More Terminal Voltage & Power

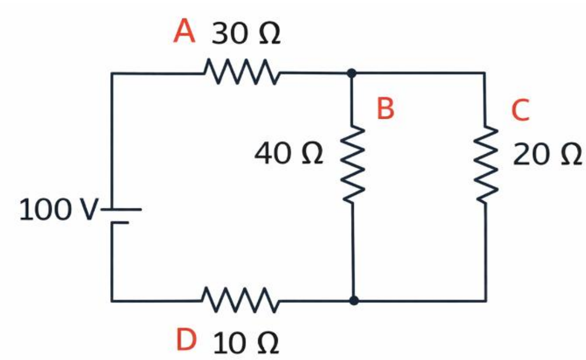
Notes for Students

- The **power dissipated** by a resistor can be calculated using:

$$P = IV \quad \text{or} \quad P = I^2R \quad \text{or} \quad P = \frac{V^2}{R}$$

- In **series circuits**, the current is the same through each component.
- In **parallel circuits**, the voltage across each branch is the same.
- The **brightness of a bulb** depends on the **power** it dissipates.

1) Four **identical light bulbs** are connected to a **100 V power source**, as shown in the diagram. The bulbs have the following resistances: **Bulb A:** 30 Ω, **Bulb B:** 40 Ω, **Bulb C:** 20 Ω, **Bulb D:** 10 Ω



The circuit has the following structure:
   - Bulbs **B** and **C** are connected **in parallel** with each other.
   - This parallel combination is connected **in series** with bulbs **A** and **D**.

   (a) Determine the **current through each bulb**.
   (b) Determine the **power dissipated by each bulb** (A, B, C, and D).

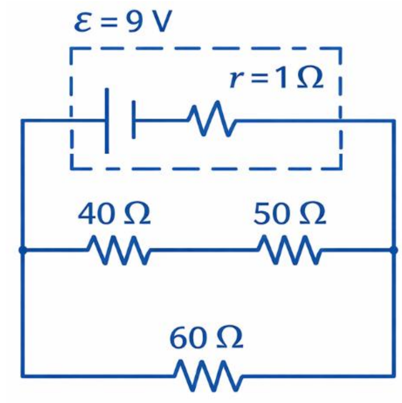
2) The circuit from **Question 1** is modified by adding a **fifth bulb** that is **identical to bulb B**.
   - The new bulb is connected **in parallel** with bulbs B and C.
   - All other aspects of the circuit remain unchanged.

   (a) Determine the **new equivalent resistance** of the parallel section.
   (b) Determine the **total current supplied by the power source** in the modified circuit.

3) Using the **modified circuit** from Question 2:
   For **each bulb**, indicate how its brightness changes compared to the original circuit in Question 1.
   ☐ brighter ☐ dimmer ☐ the same
   - Bulb A: ☐ brighter ☐ dimmer ☐ the same
   - Bulb D: ☐ brighter ☐ dimmer ☐ the same
   - Bulb B: ☐ brighter ☐ dimmer ☐ the same
   - Bulb C: ☐ brighter ☐ dimmer ☐ the same

   (Explain your reasoning clearly, referring to:)
   - how the **total resistance** of the circuit changes
   - how **current and voltage** behave in series and parallel sections
   - the relationship between **power and brightness**

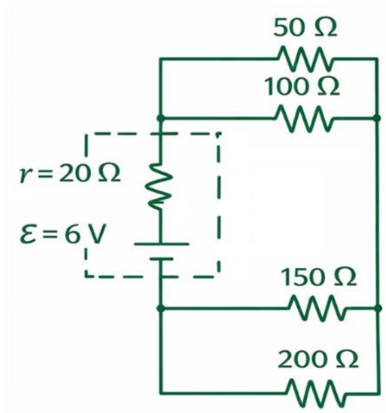
4) A **real battery** with an **emf of** $\varepsilon = 9.0$ Vand an **internal resistance of** $r = 1.0$ is connected to an external circuit, as shown in the diagram. The external circuit consists of **two branches connected in parallel**:



- **Upper branch:** two resistors in series, 40 Ω and 50 Ω
- **Lower branch:** a single resistor 60 Ω

Determine the terminal voltage of the battery.

