Physics Department
Electric and Magnetism Laboratory

PARALLEL-PLATE CAPACITATOR

1. Goal.

The goal of this practice is the study of the electric field and electric potential inside a parallel-plate capacitor.

In the first part, we will determine the relation between the electric field inside the capacitor and the voltage applied to the plates and the separation between them.

In the second part, we will study the electric potential in the space between the capacitor plates.

2. Overview.

A capacitor is an electronic component capable of storing electric charge. Capacitors consist of two conductors at different electric potentials. The net total charge stored in a capacitor is zero since each conductor stores the same charge but with different signs.

The capacitance of a given capacitor is defined as: is a reasonably general model for electric fields, without electric circuits. An ideal capacitor is characterized by a constant capacitance *C*, defined as the ratio of charge ±*Q* on each conductor and the voltage *V* between them.

$$C = \frac{Q}{\Delta V} \qquad [1]$$

where *Q* is the charge stored on each plate and ΔV is the potential difference between them. The SI unit for capacitance is the *Farad* named after the great physicist *Michael Faraday* and is denoted by F.

The parallel-plate capacitor consists of two parallel conducting plates of surface S separated a distance d between which there is a potential difference V (figure 1).

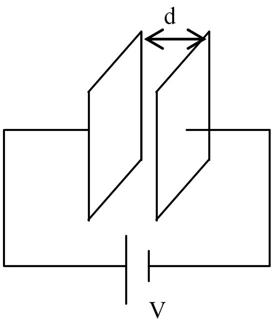

Figure 1: Sketch of a parallel-plate capacitor.

The capacitance of a parallel- plane capacitor depends on its geometry and is given by:

$$C = \varepsilon_0 \frac{S}{d} \quad \textbf{[2]}$$

Where ε_0 is the permittivity of vacuum, and has a value of 8.85×10^{-12} C^2/Nm^2, S is the area of each capacitor plate and d is the distance between them.

When the plate separation distance is much smaller than the plate dimensions ($d << \sqrt{S}$) the electric field inside the capacitor is approximately constant (edge effects can be neglected) and is given by:

$$\vec{E} = \frac{\sigma}{\varepsilon_0} \quad \textbf{[3]}$$

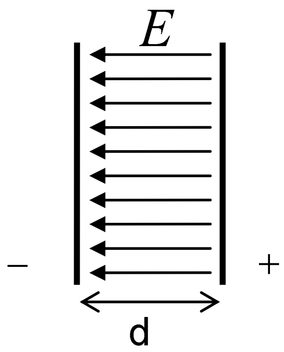

Figure 2: Electric field inside a parallel-plate capacitor.

where σ is the surface charge density on the plates of the capacitor and is given by:

$$\sigma = \frac{Q}{S} \quad \textbf{[4]}$$

The electric field [3] is an idealization which is only accurate in the central area of the capacitor since electric field lines begin to curve as we approach to the edges.

In the central part of the capacitor the electric field expression can be writen as the variation of the potential in just one direction:

$$\vec{E} = -\vec{\nabla} V = -\frac{\partial V}{\partial x} = -\frac{dV}{dx} \quad \textbf{[5]}$$

that due to the homogeneity can be further simplifyied as:

$$E = \frac{V}{d} \quad \textbf{[6]}$$

Thus, the electric field inside the capacitor is not only constant but proportional to the applied potential between the plates and inversely proportional to the distance between them.

Since the electric field is constant inside the capacitor it is easy to obtain the electric potential integrating equation [5] and imposing the boundary conditions:

$$V(x) = V_0 + \frac{V_1 - V_0}{d} x \qquad [7]$$

Where V_0 and V_1 are the potentials at the capacitor plates and $V(x)$ is the potential at a distance x from the plate 1 (see Figure 3).

