CLASS NOTES

Fundamentals of Electrical Circuits

Week 1 | Lessons 1, 2 & 3

CLO1: DC Circuit Fundamentals

Lesson 1: Voltage & Current, Resistance, Power & Energy

1.1 Voltage (V)

Voltage is the electric potential difference between two points in a circuit. It is the 'pressure' that drives electric charges (electrons) to flow through a conductor.

Formula	$V = W / Q$

Where: V = Voltage (Volts, V), W = Work/Energy (Joules, J), Q = Charge (Coulombs, C)

Key Points:

- Measured in Volts (V).
- Measured between two points using a Voltmeter (connected in parallel).
- A 9V battery has 9 joules of energy per coulomb of charge.
- Sources: batteries, generators, power supplies.

> □ **Note:** Voltage does not flow — it exists between two points. Current flows; voltage is the cause.

1.2 Electric Current (I)

Electric current is the rate of flow of electric charge through a conductor. Conventional current flows from the positive terminal to the negative terminal.

Formula	$I = Q / t$

Where: I = Current (Amperes, A), Q = Charge (Coulombs, C), t = Time (seconds, s)

Types of Current:

Type	Symbol	Description
Alternating Current	AC	Reverses direction periodically (e.g., mains supply)
Direct Current	DC	Flows in one constant direction (e.g., batteries)

- Measured in Amperes (A) using an Ammeter (connected in series).
- 1 Ampere = 1 Coulomb per second.

1.3 Resistance (R)

Resistance is the opposition a material offers to the flow of electric current. It converts electrical energy into heat.

Formula	$R = V / I = \rho L / A$

Where: R = Resistance (Ohms, Ω), ρ = Resistivity (Ω·m), L = Length (m), A = Cross-sectional area (m^2)

Factors Affecting Resistance:

Factor	Effect on Resistance
Length (L) ↑	Resistance ↑ (directly proportional)
Cross-sectional Area (A) ↑	Resistance ↓ (inversely proportional)
Temperature ↑	Resistance ↑ (for metals)
Material (ρ)	Depends on resistivity of the material

Note: Conductors have very low resistance; insulators have very high resistance. Semiconductors fall in between.

1.4 Power (P) and Energy (W)

Power is the rate at which electrical energy is consumed or generated.

Power	$P = V \times I = I^2 R = V^2 / R$

Energy	$W = P \times t = V \times I \times t$

Where: P = Power (Watts, W), W = Energy (Joules, J), t = Time (s)

Summary Table – Lesson 1 Quantities:

Quantity	Symbol	SI Unit
Voltage	V	Volt (V)
Current	I	Ampere (A)
Resistance	R	Ohm (Ω)
Power	P	Watt (W)
Energy	W	Joule (J)
Charge	Q	Coulomb (C)

Lesson 2: Ohm's Law, Branches, and Nodes

2.1 Ohm's Law

Ohm's Law states that the voltage across a resistor is directly proportional to the current flowing through it, provided the temperature remains constant.

Ohm's Law	$V = I \times R$

Rearranging:

To find	Use formula
Voltage (V)	$V = I \times R$
Current (I)	$I = V / R$
Resistance (R)	$R = V / I$

Example Problem:

A resistor has a resistance of 10 Ω and a current of 2 A passes through it. Find the voltage across it.

Solution	$V = I \times R = 2\ A \times 10\ \Omega = 20\ V$

Note: Ohm's Law applies only to linear (ohmic) resistors where R remains constant. Diodes and transistors are non-ohmic devices.

