ELECTRIC CURRENT

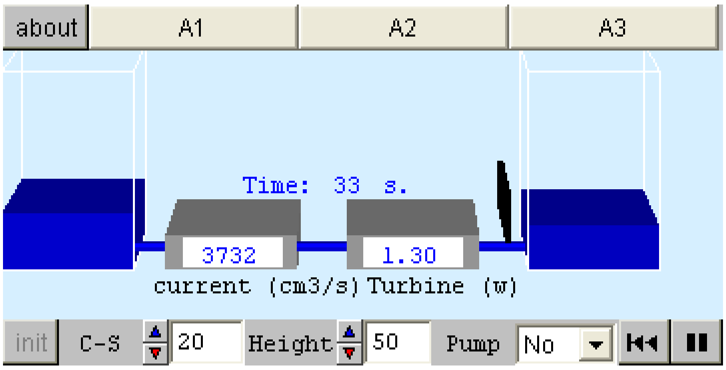
Starting with its similarity with a hydraulic supply circuit, we intend to sketch the most important characteristics and laws related to an electric circuit.

We will assume from the start, that the student understands the concepts of charge, field and electric potential covered in the unit on electricity. If this is so, then you can proceed. If not, we suggest you first study the chapter on Electricity.

OBJECTIVES

- To understand the parallelism between an electric circuit and the distribution of water in a closed circuit.
- To learn the characteristic magnitudes which describe an electric circuit: the potential difference, intensity, resistance, electromotive and counter electromotive force.
- To demonstrate and understand the fundamental laws which relate these magnitudes.
- To be able to calculate intensities, tension, power and energy in simple circuits.

THE HYDRAULIC SIMILE.



A1: Click on play. When will the flow stop? This phenomenon implies a difference in the value at two points of a certain form of energy. What kind of energy are we referring to?

A2: Change the cross-section of the tube and/or the difference in the levels of water and click on play. Try this several times with different values until you have discovered the relation between the current (cm3/s), the cross-section of the tube and the difference between the levels of water.

A3: Imagine the introduction of a pump that sends water back to the first tank of water, maintaining the difference in the levels of water constant. How does this machine affect the process?

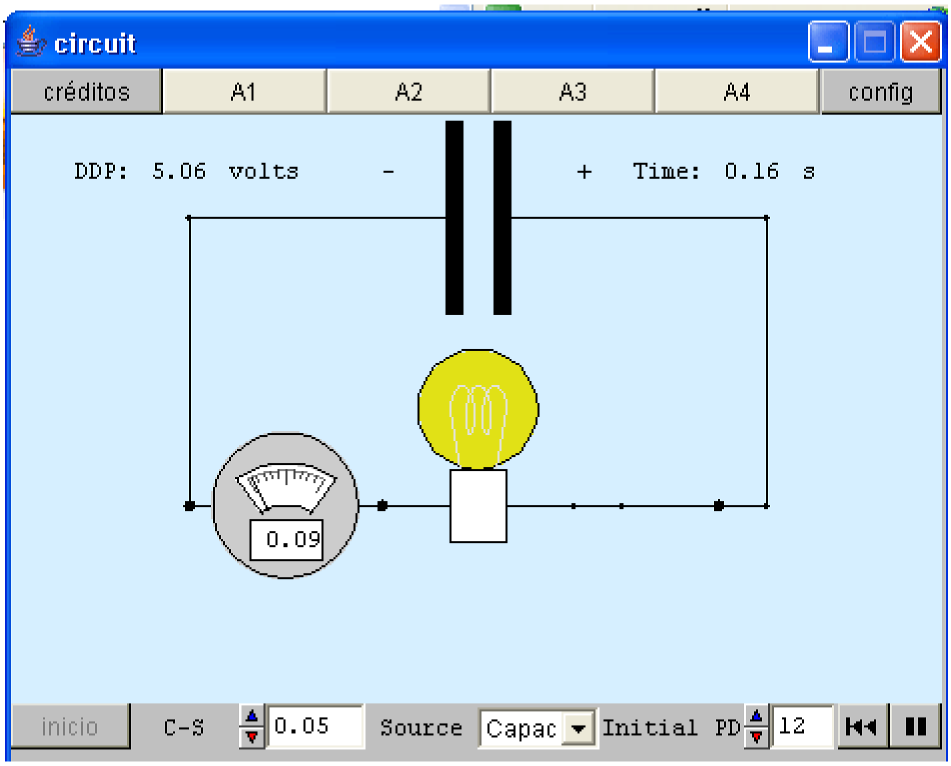
In the visual you can see two water tanks with different levels. The difference in the levels will force the liquid to circulate from one tank to the other the moment we lift the intervening barrier. We have placed a device to measure the current and a device which uses the energy of the water (a turbine for example) in the circuit. Carry out the suggested activities paying special attention to the current of water and the factors which increase or decrease it. Also think about what happens when we place a water pump between the two tanks. Would the energy we use in the pump be equal to that produced in the turbine?

ELEMENTS IN THE CIRCUIT

By clicking on **Circuit** you can compare the elements of the hydraulic circuit which you have just studied, with a simple electric circuit.

