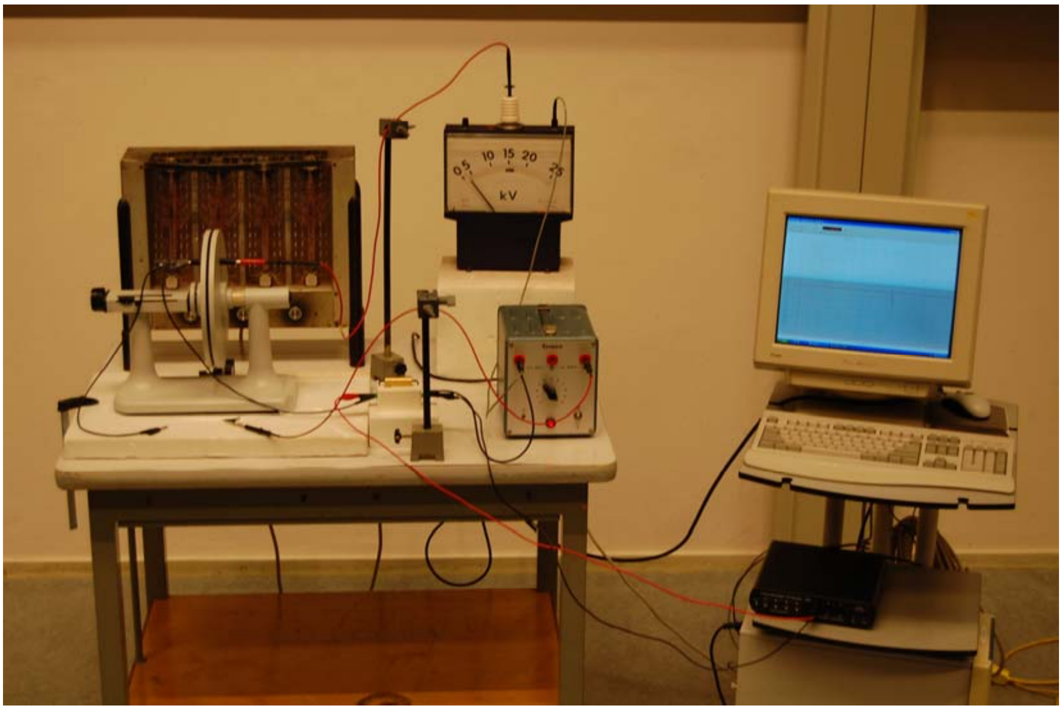
Capacitor (1)
Spacing between the plates

Aim: To show:
- how the voltage of a charged capacitor changes when changing the spacing;
- how the charge of a capacitor at constant voltage changes when changing the spacing.

Subjects: 5C10 (Capacitors)

Diagram:



Equipment:
- Parallel plate capacitor.
- Piece of isolating foam between the plate capacitor and table.
- Strip of Teflon; thickness 4mm.
- Electrostatic voltmeter, 0-25kV
- Power supply (Leybold Didactic 52237), 0-6kV (see **Safety**).
- Resistor, 50kΩ.
- Use connection leads with Teflon isolation.
- Data-acquisition system (measuring voltage across the resistor).
- Electric heater (to prevent that moisture spoils the demonstration).

Safety:
- The 6kV power supply has passive current limitation, ensuring that no dangerous contact voltage can occur[*]. Nevertheless be careful, because when you accidentally touch the high, you probably make a spastic movement, and you may hurt yourself (or somebody else).

[*]In accordance with IEC 61010-1 (Safety requirements for electrical equipment), a part is not deemed to be live (i.e. carrying a dangerous contact voltage) when, at voltages greater than extra-low voltage (> 60 V DC), the current through an induction-free resistance of 2 kOhm is not greater than 2 mA for DC, additionally, the charge for voltages up to 15 kV is less than 45 µC, and the stored energy does not exceed 350 mJ for voltages over 15 kV.

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Presentation: The setup of the demonstration is explained to the students. The plates are set at minimum distance, just separated by the Teflon strip (see Figure 1). This strip prevents that, when shifting the moveable capacitor plate you come too close to the fixed plate.

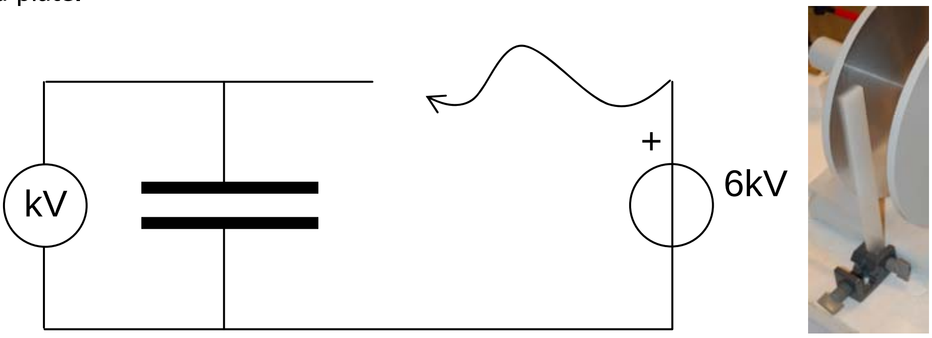

Figure 1

1. The capacitor is charged by just touching the capacitor with the free lead of the 6kV power supply (see Figure 1). After this charging of the capacitor, the voltmeter reads 6kV.
The students are asked what will happen to the voltage of a charged capacitor when the distance between the plates is increased.
-After their answers, the grounded plate is shifted to maximum separation. Now the voltmeter reads around 15kV, clearly showing the increase in voltage.
-Bringing the plates again close together lowers the voltage.
This shifting to and fro can be done several times. (See Figure 2)

