Announcements

Exam scores will be uploaded to Blackboard Learn:

Machine-graded scores will appear this week.

Hand-graded scores will appear next week.

Last Time

- Review definitions of electric potential
- Potential at one point
- Potential inside a conductor
- Potential inside an insulator
- (Energy stored in a field)

Today

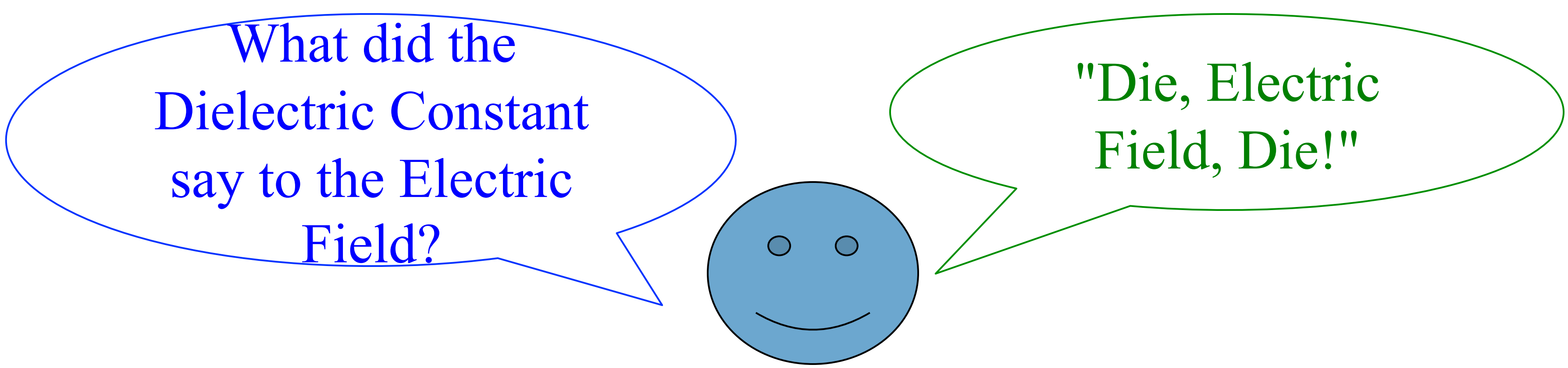
- Energy stored in a field
- Sources of Magnetic Field
- Magnetic Field due to Moving Charges
- Cross Products: Right-hand Rule
- Cross Products: Mathematically

Dielectric Constant

Inside an insulator: $\vec{E}_{\text{net}} = \dfrac{\vec{E}_{\text{applied}}}{K}$

Dielectric constant for various insulators:

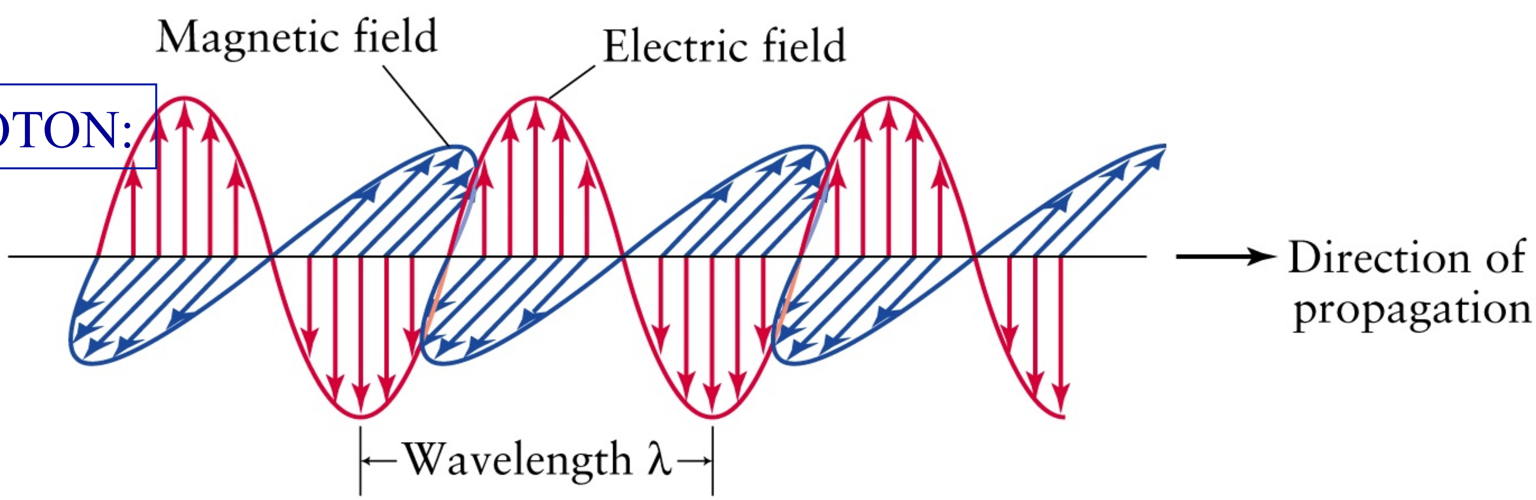
vacuum	1 (by definition)
air	1.0006
typical plastic	5
NaCl	6.1
water	80
strontium titanate	310