5) A **real battery** with an **emf of** $\varepsilon = 6.0$ Vand an **internal resistance of** $r = 20$ Ωis connected to an external circuit, as shown in the diagram. The external circuit consists of **two parallel sections connected in series**:



- **Upper parallel section,** 50 Ω **and** 100 Ω
- **Lower parallel section** 150 Ω **and** 200 Ω

Determine the terminal voltage of the battery.

6) A real battery with an emf of **ε = 18.0 V** is connected to an external circuit, as shown in the diagram. The external circuit consists of **two resistors connected in parallel**:

- Upper branch resistor: $\boldsymbol{R_1}$ **= 12 Ω**
- Lower branch resistor: $\boldsymbol{R_2}$ **= 6.0 Ω**

The **terminal voltage of the battery is measured to be 12.0 V** while the circuit is operating.

Assume:

- All connecting wires have negligible resistance
- The battery's internal resistance **r** is in series with the external circuit

(a) Determine the **equivalent resistance** of the external circuit.
(b) Determine the **total current supplied by the battery**.
(c) Determine the **internal resistance r** of the battery.

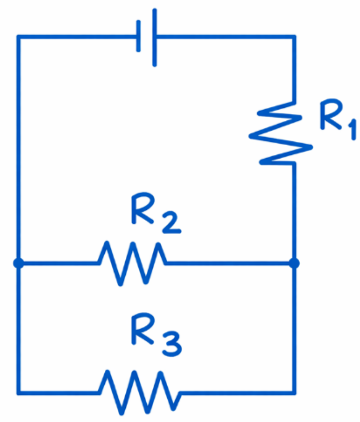
7) A **heating coil** with a resistance of 10 Ωis connected to a **120 V power supply**. The coil is immersed in a container holding **2.0 L of water**. The water initially has a temperature of **20 °C**.

Additional information:

- The **specific heat capacity of water** is $c = 4.18$ J/(g°C)
- Assume:
  - All electrical energy from the coil goes into heating the water
  - No heat is lost to the surroundings
  - The density of water is 1.0 g/mL

(a) Determine the **time required** for the heating coil to raise the temperature of the water to **100 °C**.
(b) Electricity costs **$0.11 per kWh**. Determine the **cost** to heat the water from **20 °C to 100 °C**.

8) The circuit shown consists of **three identical resistors**, labeled R_1, R_2, and R_3, connected to an **ideal battery**, as shown in the diagram.



- Resistor R_1 is connected on the **right-hand vertical branch**.
- Resistors R_2 and R_3 are connected next in parallel on **separate horizontal branches**.
- The battery is connected across the **top of the circuit**.

Assume:

- All resistors have the **same resistance** R
- The battery and connecting wires are **ideal**
- No energy is lost outside the resistors

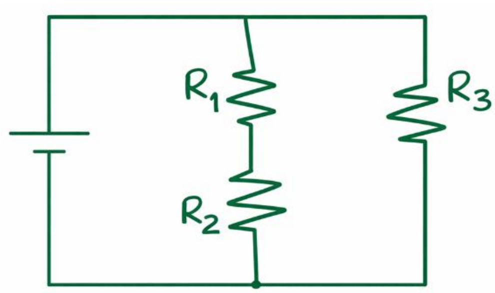
(a) Determine the **power dissipated** by each resistor: P_1, P_2, and P_3.

(b) Compare the power outputs of the three resistors by writing your answer as ratios (for example, $P_1 = 2P_2$ or $P_1 = P_2 = P_3$).

(c) Briefly **explain your reasoning**, referring to:

- which resistors share the **same current**
- which resistors share the **same voltage**
- the relationship between **power, current, and voltage**

9) The circuit shown consists of **three identical resistors**, labeled R_1, R_2, and R_3, connected to an **ideal battery**, as shown in the diagram.



