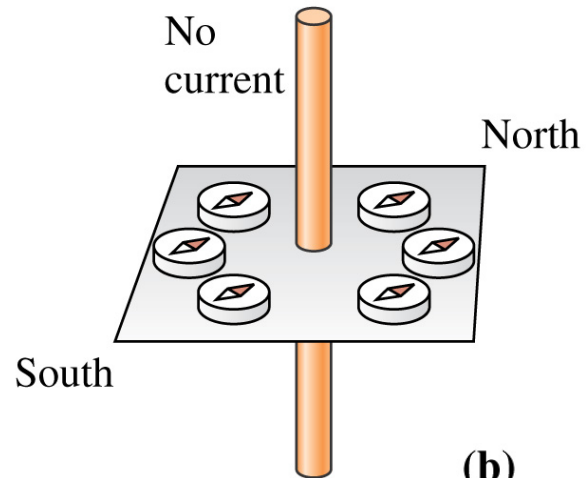


HANS CHRISTIAN OERSTED.

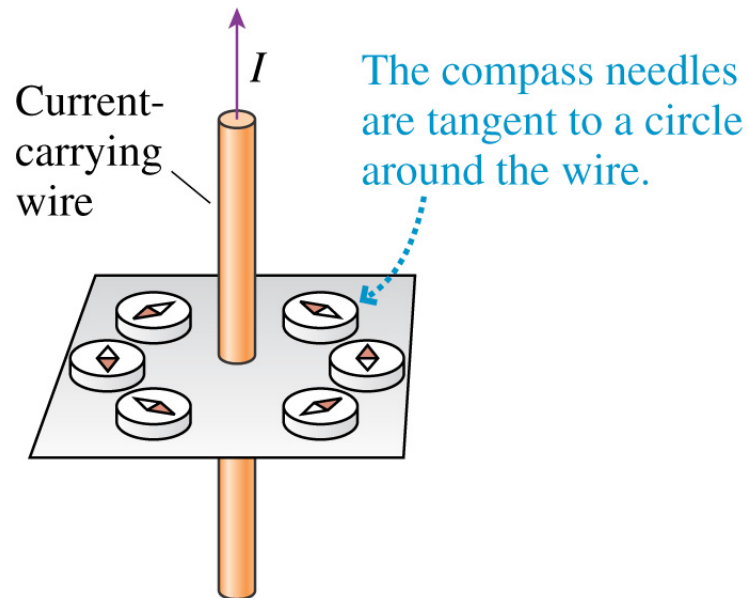
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# Direction of B field from a current

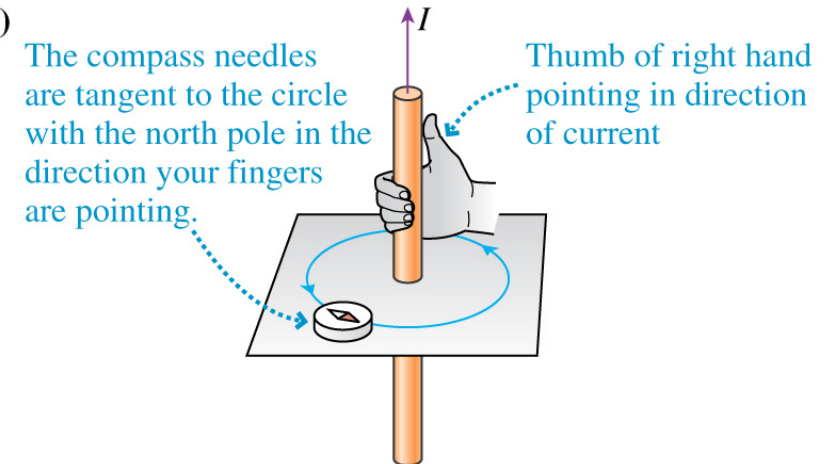
(a)



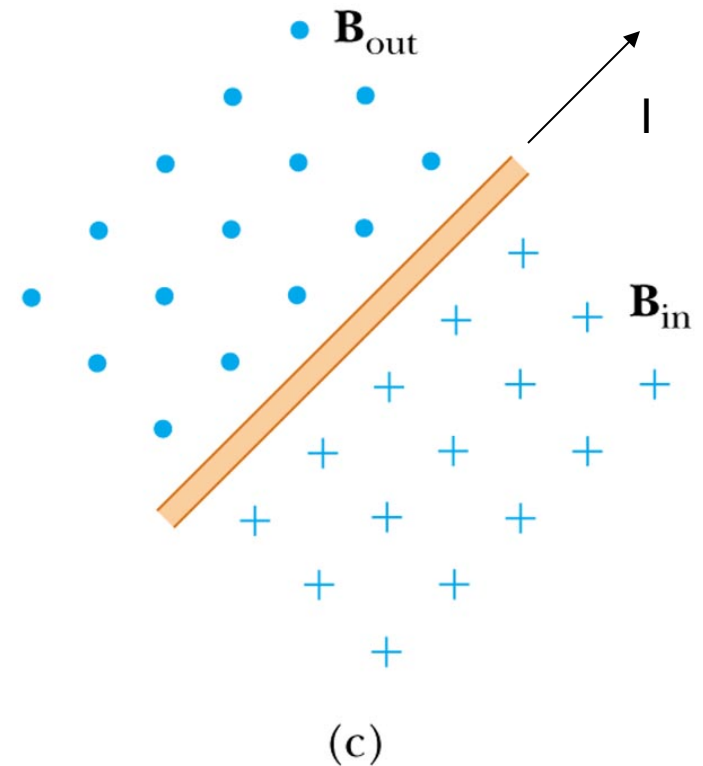
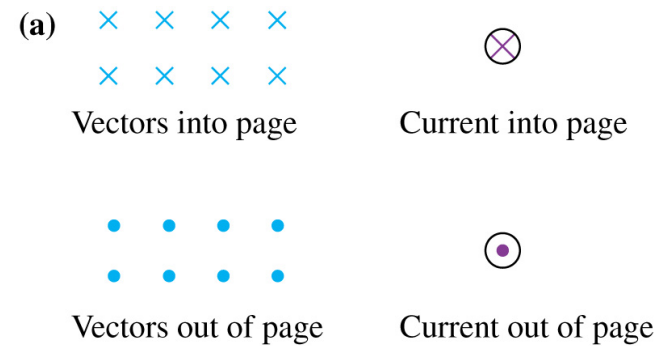
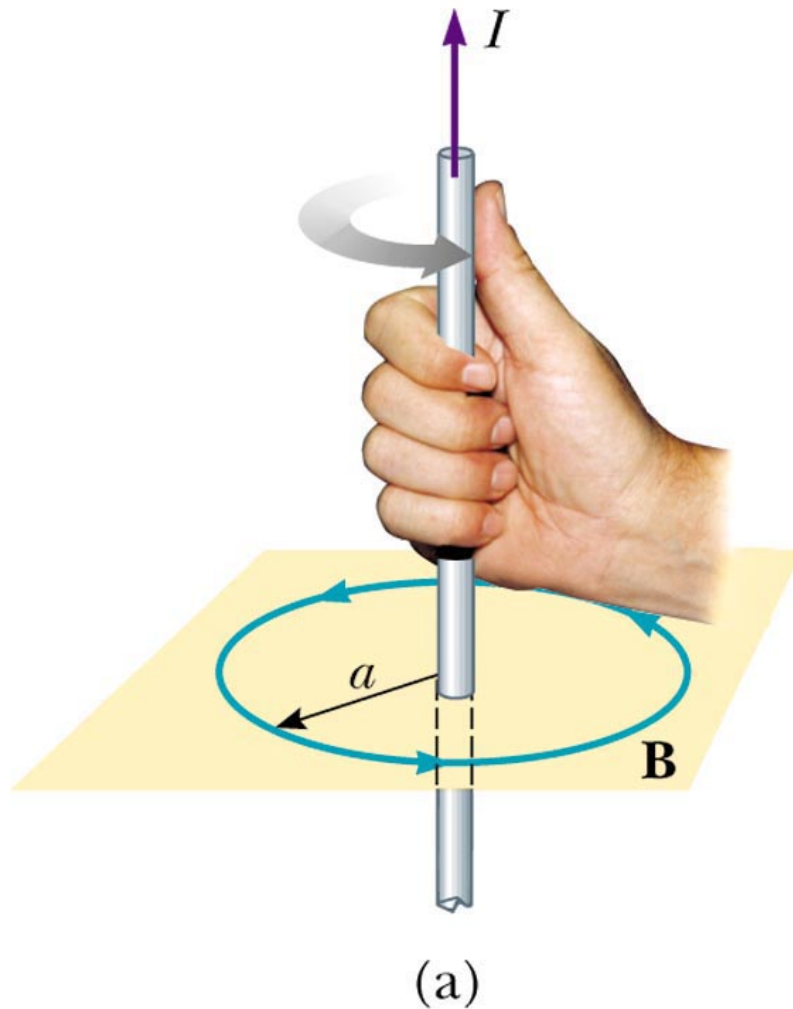
(b)



