### Constants

- \( m_e = 9.109 \times 10^{-31} \text{ kg} \)
- \( m_p = 1.673 \times 10^{-27} \text{ kg} \)
- \( m_n = 1.675 \times 10^{-27} \text{ kg} \)
- \( k = 9 \times 10^9 \text{ Nm}^2 \text{C}^{-2} \)
- \( \varepsilon_0 = 8.854 \times 10^{-12} \text{ m} \)

### Coulomb’s Law (electrostatic force)

\[
F = k \frac{|q_1 q_2|}{r^2}
\]

\[
F = \frac{1}{4\pi \varepsilon_0} \frac{|q_1 q_2|}{r^2}
\]

### Electric Field – point charge

\( \vec{E} = \frac{\vec{F}}{q} = \frac{1}{4\pi \varepsilon_0} \frac{q}{r^2} \hat{r} \)

### Potential energy - point charges

\[
U = \frac{1}{4\pi \varepsilon_0} \sum_{i<j} \frac{q_i q_j}{r_{ij}}
\]

### Potential

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

### Potential of a set of point charges

\[
V = \frac{1}{4\pi \varepsilon_0} \sum_i q_i r_i
\]

### Potential difference between two parallel plates

\[
V_a - V_b = Ed
\]

### Capacitance

\[
C = \frac{Q}{V_{ab}}
\]

\[
1 \text{ F} = \frac{1 \text{ C}}{1 \text{ V}}
\]

### Capacitance – parallel plates

\[
C = \frac{\varepsilon_0 A}{d}
\]

### Capacitance – energy storage

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

### Capacitors in series

\[
\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...
\]

### Capacitors in parallel

\[
C_{eq} = C_1 + C_2 + C_3 + ...
\]

### Resistors in series

\[
R_{eq} = R_1 + R_2 + R_3 + ...
\]

### Resistors in parallel

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...
\]

### Current

\[
I = \frac{dQ}{dt}
\]

\[
1 \text{ A} = \frac{1 \text{ C}}{1 \text{ sec}}
\]

### Voltage, Resistance, Current, Power

\[
V = I \cdot R
\]

\[
P = I \cdot V
\]

### Kirchhoff’s Rules

\[
\sum V = 0 \text{ for a closed loop}
\]

\[
\sum I = 0 \text{ for a junction}
\]

### Resistance

\[
R = \frac{DL}{A}
\]

### Constant Acceleration

\[
v_2 = v_1 + a \Delta t
\]

\[
s_2 = s_1 + \left( \frac{v_1 + v_2}{2} \right) \Delta t
\]

### Work

\[
W = \vec{F} \cdot \Delta \vec{r} = F \Delta r \cos \theta
\]

### Power

\[
P = \frac{dW}{dt}
\]

### Spring force

\[
F = k \Delta x
\]

### Force and Acceleration

\[
\vec{F}_{net} = m \vec{a}
\]

### Projectile Motion

\[
y - y_0 = (x - x_0) \tan \theta - \frac{g}{2v_0^2} (1 + \tan^2 \theta) (x - x_0)^2
\]

\( \theta \) – launch angle

\( v_0 \) – launch velocity

\( x_0, y_0 \) – launch position, positive up

### Relative Motion

\[
\vec{v}_{B/G} = \vec{V}_{A/G} + \vec{V}_{B/A}
\]

\[
\vec{v}_{B/A} = \vec{V}_{B/G} - \vec{V}_{A/G}
\]

\[
\vec{V}_{B/A} = -\vec{V}_{A/B}
\]

### Conservation of Energy

\[
U_{p1} + K_{E1} + W_{in} = U_{p2} + K_{E2} + E_{loss}
\]
Impulse / Momentum / Restitution

\[ \sum m\vec{v}' = \sum m\vec{v} + \int \sum F \, dt \]

\[ m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}'_1 + m_2\vec{v}'_2 \]

\[ e = \frac{- (\vec{v}'_2 - \vec{v}'_1)}{\vec{v}_2 - \vec{v}_1} \]  
(line of impact)
1. (12 pts) Determine the net force on charge Q2.

2. (12 pts) An electron with an initial velocity of $2.3 \times 10^6$ m/s, is accelerated through a potential difference of (-250) V. What is the electron’s final velocity?
3. (12 pts) A potential difference of 2V is applied between the ends of a wire that has a length of 4m and a radius of 0.3mm. If the resistivity of the wire is $1.5 \times 10^{-7} \Omega \cdot m$, what is the current through the wire?

4. (14 pts) An electron is shot with an initial horizontal velocity of $47 \times 10^5$ m/s through a uniform electric field of $2.0 \times 10^3$ N/C. If it traveled in the horizontal direction 26 cm, how far has it dropped in the vertical direction?
5. (14 pts) In the following circuit, how much power is consumed by the 150Ω resistor?
6. (14 pts) In the following circuit, $R_1 = 3 \, \Omega$, $R_2 = 3 \, \Omega$, $R_3 = 5 \, \Omega$ and $R_4 = 5 \, \Omega$. $\varepsilon_1 = 1 \, v$, $\varepsilon_2 = 2 \, v$, $\varepsilon_3 = 3 \, v$. Find $I_1$. 
7. (14 pts) The potential drop between points a and b ($v_{ab}$) in the following circuit is 10V. Determine the potential drop on capacitor C (the 20 $\mu$F capacitor).

8. (4 pts) Charges A and B exert repulsive forces on each other. $q_A = 4q_B$. Which statement is true?
   a. $|F_{A on B}| < |F_{B on A}|$
   b. $|F_{A on B}| > |F_{B on A}|$
   c. $|F_{A on B}| = |F_{B on A}|$

9. (4 pts) Points P and Q are connected to a battery of fixed voltage. As more resistors $R$ are added to the parallel circuit, what happens to the total current in the circuit?
   1. Increases
   2. Decreases
   3. Drops to zero
   4. Remains the same