The Gravitational Mass of a Charged Supercapacitor

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Electric double-layer capacitors (EDLCs), also known as supercapacitors, electrochemical double layer capacitors, or ultracapacitors, are electrochemical capacitors that have an unusually high energy density when compared to common capacitors, typically on the order of thousands of times greater than a high capacity electrolytic capacitor. It is shown here that when an EDLC is fully charged its *gravitational mass* is considerably greater than when it is discharged.
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1. Introduction

The electric double-layer capacitor effect was first noticed in 1957 by General Electric engineers experimenting with devices using porous carbon electrode [1]. It was believed that the energy was stored in the carbon pores and it exhibited "exceptionally high capacitance", although the mechanism was unknown at that time.

General Electric did not immediately follow up on this work, and the modern version of the devices were eventually developed by researchers at Standard Oil of Ohio in 1966, after they accidentally re-discovered the effect while working on experimental fuel cell designs [2]. Their cell design used *two layers of activated carbon* separated by a thin porous insulator, and this basic mechanical design remains the basis of most electric double-layer capacitors to this day.

An electric double-layer capacitor (EDLC), is known as *supercapacitor*, or *ultracapacitor*. Their energy density is typically hundreds of times greater than conventional electrolytic capacitors. They also have a much higher power density than batteries or fuel cells. As of 2011 EDLCs had a maximum working voltage of 5 volts and capacities of up to 5,000 farads [3].

Currently, the EDLCs are used for energy storage rather than as general-purpose circuit components. The EDLCs also have two metal plates, but they are coated with *activated carbon* immersed in an electrolyte, and separated by an intervening insulator, forming in this manner, the double-layer of activated carbon inside the capacitor. During the charging process, ions from the electrolyte accumulate on the surface of each carbon-coated plate.

Here it is shown that when an EDLC is fully charged its *gravitational mass* is considerably greater than when it is discharged.

2. Theory

Consider the cross-section of an EDLC as shown in Fig. 1. The double-layer in the EDLCs is generally made of *activated carbon* immersed in an *electrolyte whose conductivity is much less than carbon conductivity* [4]. The result is that the conductivity of the double-layer becomes much less than the conductivity of the activated carbon and, in this way, the double-layer can withstand a low voltage, and *no significant current flows through the activated carbon layers* of an ELDC [3]. This means that they are similar to dielectrics with very low *dielectric strength*. Thus, due to the electrical charge stored in the activated carbon layers, each layer can be considered as a *non-conducting plane of charge*, with density of charge, $\sigma = q/S$, where S is the area of the plates of the capacitor, and $q = CV$ is the amount of electrical charge stored in the activated carbon layers; C is the capacity of the EDLC. Thus, according to the well-known expression of the electric field produced by a *non-conducting plane of charge* [5], we can conclude that the electric field *through the layers* of activated carbon (See Fig.1) is given by

$$E_{(layer)} = E^{-} = E^{+} = \frac{\sigma}{2\varepsilon_{r(layer)}\varepsilon_0} = \frac{CV}{2\varepsilon_{r(layer)}\varepsilon_0 S} \quad (1)$$

Consequently, the density of electromagnetic energy in the carbon layers is

$$W_{layer} = \tfrac{1}{2}\varepsilon_{r(layer)}\varepsilon_0 E^2_{layer} = \frac{1}{8\varepsilon_{r(layer)}\varepsilon_0}\left(\frac{CV}{S}\right)^2 \quad (2)$$

It was shown that the *relativistic gravitational mass* M_g is correlated with the *relativistic inertial mass* M_i by means of the following factor [6]:

$$M_g = \left|\chi\right| M_i \quad (3)$$

where χ can be expressed by

$$\chi = \left\{1 - 2\left[\sqrt{1 + \left(\frac{n_r W}{\rho\, c^2}\right)^2} - 1\right]\right\} \quad (4)$$

where n_r is the refraction index and ρ the density of the material.

Substitution of Eq. (2) into Eq. (4), yields

$$\chi = \left\{1 - 2\left[\sqrt{1 + \left[\frac{n_{r(layer)}\mu_0}{8\varepsilon_{r(layer)}\rho_{layer}}\left(\frac{CV}{S}\right)^2\right]^2} - 1\right]\right\} \quad (5)$$

In the case of activated carbon layer: $n_{r(layer)} \cong 1$; $\varepsilon_{r(layer)} \cong 12$ and $\rho_{layer} \cong 800 kg.m^{-3}$. Thus, if the *supercapacitor* has $C = 3{,}000F$; $S = 0.08 \times 0.45 = 0.036 m^2$ and is subjected to $V = 4 Volts$ then Eq. (5) gives

$$\chi = -1.14 \quad (6)$$

Substitution of Eq.(6) into Eq. (3) yields

$$M_{g(layer)} = \left|-1.14\right| M_{i(layer)} = 1.14 M_{i(layer)} \quad (7)$$

This means an *increase* of 14% in the gravitational mass of the double-layer when the supercapacitor is fully charged. Since the mass of the double-layer is a significant part of the total mass of the supercapacitor, we can conclude that, *when fully charged the supercapacitor will display considerably more mass than when it is discharged.*

It is important to note that the gravitational mass of the double-layer can also be *reduced*, *decreasing the total mass* of the supercapacitor. This can occur, for example, when $1.5 Volts < V < 3.1 Volts$.

