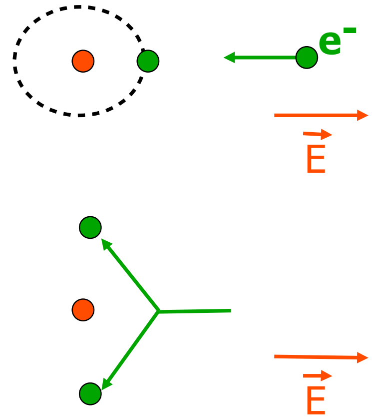
Review for 8.02x Quiz #3

Experiment EB



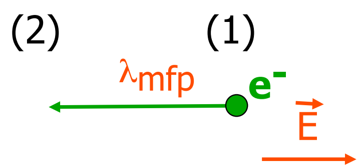
$U_{kin} > \Delta U$

- Define $V_{ion} = \Delta U/q$

  Ionization potential

- One e^- in, two e^- out: avalanche?

Experiment EB



λ_{mfp}: **Mean Free Path**

- To get avalanche we need:

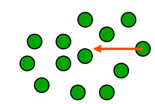
  ΔU_{kin} between collisions (1) and (2) $> \Delta U = V_{ion}\ e$
- Acceleration in uniform field: change in kinetic energy

  $$\Delta U_{kin} = e\,(V_2 - V_1) = e\,E\,d_{12}$$
- The avalanche condition is then:

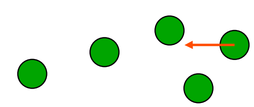
  $$E = V_{gap}/d > V_{ion}/\lambda_{mfp}$$

Experiment EB

(i) If Density n is big → λ_{mfp} small



(ii) If size σ of molecules is big → λ_{mfp} small

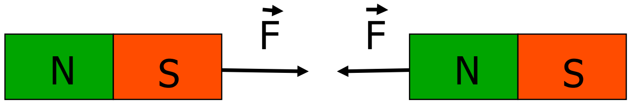


$$\lambda_{mfp} = \frac{1}{n\,\sigma}$$

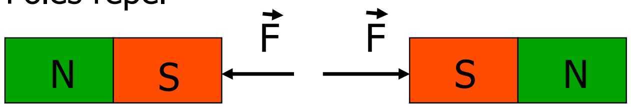
Understand the relationship between V_{gap}, d, V_{ion} and mean free path
Understand the relationship between mean free path, density and cross-section
Understand how measurement was performed and key steps of analysis

Magnetic Force

- Unlike Poles of a magnet attract

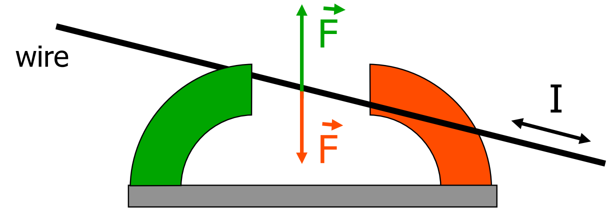


- Like Poles repel



Understand the Magnetic Field of a dipole magnet
Understand the direction of force between dipoles
Understand the net force on dipole in non-uniform field
Understand the absence of magnetic charges (monopoles)

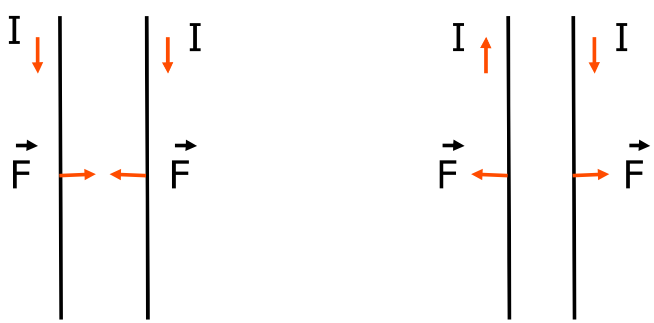
Magnet and Current



- Force on wire for nonzero current I
- The direction of Force depends on sign of I
- Force perpendicular to I and field B

