IIE2

Modul Electricity II

Dielectrics

The goal of this experiment is to understand the operation of a capacitor with a dielectric. Furthermore, the capacitance of the capacitor and the relative permittivity ϵ_r of air, plastic, and glass will be measured.

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1.1 Preliminary Questions

- How does a capacitor function? Explain in your own words.
- Which influences does the dielectric have? Explain in your own words.
- What is an electric field meter and how does it works?
- For which applications are capacitors used?

1.2 Theory

1.2.1 The Capacitor

A capacitor is a passive electrical component with the ability to save electric charge. The ability to store the electrical energy in the form of charge is called capacitance. It is measured in farads [F]. The simplest capacitor consists of two parallel oriented metal plates. When a voltage is applied to it, the base charges settle on the potential difference on its surface. These charges produce an electrostatic field between the two plates. The electrical energy is stored in this field. The area of âĂŃâĂŃthe capacitor plates is large compared to their spacing, so one can consider the electric field to be homogeneous. Then we have:

$$E = \frac{U}{d}, \tag{1.1}$$

where U is the applied voltage and d is the spacing of the two plates. Therefore, the electric field E has the units Vm^{-1}.
The capacitance is defined as the charge Q which the capacitor at a voltage U can take:

$$C = \frac{Q}{U} \tag{1.2}$$

This applies for: 1 farad = 1 coulomb per volt.
The energy that can be stored in a capacitor is then calculated as follows:

$$E_{pot} = \frac{1}{2}CU^2 \tag{1.3}$$

Capacitors do not necessarily consist of two plane-parallel plates. Theoretically, there are all forms possible in which the two conductive surfaces face each other. The Equations 1.1 and 1.2 must then be adapted. In electronics usually rolled foil, ceramic, or plastic capacitors are used.

1.2.2 The Dielectric

The dielectric can be designated as any electrically non-conductive or weakly, nonmetallic substance. It may be a liquid, a gas, or a solid state. Bringing a dielectric into the electric field of a capacitor, can causes polarization of the substance. That is, in the substance, the molecules of the capacitor can align with a dipole relative to the electric field and thereby, produces an opposing field. The electric field between the capacitor plates is attenuated by introducing a dielectric. This leads to an increase in the capacity of the capacitor. This can be shown by Equations 1.1 and 1.2. The following applies:

$$E \sim U \Rightarrow C \sim \frac{1}{E}$$

The relative permittivity ϵ_r indicates the factor by which the capacitance of a dielectric is increased by introducting a capacitor. Thus:

$$C = \epsilon_0 \epsilon_r \frac{A}{d} \tag{1.4}$$

Here, A corresponds to the area of âĂŃâĂŃa capacitor plate and $\epsilon_0 = 8.8541 \cdot 10^{-12} \frac{F}{m}$ of electric field constant. For a capacitor in a vacuum, $\epsilon_r = 1$ applies. Equations 1.1) und (1.2 are obtained for the electric field from the following relationship:

$$E = \frac{Q}{\epsilon_0 \epsilon_r \cdot A} \tag{1.5}$$

A capacitor N comprising of different dielectrics having the relative permittivity $\epsilon_r^{(i)}$ with thicknesses $d^{(i)}$ can be thought of as a separate capacitor for each layer. If one switches N capacitors in series, the total capacity is calculated as follows:

$$\frac{1}{C^{(total)}} = \sum_{i=1}^{N} \frac{1}{C^{(i)}} \tag{1.6}$$

Therefore, using Equation 1.4 results in the total capacitance for N different dielectrics:

$$\frac{1}{C^{(total)}} = \frac{1}{\epsilon_0 \cdot A} \sum_{i=1}^{N} \frac{d^{(i)}}{\epsilon_r^{(i)}} \tag{1.7}$$