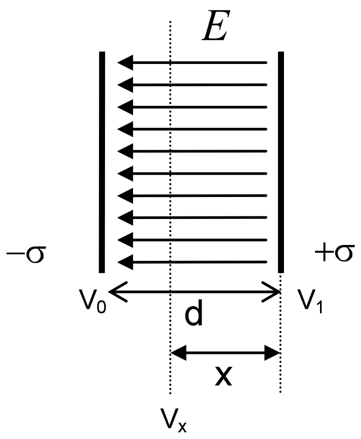

Figura 3: Potential variation inside a capacitor parallel-plate.

3. To learn more...

Bibliography:

- **TIPLER P.A. y MOSCA, G.**, **"Physics" 4th edition Ed W.H Freeman and company 1999.**
    - **Chapter 31**. Pages 959-996.

In Internet:

1) In Spanish:

   http://www.sc.ehu.es/sbweb/fisica/elecmagnet/campo_electrico/plano/plano.htm

   http://www.studiow3.com/em/applets/condensador_plano_paralelo.html

   http://www-fen.upc.es/wfib/virtualab/marco/campoei.htm

2) In English:

   http://hyperphysics.phy-astr.gsu.edu/hbase/electric/pplate.html

   http://webphysics.davidson.edu/physlet_resources/bu_semester2/c03_parallel_plate.html

   http://www.ac.wwu.edu/~vawter/PhysicsNet/Topics/Capacitors/ParallCap.html

4. Material.

1. Parallel-plate capacitor.
2. Electric Field Meter.
3. Potential probe.
4. Butane gas burner.
5. Graduated ruler.
6. Power supply.
7. 2 multimeters.
8. Connectors.(10)
9. Screwdriver.
10. Lighter.
11. Potential probe adapter.

