48510 LEC 1

Basic concepts of electrical circuit

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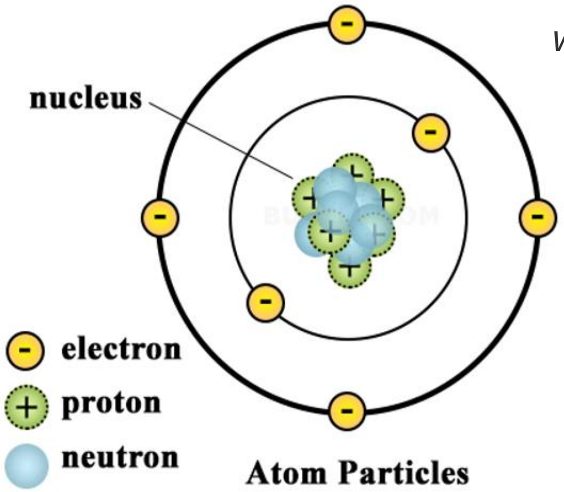
ELECTRIC CHARGE

Electricity is the movement of electric charge.

Each atom contains protons taking positive charge and electrons taking negative charge.

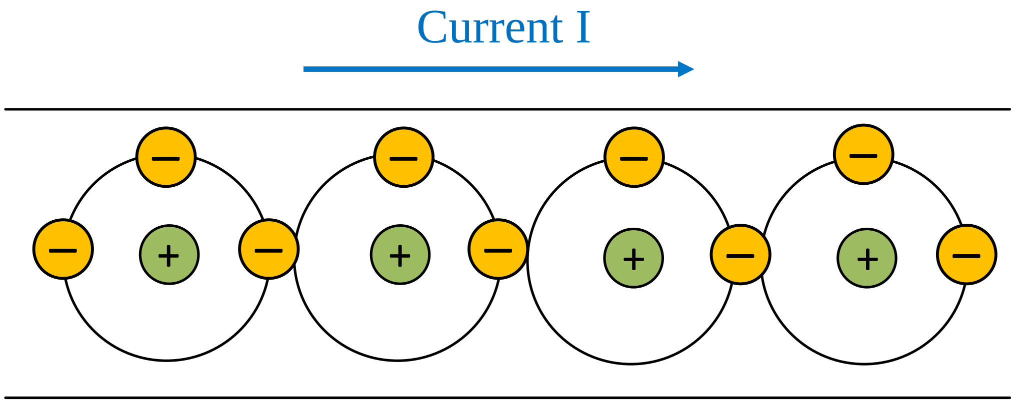
*PS: each electron take **-1e** charge, each proton take **+1e** charge, where **e** is elementary charge = **1.6 $\times$ 10^{-19} coulombs (C).***



Conductors are materials that permit electrons to flow freely from particle to particle, while isolators impede free flow of electrons from atom to atom and molecule to molecule. (Note that the protons in the nucleus are not movable.)

ELECTRIC CHARGE

Considering an extremely thin conducting wire



ELECTRICAL CHARGE

Knowing the electrical charge will help us to understand the very basic three principles including **Current (I)**, **Voltage (V)** and **Resistance (R)**.

