Name: Álvaro Puebla Ruisánchez

ELEMENTARY CIRCUITS: OHM'S LAW

Goals of the experiment:

–Get introduced to the basic elements of a circuit.
–Learn how to use a multimeter.
–Design simple circuits.
–Verify Ohm's law and use it to find the value of a resistance.
–Verify the rules of equivalence of a combination of resistors in series and in parallel.

1. Theoretical background. When two points of a conductor are at a different potential, free charges flow, driven by the electric field, towards a region where their potential energy is reduced. The motion of the charges inside the conductor is the electric current. To prevent current from being transient, the potential difference shall be maintained permanently by means of a certain device (battery, dynamo, etc.), generically called a source of electromotive force or, abbreviated, *emf*. For metallic conduction, the *emf* acts by pumping electrons back to the point of the circuit at a lower potential increasing their potential energy by an amount $U = qV$ in the process.

When an *emf* source (say, a battery) is connected to the ends of a conducting material, an electric field that accelerates its free charges is established. These charges are slowed down by collisions with the ions that comprise the structure of the material. As an outcome of both processes, charge carriers acquire a speed v_d, the drift speed, the orientation of which depends on the sign of the charges.

The electric current through a surface S is defined as the net charge quantity passing through the surface per unit of time. Its unit in the SI is the ampere, $1\text{A} = 1\text{C/s}$. By convention, the orientation of the current is the one followed by the positive charges, despite for metals it is quite the opposite, as the charge carrier is the electron.

The current density J is the electric current I per unit of surface S. For certain conductors, called 'ohmic', metals among them, it is directly proportional to the electric field produced by the motion of charges. In the case of a long wire-like conductor, this dependence becomes simpler, and a proportionality between the intensity I and the potential between its two ends, V (in Volts, V), is found[1]. The proportionality factor is called electric resistance of the conductor, R, and it is a property of the material (i.e. resistivity) and its geometry. *Ohm's law* states that there is a relationship between potential, V, and current, I, given by:

$$V = RI \tag{1}$$

Volts (V) ohm (Ω) Ampere (A)

The unit of electric resistance is the Ohm (Ω), $1\Omega = 1\text{V/A}$.

When two or more resistors are connected, the combination verifies Ohm's law as well: the ratio between the applied tension and the total flowing current is a constant known as equivalent resistance of the combination. Considering the two basic ways of connecting the resistors, namely, in series or in parallel, it may be easily derived.

Two resistors of resistances R_1 and R_2 are said to be combined in *series* if the same current flows through each one of them (see Figure 1a). Using Ohm's law, the equivalent resistance in this case is found to be:

$$R_{eq}^{\text{AB,serie}} = R_1 + R_2. \tag{2}$$

Two resistors are said to be combined in *parallel* if the potential drop across each resistor is the same (see Figure 1b). In that case the equivalent resistance is given by:

$$\frac{1}{R_{eq}^{\text{AB,paral}}} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{3}$$

[1] Although we have studied a potential difference to be written as ΔV, here V will be, in fact, the potential difference

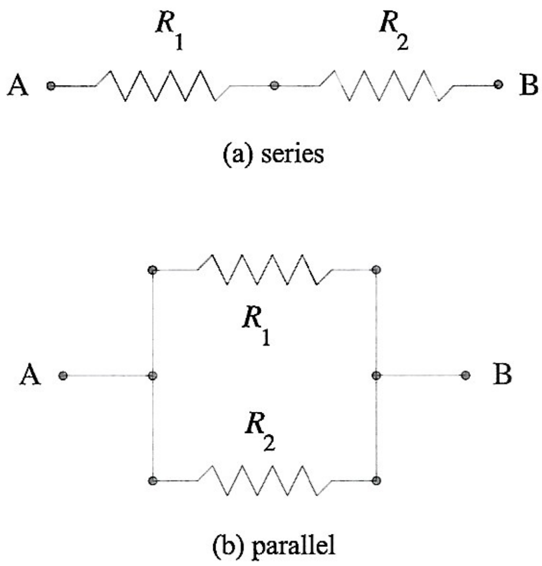


Fig. 1. Resistor combinations (a) in series and (b) in parallel.

