Physics 2. Electrical Engineering

Week 2 Resistive Circuits

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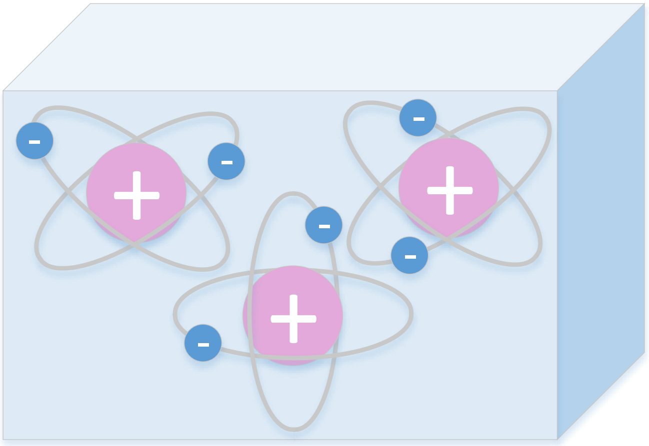
Objectives

The main objectives of today’s lecture are:

- Review the basic concepts of open and short circuits
- Study parallel resistors
- Learn to find equivalent resistance

Last Week’s Review: Conductivity & Resistors

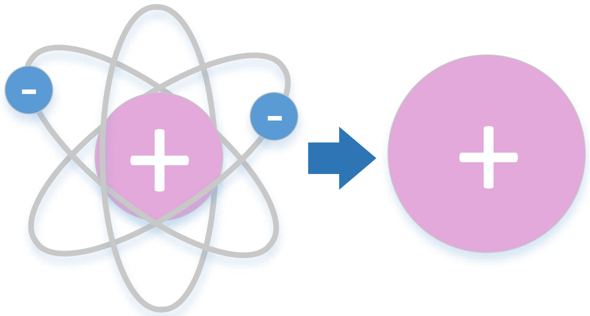
Electric Charge (1)



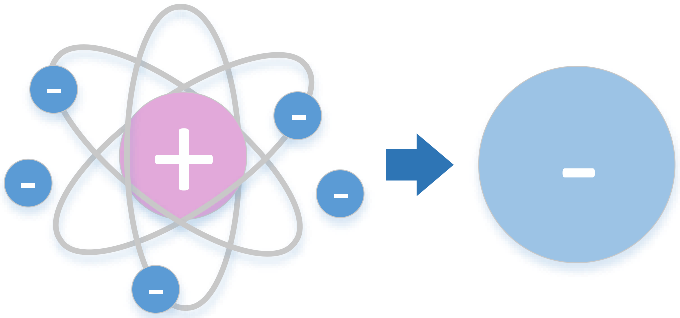
Assume you have a bulk of some material that contains many atoms ($6 x 10^{23}$ per mole).

Atoms that have either a deficit or a surplus of electrons are called ions.

- If there is an excess of positive ions in a bulk of material, its net charge Q will be positive, and vice versa.
- Electric charge is measured in coulomb [C].

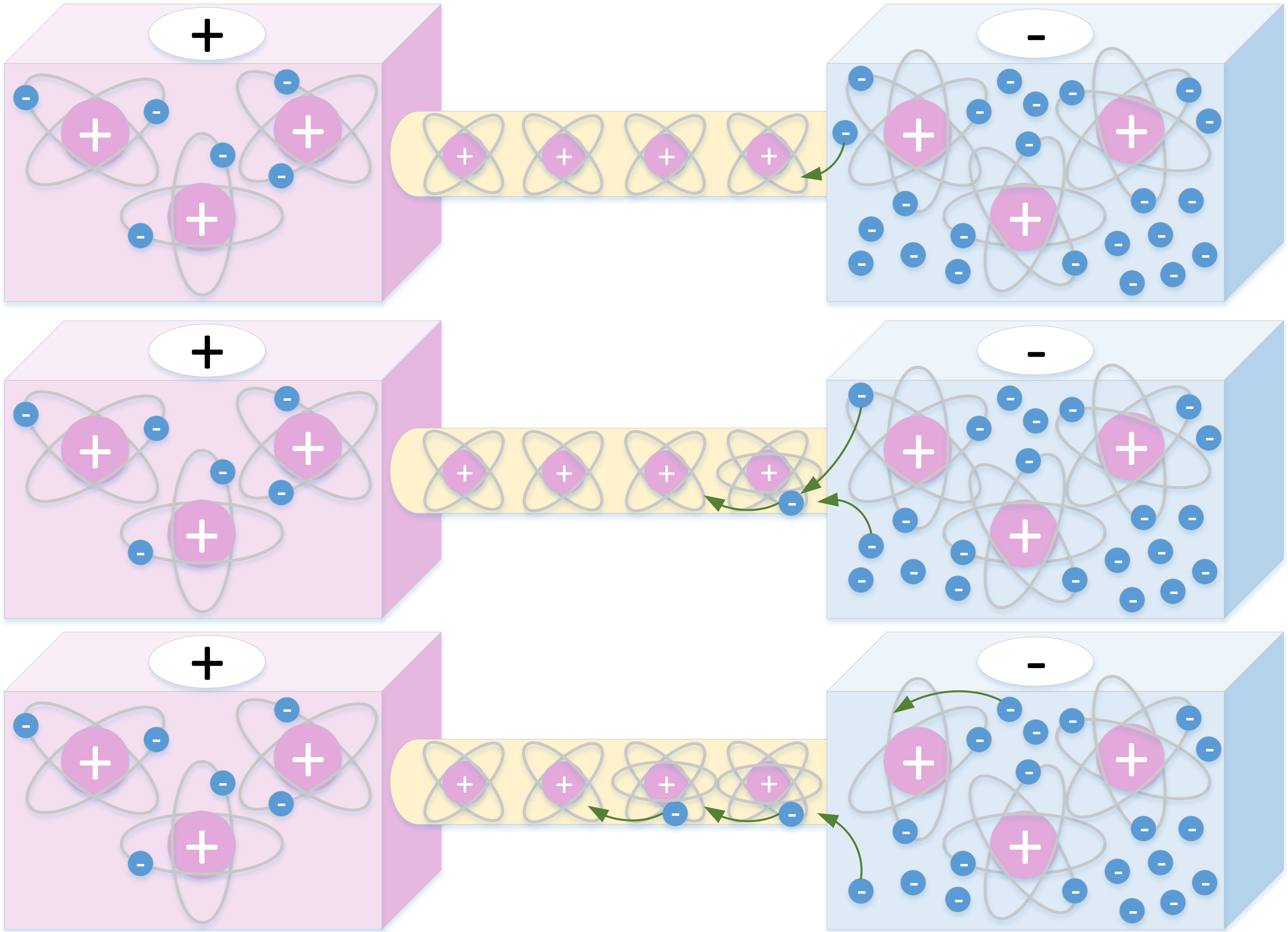


Positive ion

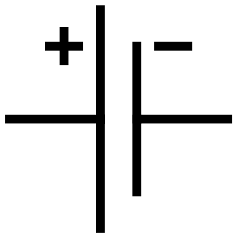


Negative ion

Electric Charge (2)



There is a difference in charge levels (electric potential)!



Electric Current

Electric charge can be carried by subatomic particles, typically – by moving electrons.

