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 the ratio of the charge $\pm Q$ on each conductor and the voltage ΔV between:

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

The SI unit for capacitance is the *Farad* named after the great physicist *Michael Faraday* and is denoted by F.

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

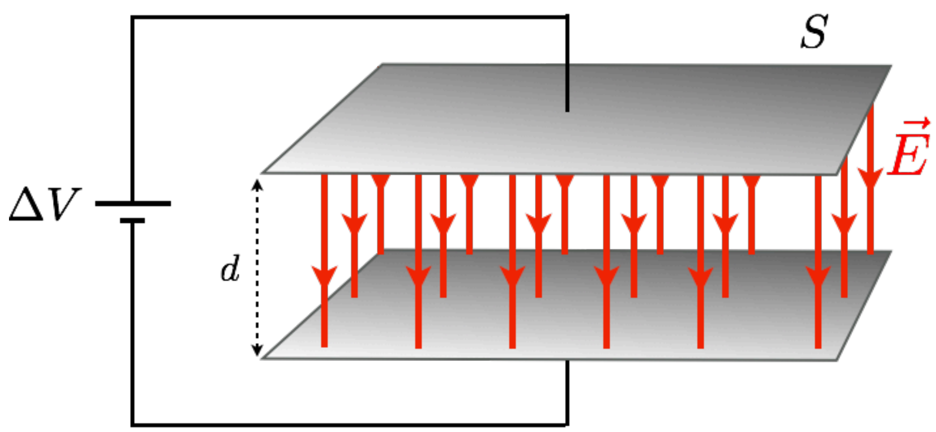

Figure 1: Sketch of a parallel-plate capacitor.

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

$$C = \epsilon_0 \frac{S}{d} \qquad \textbf{[2]}$$

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:

$$E = \frac{\sigma}{\epsilon_0} \qquad \textbf{[3]}$$

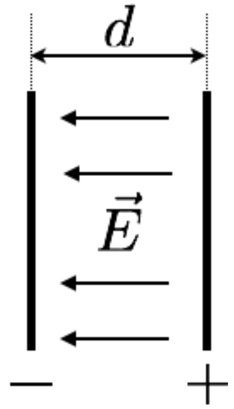

Figure 2: Electric field inside a parallel-plate capacitor.

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

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

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 written as the variation of the potential in just one direction:

$$E_x = -\frac{dV}{dx} \qquad \textbf{[5]}$$

that due to the homogeneity can be further simplified as:

$$E_x = -\frac{\Delta V}{d} \qquad \textbf{[6]}$$

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:

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

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).

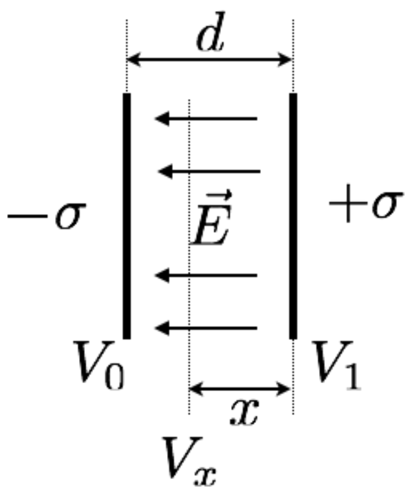

Figura 3: Potential variation inside a capacitor parallel-plate.

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. Variable Power supply.
7. 2 multimeters.
8. Connectors. (10)
9. Screwdriver.
10. Lighter.
11. Potential probe adapter.