The above expressions may be extended to any number of resistors in series or/and in parallel.

In order to study these physical magnitudes, we will make use of electric circuits, in which we may introduce some of the elements, such as resistors, capacitors, batteries, etc. These elements, as well as the measuring devices, are drawn by symbols (see Fig. 2) in order to schematize the circuits.

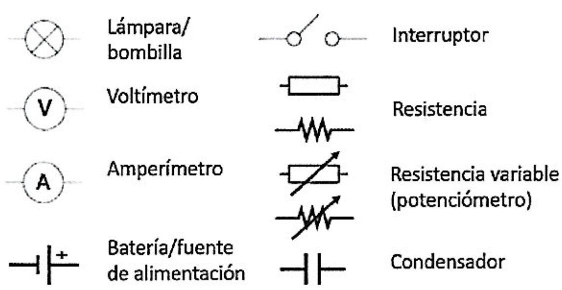


Fig. 2. Symbols in electric circuits.

2. Set-up and experimental procedure.

2.1 Required material:

–Circuit board, including light bulbs and rheostat (or potentiometer) (see Fig. 3).

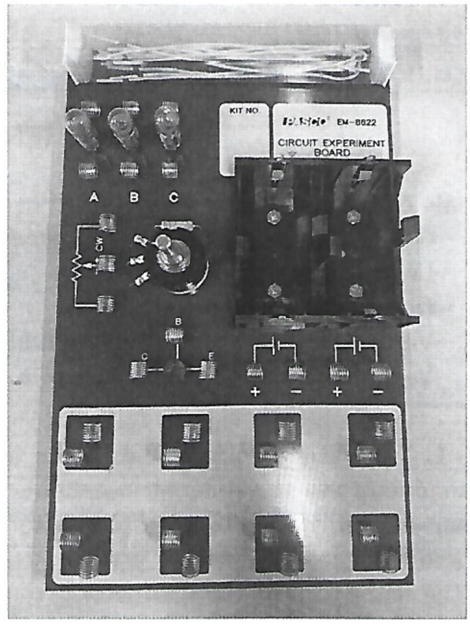


Fig. 3. Circuit board.

–Resistors, capacitors multimeters, batteries and connecting cords (see Fig. 4).

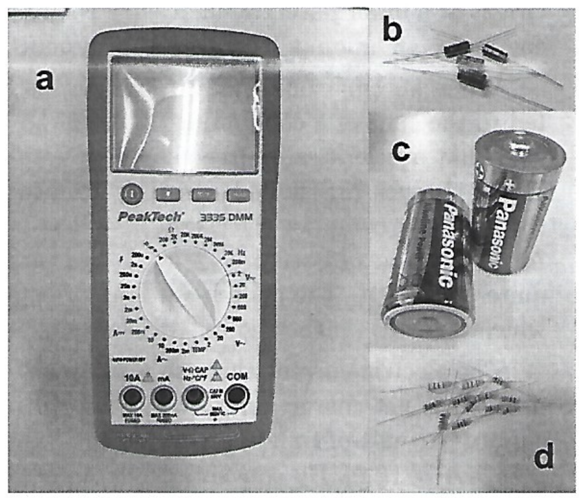


Fig. 4. Elements of the electric circuits: (a) Multimeter, (b) capacitors, (c) batteries and (d) resistors.

2.1.1 Notes on the board:

–The springs are soldered to the board, so the two springs in each of the blue squares act as a single point for connecting wires or other circuit components. Some of the springs are soldered to some components of the circuit, such as the potentiometer, the bulb sockets or the cells where the batteries are placed.

