# AP Physics C: Chapter 26

Zach Baylin

April 18, 2019

## 1 Magnetism

- magnetic poles always come in dipoles, unlike electric charge
- **magnetic force** $(F_B)$: the force as a result of magnetic interaction
- **magnetic field** $(B)$: a vector field (direction and strength) that represents what would happen to a magnetic dipole
  - measured in **Teslas** $([T] = [N]/[Am])$

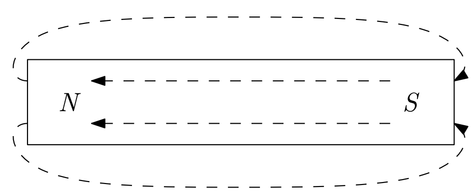



Figure 1: The direction of flow from $N \to S$

- magnetism is caused by moving charge
- **right hand rule**

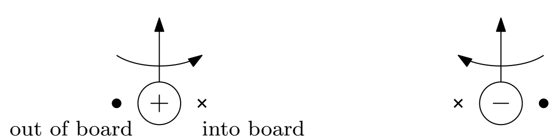
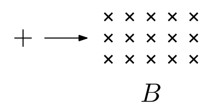
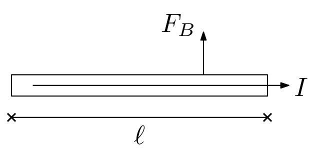



Figure 2: How to determine direction using the right hand rule




$$F_B = q\vec{v} \times \vec{B}[N]$$

Figure 3: How to calculate force on a moving charge




$$F_B = I\vec{L} \times \vec{B}$$

Figure 4: How to calculate force on a straight wire

- **Biot-Savart Law**: an equation that describes the magnetic field in space
  - <u>Formula</u>:

$$\begin{aligned} |B| &= \frac{\mu_0}{4\pi} \cdot \frac{qV\sin(\theta)}{r^2} \\ &= \frac{\mu_0}{4\pi} \cdot \frac{I\Delta S \times \hat{r}}{r^2} \end{aligned}$$

$\mu_0$: permeability of free space $\left[\frac{T \cdot m}{A}\right]$

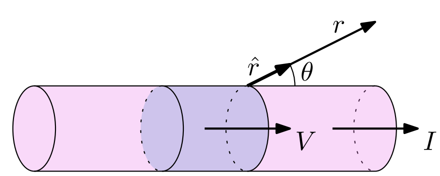



Figure 5: A diagram of the variables in Biot-Savart

  - <u>Process</u> (to solve for $|B|$):
    1. Draw a picture and choose coordinate axes
    2. Identify a point $P$
    3. Label "$r$", $\theta$ for at least two small sections $\Delta s$
    4. Use right hand rule to draw $B_i$ for each section
    5. Check for symmetry
    6. $B_{\text{net}} = \sum B_i$
    7. Need algebraic expression for $B_x, B_y, B_z$

8. Write $r$ and $\theta$ in terms of $x, y, z$
9. Identify limits of integration
10. Integrate

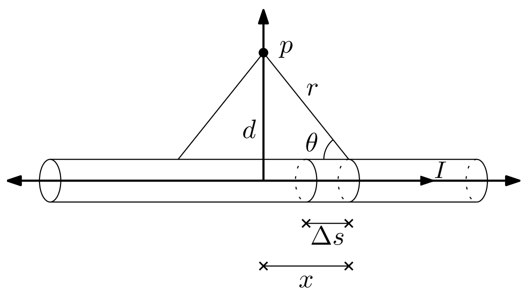



Figure 6: How to setup solving Biot-Savart for a straight wire

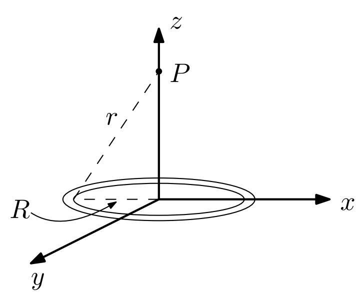



Figure 7: How to setup solving Biot-Savart for a ring

- **Ampere's Law**
  - Ampere vs. Gauss
    - Gauss: used to find $\vec{E}$ in *highly symmetrical charge distribution*
      - $\oint \vec{E} \cdot \mathrm{d}A = \frac{Q_{\text{enc}}}{\varepsilon_0}$
    - Ampere is the same principle
  - only works when $\vec{B}$ is highly symmetric, i.e. $\vec{B}$ is the same magnitude at $r$ and is tangent to line $\mathrm{d}\ell$
  - Equation

