Voltage, Current and Resistance

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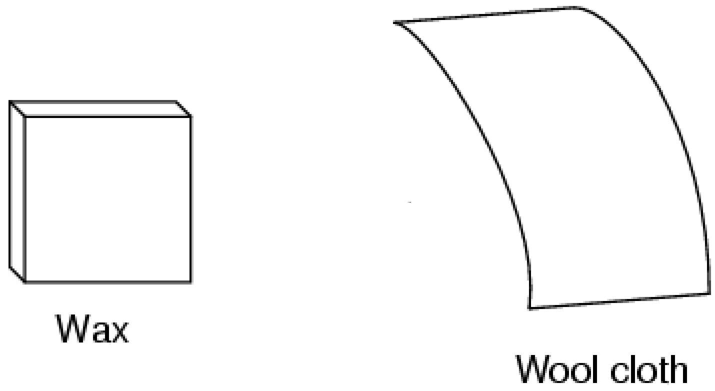
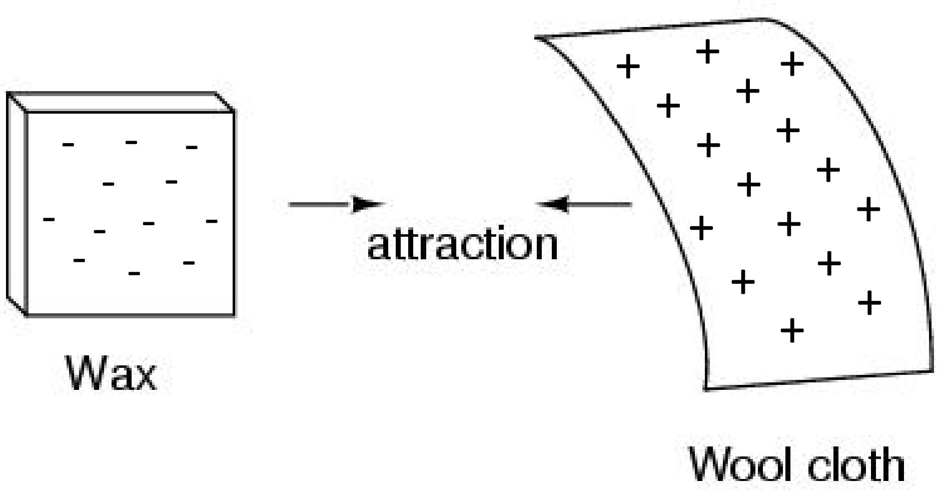
Introduction to Charge

It was discovered centuries ago that certain types of materials *would attract each other*, after being rubbed together.



If we take a piece of wax and rub it with some wool cloth, *we can transfer electrons from the wool to the wax*.

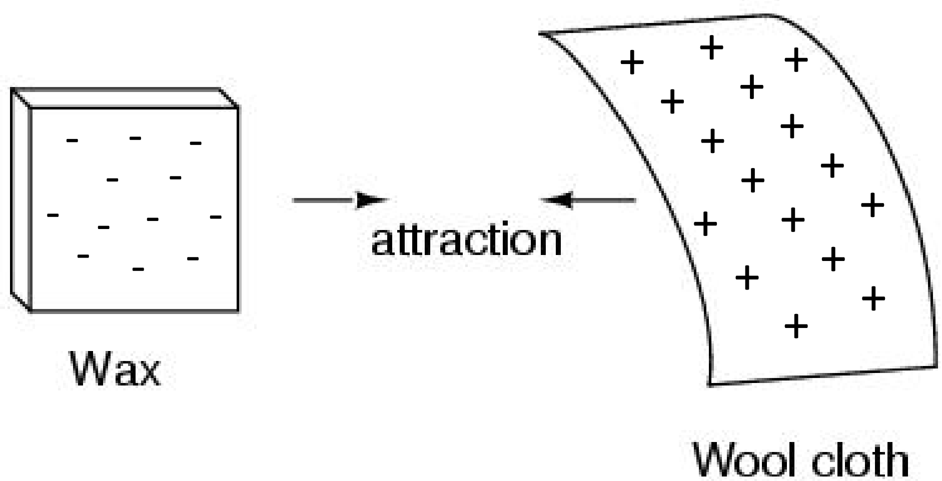
Introduction to Charge



The wax will end up with an excess of electrons, while the wool will end up with a loss of electrons.

So *the wax is negatively charged*, while *the wool is positively charged*.

Introduction to Charge

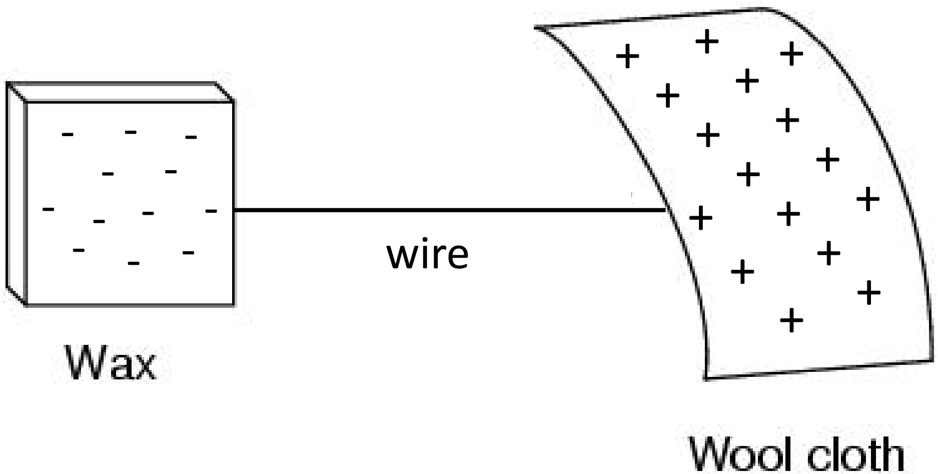


This *imbalance of charges* between the two objects, manifests an attractive force between them.

By rubbing the wax and the wool cloth together, we created an *electric field* between them and the two charges attracted to each other.

Introduction to Charge

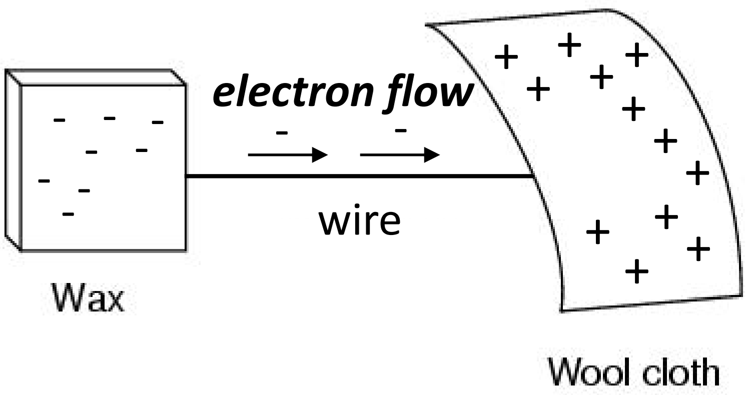
Let's now think .. What will happen if we place a conductive wire between the charged wax and wool?