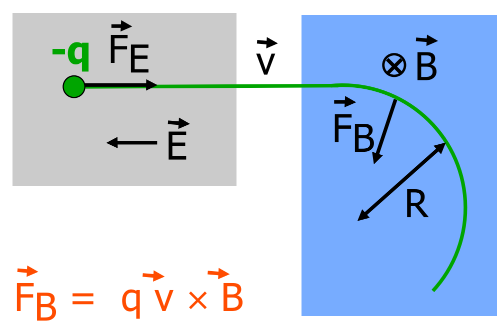
Current and Current

Experiment MF



Attraction **Repulsion**

Force on moving charge

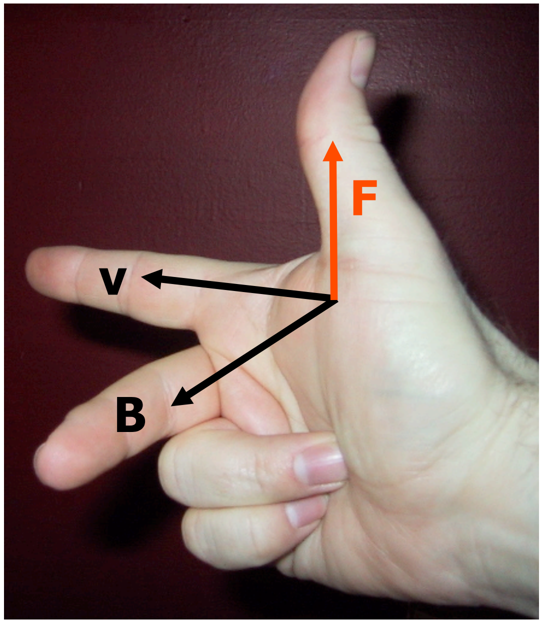


Understand how to use the right-hand rule to relate F,v and B (keep sign of q in mind!)

Understand the connection between momentum, q, B and R.

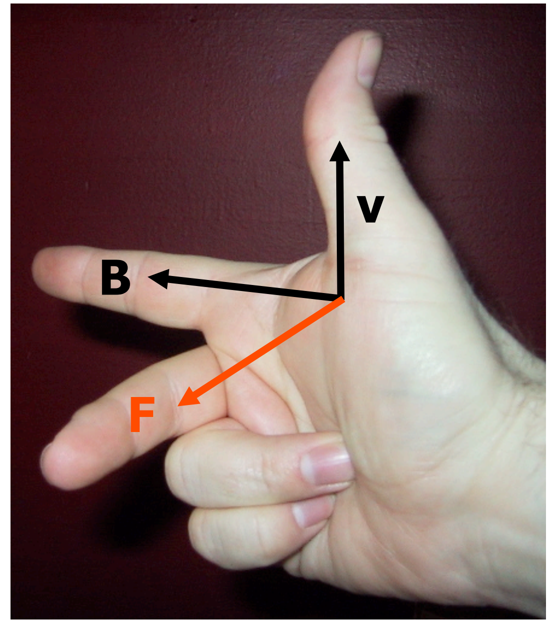
$$\vec{F}_B = q\,\vec{v} \times \vec{B}$$

Cyclotron Radius $R = \frac{m\,v}{q\,B}$



$\vec{F} = q\,\vec{v} \times \vec{B}$

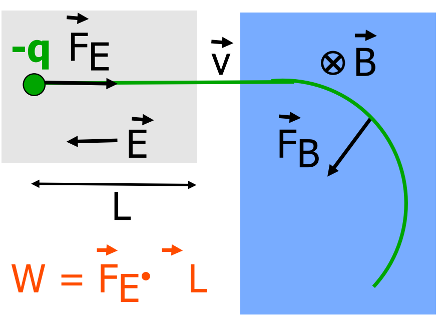
Right-Hand Rule



$\vec{F} = q\,\vec{v} \times \vec{B}$

Right-Hand Rule
(version 2)

Work done on moving charge



$dW = \vec{F}_B \cdot \vec{dL}$

$= (q\,\vec{v} \times \vec{B}) \cdot \vec{dL}$

$= (q\,\vec{dL}/dt \times \vec{B}) \cdot \vec{dL}$

$= 0$

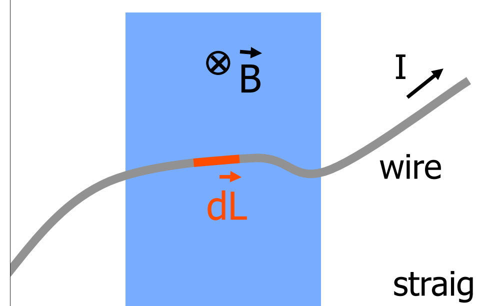
$W = \vec{F}_E \cdot \vec{L}$

$= q\,E\,L$

$W = 0$

Magnetic Field does no Work!