Energy stored in a field

- Rather than potential energy, we can talk about the energy of the EM field
- This is useful because radiation (e.g. light) carries energy, and we may want to know how much
- Instead of a change in potential energy, we can say that rearranging charges changes the field energy

PHOTON:



http://www.physast.uga.edu/~jss/1010/ch5/ovhd05.html

iClicker question

Field energy density

$$E \approx \frac{Q/A}{\epsilon_o} \qquad W = (Q^2/2A\varepsilon_o)\,\Delta s$$

- We could write
- $\Delta K + \Delta U = W$, since $\Delta K = 0$, $\Delta U = W$
- Or, instead of potential energy, we can think of it as field energy
- $\Delta K + \Delta U_{field} = W$, $\Delta K = 0$, $\Delta U_{field} = W$
- This means $\Delta U_{field} = Q^2/2A\varepsilon^{o}\Delta s = ½\varepsilon_0 E^2 A\Delta s = ½\varepsilon_0 E^2 \Delta V$

Volume, not potential

Energy density

- So, $\frac{\Delta U}{\Delta V} = \frac{1}{2} \epsilon_0 E^2$

Key Ideas in Chapter 18: Magnetic Field

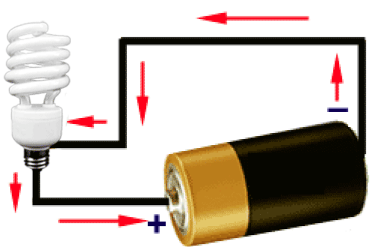
- **Moving charged particles make a magnetic field, which is different from an electric field.**
- **The needle of a magnetic compass aligns with the direction of the net magnetic field at its location.**

- **A current is a continuous flow of charge.**
  - Electron current is a number of electrons per second entering a section of a conductor.
  - Conventional current (Coulombs/second) is opposite in direction to the electron current, and is assumed to be due to positively charged particles.
- **The superposition principle can be applied to calculate the expected magnetic field from current-carrying wires in various configurations.**
  - A current-carrying loop is a magnetic dipole.
  - A bar magnet is also a magnetic dipole.
  - Even a single atom can be a magnetic dipole!

What happens when...

- Compass is isolated?

- Magnet is near a compass?



- Current-carrying wire is near compass?

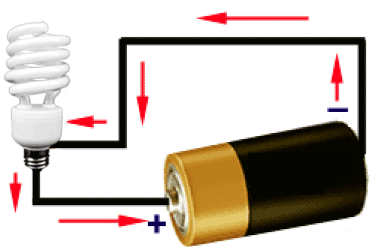
What happens when...

- Compass is isolated?

  Points to Earth's (magnetic) North Pole

- Magnet is near a compass?