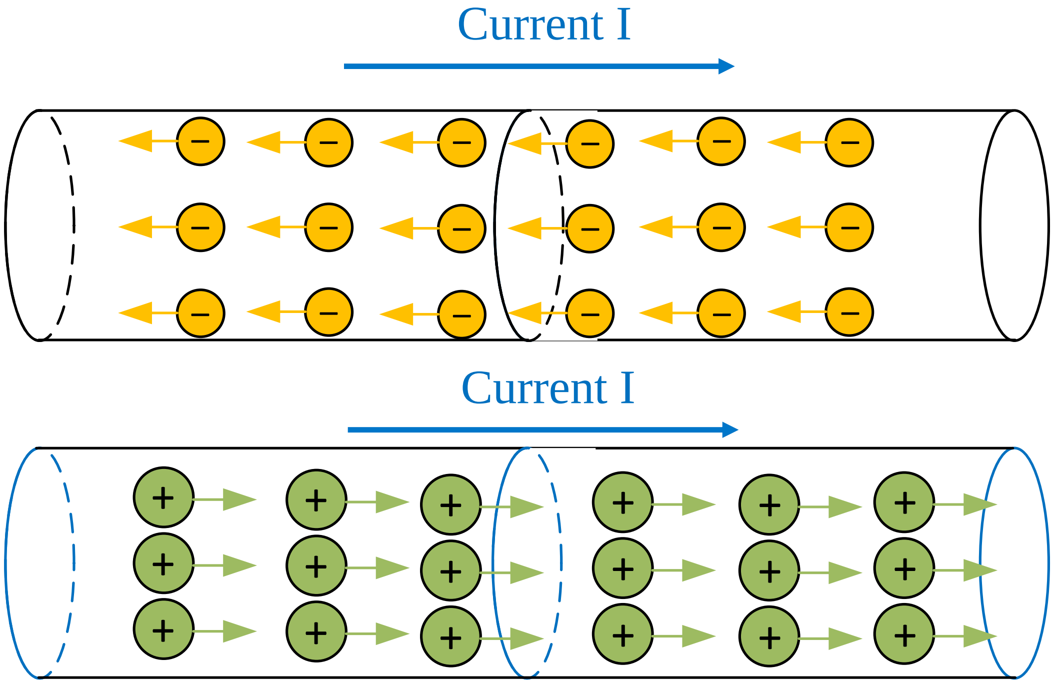
Current (I) is the rate at which charge is flowing.

Voltage (V) is the difference in charge between two points.

Resistance (R) is a component’s tendency to resist the flow of charge (current).

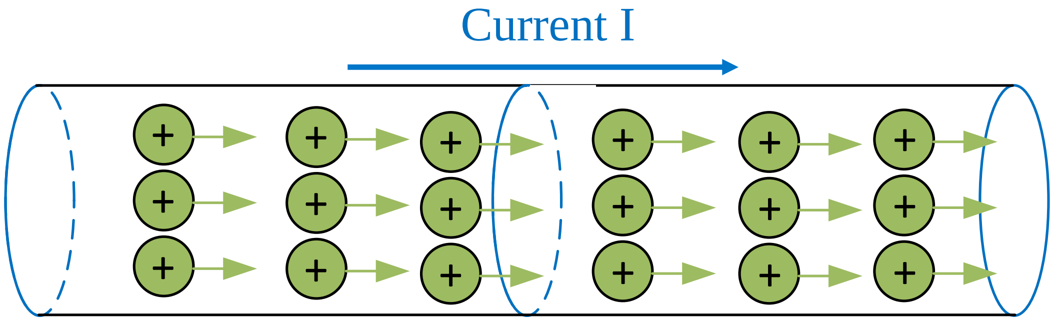
CURRENT

Definition of current: Electrical current is the **time rate** of flow of electric charge through a metallic wire (conductor) or transferred through a circuit element.



CURRENT

The magnitude of the current can be calculated using this formula.



Current through the element in the reference direction

Net charge in coulombs

$$\boxed{i(t) = \frac{dq(t)}{dt}}$$

where $\frac{d}{dt}$ is time rate.

The unit of current is the ampere (A), which is equivalent to coulomb per second (C/s).

CURRENT

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★ $$i(t) = \frac{dq(t)}{dt}$$

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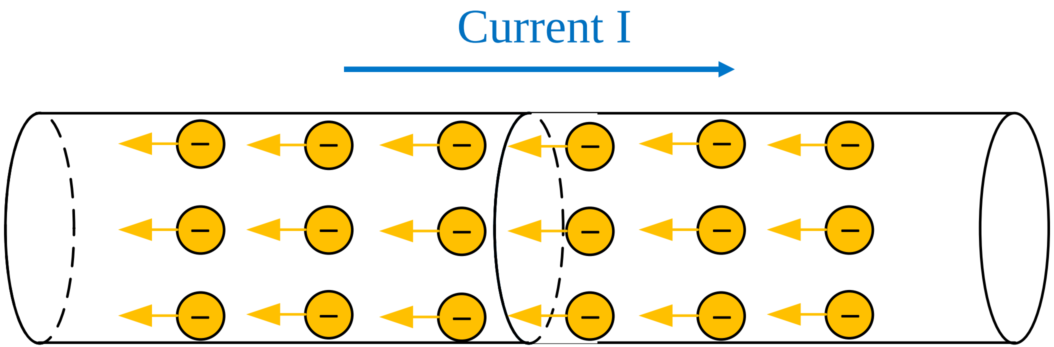
On the contrary, if the current $i(t)$ is known, you are able to find out the amount of charges that pass through the cross section of a metallic wire in a period of time.