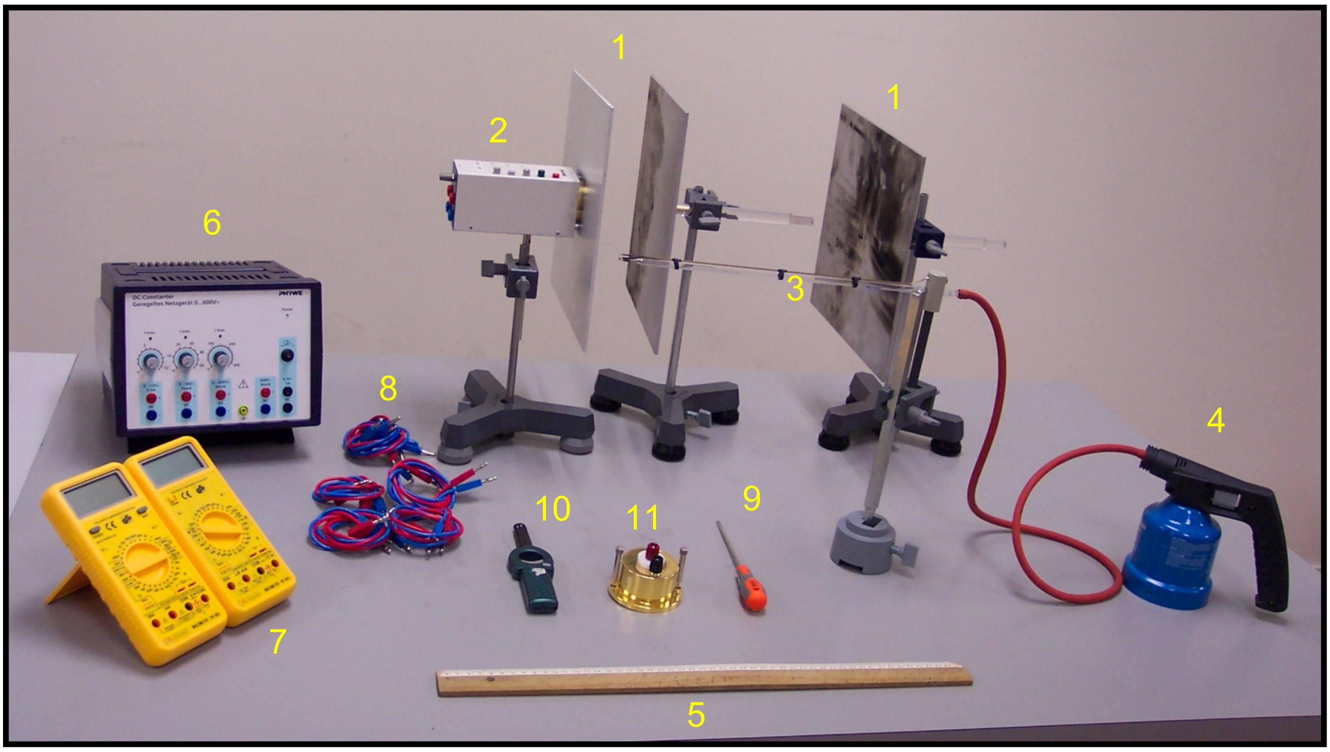

Figure 4: Laboratory equipment for the experiments practice.

If you have any doubt about the use any equipment, please consult the "Electrical Measurements" guide.

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 pay special attention to properly make the connections of 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 to the leftmost output (marked from 0-12 V) of the power supply. It is very important to respect the polarization. The Blue (-) Output from the power supply must be connected to the Black IN of the field meter and the Red (+) output of the power supply to the Red input of the field meter. Once all connections are made, set the power regulator to the maximum value of 12 V.

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

Assemble the circuit as shown in Figure 5. You should pay special attention to properly make the connections of 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 to the leftmost output (marked from 0-12 V) of the power supply. It is very important to respect the polarization. The Blue (-) Output from the power supply must be connected to the Black IN of the field meter and the Red (+) output of the power supply to the Red input of the field meter. Once all connections are made, set the power regulator to the maximum value of 12 V.