(c)

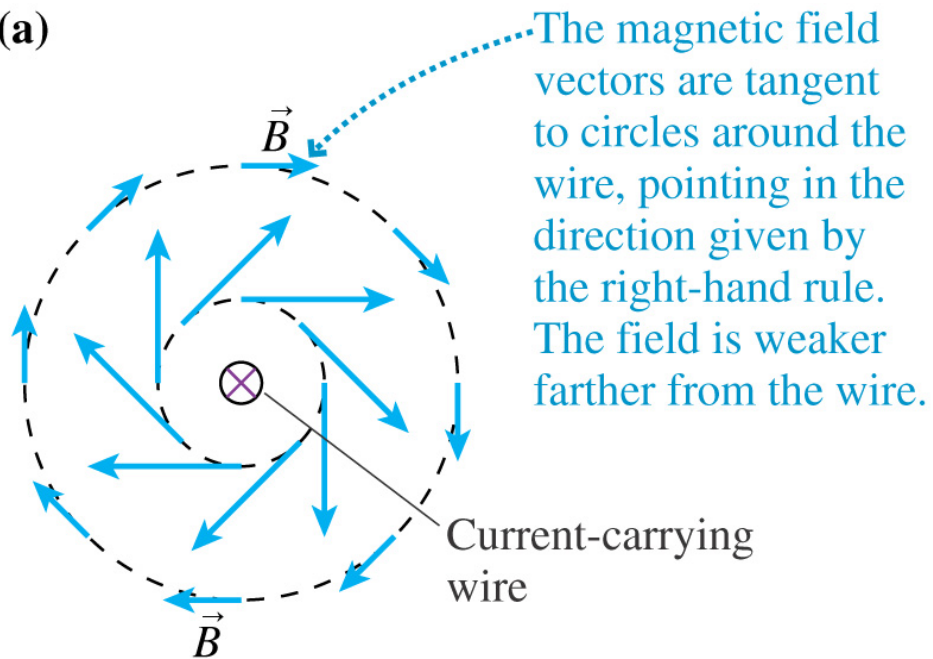


# With magnetic fields, you have to work with all 3 dimensions

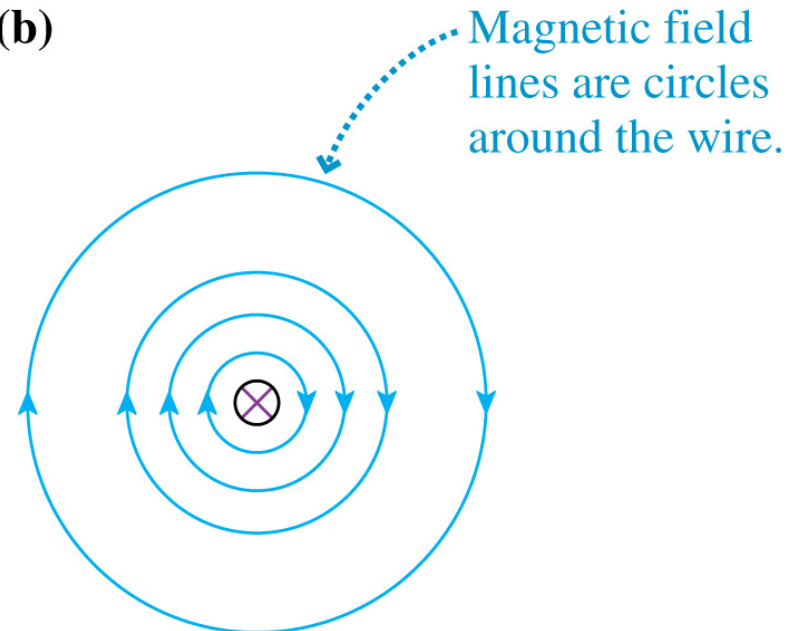


# Magnetic field from a long straight wire

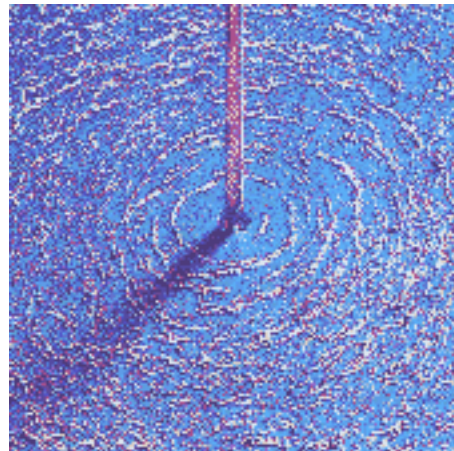
(a)