Introduction to Charge

Let's now think .. What will happen if we place a conductive wire between the charged wax and wool?

Electrons will flow through the wire.
Shortly, the charges will have neutralized and the flow of electrons will stop.



The electron flow in the conductor is called *current*.

The water analogy

We will use through this course *the flow of water* as an analogy for *electrical current*.

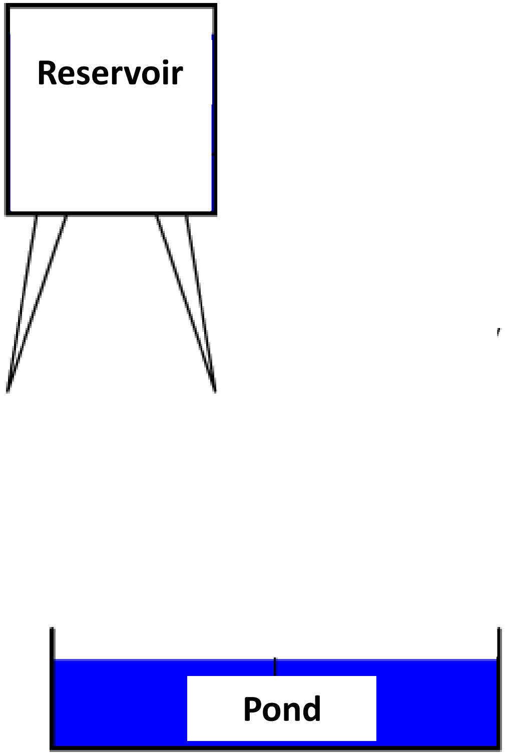
This analogy is useful from a *conceptual perspective*, but we should understand that it is still an analogy (for example electrical currents don’t freeze at 0 degrees of Celsius).

The water analogy

In the water analogy:

- Charge (coulomb)
- Current (ampere)
- Potential difference (voltage)
- Resistance (ohm)

The water analogy

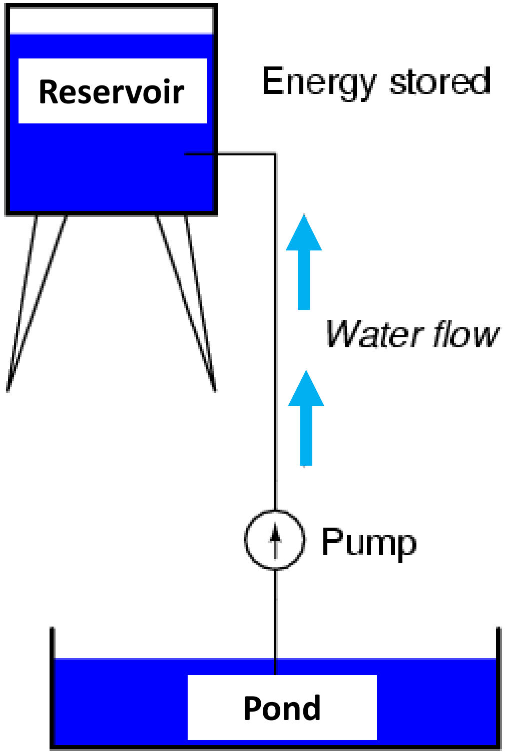


- How can we produce a reservoir of water from the pond?

- We need to pump water up to a certain height in order to produce the reservoir.

The water analogy

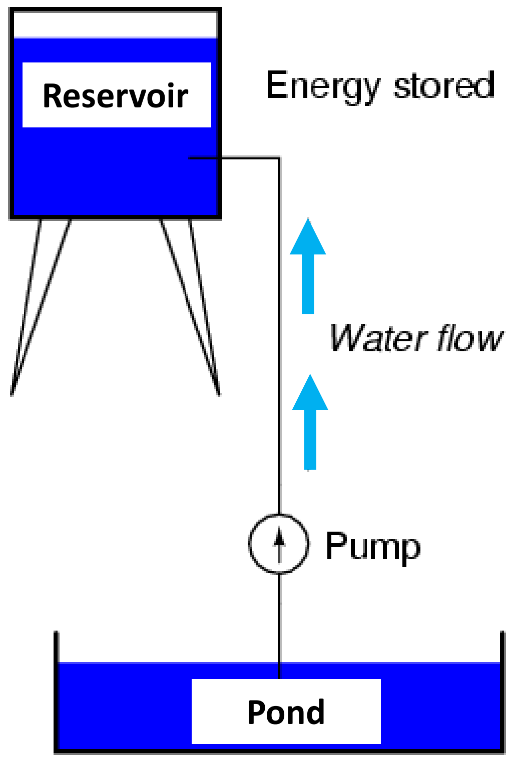
Need for a pipe and a pump!

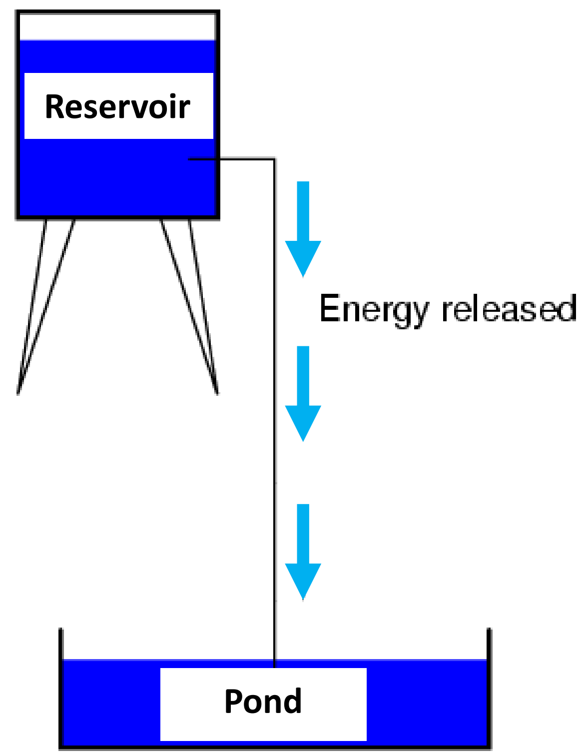


We need to pump water up to a certain height in order to produce a reservoir (energy is required).

The water analogy

Need for a pipe and a pump!

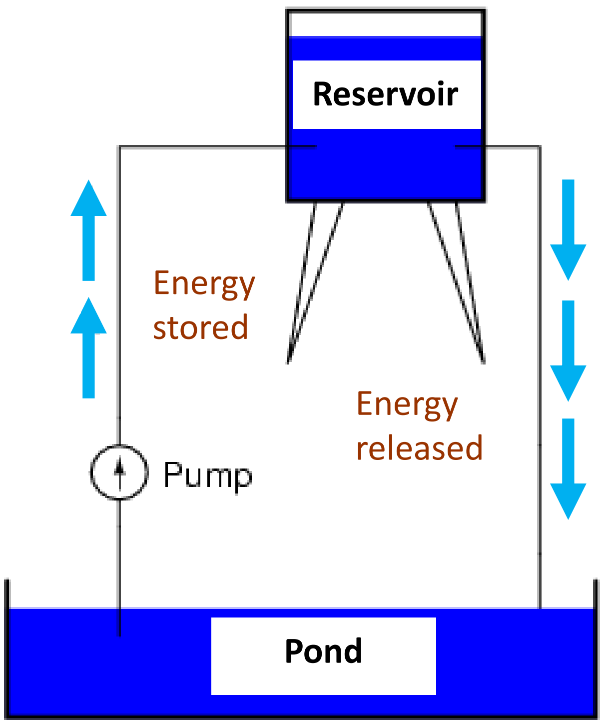




We need to pump water up to a certain height in order to produce a reservoir (energy is required).