★ $$q(t) = \int_{t_1}^{t_2} i(t)dt$$

VOLTAGE

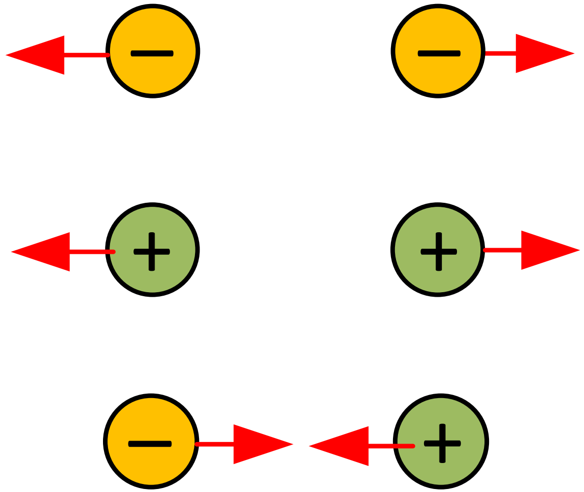
Electrical current is generated when charges are moving towards a certain direction. But why the charges decide to move?

Voltage is the reason that there is a current flow. It generates the “force” pushing or pulling the charges.



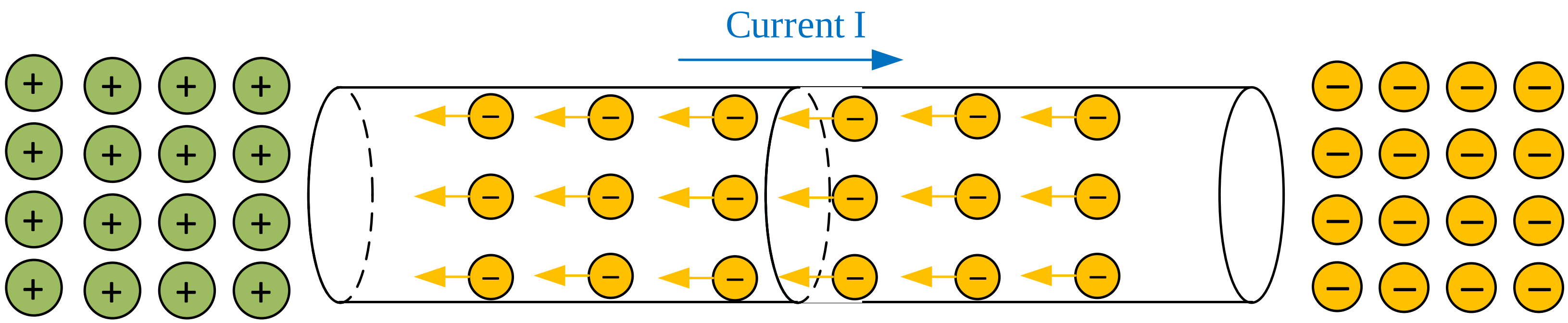
VOLTAGE

Electrostatic force exists between charges. A basic rule is that, like charges repeal each other and dislike charges attract each other.



