The plate capacitor

Experiment number	136930_EN	*Topic*	Electrostatics, capacitor				
Version	2018-01-04 / HS	*Type*	Student Exercise	*Suggested for*	Grade 11+	*p.*	1/4

Objective
To investigate the plate capacitor with and without a dielectric and to find an experimental value of the vacuum permittivity ε_0.

Principle
The capacitor is charged from a power supply to a voltage U and discharged into an electrometer, thus measuring the charge Q. Capacitance is then given as $C = Q/U$.

The voltage and the distance between the capacitor plates are varied.

Equipment
(See detailed list on p. 4)

Plate capacitor with distance spacers
Dielectric for plate capacitor
High voltage supply
Electrometer

Stand base
Cables

Caution
The high voltage power supply used in this experiment ***must*** be equipped with a current limiter that prevents it from delivering more than 2 mA.

This is the case with Frederiksen's model 367060 (as well as earlier models 366060 and 366050).

It is highly dangerous to use a high voltage supply that can deliver higher currents.

Note: Keep the voltage below 1500 V (i.e. 1.5 kV) in this lab.

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Preparations

The complete setup can be seen on p. 1.

Take care to use a grounded power outlet and to use a power cord with ground for the power supply!

Connect the minus socket (black) on the high voltage supply to ground (green/yellow socket).

Turn the voltage completely down.

Mount one of the capacitor plates in the stand base. Connect this plate to minus on the power supply and to the ground socket on the electrometer (green/yellow socket).

Place tree of the provided spacers in a large triangle on this plate and the other plat on top of them.

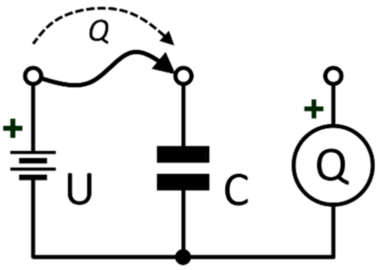
Connect a wire from the plus socket on the voltage supply to an insulated rod (441002). This lead is used for charging the capacitor.

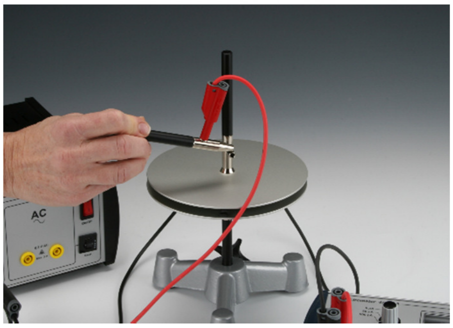
Connect another wire from an insulated rod to the "Q" socket on the electrometer. This lead is used for discharging the capacitor.

Turn the electrometer switch to "500 nC" and tur on.

> ⚠ Note: Avoid creating a connection between the power supply directly to the electrometer (i.e. between the charging and the discharging leads)!
>
> It may destroy the electrometer.

Charging from the high voltage power supply





Procedure

1 – Varying the voltage

Adjust the voltage *U* initially to about 300 V.

Take up one insulating rod in each hand so they in turns easily can touch the socket on the upper capacitor plate.

Zero the electrometer.

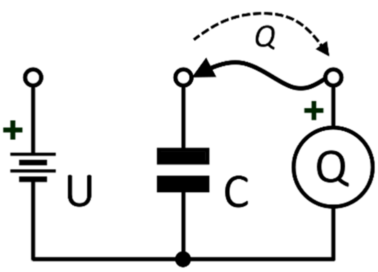
Charge and discharge the capacitor and note how far the pointer on the electrometer moves (the charge *Q*).

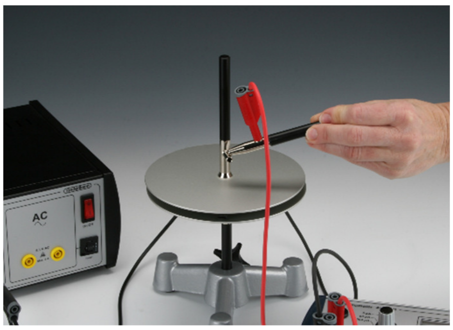
Repeat, while you *count the number of discharges* (*N*) – stop, when you think the *next* discharge would send the pointer off the scale.

Did you forget to count? – or did the pointer go too far? – simply press zero and start over.

Note the results in a table as the one on p. 3. The *total* charge for all the discharges *N*·*Q* is read on the meter – notice that the *full* scale of the meter is 500 nC, corresponding to the range you selected on the switch.

Discharging through the electrometer





Increase the voltage by 75 – 150 V and *repeat* the procedure. Continue until you approach 1500 V – which must not be exceeded!