The conducting plates of a capacitator provide us with the potential energy difference which will begin the movement of the charges.

We also have a switch, a flow meter for the current and a device which uses it, a light bulb. What do we have to do if we want to keep a constant current for the light bulb?



A1: Compare the elements of this circuit with the elements in the hydraulic circuit. Find a correspondence between the elements that make up both circuits.

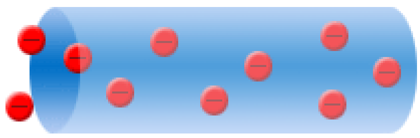
A2: Set the initial potential difference (PD) to 12 volts and observe the difference between the circuit without a battery and the circuit with a battery. What is the difference?

A3: The measuring device in the visual is an ammeter. What does it measure in the circuit? How does the value measured change when the potential difference is changed?

A4: Change the cross-section of the conductor. What is the effect of this change on the strength of the electrical current? How does it affect the potential difference?

CHARACTERISTIC MAGNITUDES

In every circuit there are several physical magnitudes which have to be considered:



The equivalent of the current of water is the **electrical current**, which measures the quantity of electric charge which passes along a section of the circuit each second. Its unit is the ampere which we can consider to be the rate of one coulomb per second.

In reality, the moving charges of an ordinary circuit are the electrons which circulate from the negative pole to the positive pole of the battery. However, traditionally, the official direction is still that of positive charges circulating from the positive pole to the negative one. Click on next to study how the current is measured.

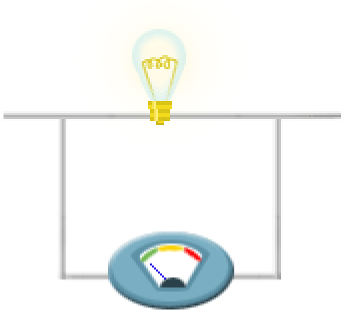
The intensity of a current is measured with an **ammeter**.

The ammeter, using magnetic effects which do not concern us for the moment, measures the current in amperes, milliamperes or microamperes.

Notice that the ammeter is always connected in "series", that means, in such a way that all the charge in the circuit passes through it.

We can now ask ourselves what the circulating current depends on.

In the hydraulic circuit the different height of the water in the tanks was important to determine the current. In the electric circuit the potential difference between the poles of the generator will play the same role with regard to the electric current.



The **voltmeter** is the device which measures the potential difference between two points in the circuit in **volts**.

Notice that the voltmeter is inserted into the circuit in **parallel**. In the rest of the unit we will assume that the intensity of the current which is diverted through the voltmeter is negligible.

We have also seen that in the hydraulic circuit and also in the electric circuit the rate of flow (or current) changes according to the cross sectional area of the pipe (or the conductor).

The cross sectional area of the conductor influences the current because a larger cross sectional area means the charge can pass through it more easily.

The type of conductor and its length also have an influence. All of these factors which have an influence are brought together in a magnitude which we call resistance.

Resistance measures the opposition of the conductor to the flow of an electric current. Its unit is called the ohm. All the elements in a circuit have their own resistance. When we study Ohm's Law we will see the important role that it plays.

In the visual, try to see the relation of resistance with length, diameter and the type of conductor (the diameter is seen on an exaggerated scale to heighten its effect).

CONCLUSIONS ABOUT THE CONCEPT OF THE CIRCUIT

In the same way that water can circulate between two tanks with different levels of water; the **electric charge between two points with different potential, joined by a conductor** can also circulate.

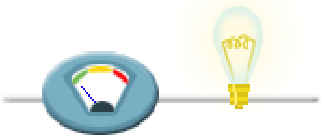
The **current** measures the charge that flows each second. Its unit is the **ampere**. The device which measures it is called an **ammeter**. The ammeter is connected to the circuit in series.

The **potential difference** between two points in the circuit is measured in **volts** . The device which measures it is called a **voltmeter**. The voltmeter is connected to the circuit in parallel.

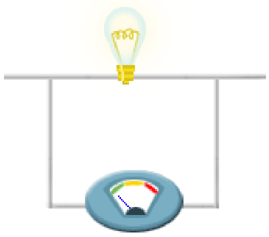
The **opposition of the conductor to the flow of the current is called resistance**. It is measured in **ohms.** Its value is expressed as **R= k·l /S** where l is the length of the conductor, S is its cross sectional area and K (resistivity) is a coefficient which depends on the material.