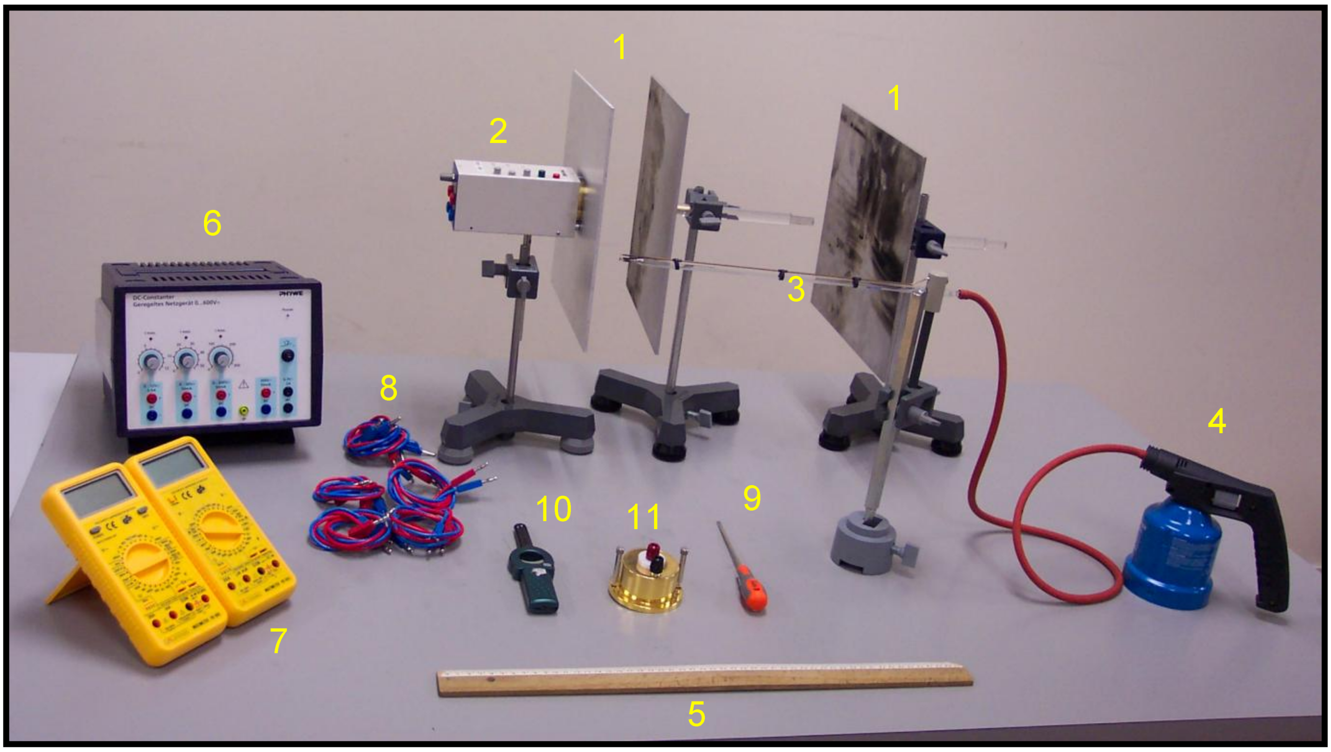

Figure 4: Material to be used in practice.

5. Experimental procedure.

5.1 Electric field intensity as a function of distance between plates.

Assemble the circuit as shown in Figure 5. You should take special care to properly feed the electric field meter. The input of the electric field meter is found to the left and is marked with 14 ... 18 V-IN. These two entries need to be connected the output of the power supply situated at leftmost position (output 0-12 V) taking special care to respect the polarization. Output - (Blue) from the power supply must be connected to the IN (Black) and the output meter + (Red) from the source to the red socket of the meter. Once the connections are made, rotate the power regulator to the maximum value of 12 V.

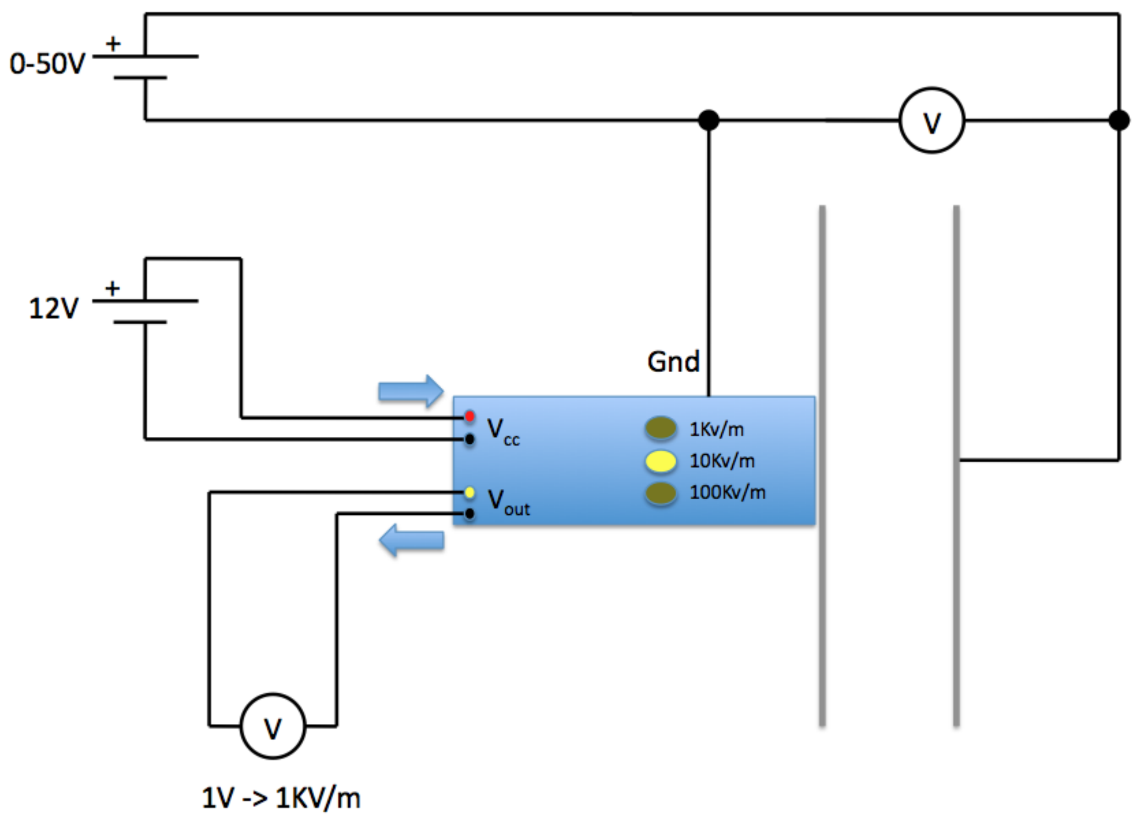

Figure 5: Schematic view of the assembly for measuring the electric field inside the capacitor.