(b)



The magnetic field from a current decreases as  $1/r$

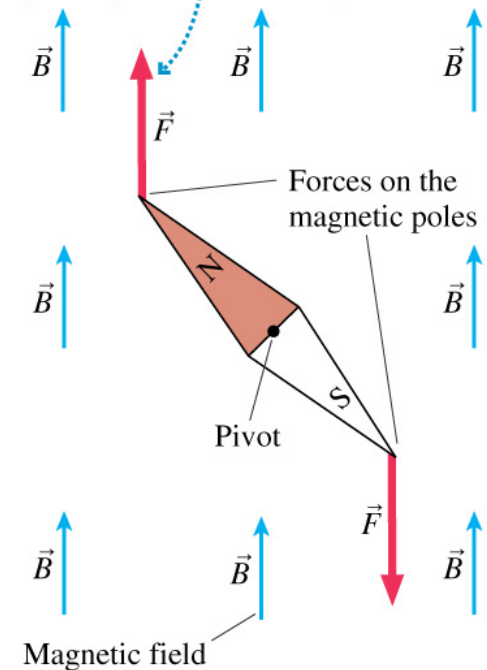


video

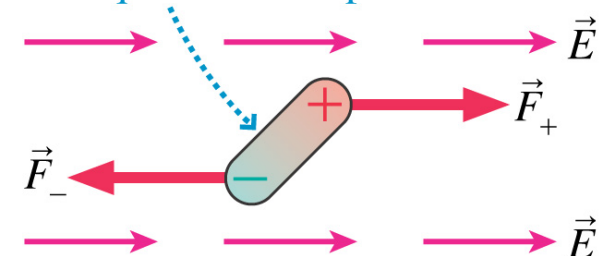
# Magnetic forces

- The force on a north magnetic pole is in the direction of the field
- The force on a south magnetic pole is opposite the direction of the field
- Thus on a compass needle (a bar magnet) there is a torque that tries to align it with the magnetic field
- This also happens with an electric dipole in an electric field

The magnetic force on the north pole is parallel to the magnetic field.



The electric field exerts a torque on this dipole.

