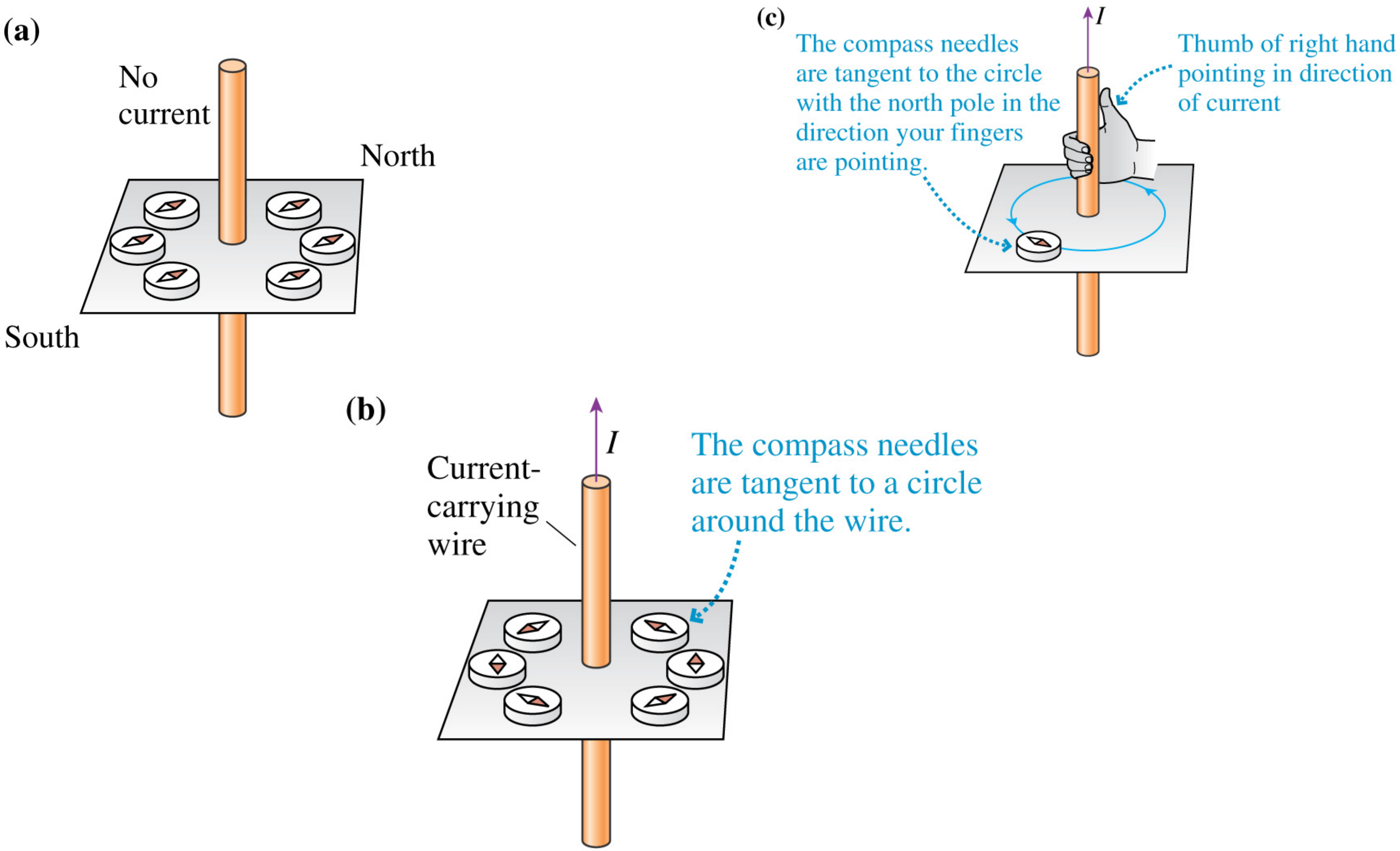
PHY294H

- 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: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **hand-in problem for next Wed: 31.79**
- 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

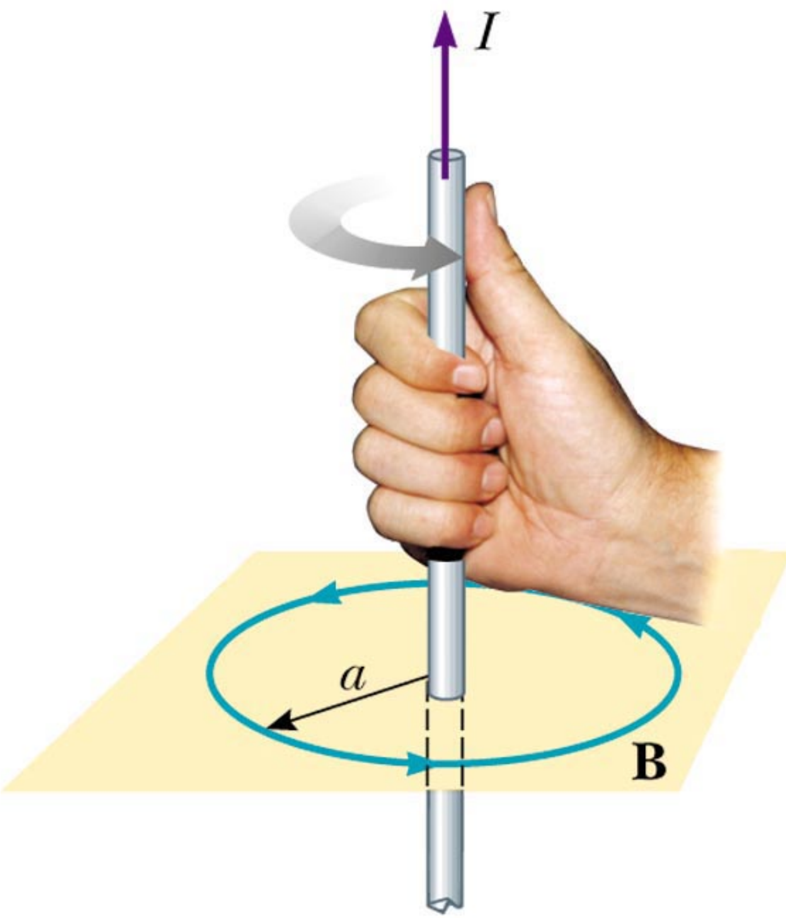
Heinrich Hertz

- I'm sure you already marked it on your calendars, but today is his birthday (b:1857)
- His experiments (to be discussed later) showed the existence of electromagnetic waves (intuited by Faraday, predicted by Maxwell)