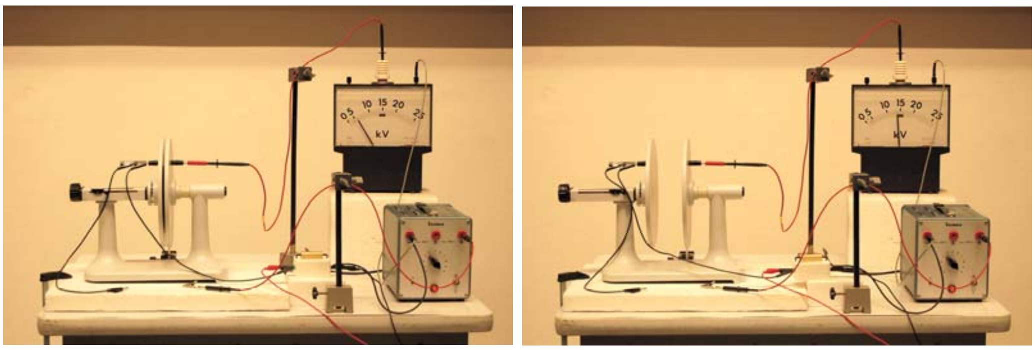

Figure 2

2. Again the plates are set at minimum distance, just separated by the Teflon strip.
A 50kΩ resistor is inserted in the ground-lead and a connection is made to the data-acquisition system (see Figure 3). The 6kV power supply is connected to the capacitor.
The voltmeter now reads 6kV in all situations.

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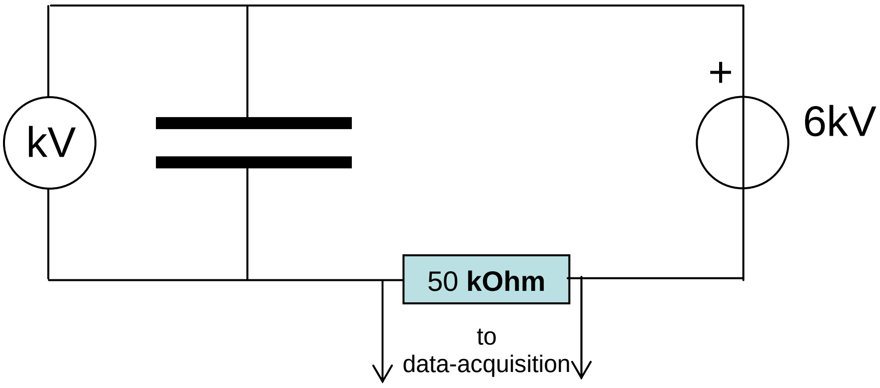

Figure 3

-The data acquisition is started. Then the grounded plate is shifted to maximum separation. The software shows that very short a current is flowing (see figure 4A).
-Bringing the plates again close together shows that again very short a current is flowing but now in the opposite direction (see Figure 4B).

Figure 4

Explanation: <u>1.</u> *Constant charge:*

<u>Explanation 1:</u> When charging, *Q* has a certain, constant value. Increasing the distance between the plates means that you do work, because there is an attracting force between the plates. Ding work means an increase in voltage.
Decreasing the distance is doing negative work, so lowering the voltage.

<u>Explanation 2:</u> When the separation *d* increases, *C* decreases ($C = \varepsilon \frac{A}{d}$) and since *Q* is constant this will cause *V* to increase (*Q=CV*).

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2. *Constant voltage:*
When the voltage is constant, the amount of work (ΔW) done in shifting the capacitor plate equals: $\Delta W = V\Delta Q$. So there is a ΔQ , meaning that for a certain time a current will flow: $\Delta Q = I\Delta t$.
Positive work means current in one direction; negative work current into the other direction. This is directly visible in: $I = \frac{\Delta Q}{\Delta t} = \frac{\Delta W}{V\Delta t}$. $+\Delta W$ makes $+I$ and $-\Delta W$ makes $-I$.
(The direction of the current flow in the circuit that is demonstrated can be shown to the students. But then it is needed that in your set-up all connections are clearly visible, so they can see where plus and minus of the power supply and of the resistor and of the data acquisition box are situated.)

Remarks:

- In the explanation of the demonstration it is supposed that the charge on the capacitor is constant. This is true only if the capacitance of the electrostatic voltmeter is small compared to that of the parallel plate capacitor.
- In the first part of the demonstration the 50kΩ resistor is already in the circuit, but shorted.

Sources:

- Mansfield, M and O'Sullivan, C., Understanding physics, pag. 455-458.