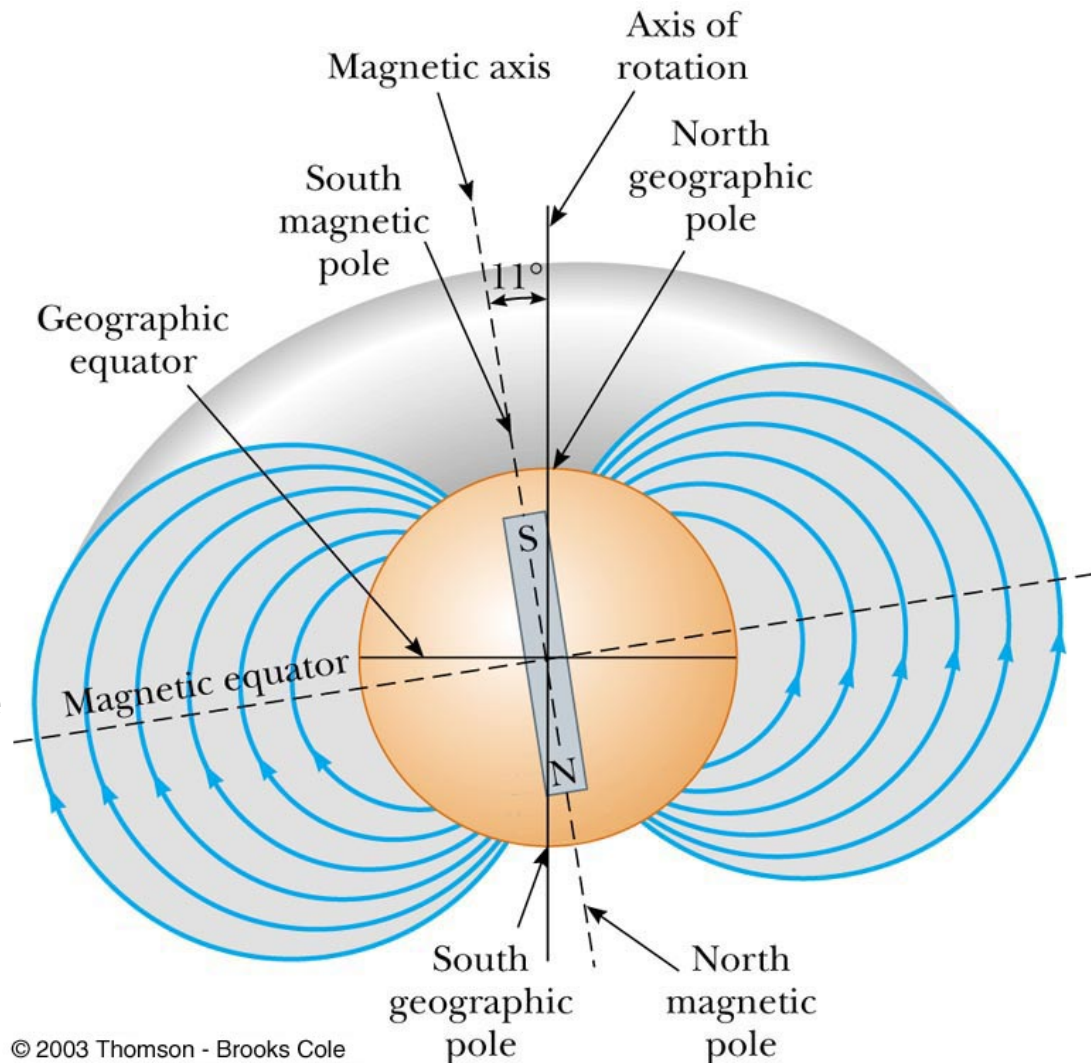




# Earth's magnetic field

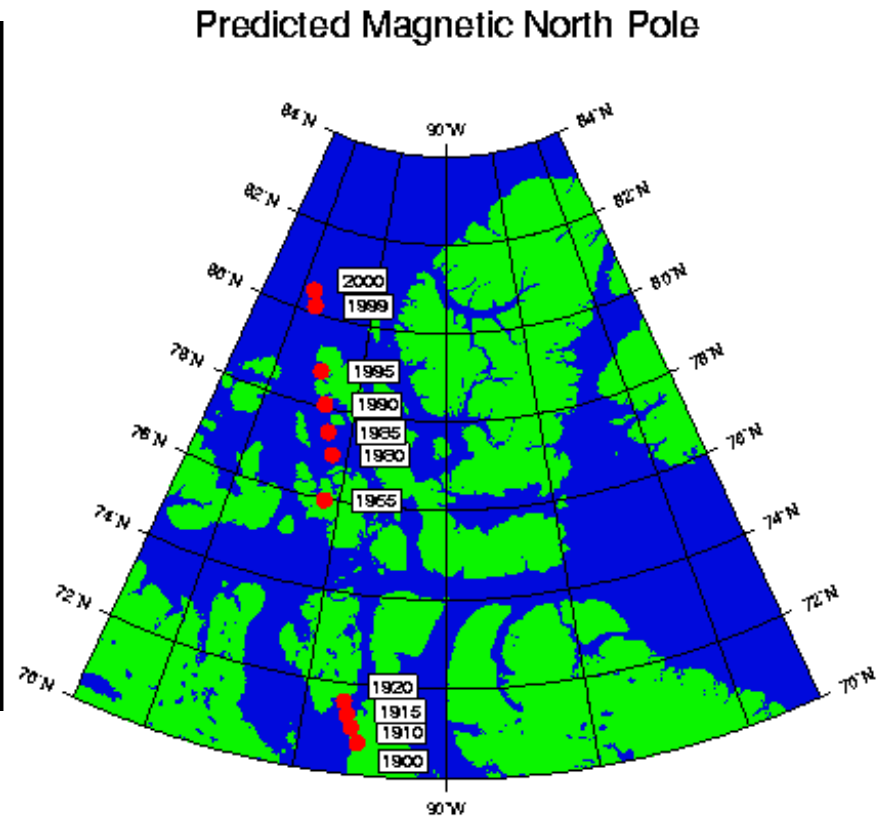
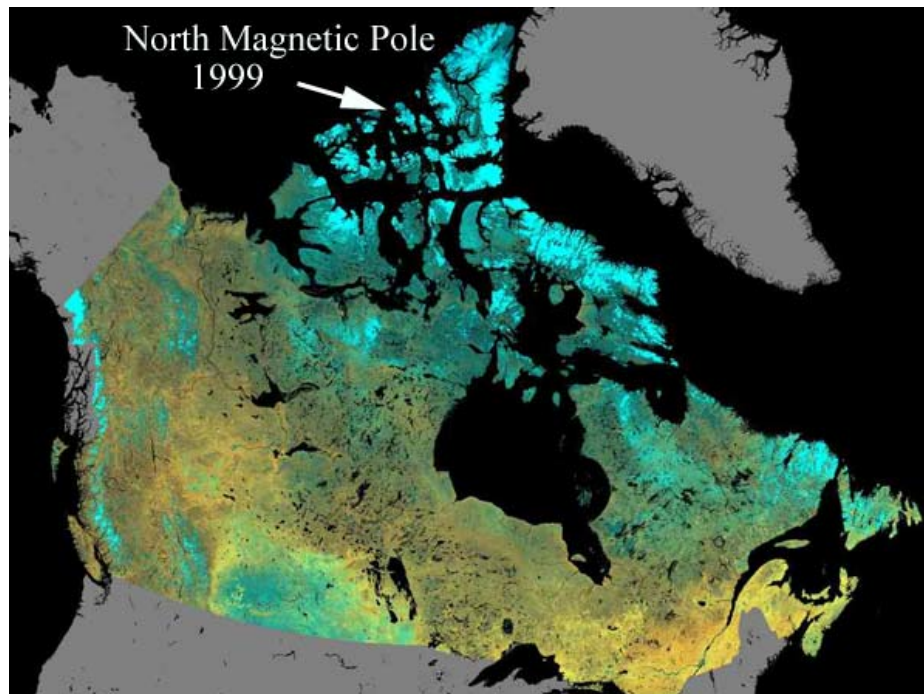
If you've ever used a compass, you've done an experiment with a magnetic field, that from the earth

Note that the magnetic poles don't quite match up with the geographic poles  
...and the N magnetic pole is near the S geographic pole and vice versa



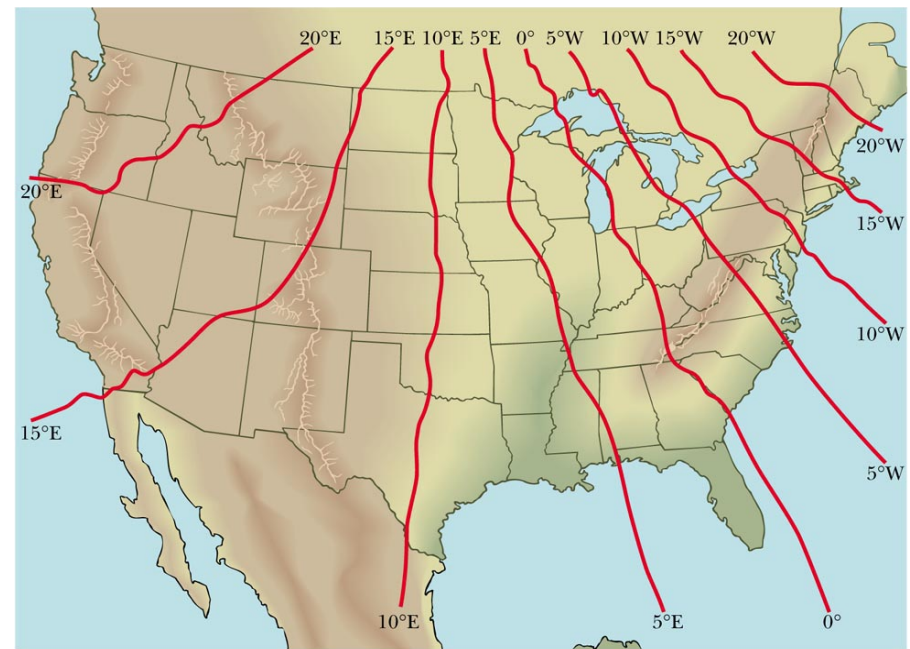


# And it moves



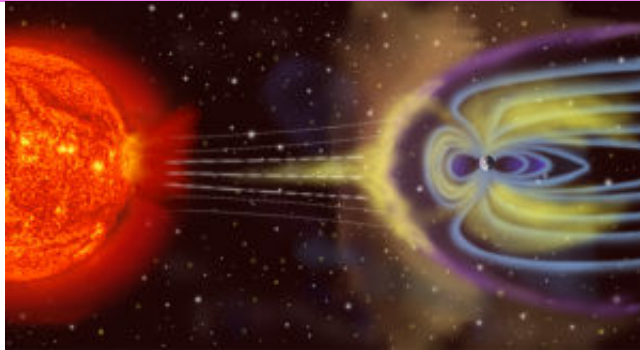
# Magnetic declinations

- Because the magnetic pole does not coincide with the N geographic pole, there is a correction that needs to be made to compass readings
- Not so bad in Michigan