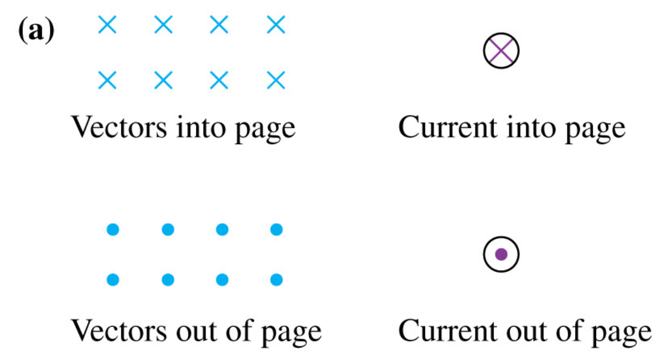
Direction of B field from a current

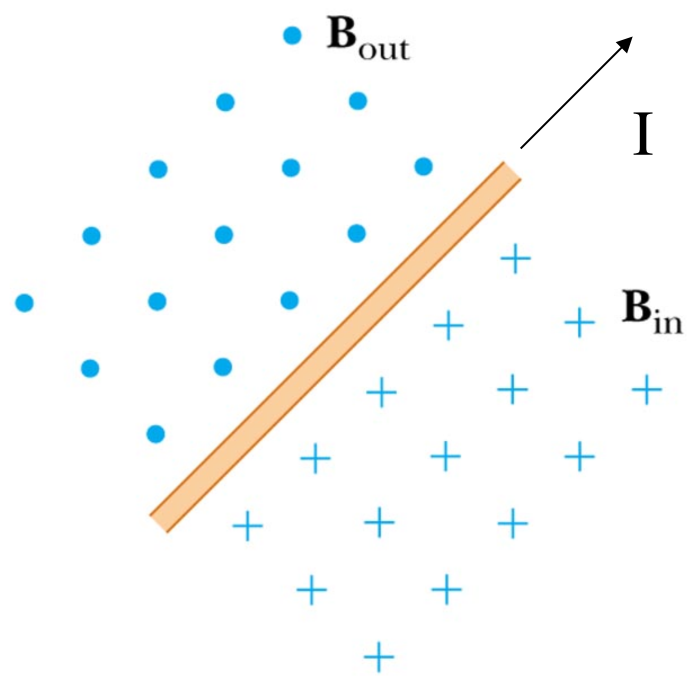


With magnetic fields, you have to work with all 3 dimensions



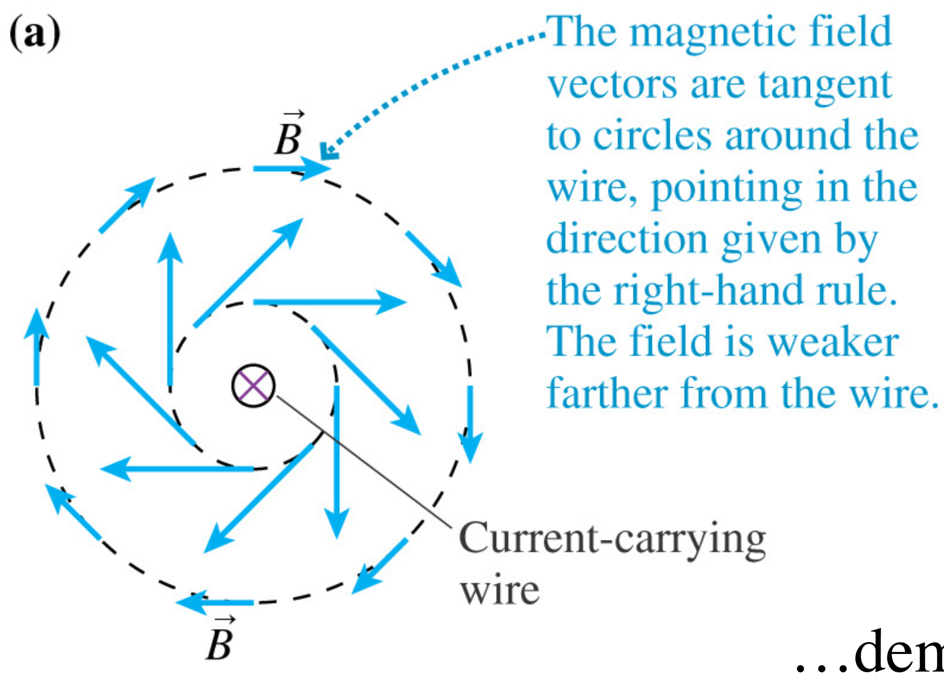
(a)

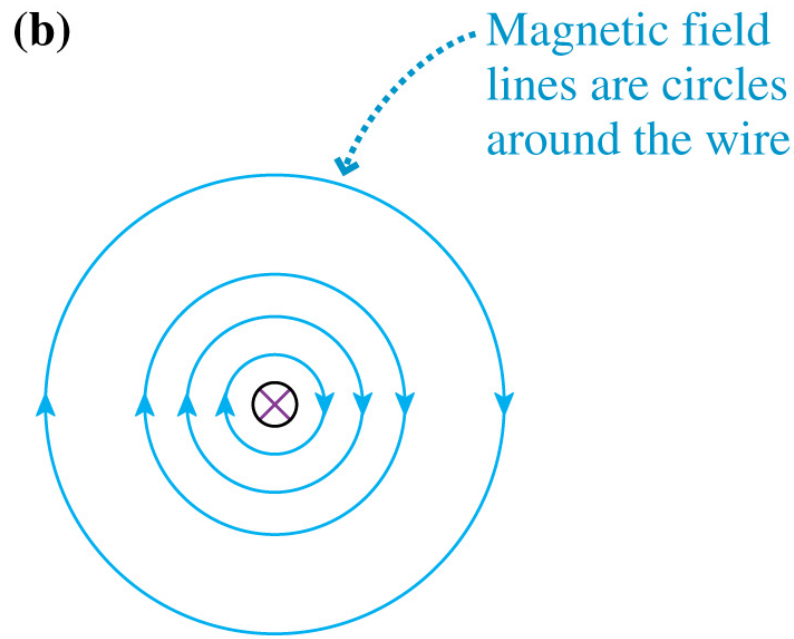




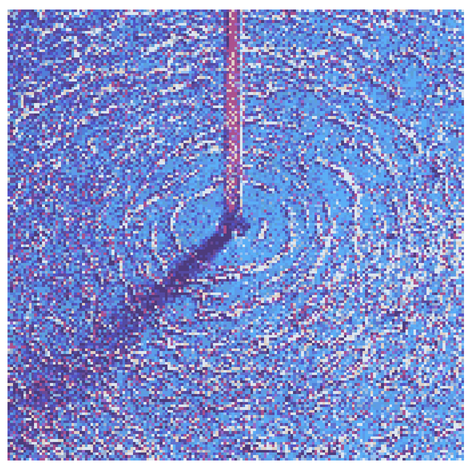
(c)

