Unit 6: Electrostatics and Electric Circuit
Grade 11 Physics - Advanced Workbook

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Unit 6: Electrostatics and Electric Circuit Workbook

6.1 Coulomb's Law Workbook

Multiple Choice Questions

1. Two point charges are separated by a distance r. If the distance between them is doubled, the electrostatic force between them becomes:

   (A) Twice as large

   (B) Half as large

   (C) Four times as large

   (D) One-quarter as large

   Answer: (D) Explanation: Coulomb's Law states that the force is inversely proportional to the square of the distance ($F \propto 1/r^2$). If the distance r becomes $2r$, the force becomes proportional to $1/(2r)^2 = 1/(4r^2)$, which is one-quarter of the original force.

2. The fundamental property that dictates whether two charges attract or repel is:

   (A) Their mass

   (B) Their size

   (C) Their sign (positive or negative)

   (D) Their location

   Answer: (C) Explanation: The law of electrostatics states that like charges repel and unlike charges attract. This interaction is determined by the sign of the charges.

3. The SI unit of electric charge is the:

   (A) Ampere (A)

   (B) Volt (V)

   (C) Ohm (Ω)

   (D) Coulomb (C)

   Answer: (D) Explanation: The Coulomb is the standard unit of electric charge. The Ampere is the unit of current, the Volt is the unit of electric potential, and the Ohm is the unit of resistance.

Short Answer Questions

1. State Coulomb's Law in words and write its mathematical formula.

2. Explain the principle of superposition as it applies to electrostatic forces.

Workout Problems

1. Two point charges, $q_1 = 2.0\,\mu C$ and $q_2 = -4.0\,\mu C$, are placed 10 cm apart. What is the magnitude and nature of the force between them? (Use $k = 9 \times 10^9\,N\,m^2\,C^{-2}$).
Solution:
Given: $q_1 = 2.0 \times 10^{-6}\,C$, $q_2 = -4.0 \times 10^{-6}\,C$, $r = 10\,cm = 0.1\,m$.
Find: The electrostatic force, F.
Formula: Coulomb's Law: $F = k\frac{|q_1 q_2|}{r^2}$.
Calculation:

$$F = (9 \times 10^9\,N\,m^2\,C^{-2}) \times \frac{|2.0 \times 10^{-6}\,C \times -4.0 \times 10^{-6}\,C|}{(0.1\,m)^2}$$

$$F = (9 \times 10^9) \times \frac{8.0 \times 10^{-12}}{}$$

$$F = (9 \times 10^9) \times (8.0 \times 10^{-10}) = 7.2\,N$$

Answer: The magnitude of the force is 7.2 N. Since the charges have opposite signs, the force is attractive.

2. Three point charges are placed on the x-axis: $q_1 = 1\,\mu C$ at $x = 0$, $q_2 = -2\,\mu C$ at $x = 2\,cm$, and $q_3 = 3\,\mu C$ at $x = 5\,cm$. Find the net force on charge q_2. **Solution:**
Given: $q_1 = 1 \times 10^{-6}\,C$ at $x = 0$, $q_2 = -2 \times 10^{-6}\,C$ at $x = 0.02m$, $q_3 = 3 \times 10^{-6}\,C$ at $x = 0.05m$.
Find: Net force on q_2, $F_{net,2}$.
Formula: Superposition principle: $F_{net,2} = F_{12} + F_{32}$. (Forces are vectors).
Calculation:
1. Force on q_2 due to q_1 (F_{12}): q_1 and q_2 are opposite, so it's attractive. F_{12} points to the left (negative x-direction).

$$F_{12} = k\frac{|q_1 q_2|}{r_{12}^2} = (9 \times 10^9)\frac{|1 \times 10^{-6}\,C \times -2 \times 10^{-6}\,C|}{(0.02\,m)^2} = 45\,N \text{ (to the left)}$$