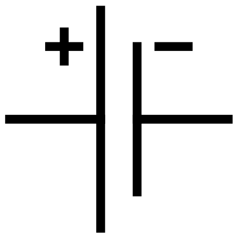
The stream of such charged particles is called by electric current (think water current).

More precisely,

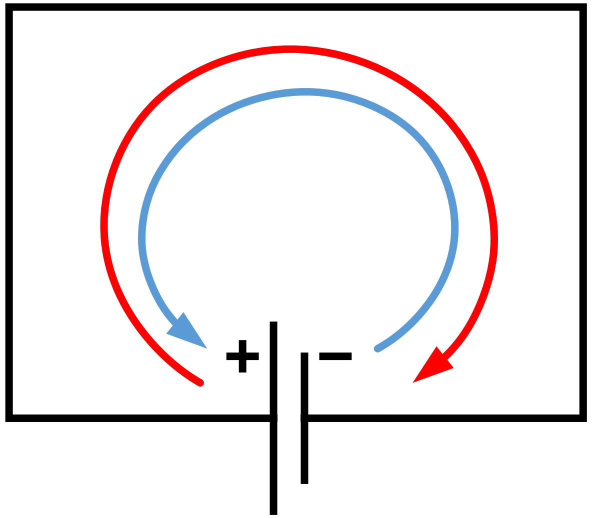
- Electric current is the rate of flow of electric charge Q in a region over time t: $I = \dfrac{Q}{t}$
- Notation: I
- Unit: Ampere [A] (*coulomb per sec*)

Electric Voltage

Electric voltage is the difference in electric potential between two points.



- Notation: V
- Unit: Volt [V]
- The voltage between two points is a short name for the electrical driving force (electromotive force: emf) that could determine an electric current between those points.



Electrical Resistivity

The electric resistivity and its inverse, electrical conductivity, is a fundamental property of a material that quantifies how strongly it resists or conducts electric current.

Various materials have different resistivity and conductivity (shown here for 20 °C).

Material	Resistivity, ρ	Conductivity
Silver	1.59×10^{-8}	6.30×10^{7}
Copper	1.68×10^{-8}	5.96×10^{7}
Gold	2.44×10^{-8}	4.11×10^{7}
Calcium	3.36×10^{-8}	2.98×10^{7}
Carbon (graphite)	3.10×10^{-3}	3.3×10^{2}
Sea water	2.00×10^{-1}	5
Diamond	10^{12}	10^{-12}
Rubber	10^{13}	10^{-13}
PET	10^{21}	10^{-21}
Teflon	10^{24}	10^{-24}

Electrical Resistance

The electric resistance of an electrical element measures its opposition to the passage of an electric current.

- Notation: R
- Unit: Ohm [Ω]
- The reciprocal quantity is electrical conductance (the ease with which an electric current passes).
- Electrical resistance is a function of conductor's volumetric properties:

$$R = \rho \frac{l}{A}$$

where ρ is electrical resistivity, l is the length of conductor and A is its cross-sectional area.

Electrical Conductance

The electric conductance is the ability for electricity to flow a certain path.

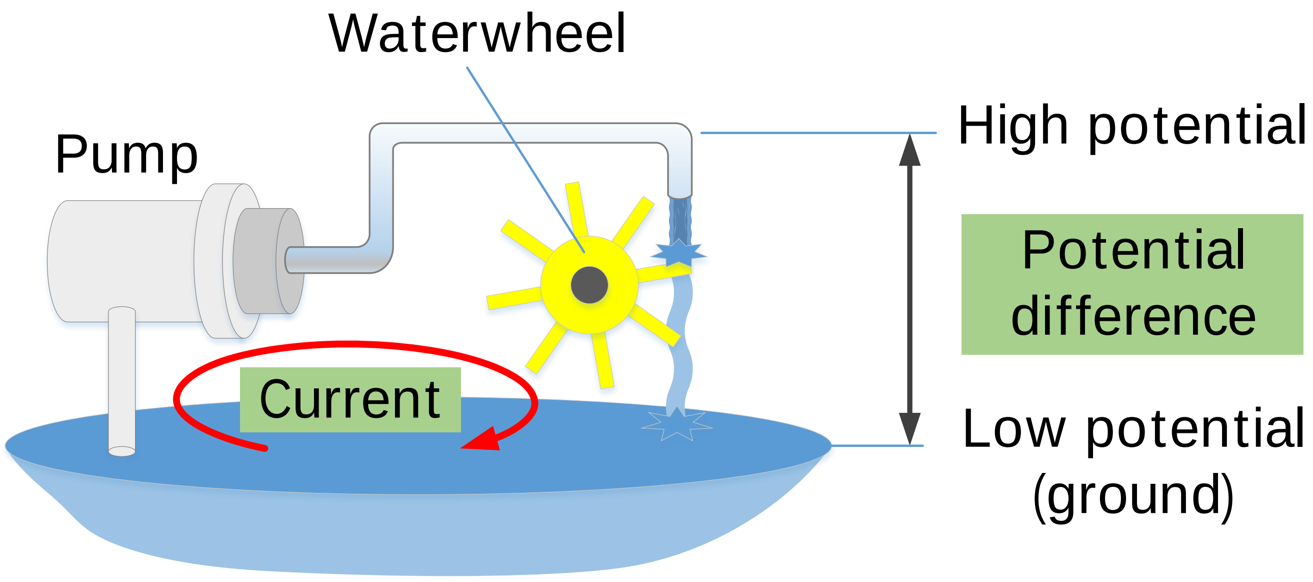
- Conductance is the inverse of resistance

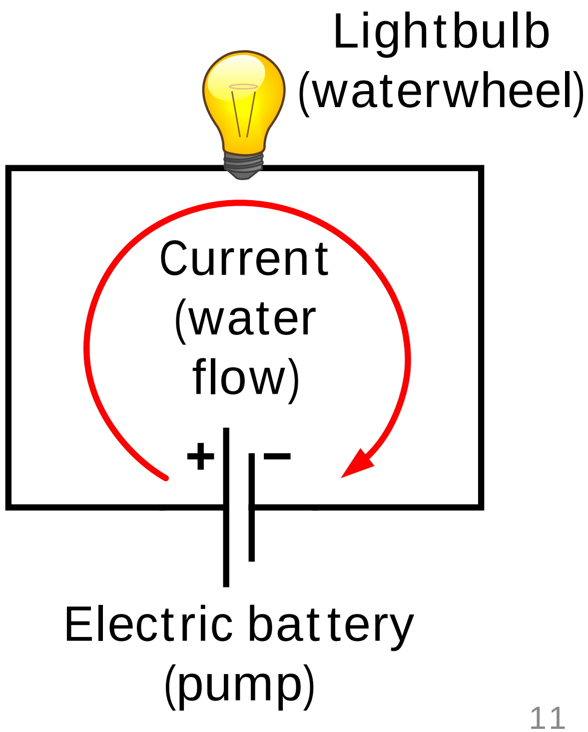
$$G = \frac{1}{R}$$

Electricity and Mechanics

If there is a water pressure difference between two points, then

- the water flow (created by the pump) from the will be able to do work, such as spinning the waterwheel.
- In a similar way, work can be done by the electric current driven by the potential difference due to an electric battery.



