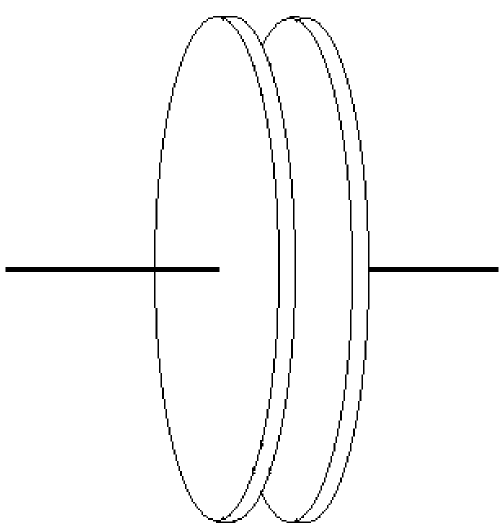
The Parallel Plate Capacitor

Equipment	Qty.
Pasco Basic Variable Capacitor	1
LCR meter	1
BB Wires	2
Alligator Clips	2
Microsoft Excel	1
ruler	1
Vernier caliper	1

Capacitors take many forms, but perhaps the simplest is the parallel plate capacitor, in which two conducting plates are separated by an insulator. An applied voltage difference causes electrons to flow out of one and into the other, giving them a positive and a negative (respectively) net charge. The closer the plates are to each other, the greater the charges because the positively charged plate exerts an attractive force to hold the negative charge in place.



Whereas charging an isolated plate requires high voltage, the close proximity of the two oppositely charged plates requires a smaller voltage. A measure of the quantity of charge that a capacitor can hold is its **capacitance**. An expression for the approximate capacitance of a parallel plate capacitor can be derived as follows.

The electric flux from the charge on one of the plates is

$$\Phi = \frac{Q}{\epsilon_o}$$

The flux from one side of a plate is half of this, but since there are two plates with charges Q and - Q, each contributes $Q/2\epsilon_o$ to the region between the plates and the above expression gives the total flux in this region.

Electric field is flux density, so for a uniform electric field (like the one between plates with area A)

$$E = \frac{\Phi}{A} = \frac{Q}{\epsilon_o A}$$

Since electric field is the gradient of the electric potential, the potential difference across the (relatively) uniform field between the plates is

$$V = Ed = \frac{Qd}{\epsilon_o A}$$

The charge on one plate of the capacitor is thus

$$Q = \frac{\epsilon_o A}{d} V$$

The fraction in the above expression is called the capacitance of the capacitor.

$$C = \frac{\epsilon_o A}{d} \qquad \text{Eq. 1}$$

Here A is the area of one plate, and d is the distance between the plates. So the amount of charge on one plate is dependent on the voltage applied between the plates.

$$Q = CV \qquad \text{Eq. 2}$$

The capacitance meter is designed to measure C, so we'll vary d and test the relationship between d and C. If we plot C as a function of $1/d$, then we're plotting equation 1, and the slope of that line should be $\epsilon_o A$, so that dividing the slope by the surface area A of one of the plates should yield ϵ_o, the permittivity of free space. This constant has been measured to great precision, and its value is

$$\epsilon_o = 8.85 \times 10^{-12}\ C^2/(N \cdot m^2)$$

You will compare this with the value that you determine.

Procedure:

1. Assemble the setup as in picture 1.
2. Push the Plates together until they touch and use the two adjusting knobs to make them parallel (picture 2).
3. Use the scale to set the plate separation at 4.0 cm.
4. Measure the capacitance and record both d and C. Remember to use SI units.
5. Position the plates so that they're 0.50 cm closer together.
6. Repeat steps 4 & 5 until the plates are 0.50 cm apart.
7. Use Excel to plot C as a function of 1/d (C on the vertical axis).
8. Use the Excel fitting tool to fit a straight line.

d (m)	1/d	C (F)

The slope of this graph, according to our reasoning, is $\epsilon_o A$ (the y intercept is capacitance due to other parts of the apparatus). Make whatever measurements are necessary to find the surface area of one of the plates and then use this to find ϵ_o. Then calculate the percent error using the value above as the accepted value.

$$A = \_\_\_\_\_\_\_\_\_\_ m^2$$
$$\epsilon_o = \_\_\_\_\_\_\_\_\_\_ Fm^{-1}$$

$$\%error = \_\_\_\_\_\_\_\_\_\_ \%$$

Electric Permittivity of Various Materials

If some material other than air is introduced into the gap between the plates, the capacitance may change. It will now be approximated by the following equation.

$$C = \frac{\epsilon A}{d}$$

The only difference between this capacitance equation and the first one is that ϵ_o is replaced by ϵ. The value of this new constant depends on the material that is in the gap. It's the material's electric permittivity, and is a measure of the extent to which the electrons within the substance are displaced by the electric field. Materials in which there is a large displacement of electrons (large polarization) enable higher capacitances.

We'll introduce several different materials into the gap in our capacitor and measure the capacitance, and then use the equation above to determine ϵ for the material.

Procedure:

1. Obtain a stack of paper from the front desk. The stack should be at least 0.5 cm thick.
2. Use the vernier caliper to measure the thickness of the stack. This is d, the distance between the capacitor plates. Enter this value in the appropriate cell in the table below.
3. Put the stack between the plates of the capacitor, & press the plates together to gently squeeze the paper while someone reads the capacitance. Enter this capacitance value into the appropriate cell in the table.
4. The area A is the same as the one that you determined for the first part, the area of the capacitor plates.
5. We can only do this for a single distance, so we'll directly calculate the permittivity of the paper using:
$$\epsilon = \frac{dC}{A}$$
6. Repeat this procedure to find the electric permittivity of the other materials in the table.

Material	$\boldsymbol{d}$ $(\boldsymbol{m})$	$\boldsymbol{C}$ $(\boldsymbol{F})$	$\boldsymbol{\epsilon}$
paper			
plexiglas			
glass			
wood			
paint			