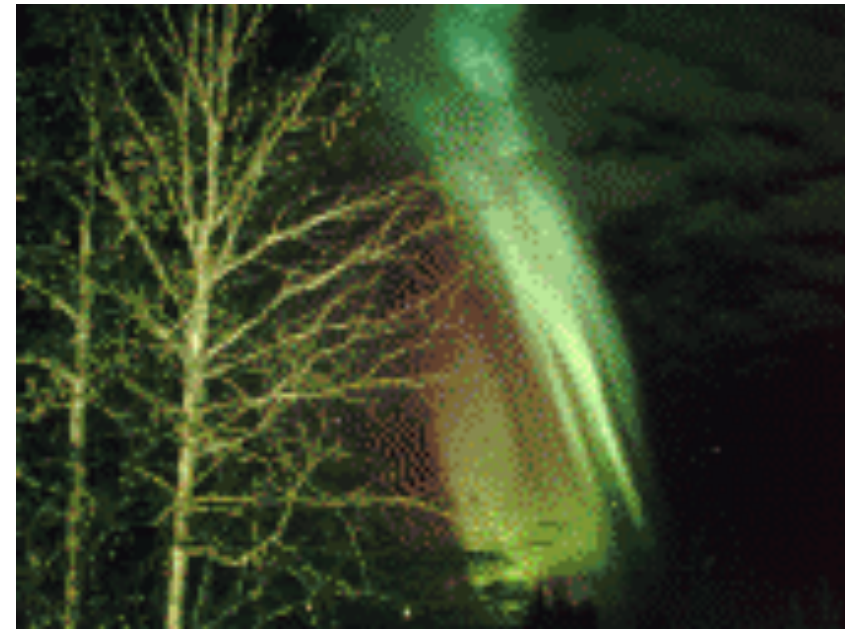


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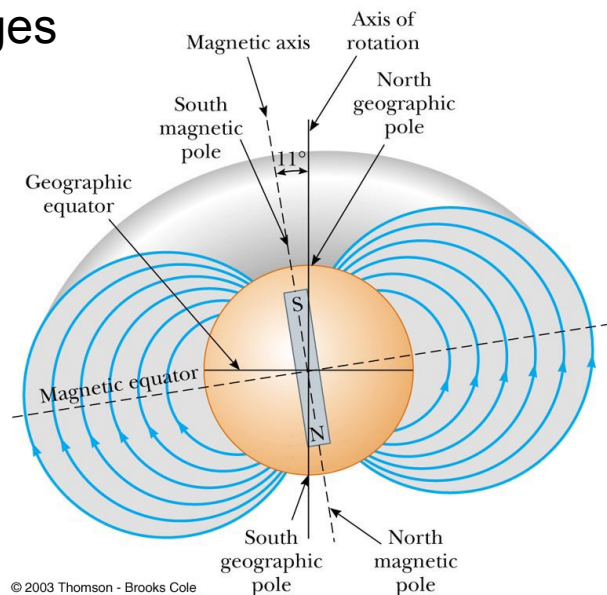
# Earth's magnetic field



creating the  
Aurora Borealis



Charged particles from the sun  
tend to follow magnetic field  
lines to Earth's surface...there's a  
magnetic force on moving  
electric charges



...and the Aurora Australis in  
the southern hemisphere

# More pictures

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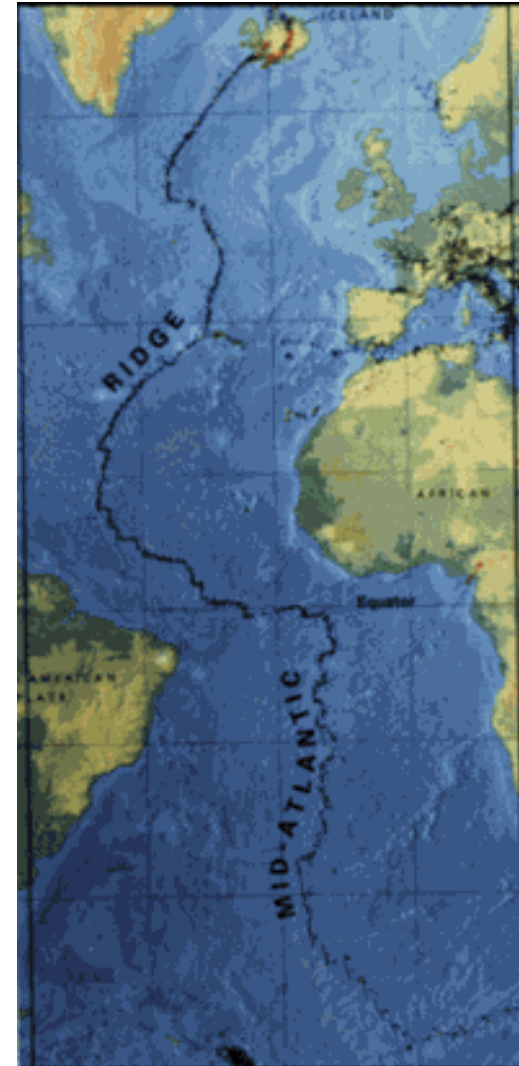
# Earth's magnetic field

- About every million years or so, the earth's magnetic field reverses
  - ◆ S magnetic pole becomes a N magnetic pole and vice versa
  - ◆ we have a complete history of this due to the mid-Atlantic ridge
  - ◆ when lava solidifies, it preserves the direction of the earth's magnetic field at that moment in time
- Wear your radiation badge when this happens

What causes the Earth's magnetic field? Related to large electric currents in liquid portion of Earth's interior.

What causes the Earth's magnetic field to flip?

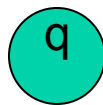
We don't know. There are models.