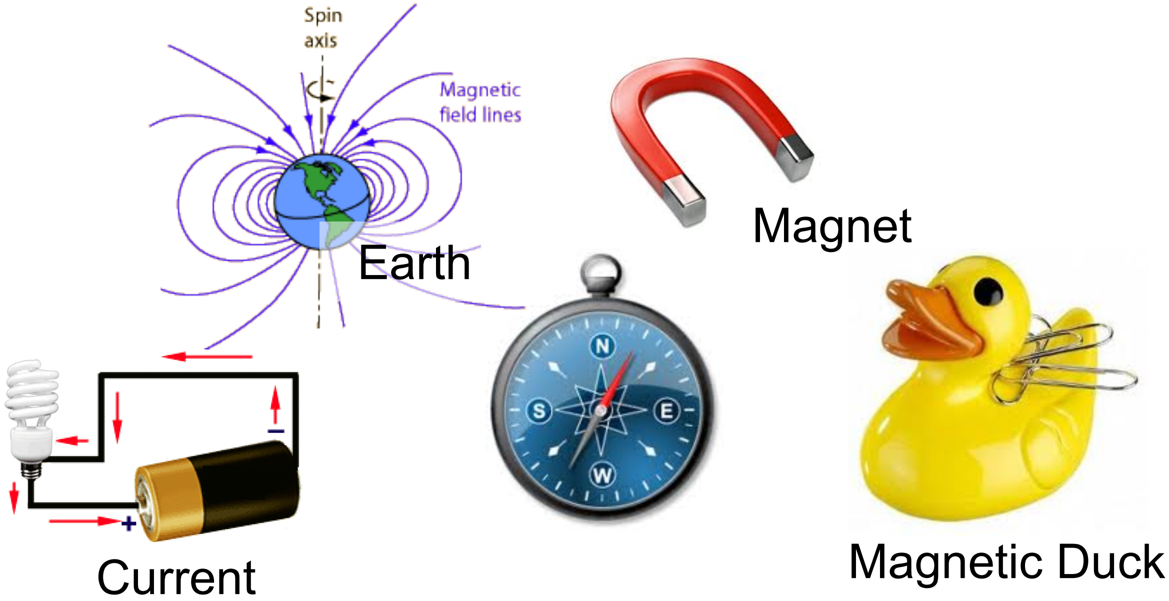
  Needle deflects



- Current-carrying wire is near compass?

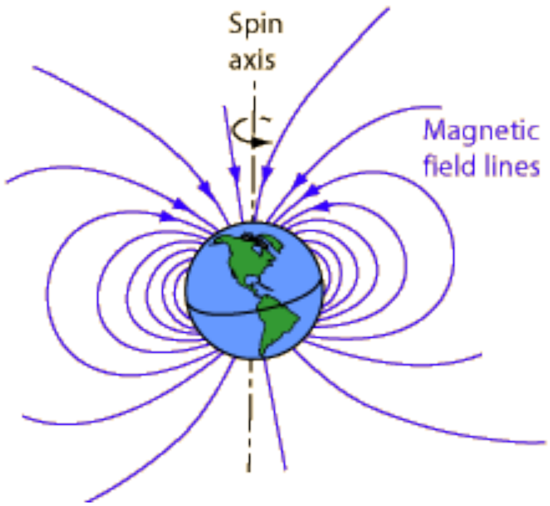
  Needle deflects!

Compass Needle and Magnetic Field

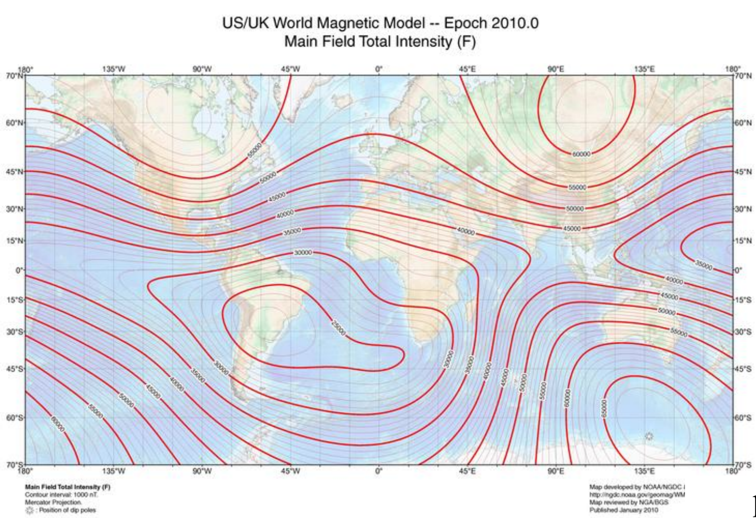


Key Idea: Needle of a compass aligns with the Net Magnetic Field (no matter what the source).

