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Where are charges stored in a parallel plate capacitor?

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ABSTRACT

In this paper we reexamined the Benjamin Franklin's 18th century demonstration. We conducted three demonstrations to decide where charges are in a parallel plate capacitor. Contrary to the common knowledge about the storage of the charges, which is the surface of the dielectric material, we propose that charges are stored deeper in the dielectric material.

1. Background

Capacitors are instruments used to store energy in an electric field. In its simple form, a capacitor is made of two or more parallel conductive plates which are separated by dielectric material.

Sometimes, the most primitive physical instruments may have counterintuitive nature. In this work, we want to talk about one of such a seemingly simple circuit element that is parallel plate capacitor. More precisely, it will not be about the capacitor itself, but about the charge of the capacitor. Here we want to understand where the charge is stored in the capacitor; on the parallel metal plates of the capacitor or in the dielectric material placed between the metal plates of the capacitor. Benjamin Franklin was one of the first to become interested in this question as early as 1752 (Addenbrooke, 1922). In order to accomplish his experiment, Franklin used a Leyden Jar. He wanted to find out which of these parts of the apparatus serves as a reservoir for electrical energy. He proved that the glass, which is a kind of dielectric, serves as a reservoir for electric charge (Gross, 1944; Smith, 2017). This experiment paved the way for the famous theories of electrodynamics, and based on these assumptions, Maxwell wrote his equations.

This is the old experiment, but we went little bit deeper inside of the process. By some series of demonstrations, we would like to reveal where exactly charges stored in a parallel plate capacitor.

2. Demonstrations

We set up a capacitor (figure 1) with round aluminum plates and plastic dielectric material between them. The parallel plate capacitor is formed from two circular aluminum discs of 24.1 cm in diameter and 3.18 mm thickness. The dielectric is an acrylic plastic sheet of 27.9 cm by 33.7 cm and 1.17 mm thickness. Since the voltage is so high to prevent a shock hazard while moving the plates together safely after they have been charged we used ceramic insulating handles that are attached at the center of the plates.

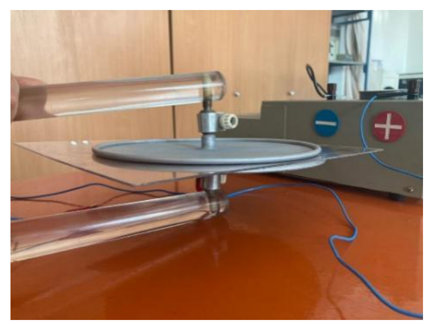

Fig. 1. The capacitor used in the experiment.

2.1. 1st Demonstration

We removed the dielectric between the capacitor plates and separated the plates by an air gap by simply keeping the plates 2 cm apart. Then, we charged the capacitor plates with 25KV source. After turning off the external voltage source, we slowly brought them close to each other. There we noticed a powerful spark when the plates came close to each other. This means that with an air gap between the metal plates, the charge was stored on the surface of the metal plates, and in touching them the plates were discharged.

2.2. 2nd Demonstration

We firstly charged our capacitor with external high voltage source, then we took the plates apart and removed the dielectric material between the plates, then we touched plates of the capa-

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itor to each other (https://www.youtube.com/watch?v=1ot3mPsmWtY).Here contrary to the expectation of many students and teachers we noticed a very small spark when we brought the plates near to each other. This means that there is almost no charge on the metal plates. Next, we placed the dielectric material in between the plates again without additional external charging. Then, we touched the capacitor plates (while the dielectric material was in between the plates) using a conductor and during this process relatively a strong electric spark was observed which indicated the discharging of the capacitor. Thus, where charges came from?

This demonstration indicates that the charge was stored on the surface of the dielectric material because we charged the system, removed the dielectric, touched capacitor plates, inserted the dielectric again, and finally observed the spark by touching the two plates without charging them again.

2.3. 3rd Demonstration

Next, we decided to check where exactly the charge is stored in the dielectric. Suppose that the charge is located on the surface of the dielectric and a positive charge is located on one of its surfaces and a negative charge on the other one. This is what previous research suggest for the place of the charges (Gross, 1944; Huff, 1986; Smith, 2017; White, 1903).

To check the existence of the charges on the surfaces of the die-lectric material, we inserted two dielectric materials in between t-he plates. Namely, we assembled a capacitor from two dielectrics between two metal plates, and then charged our capacitor using t-he same high voltage source. After turning off the external power supply, we removed the dielectric materials and touched the met-al plates t-o each other. Then, we put the dielectric plates together so that the positively charged side of one dielectric material is in contact with t-he negatively charged side of the other dielectric m-aterial. Thus, having assembled the capacitor, again without external charging the capacitor, we connected the metal plates using a conductor (https://www.youtube.com/watch?v=GvbwlkfD_J8).

Here we also noticed a good spark which indicated the existence of the charges after the interaction of the positive and negative sides of the dielectric material. This demonstration showed that during charging a capacitor the charges are stuck on plastic and cannot jump off it easily. This also implies that charges are stored a little bit more deep in the dialectic material.

3. Conclusion

In this study we showed that (1) when there is air gap in between metal plates charges are stored on the metal plates, (2) when there is a dielectric material in between the plates, contrary to the current knowledge, the charges are stored within the dielectric material. Thus, we recommend teachers and textbook writers to handle the parallel plate capacitors in caution. Finally, we recommend these series of demonstrations to schoolteachers for having discussions with students and having new insight into capacitors and in science. To repeat we presented that results of the second and third demonstrations contradict with current explanations (Gross, 1944; Huff, 1986; Smith, 2017; White, 1903) for the storage of the charge in a capacitor.

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