

Capacitor Electrostatic Discharge WIP

Keywords: 2017, Capacitor, Electrostatic, Physics, Sparks, Static Electricity

Meta Description

DIY capacitor able to produce miniature lightning bolts with voltage in the thousand-volt range.

Learning Objectives

To investigate the science behind lightning.

To understand how capacitors work.

Key Terms

Capacitance

The measure of the charge stored by a capacitor.

Capacitor

Capacitors are made from two metals separated by an insulator. The capacitor is able to store electrical energy and instantly release it back when necessary.

Conductor

A material that allows electric flow to pass easily through it.

Dielectric

An electric insulator that can be polarized in an electric field. It is usually used to separate the two metal plates in capacitors.

Discharge wand

The equipment used to easily discharge the capacitor.

Electrostatic Discharge

The sudden release of electrical energy, usually caused by contact.

Polarized

In this context, polarization refers to the alignment of molecules within a material due to an external electric field.

Method

Building the capacitor**Step 1**

Create a wand by stripping the insulation from a copper wire and tape the wire to the metal cake pan using metal tape.

Step 2

Make the end of the wand by threading the copper wire around the large metal bolt and secure it with metal tape. Add generous amounts of insulating tape to the metal bolt such that it can fit snugly in a PVC pipe.

Step 3

To complete the wand, use tape to attach a spherical neodymium magnet to the metal bolt and a smaller neodymium magnet separated by a plastic washer.

Step 4

Place the polycarbonate sheet on the metal cake pan.

Step 5

Cut a smooth circle from the metal sheet and put it underneath the metal bowl. Make sure it is well connected to the bowl by using metal tape.

Step 6

Place the bowl on the polycarbonate sheet such that it is aligned with the metal cake pan underneath.

Step 7

Secure the bowl to the polycarbonate sheet using insulating tape and the capacitor is complete.

Performing the demonstration**Step 1**

Wrap the paper towel around the PVC pipe.

Step 2

Cover the paper towel with foam and a cloth for some grip.

Step 3

Charge the metal bowl by rubbing the PVC pipe whilst touching the surface of the bowl.

Step 4

Keep rubbing for about 30 seconds.

Step 5

Move the discharge wand near the metal bowl slowly until a spark is observed.

Precautions

1. Electrostatic discharges should only be carried out using the discharge wand.
2. **Electrical discharges can damage electronic equipment.**
3. It is advisable that **people with a pacemaker or heart conditions do not participate** in such demonstrations.

Narrative

Explaining lightning:

In a thunderstorm electric charges are separated by updraft and downdrafts. Negative charges usually accumulate at the base of the cloud in the same way charges accumulate on the metal bowl.

The positive charge is induced in the ground. The same happens in our capacitor, positive charge is induced in the plate below the dielectric. In the case of a thunderstorm the dielectric is the layer of air separating the ground and the cloud.

When the charge accumulated is great enough to breakdown the air, lightning occurs. This won't occur in our capacitor since no charges can flow through the dielectric but the same phenomenon occurs when bringing the discharge wand near the metal bowl.

Questions

Is it dangerous to touch the spark?

No but it can be painful.

What is the largest spark we can get?

About 10 cm.

For how long should you rub the PVC pipe?

5 to 10 times is enough.

What is the voltage of the spark?

In the thousand-volt range.

Why the spark won't kill you?

High voltage but low current.

Brief Explanation

Capacitors are energy-storing devices having many applications, ranging from microelectronics to particle accelerators. Natural capacitors can be observed floating over our head. Yes, the science behind lighting is exactly the same as the science of capacitors used in electronics running our computers!

Our capacitor is composed of two metal plates, separated by a polycarbonate sheet known as a dielectric. (Video). The capacitor is charged by rubbing the PVC pipe against the metal bowl dumping negative charges in the process. The negative charges accumulated on the metal bowl attract positive charges from the metal cake pan underneath the polycarbonate sheet. The dielectric has the special property of allowing electric fields to pass through but doesn't allow any charges to flow. The built up charges store energy ready to be released.

