11 D.C. Circuits

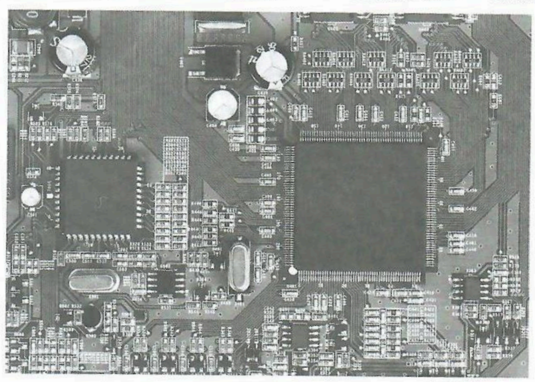
Study Station ▸▸

A Series Circuits

Learning Outcomes

- Draw circuit diagrams with power sources (cell or battery), switches, lamps, fixed and variable resistors (rheostats), fuses, ammeters and voltmeters, and light-emitting diodes (LEDs).
- State that in a series circuit, the current at each point is the same and use the principle to solve related problems.
- State that in a series circuit, the sum of the potential differences across each component is equal to the potential difference across the whole circuit and use the principle to solve related problems.
- State that in a series circuit, the effective resistance is the sum of resistances and use the principle to solve related problems.

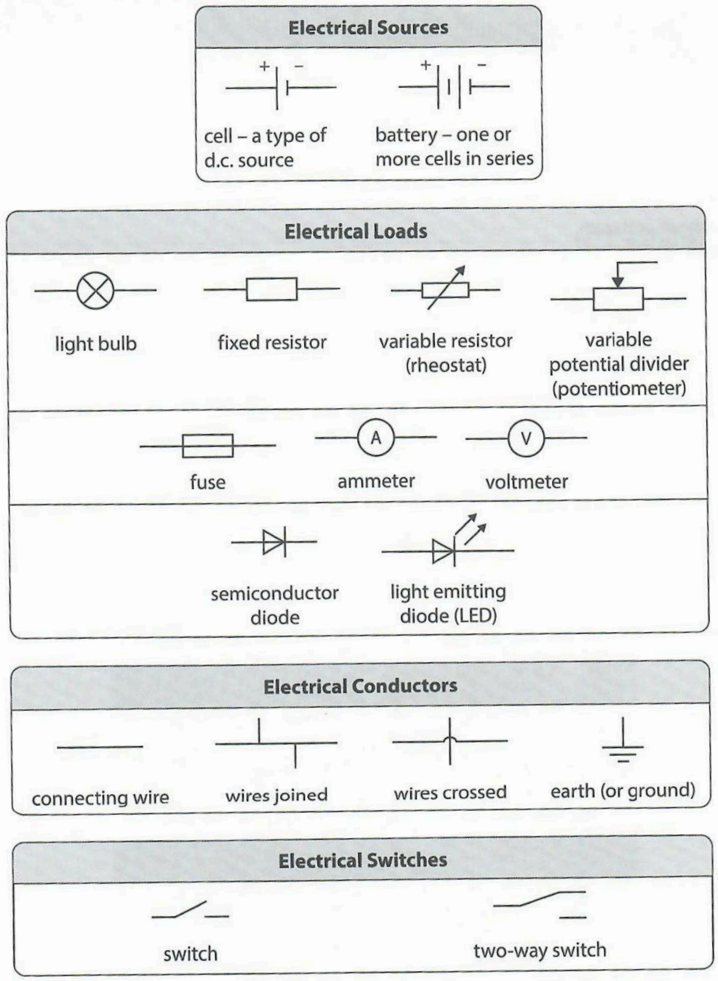
1. In electric circuits, the electrical components can be arranged in many different ways to produce different currents, potential differences and effective resistances.
2. If you look inside electronic devices such as mobile phones and computers, you will find many electrical components in complicated circuits which enable their advanced functions.



