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Direct Current Circuit

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Chapter Description

- Aims

  Students will understand how to calculate the effective resistance in a circuit, and describe the rules of current flow in direct current circuits.

- Expected Outcomes
  - ➢ Able to analyse electrical circuits with multiple resistors connected in parallel or in series
  - ➢ Able to describe the rules for circuits with more than one loop
  - ➢ Able to use ammeters and voltmeters correctly

Content

6.1 Resistance in Series and Parallel

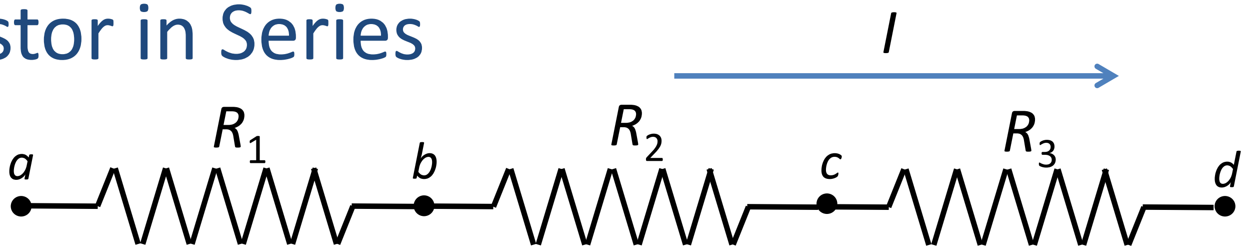
6.2 Kirchhoff's Rules

6.3 Electrical Measuring Equipment

6.1 Resistance in Series and Parallel

- Just like capacitors, resistors in come in specific resistance ratings such as 100 Ω, 330 Ω and 1 kΩ
- In order to use a specific resistance value in an electrical circuit, several resistors can be connected either in series or in parallel to achieve resistance value that may not be available in a single resistor

Resistor in Series



- In a series, the current is the same in all resistors. From Ohm's law, $V_{ab} = IR_1$ $V_{bc} = IR_2$ $V_{cd} = IR_3$
- The potential difference across the entire combination is the sum of the individual potential differences,

$$V_{ab} = V_{ax} + V_{xy} + V_{yb} = I(R_1 + R_2 + R_3)$$

$$\therefore R_{\text{eq}} = R_1 + R_2 + R_3$$

$$R_{\text{eq}} = R_1 + R_2 + R_3 + \ldots$$ (resistors in series)

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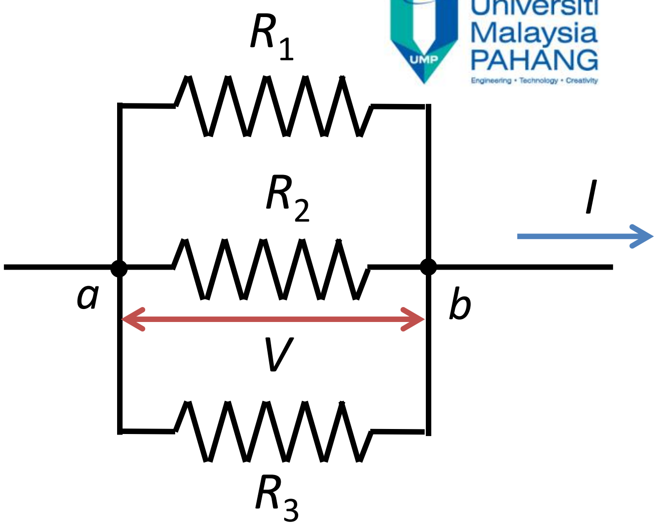
Resistor in Parallel



- If the resistors are in parallel, current though each resistors are different.
- However, the potential difference between the terminals must be the same and equal to V_{ab}

$$I_1 = \frac{V_{ab}}{R_1} \qquad I_2 = \frac{V_{ab}}{R_2} \qquad I_3 = \frac{V_{ab}}{R_3}$$

- Total current must equal the sum of all three currents in the resistors

$$I = I_1 + I_2 + I_3 = V_{ab}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\therefore \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$ (resistors in parallel)

6.2 Kirchhoff's Rules

- Many practical resistor networks cannot be reduced to simple series-parallel combinations. And current calculation is complex for circuits with more than one power source.
- A technique developed by German physicist, Gustav Kirchhoff can be employed in cases like these.

- Two important terms:
  1. **Junction**: A point in the circuit where three or more conductors meet
  2. **Loop**: Any closed conducting path.