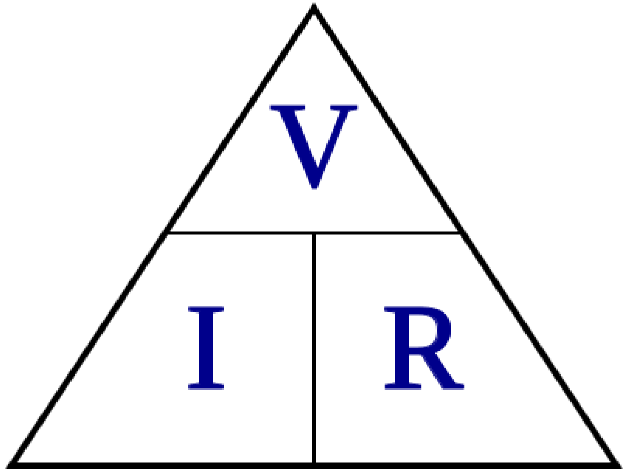


Ohm's Law

This observation forms one of the most fundamental laws of electricity, the Ohm's law:

- Current through a conductor between two points is directly proportional to the voltage across the two points, and inversely proportional to the resistance between them.

$$\text{Current}(I) = \frac{\text{Voltage}(V)}{\text{Resistance}(R)}$$



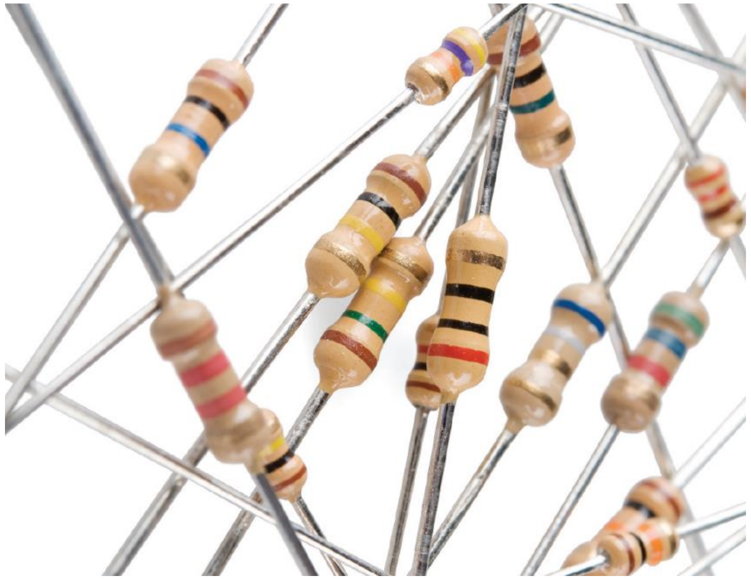
Resistors

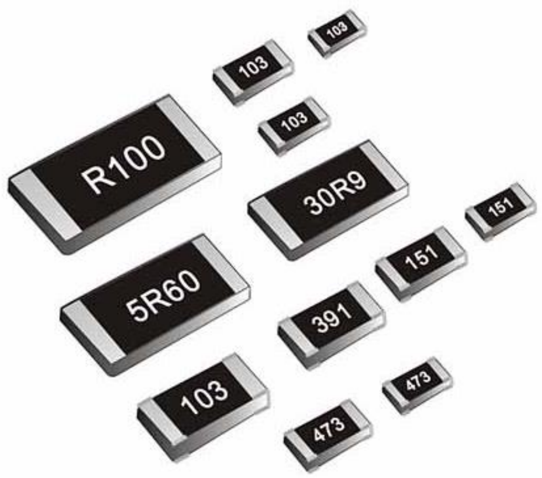
A resistor is a two-terminal electrical component that implements electrical resistance as a circuit element.

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment.

- Q: Why do we need resistors?

Electronic symbol





Axial-lead vs. SMD resistors

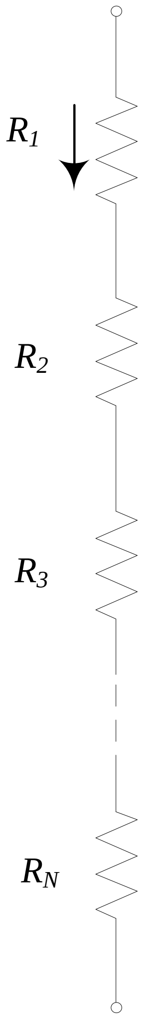
Resistors : Series

The equivalent resistance R_{EQ} of all the resistors in series can be found as

$$R_{EQ} = \sum_{n=1}^{N} R_n$$

- Thus, for instance, for 3 resistors connected in series to the voltage supply V_{supply}, the electrical current is

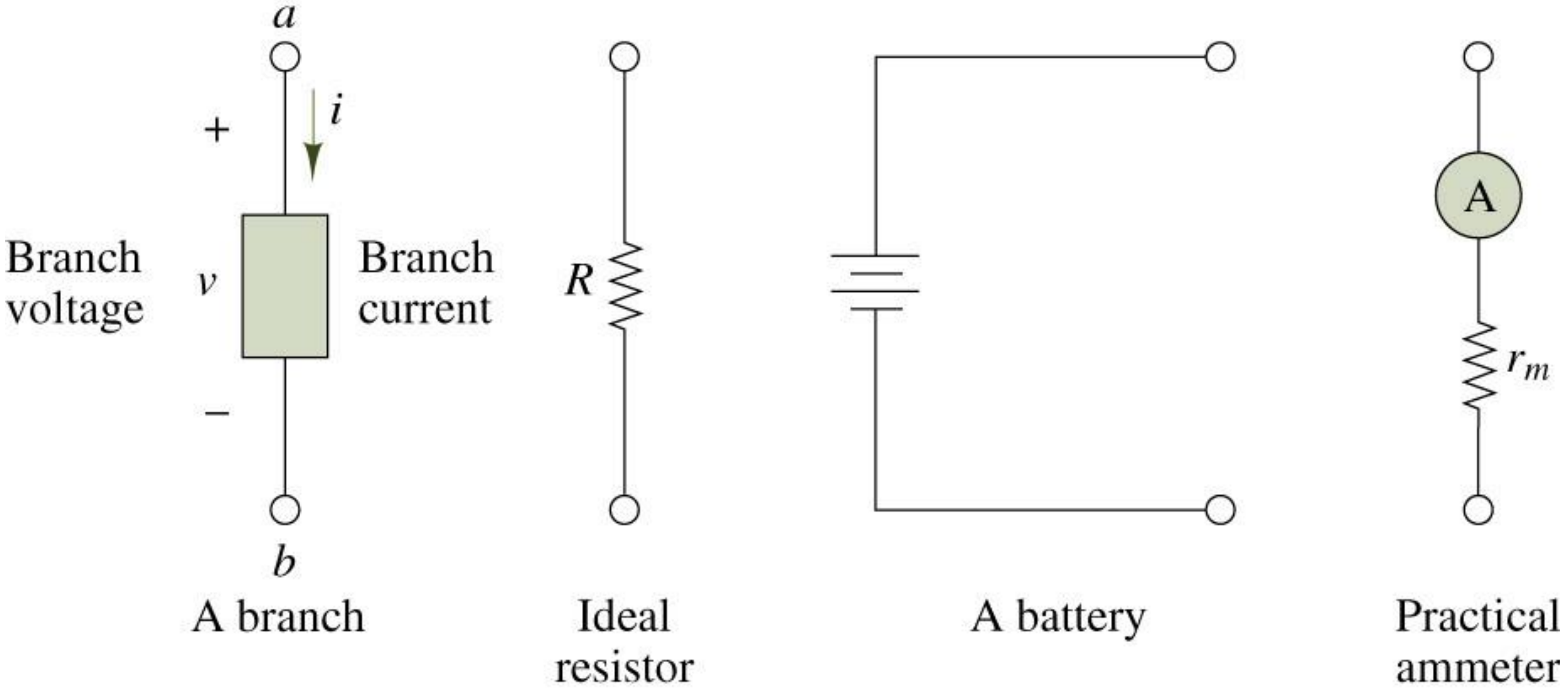
$$i = \frac{V_{\text{supply}}}{R_1 + R_2 + R_3} = \frac{V_{\text{supply}}}{R_{EQ}}$$