When the discharge wand, connected to the metal pan underneath the dielectric, is placed near the metal bowl the voltage stored is high enough to break down air and allowing charges to flow, producing a giant spark.

Detailed Explanation

A capacitor simply consists of two conductors separated by a dielectric. A capacitor is characterised by its capacitance, that is, the amount of charge that can be stored within the capacitor. The capacitance is formally defined as the ratio of electric charge stored Q to the voltage V between the two plates:

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

where C is the capacitance.

The capacitance can also be given in terms of the physical characteristics of the capacitor:

$$C = \frac{\epsilon_r \epsilon_0 A}{d} \quad [2]$$

where A is the plate area, d is the plate separation, ϵ_r is the relative permittivity of the dielectric and ϵ_0 is the permittivity of free space.

Equation (2) indicates that a capacitor having high capacitance must be designed such that the area of the plates is very large whilst the separation between the plates is small as possible.

When rubbing the PVC pipe against the metal bowl, negative charges are deposited on the conductor and since like charges repel, the charge spreads evenly around the metal bowl. The negatively charged bowl induces a positive charge on the metal plate underneath the dielectric. In the dielectric polarized molecules get aligned with the electric field generated by the charged plates. This makes the molecules of the dielectric shift slightly in such a way that the positives in the molecules face the negative plate whilst the negatives of the molecules face the positive plate. This reduces the voltage between the capacitor plates since the contribution to the voltage by the plates is partially cancelled. From equation (1) it can be deduced that a lower voltage results in higher capacitance. The fact that dielectrics increase the capacitance is the sole reason why they are used to separate the charged plates.

When the plates are brought to vicinity from the other side by using the discharge wand, the charge stored in the capacitor is released producing a large spark. The spark produced can be up to 10 cm. Since the dielectric strength of air is 3×10^6 V/m, the spark must be 300,000 volts in order to breakdown air!

Applications and Research

Applications

Capacitors are essential in particle accelerators. The two main uses are: voltage stabilization and filtering of harmonic waves generated by inverters. CERN have very sophisticated capacitors to ensure high reliability.

Research

Suitable capacitors can provide a large current in a very short time. This is essential in producing powerful laser beams used in nuclear fusion experiments. Fusion energy research is being carried out all over Europe.

Investigation

- The dielectric strength of air varies (e.g. with relative humidity). This can be investigated by measuring the length of the spark.
- The area of the metal plates can be varied to change the capacitance.
- The plate separation can be varied to change the capacitance.
- Different dielectrics may be used.

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Time Required

~45 minutes

Preparation: 20 minutes

Conducting: 10 minutes

Clean Up: 15 minutes

Cost

10 – 25 €

Recommended Age

13 – 16

>16

Number of People

2 participants

Supervision

Required

Location

Indoors

Outdoors

Festivals

Laboratory

Materials

Cloth

Copper wire (1 m)

Foam

Insulating tape

Metal cake pan

Metal sheet

Metal tape

Paper towel

Plastic washer

Polycarbonate sheet

PVC pipe

Round metal bowl

Spherical neodymium magnet

Small metal ball bearing

Wire stripper

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Sources

Capacitors

Capacitors Theory

Dielectrics in Capacitors

Dielectric Strength of Air

European Consortium for the Development of Fusion Energy.

How Lightning Works

Van de Graaff Generator Safety

Vishay ESTA Supplies Filter Capacitor Banks for Particle Accelerator

What are some Uses of Capacitors?

Additional Content

Capacitor(Beginner)

Dielectrics in Capacitors(Intermediate)

Advanced Dielectrics for Capacitors(Advanced)

Control Method of the Transient Compensation Process of a Hybrid Energy Storage System Based on Battery and Ultra-capacitor in Micro-Grid.(Advanced)

Cite this Experiment

Vella, R., & Fenech Salerno, B. (2017, September 29). Capacitor Electrostatic Discharge. Retrieved from <http://steamexperiments.com/experiment/capacitor-electrostatic-discharge/>

First published: **September 29, 2017**

Last modified: **October 30, 2017**