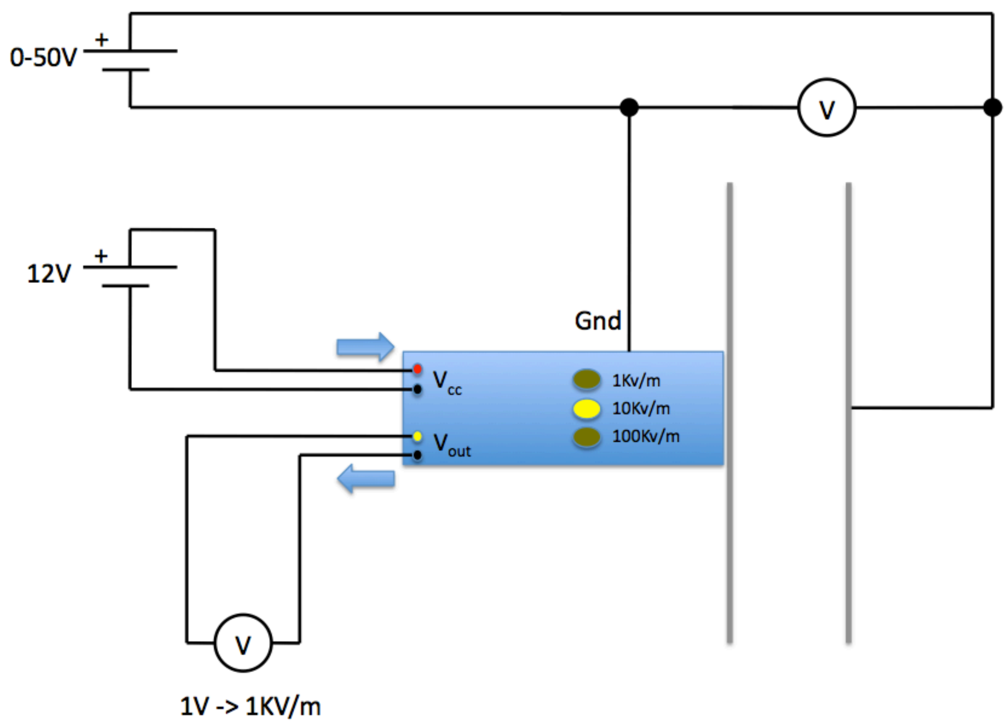

Figure 5: Schematic view of the assembly for measuring the electric field inside the capacitor.

To set the potential difference for the plates you should use the second outlet from the power supply (marked from 0-50 V).

The 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. When no potential difference is applied to the plates the electric field should be zero and the electric field meter should indicate zero, therefore, **before doing any measurement make sure that the multimeter indicates a cero voltage using the gauge of the electric field meter.**

In 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 by changing the plate separation distance between 2 to 12 centimeters every centimeter. It is important to keep the plates as parallel as possible before each measurement.

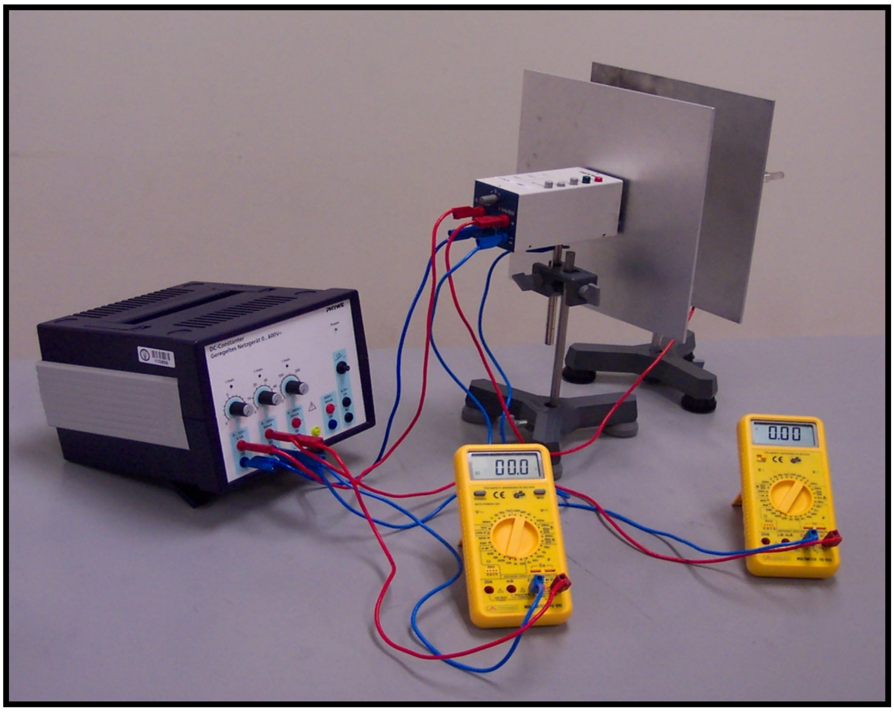

Figure 6: Photograph of the assembly for measuring the electric field inside the capacitor.

