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

- **Electrical Power:**

\[ P = I\Delta V \]

- **For Ohmic Devices:**

\[ P = I^2R, \quad P = \frac{\Delta V^2}{R} \]
Consider three light-bulbs rated \((\Delta V = 120V)\) at 75W, 60W, and 40W. Which light-bulb has the highest resistance?

- a) The 75W light-bulb.
- b) The 60W light-bulb.
- c) The 40W light-bulb.
- d) They all have the same resistance.

\[
R = \frac{\Delta V^2}{P} = \frac{(120V)^2}{75} < \frac{(120V)^2}{60W} < \frac{(120V)^2}{40W}
\]
Direct Current

• In a circuit, the potential difference at the battery terminals is (nearly) constant.

• The current in the circuit is constant in magnitude and direction and is called direct current.

• A battery is a source of emf “\(\mathcal{E}\)”. The emf of a battery is the maximum possible voltage that the battery can provide between its terminals.
EMF

- A real battery is made of matter so there is resistance to the flow of charge within the battery.
- This resistance is called the internal resistance, $r$.
- R is called the load resistance.
Under some current, $I$, the terminal voltage of the battery, $\Delta V = V_b - V_a$ is:

$$\Delta V = \mathcal{E} - Ir$$

Note that $\mathcal{E}$ is equivalent to the open-circuit voltage (i.e. the terminal voltage when the current is zero).

The potential difference across the load resistor is $\Delta V_R = IR$, then:

$$\mathcal{E} = I(R + r) \quad and \quad I = \frac{\mathcal{E}}{R + r}$$
Power

• The total power output of the battery:

\[ P = I \mathcal{E} = I^2 R + I^2 r \]

• P is delivered to the external load resistance in the amount \( I^2 R \) and to the internal resistance in the amount \( I^2 r \).

• If the load resistance is much greater than the internal resistance (i.e. \( R \gg r \)), then we can neglect \( r \).
Resistors In Series

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

[Resistors in Series]
Resistors In Parallel

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

[Resistors in Parallel]
ICLICKER QUESTION

Find the equivalent resistance between points c and d.

a) 0.5 Ω  
b) 1.0 Ω  
c) 1.5 Ω  
d) 2 Ω  
e) 5 Ω
Find the equivalent resistance between points a and b.

- a) 1 Ω
- b) 1.2 Ω
- c) 1.5 Ω
- d) 2 Ω
- e) 5 Ω
Kirchhoff’s Rules

- Some circuits cannot be broken down into series and parallel connections.

- We can use conservation of energy and conservation of charge!
Kirchhoff’s Rules

**Junction rule** (conservation of charge): The sum of currents entering a junction equals the sum of the currents leaving it.

\[ \sum_{\text{in}} I = \sum_{\text{out}} I \]

**Loop rule** (conservation of energy): The sum of the changes in potential around a closed loop is zero.

\[ \sum_{\text{Closed Loop}} \Delta V = 0 \]
ICLICKER QUESTION

What is the current in branch P?

a) 2 A
b) 3 A
c) 5 A
d) 6 A
e) 10 A

© Rutgers, The State University of New Jersey. Department of Physics & Astronomy
Problem Solving Using Kirchhoff’s Rules

1. Label each current (if the label direction is wrong you will get a negative current after solving the equations which means the current flows in the opposite direction).

2. Identify unknowns.

3. Apply junction (conservation of charge) and loop (conservation of energy) rules (for a full solution you will need as many independent equations as there are unknowns).

4. Solve the equations, being careful with signs.
Example: Find the current through each resistor

\[ \sum_{in} I = \sum_{out} I \]

At c: \[ I_1 + I_2 = I_3 \]

\[ \sum \Delta V = 0 \]

Closed Loop

febadcf loop: \[ 14 + 4I_2 + 2I_3 = 0 \]

bcdab loop: \[ 10 - 6I_1 - 2I_3 = 0 \]

As labeled: \[ I_1 = 2.0A, I_2 = -3.0A, I_3 = -1.0A \]

\[ \Rightarrow I_2 \text{ and } I_3 \text{ are both } < 0 \text{ then the currents are opposite the directions chosen.} \]
ICLICKER QUESTION

Which of the equations is valid for the circuit below?

(a) \(2 - I_1 - 2I_2 = 0\)
(b) \(2 - 2I_1 - 2I_2 - 4I_3 = 0\)
(c) \(2 - I_1 - 4 - 2I_2 = 0\)
(d) \(I_3 - 4 - 2I_2 + 6 = 0\)
(e) \(2 - I_1 - 3I_3 - 6 = 0\)
What happens to the potential across the resistor $R_1$ ($\Delta V_{R_1}$) when the switch is closed?

- a) $\Delta V_{R_1}$ will increase
- b) $\Delta V_{R_1}$ will decrease
- c) $\Delta V_{R_1}$ will stay the same
The lightbulbs in the circuit are identical. When the switch is closed, what happens?

a) both bulbs go out
b) intensity of both bulbs increases
c) intensity of both bulbs decreases
d) A gets brighter and B gets dimmer
e) nothing changes