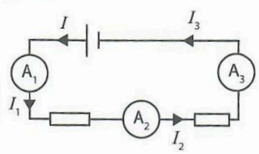
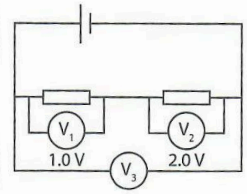
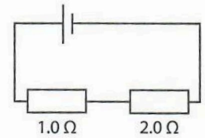
Circuit board

3. Simple electric circuits usually consist of four types of components:
   - a **source** to drive electric charges in the circuit, e.g. a battery
   - a **load** on which the moving charges can do a useful job, e.g. a lamp
   - **conductors** to connect the components together, e.g. copper wires
   - a **switch** to open or close the circuit

4. A **circuit diagram** is a simplified diagrammatic representation of an electric circuit. Each of the components is represented by a circuit symbol in circuit diagrams.



5. In a series circuit, the electrical components are connected one after another in a single loop. The table explains current, potential difference and effective resistance in a series circuit.

Current	Potential Difference (P.D.)	Effective Resistance
Current I is the same at every point (same rate of electron flow).	Potential difference across the whole circuit is the sum of individual p.d.	Effective resistance R_E is the sum of individual resistances.
$I_1 = I_2 = I_3 = \ldots = I_N$	$V = V_1 + V_2 + \ldots + V_N$	$R_E = R_1 + R_2 + \ldots + R_N$
Example:  Ammeters A_1, A_2 and A_3 show the same reading.	Example:  Voltmeter V_3 shows a reading of 1.0 V + 2.0 V = 3.0 V.	Example:  $R_E = 1.0\ \Omega + 2.0\ \Omega = 3.0\ \Omega$ (i.e. the two resistors can be replaced with a single 3.0 Ω resistor for the same effect)

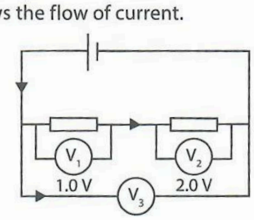
Tip

Usually, ammeters and voltmeters are assumed to be perfect.

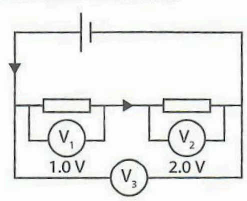
- Perfect ammeters have zero resistance, thus the p.d. across them is zero.
- Perfect voltmeters have infinite resistance, thus the current through them is zero.

Common Error

✗ The circuit diagram below shows the flow of current.



✓ The circuit diagram below shows the flow of current.

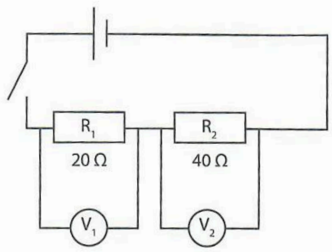


Explanation

Perfect voltmeters do not allow current to flow through them.

Worked Example 11.1

The circuit diagram below is a simple representation of the call function of a phone. The microphone (sound capture component) and speakers (sound production component) are represented by resistors R_1 and R_2 respectively. During a phone call (i.e. switch is closed), a current I of 50 mA flows in the circuit.



(a) Calculate the potential difference across R_1.

(b) Calculate the potential difference across R_2.

(c) Determine the e.m.f. of the cell.

Solution

(a) $V_1 = IR_1$

$= (50 \times 10^{-3}\ \text{A}) \times 20\ \Omega$

$= 1.0\ \text{V}$

(b) $V_2 = IR_2$

$= (50 \times 10^{-3}\ \text{A}) \times 40\ \Omega$

$= 2.0\ \text{V}$

(c) E.m.f. = 1.0 V + 2.0 V

= 3.0 V

OR

Effective resistance, $R_E = 20\ \Omega + 40\ \Omega = 60\ \Omega$

Total p.d. = e.m.f. = $I \times R_E$

$= (50 \times 10^{-3}\ \text{A}) \times 60\ \Omega$

$= 3.0\ \text{V}$

Explanation

Note that both components work at the same time.
When the switch is open, no current flows through either component.
When the switch is closed, the same current flows through both components.