Kirchhoff’s Laws

Electric Circuits : Branch

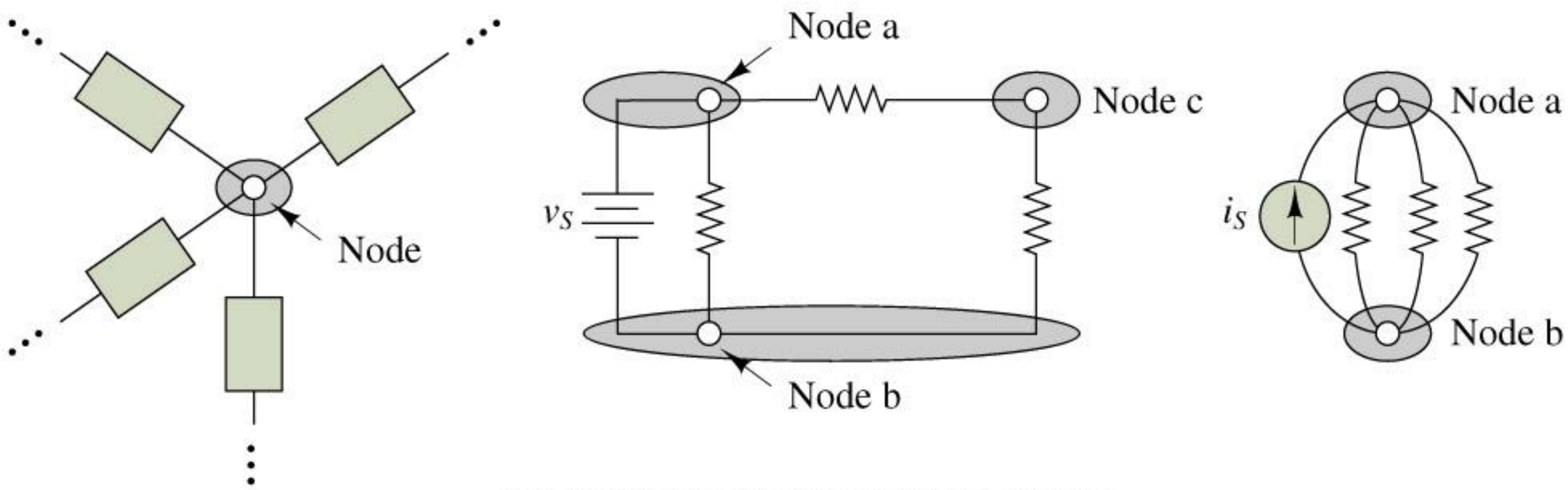
A branch is any portion of a circuit with two terminals connected to it.



Examples of circuit branches

Electric Circuits : Node

- A node is a junction of two or more branches.



Examples of nodes in practical circuits

Kirchhoff's Current Law

KCL: The sum of the currents at a node must equal zero.

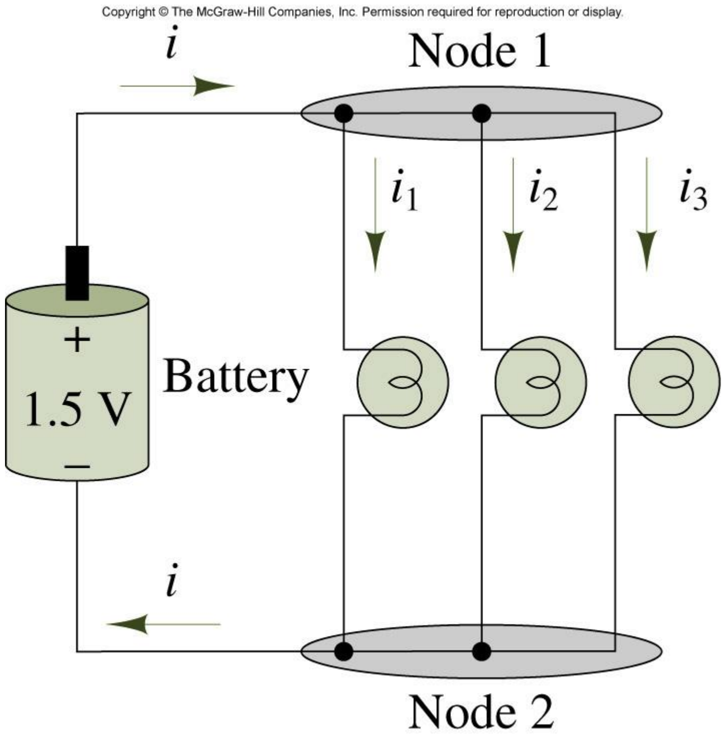
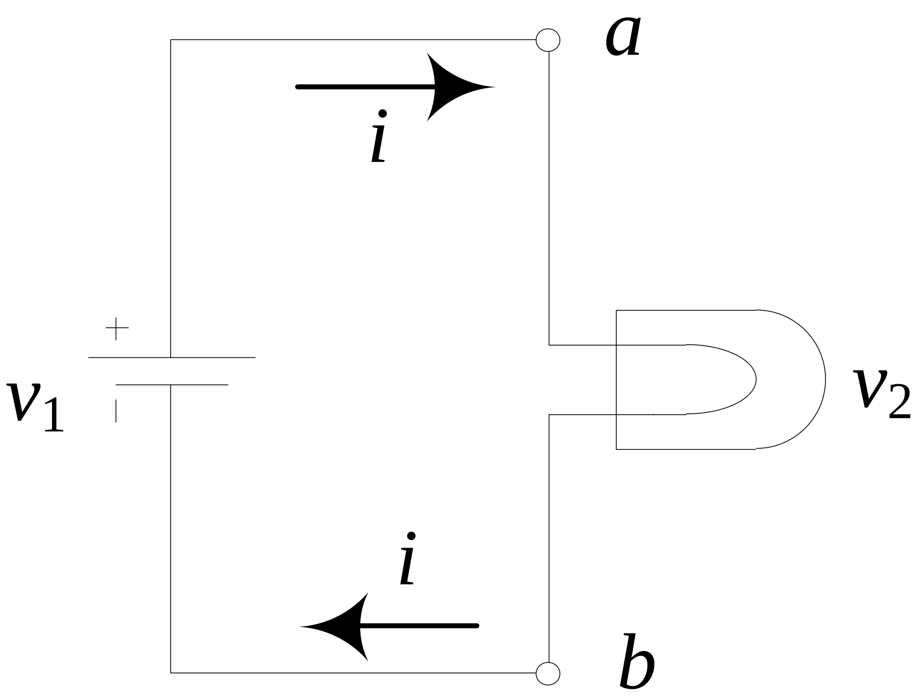