So, $\vec{F}_{12} = -45\,N\hat{\imath}$. 2. Force on q_2 due to q_3 (F_{32}): q_2 and q_3 are opposite, so it's attractive. F_{32} points to the right (positive x-direction). The distance is $r_{32} = 0.05\,m - 0.02\,m = 0.03\,m$.

$$F_{32} = k\frac{|q_3 q_2|}{r_{32}^2} = (9 \times 10^9)\frac{|3 \times 10^{-6}\,C \times -2 \times 10^{-6}\,C|}{(0.03\,m)^2} = 60\,N \text{ (to the right)}$$

So, $\vec{F}_{32} = 60\,N\hat{\imath}$. 3. Net force:

$$\vec{F}_{net,2} = \vec{F}_{12} + \vec{F}_{32} = (-45\,N)\hat{\imath} + (60\,N)\hat{\imath} = 15\,N\hat{\imath}$$

Answer: The net force on charge q_2 is 15 N to the right.

6.2 Electric Fields Workbook

Multiple Choice Questions

1. The direction of the electric field at a point is defined as:

   (A) The direction of the force on a negative test charge placed at that point.

   (B) The direction of the force on a positive test charge placed at that point.

   (C) Always pointing away from a positive source charge.

   (D) Both (B) and (C) are correct.

   Answer: (B) Explanation: By convention, the electric field direction is the direction of the electrostatic force that would be exerted on a small positive test charge. While it does point away from a positive source charge (C), option (B) is the fundamental definition that also works for complex charge distributions.

2. If electric field lines are drawn close together, it indicates that the electric field is:

   (A) Weak

   (B) Strong

   (C) Uniform

   (D) Caused by a negative charge

   Answer: (B) Explanation: The density of electric field lines (how close they are to each other) is proportional to the strength of the electric field. Closer lines mean a stronger field.

3. Which of the following statements about electric field lines is FALSE?

   (A) They start on positive charges and end on negative charges.

   (B) They can never cross each other.

   (C) They are always parallel to the surface of a conductor.

   (D) They point in the direction of the force on a positive charge.

   Answer: (C) Explanation: Electric field lines are always perpendicular (normal) to the surface of a conductor in electrostatic equilibrium.

Short Answer Questions

1. Sketch the electric field lines for an electric dipole (one positive and one negative charge of equal magnitude).

2. Explain what a uniform electric field is and how it can be created.

Workout Problems

1. Calculate the magnitude and direction of the electric field at a point 30 cm away from a point charge of $Q = 5.0\,\text{nC}$. **Solution:**
Given: Charge, $Q = 5.0 \times 10^{-9}\,\text{C}$. Distance, $r = 30\,\text{cm} = 0.3\,\text{m}$.
Find: Electric field, E.
Formula: $E = k\frac{|Q|}{r^2}$.
Calculation:

$$E = (9 \times 10^9\,\text{N}\,\text{m}^2\,\text{C}^{-2}) \times \frac{5.0 \times 10^{-9}\,\text{C}}{(0.3\,\text{m})^2}$$

$$E = (9 \times 10^9) \times \frac{5.0 \times 10^{-9}}{}$$

$= 500\,\text{N}\,\text{C}^{-1}$

Answer: The magnitude of the electric field is $500\,\text{N}\,\text{C}^{-1}$. Since the source charge is positive, the field is directed radially away from the charge.

2. An electric field of $2000\,\text{N}\,\text{C}^{-1}$ points to the right. What is the magnitude and direction of the force on an electron placed in this field? (Charge of electron $e = -1.6 \times 10^{-19}\,\text{C}$).
Solution:
Given: Electric field, $\vec{E} = 2000\,\text{N}\,\text{C}^{-1}$ to the right. Charge, $q = e = -1.6 \times 10^{-19}\,\text{C}$.
Find: Force on the electron, $\vec{F}$.
Formula: $\vec{F} = q\vec{E}$.
Calculation:

$$\vec{F} = (-1.6 \times 10^{-19}\,\text{C}) \times (2000\,\text{N}\,\text{C}^{-1}\text{ to the right})$$

$$\vec{F} = -3.2 \times 10^{-16}\,\text{N to the right}$$

The negative sign indicates the direction is opposite to the field.

$$\vec{F} = 3.2 \times 10^{-16}\,\text{N to the left}$$

Answer: The force on the electron is $3.2 \times 10^{-16}\,\text{N}$ directed to the left.