OHM's LAW

Ohm investigated the relation between the intensity of a current which flows through an element in a circuit and the potential difference between the two ends of this element. To reproduce his investigation we will use two devices you are already familiar with:

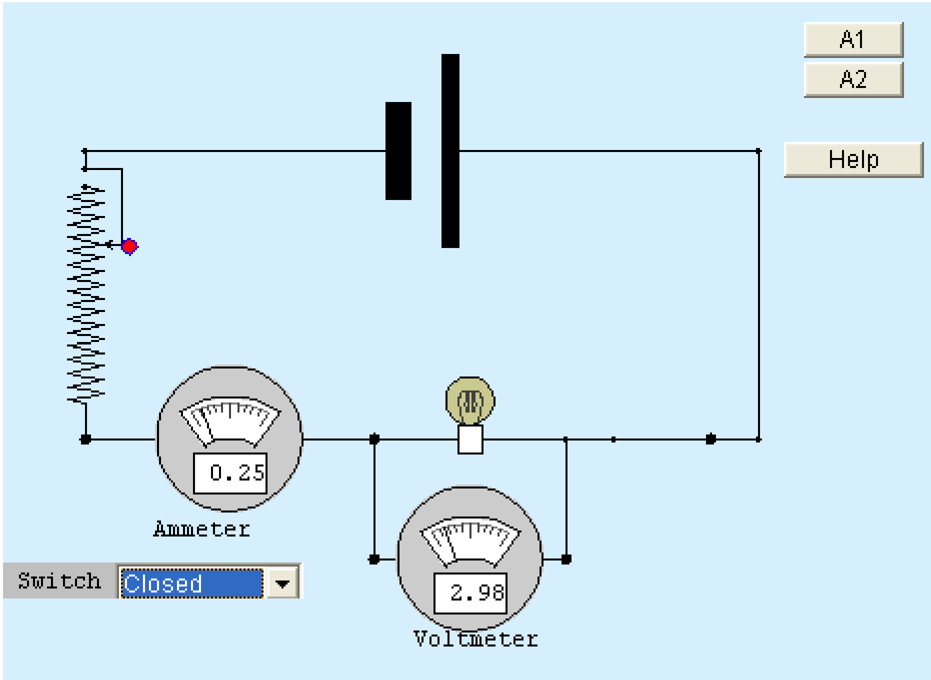


The ammeter, connected in series with the element we are studying.



The voltmeter, connected in parallel between the two ends of this element.

The HELP control will explain how to work with the visual.

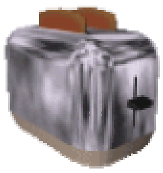


A1: Set the switch to closed and note down the values of the current (amperes) and the potential difference (volts). Drag the red dot on the potentiometer and note down the values of the potential difference. Divide each value of the potential difference by its corresponding value of the current. What can you observe?

A2: Search for Ohm´s law in your textbook and compare it to your results. What is the value of the resistance of the light bulb?

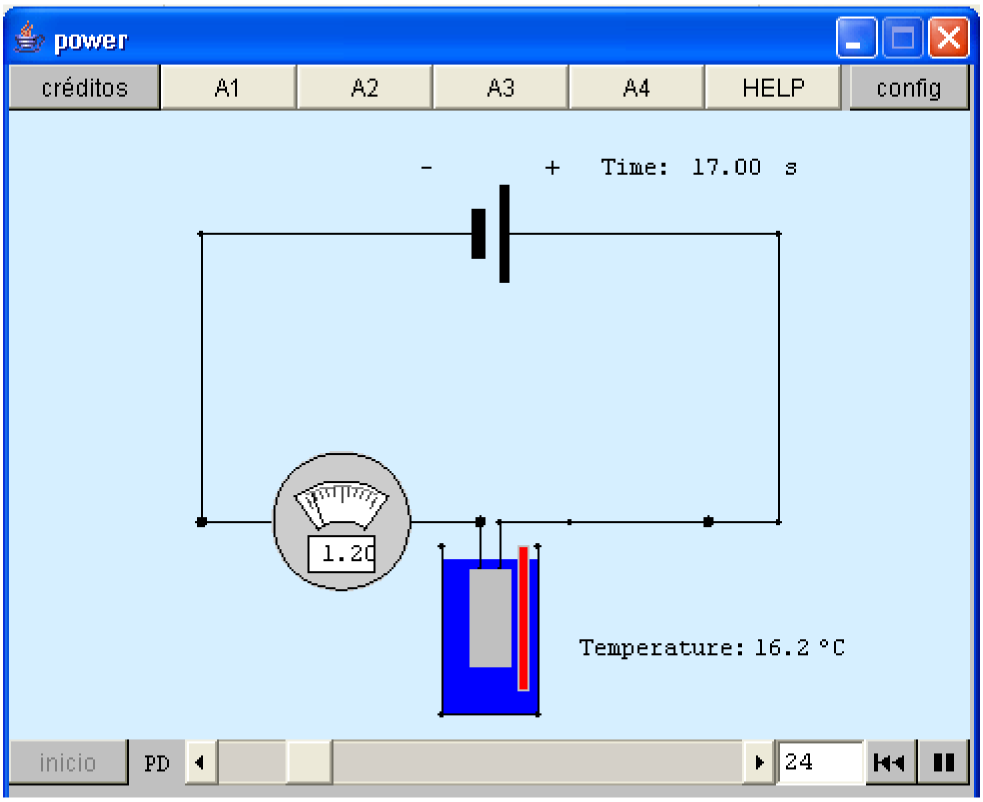
Help: The circuit in the visual will help you study the relation between the potential difference between the terminals of the light bulb and the current. The red dot can be dragged along to change the value of the potential difference. We will assume that the current through the voltmeter is negligible. You must set the switch to closed to allow the current to circulate.