Fun Facts: Earth's Magnetic Field



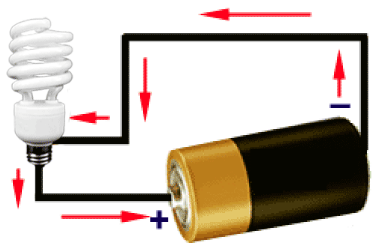
- $\boxed{|B_{Earth}| \sim 20 \text{ microTesla}} = 2 \times 10^{-5}$ T
- Tilted by 11.3 degrees from Rotational Axis
- "Sign reversals" throughout Earth's history
- Not due to liquid core!   Rocks would look solid.
- Rocks slowly "creep" due to defects, cracks...



http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html

http://www.ngdc.noaa.gov/geomag/WMM/data/WMM2010/WMM2010_F_MERC.pdf

Compass Near a Wire



- Depends on amount of current in wire
- No current → no Magnetic field (**B**) from wire
- **B**-field of wire is perpendicular to the wire

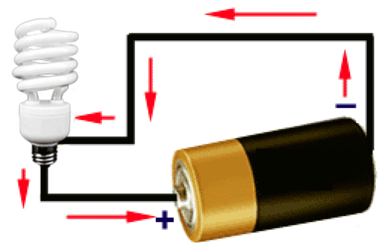
What happens when wire is below vs. above compass?

- **B**-field switches direction!

Key Idea: Needle of a compass aligns with the net magnetic field.

Current and Magnetic Field

Why does the wire act like a magnet?



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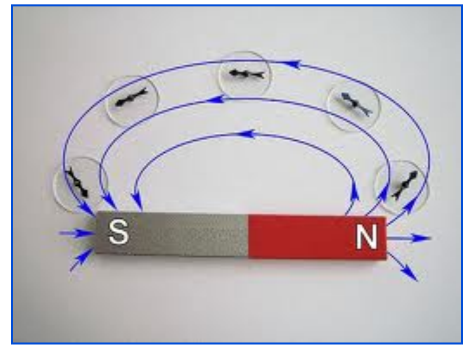
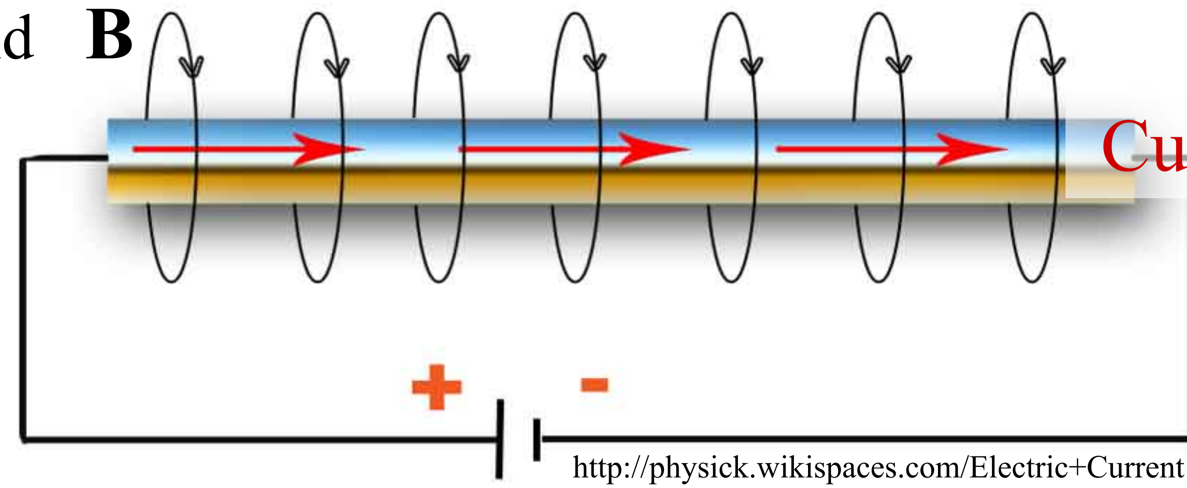