If a suitable pipe is placed from the reservoir back to the pond, the water will flow (thanks to gravity) down from the reservoir, through the pipe.

The water analogy

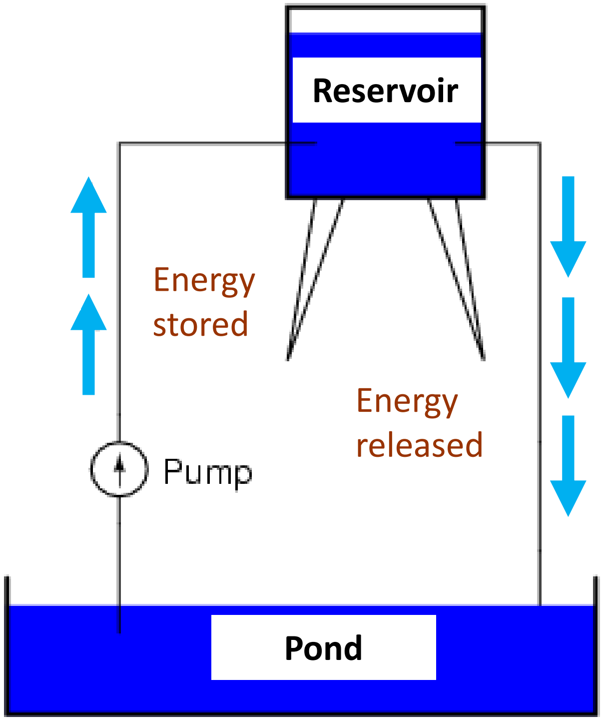


The influence of *gravity* on the water in the reservoir creates a force that tries to move the water down to the lower level again.

In order to keep the tank full, we need to have a pump that restores the water in the tank as fast as it is being drained.

Like water, charge must go somewhere… ideally to the point of lowest potential available.

Current



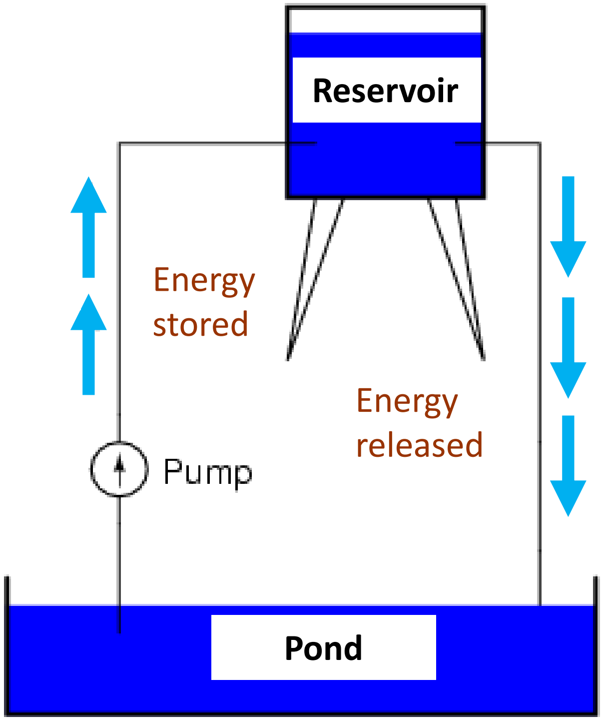
Current is the movement of electrons from a high potential region to that of a lower potential region.

The quantity of charge that is flowing is measured in **amperes** and is **coulombs/second.**

For current to flow, there must be a **path (pipe)** through which it can flow.

Without such a conduit, the electrons cannot move and there is no current!

Voltage



The potential energy is able to provoke electrons to flow through a conductor and can be expressed in terms of the *voltage*.

Voltage is the amount of potential energy available per unit charge, to move electrons through a conductor.

Because voltage presents the possibility that electrons will move from one level to another, *it is referenced between two points*.

But, let's think now, how can voltage be generated?

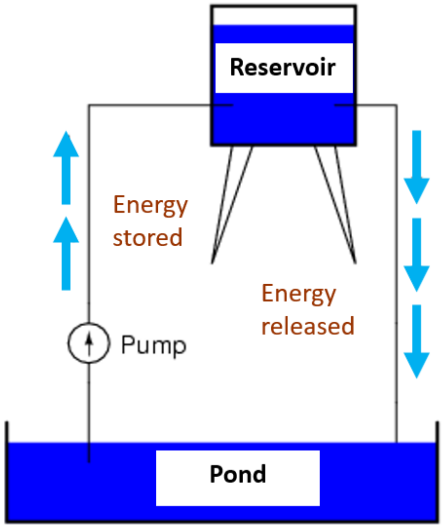
The water analogy

How can we produce a reservoir of charge in an electrical system?
- By using a power station (which continually pumps up the reservoir)
- By using a battery (a static finite-sized reservoir).

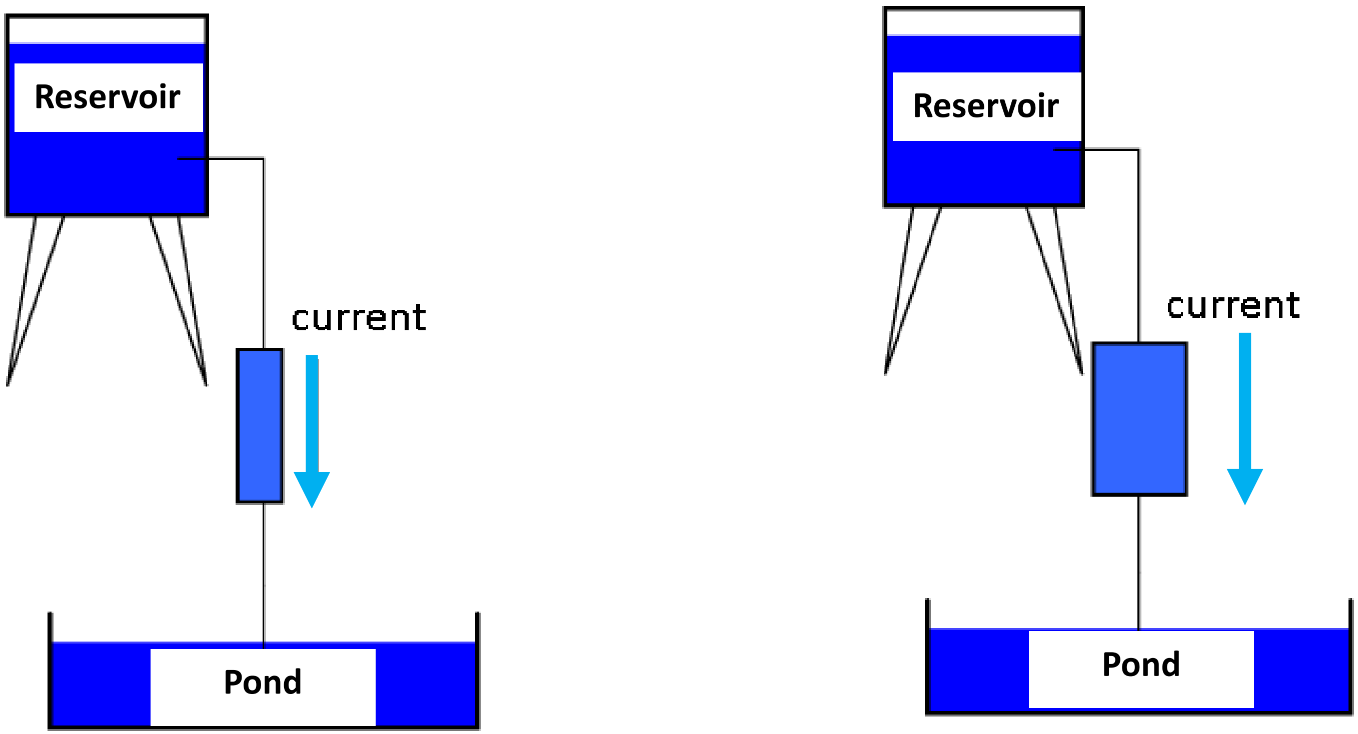
Batteries hold charge through electro-chemical reactions between materials. Batteries have two main characteristics:

- they must be able to hold charge at the higher potential without it leaking away.
- the charge should easily leave when requested.

Power stations have no ability to hold charge, they just continually pump the system.

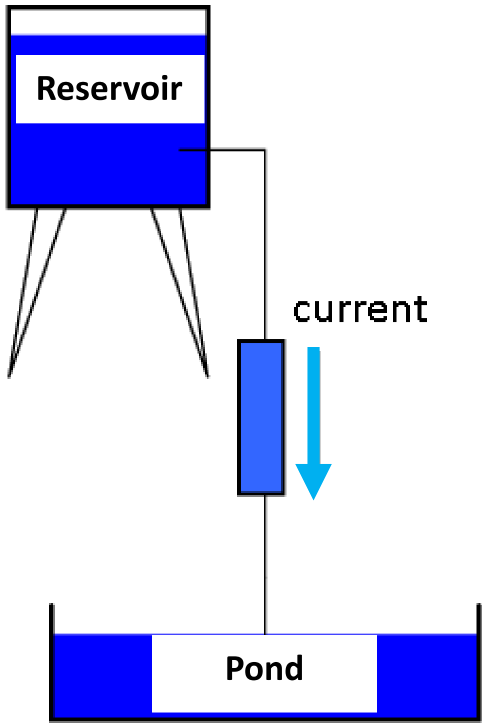


Resistance



Resistance: is a measure of the difficulty for current to pass through a material.

Insulators and Conductors



Conductors: **electrons can move very well** but will not allow the accumulation of charge as they can move so easily.

Metals are the best conductors.

Insulators: **electrons do not move easily** and thus it would require a lot of work to make the electrons move. They can hold charge well.

Air is a pretty good insulator.

A conductor has low resistance, an insulator has high resistance, and there's a fuzzy boundary between the two.

Resistance

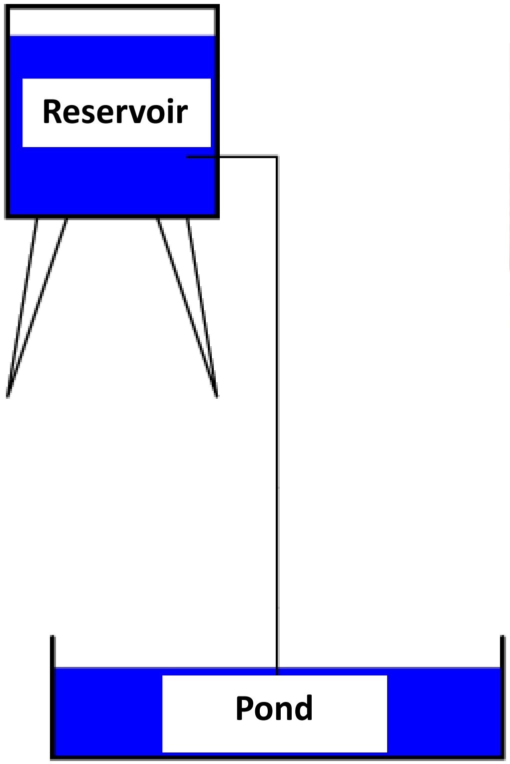
Resistance is the measure of opposition to electrical current.
A measure of how hard it is for the electrons to move.

We measure resistance with the unit of ohms (Ohm or Ω) and we measure the amount of current that will flow given a certain "pressure" or electrical potential difference.

When a connection is made, there are two special types:

- A **short circuit** is where there is ZERO resistance between two points. Short circuits are dangerous as even low voltages can produce very high currents. This is like when a switch is closed (light bulb).
- An **open circuit** is one where there is INFINITE resistance. This means no current will flow irrespective of voltage. This is like when a switch is open (light bulb)

A Circuit



Flow can be measured in litres/sec.

With the tank at a certain height/pressure, a pipe of a certain size will result in a certain amount of water flow.

Summary

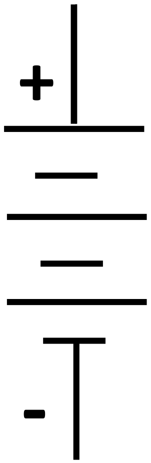
Potential difference (voltage) – water stored at a height (pressure)

Charge (coulomb) – a quantity of water

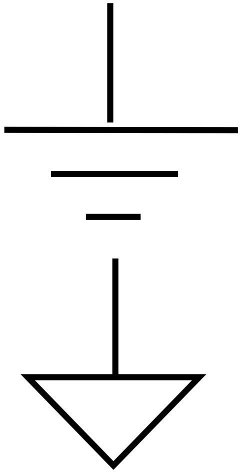
Current (ampere) – the flow of water

Resistance (ohm) – pipe diameter… controlling the flow of water.