Magnetic field from a long straight wire



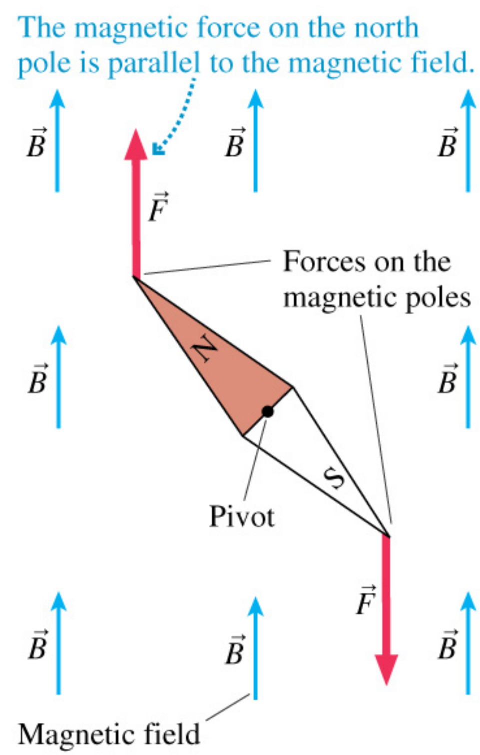


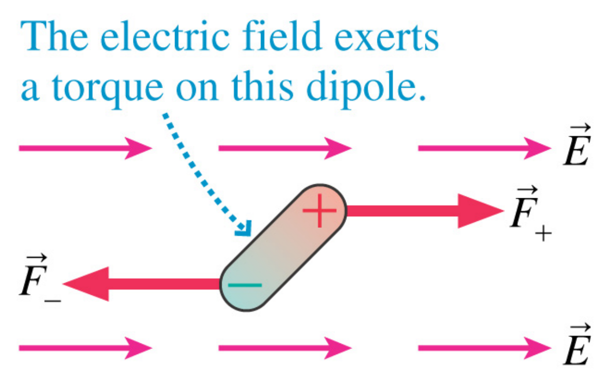
…demo



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
- We’ve seen this before, with an electric dipole in an electric field