1. Make a plot with the measured electric field strength E as a function of the distance between plates d.

2. Since you also measured de voltage, plot, on the same graph, the theoretical values of the electric field strength obtained from equation [6]. Discuss the results of the plot.

3. Make a table and plot the natural logarithm of d and E from the measurements above and perform a least square fit of the data. What is the meaning of each fitting parameter?

4. Calculate the capacitance and the surface charge density for a plate separation of 3 cm. Explain how do you obtain the result.

Note: do not forget to measure the area of the plates nor to include error estimations of all quantities.

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 for potentials between 0 and 50 volts every 5 volt.

1. Plot the electric field strength, E, as a function of the voltage difference between plates, ΔV.

2. Make a least squares fit of the data. What is the meaning of each fitting parameter?

Note: do not forget to include error estimations of all quantities.

5.3 Potential inside a parallel plate capacitor.

For this study, it is necessary to arrange the equipment as 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).

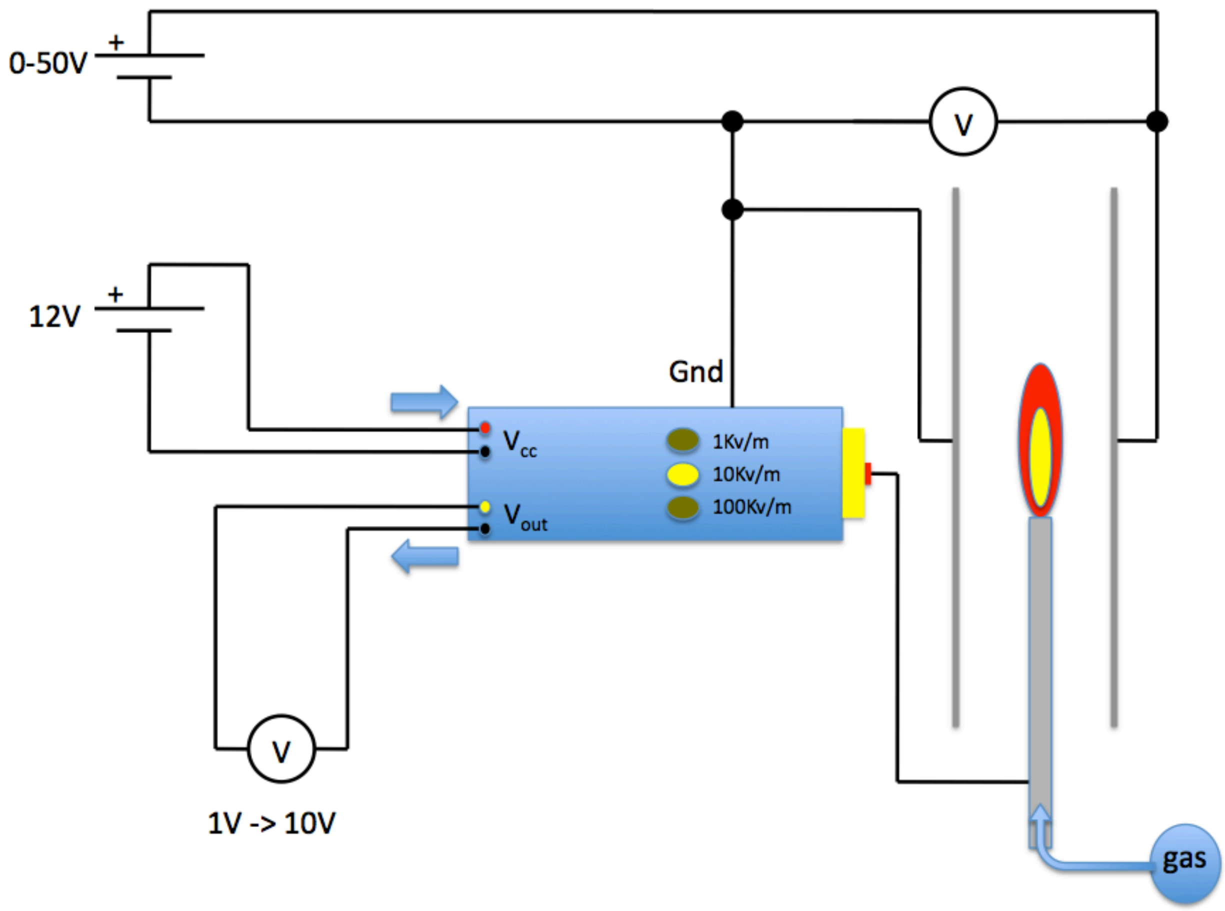

Figure 7: Scheme of the assembly for measuring electrical potential inside the capacitor.

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 at different points between the capacitor plates, set the plates at a distance of 10 cm and apply a voltage of 50 V between them. Next, keeping fixed the distance between plates determine the electric potential 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.

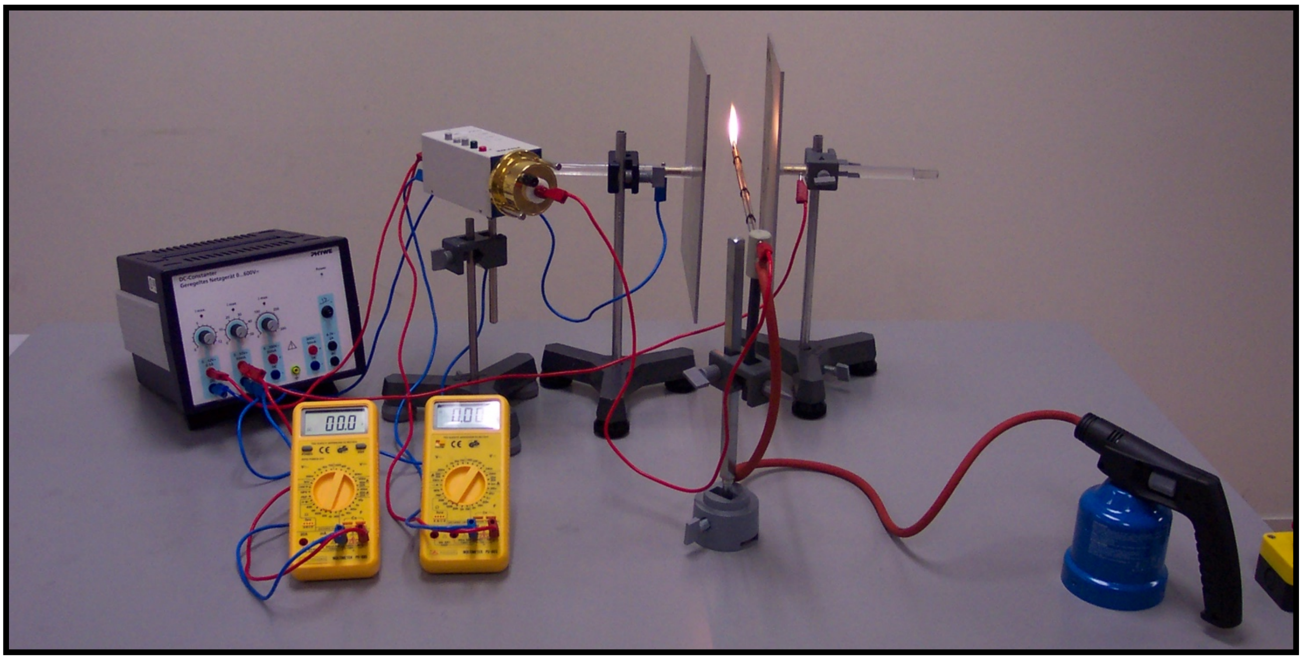

Figure 8: Photograph of the assembly for measuring electrical potential inside the capacitor.

1. Plot the potential inside the capacitor as a function of probe position with respect to the plate connected to the positive output of the source.

2. Make a least squares fit of the measurements. What is the meaning of each fitting parameter?

3. Based in your experimental results, do you think that the electric field inside the parallel-plate capacitor is approximately constant? Justify your answer.

IMPORTANT: <u>All</u> plots must be accompanied by a table with the data represented. Don't forget to include in the tables the units and uncertainties of the measurements.