Electrical Concepts & Symbols



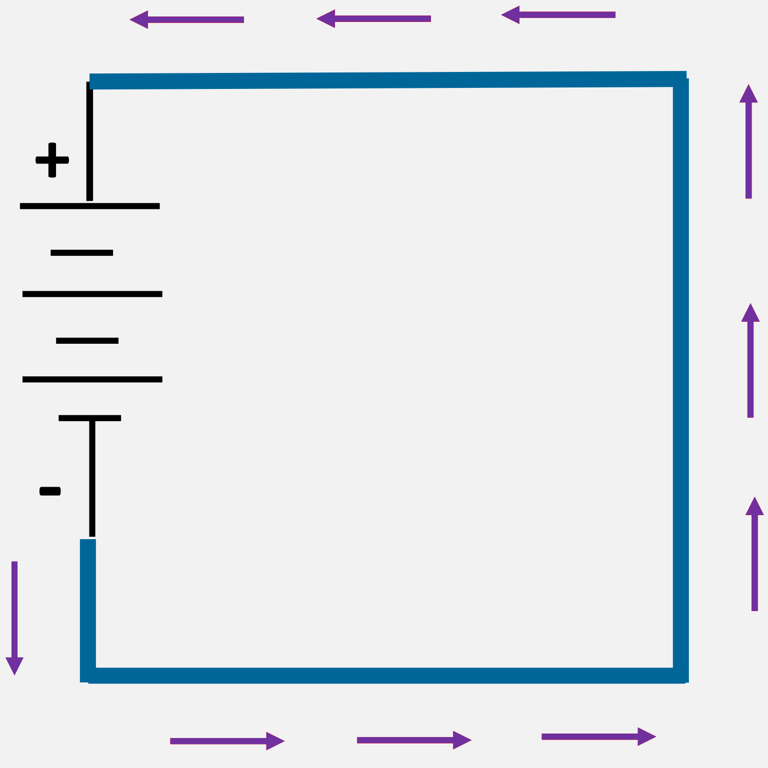
A **battery** or constant voltage supply (assumed to be infinite)



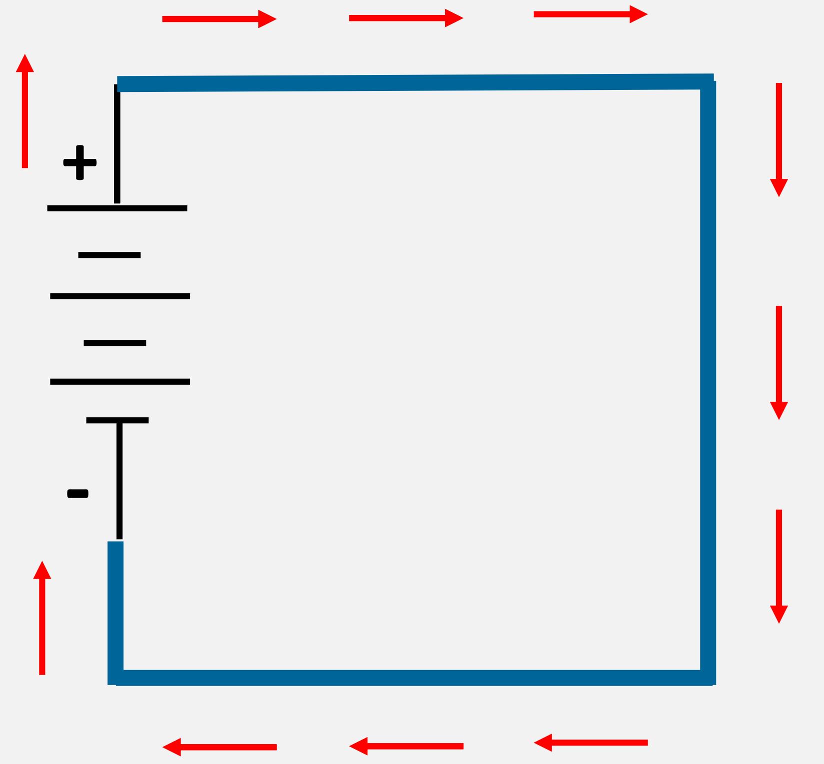
The reference node is commonly called the **ground**, since it is assumed to have zero potential.

Ground or ***earth*** is the reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the earth .

Conventional vs electron flow



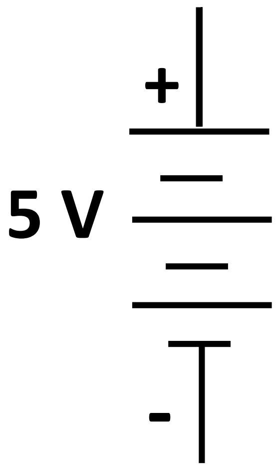
Electron Flow



Conventional Current Flow: current flows from the positive terminal to the negative.

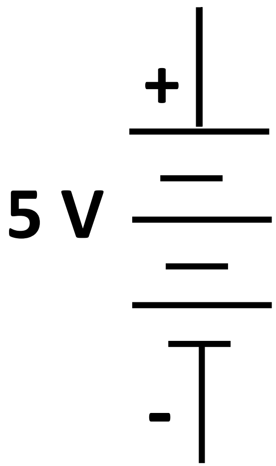
Conventional flow is used around the world.

Electrical Concepts & Symbols



What will happen if we have a battery whose terminals ("+" and "-" ends) are not connected to anything?

Electrical Concepts & Symbols

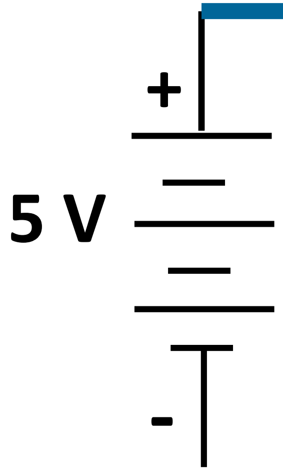


What will happen if we have a battery whose terminals ("+" and "-" ends) are not connected to anything?

In such a case, there will be voltage between the end terminals.

However, there will be no flow of electrons through the battery, ***because there will not be a continuous path for the electrons to move***.

Electrical Concepts & Symbols



Current is indicated with an arrow.

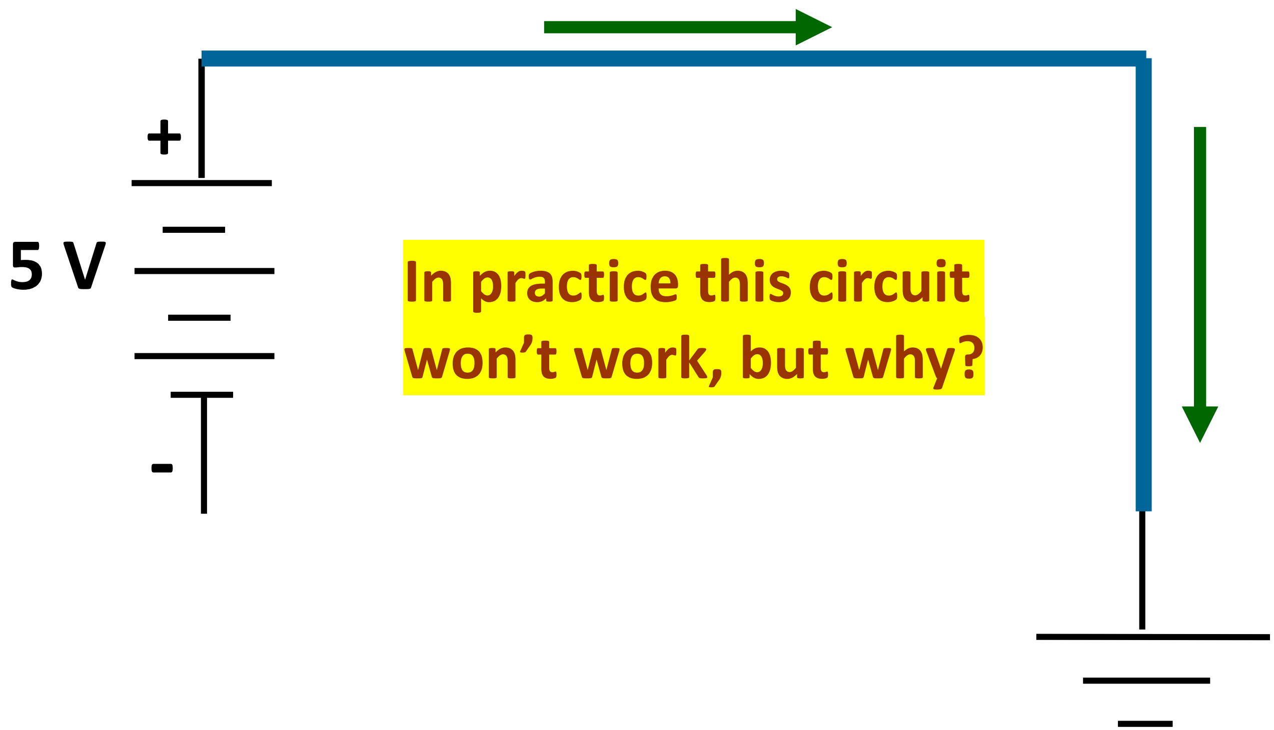
Convention is that current flows from POSITIVE TO NEGATIVE