$$\oint_{\mathrm{c}} \vec{B} \cdot \mathrm{d}\ell = \mu_0 I_{\text{enc}}$$

$$B_t = \frac{\mu_0 I_0}{2\pi r}$$

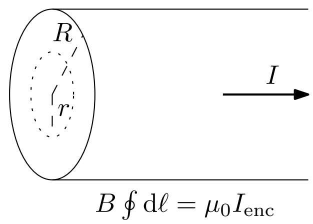



Figure 8: Setting up Ampere's law for a wire

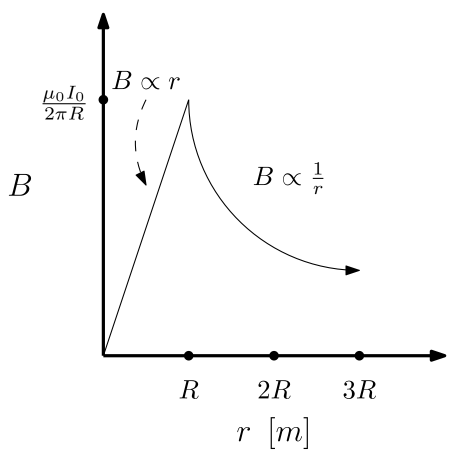



Figure 9: $B$ vs. $r$ in a constant-current circuit (wire)

– Solving:

$$B_t \oint \mathrm{d}l = \mu_0 I_{\text{enc}}$$

$$2B_t = \frac{\mu_0}{2\pi r} \cdot I_0 \cdot \frac{r^2}{R^2}$$

$$= \frac{\mu_0}{2\pi \cancel{r}} \cdot I_0 \cdot \frac{r^{\cancel{2}}}{R^2}$$

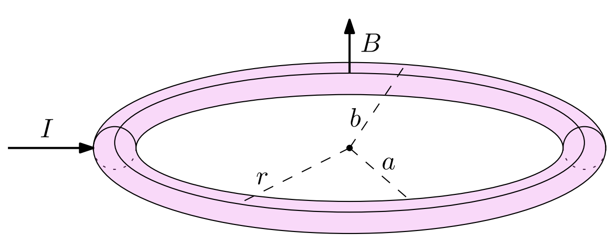



Figure 10: Setting up Ampere's law for a toroid

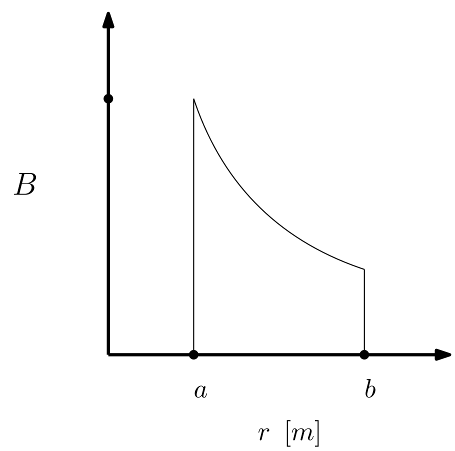



Figure 11: $B$ vs. $r$ in a constant-current circuit (toroid)

- **magnetic flux ($\Phi_m$)**: the amount of magnetic field that passes through a coil

$$\Phi_m = \vec{B} \cdot \vec{A} = |B||A|\cos(\theta)$$

# 2 Induction

- **electromagnetic induction**: moving magnet creating an electric field
- $I$ induced only occurs when $\vec{B}$ is changing within the coil
  - Keep coil stationary and change $\vec{B}$
  - Keep $B$ stationary and change coil
    - Change either area or orientation of the coil

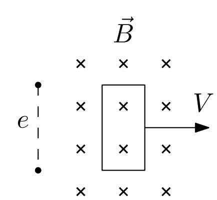



Figure 12: Motional EMF

- Solving (to find EMF):

$$\begin{aligned}
\sum F &= 0 \\
F_B &= F_E \\
\cancel{q}vB &= \cancel{q}E \\
E_{\text{inside}} &= vB
\end{aligned}$$