Conclusion

The theoretical results here obtained for the gravitational mass of an EDLC are general for *energy accumulator cells* which contain *non-conducting planes of charges* similar to the *activated carbon* + *electrolyte* layers of the EDLCs.

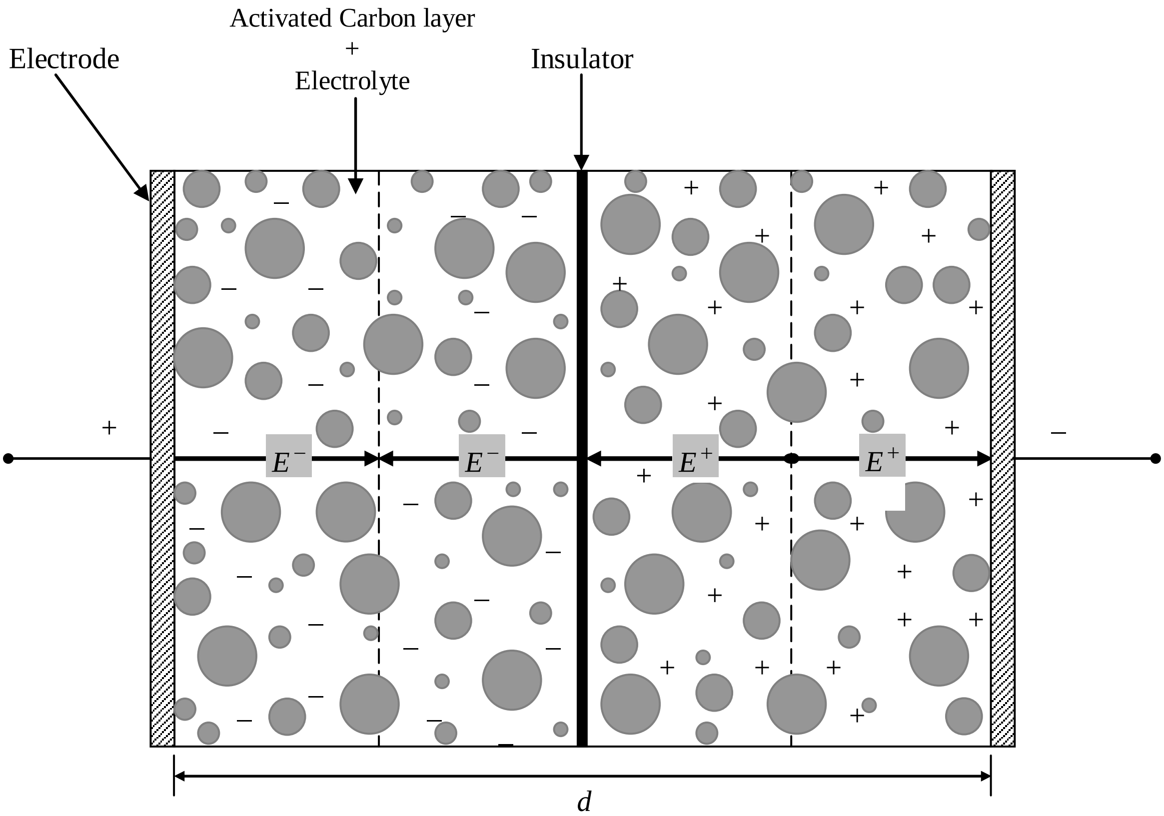

Fig. 1 – Cross-section of an *Electric Double-Layer Capacitor* (Supercapacitor) - Each *activated carbon + electrolyte* layer works as a *non-conducting plane of charge,* with density of charge $\sigma^- = q^- / S$ and $\sigma^+ = q^+ / S$ respectively. The electric fields *through the layers*, due to these densities of charges $\left(E^-, E^+\right)$, are shown in the figure above.

References

[1] Becker, H.I., (1957) *Low voltage electrolytic capacitor*, US Patent 2800616 (A), 1957-07-23.

[2] Schindall, J. (2007) *The Charge of the Ultra-Capacitors,* IEEE Spectrum, November 2007.

[3] Electric Double-Layer Capacitor http://en.wikipedia.org/ wiki / Electric_double-layer_capacitor

[4] Miller, J. and Simon, P. (2008) *Fundamentals of Electrochemical Capacitor Design and Operation*, The Electrochemical Society Interface, Spring 2008.

[5] Halliday, D. and Resnick, R. (1966) *Physics*, vol.2, John Wiley & Sons, NY. Portuguese version (1968) Física, Vol. 2, Ao Livro Técnico SA, Rio de Janeiro, Brasil, pp. 768-769.

[6] De Aquino, F. (2010) *Mathematical Foundations of the Relativistic Theory of Quantum Gravity*, Pacific Journal of Science and Technology, **11**(1), pp. 173-232.