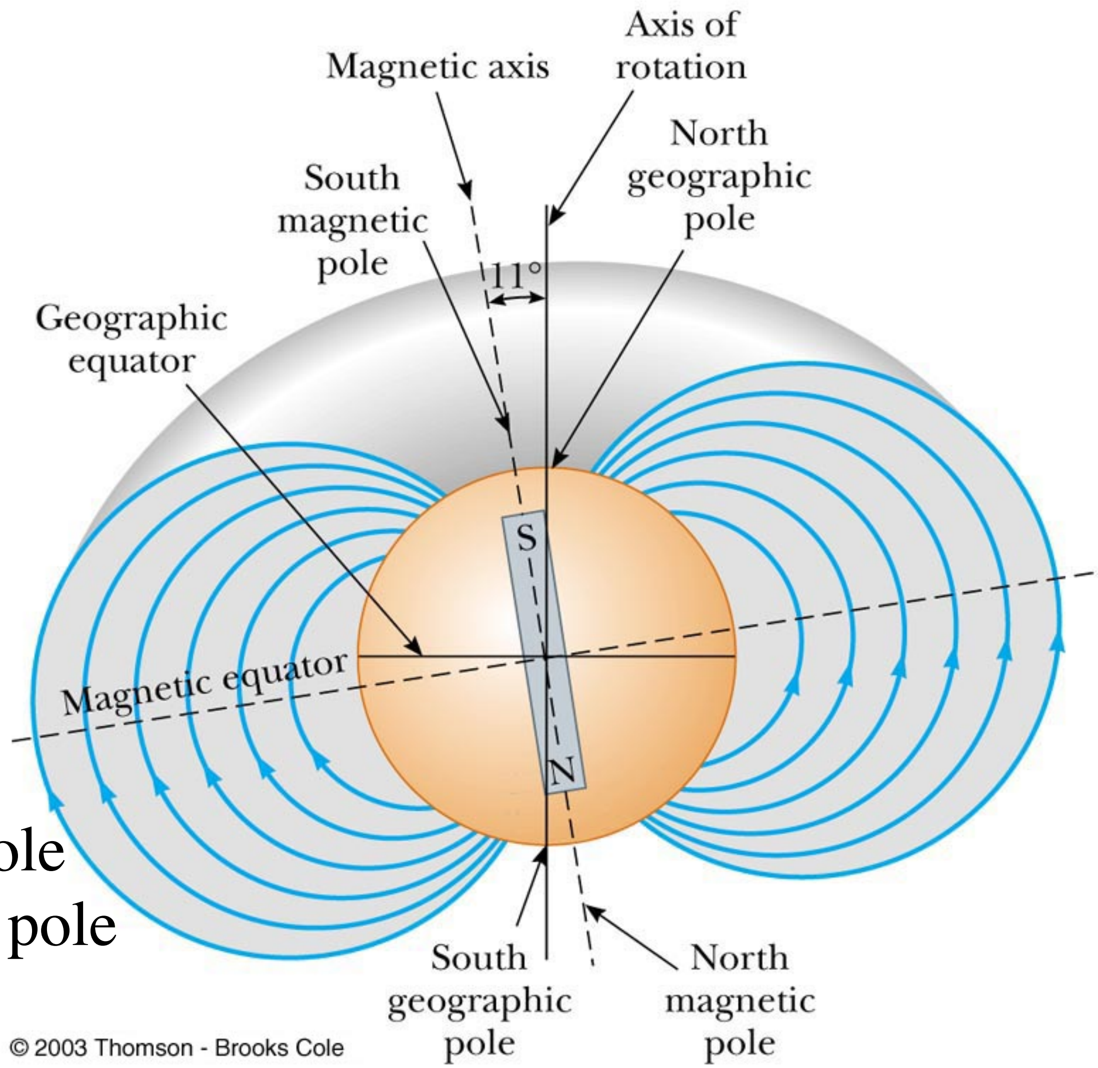




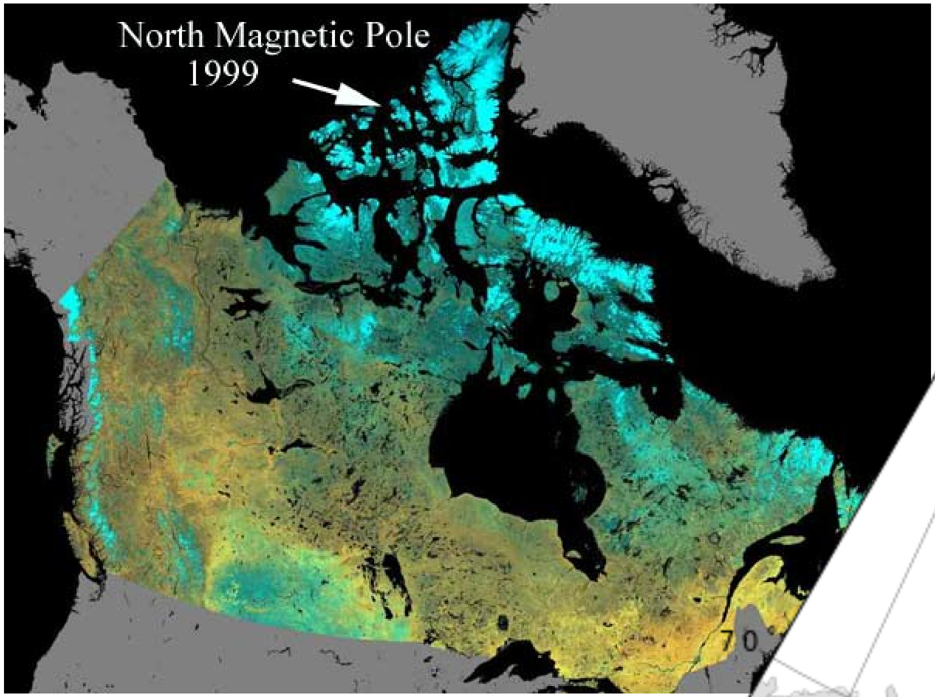
Earth's magnetic field

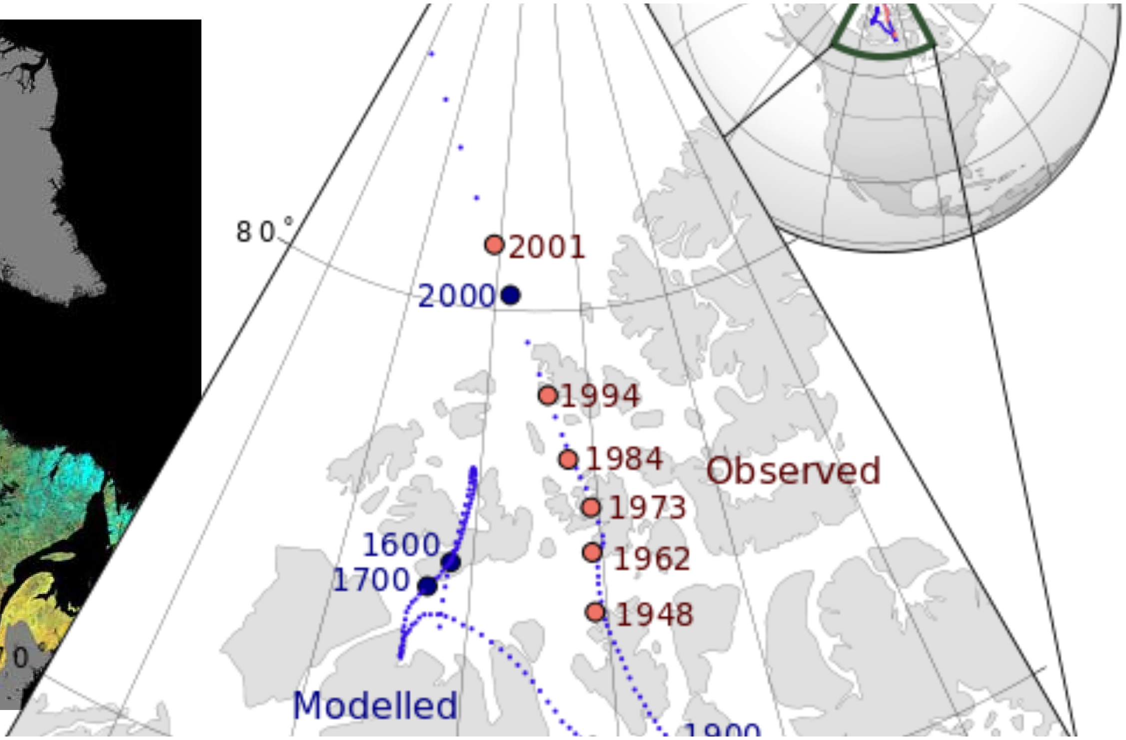
If you've ever used a compass, you've done an experiment with a magnetic field, that from the earth

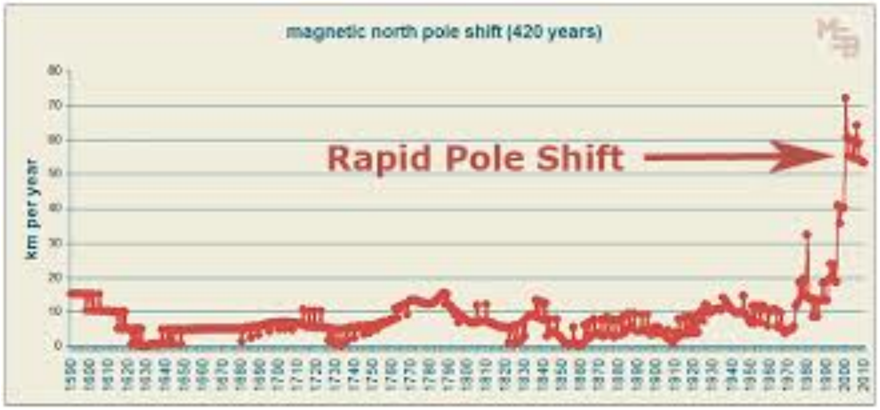
Note that the magnetic poles don't quite match up with the geographic poles
…and the N magnetic pole is near the S geographic pole and vice versa



And it moves



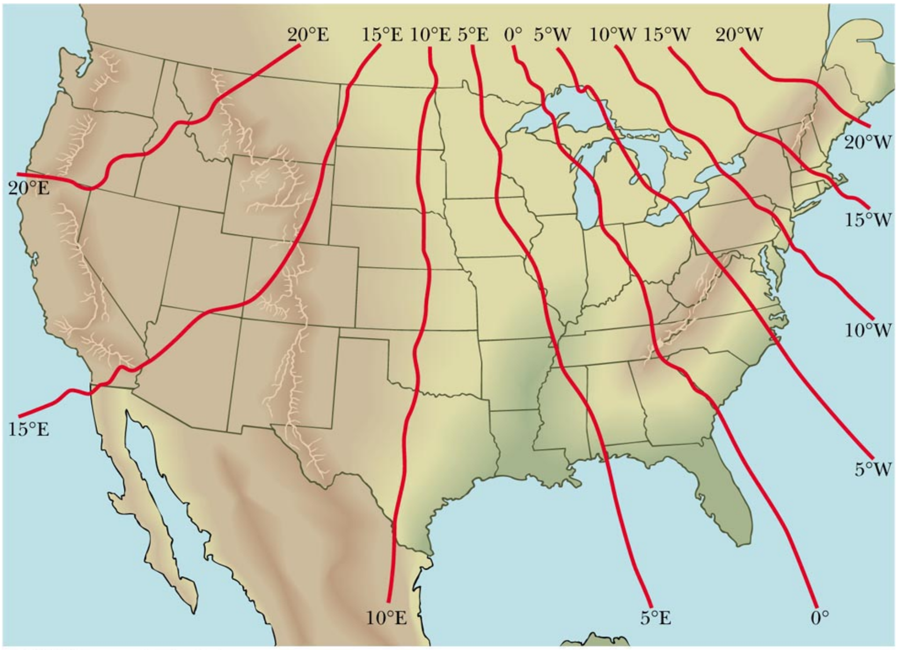




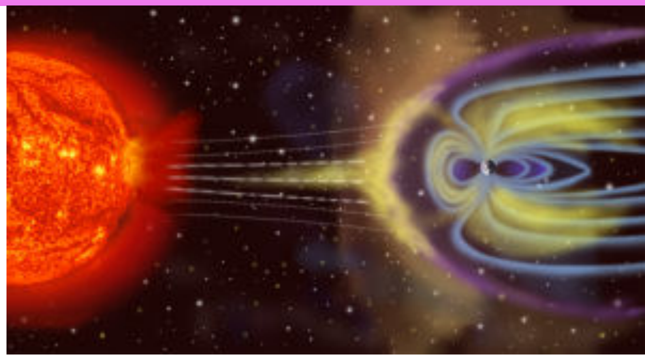
The shifting seems to be accelerating.