6.3 Electric Potential Workbook

Multiple Choice Questions

1. Electric potential is defined as:

(A) Electric potential energy per unit charge.
(B) Force per unit charge.
(C) Work done on a charge.
(D) The flow of charge.

Answer: (A) Explanation: Electric potential (V) at a point is the electric potential energy (U) that a test charge (q) would have at that point, divided by the charge itself ($V = U/q$). Force per unit charge is the definition of the electric field.

2. The unit of electric potential difference is the Volt (V), which is equivalent to:
   (A) Coulomb per second
   (B) Newton per Coulomb
   (C) Joule per Coulomb
   (D) Newton-meter

   Answer: (C) Explanation: Since potential difference is work (energy) per unit charge, its unit is Joules per Coulomb ($\mathrm{J\,C^{-1}}$), which is defined as the Volt.

3. An equipotential surface is one on which:
   (A) The electric field is zero everywhere.
   (B) The electric potential is zero everywhere.
   (C) All points have the same electric potential.
   (D) No work is done by the electric field when a charge moves along the surface.

   Answer: (D) Explanation: An equipotential surface has the same potential at all points. Because the work done by the electric field is $W = -q\Delta V$, and $\Delta V = 0$ for any movement along the surface, no work is done. Note that (C) is also true, but (D) is the physical consequence and a key defining property.

Short Answer Questions

1. How is the direction of the electric field related to the direction in which electric potential decreases most rapidly?

2. Can the electric potential be zero at a point where the electric field is not zero? Give an example.

Workout Problems

1. What is the electric potential at a point 0.5 m away from a point charge of $Q = -2.0\,\mu\mathrm{C}$? **Solution:**
   Given: Charge, $Q = -2.0 \times 10^{-6}\,\mathrm{C}$. Distance, $r = 0.5\,\mathrm{m}$.
   Find: Electric potential, V.
   Formula: $V = k\frac{Q}{r}$. Note that for potential, we use the sign of the charge.
   Calculation:
   $$V = (9 \times 10^9\,\mathrm{N\,m^2\,C^{-2}}) \times \frac{-2.0 \times 10^{-6}\,\mathrm{C}}{0.5\,\mathrm{m}}$$
   $$V = (9 \times 10^9) \times (-4.0 \times 10^{-6}) = -36\,000\,\mathrm{V} = -36\,\mathrm{kV}$$
   Answer: The electric potential is $-36\,000\,\mathrm{V}$ or $-36\,\mathrm{kV}$.

2. How much work is required to move a $3.0\,\mu\mathrm{C}$ charge from a point with a potential of 100 V to a point with a potential of 250 V? **Solution:**
   Given: Charge, $q = 3.0 \times 10^{-6}\,\mathrm{C}$. Initial potential, $V_i = 100\,\mathrm{V}$. Final potential, $V_f = 250\,\mathrm{V}$.
   Find: Work done, W.

Formula: The work done by an external agent is $W = q\Delta V = q(V_f - V_i)$.
Calculation:

$$\Delta V = 250\,\text{V} - 100\,\text{V} = 150\,\text{V}$$
$$W = (3.0 \times 10^{-6}\,\text{C}) \times (150\,\text{V})$$
$$W = 4.5 \times 10^{-4}\,\text{J}$$

Answer: The work required is 4.5×10^{-4} J.

6.4 Electric Current, Resistance, and Ohm's law Workbook

Multiple Choice Questions

1. A resistor is connected to a battery. If the resistance is doubled while the voltage remains the same, the current will:

   (A) Be doubled
   (B) Be halved
   (C) Remain the same
   (D) Be quadrupled

   Answer: (B) Explanation: According to Ohm's Law ($I = V/R$), current is inversely proportional to resistance. If R is doubled, I is halved.