–If the coils of the spring are separated, gently press them together to make electrical contact with the wires or circuit elements that are placed between them.

–Carefully treat all the elements that make up the board as well as the consumables that will be used in this practice. In this way, your classmates will also be able to practice.

–In some cases, the polarity of the components is important, so make sure that you place these elements in the correct direction. For example, batteries have '+ánd '-'signs, which have to match those of the cell that contains them.

2.2.1 Learn how to use a multimeter.

–The multimeter is a device (see Fig. 4a) with which we can measure several electrical magnitudes, such as current intensity (I), potential difference or voltage (V), resistance (R) and, in some cases, the capacity of a capacitor (C). If it is used exclusively to measure the current intensity, we will call it an ammeter and if it is the voltage, a voltmeter.

–The magnitudes I and V can be measured in both alternating current (AC) and direct current (DC). In this practice, we will only work with direct current, so the wheel of the multimeter, regardless of what we measure with it, must always be set to the direct current symbol (see Fig. 5).

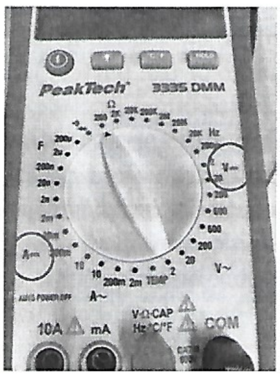


Fig. 5. The multimeter, in this case, will always be used in direct current (in red) both to measure electric current and voltage.

–The multimeter contains several cable outputs, and we will have to choose 'COM'(always), in addition to the appropriate one for each measurement, which is indicated on the output itself.

–Now, notice that there are several scales for each magnitude: depending on the value that you are going to measure, you will have to place the wheel on one scale or another. To do this, start at the highest scale and work your way down so that you can measure the value correctly, as accurately as possible.

–Depending on the magnitude that we want to measure, in addition, we must place the multimeter in our circuit in one way or another. In the case of using it as an *ammeter* (current), what we want to know is the flow of charges through the conducting wire (similar to the flow of water through a pipe), so the ammeter will have to be placed *in series* with the rest of the elements. On the contrary, if we are going to use it as a *voltmeter* (potential difference), what we measure are not absolute values, but differences, so we need two values at two different points in the circuit to be able to calculate that difference (which is the value provided by the voltmeter), so it will have to be placed *in parallel* with the element of the circuit in which we want to measure that potential drop.

–Measure the potential difference (V) between the ends of a battery, placed in the circuit.

1'503 V

Now place the two batteries in the circuit, connected in series, and measure the potential difference.

3'00 V

What is happening?

The voltage is doubled because we have the batteries in series

2.2.2 Resistors. Resistors are circuit elements with which we restrict the electric current to go through. We can measure the value of those resistors in several ways:

(1) Check and write down, using the color code, the value of the two resistors (with their units), which we will call R_1 and R_2. Don't forget to note down the tolerance.

$R_1 = 22{,}0 \pm 1{,}1\,\Omega$
$R_2 = 220 \pm 11\ \mathrm{k}\Omega$

(2) Now measure the value of the resistors, using the multimeter. You can do it directly or by placing the resistor on the board. Take this value 3 times for

each of the resistors.

$R_1 =$	$R_2 =$
$R_1 =$	$R_2 =$
$R_1 =$	$R_2 =$

What is the accuracy of the apparatus for each resistor?