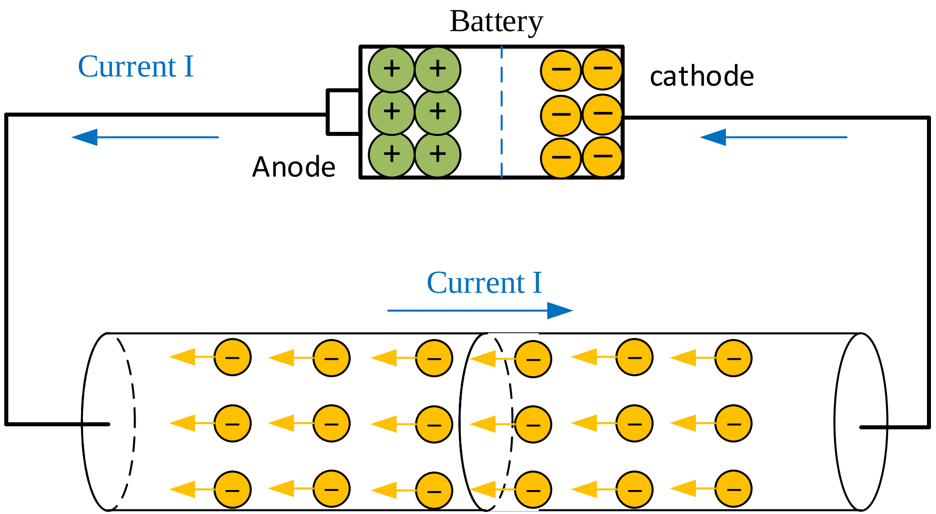
VOLTAGE

If we have a large amount of positive charges at one end and negative charges at the other end of a wire, the electrostatic force will drive the electrons to move, leading to current.



VOLTAGE

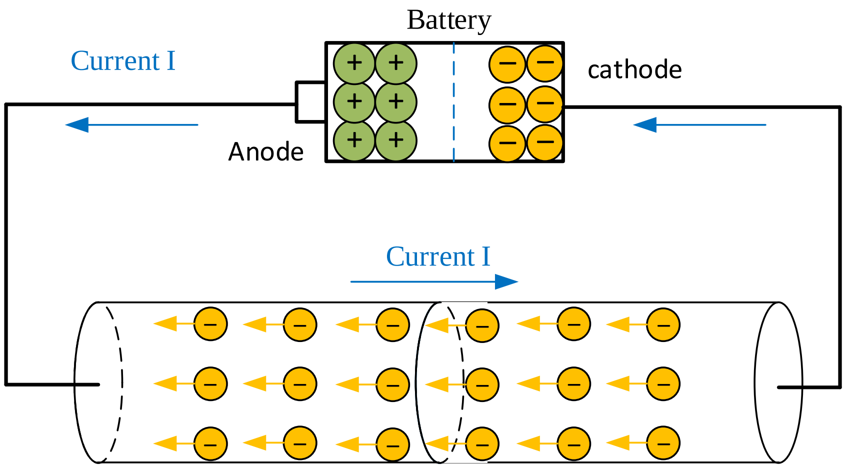
Considering a battery connected to a wire, we have positive charges stored at the anode and negative charges stored at the cathode. When connecting the two poles of a battery to a conducting wire, it provides voltage and drives current. (Note that the current always flows from Anode to Cathode.)



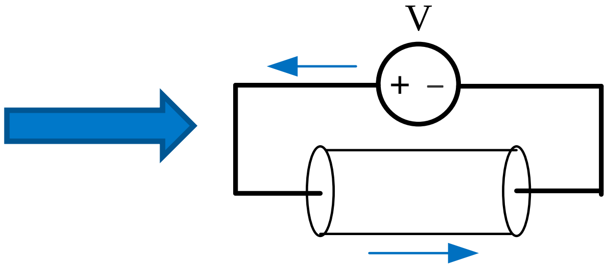
The presence of electrostatic force gives potential difference. Like gravity potential will drive water flow from higher height (more gravity potential energy) to lower height (less gravity potential energy), **electrical current flows from point with higher electric potential to point with lower electric potential.**

VOLTAGE

We define voltage as the **amount of potential energy between two points** on a circuit. It is measured in **volts (V)**. The potential difference or voltage can be calculated from the distribution of electrical charges, but it is out of the scope of this subject. (If you are interested, you can google “electric potential difference”.)