2. For resistors connected in series, which of the following quantities is the same for all resistors?

   (A) Voltage across each resistor
   (B) Power dissipated by each resistor
   (C) Resistance of each resistor
   (D) Current through each resistor

   Answer: (D) Explanation: In a series circuit, there is only one path for the charge to flow, so the current is the same through every component in the series.

3. For resistors connected in parallel, which of the following quantities is the same for all resistors?

   (A) Voltage across each resistor
   (B) Power dissipated by each resistor
   (C) Resistance of each resistor
   (D) Current through each resistor

   Answer: (A) Explanation: In a parallel circuit, the components are connected across the same two points, so the potential difference (voltage) is the same across each parallel branch.

Workout Problems

1. Three resistors with resistances of $R_1 = 2\,\Omega$, $R_2 = 4\,\Omega$, and $R_3 = 6\,\Omega$ are connected in series to a 12 V battery.

   (a) What is the equivalent resistance of the circuit?
   (b) What is the total current flowing from the battery?
   (c) What is the voltage drop across the $4\,\Omega$ resistor?

   Solution:
   (a) Equivalent Resistance (R_{eq}):
   For series circuits, $R_{eq} = R_1 + R_2 + R_3$.

   $$R_{eq} = 2\,\Omega + 4\,\Omega + 6\,\Omega = 12\,\Omega$$

   (b) Total Current (I_{total}):
   Using Ohm's Law, $I_{total} = V/R_{eq}$.

   $$I_{total} = \frac{12\,\text{V}}{12\,\Omega} = 1\,\text{A}$$

   (c) Voltage Drop across R_2 (V_2):
   In a series circuit, the current is the same through all resistors ($I_2 = I_{total} = 1\,\text{A}$).

   $$V_2 = I_2 R_2 = (1\,\text{A}) \times (4\,\Omega) = 4\,\text{V}$$

   Answers: (a) $12\,\Omega$, (b) 1 A, (c) 4 V.

2. The same three resistors ($R_1 = 2\,\Omega$, $R_2 = 4\,\Omega$, $R_3 = 6\,\Omega$) are now connected in parallel to the same 12 V battery.

   (a) What is the equivalent resistance of the circuit?
   (b) What is the total current flowing from the battery?
   (c) What is the current through the $6\,\Omega$ resistor?

   Solution:
   (a) Equivalent Resistance (R_{eq}):
   For parallel circuits, $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$.

   $$\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{6}{12} + \frac{3}{12} + \frac{2}{12} = \frac{11}{12}\,\Omega^{-1}$$

   $$R_{eq} = \frac{12}{11}\,\Omega \approx 1.09\,\Omega$$

   (b) Total Current (I_{total}):
   Using Ohm's Law, $I_{total} = V/R_{eq}$.

   $$I_{total} = \frac{12\,\text{V}}{12/11\,\Omega} = 11\,\text{A}$$

   (c) Current through R_3 (I_3):
   In a parallel circuit, the voltage is the same across all resistors ($V_3 = 12\,\text{V}$).

   $$I_3 = \frac{V_3}{R_3} = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

   Answers: (a) $\approx 1.09\,\Omega$, (b) 11 A, (c) 2 A.

6.6 Capacitors and Capacitance Workbook

Multiple Choice Questions

1. Inserting a dielectric material between the plates of a parallel-plate capacitor, while the capacitor is isolated (not connected to a battery), will:

   (A) Increase the charge on the plates.

   (B) Decrease the charge on the plates.

   (C) Increase the capacitance.

   (D) Increase the voltage between the plates.

   Answer: (C) Explanation: A dielectric material increases the capacitance by a factor of the dielectric constant, $C = kC_0$. Since the capacitor is isolated, the charge Q must remain constant. From $V = Q/C$, if C increases and Q is constant, the voltage V must decrease.