Magnetic declinations

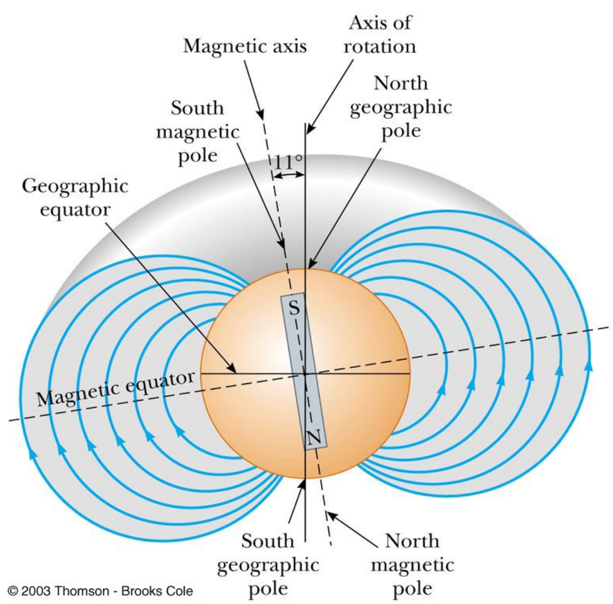
- Because the magnetic pole does not coincide with the N geographic pole, there is a correction that needs to be made to compass readings
- Not so bad in Michigan



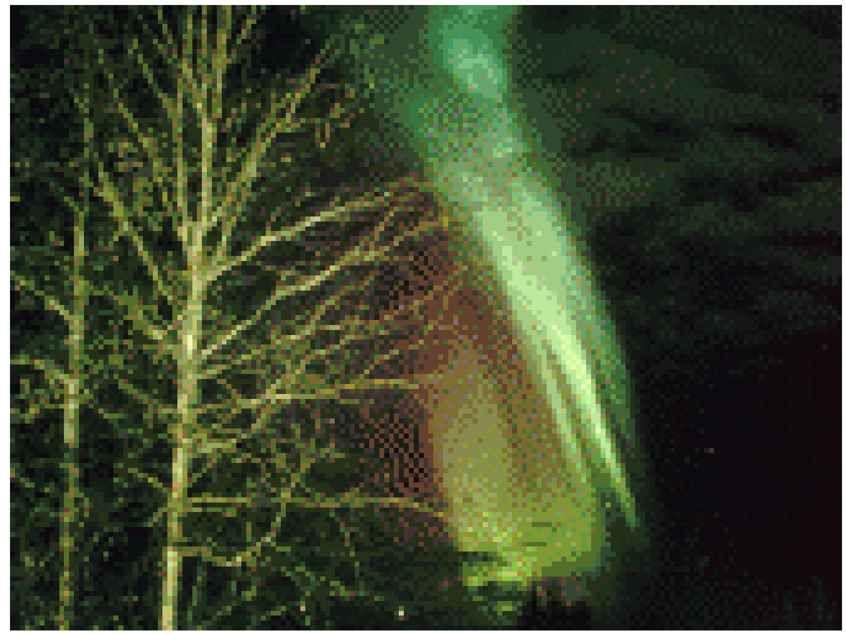
Earth's magnetic field



Charged particles from the sun tend to follow magnetic field lines to Earth's surface



creating the Aurora Borealis

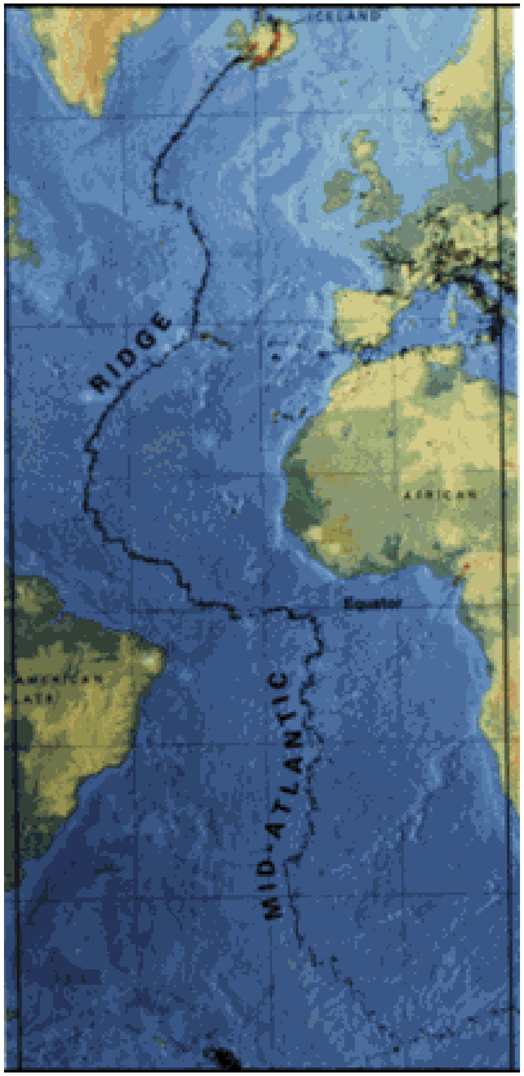


…and the Aurora Australis in the southern hemisphere

More pictures

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



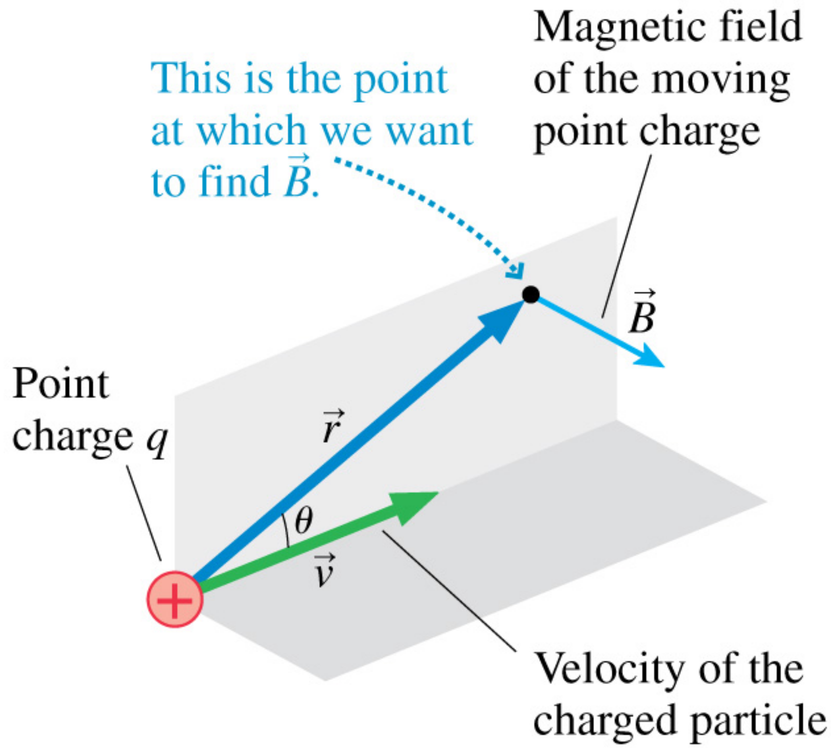
What causes the Earth's magnetic field? Related to large electric currents in liquid portion of Earth's interior.

What causes the Earth's magnetic field to flip?