Illustration of KCL at node 1: $-i + i_1 + i_2 + i_3 = 0$

$$\sum_{n=1}^{N} i_n = 0$$

Kirchhoff's Voltage Law

KVL: The sum of all voltages associated with sources must equal the sum of the load voltages, so that the net voltage around a closed circuit is zero.



$$\sum_{n=1}^{N} V_n = 0$$

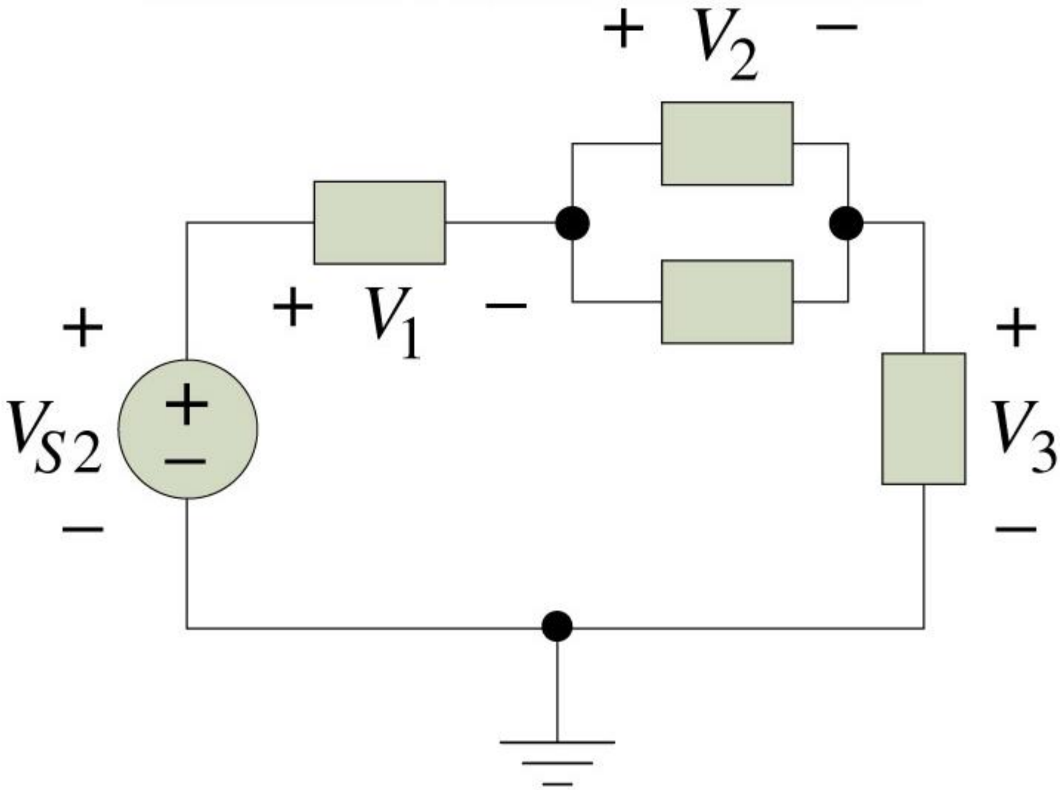
Kirchhoff’s Voltage Law : Example

Known Quantities:

V_{S2} = 12 V V_1 = 6 V V_3 = 1 V.

Find:

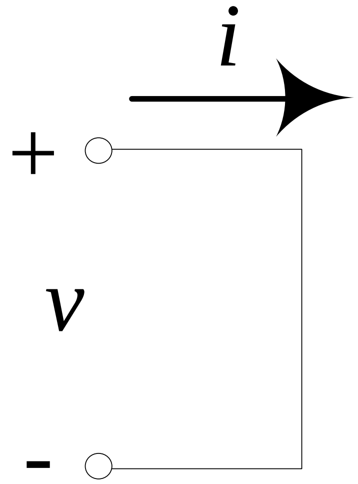
V_2



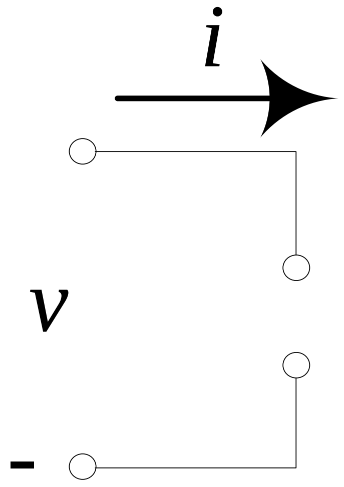
Open and Short Circuits

Open and Short Circuits (1)

- A circuit element with resistance approaching zero is called a short circuit.



- A circuit element whose resistance approaches infinity is called an open circuit.

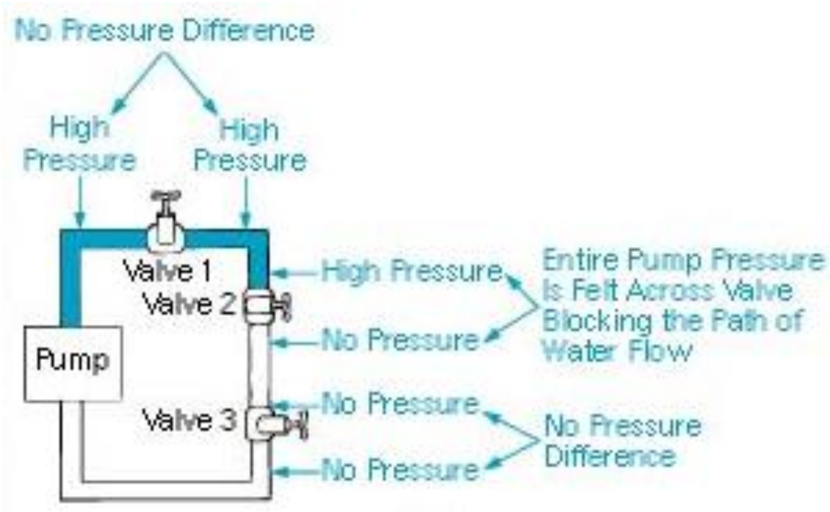


Open and Short Circuits (2)

Imagine a hydraulic circuit with 3 valves connected in series. Initially, all valves are open.

At some point in time, we close valve 2.