Kirchhoff's Junction Rule

- The sum of the currents into any junction is zero. That is

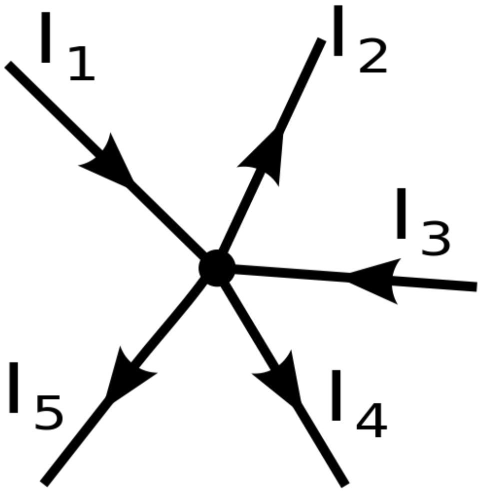
$$\sum I = 0 \quad \text{(junction rule, valid at any junction)}$$

- For example, in the complex junction shown to the right, all the current going into the junction I_1 and I_3 flows out as current I_2, I_4 and I_5

- If the current going into the junction is taken as positive, the junction rule can be written as

$$\sum I = I_1 - I_2 + I_3 - I_4 - I_5 = 0$$

$$I_1 + I_3 = I_2 + I_4 + I_5$$



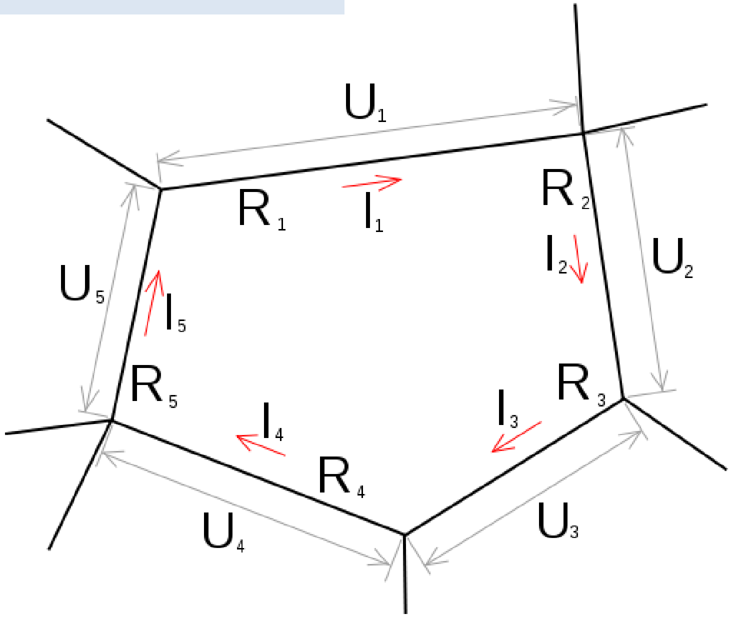
Source: Philnate, Wikimedia Commons

Kirchhoff’s Loop Rule

The sum of the potential differences in any closed loop, including those associated with emfs and those of resistive element, must equal zero.

$$\sum V = 0 \quad \text{(loop rule, valid at any closed loop)}$$

- For sources of emfs, the voltage is positive when going from – to +
- While for resistors etc, the voltage is negative when going from – to +



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6.2 Electrical Measuring Instruments

- Potential difference, current and resistance in a circuit can be measured using a *d'Arsonvale galvanometer*

- A coil of wire is placed in a magnetic field of a permanent magnet. When there is current in the coil, the magnetic field exerts a torque on the coil. As the coil turns, the spring exerts a restoring torque to push it back to zero.

- The maximum deflection, typically 90°, is called *full-scale deflection*. The current at this deflection is called full-scale current, I_{fs}
- The difference between the method of measuring the three parameters has something to do with the meter's internal connections

Ammeters

- A meter to measure current passing through it.
- An ideal ammeter would have zero resistance
- Real ammeters always have some finite resistance, denoted R_C, which is the resistance of the coil.

- The ammeter can be adapted to measure current larger than its full-scale reading by connecting a resistor in parallel to the coil, so that some of the current bypasses the meter coil.
- The parallel resistor is called a shunt resistor, denoted as R_{sh}

- For example, suppose we want to make a meter with full-scale current I_{fs} into an ammeter with full scale reading I_a. To determine the shunt resistor needed, note that at full-scale deflection, the total current through the parallel combination is I_a, the current through the coil of the meter is I_{fs}, and the current through the shunt resistor is I_a - I_{fs}. Since V is the same for both *R,*

$$I_{fs}R_C = (I_a - I_{fs})R_{sh}$$

Voltmeters

- The same basic meter used as ammeters can also be used to measure voltage.
- An ideal voltmeter would have infinite resistance
- Real voltmeters should always have some large enough resistance, so connecting it between two points in a circuit does not change the current in the circuit

- Like the ammeter, full scale reading in voltmeters can be changed by connecting a shunt resistor, R_S in series with the coil.

- Then only a fraction of the total potential difference appears across the coil itself, an the remainder appears across R_S. For a voltmeter with full scale reading V_a, we need series resistor so that

$$V_{\mathrm{a}} = I_{\mathrm{fs}}\left(R_{\mathrm{C}} + R_{\mathrm{S}}\right)$$

Conclusion

- Resistance calculation
  - Resistors are typically connected in series and parallel to achieve desired resistance value
  - The calculation for resistors in series and parallel are different
- Kirchhoff's Rules
  - Kirchhoff's rules are useful to analyse the current flowing in a circuit with more than one loop
- Ammeters and Voltmeters
  - Ammeters and voltmeters are similar to each other except for the way the shunt resistor is connected inside them

References

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- **Physics for Scientists & Engineers 4th Edition**, Douglas C. Giancoli, Pearson, 2008

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Thank you!

Next chapter:
Magnetic Forces and Fields

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