We don't know. There are models.

Magnetic field from a moving charge

- As I stated earlier, moving electric charges are the source of magnetic fields
- Suppose I have a charge q moving with a velocity v
- Then I can write that the magnetic field B created by this charge is

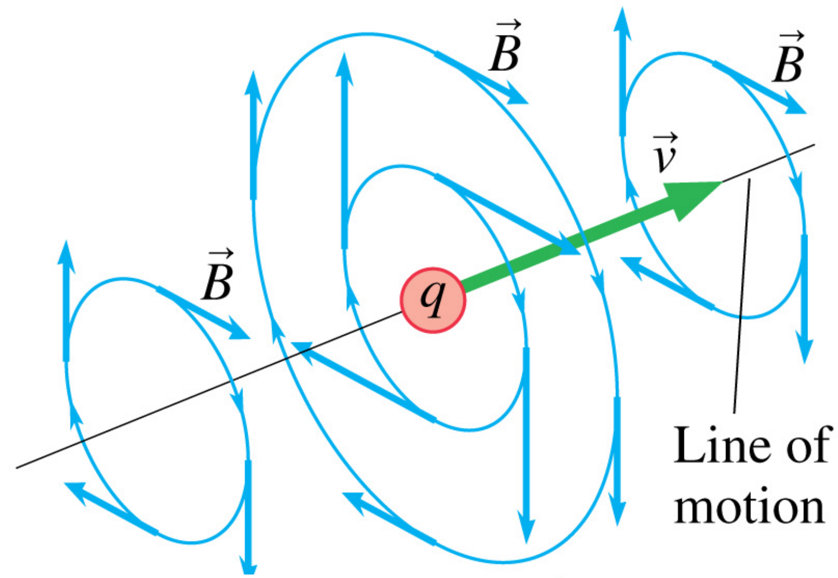


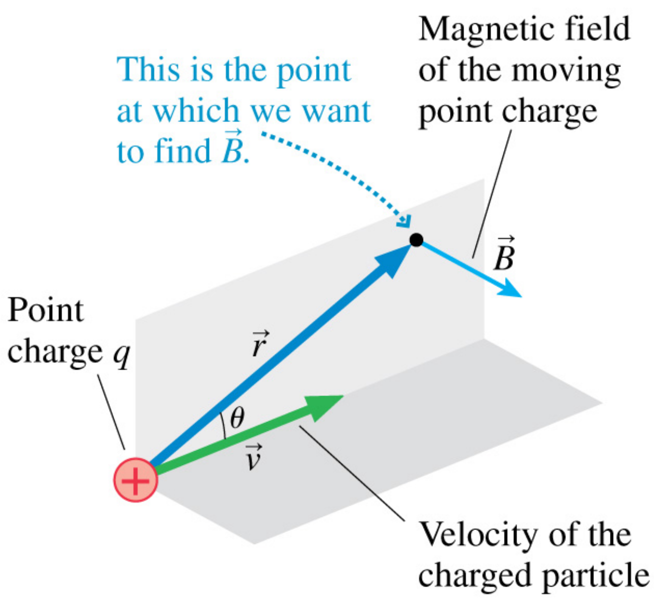
$$\vec{B} = \frac{\mu_o}{4\pi}\frac{qv\sin\theta}{r^2}$$

…where the direction of B is perpendicular to the plane determined by v and r and is given by the right-hand rule

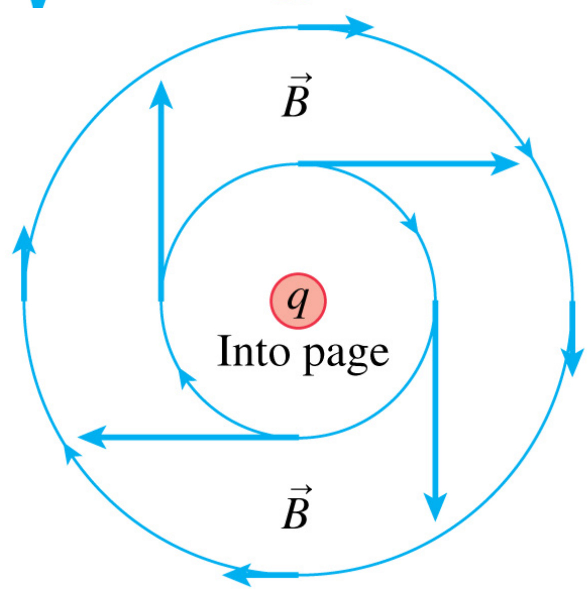
Direction given by RHR

- Place your thumb in the direction of $\vec{v}$
- The magnetic field $\vec{B}$ is perpendicular to the plane defined by $\vec{v}$ and $\vec{r}$, in the direction your fingers curl





note that if q were -, the field would be in the opposite direction



Biot-Savart Law

$$\vec{B} = \frac{\mu_o}{4\pi}\frac{qv\sin\theta}{r^2}$$

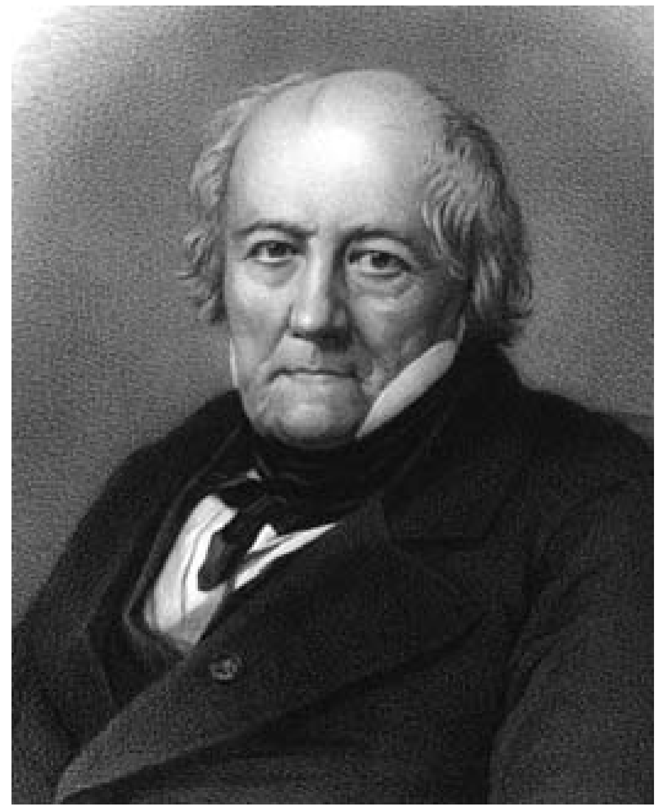
this is an empirical law, i.e. based on experimental measurements

where we now have a new constant μ_o as important for B fields as ε_o is for E fields

$\mu_o = 4\pi \text{ X } 10^{-7}$ T·m/A

T (Tesla) is the unit for magnetic fields; 1 T = 1N/A·m

surface of the earth	$5\text{X}10^{-5}$ T
refrigerator magnet	$5\text{X}10^{-3}$ T
superconducting magnet	10 T