U	*N*	*N·Q*	*Q*
V		nC	nC

2 – Varying the distance

Now, adjust the high voltage to 1400 – 1450 V. Write down the precise value of the voltage *U*.

The distance between the plates should still be *one* plastic spacer thickness (which is d = 2 mm.)

Repeat the procedure from part 1 with (possibly repetitive) charging and discharging.

Note the result in a table as shown below.

d	*N*	*N·Q*	*Q*	*C*
mm		nC	nC	pF

Next, place two spacers on top of each other in each of the three support points.

Repeat the measurement.

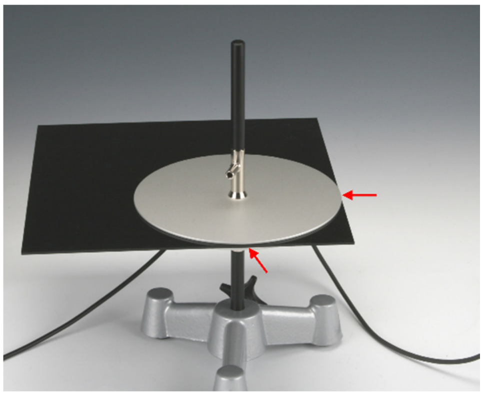
Continue, until you have 5 spacers in each of the piles.

3 – Varying the material

By and large, until now the gap between the capacitor plates have consisted of air.

You must now repeat measurement series 2, but this time with plastic between the plates. The dielectric kit (item number 431600) consists of completely the same type of plastic sheet as is used for the spacers, i.e. they have also the same thickness.

Place these sheets between the capacitor plates as shown below – then it is easy to ensure that the capacitor plates are aligned precisely.



Start with one sheet an continue until there is 5-6 sheets on top of each other.

Use the same kind of table as before.

Finally, measure the capacitor plate diameter *D*.

Theory

The relation between voltage *U* and charge *Q* for a capacitor is given by

$$Q = C \cdot U$$

The proportionality constant *C* is called the *capacitance.*

In a vacuum, the capacitance of a plate capacitor is given by the expression

$$C = \varepsilon_0 \cdot \frac{A}{d}$$

where *A* is the area of the plates, *d* is their distance and ε_0 is the so-called *vacuum permittivity*. This expression presumes that $d \ll \sqrt{A}$, i.e. that the distance is very small compared to the extent of the plates.

If another insulator fills the gap between the plates, the equation changes into

$$C = \varepsilon_R \cdot \varepsilon_0 \cdot \frac{A}{d}$$

Where ε_R is the *relative permittivity* of the material.

It always applies that $\varepsilon_R > 1$. For air, ε_R is *very* close to 1.

(You sometimes see the name *dielectric constant* instead of permittivity.)

Calculations

(A spreadsheet could be used with advantage.)

Calculate the *Q* column in all three measurement series.

For series 1, Plot *Q* as a function of *U*. Determine *C*.

Calculate the *C* column in the two last series. (Take care with the different powers of 10 involved.)

Calculate the area *A* of the capacitor plates from the diameter.

Plot *C* as a function of $\frac{1}{d}$ for series 2 and 3.

From the slope of the graph for series 2, calculate a value for ε_0.

From the slope of the graph for series 3, calculate a value for ε_R for the type of plastic used.

Discussion and evaluation

Is the graph for series 1 a proportionality as expected?

Find a table value for the vacuum permittivity. – How close is your experimentally determined value? (Specify the deviation in percent.)

Try to explain that series 2 and 3 are clearly not a pure proportionality.

Teacher's Notes

Concepts used

Voltage
Charge
Capacitance

Mathematical skills

Graph plotting
Equation solving

About the equipment

By design, measuring charges with the electrometer results in a maximum voltage drop of 0.5 V across the input sockets – compared with the other voltages used in this lab, you can consider the capacitor to be completely discharged through the electrometer.

The manual for the electrometer states the maximum continuous input voltage that can be applied to the input without damaging the instrument – this value is not relevant here. Instead, it is the energy spike that is deposited in the instrument per discharge that is important. If you keep the voltage below 1.5 kV as specified in this lab manual, the electrometer will not suffer any damage.

Detailed equipment list

Specifically for the experiment

431510	Plate capacitor, 15 cm	
431600	Dielectric for plate capacitor	
441030	Electrometer	
367060	Power supply, 0 – 6000 V (alternatives: 366060 or 366050[1])	
441002	Insulated rod	(2 pcs.)

Standard lab equipment

000600	Stand base, 1 kg.	
105720	Silicone cable, black 50 cm	(2 pcs.)
105721	Silicone cable, red 50 cm	(2 pcs.)
105710	Silicone cable, black 25 cm[1]	

[1]) The older power supplies have the ground socket placed on the back panel, which requires a longer cable. 50 cm is OK.