2.2 Circuit Terminology: Branches, Nodes, and Loops

Understanding the structure of a circuit is essential for analysis. The three fundamental terms are:

Branch

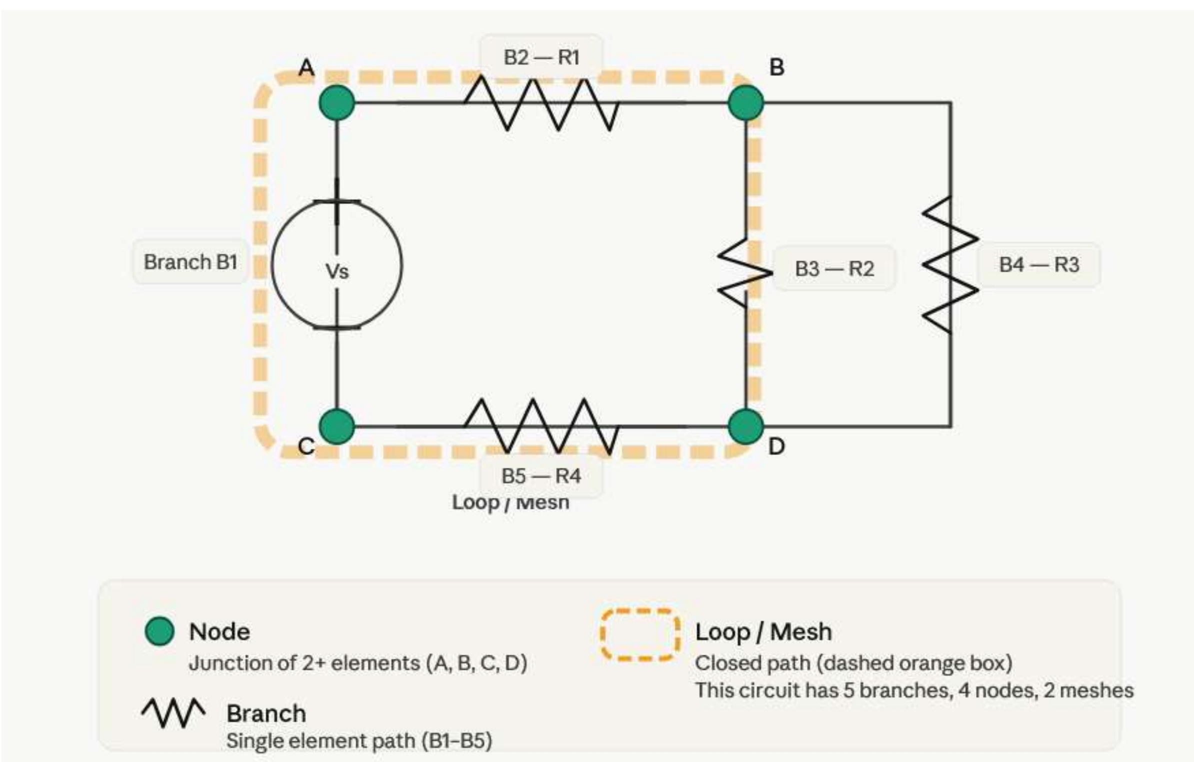
- A branch is a single two-terminal element in a circuit (e.g., a resistor, capacitor, voltage source, or current source).
- Each branch carries its own current.
- A circuit with 5 elements has 5 branches.

Node

- A node is a point where two or more circuit elements join together.
- At any node, all connected elements share the same voltage.
- A principal (essential) node connects three or more branches.

Loop

- A loop is any closed path in a circuit.
- A mesh is a loop that does not contain any other loop within it (smallest possible loop).



Here's the circuit diagram illustrating all three key concepts:

Nodes (green dots) — Points A, B, C, and D are junctions where two or more branches meet. Every element connected to the same node shares the same voltage.

Branches (B1–B5) — Each individual element is its own branch: the voltage source (B1), and four resistors R1–R4 (B2–B5). Current in each branch can be different.

Loop / Mesh (dashed orange box) — The closed path formed by Vs → R1 → R2 → R4 going around the left rectangle. KVL applies to this loop: the sum of all voltages around it equals zero.