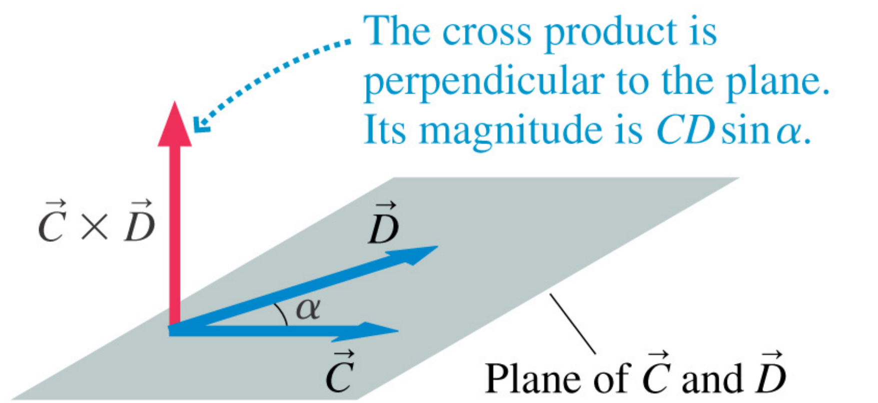
Biot (couldn't find Savart)

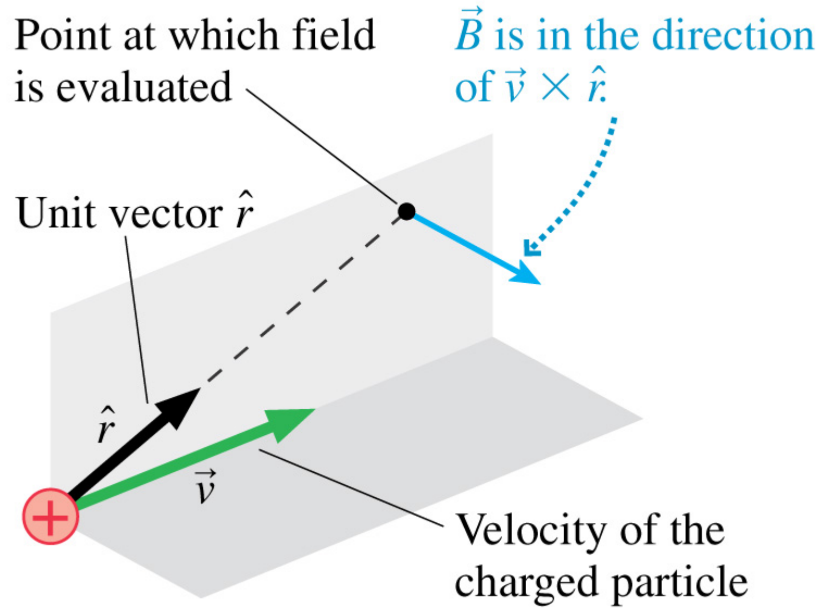
Cross product

- Using the vector cross product, I can write the expression for the magnetic field from a moving charge in a more concise way

$$\vec{B} = \frac{\mu_o}{4\pi}\frac{q\vec{v}x\hat{r}}{r^2}$$

…where $\hat{r}$ is a unit vector from the charge to the point we want to calculate the field





Biot-Savart law in terms of currents

- We have written the B-S law in terms of a charge ΔQ moving with a velocity v

$$\vec{B} = \frac{\mu_o}{4\pi}\frac{\Delta Q \vec{v} x \hat{r}}{r^2}$$

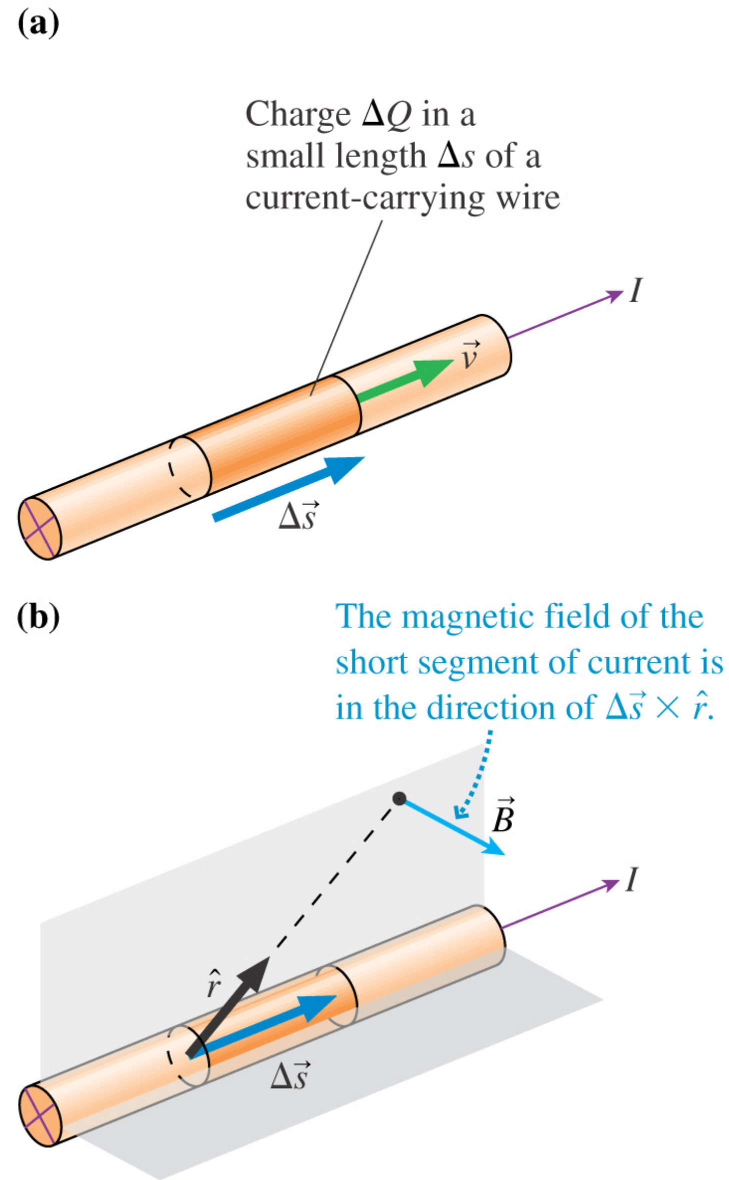
- But it's usually more convenient to define in terms of a current I

$$\Delta Q v = \Delta Q \frac{\Delta s}{\Delta t} = I \Delta s$$

- so

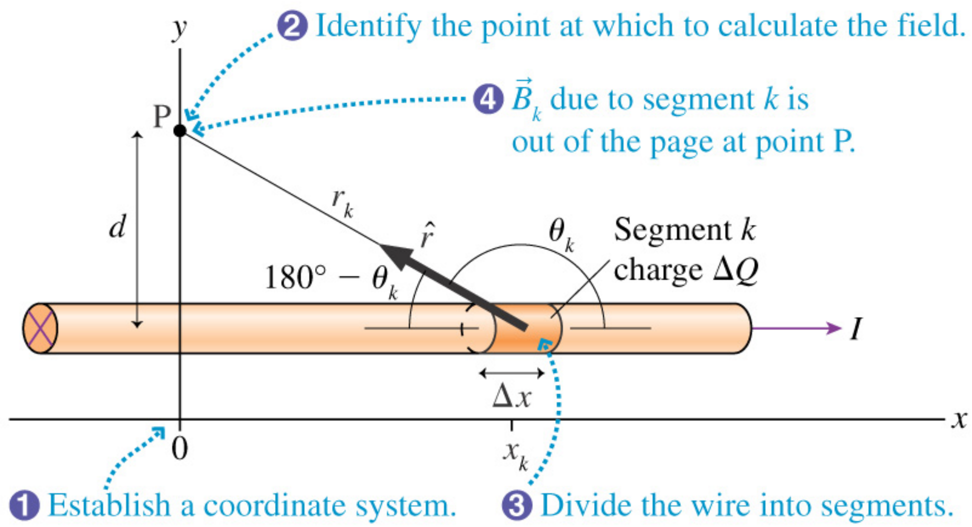
$$\vec{B} = \frac{\mu_o}{4\pi}\frac{I \vec{\Delta s} x \hat{r}}{r^2}$$