POWER AND ENERGY IN THE CIRCUIT



The electric current can have many uses: lighting, heating, a means of communication, the production of mechanical energy, etc

In all cases there is a point in common: the transformation of electric energy into another form of energy. The control **Power** will allow you to study the simplest of these conversions, the production of heat from an electric current.



A1: You will probably remember that the amount of heat that a body receives is C = m·c·(Tf - Ti). What does each of these magnitudes represent? What is the value of c for water?

A2: Set the potential difference to 100 volts, note down the current and flick the switch with the play control. Stop the animation after 10 seconds and note down the temperature. Repeat the process with 25 and 50 volts of potential difference. Complete your data table with a calculation of the heat transferred to the water in each case.

A3: Try to find a simple arithmetic relation that includes the potential difference, current, time and heat produced in each case. This relation is known as Joule´s law. If you divide your formula by time you will get the electric power.

A4: Using Ohm´s law, write the laws you have discovered without using the potential difference. Use your textbook to check that your deductions were correct.

Help: A container with 100 grams of water at 15ºC increases its temperature due to an electric heater. Change the potential difference of the generator and the visual will tell you the current circulating and the temperature of the thermometer.

THE GENERALIZATION OF THE LAWS

The potential difference can be understood as the energy which can be extracted from each unit of charge which passes through a circuit. Therefore the power output is P= V·I where V is the potential difference and I is the current (I is typically used as a symbol for the current, from the German word Intensität, which means 'intensity').

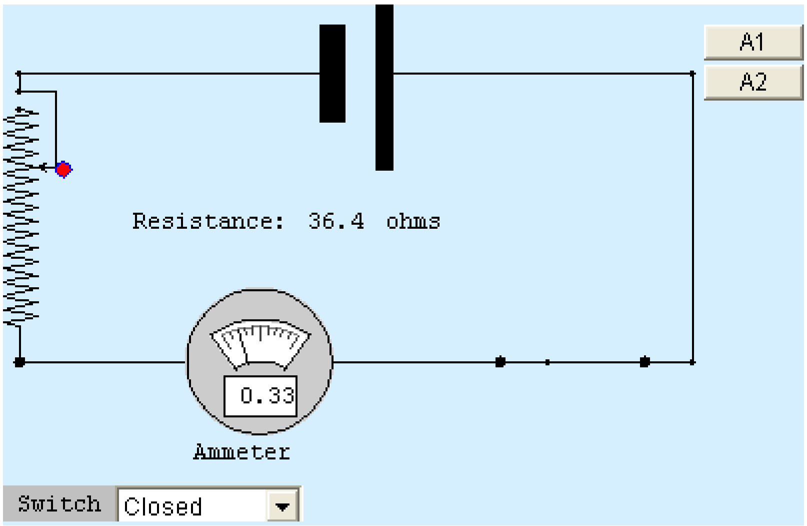
At the same time we call the energy consumed for each unit of charge which passes through the circuit the **the electromotive force** of a generator. So the power supplied by a generator or battery will be:

$$P_g = EMF \cdot I$$

where we have called the electromotive force EMF.

Are EMF and V equal? Is the power consumed in the circuit equal to that supplied by the generator? The two answers are linked

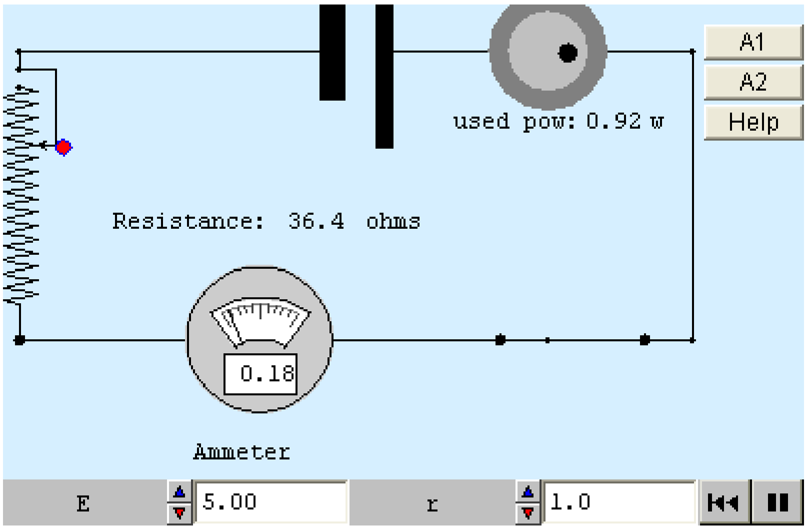
The generator in the figure has an EMF of 12 volts. Click on A1 and A2



A1: Close the circuit and decrease the resistance of the potentiometer until its value is zero. What is the value of the current? If we wish to explain why this value is not infinite, what must we claim about the value of the internal resistance of the generator?