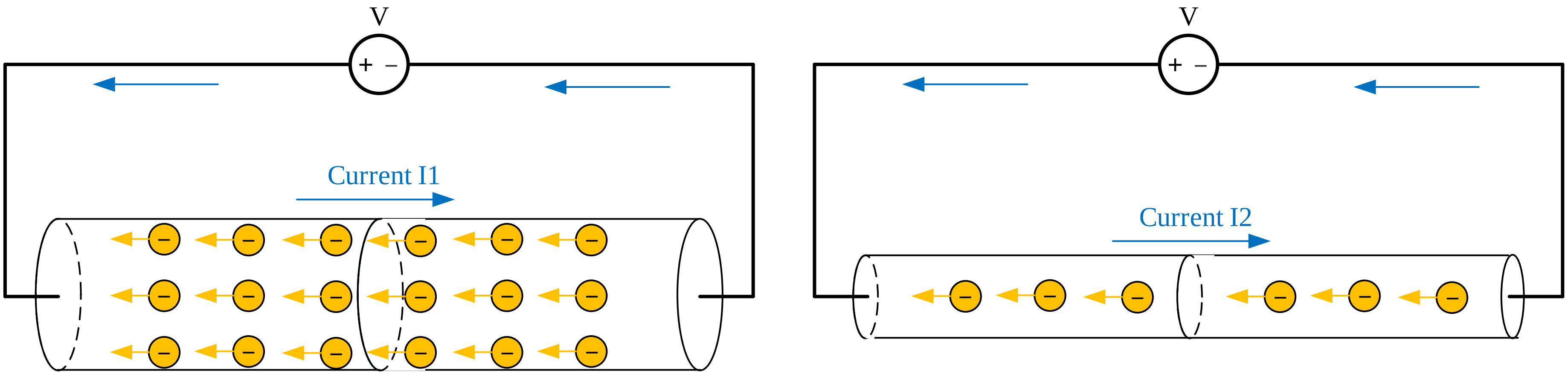


We usually label the node with higher potential with “+” and the node with lower potential with “–”. The current flows from “+” to “–”.



RESISTANCE

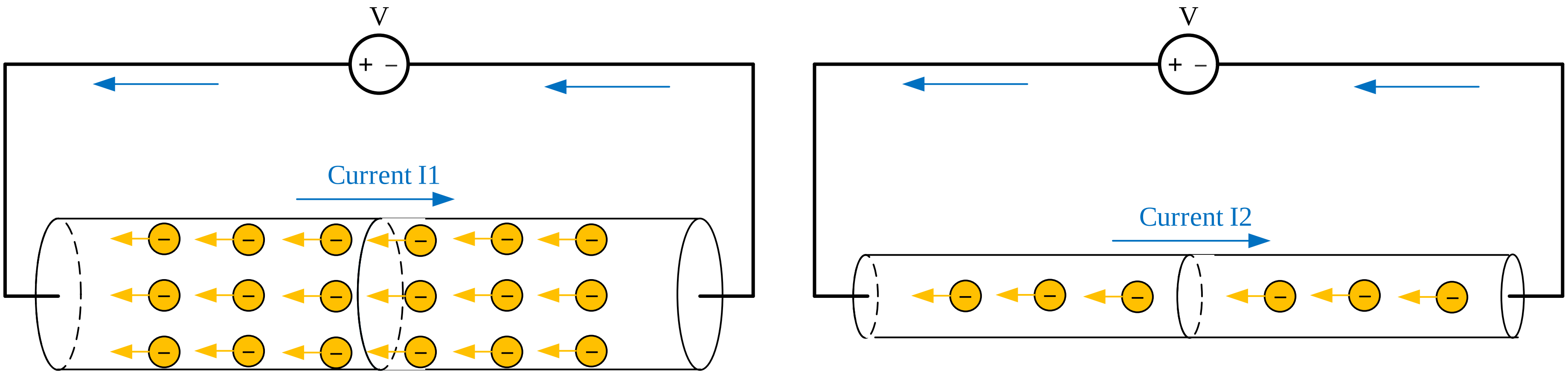
Considering two wires with different diameter shown as below.



Even with the same voltage, the resultant currents in the two cases are different. The wire with larger diameter allows more charges to pass through the cross section at a time than that of the wire with smaller diameter, meaning that **I1 is larger than I2.**

RESISTANCE

Resistance is a component's tendency to resist the flow of charge (current). And apparently, the wire in Case 1 has a smaller resistance than that in Case 2.



