Contents of MTE2

- Work of the electric force and potential energy
- Electric Potential and Field
- Capacitors and capacitance
- Current and resistance, Ohm’s law
- DC Circuits and Kirchoff’s laws
- RC circuits
- Lorentz force and motion of charge in a magnetic field
- Biot and Savart
- No Ampere’s law, No magnetic properties of matter

Study chapters 27-32 (no 32.6, 32.10, no 32.8 forces between wires)
Alternate Exams will be:
Wed 26
2:30-4:00pm Lab room (Ch 3254)
6:00-7:30pm Lab room (Ch 3254)
This week Honor Lecture

- Susan Nossal: Climate change
Magnetic Fields

- A vector quantity ($\mathbf{B}$)
- Compass needle traces B field lines and points towards N
- B-field lines start in N and go to S
- They do not start or stop (no magnetic monopoles)

Iron filings show pattern of B-field lines

Electric dipole
Earth’s A Magnet!

- N geographic pole almost at magnetic S pole
- S geographic pole almost at magnetic N pole

A the N pole of a compass needle is attracted toward the geographic N pole (S pole of the B-field)
Electric vs Magnetic Field Lines

- **Similarities**
  - Density gives strength
  - Arrow gives direction
    - Leave +, North
    - Enter -, South

- **Differences**
  - Start/Stop on electric charge
  - No Magnetic Charge ⇒
    lines are continuous!
Charged particle in a B-field: Lorentz force

\[ \vec{F} = q\vec{v} \times \vec{B} \]  

vector ‘cross product’

Units: \( N = C \times m/s \times \text{Tesla} \)

- \( F \) is zero when \( \vec{v} \) and \( \vec{B} \) are parallel or antiparallel
- \( F \) is a maximum when \( \vec{v} \) and \( \vec{B} \) are perpendicular

\[ F_B = |q|vB \sin \theta \]
Effect of uniform magnetic field

- Effect of uniform B-field on charged particle
  - If charged particle is not moving - no effect
  - If particle is moving: force **perpendicular** to both field and velocity
  - the charge sign must be accounted for
Magnetic Force and Work

Magnetic force perpendicular to the particle displacement => the magnetic force does not do work!

B field can alter direction of velocity, but not the speed or the kinetic energy
Quick Quiz

The three charges below have equal charge and speed, but are traveling in different directions in a uniform magnetic field.

Which particle experiences the greatest magnetic force?

A) B) C) D) 

1 2 3 Same

\[ F = q v B \sin(\theta) \]
**Cyclotron Motion**

- $\mathbf{F} \perp \mathbf{v}$ and $\mathbf{B}$

- Particle path is a circle of radius $R$.

- $a = \frac{v^2}{R}$ is the centripetal acceleration

- $R$ depends on $m$, $q$, $v$, $B$

In how much time does the particle complete an orbit?

\[
\mathbf{F} = qv\mathbf{B} \quad \Rightarrow \quad qv\mathbf{B} = m\frac{v^2}{R} \quad \Rightarrow \quad \mathbf{F} = ma
\]

- \(\omega = \text{angular velocity} = \frac{v}{R} = \frac{qB}{m}\)

- \(\omega = \frac{2\pi}{T}, \ T = \text{period} = \frac{2\pi m}{qB}\)
Mass spectrometer and v selector
Experiment in Lab: motion of charges in B-field

1) Turn on electron ‘gun’

\[ \frac{1}{2} m v^2 = q \Delta V \]

2) Turn on magnetic field B (Helmoltz coils)

\[ R = \frac{m v}{q B} \]

3) Measure electron charge/mass as a function of \( \Delta V \), \( R \) and \( B \)

\[ v^2 = 2 \frac{q}{m} \Delta V \]
\[ R^2 = \frac{m^2 v^2}{q^2 B^2} = 2 \frac{q}{m} \Delta V \frac{m^2}{q^2 B^2} \]

\[ \frac{q}{m} = \frac{2 \Delta V}{R^2 B^2} \]
Magnetic Force on a Current

- Force on each charge: \( qv \times B \)

- Force on length \( ds \) of wire: \( qv \rightarrow Ids \)
  \[ dF = Ids \times B \]

\[ F_B = IL \times B \]
A **homopolar motor** has a B-field along the axis of rotation and an electric current produced by the battery that moves radially through the magnet.

The resulting Lorentz force in the tangential direction produces a torque in the magnet, which is free to rotate with the attached screw. The name *homopolar* refers to the absence of polarity change.

\[ F_B = I L \times B \]
Consider current loop in magnetic field perpendicular to the plane of the loop => Zero net force

- Force on top path cancels force on bottom path \( (F = IBL) \)
- Force on right path cancels force on left path. \( (F = IBL) \)

If plane of loop is not \( \perp \) to B-field, there is a torque on the loop (force couple as for electric dipole in E-field)
Calculation of Torque

- Square loop has width $W$ and length $L$ (into the screen). The torque is given by:

$$\tau = \vec{r}_1 \times \vec{F} + \vec{r}_2 \times \vec{F}$$

$$\tau = 2\left(\frac{w}{2} F \sin \theta\right)$$

$F = IBL \Rightarrow \tau = IBLw \sin \theta = IBA \sin \theta$

$A = wL = \text{area of loop}$

$magnetic \ dipole \ moment$

$\mu = A I$

direction: $\perp$ to plane of the loop according to RH rule (hands curls on current)

- Note: if loop consists of $N$ turns, $\mu = N A I$
Potential Energy of Magnetic Dipole

- Work must be done to change the orientation of a dipole (current loop) in the presence of a magnetic field.
- Define a potential energy $U$ corresponding to this work ($U=0$ when magnetic dipole moment orthogonal to B-field = equilibrium position corresponding to max torque)

$$ U = -\vec{\mu} \cdot \vec{B} $$
Quick Quiz

Which configuration has the greatest potential energy?

\[ \tau = 0 \]
\[ U = -\mu B \]

\[ \tau = \mu B \]
\[ U = 0 \]

\[ \tau = 0 \]
\[ U = \mu B \]

A)    B)   C)
Surprise! Electric current produces magnetic field

- Current (flow of electric charges) in wire produces B-field.
- The magnetic field aligns compass needle.
- 2 kind of magnetism due to permanent magnets and currents or the same?

1819 Hans Christian Oersted
Magnetic field from a current

Iron filings align with magnetic field lines

Magnetic field loops around the current. *(Right hand rule)*
A current loop is an electromagnet: it behaves like a permanent magnet. Two current loops with current in the same direction attract like 2 magnets (since the opposite poles are closer).
Biot-Savart Law

For a single charge in motion

For a wire with current

Each element of current produces a contribution to the magnetic field.

$qv \rightarrow Ids$

$d\mathbf{B} = \frac{\mu_0}{4\pi} I \frac{ds \times \mathbf{u}_r}{r^2}$

\( \mu_0 = 4\pi \times 10^{-7} \text{Tm/A} = 1.257 \times 10^{-6} \text{Tm/A} \)
Field from a circular loop

At the center of the loop:

\[
\begin{align*}
    dB &= \frac{\mu_0}{4\pi} \frac{Idl \sin \theta}{R^2} \\
    \theta &= 90^\circ \\
    dB &= \frac{\mu_0}{4\pi} \frac{Idl}{R^2}
\end{align*}
\]

\[
B = \frac{\mu_0}{4\pi} \frac{I}{R^2} \oint dl
\]

\[
B = \frac{\mu_0}{4\pi} \frac{I}{R^2} 2\pi R = \frac{\mu_0 I}{2R}
\]
- Happy spring break to all!