Term	Definition
Branch	A single two-terminal element (resistor, source, etc.)
Node	A junction point connecting two or more elements
Essential Node	A junction connecting three or more branches
Loop	Any closed path through the circuit
Mesh	A loop with no other loops inside it

2.3 Relationship: Branches, Nodes & Loops

For any circuit, the following relationship holds (Euler's formula for networks):

Network Theorem	$b = l + n - 1$

Where: b = number of branches, l = number of independent loops, n = number of nodes

Lesson 3: Series DC Circuits & Kirchhoff's Voltage Law (KVL)

3.1 Series DC Circuits

In a series circuit, all components are connected end-to-end in a single path. The same current flows through every element.

Characteristics of a Series Circuit:

Property	In Series Circuit
Current (I)	Same through all elements: $I_T = I_1 = I_2 = I_3$
Voltage	Divides across elements: $V_T = V_1 + V_2 + V_3$
Resistance	Adds up: $R_T = R_1 + R_2 + R_3$
Power	Adds up: $P_T = P_1 + P_2 + P_3$

Total (Equivalent) Resistance:

Series Resistance	$R_T = R_1 + R_2 + R_3 + ... + R_n$

Example Problem – Series Circuit:

Three resistors $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$, and $R_3 = 10\ \Omega$ are connected in series to a 40 V battery. Find the total resistance, current, and voltage across each resistor.

Step 1: R_T	$R_T = 4 + 6 + 10 = 20\ \Omega$

Step 2: I	$I = V_T / R_T = 40V / 20\Omega = 2\ A$

Step 3: V_1, V_2, V_3	$V_1=8V$, $V_2=12V$, $V_3=20V$ (sum = 40V ✓)

3.2 Kirchhoff's Voltage Law (KVL)

KVL is one of the two fundamental laws of circuit analysis (the other being KCL). It is based on the principle of conservation of energy.

KVL Statement:

The algebraic sum of all voltages around any closed loop in a circuit equals zero.

ΣV = 0   (around any closed loop)

Sign Convention for KVL:

- Assign a direction to traverse the loop (clockwise or counter-clockwise).
- Voltage Rise (+): When traversing from − to + terminal of a source.
- Voltage Drop (−): When traversing from + to − terminal across a resistor in the direction of assumed current.

Applying KVL – General Procedure:

- Step 1: Assign a reference direction to the loop (e.g., clockwise).
- Step 2: Assign current direction (assume if unknown).
- Step 3: Label all voltage drops and rises.
- Step 4: Write the KVL equation: sum of all voltages = 0.
- Step 5: Solve for the unknown.

KVL Example:

A circuit has a 20 V source, and two resistors R_1 = 5 Ω and R_2 = 15 Ω in series. Using KVL, find the current.

KVL Equation	`+20 - V_R1 - V_R2 = 0`

Expand	`+20 - 5I - 15I = 0   =>   20 = 20I   =>   I = 1 A`

□ **Note:** KVL works for any loop in any circuit — DC or AC. Always verify that voltage drops sum up to the total source voltage.

3.3 Physical Meaning & Intuition

Law / Concept	Physical Meaning
Ohm's Law	More voltage = more current for same resistance
Series circuit	One path; break anywhere opens whole circuit
KVL	Energy supplied by source = energy consumed by resistors

Week 1 Summary & Key Formulas

Topic	Key Formula	Unit
Voltage	$V = W/Q$	Volt (V)
Current	$I = Q/t$	Ampere (A)
Resistance	$R = V/I = \rho L/A$	Ohm (Ω)
Power	$P = VI = I^2R = V^2/R$	Watt (W)
Energy	$W = Pt$	Joule (J)
Ohm's Law	$V = IR$	—
Series Resistance	$R_T = R_1 + R_2 + R_3$	Ohm (Ω)
KVL	$\Sigma V = 0$ (around loop)	—
Network	$b = l + n - 1$	—

— End of Week 1 Class Notes —