Specifically, the resistance of a wire can be calculated via ★

$$\boxed{R = \rho \times \frac{L}{A}}$$

*where R is the resistance in Ω (Ohm), ρ is the resistivity of the material in (Ω*m), L is the length of the wire and A is the cross-sectional area of the wire.*

RESISTANCE

Resistance is a component's tendency to resist the flow of charge (current).

$$R = \rho \times \frac{L}{A}$$

where *R* is the resistance in Ω (Ohm), *ρ* is the resistivity of the material in (Ω*m), *L* is the length of the wire and *A* is the cross-sectional area of the wire.

*Note that **conductance (G)** is the reciprocal of resistance (R) and its unit is siemens (S); conductivity (σ) is the reciprocal of resistivity (ρ) and its unit is S/m.*

As can be concluded from the equation, the resistance of a wire depends on its dimensions and its material.

The longer the wire, the larger the resistance;

The wider the wire, the smaller the resistance;

The better the conductivity of the material, the smaller the resistance. (A wire made of gold has smaller resistance than the wire made of copper with the same dimensions.)

OHM'S LAW

Georg Ohm found that, at a constant temperature, **the electrical current** flowing through a fixed linear resistance is **directly proportional to the voltage** applied across it, and also **inversely proportional to the resistance**. This relationship between the **Voltage**, **Current** and **Resistance** forms the basis of Ohms Law and is shown below.

$$\boxed{V = IR}$$

where *V* is voltage in volts, *I* is current in amps and *R* is resistance in ohms.

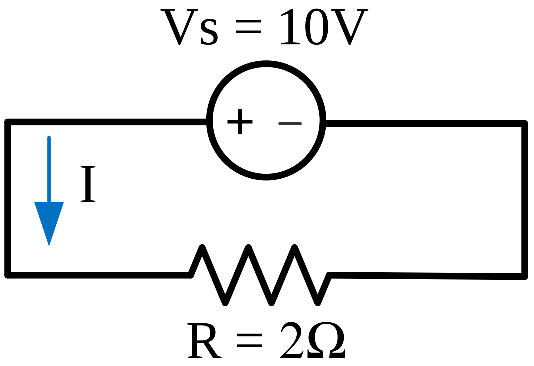
Alternatively, it also can be expressed as

$$\boxed{I = \frac{V}{R}} \qquad \boxed{R = \frac{V}{I}}$$

OHM'S LAW

$V = IR$ $\quad$ $I = \frac{V}{R}$ $\quad$ $R = \frac{V}{I}$

Example 1: See the figure below, if a voltage source of 10 V is connected to a resistor of 2 Ω, please determine the value and direction of the current in the circuit.



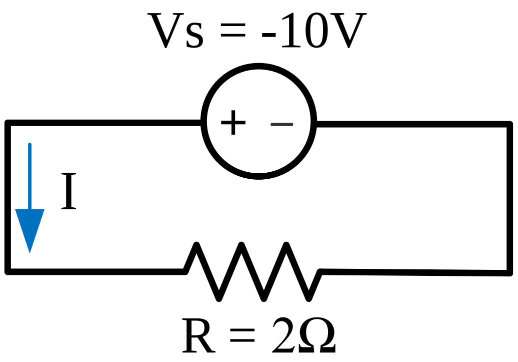
One can easily determine using Ohm's law that the current go through the resistor is **I = V/R = 5 A**.

The direction of current is from the larger potential point to lower potential point (from "+" sign to "–" sign).

OHM'S LAW

$V = IR$ $I = \frac{V}{R}$ $R = \frac{V}{I}$

Example 1: What if the voltage changed to -10 V?



You can always assume a reference direction and conduct calculation. If the result is negative, then the real current direction is opposite.

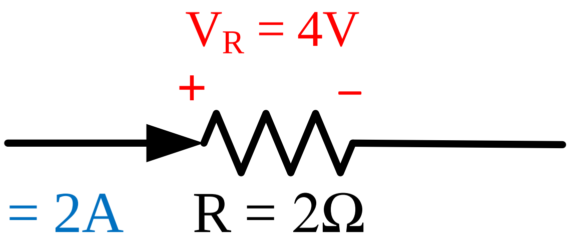
One can easily determine using Ohm's law that the current go through the resistor is **I = V/R = -5 A**.

The direction of current is from the larger potential point to lower potential point (from "+" sign to "–" sign).