Force on a Wire carrying current I



$\vec{dF}_B = dq\,\vec{v} \times \vec{B}$

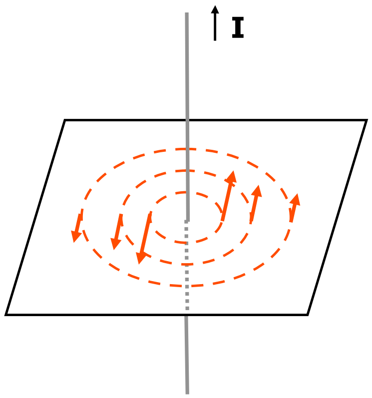
$= dq\,\vec{dL}/dt \times \vec{B}$

$= \underline{I\,\vec{dL} \times \vec{B}}$

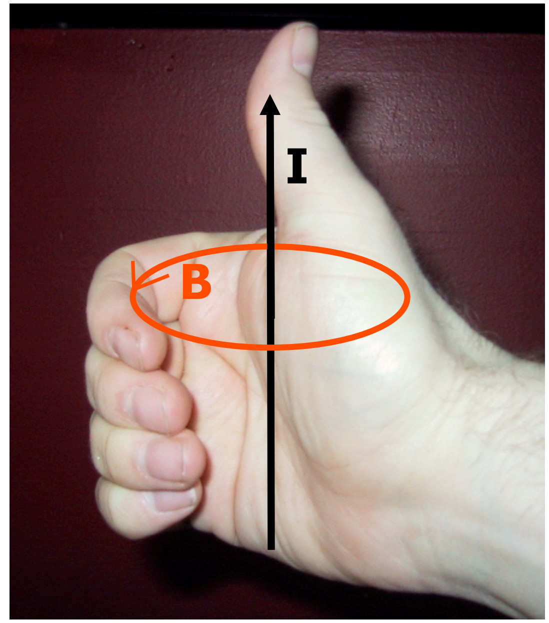
straight wire: $F = I\,L\,B \sin\alpha$

Understand the connection to Lorentz-Force
Understand how to use right hand rule to find
the direction of force (or dl or B)
Understand how to calculate the force for a simple geometry

Current: Source of B-Field

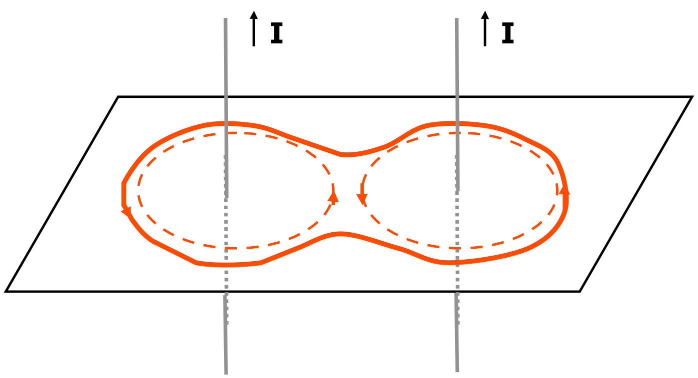


- Current as Source of B
- Magnetic Field lines are always closed
  - no Magnetic Charge (Monopole)
- Corkscrew Rule



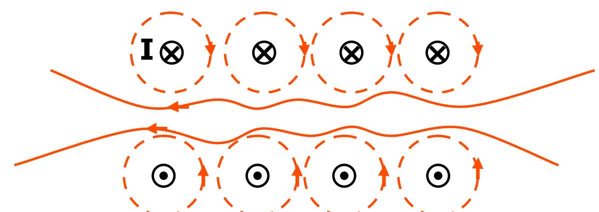
Corkscrew Rule

Currents and B-Field



Understand the use of the superposition principle to add fields from different sources

Currents and B-Field



- Solenoid: Large, uniform B inside
- Superposition Principle!