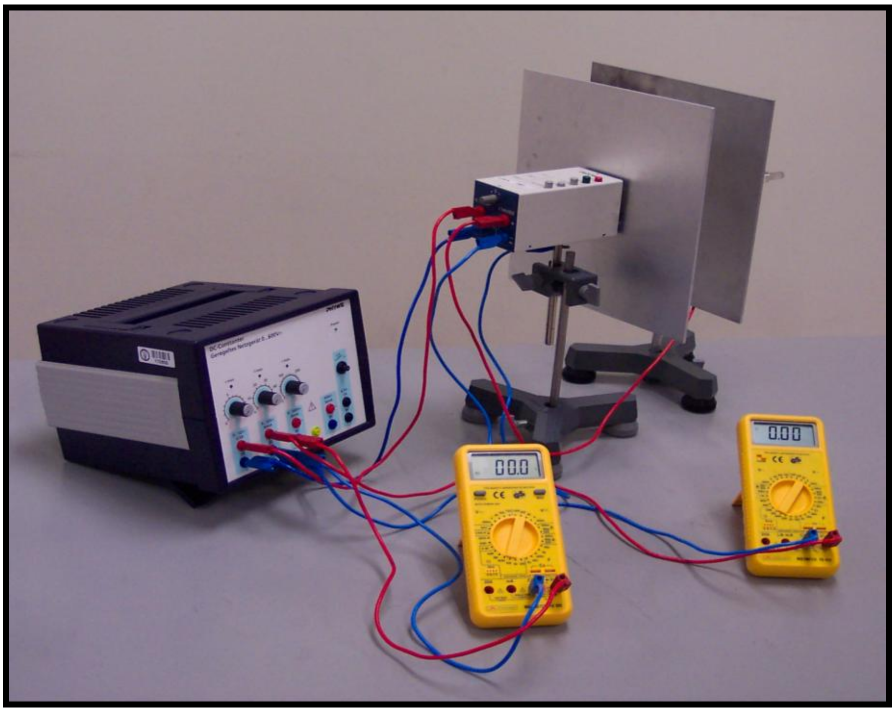

Figure 6: Photograph of the assembly for measuring the electric field inside the capacitor.

Capacitor plates must be fed using the second outlet from the power supply (0-50 V output).

Measurement of electric field intensity will be made with the help of a multimeter connected to the OUT (± 10 V) electric field meter. Set the multimeter input to measure potential (V) and select the 2 to 4 volts range. For the field meter use the scale of 10kV/m that can be selected by pressing the "Range" button. In this way the multimeter lecture will correspond to the electric field intensity between the parallel-plate capacitor in kV/m units.

Before doing any measurement make sure to set the electric field meter to zero.

When no potential difference is applied to the plates the electric field should be zero and therefore the electric field meter should indicate zero. If the meter lecture is not zero use the electric field meter gauge until the multimeter measurement signals a zero.

At the first part of the practice we will study the electric field intensity as a function of distance between plates. To do this, apply a voltage of 50 volts (as measured by the multimeter) between the capacitor plates, and measure the electric field intensity as a function of plate separation distance between 2 to 12 centimeters every centimeter. It is important to keep the plates as parallel as possible before each measurement.

5.2 Electric field intensity as a function of the applied potential difference between the capacitor plates.

Using the same setup as in the previous section and with a plate separation of 5 cm measure the electric field intensity as a function of the applied potential difference between the capacitor plates between 0 and 50 volts every 5 volt.