OHM'S LAW

$V = IR$ $\quad I = \frac{V}{R}$ $\quad R = \frac{V}{I}$

Example 2: See the figure below: a current of I = 2 A passes through a resistor or 2 Ω, what is the voltage? Which side of the resistor has a higher voltage?



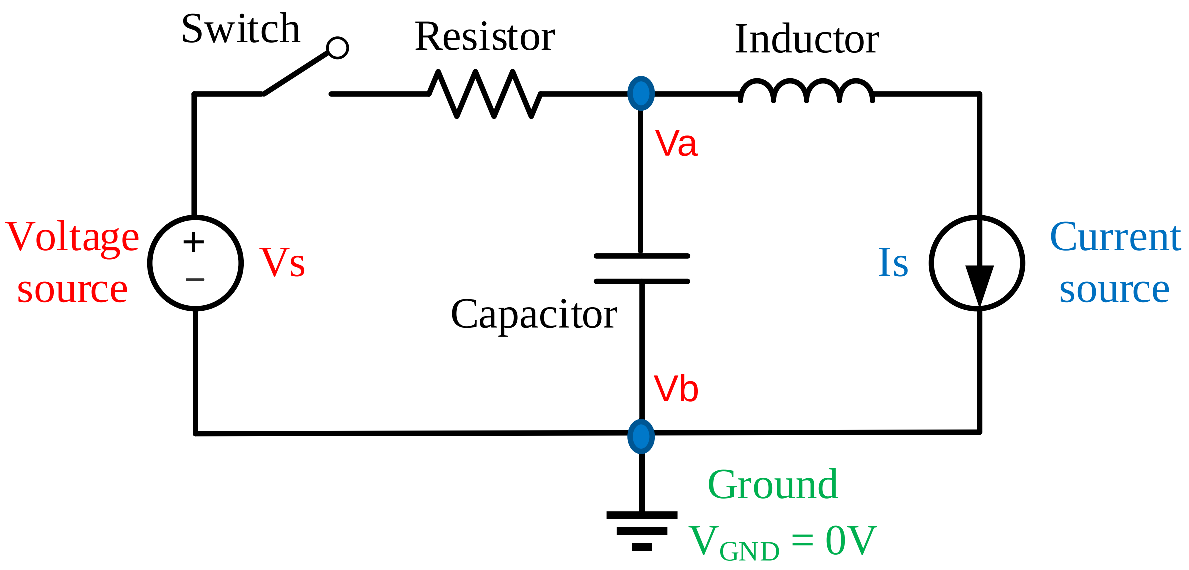
According to Ohm's law, one can easily found that the voltage is V = R*I = 4 V.

As mentioned before, current always flow from higher potential (voltage) to lower potential (voltage).

Follow the current direction, there is always a voltage drop. The value of voltage drop can be calculated using Ohm's law.

ELECTRIC CIRCUIT

An electric circuit is a closed path in which electrons move to produce electric currents. *A typical circuit is shown as below:*



Voltage source provide constant voltage output but we don't know the current passing through it.

Current source provide constant current output but we don't know the voltage across it.

We usually assume the voltage at ground is 0.

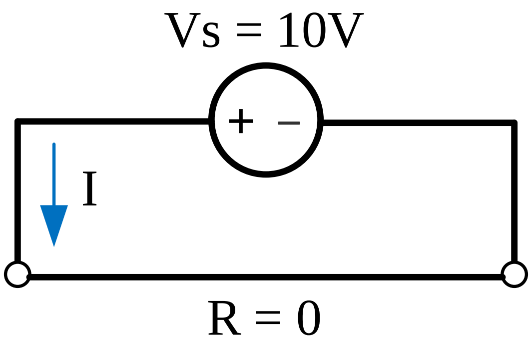
The voltage difference between two nodes is Vab = Va – Vb.