- Resistors R_1 **and** R_2 are connected **in series** on the **middle vertical branch** of the circuit.
- Resistor R_3 is connected on the **right-hand vertical branch**.
- The **series combination** $R_1 + R_2$ is connected **in parallel** with resistor R_3.
- The battery is connected across the **top and bottom nodes** of the circuit.

Assume:

- All resistors have the **same resistance** R
- The battery and connecting wires are **ideal**
- No energy is lost outside the resistors

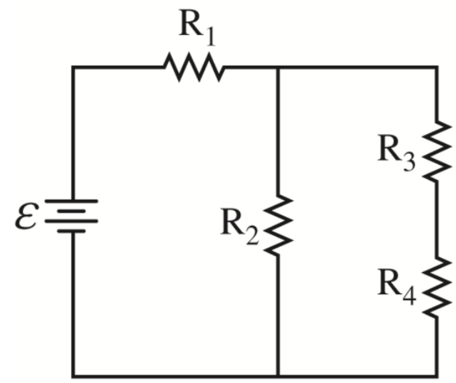
(a) Determine the **power dissipated** by each resistor: P_1, P_2, and P_3.

(b) Compare the power outputs of the three resistors by writing your answer as ratios (for example, $P_1 = 2P_2$ or $P_1 = P_2 = P_3$).

(c) Briefly **explain your reasoning**, referring to:

- which resistors share the **same current**
- which resistors share the **same voltage**
- the relationship between **power, current, and voltage**

10) A circuit consists of an **ideal battery** with emf εconnected to **four identical resistors**, each with resistance R, arranged as shown in the diagram.



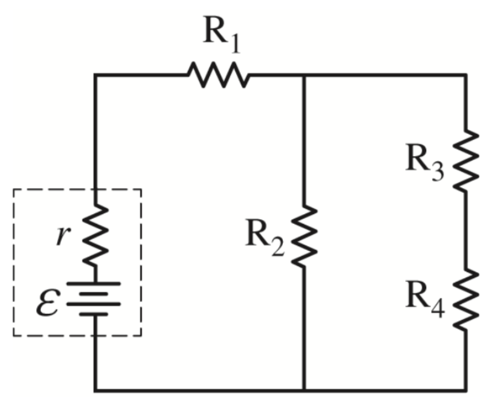
- $R_1$is connected **in series** with the rest of the circuit.
- After R_1, the circuit splits into **two parallel branches**:
  - One branch contains a **single resistor** R_2.
  - The other branch contains **two resistors** R_3**and** R_4**connected in series**.
- The two branches then rejoin and return to the battery.

Assume:

- All resistors have resistance R
- The battery and connecting wires are ideal
- All results should be expressed **symbolically** in terms of $\varepsilon$and R

(a) Derive an expression for the **current** I_1through resistor R_1.
(b) Derive an expression for the **current** I_3through resistor R_3.
(c) Derive an expression for the **total power dissipated** in the circuit.

11) A circuit consists of **four identical resistors**, labeled R_1, R_2, R_3, and R_4, arranged as shown in the diagram.



- $R_1$is connected **in series** with the rest of the circuit.
- After R_1, the circuit splits into **two parallel branches**:
  - One branch contains a **single resistor** R_2.
  - The other branch contains **two resistors,** R_3**and** R_4**, connected in series**.
- The branches rejoin and return to the battery.

Original Circuit

- The circuit is first connected to an **ideal battery** (no internal resistance).
- The **total power dissipated** in the resistors is P_{original}

Modified Circuit

- The ideal battery is then replaced with a **non-ideal battery** having:
  - an emf ε
  - an **internal resistance** r, as shown in the dashed box in the diagram
  - The **total power dissipated in the circuit** is now P_{new}

Is P_{new}greater than, less than, or equal to P_{original}?

☐ greater than ☐ less than ☐ equal to

Explain your reasoning clearly, referring to:

- how the internal resistance affects the **total current**
- how power depends on current and resistance
- where energy is dissipated in each case