Link Discover Physics (5th Edition) Textbook — Section 14.1

Checkpoint 11.1

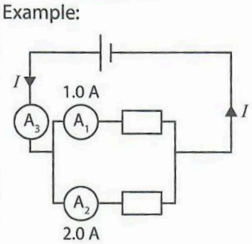
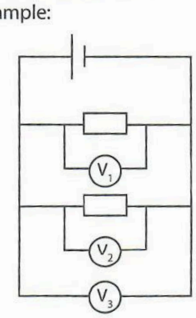
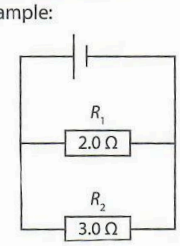
1. What is the effective resistance of three resistors of 2 Ω arranged in series?

B Parallel Circuits

Learning Outcomes

- State that in a parallel circuit, the sum of the currents in the individual branches is equal to the current from the source and use the principle to solve related problems.
- State that in a parallel circuit, the potential difference across each branch is the same and use the principle to solve related problems.
- Recall the formula for the effective resistance in parallel circuits and use it to solve related problems.
- Recall the various relationships for current, potential difference and resistance, including $R = \frac{V}{I}$, in series and in parallel circuits, and use them to solve related problems of whole circuits.

1. In a **parallel circuit**, the electrical components are arranged in parallel.

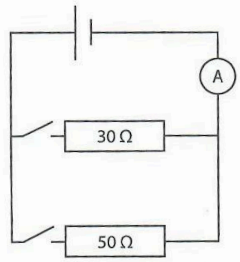
Current	Potential Difference (P.D.)	Effective Resistance
Current I from the source is the sum of current in each branch. Electron flow is split at branch junction.	Potential difference is the same across each branch.	Reciprocal of effective resistance R_E is the sum of reciprocal of individual resistances.
$I_1 = I_2 + I_3 = \ldots = I_N$	$V_1 = V_2 = V_3 = \ldots = V_N$	$\frac{1}{R_E} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_N}$
Example:  Ammeter A_3 shows a reading of 1.0 A + 2.0 A = 3.0 A	Example:  Voltmeters V_1, V_2 and V_3 show the same reading.	Example:  $\frac{1}{R_E} = \frac{1}{2.0\ \Omega} + \frac{1}{3.0\ \Omega}$ $= \frac{5.0}{6.0\ \Omega}$ $R_E = \frac{6.0\ \Omega}{5.0} = 1.2\ \Omega$

Tip

Notice that R_E is always smaller than any one of the individual resistances of the resistors arranged in parallel. In the example, R_E (1.2 Ω) is smaller than both R_1 (2.0 Ω) and R_2 (3.0 Ω).

Worked Example 11.2

The circuit diagram below is a simple representation of the bluetooth and WiFi connection functions of a smartphone. The bluetooth and WiFi components are represented by resistors of 30 Ω and 50 Ω respectively.



(a) When the bluetooth function is turned on (i.e. the switch is closed), a current of 60 mA flows through the bluetooth component. Calculate the potential difference across the bluetooth component.

(b) When the WiFi function is turned on, calculate the current passing through the WiFi component.

(c) Determine the ammeter reading.

Solution

(a) $V_1 = I_1R_1$
$= (60 \times 10^{-3}\ \text{A}) \times 30\ \Omega$
$= 1.8\ \text{V}$

(b) $I_2 = \frac{V_2}{R_2}$
$= \frac{1.8\ \text{V}}{50\ \Omega}$
$= 0.036\ \text{A}$

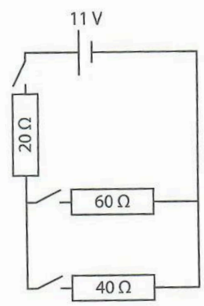
(c) $I = I_1 + I_2$
$= (0.060 + 0.036)\ \text{A}$
$= 0.096\ \text{A}$

Explanation

Note that both components can function independently of each other.