Then to find EMF:

$$\begin{aligned}
\text{EMF} &= \Delta V \\
\Delta V &= V_f - V_i = -\int E \cdot \mathrm{d}\ell \\
\text{EMF} &= -\int E_{\text{inside}} \cdot \mathrm{d}\ell \\
&= -(-Bv)\ell \\
\varepsilon &= Bv\ell
\end{aligned}$$

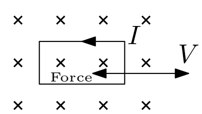



Figure 13: Loop in magnetic field

- **loop in magnetic field**
  - drag force is opposite the velocity
  - due to $B$ acting on $I$ induced
  - Solving (for $I$ induced):

$$\begin{aligned}
I_{\text{induced}} &= \frac{V}{R} \\
&= \frac{Bv\ell}{R}
\end{aligned}$$

- **Lenz's Law**
  - Induced current creates a magnetic field that opposes the change in $B$
- **Faraday's Law**
  - Formula:

$$\varepsilon = \left| \frac{\mathrm{d}\Phi_m}{\mathrm{d}t} \right|$$

- $\varepsilon_{\text{induced}}$ is the rate of change of magnetic flux in the coil

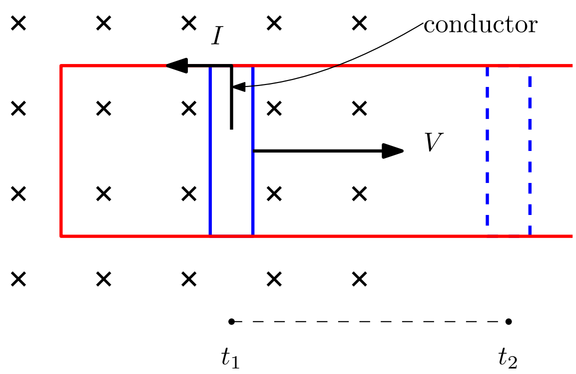



Figure 14: The change in area

- Solving:

$$\begin{aligned} \varepsilon &= \left|\frac{\mathrm{d}\Phi_m}{\mathrm{d}t}\right| \\ &= \frac{\mathrm{d}B\ell x}{\mathrm{d}t} && \Rightarrow \frac{\mathrm{d}x}{\mathrm{d}t} = v \\ &= B\ell v \end{aligned}$$

# 3 Circuits

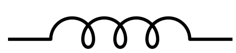


Figure 15: The circuit symbol for an inductor

- **inductor**: slows down or resists a change in current
  - has a unifrom magnetic field
- **inductance** ($L$ $[H] = \frac{\text{Wb}}{\text{Amp.}}$): the ratio of flux to current induced
  - Formula:

$$L = \frac{\Phi_m}{I}$$

- **solenoid**: the only inductor with uniform magnetic field
  - Formula ($L$):

$$L = \frac{\mu_0 N^2 A}{\ell}$$

– <u>Fomula</u>: ($\varepsilon$):

$$\begin{aligned}\varepsilon &= -\frac{\mathrm{d}\Phi_m}{\mathrm{d}t}\\ &= -\frac{\mathrm{d}LI}{\mathrm{d}t}\\ &= \boxed{-L\cdot\frac{\mathrm{d}I}{\mathrm{d}t}}\end{aligned}$$

– <u>Formula</u> (SHM):

$$\Delta V_c - \Delta V_L = 0$$

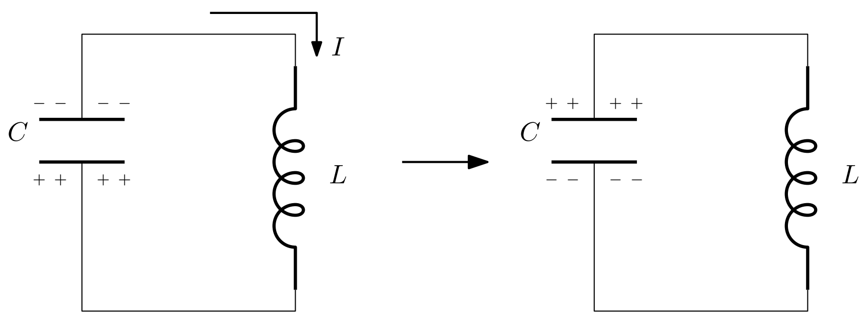



Figure 16: How SHM is created by an inductor