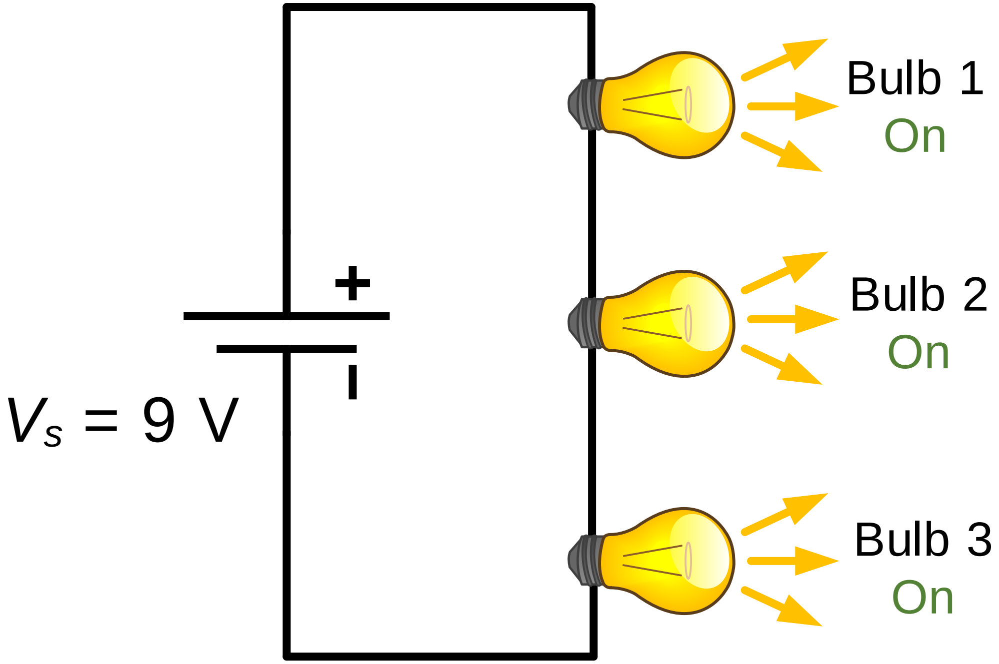
- What will happen with the water flow (current)?

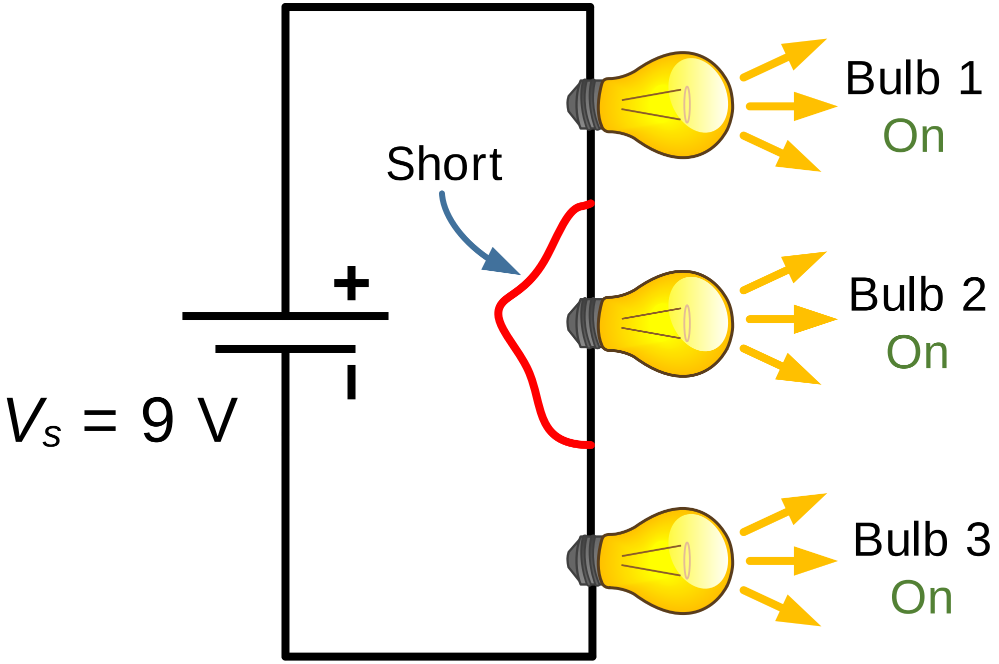


Short Circuits

Assume you have a short Christmas lights line with 3 lightbulbs in series, as shown below.

- What will happen within the circuit if you short circuit lightbulb 2?





Open and Short Circuits (3)

Open circuit increases the overall resistance. Therefore, the total current decreases.

- When the opened branch is in series, the voltage across it becomes equal to the supply voltage.
- In the case of a parallel branch, the voltage across it has a parallel branching voltage.

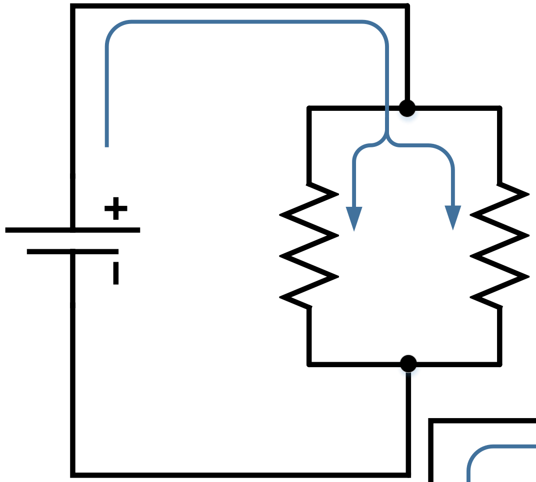
Short circuit decreases the overall resistance. Therefore, the total current increases.

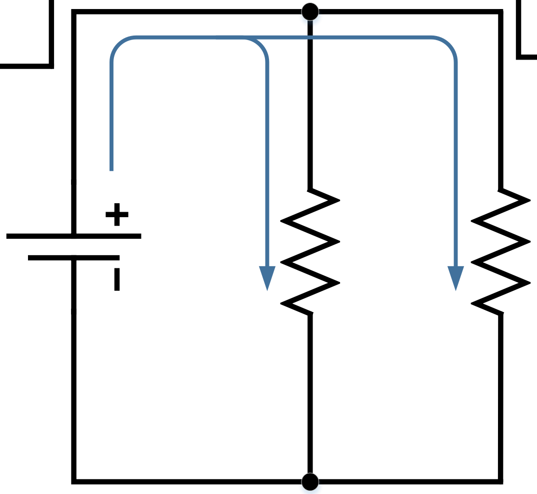
- When the shorted elements are in series or parallel branches, the voltage drop across them is 0 V.