A2: The circuit satisfies the following equation: $E = R \cdot I + r \cdot I$, where E is the electromotive force of the battery, R is the resistance of the circuit and r is the internal resistance of the generator. Check that the law is true for different values of the resistance R.

We will now also include a motor. Click on HELP to understand its characteristics. Carry out activities A1 and A2.



A1: Click on play. Check that the circuit satisfies the equation $E - E' = R \cdot I + r \cdot I + r' \cdot I$. Check that the current measured by the ammeter is compatible with this equation for several values of the parameters that you are allowed to change.

A2: If you multiply the generalization of Ohm´s law by I you will get the power of each element. The power of the generator is E·I, the power of the motor, E´·I, etc. Search for the parameters that increase the power of the motor. What percentage of the power of the battery is used by the motor?

Help: The generator has an electromotive force of 12 volts and an internal resistance of 0.5 Ohms. The counterelectromotive force is the work done by the motor per unit of charge that goes through it. r´is its internal resistance.

Conclusions about the laws of circuits

The potential difference between the ends of a resistance in a circuit is **V=R·I** where I is the current and R is the value of the resistance (**Ohm's Law).**

The power consumed in the resistance is **P= V·I** or rather **P=R·I²** and the energy after a time t will be: **W=R·I²·t** (Joule's Law)

We call the energy a generator produces for each unit of charge the electromotive force. It is measured in volts.

We call the energy an engine consumes per unit of charge the counterelectromotive force. It is also measured in volts.

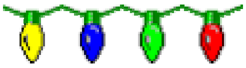
Generators and engines behave as though they had a certain internal resistance in which heat is dissipated.

Ohm's Law generalized to a circuit with generators and motors is: **E - E'= R·I+r·I+r'·I** where E is the electromotive force of the generator, and E' is the counterelectromotive force of the engine. R is the resistance of the circuit, while r and r' are the internal resistances of the generator and the engine respectively.

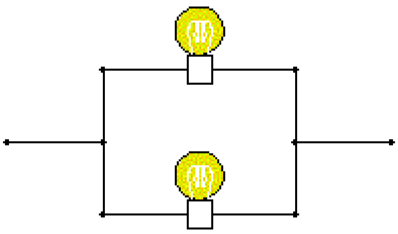
The power supplied by the generator is **Pg=E·I** and that used in the engine is: **Pm=E'·I.** The difference between the two powers is lost in the form of heat in the different resistances.

THE ASSOCIATION OF RESISTANCES

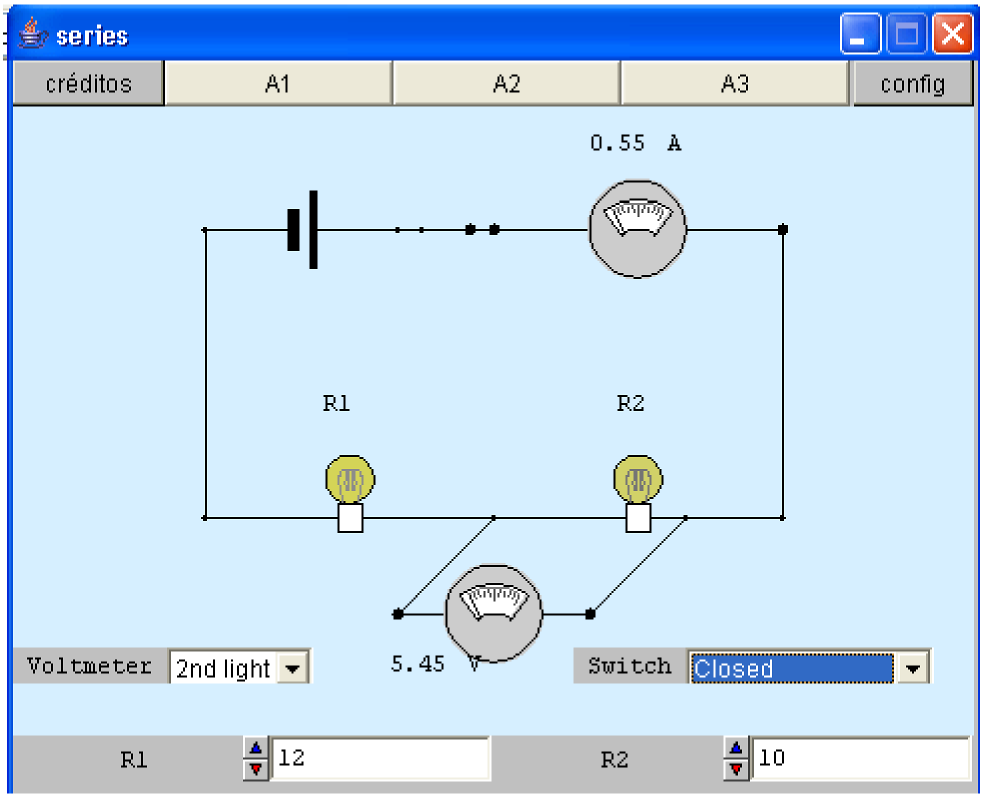
We often want to connect more than one device to the same circuit. You will study the case in which we connect several light bulbs, but the conclusions are valid for the resistances of any device we connect.