2. When capacitors are connected in parallel, the equivalent capacitance is:

   (A) Always less than the smallest individual capacitance.

   (B) The average of the individual capacitances.

   (C) The sum of the individual capacitances.

   (D) The reciprocal of the sum of the reciprocals of the individual capacitances.

   Answer: (C) Explanation: For capacitors in parallel, the total capacitance is the sum of the individual capacitances: $C_{eq} = C_1 + C_2 + C_3 + ...$

3. When capacitors are connected in series, the equivalent capacitance is:

   (A) Always less than the smallest individual capacitance.

   (B) The average of the individual capacitances.

   (C) The sum of the individual capacitances.

   (D) The reciprocal of the sum of the individual capacitances.

   Answer: (A) Explanation: The formula for series capacitors is $1/C_{eq} = 1/C_1 + 1/C_2 + ...$ This mathematical relationship ensures that the equivalent capacitance is always smaller than the smallest individual capacitance in the series.

Workout Problems

1. A parallel-plate capacitor has plates with an area of $200\,\text{cm}^2$ and a separation of $2\,\text{mm}$. It is filled with a dielectric material with a dielectric constant $k = 6$. What is its capacitance? (Use $\epsilon_0 = 8.85 \times 10^{-12}\,\text{F}\,\text{m}^{-1}$). **Solution:**
   Given: Area, $A = 200\,\text{cm}^2 = 200 \times 10^{-4}\,\text{m}^2 = 2 \times 10^{-2}\,\text{m}^2$. Separation, $d = 2\,\text{mm} = 2 \times 10^{-3}\,\text{m}$. Dielectric constant, $k = 6$. $\epsilon_0 = 8.85 \times 10^{-12}\,\text{F}\,\text{m}^{-1}$.
   Find: Capacitance, C.
   Formula: $C = k\epsilon_0 \frac{A}{d}$.
   Calculation:

$$C = (6) \times (8.85 \times 10^{-12}\,\text{F}\,\text{m}^{-1}) \times \frac{2 \times 10^{-2}\,\text{m}^2}{2 \times 10^{-3}\,\text{m}}$$

$$C = (6) \times (8.85 \times 10^{-12}) \times (10)$$
$$C = 5.31 \times 10^{-10}\,\mathrm{F} = 531\,\mathrm{pF}$$

Answer: The capacitance is $5.31 \times 10^{-10}\,\mathrm{F}$ or $531\,\mathrm{pF}$.

2. Three capacitors, $C_1 = 2\,\mu\mathrm{F}$, $C_2 = 4\,\mu\mathrm{F}$, and $C_3 = 6\,\mu\mathrm{F}$, are connected to a $12\,\mathrm{V}$ battery. Find the equivalent capacitance and the total charge stored if they are connected:

   (a) in parallel.

   (b) in series.

Solution:
(a) Parallel Connection:
Equivalent Capacitance (C_{eq}):

$$C_{eq} = C_1 + C_2 + C_3 = 2\,\mu\mathrm{F} + 4\,\mu\mathrm{F} + 6\,\mu\mathrm{F} = 12\,\mu\mathrm{F}$$

Total Charge (Q_{total}):

$$Q_{total} = C_{eq}V = (12\,\mu\mathrm{F}) \times (12\,\mathrm{V}) = 144\,\mu\mathrm{C}$$

(b) Series Connection:
Equivalent Capacitance (C_{eq}):

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{6+3+2}{12} = \frac{11}{12}\,(\mu F)^{-1}$$

$$C_{eq} = \frac{12}{11}\,\mu\mathrm{F} \approx 1.09\,\mu\mathrm{F}$$

Total Charge (Q_{total}): In a series circuit, the charge is the same on all capacitors and equals the total charge.

$$Q_{total} = C_{eq}V = (\frac{12}{11}\,\mu\mathrm{F}) \times (12\,\mathrm{V}) = \frac{144}{11}\,\mu\mathrm{C} \approx 13.1\,\mu\mathrm{C}$$