From an energy perspective, one can make the following considerations: the more charges brought on the capacitor plates, the stronger the electric field will be and thus, the amount of energy stored therein. It can take longer as more charges are applied to the plates until the potential difference (= voltage) of the plates corresponds to that of the source. The maximum potential difference is only from Field E_t and the distance d between the plates, but is not dependent on the dielectric (see Eq. 1.1). Bringing only the dielectric in the capacitor, the following equation must be valid:

$$E_t = E_{air} - E_{Dielectric} \tag{1.8}$$

The negative sign in $E_{Dielectric}$ describes the opposing field. The field E_{air} is now stronger than before after bringing the dielectric, but the total field E_t remains equal. Since the charge is proportional to the field, according to equation 1.5, than at the same voltage, more charges can be brought to the plates. Due to the larger field E_{air}, more energy can be stored in the capacitor. One can also argue that more energy can be stored as a part of the energy is not invested in the electric field, but in the polarization of the dielectric.

1.3 Experiment

1.3.1 Equipment

Components	Number
Electric field meter	1
Display unit for electric field meter	1
Capacitor plates on an optical bench	1
Spacer	4
Holder for dielectrics	1
Glass plate	1
Plastic plate (Polystyrene)	1
Adjustable transformer 450 V	1
Multimeter	1
Connecting cable	5
Switch 1-Pole	1

1.3.2 Experimental Setup and Adjustment

- Attach the capacitor plates to the optical bench.
- The rods of the capacitor plates to the corresponding holes of the holding position be performed for the dielectrics; the side with the electric field meter at the round and the other side in the elongated opening.
- Connect the electric field meter to the display device.
- Connect the connecting cables of the electric field meter to the negative pole of the transformer. The other capacitor plate is connected to the switch, and this with the positive the transformer is connected.
- The multimeter is connected to the transformer so that its voltage can be read.
- This test is very susceptible to leakage currents. Make sure that it is not possible for the connecting cable to touch the table at all.

1.3.3 Implementation

- Place the spacers with the first distance (approximately 10 mm, measure it!).
- Connect the capacitor to the transformer.
- A voltage of the transformer should be 0 V and the electric field 0 kVm^{-1}. If this is not the case, you can zero the display device.
- Increase the voltage of the transformer slowly to 300 V and continuously read the electric field strength.
- Put the voltage to 0 V and bring the glass plate between the capacitor plates.
- Make sure that you down in the bracket for the dielectrics in the correct score located so that it is located right in the middle of the capacitor.
- The glass of the capacitor plates should not touch, since it may charge and could distort the measurement.

- Take a reading of the electric field. If it is not zero, the glass is charged. You can discharge it by holding it under running water and washing it with soap. After that, allow ot to dry and wipe it dry in any case!
- Take again now an U-E curve with a maximum voltage of 300 V.
- Repeat the experiment with the plastic plate.
- Repeat the experiment with the second distance (about 20 mm, measure it!).

1.3.4 Tasks for Evaluation

The electric field meter does not measure the entire field of the capacitor, but that of the charge Q generated field in the air at the front of the capacitor plate.

1. Create a plot for both distances of the voltage versus the electric field. In each plot, the readings for air, glass, and plastic should be displayed together.
2. For each measurement series, make a linear fit and specify the slope. Which physical quantity does it match?
3. Determine the relative permittivity of air. Hint: Assume that you are viewing a capacitor in a vacuum, which is filled with the dielectric air. Use Equations 1.1 und 1.5.
4. Determine the relative permittivity of glass and plastic. Hint: Use addition Eq. 1.8.
5. Average ϵ_r for each material over all the measurements and enter the statistical error and compare it with the literature values.
6. Determine the capacitance of the capacitor for the various configurations.

1.4 Literature

- Paul A. Tipler, *Physik für Naturwissenschaftler und Ingenieure*, Spektrum
- Horst Stöcker, *Taschenbuch der Physik*, Verlag Harri Deutsch
- Horowitz & Hill, *The Art of Electronics*, Cambridge University Press