When all the devices are connected in such a way that the same intensity of current passes through all of them, we say they are in **series.** This is the case, for example, of the lights on a Christmas tree. Click on **Series** to study this case.



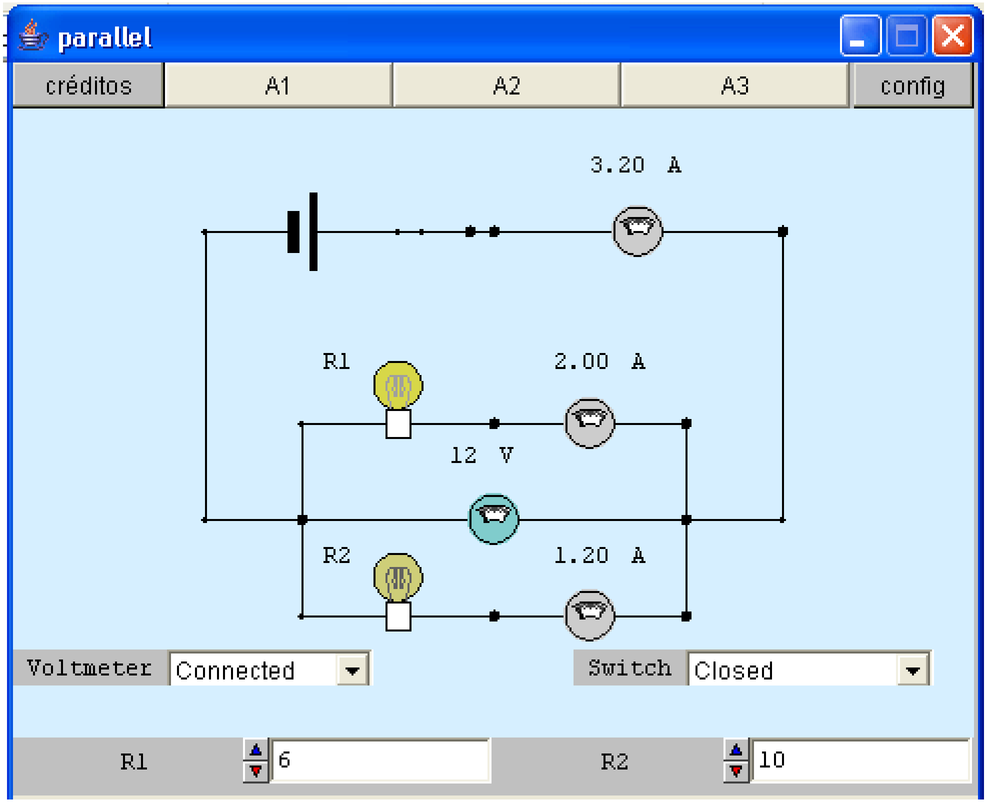
However, when the different elements are joined to common connections, we say they are in **parallel.** This is how almost all the devices in our homes are connected. Click on **Parallel** to study this case.



A1: Having connected the circuit, change the values of one of the resistances. What can you observe in reference to the light emitted by the light bulbs? Repeat the experiment until you are sure of the relation between the light emitted and the value of the resistance.

A2: Connect the voltmeter to one of the resistances and change its value. What is the relation between potential difference and resistance? Measure the potential difference between both sides of the other resistance. What is the sum of both potential differences always equal to?

A3: Divide the total potential difference (12 volts) by the current. What is the relation between this value and the values of the resistances? You have just measured the equivalent resistance.



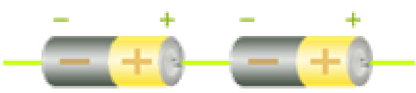
A1: Close the circuit and give different values to the resistances. Note down the values of the current measured by each of the ammeters. What is the relation between these values? What is the relation between the current through each resistance and its value in ohms?

A2: Connect the voltmeter to the circuit. Give several values to each of the resistances. What value does the voltmeter always show? What general conclusion can you deduce from this fact?

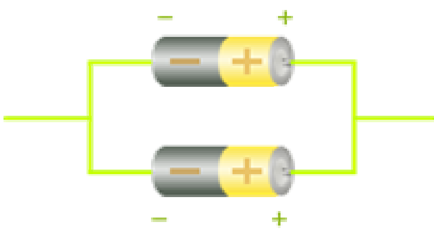
A3: In order to find out the value of the equivalent resistance, divide the potential difference (12 volts) by the total current for a given value of R1 and R2. To see the relation between these values, invert the value of the resistance you have calculated and invert the values of R1 and R2. ¿What can you observe?

THE ASSOCIATION OF GENERATORS

Nearly all of us have devices which work with several batteries connected at the same time.