Key Idea: Moving charges create a Magnetic Field

Biot-Savart Law

Key Idea: Moving charges create a Magnetic Field

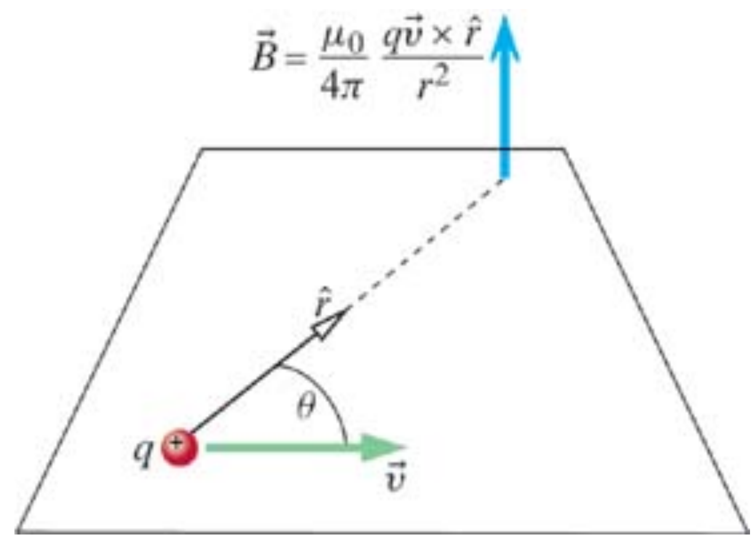
$$\vec{B} = \left(\frac{\mu_o}{2\pi}\right)\frac{q\vec{v} \times \vec{r}}{|r|^2}$$

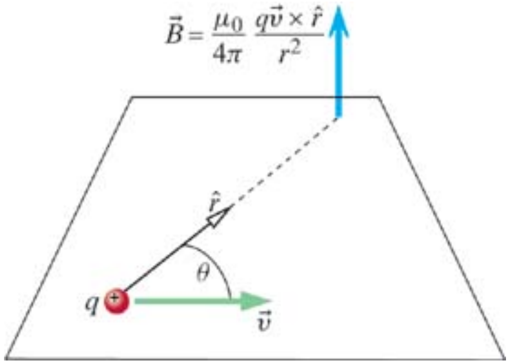
BIOT-SAVART LAW
point charge

q = charge

$\vec{v}$ = velocity of charge

$\vec{r}$ = observation point
(charge at origin)

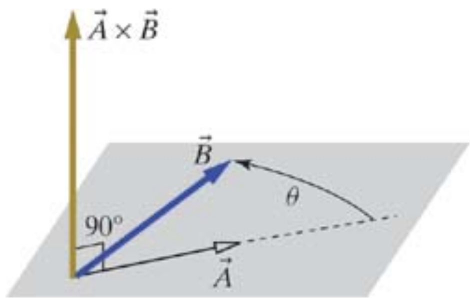




Right-Hand Rule

$$\vec{B} = \left(\frac{\mu_o}{2\pi}\right)\frac{q\vec{v}\times\vec{r}}{|r|^2}$$

BIOT-SAVART LAW
point charge

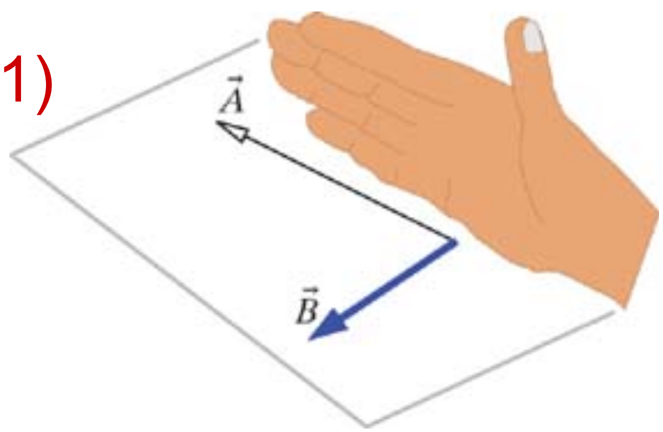


Result of Cross Product $\vec{v}\times\vec{r}$

is Perpendicular to both $\vec{v}$ and $\vec{r}$

Right-Hand Rule:

1)



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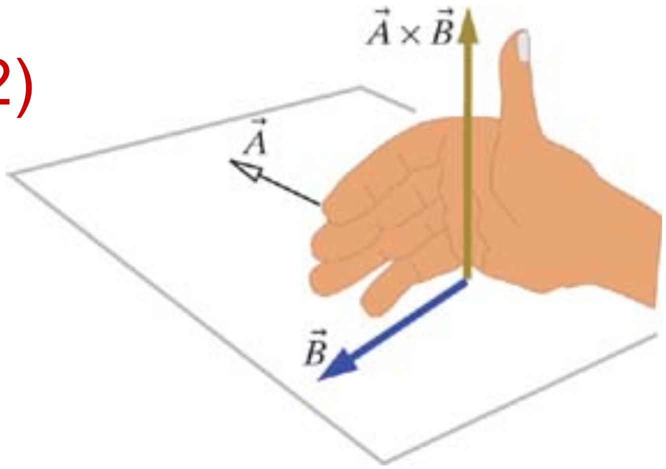
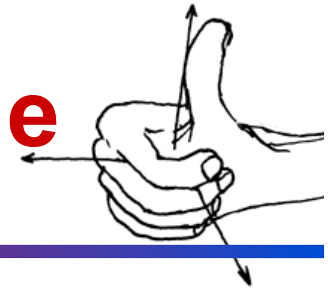
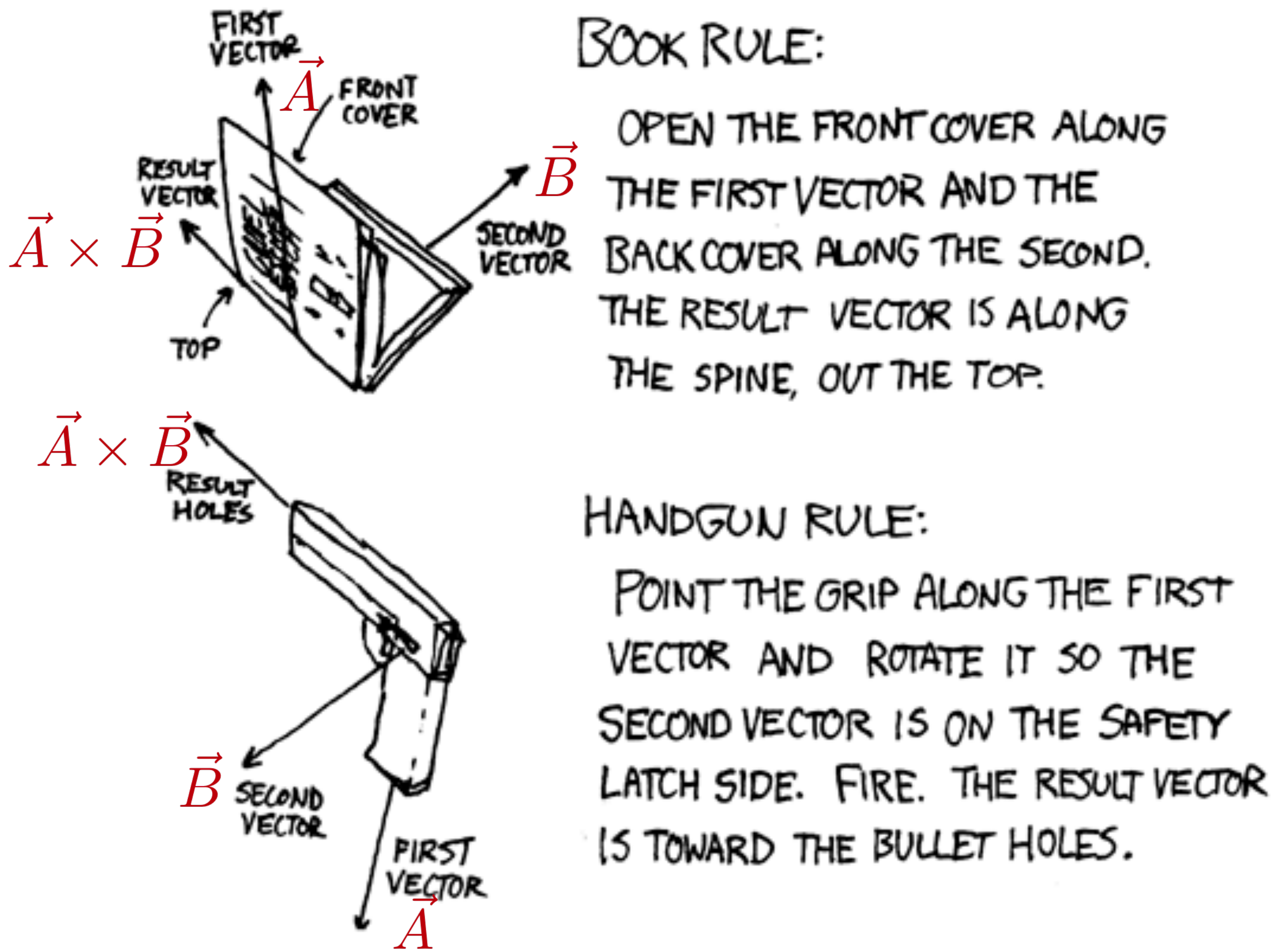


