1. **Coulomb's Law** - electrostatic force between two charges
   \[ F = \frac{kq_1q_2}{r^2} \]

2. **Electric Field** - force experienced by **positive** test charge \( q_0 \)
   \[ E = \frac{F}{q_0} \]
   a. Force on charge in electric field:
   \[ F = qE \]
   b. Direction of field lines (tangent to curve) indicates direction of force experienced by positive test charge.
   c. **Number** of field lines in given area indicates **intensity** of field.
   d. **Field lines begin on +, end on -**

3. **Flux** – number of field lines passing through given area.
   \[ \Phi_E = E \cdot A \]
   \[ \Phi_B = B \cdot A \]
   (\( A \) is a vector perpendicular to surface.)
ELECTRIC FIELD AND POTENTIAL

4. Electric Potential

\[ V = \frac{U}{q_0} \quad \text{(joule/coulomb = volt)} \]

\[ \Delta V = \frac{\Delta U}{q_0} \]

a. A **potential difference** means that a **charge will lose or gain** a certain amount of **potential energy** as it goes from spot to another.

b. For a test charge moving in the field of a **point charge**, its potential is

\[ V_{pt\ chg} = \frac{kq}{r} \]

c. **Equipotential lines** - contours of equal potential. Field will be perpendicular to these lines.

PROBLEM 1
1. **Capacitors**- device for storing charge; capacity depends on geometry, materials

\[ C = \frac{Q}{V} \] (coulomb/volt = farad)

a. Combinations of capacitors

- **Series** \[ \frac{1}{C_{eq}} = \left( \frac{1}{C_1} + \frac{1}{C_2} + \ldots \right) \]
- **Parallel** \[ C_{eq} = C_1 + C_2 + \ldots \]

b. Energy is stored in capacitors:

\[ U = \frac{1}{2} CV^2 \]

c. The capacitance of a capacitor can be changed by inserting a material between the plates which has a high dielectric constant (\( \kappa \)).

\[ C' = \kappa C \]

(\( \kappa \) of vacuum is 1, for air ~ 1)

2. **Resistors**- objects that resist flow of charge in circuit

\[ R = \frac{V}{i} \] (for elements that obey Ohm's law)

a. Combinations of resistors

- **Series** \[ R_{eq} = R_1 + R_2 + \ldots \]
- **Parallel** \[ \frac{1}{R_{eq}} = \left( \frac{1}{R_1} + \frac{1}{R_2} + \ldots \right) \]

b. **Power dissipated** in resistors: \[ P = i^2R = VI = \frac{V^2}{R} \]
2. **Resistors** (continued)
   c. **Resistivity** - inherent property of materials

   \[ R = \rho L / A \]  
   (water analogy)

3. **Batteries** - supply **emf (electromotive force)** to circuit; somehow they "pump up" the energy of charges so that they are capable of making a round trip through the circuit

   a. Supplies power at rate \( P = \varepsilon i \)

   b. Often has **internal resistance** \( r \) to be considered.

   c. emfs are **added if in series**

4. **DC Circuits**

   a. **Current** \( i = \Delta q / \Delta t \) (ampere - 1 coulomb/s)

   1) **junction rule**
      sum of currents = sum of currents out

   2) **conventional current** is flow of **positive** charge carriers

   3) **current density**

      \[ J=i/A \]
4. DC Circuits (continued)

b. Ohm's Law

\[ V = IR \quad \text{or} \quad E = \rho J \]

(does not work for all materials)
Resistance increases with increasing temperature

c. Loop rule - sum of potential differences must sum to zero

1) go with current - lose potential
2) go from - to + on emf source, increase potential

d. RC circuits show time-dependent behavior:

\[ i = \frac{\varepsilon}{R} \, e^{-t/RC} = i_0 \, e^{-t/RC} \quad \text{(discharging capacitor)} \]

What fraction of the original current remains after one time constant has passed? Could you draw the curve?

5. AC Circuits

a. The voltage varies

\[ \varepsilon = \varepsilon_0 \sin(\omega t) \]
5. **AC Circuits** (continued)

b. The current can be calculated using the emf and the impedance (Z)

\[ i = \frac{\varepsilon}{Z} \]

(the current will also have a sinusoidal behavior)

c. Since the direction of current varies, \( i^2 \) is averaged in order to average power:

\[ P_{av} = i^2_{\text{rms}}R \]

Average power is 1/2 maximum power
(because average of \( \sin^2 \theta \) is \( \frac{1}{2} \)

PROBLEM 3
MAGNETIC FIELDS

1. Magnetic fields are created by moving charges. They can also exert a force on moving charges:

\[ F = q \, v \times B \]

right hand rule
fingers point along \( v \), curl toward \( B \); thumb points along \( F \)

a. The force always acts \( \perp \) to \( v \) and \( B \)
b. mks unit of magnetic field is the **Tesla**
\[
1 \text{ tesla (T)} = 10000 \text{ Gauss (Ga)}
\]

2. Because of the nature of the force, **B never increases the speed** of charges, only **changes their direction**.

3. **Currents** also feel a force in a magnetic field

\[ F = i \, L \times B \]

4. Right hand rules

a. magnetic field of a current carrying wire
   thumb - \( i \); fingers – \( B \)

b. magnetic field of a current loop or solenoid
   fingers - \( i \); thumb - \( B \)
MAGNETIC FIELDS

5. Magnetic field lines do not have beginning/ending points; they are loops.
   a. Bar magnets do have a north and south pole.
   b. Field lines run externally from north to south, internally from south to north.

6. Electromagnetic Induction - a changing magnetic field can induce an emf

PROBLEM 2