Magnetic Field for a Moving Charge

$d\vec{B} = \frac{\mu_0}{4\pi}\, dq\, \vec{v} \times \frac{\hat{r}}{r^2}$ **moving charge dq**

Magnetic Field dB for a moving charge dq

Magnetic Field for Current I

$d\vec{B} = \frac{\mu_0}{4\pi}\, I\, d\vec{l} \times \frac{\hat{r}}{r^2}$ **Law of Biot-Savart**

Magnetic Field dB for current through segment dl

For total B-Field: Integrate over all segments dl

No extensive calculations in Quiz ☺

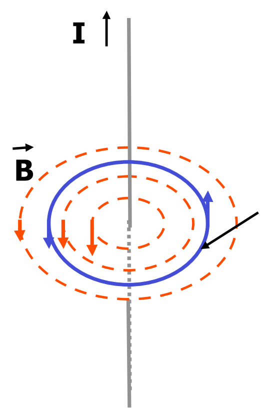
Understand how to use Biot-Savart to find the direction of field for current-element Idl and distance R

Gauss' Law for Magnetic Fields

$$\Phi_B = \oint_A \vec{B} \cdot d\vec{A} = 0$$

- Magnetic Flux through closed surface is 0
- This says: There are no magnetic monopoles
- Important Law – one of Maxwell's equations
- Unfortunately of limited practical use

Ampere's Law

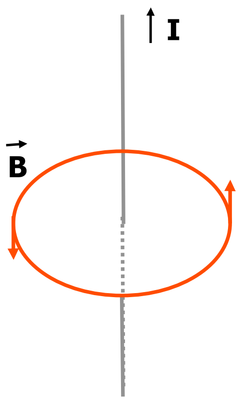


Ampere's idea:
relate the Field $\vec{B}$ to its Source: I

Closed Line instead of closed surface!

$$\oint_L \vec{B} \cdot d\vec{l} = \mu_0\, I_{encl}$$

Ampere's Law



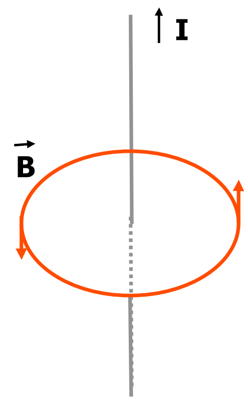
Ampere's Law helps because we can choose the integration path!

$$\vec{B} \perp d\vec{l} \;\Rightarrow\; \vec{B}\cdot d\vec{l} = 0$$

$$\vec{B} || d\vec{l} \;\Rightarrow\; \vec{B}\cdot d\vec{l} = B\; dl$$

Use the corkscrew rule for relating the direction of B and I

Ampere's Law



Ampere's Law helps because we can choose the integration path!

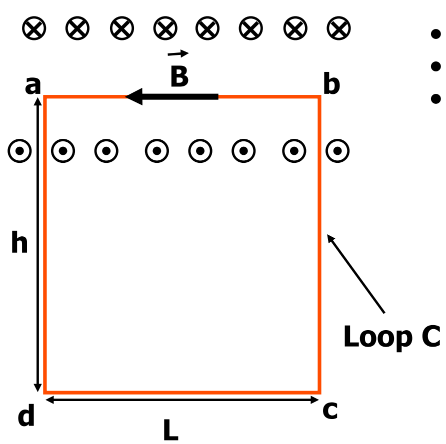
$$\oint_L \vec{B}\cdot d\vec{l} =$$

$$B \oint_L d\vec{l} =$$

$$B\; 2\pi\; r = \mu_0 I_{encl}$$

$$\Rightarrow\; B = \mu_0 \frac{I}{2\pi r}$$

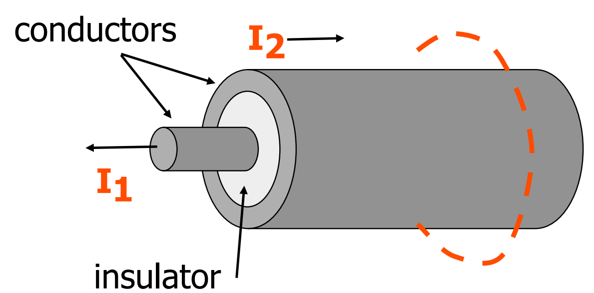
Field of a Solenoid



- Current I
- n turns per unit length
- (infinite length)