5.3 Potential inside a capacitor plane-parallel plate.

For this study it is necessary to prepare the assembly shown in Figure 7. We will make use of the potential probe and the third capacitor plate. Unscrew the plate that is in the field meter and replace it with the other plate. Install the potential adapter tip in the field meter as shown in Figure 7. Connect the potential probe to the red input. Ground the field meter through the support structure as indicated in the sketch of Figure 8 (Gnd).

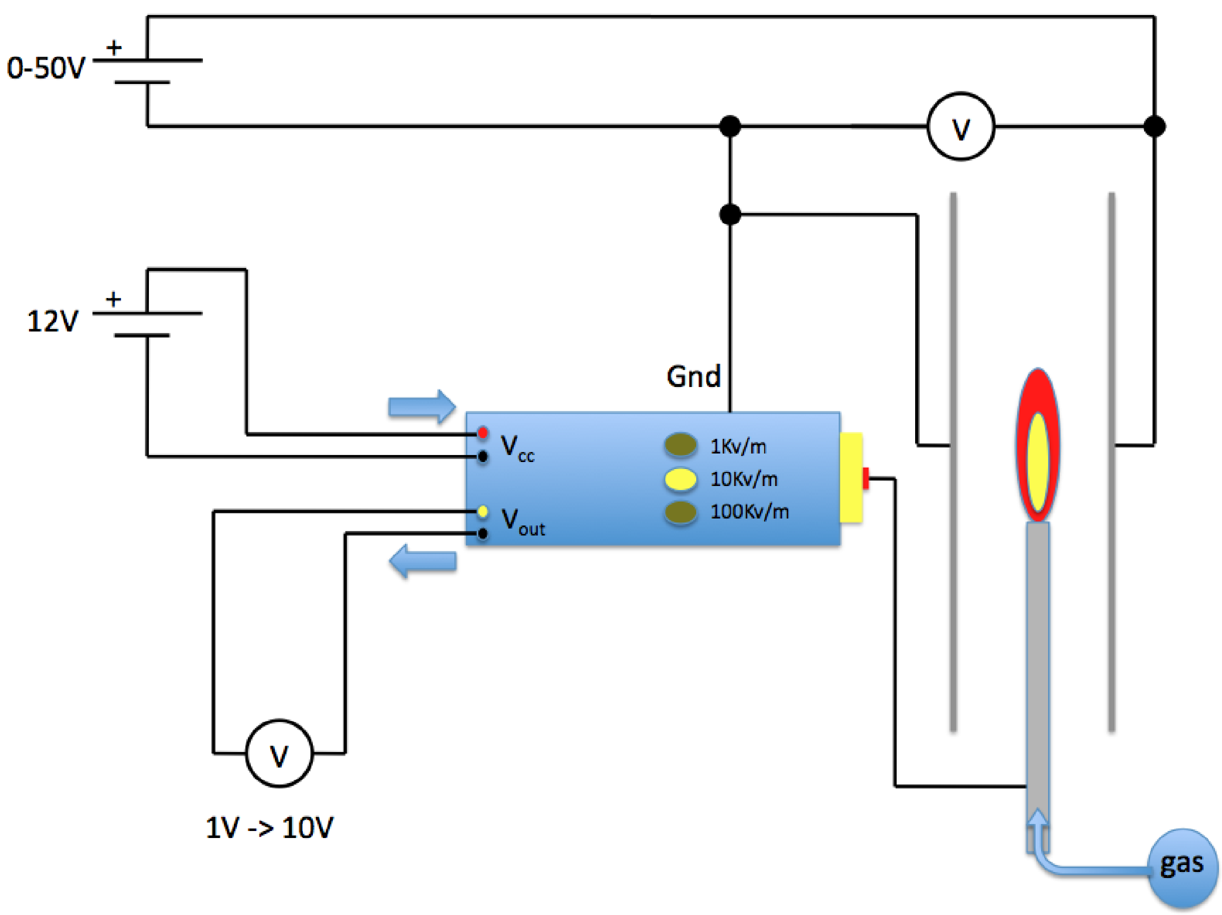

Figure 7: Scheme of the assembly for measuring electrical potential inside the capacitor.