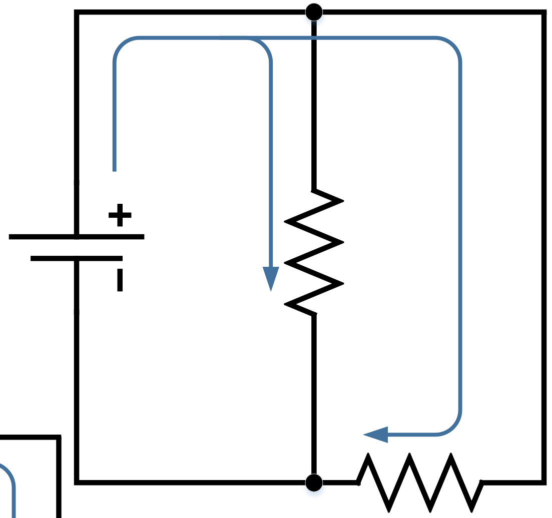
Parallel Circuits

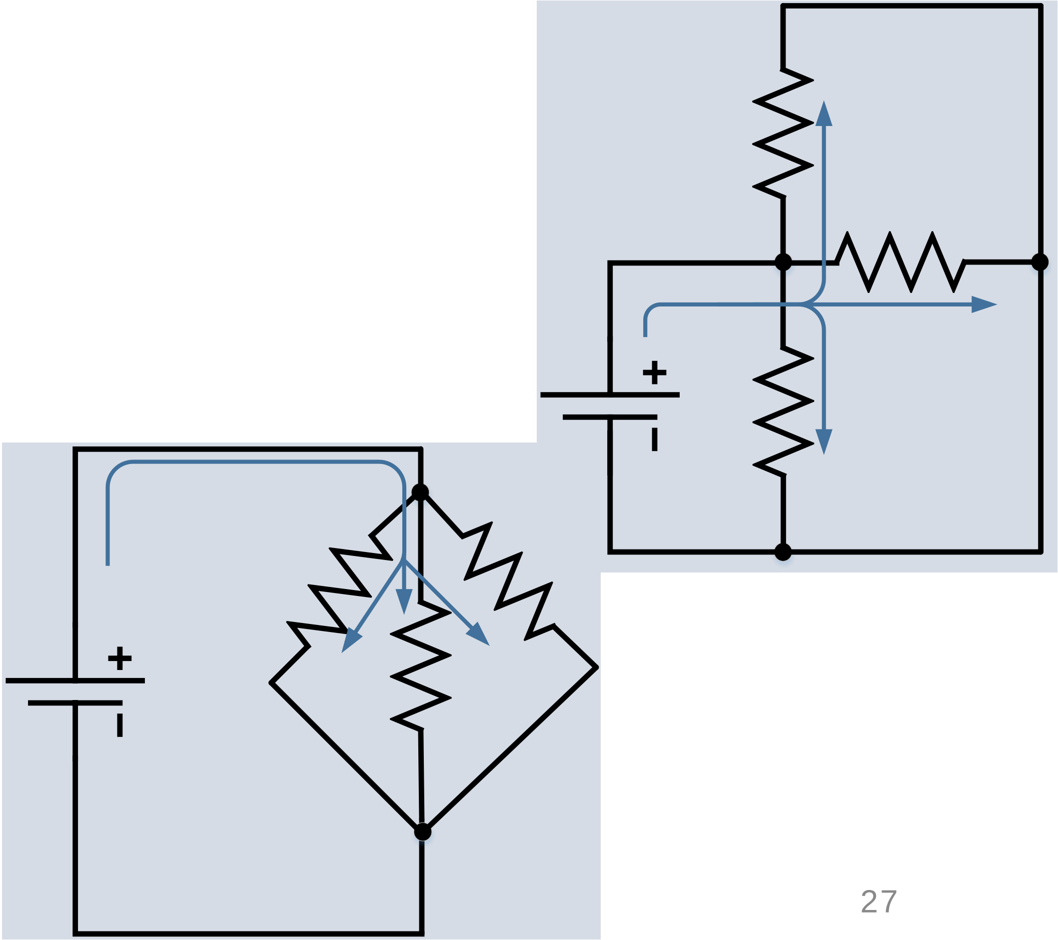
Parallel Circuits (1)

- Circuits with at least 2 paths for the current to flow are call parallel circuits