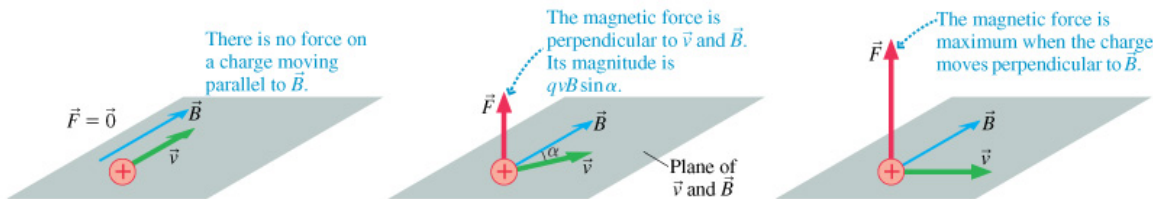
# Magnetic forces on electric charges

- So we believe in the existence of magnetic fields
  - ◆ and magnets exert forces on each other
- What kind of force is exerted on an electric charge?
- Suppose I do a series of experiments involving electric charges and magnetic fields

a charge  $q$  in a region of magnetic field



1. The force on  $q$  is proportional to the magnitude of  $q$
2. The force on  $q$  is proportional to the magnitude of  $B$
3. The force on a negative charge is opposite the force on a positive charge
4. The force is proportional to the velocity  $v$
5. The magnitude and direction of  $F$  depends on the angle between  $v$  and  $B$



$$F = qvB \sin \theta$$

# Magnetic forces on electric charges

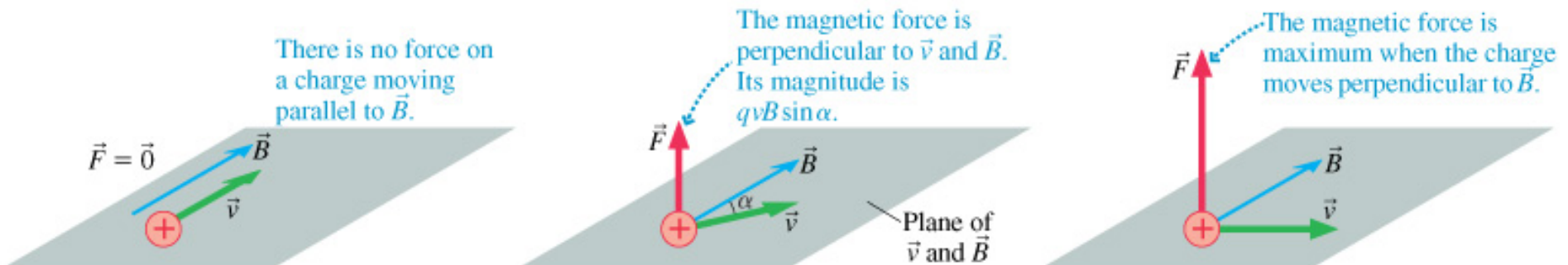
## Like electric forces

1. The force on  $q$  is proportional to the magnitude of  $q$
1. The force on  $q$  is proportional to the magnitude of  $B$
2. The force on a negative charge is opposite the force on a positive charge

## Not like electric forces

4. The force is proportional to the velocity  $v$
5. The magnitude and direction of  $F$  depends on the angle between  $v$  and  $B$

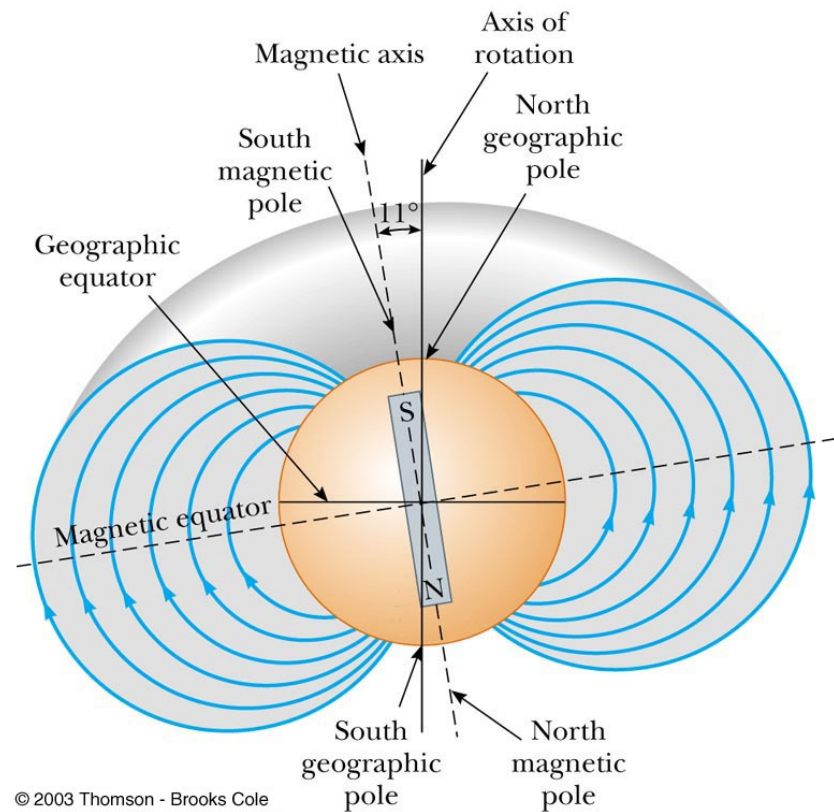
$$F = qvB \sin \theta$$





# Magnetic fields

- Unit for magnetic fields is T(Tesla)
- A 1 T field is a large magnetic field
- The Earth's magnetic field is only about 0.0005 T
- A superconducting magnet can be on the order of 10 T



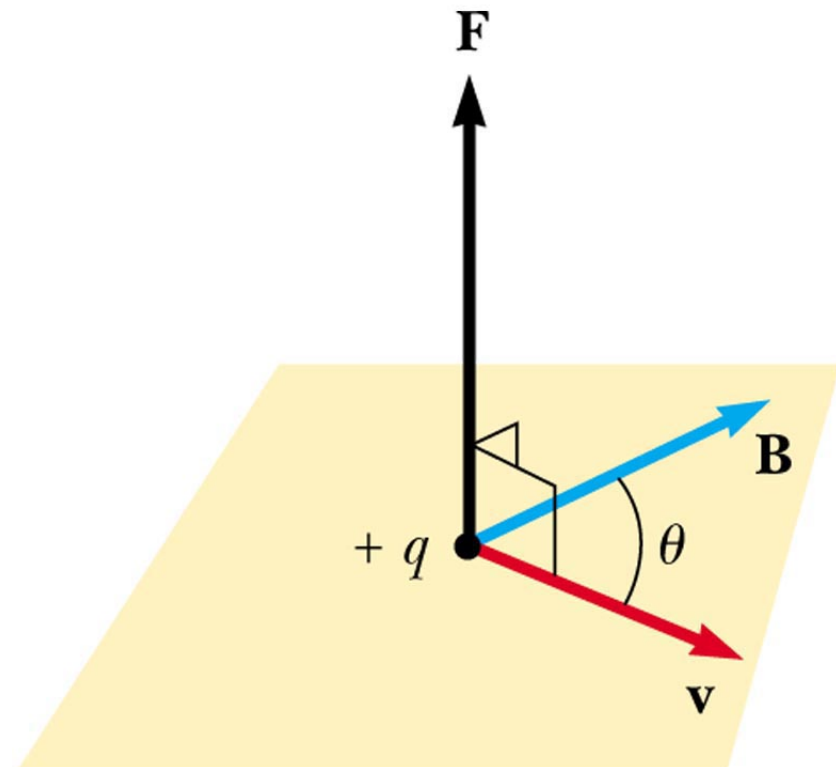
# Clicker question

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- The magnetic force on a charge  $q$  depends on:
  - ◆ a) the value of the charge
  - ◆ b) the value of the magnetic field
  - ◆ c) the value of the velocity of the charge
  - ◆ d) the angle between  $v$  and  $B$
  - ◆ e) all of the above