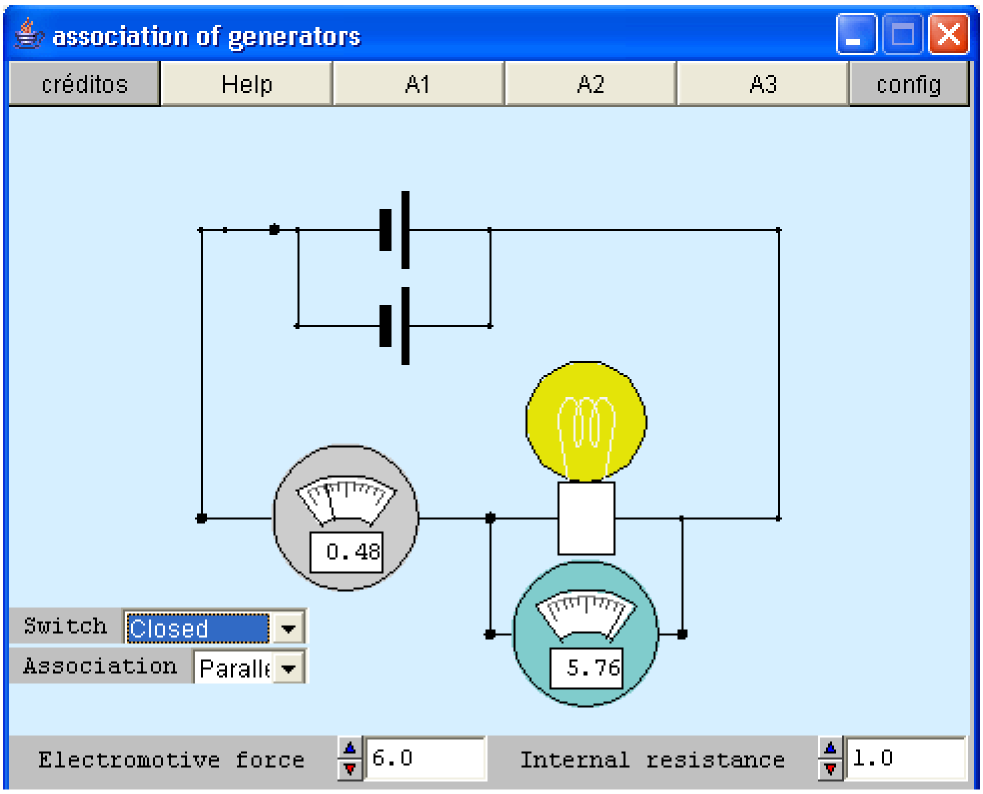


When they are connected with the opposite poles together we say that they are in **series**. You will soon see that this type of connection permits us above all to increase the electromotive force.



When they are connected with the poles of the same sign together we say that they are connected in **parallel**. You will see that batteries connected in parallel permit us to increase the current.

Click on **Association of generators** to see the characteristics of these connections.



Help: This visual only represents the case where the two batteries are identical. You can alter the electromotive force and the internal resistance of each battery. You can also change the way they are associated.

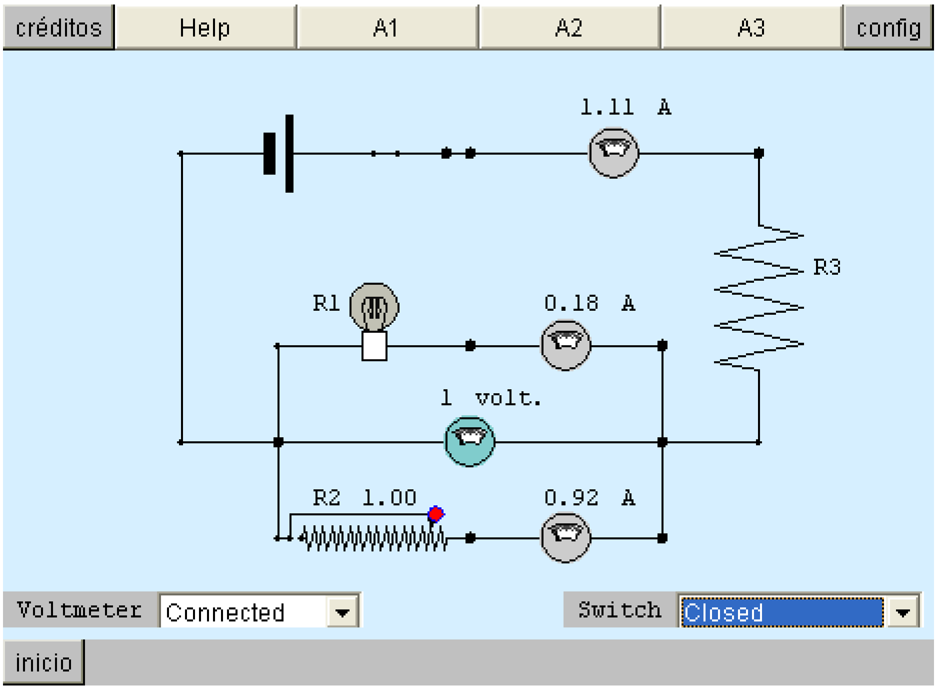
A1: Choose an association in series for the batteries. Change the values of the electromotive force. What happens to the potential difference between the terminals of the light bulb? What is the value of the current? Do both magnitudes increase or decrease by the same amount? Why? Try changing the internal resistance. What happens to the total internal resistance?