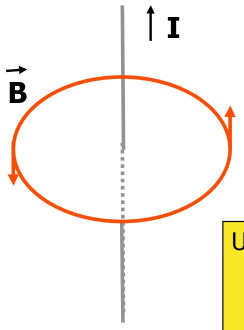
$$B = \mu_0\, I\, n$$

Coaxial Cable



The outside field vanishes for $I_2 = - I_1$

Ampere's Law



$$\oint_L \vec{B} \cdot d\vec{l} = \mu_0 \, I_{encl}$$

Understand how to use the right
hand rule or corkscrew rule to find
the direction of B relative to I

Understand how to find the total enclosed current

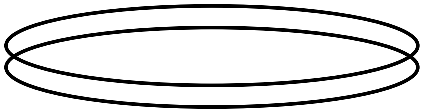
Understand the use of symmetry
to simplify the use of Ampere's law

Experiment MF

Understand the relationship between current in coils
and direction and magnitude of force between them

Understand the shape of the magnetic field produced
by a current loop or thin coil

Understand how measurement was performed
and key steps in the analysis



Magnetic Induction

→ Currents give rise to B-Field.

Q: Can B-Field give rise to current?

A: Only if the **Magnetic Flux** changes with time!

Understand how to calculate magnetic flux
Understand how to apply Lenz' Rule
to find direction of induced current
Understand connection between induced EMF
and induced current
Understand how to use Faradays Law
to connect magnitude of EMF and dΦ/dt

Faraday's Law

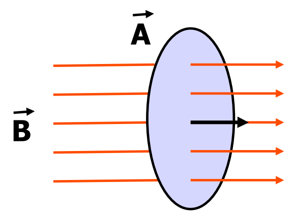
$$\Phi_B = \int_A \vec{B} \cdot d\vec{A}$$

Magnetic Flux
(usually, A is not a closed surface)

$$\xi_{ind} = -\frac{d\Phi_B}{dt}$$

Faraday's Law

$$\Rightarrow I_{ind} = \frac{\xi_{ind}}{R}$$



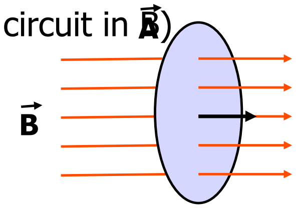
Faraday's Law

magnetic flux Φ_B can change, because

→ the magnetic field |B| changes

→ the angle between B and A changes

→ the area |A| (size of circuit in $\vec{B}$) changes



Lenz' Rule

$$\xi_{ind} = -\frac{d\Phi_B}{dt}$$

$$\Rightarrow I_{ind} = \frac{\xi_{ind}}{R}$$

Lenz' Rule:

Sign of I_{ind} such that it opposes the flux change that generated it

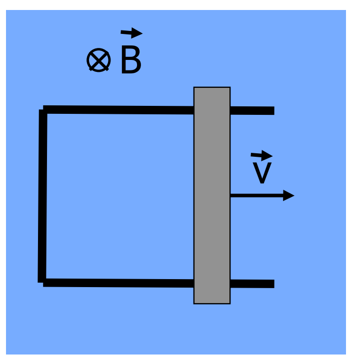
Use of Faraday's Law

To find direction of I_{ind}:

→ Determine Φ_B

→ Does $|\Phi_B|$ increase or decrease?

→ Find sign of I_{ind} using Lenz' rule



Use of Faraday's Law

To find direction of I_{ind}:

→ Determine Φ_B

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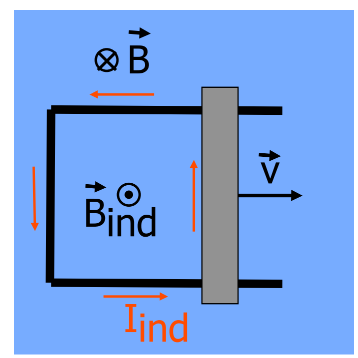

Lenz' Rule

The Field of I_{ind} DOES NOT necessarily oppose Φ_B!

The Field of I_{ind} DOES oppose the change of Φ_B ($=d\Phi_B/dt$)**.**

Lenz' Rule redux

In most cases:

If $|\Phi_B|$ increases :
$B(I_{ind})$ opposite direction to B_{ext}

If $|\Phi_B|$ decreases :
$B(I_{ind})$ same direction as B_{ext}