# Direction of force

- $|F| = qvB \sin \theta$  gives the magnitude
- What about the direction?
- $F$  is perpendicular to  $v$  and to  $B$
- What if I have a magnetic force acting on a charge over a distance  $d$ ?
- How much work does it perform?
  - ◆  $W = Fd(\cos\theta)$
  - ◆ where  $\theta$  is the angle between  $F$  and  $d$
- Zero
- The force is always perpendicular to the displacement



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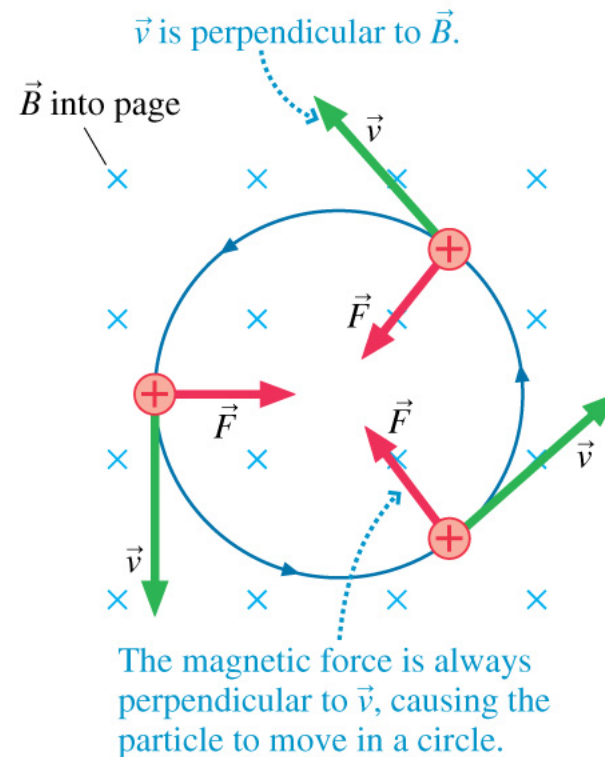
The force changes the direction of the particle, it causes an acceleration, but no change of kinetic energy.

# Motion in a magnetic field

- 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

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

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

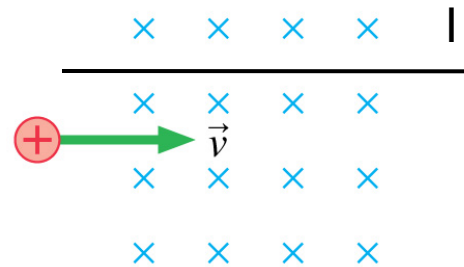


This is what happens in a cyclotron, like the NSCL next door.

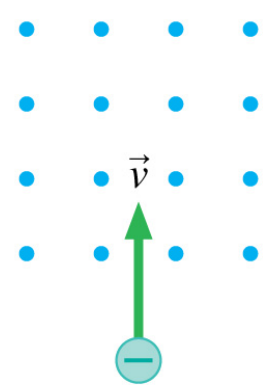
# Forces on currents

- 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 in the same direction as the force would be on the individual moving charges

(a)

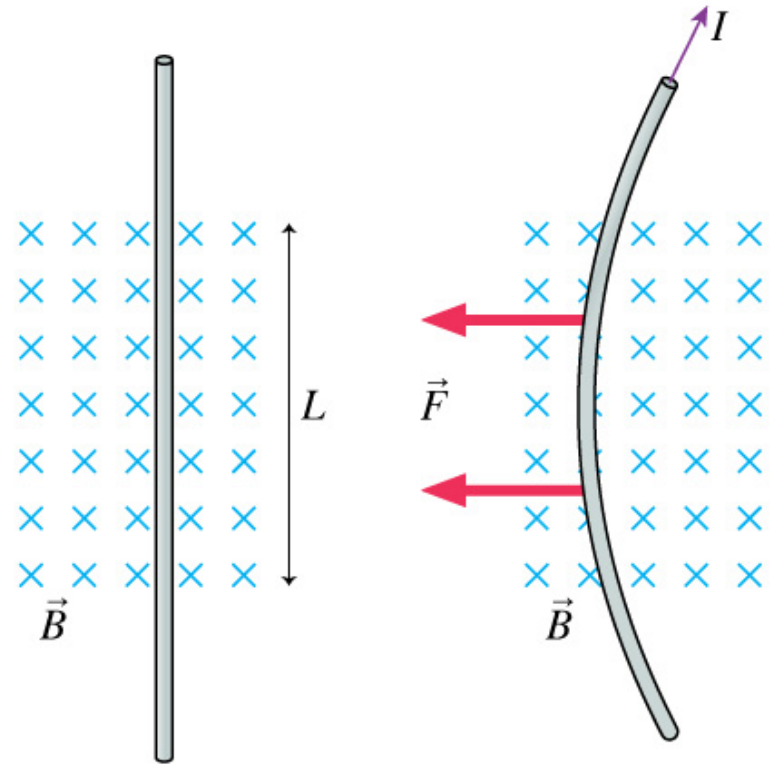


(b)



# Force on a current

- Same direction as force on a positive charge moving in the direction of the current
  - ◆ where we define the direction of the current as the direction that positive charges would move
  - ◆ even though a current is the flow of electrons



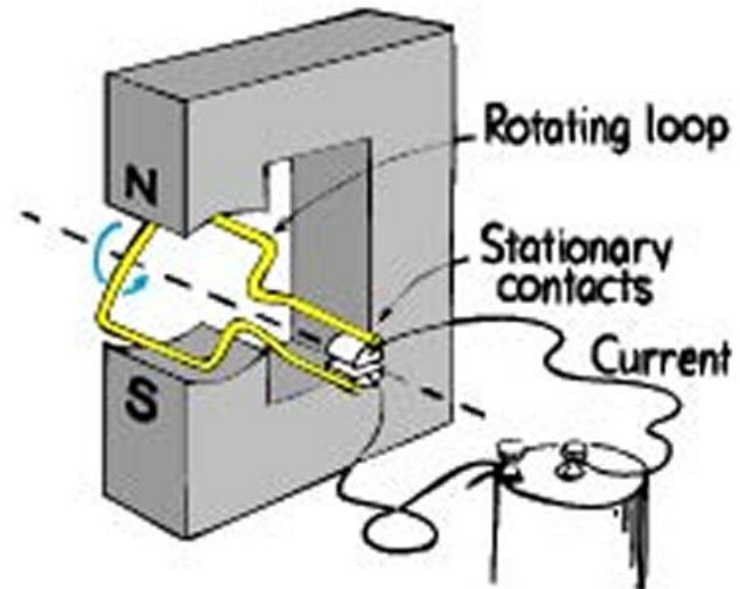
A wire is perpendicular to an externally created magnetic field.