A2: Choose an association in parallel for the batteries and change the values of the electromotive force. What happens to the potential difference between the terminals of the light bulb? What about the current? Do both magnitudes increase or decrease by the same amount?
Why? Change the internal resistance. What happens to the total internal resistance?

A3: How can we change the values of the electromotive force and the internal resistance to make the consumption of power in the light bulb maximum?

A COMBINED CIRCUIT

The circuits you have been studying are very simple. Here we present a more complex one so that you can practise what you have learned.



Help: The battery in the circuit has an electromotive force of 12 volts and a negligible internal resistance. R3 has a random value that changes each time you click on init. By dragging the red dot along, you can change the resistance of the potentiometer.

A1: Close the circuit and give different values to the variable resistance (potentiometer), noting down the values measured by the ammeters for each case. How do the different values relate to one another?

A2: Connect the voltmeter to the circuit. Give the potentiometer different values of resistance. Use the voltmeter to find out the right value of the potential difference between the terminals of R3. What is the value of this resistance?

A3: Use the data from the voltmeter and the ammeter to calculate the resistance of the light bulb. Change the value of the resistance of the potentiometer to find out the point at which the light bulb fuses (you might have to click on init a few times). What is the maximum power of the light bulb before it fuses? What happens with the current after it fuses?

CONCLUSIONS ABOUT THE ASSOCIATION OF ELEMENTS

When two resistances are in **series**, the equivalent resistance is the sum of the resistances: **R=R1+R2.**

In this case, the same current passes through the two resistances and the potential difference between the limits of the association is the sum of the drop in each resistance: **V=V1+V2**

When two resistances are in **parallel**, the equivalent resistance is calculated as: **1/R=1/R1+1/R2**

In this case the current which comes from the generator is shared in the two branches in an inversely proportional manner to the resistance in each branch: **I=I1+I2** while the potential difference is equal in both branches.

If we associate two identical generators in **series**, we obtain an emf equivalent to the sum of that of the two batteries; although the internal resistances will also be added up : **Total emf = 2·emf-battery rtotal=2·r**

If the two generators are in **parallel**, the equivalent emf is the same as that of one of them but the internal resistance is reduced to half: **rtotal=r/2**

EVALUATION

Choose the correct answer to each question

1 What is the relation between the potential difference between the terminals of an element of the circuit and the electrical current that is going through it?

It is a good moment to revise Ohm´s law

- [ ] These magnitudes are inversely proportional.
- [ ] These magnitudes are proportional.
- [ ] The potential difference is inversely proportional to the square of the current.
- [ ] These magnitudes are independent of each other.
- [ ] The potential difference is proportional to the square of the current.

2 When we connect two resistances in parallel...

If you do not know how to complete this sentence, revise resistances in parallel

- [ ] The inverse of the equivalent resistance is equal to the sum of the inverse value of the resistances and the total potential difference is divided between them.
- [ ] The inverse of the equivalent resistance is equal to the sum of the inverse values of the resistances and the total current is divided between them.
- [ ] The resistances are added together and the total potential difference is divided between them.
- [ ] The resistances are added together and the total intensity is divided between them.

3 When you connect two resistances in series...
If you do not know how to end this sentence, revise the association of resistances

- [ ] the resistances are added together and the total potential difference is divided between them.
- [ ] The inverse of the equivalent resistance is equal to the sum of the inverse values of the other two resistances and the total current is divided between them.
- [ ] The resistances are added together and the total current is divided between them.
- [ ] The inverse of the equivalent resistance is equal to the sum of the inverse values of the resistances and the total potential difference is divided between the resistances.

4 Two batteries can be connected in series or in parallel. Which association gives a greater electrical current? If you do not know the answer, revise the association of generators

- [ ] The same current is produced in both cases.
- [ ] When they are connected in series.
- [ ] The answer depends on the electromotive force of the batteries.
- [ ] The answer depends on the internal resistance of the batteries.
- [ ] When they are connected in parallel.

5 When the potential difference between the terminals of a resistance is doubled, the power consumed by the resistance...

- [ ] stays the same, because the resistance and the power are independent magnitudes.
- [ ] is divided by four.
- [ ] is doubled.
- [ ] is multiplied by four.
- [ ] is halved.

Fill in the blanks.

Make sure that your concepts are clear

Charges move spontaneously along a conductor due to the _____ between two points. There is a characteristic magnitude of conductors called _____ that has an influence on how easily this movement takes place. This magnitude is measured in _____.
The _____ measures the amount of charge that goes through a section of the conductor per unit of time. It is measured in _____. _____ relates the three above mentioned magnitudes.
When several resistances are arranged in series, the _____ is the same for all of them. When they are arranged in parallel, the _____ is the same.
If you wish to get a greater electromotive force out of two generators, you should arrange them in _____, but if you wish to get a greater current, you should arrange them in _____.
In a circuit formed by a generator and a motor connected by a conductor with a negligible resistance, not all the _____ of the generator is transferred to the motor, as part of it is lost in the _____.