ELECTRIC CIRCUIT

$V = IR$ $I = \frac{V}{R}$ $R = \frac{V}{I}$

Short circuit:

If the circuit is “short”, the total resistance is 0. According to Ohm’s law, the current is infinitely large. (*Although in reality, the current will not reach infinity, the resultant large current might damage the circuit or source.*)

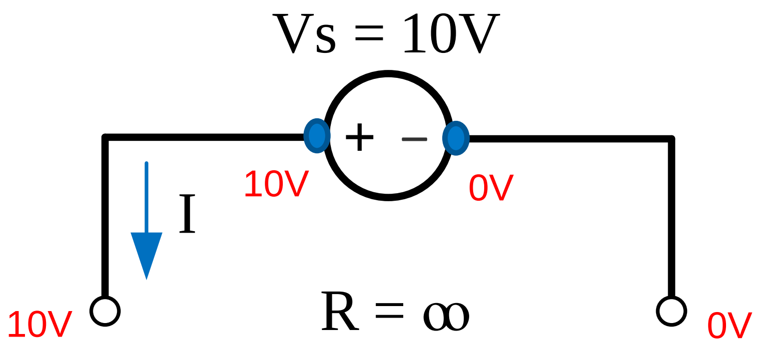


ELECTRIC CIRCUIT

$V = IR$ $I = \frac{V}{R}$ $R = \frac{V}{I}$

Open circuit:

If the circuit is left "open", the resistance between the two nodes are infinitely large, therefore the current is 0. The voltage difference between the two nodes are 10 V.

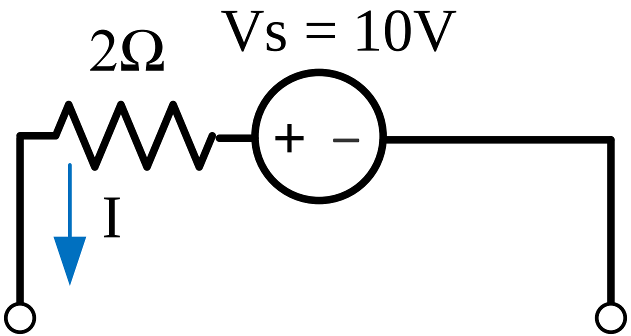


Follow the current direction, there is always a voltage drop. The value of voltage drop can be calculated using Ohm's law.

ELECTRIC CIRCUIT

Open circuit:

Question: If we have a resistor connected to the voltage source in the open circuit, what is the voltage across the resistor? What is the voltage difference between the two nodes?



The voltage across the resistor is 0 because the current is 0.

Since there is no voltage drop on the resistor, the voltage difference between the two nodes is the same as the source voltage, which is 10 V.

POWER AND ENERGY

We can define **electrical energy (E)** as the energy generated by the movement of electrons from one point to another. When current flows through an element and voltage appears across the element, energy is transferred.

In any given time interval, the energy consumed (or provided, depending on your perspective) is given by ***E = qV***, where E is the electric energy, V is the voltage, and q is the amount of charge moved in the time interval under consideration. The unit of energy is **Joule (J)**.

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit. The unit of power is the **watt (W)**, **one joule per second**. It can be calculated as

$$P = \frac{dE}{dt} = \frac{dq}{dt}V = IV$$

POWER AND ENERGY

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit. The unit of power is the **watt (W)**, **one joule per second**. It can be calculated as

Specifically, for the power dissipated on a resistor, it can also be written as

$$\boxed{P = VI = I^2R = \frac{V^2}{R}} \quad \star$$

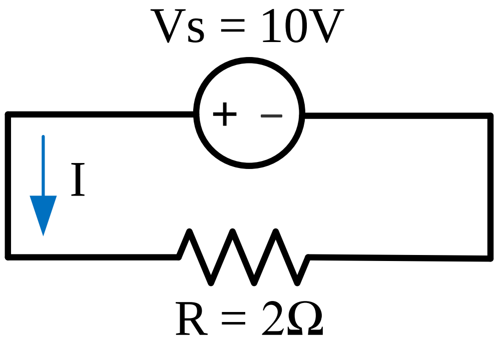
On the other hand, to calculate the energy **E** delivered to a circuit element between time instant t1 and t2, we can integrate power:

$$\boxed{E = \int_{t1}^{t2} p\,dt} \quad \star$$

If the power is constant, it can be simplified as $E = Pt$

POWER AND ENERGY

For the circuit shown below, calculate the electrical power delivered to the resistor. How much energy is delivered to the resistor in 1 minute?



$$P = VI = I^2R = \frac{V^2}{R}$$

I = Vs/R = 5 A

P = VI = 10 * 5 = 50 W.

E = Pt = 50*60 = 3000 J