A look into the factors affecting capacitance

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ABSTRACT

This research aims to study the effect of factors such as plate area, plate separation distance, dielectric material on a parallel plate capacitor and why we cannot use an isolated spherical conductor as a capacitor. Through the use of multiple formulas and study of other papers, I reached the conclusion that capacitance increases with larger plate areas and decreases with a greater plate separation distance. Moreover, dielectric materials with a higher value increased the capacitance of a capacitor. However, the same is not true for metals as they are primarily conductors and if we use a metal as a dielectric material, the capacitor would cease to exist . Lastly, an isolated spherical conductor cannot act as a capacitor as it would require a radius of 9 * 10^9 m to achieve a capacitance of 1 Farad, this is physically impossible as that radius is even bigger than that of the earth.

INTRODUCTION

A capacitor is a device that is used for storing electrical energy inside an electric field and using that stored energy later on for different purposes in the devices and appliances it is connected to. Capacitance is the fundamental property of capacitors, it is defined as the ability to store electric charge per unit voltage. The relationship between capacitance, area, permittivity and distance is expressed as follows -

$$C=K\varepsilon A/d$$

In the above relation ‘C’ stands for capacitance, ‘A’ stands for area and ‘ε’ is the permittivity of the dielectric material, it is expressed in different ways, for example- if the dielectric material between the two plates is air, the permittivity is expressed as ‘ε’ and if it is any other material it is represented with a ‘K’ before the ‘ε’ as ‘Kε’ i.e. an additional ‘K’ is added, the reason a ‘K‘ is not added in the case of air is because the value of ‘K’ for air is roughly 1. The ‘K’ stands for dielectric constant (Eshop, n.d.).
Another formula used in the paper is as follows -

$$C=Q/V$$

‘C’ being capacitance, ‘Q’ being charge and ‘V’ being potential. The formula for potential is $V=(1/4\pi\varepsilon)*(Q/r)$. ‘r’ being used to express radius.

Hence, the formula for potential is -

$$C=Q/((1/4\pi\varepsilon)*(Q/r))$$ (Electrical Academia, n.d.).

PREREQUISITE INFORMATION

The value of ‘ε’ is 8.854 ×10^−12 F/m and the value of ‘1/4πε’ is roughly 9 * 10^9 N\cdotpm²/C².

PROCEDURE

1) **To study the effect of plate size** - Assume capacitors with plate area of $25cm^2$, $50cm^2$ and $75cm^2$ and we can assume the separation distance between the plates as 1mm.

2) **To study the effect of distance between plates** - Assume capacitors with a separation distance of 1mm, 2mm and 3mm and we can have the plate area as $50cm^2$.

3) **To study the effect of various dielectric materials** - We can take plates of area $100cm^2$ and a separation of 1mm between them and the dielectric material between the plates would be air, water and gold respectively.

4) **To study why an isolated spherical conductor cannot be a capacitor** - To understand why an isolated spherical conductor cannot act as a capacitor, we have to continue solving the last formula in the introduction section. (It has been solved in the appendices section at the end of the paper).

RESULTS

The Effect of Plate Size

Plate Area (cm²)	Plate Area (m²)	Separation Distance (m)	Capacitance (F)
25	25×10^{-4}	1×10^{-3}	2.2135×10^{-11}
50	50×10^{-4}	1×10^{-3}	4.4271×10^{-11}
75	75×10^{-4}	1×10^{-3}	6.6406×10^{-11}

The above table proves that capacitance is directly proportional to the area of the plates, provided that the distance between the two plates of a parallel plate capacitor remains the same (Electrical Academia, n.d.).

The Effect of Distance Between Plates

Plate Area (cm²)	Plate Area (m²)	Separation Distance (m)	Capacitance (F)
50	0.005	0.001	4.427×10^{-11}
50	0.005	0.002	2.2135×10^{-11}
50	0.005	0.003	1.4757×10^{-11}

The above table proves that capacitance is inversely proportional to the distance between the plates of the capacitor given that the area remains constant (Electrical Academia, n.d.).

The Effect of Various Dielectric Materials

Plate Area (m²)	Separation Distance (m)	Dielectric Material	Dielectric Constant (κ)	Capacitance (F)
0.01	0.001	Air	1	8.859×10^{-11}
0.01	0.001	Water	80.4	7.120×10^{-9}
0.01	0.001	Gold	∞	∞

From the examples of air and water we can decipher that more the dielectric constant more is the capacitance. However, metals like gold are exception (proved in the appendices section).

Note: The above findings were made using the formula 'C=εA/d'

CONCLUSION

From the above results, we can reach the conclusion that increasing the plate area and using dielectric material with higher dielectric constants (Metals being an anomaly) boost the capacitance of a parallel-plate capacitor. On the other hand, increasing the distance between the plates of a parallel plate capacitor decreases the capacitance. Moreover, an isolated spherical conductor cannot act as a capacitor due to physical limitations. All the above findings remain in tune with the formulas mentioned in the 'Introduction' section.

APPENDIX

Why is the capacitance infinity for gold?

K for metals is ∞ and as it stands, infinity multiplied by anything is considered as infinity i.e. 8*∞ = ∞. Likewise,

C= K.εA/d, where 'K' is infinity, would result in C=∞

Why can't an isolated spherical conductor be used as a Capacitor?

There is a capacitor with radius=r

Assume it possesses a charge 'Q'

$$C = \frac{Q\text{ (charge)}}{V\text{ (potential)}}$$

$$V = \frac{Q}{4\pi\varepsilon r}$$

$$C = \frac{Q}{\frac{Q}{4\pi\varepsilon r}}$$

$$C = 4\pi\varepsilon r$$

$$\text{If C (fixed) } = 4\pi\varepsilon r$$

$$r = \frac{C}{4\pi\varepsilon}$$

$$r = 9 \cdot 10^9 m$$

Note: *The example about gold and metals as dielectric materials is completely theoretical and cannot actually be used as dielectric materials as that would lead to a short circuit. The infinite dielectric constant 'K' is only a theoretical concept used in electrostatics (Electrotopic, n.d.).*

Capacitance Of Parallel Plate Capacitor Derivation

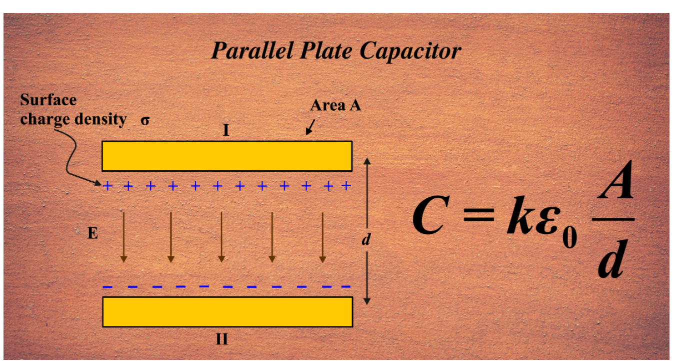

Image from Weishi Innovation (2024).

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