To avoid the disturbing influence of surface charges, the air around the tip of the probe is ionized with a flame. Try to use the smallest possible flame to avoid excessive fluctuations in the potential measurement. Since the measurement often vary considerably the best practice is to estimate a maximum and minimum values and take an average value as a result of the measure.

In this assembly you should not change the connection of the multimeter nor the multimeter field scale (10kV/m). The result of the electrical potential is obtained by multiplying by 10 the value given by the meter and its units are volts (V).

To measure the electric potential, in terms of distance from the capacitor plate connected to the positive output of the power supply, we will separate the plates a distance of 10 cm and apply a voltage of 50 V between them. Then, keeping fixed the distance between plates to 10 cm, the electric potential is determined with the help of the potential probe by varying the distance between the probe and the positive plate from 1 to 9 cm in 1 cm steps. Ensure that the probe is in the central region of the capacitor to avoid edge effects.

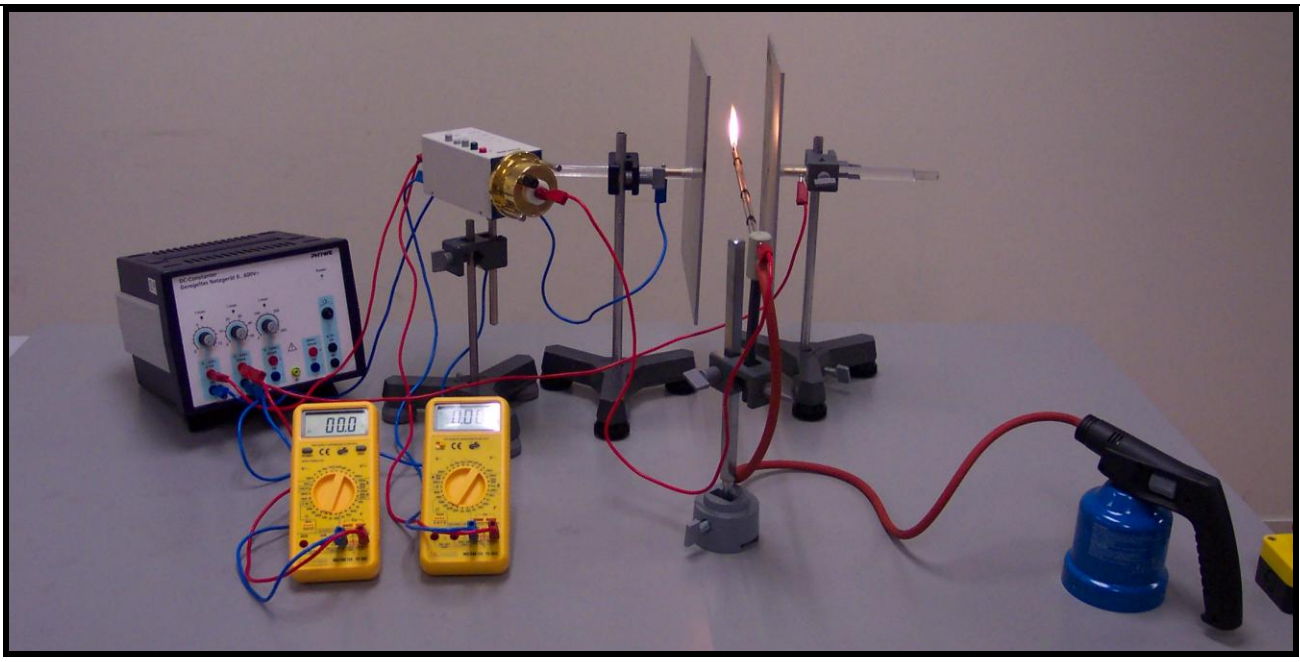

Figure 8: Photograph of the assembly for measuring electrical potential inside the capacitor.