(or to a lower voltage value)

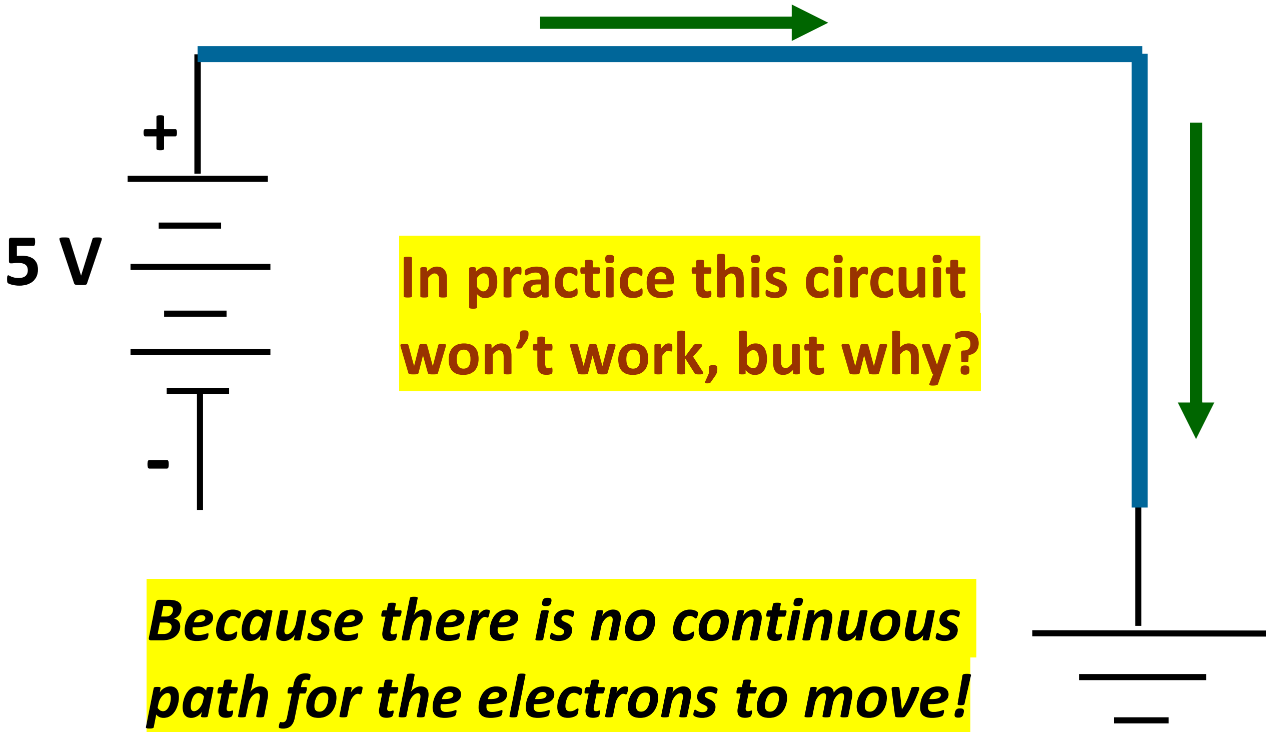
(remember electrons flow in the opposite direction to conventional current)

A wire connects two points in a circuit (in practice a bit of copper wire).