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



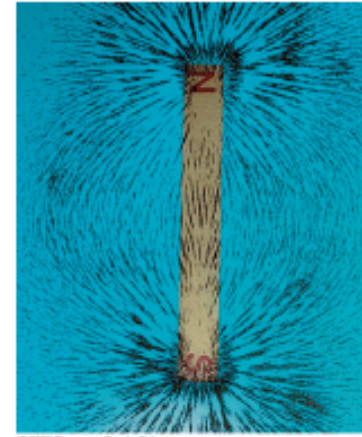
# Electric motors

- How does an electric motor work?
- A current flows through a loop inside a magnetic field
- There's a force (actually a torque) because of the current interacting with the magnetic field that causes the loop to rotate
  - ◆ current in the motor made to change direction every time the coil makes a half rotation
- The rotating coil can be used to run clocks, operate gadgets etc
  - ◆ electricity goes in, work comes out (plus heat)

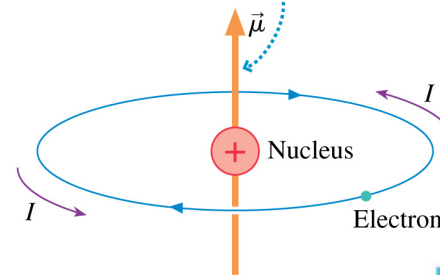


# Magnetism in materials

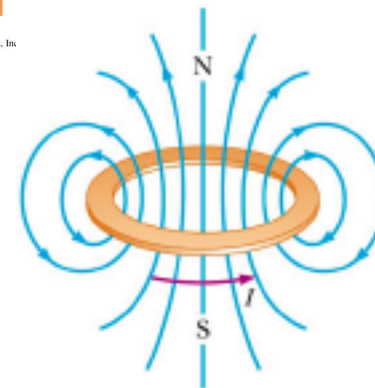
- What causes magnetism in materials?
- We said it has something to do with current loops
- Where do the current loops come from?
- Well the electrons are orbiting around the nucleus and each electron is spinning like a top
- Both of these actions produce current loops, which then produce magnetic moments
- In most materials, the magnetic effects from the electrons cancel each other out
- For some materials this doesn't happen, and they have magnetic properties



Magnetic moment due to the electron's orbital motion

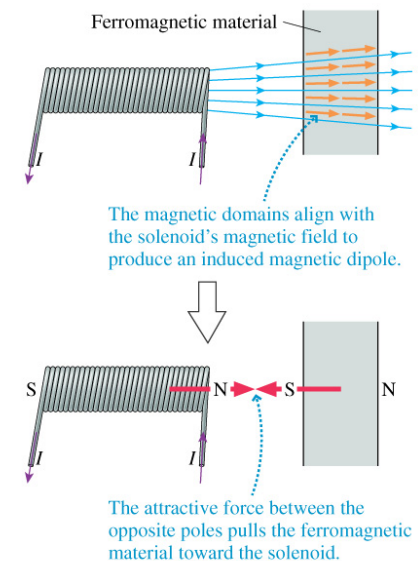
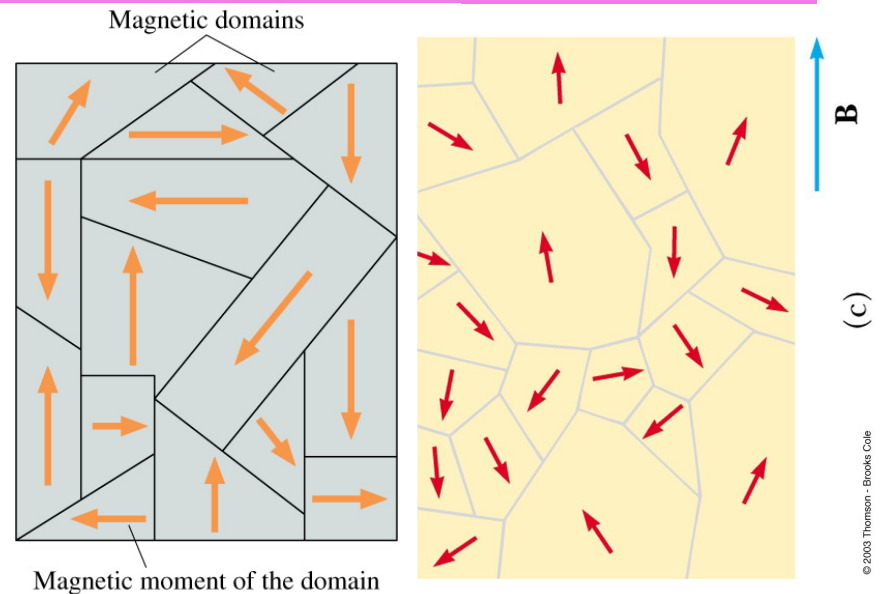


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# Ferromagnetism

- In a ferromagnetic material like iron, all atoms in a domain (typical size 0.1 mm) have their magnetic fields pointed in the same direction
- However, all of the domains are random with respect to each other, unless there is an external magnetic field lining up the domain directions
  - ◆ the domains aligned with  $B$  tend to grow
- In that case, we see an attractive force between the magnet and the ferromagnetic material
- If I can randomize the directions of the domain magnetic moments, then I can eliminate the magnetic force
- I can do that by increasing the temperature which will increase the random motion of the atoms
- I can apply a varying magnetic field which randomizes the directions of the domains
- Or I can bang on it



# Ferromagnetism

- What makes a permanent magnet?
- Depends on crystalline structure of material
- Pure iron does not make a good magnet because it's easy to get the domains to un-align themselves
- But an alloy of steel with 51% iron, 24% cobalt, 14% nickel, 8% aluminum and 3% copper has permanent magnetic properties and is used to make permanent magnets
- Most stainless steels, with chromium and nickel, have virtually no magnetic properties