Alternatives to the Right-Hand Rule





http://xkcd.com

iClicker

$$\vec{B} = \left(\frac{\mu_o}{2\pi}\right)\frac{q\vec{v}\times\vec{r}}{|r|^2}$$

BIOT-SAVART LAW
point charge

Cross Product: Here's the Math

$$\vec{A}\times\vec{B} = \left|\begin{array}{ccc} \hat{x} & \hat{y} & \hat{z} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{array}\right| \underbrace{\begin{array}{cc} \hat{x} & \hat{y} \\ A_x & A_y \\ B_x & B_y \end{array}}_{\text{copy } 1^{\text{st}} \text{ two colums}} = \underbrace{\begin{array}{l} +(\qquad - \qquad)\,\hat{x} \\ +(\qquad - \qquad)\,\hat{y} \\ +(\qquad - \qquad)\,\hat{z} \end{array}}_{\text{set up the answer}}$$

Cross Product: Here's the Math

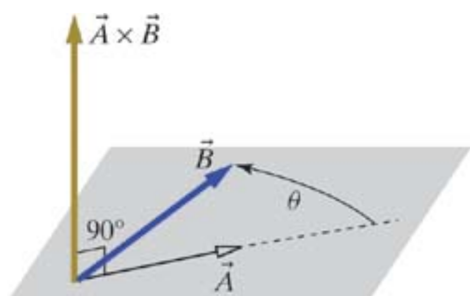
$$\vec{A} \times \vec{B} = \left|\begin{array}{ccc|cc} \hat{x} & \hat{y} & \hat{z} & \hat{x} & \hat{y} \\ A_x & A_y & A_z & A_x & A_y \\ B_x & B_y & B_z & B_x & B_y \end{array}\right. = \begin{array}{l} + \,(A_y B_z \;-\; A_z B_y)\,\hat{x} \\ + \,(A_z B_x \;-\; A_x B_z)\,\hat{y} \\ + \,(A_x B_y \;-\; A_y B_x)\,\hat{z} \end{array}$$

Cross Product: Here's the Math

$$\vec{A}\times\vec{B} = \left|\begin{array}{ccc|cc} \hat{x} & \hat{y} & \hat{z} & \hat{x} & \hat{y} \\ A_x & A_y & A_z & A_x & A_y \\ B_x & B_y & B_z & B_x & B_y \end{array}\right| = \Big\langle (A_yB_z - A_zB_y),\ (A_zB_x - A_xB_z),\ (A_xB_y - A_yB_x) \Big\rangle$$

$$-$$

$$+$$



The resulting vector has magnitude:

$$|\vec{A}\times\vec{B}| = |A||B|sin\theta$$

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