Electrical Concepts & Symbols



Electrical Concepts & Symbols

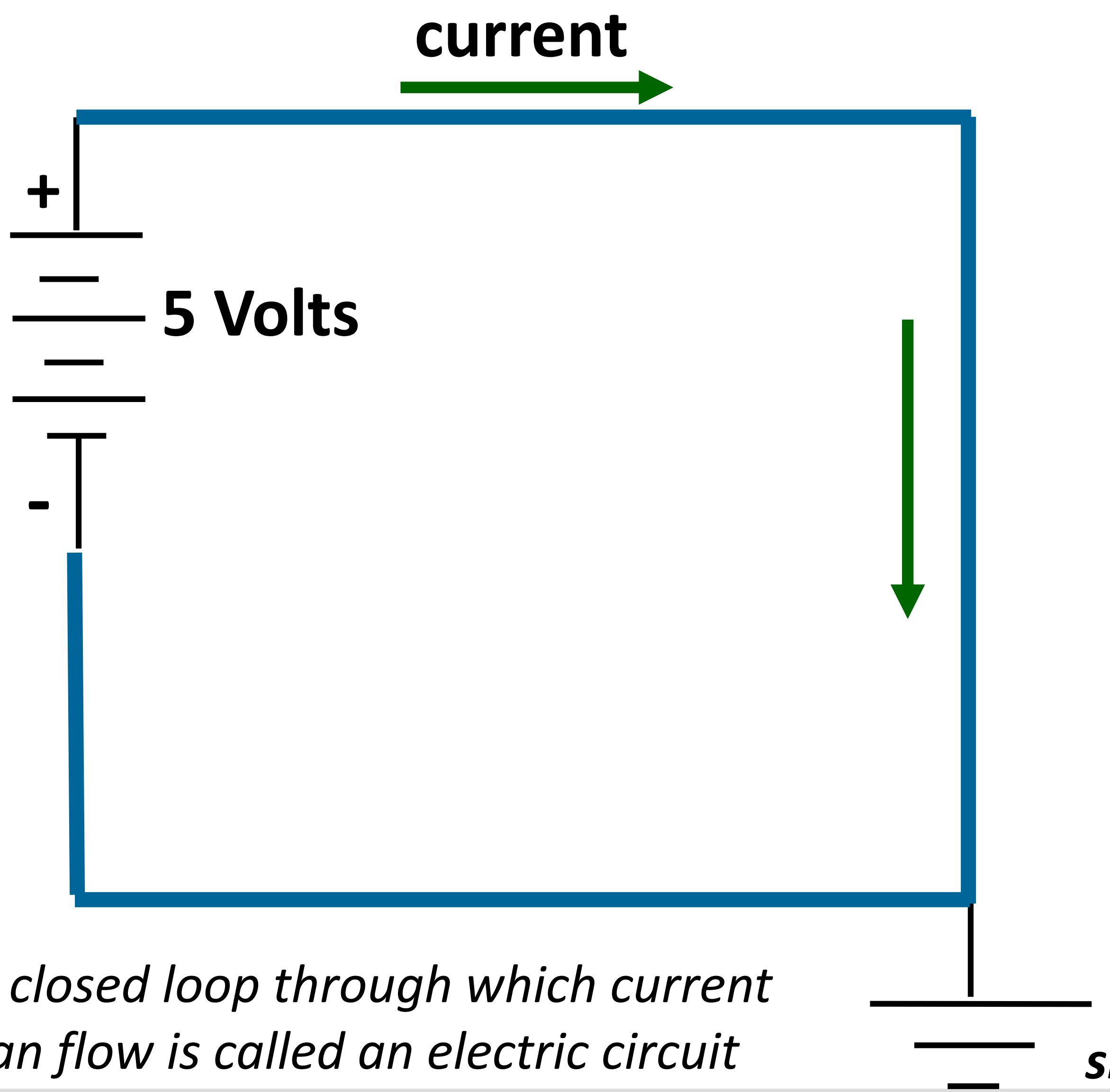


In practice this circuit won't work, but why?

Because there is no continuous path for the electrons to move!

Electric current can flow through a wire only if it forms a closed loop.
Charges must have an unbroken path between the battery's '+' and '–' ends.

Electrical Concepts & Symbols



A closed loop through which current can flow is called an electric circuit

Note: this is just an illustrative example to show the continuous path

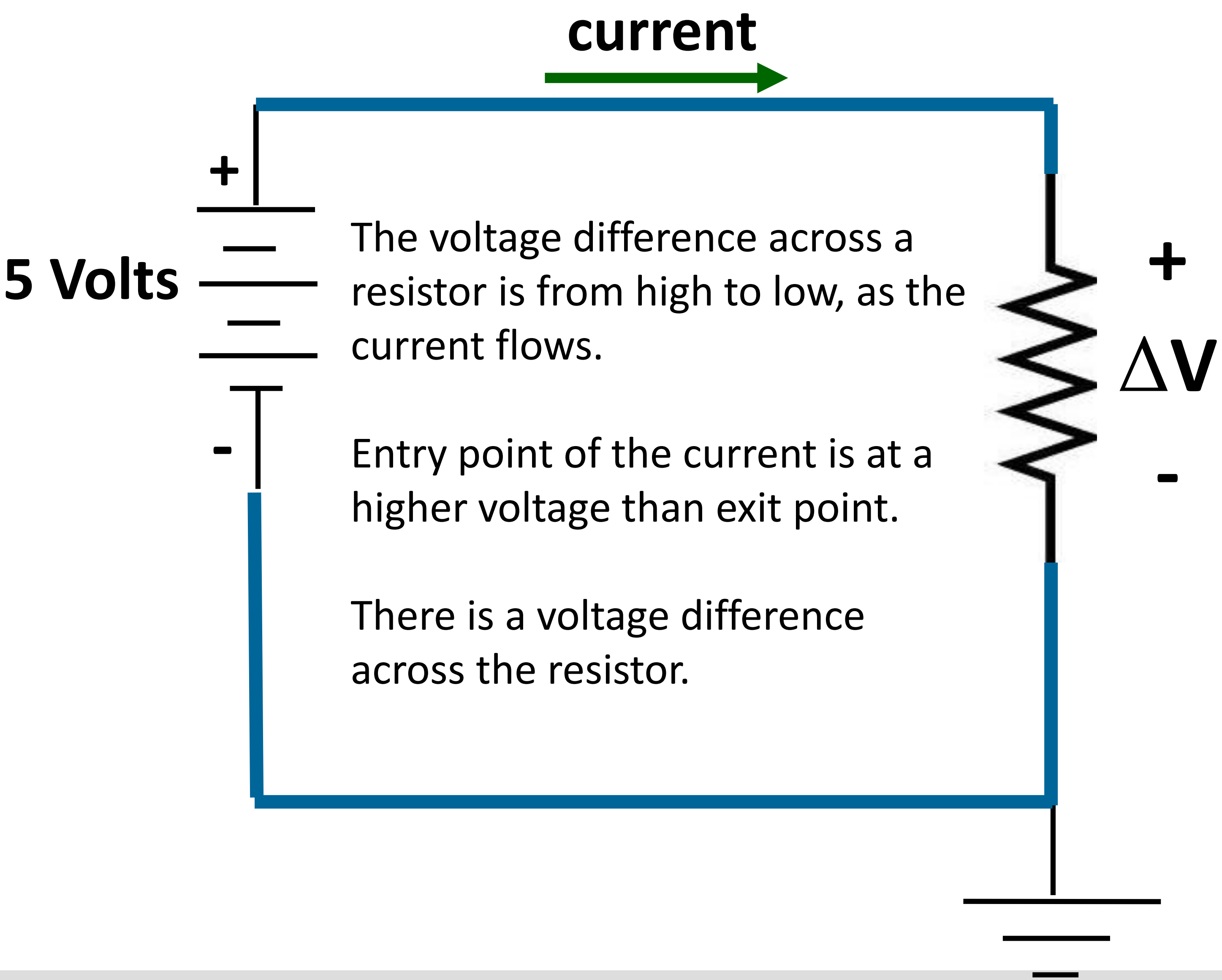
Resistance

An important question:

What is the amount of current you can get for a certain voltage difference?

The degree of difficulty for current to flow is called resistance and has units called Ohm (Ω).

Resistance



The voltage difference across a resistor is from high to low, as the current flows.

Entry point of the current is at a higher voltage than exit point.

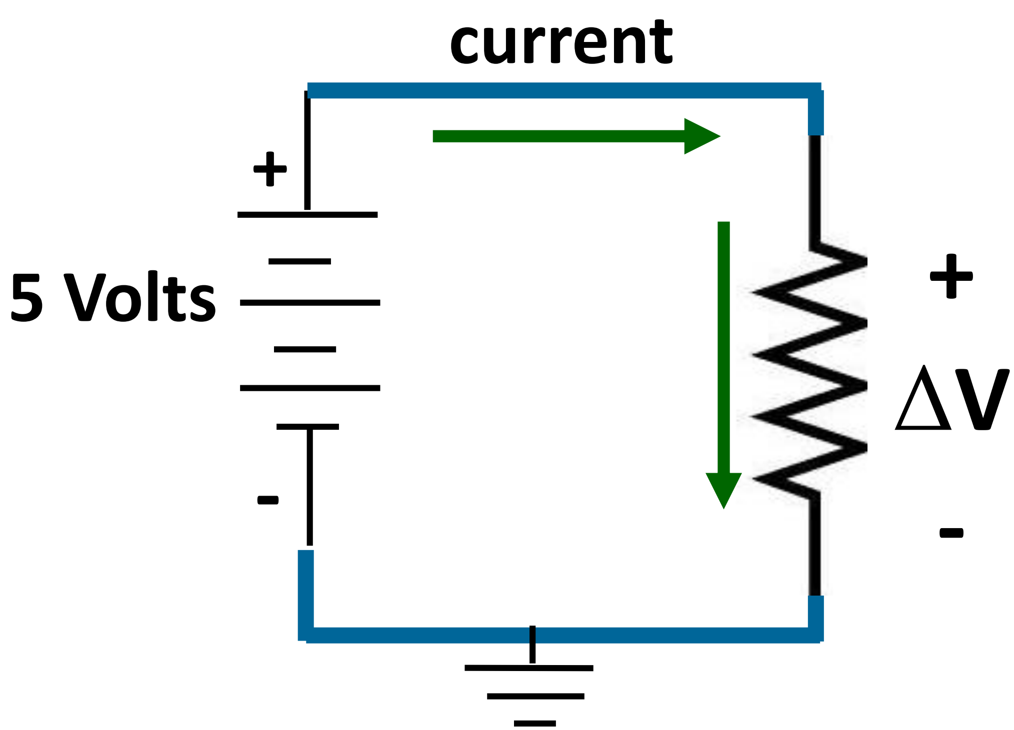
There is a voltage difference across the resistor.