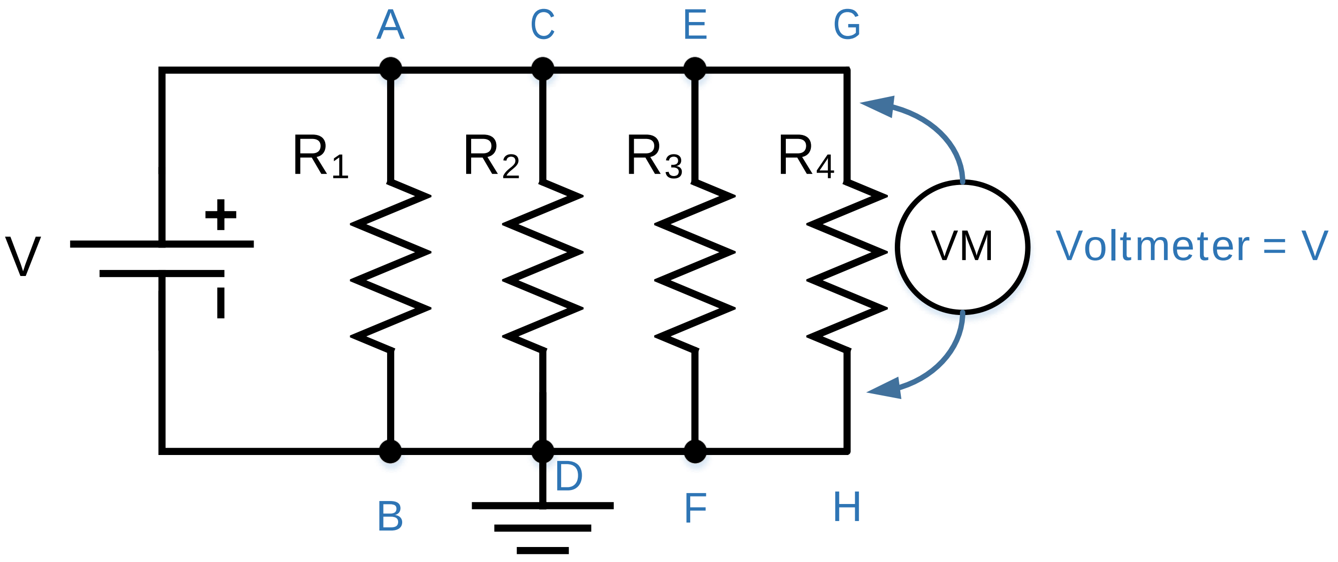


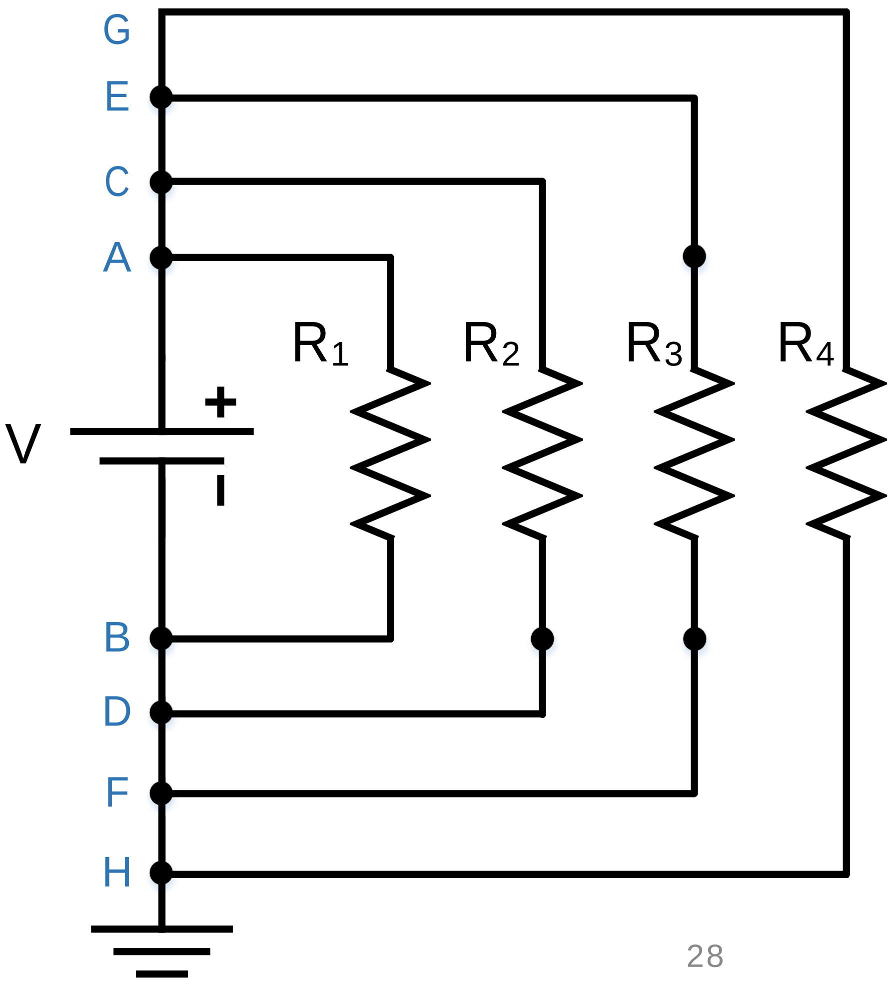




Parallel Circuits (2)

- Voltage drop across each branch of a parallel circuit is the same





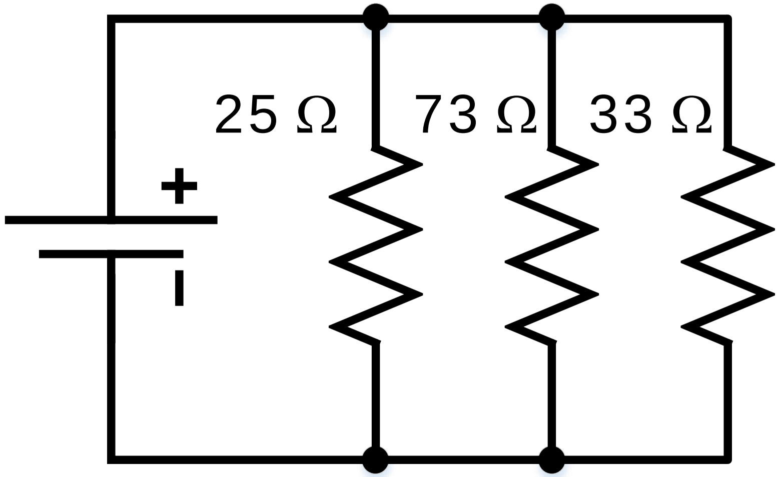
Conductance in Parallel Circuits

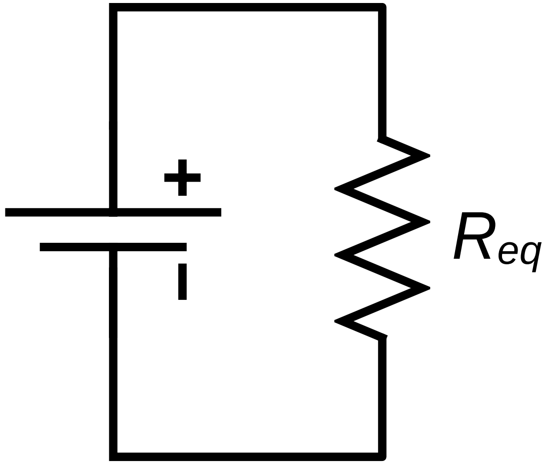
Conductance is the inverse of resistance $G = \frac{1}{R}$

The conductance of a parallel circuit is equal to a sum of conductances of each branch

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

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





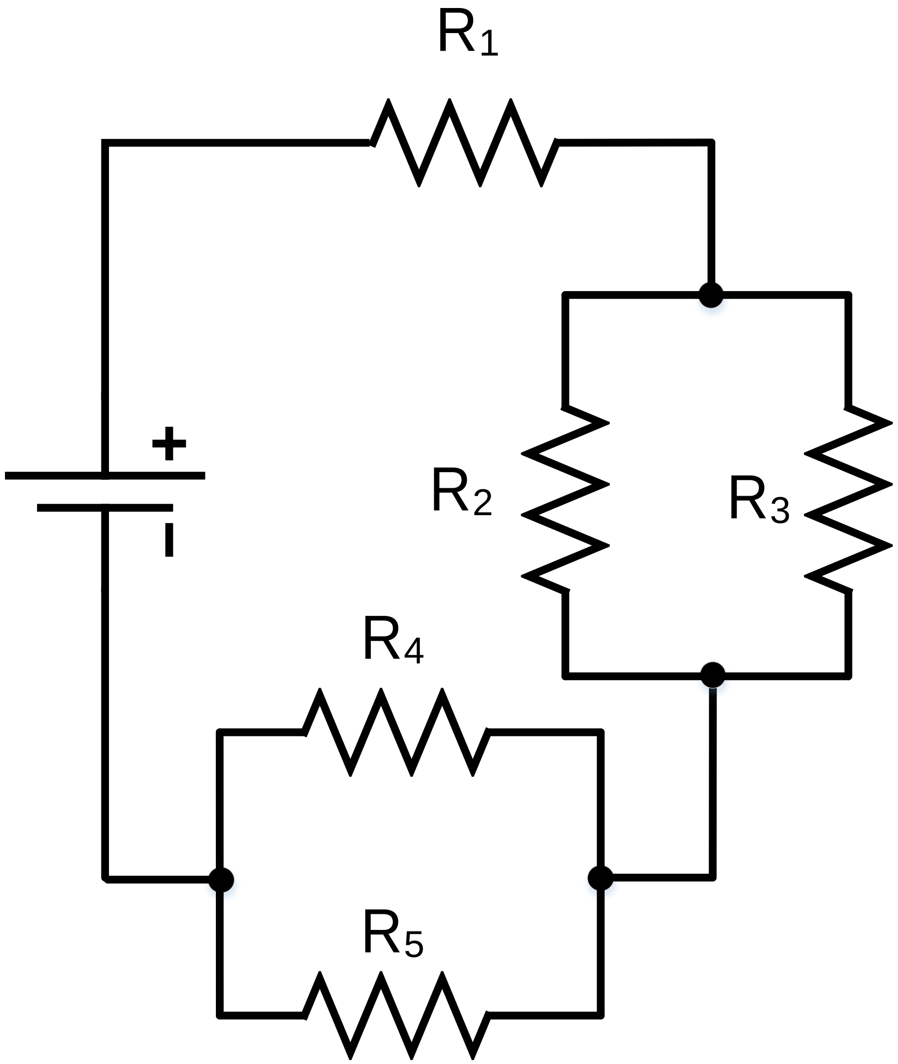
Parallel Circuits (3)

In general, all electronic circuits consist of combinations of series circuit and parallel circuit.

- Series circuit: Current has only 1 path to flow
- Parallel circuit: Current has 2 or more paths

How to find the equivalent resistance of complex circuits:

1. Find the equivalent resistance of all resistors in series
2. Repeat of all resistors in parallel
3. Finally, find the total resistance of resulting series circuit



Thank you for your attention!

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