And what about that of the measurements? Remember that having measured *N=3* times, you have to obtain the average of the taken values, as well as the error of the measurement by means of the standard deviation (statistical error), from:

$$\bar{R} = \frac{1}{N}\sum_{i=1}^{N} R_i \tag{4}$$

$$\Delta_e R = \sqrt{\frac{\sum_{i=1}^{N}(R_i - \bar{R})^2)}{N-1}} \tag{5}$$

The statistical error of the measurement, for each of the resistors is:

2.3 Ohm's law:

(1) Set up the circuit depicted in Figure 6, the components of which are:

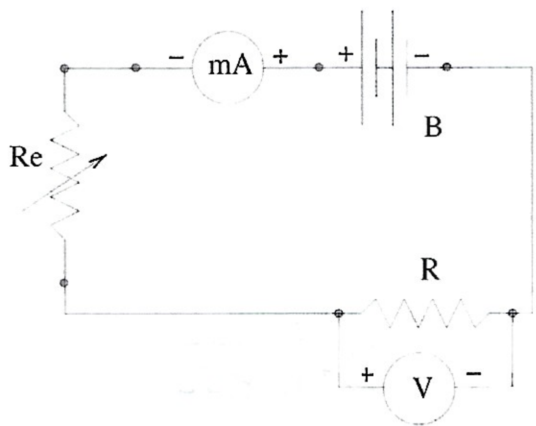


Fig. 6. Sketch of a circuit designed to study Ohm's law, where B is the power source (in this case, the two batteries connected in series), Re is the rheostat (a variable resistor; by turning the dial the value of the resistance is modified), mA is the ammeter (multimeter connected in series to the circuit as yet another component), V is the voltmeter (multimeter connected in parallel between the points of the circuit whose potential difference should be measured) and R is the resistor or resistors combination.

Please be specially careful with the polarities of both milliammeter and voltmeter.

(2) Turn up the rheostat knob to the maximum and read the minimum potential difference V_{min} after closing the switch.

(3) Turn down the rheostat to the minimum and read the maximum potential difference V_{max}.

Those values will set your potential difference range for the next part.

(4) Now, every measurement proceeds according to the following steps:

1. Select the position of the rheostat.
2. Measure the potential difference in the resistor (V) and the current flowing through the circuit (I).
3. Open the switch (to avoid unnecessary discharge of the battery).

(5) Perform 5 measurements that homogeneously cover the complete potential difference range (by varying the position of the rheostat) and note them down in a table, as well as the accuracy (*deltaI*, *deltaV*) of each measurement (remember, it depends on the scale you are using). Repeat this procedure for the other resistor.

For R_1 :

I (mA)	δI (mA)	V (V)	δV (V)
54,7	0,1	1'21	0,01
56,1	0,1	1'24	0,01
56,8	0,1	1'26	0,01
59,8	0,1	1'32	0,01
98,5	0,1	2,17	0,01

For R_2 :

I (mA)	δI (mA)	V (V)	δV (V)

(6) Plot the potential difference vs. the current, for the two series on a graph, via a spreadsheet or on graph paper. You must include this graph (on paper or by any software) when sending this booklet for assessment, together with next steps.

(7) Perform a linear least-squares-fit of the form $y = ax + b$, where $y \equiv V$, $x \equiv I$, and obtain the values of a and b, as well as their uncertainties, for each series (e.g., by using the LINEST() function on Microsoft Excel[2]).

For R_1 :

a = 0,0218839 kΩ
b = 0,0135424 V

For R_2 :

So what are the values of the resistors (with their precision)? Remember, round the error to one significant figure and the magnitude, accordingly.

$R_1 \pm \Delta R_1 =$ 21'88 ± 0'32 Ω
$R_2 \pm \Delta R_2 =$

23'1
22'0
21'88
20'9

The experimental value obtained in class (21'88 ± 0'32 Ω) is in good agreement with the value given by the supplier (22'0 ± 1'1 Ω)

[2]Or ESTIMACION.LINEAL() if using it in Spanish

2.4 Combination of resistors in series and in parallel:

Using Eqs. (2) and (3) find $R_{eq}^{\text{AB,ser}}$ and $R_{eq}^{\text{AB,par}}$ from the values obtained above after fitting R_1 and R_2, with their corresponding errors. These must be determined by propagation of uncertainties (using partial derivatives):

(1) Replace resistor R by the series combination in the previous set-up (Fig. 6).