Ohm's Law

Ohm's law states that the current (I) through a *resistive path* is directly proportional to the potential difference or voltage (V) across the two points, and inversely proportional to the resistance (R) between them.

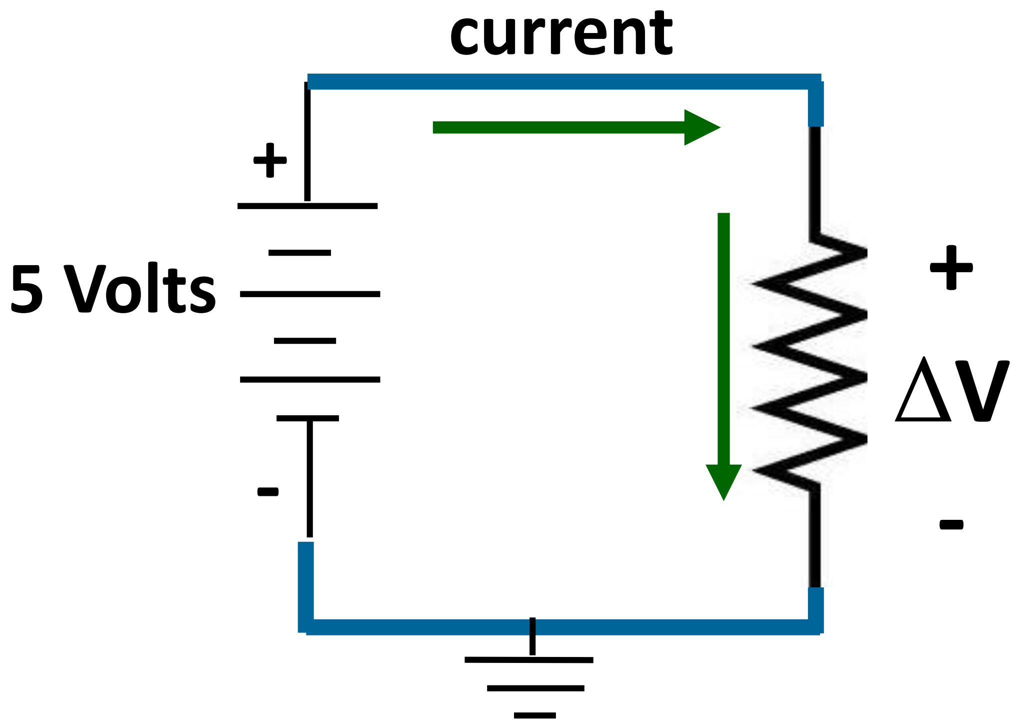
$$I = \frac{V}{R}$$

$$V = IR$$



Example

A 5 volt battery is connected to the ground via a resistor. Calculate the current that can flow for the following resistance values: 100000, 100, 1 and 0 Ohms.



Example

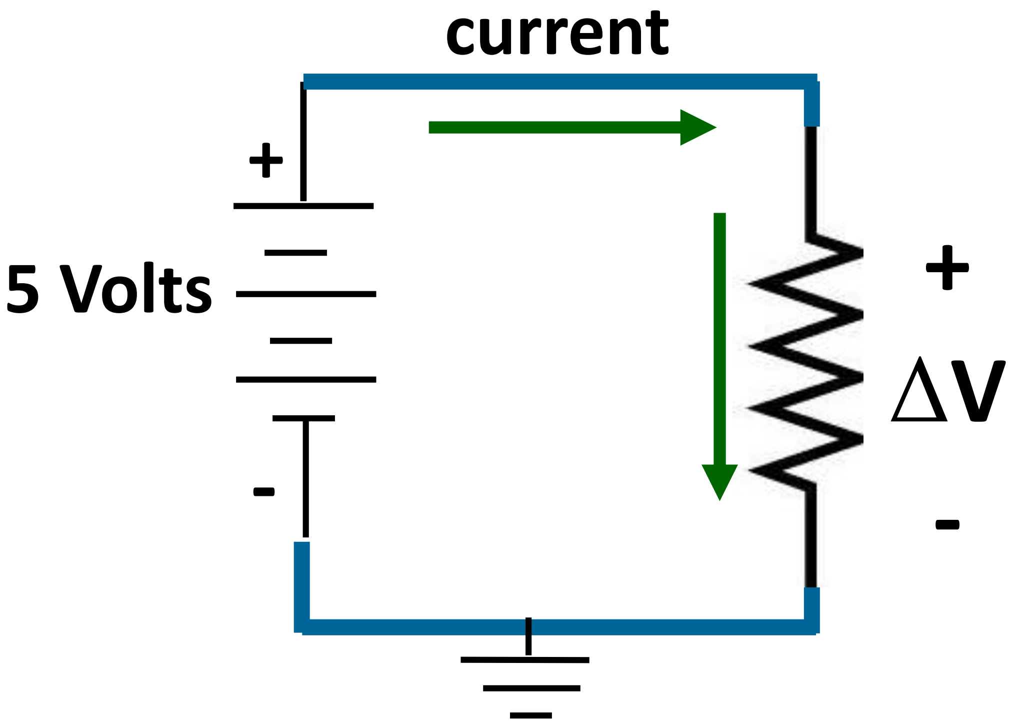
A 5 volt battery is connected to the ground via a resistor. Calculate the current that can flow for the following resistance values: 100000, 100, 1 and 0 Ohms.

$$I_{100k} = \frac{5}{100{,}000} = 50\mu A$$

$$I_{100} = \frac{5}{100} = 50mA$$

$$I_1 = \frac{5}{1} = 5A$$

$$I_0 = \frac{5}{0} = \infty$$



Electrical Power

Power is the rate at which work is done.

Work is done by moving electrons through an electric field.

$$work = q * V$$

$$\frac{work}{second} = \frac{q}{second} * V$$

$$\frac{work}{second} = I * V$$

$$power = V * I$$

The power generated/consumed at any point in an electrical circuit is the current multiplied by voltage difference.

Electrical Power

$$P = V * I$$

This is a useful equation, but we can make two more useful ones from using Ohms Law (V=IR):

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

This (and Ohm's Law) are fundamental equations.
You will need to always know these equations!