…or $$d\vec{B} = \frac{\mu_o}{4\pi}\frac{I d\vec{s} x \hat{r}}{r^2}$$



Magnetic field from a current in a straight wire

- We want to calculate the magnetic field at point P, which we have chosen to be on the y axis, from a current I
- We will apply the Biot-Savart law to a section of the wire Δx and then integrate over the entire length of the wire
- Note that from the right-hand rule that the resulting magnetic field (at point P) is out of the plane of the page

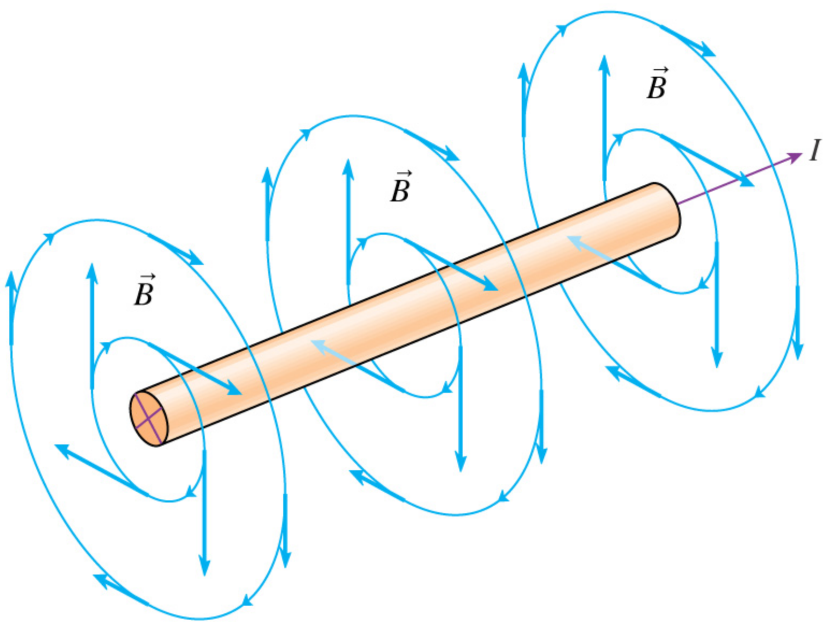


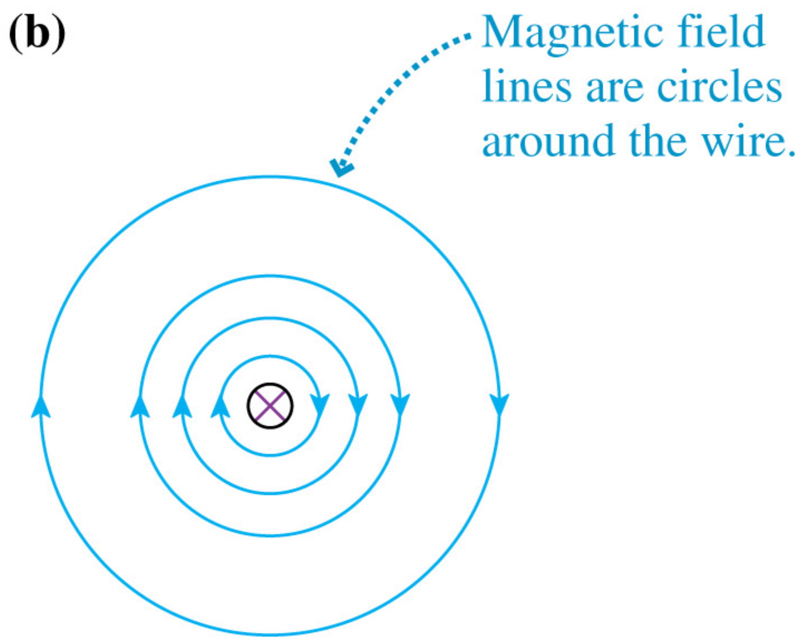
$$\vec{B}_k = \frac{\mu_o}{4\pi}\frac{I\,\vec{\Delta x} x \hat{r}}{r^2}$$

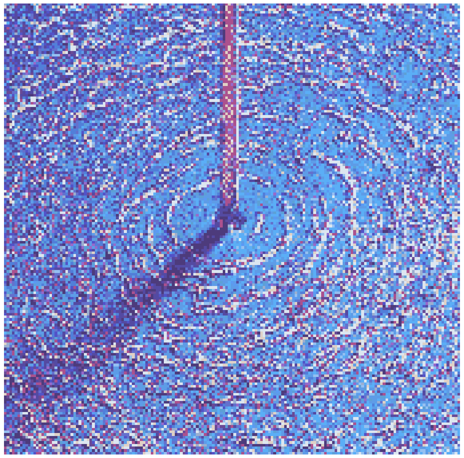
Magnetic field from a straight wire

- The magnetic field falls off as 1/r (or 1/d using the variable from the previous page)

$$B_k = \frac{\mu_o}{2\pi}\frac{I}{d}$$

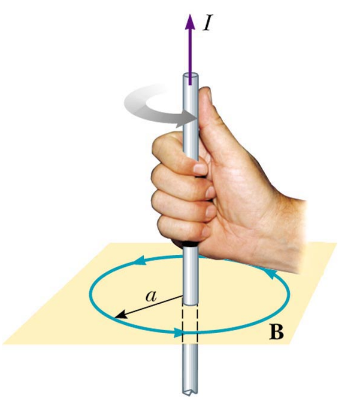




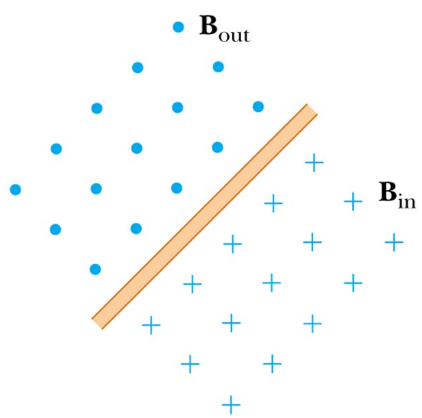


Example

- Suppose I_1=6.69 A and I_2=5.40 A
- What is the magnetic field at point P (3.79 m, 2.14 m)?



(a)



(c)