(2) By means of just one measurement of the potential difference (V) between the terminals of the resistor combination and of the current (I) flowing through it, and using Ohm's law, obtain the value of the equivalent resistance, using Eq. (1).

In series:

$V =$
$I =$
$R_{eq}^{\text{AB,ser}} =$

(3) Proceed in the same way replacing the in series combination for the two resistors, now combined in parallel, and repeat the measurement.

In parallel:

$V =$
$I =$
$R_{eq}^{\text{AB,par}} =$

(5) Compare both results with the ones obtained through (2) and (3), checking if they lie, at least approximately, within the uncertainty limits.

CIRCUITOS DE CORRIENTE CONTINUA.

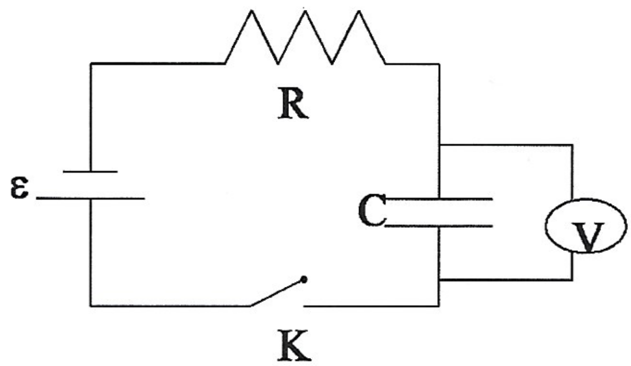
Loading process of a Capacitor

TEORIA

A capacitor is an electrical component capable of stocking a certain charge proportional to the potential difference between its electrodes. The proportionality constant the capacity of the capacitor C, so Q= CV. C units is the Farad, F (1 F= 1 C/V).

No current flows between the electrodes of a loaded capacitor. In a circuit with a capacitor, there is only a flowing current during the time the capacitor loads up.

Figure 2 shows the circuit to be studied in the session, that will load the capacitor, which initially will be considered to be unloaded (empty).



The fem provided by the battery ε is equal to the potential difference between the resistor plus the potential difference in the capacitor.

$$\varepsilon = IR + \frac{Q}{C} \qquad (2)$$

In this circuit, the current intensity is equal to the time variation of the charge, so:

$$I = \frac{dQ}{dt} \qquad (3)$$

Introducing this in equation (2) and integrating:

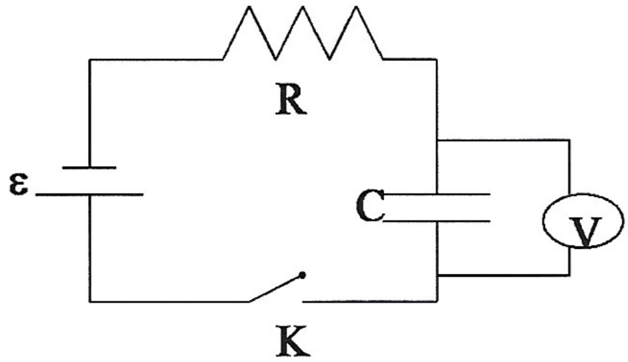
$$\boxed{V_{teo} = \frac{Q}{C} = \varepsilon\left(1 - e^{-t/RC}\right)} \qquad (4)$$

Where:

V: Potential difference in the capacitor as a function of time.
ε : Electromotive forze of the battery.
R: Resistor through which the capacitor charges.
C: Capacity of the capacitor.