Worked Example 11.3

The circuit diagram below is a simple representation of the recording function of a smartphone. The recording, image capture and sound capture components are represented by resistors of 20 Ω, 60 Ω and 40 Ω respectively.



Determine the current flowing from the battery if all three switches are closed.

Strategy

Note that the 60 Ω and 40 Ω resistors are arranged in parallel.

The 20 Ω resistor is in series with the combined resistance of the 60 Ω and 40 Ω resistors.

Solution

Let the combined resistance of 60 Ω and 40 Ω resistors be R'.

$$\frac{1}{R'} = \frac{1}{60\ \Omega} + \frac{1}{40\ \Omega} = \frac{1}{24\ \Omega}$$

$R' = 24\ \Omega$

Total resistance of circuit $R_T = R' + 20\ \Omega$
$= (24 + 20)\ \Omega$
$= 44\ \Omega$

$$I = \frac{V}{R_T} = \frac{11\ \text{V}}{44\ \Omega} = 0.25\ \text{A}$$

Explanation
There are three possible modes of recording depending on which switches are closed, namely photo (image), sound and video (image and sound) recordings.

Link Discover Physics (5th Edition) Textbook — Section 14.2

Checkpoint

1. What is the effective resistance of three resistors of 2 Ω arranged in parallel?

Test Station ▸▸

1. Figure 14.1 shows part of a circuit. Which of the following equations is **correct**?

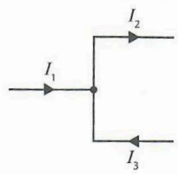


Figure 14.1

A $I_1 = I_2 + I_3$

B $I_2 = I_1 + I_3$

C $I_3 = I_1 + I_2$

D $I_1 + I_2 + I_3 = 0$

2. A circuit is to be connected to two points in the set-up **PQRS** shown in Figure 14.2. Which **two** points give the minimum resistance in the circuit?

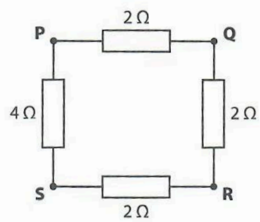


Figure 14.2

A **P** and **Q**

B **P** and **R**

C **P** and **S**

D **Q** and **S**

3. A Christmas tree is decorated with 20 filament light bulbs that are connected in series. The light bulbs are supplied with electricity by a plug that delivers a current of 100 mA at 24 V.

(a) What is the current flowing through each bulb? [1]

(b) What is the potential difference across each bulb? [1]

(c) Explain why none of the bulbs will light up if one of them blows. [1]

4. Figure 14.3 shows a cell connected to three resistors **A**, **B** and **C**. The current flowing through each resistor is indicated on the diagram.

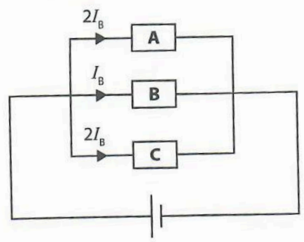


Figure 14.3

(a) If resistor **A** has a resistance of 3 Ω, what is the resistance of resistor **B**? [3]

(b) Calculate the total resistance in the circuit. [3]

5. As an electrical engineer, you are tasked to design a new portable lamp that uses only one cell. Some electrical components are provided below.

- 1.5 V dry cell (×1)
- 12 Ω LED bulbs (as many as you need)

The LED bulbs can withstand a maximum electric current of 0.5 A, beyond which the bulbs blow. For a current less than 0.5 A, the bulbs do not shine as brightly.

Determine the best arrangement for the new portable lamp. Support your design with calculations and a circuit diagram. [3]