INSTALACION Y PROCEDIMIENTO DE MEDIDA:

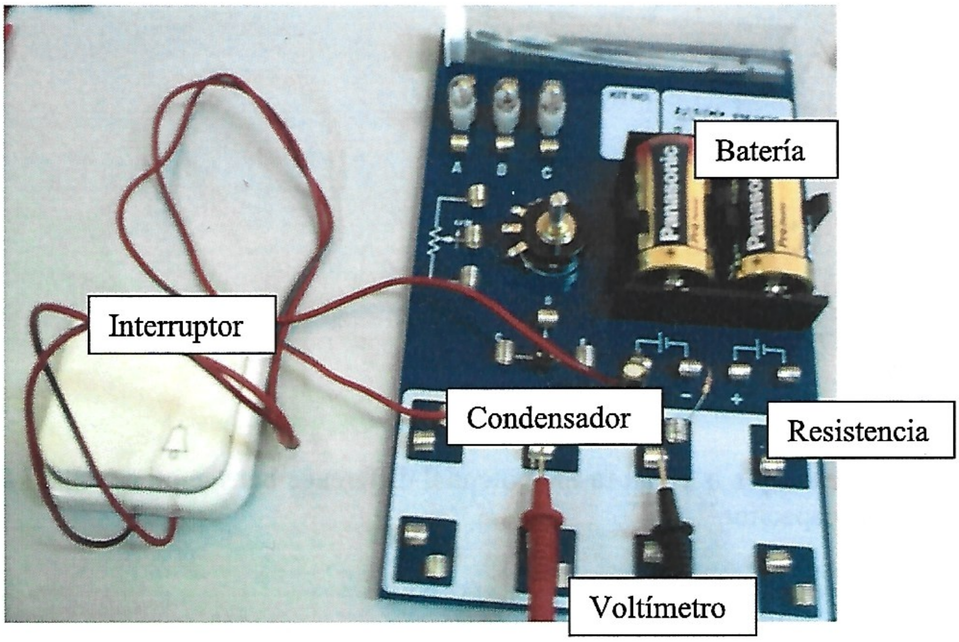
- Mount the following circuit:



ε = battery fem = 3 ± 0,01 V
K- Switch.

R- Resistance= 220 ± 11 kΩ

C- Capacity = 330 μF



- Make sure the capacitor empty by measuring the potential between its electrodes (it must be zero). If that is not the case, connect the electrodes with a wire to unload it.

- Close the switch and simultaneously start the timer.

- Every five seconds stop the timer and open the switch. Write down the potential difference and the time as fast as possible to avoid the capacitor to lose charge. Restart the timer, close the switch and repeat until the potential is almost constant. This will mark the capacitor is fully loaded.

TRATAMIENTO DE LOS RESULTADOS:

Table 2: Time and potential difference.

t (s)	5	10	15	20	25	30	35	40	45
Vexp(V)	0'19	0'38	0'56	0'71	0'86	0'98	1'12	1'24	1'35

Vteo(V)	0'1997	0'3860	0'5600	0'7224	0'8740	1'0155	1'1475	1'2708	1'3859

t (s)	50	55	60	65	70	75	80	85	90
Vexp(V)	1'45	1'55	1'64	1'72	1'81	1'88	1'94	2'01	2'07
Vteo(V)	1'4933	1'5936	1'6872	1'7746	1'8561	1'9322	2'0033	2'0696	2'1316

t (s)	95	100	105	110	115	120	125	130	135
Vexp(V)	2'13	2'18	2'23	2'28	2'31	2'35	2'39	2'43	2'46
Vteo(V)	2'1894	2'2433	2'2937	2'3407	2'3846	2'4255	2'4637	2'4994	2'5328

t (s)	140	145	150	155	160	165	170	175	180
Vexp(V)	2'49	2'52	2'54	2'57	2'59	2'62	2'64	2'65	2'67
Vteo(V)	2'5638	2'5929	2'6200	2'6453	2'6689	2'6909	2'7117	2'7307	2'7486

- Measure the fem ε and the resistance of the resistor R
- Plot in the same graph the theoretical function (equation 4) with the fem and the resistor, taking C = 330 μ F; and the experimental values of the potential difference. Compare the theoretical and experimental graphs.