Theory of the Capacitor
third revision

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Abstract

This paper compares the Reciprocal System theory of the capacitor to the conventional one. Conventional theory posits that neutral matter contains an equal number of positive and negative charges. Likewise, it says that capacitors, which are neutral overall, have positive charges on one plate and an equal number of negative charges residing on the other plate. In contrast, the Reciprocal System says that neutral matter is charge-free. And, likewise, the Reciprocal System says that capacitors store *uncharged* electrons; the capacitor "charge" is actually just another form of energy. Consider an electrical circuit with two capacitors, one "charged" and one not, connected by an initially-open switch. When the switch is closed, part of the capacitor "charge" flows to the the uncharged capacitor. According to conventional physics, this action does not conserve energy; according to the Reciprocal System it does.

keywords: capacitor, capacitance, electric theory, electron, charge, Reciprocal System

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Introduction

The Reciprocal System of physical theory is described in the books by Dewey B. Larson, such as Ref. [1] and [2]. In this theory, ordinary electric current is comprised of massless, uncharged electrons, which is quite different from conventional theory which says that the current electrons have negative charges and mass. In the Reciprocal System, capacitors do not store charge; rather, they store uncharged electrons. Conventional theory confuses electric quantity with electric charge, resulting in dimensional confusion. In what follows, we will remove this confusion and illustrate how a capacitor actually works. In the Reciprocal System, all dimensions are expressed in terms of space and time only. This paper is based on, and helps to explicate, Chapter 15, "Electrical Storage," of Ref. [2]. It is a runnable *Mathcad* program, so the equations are more detailed than they otherwise would be.

Nomenclature

A_{cm2} = area of either plate of parallel plate capacitor, cm^2

C = general expression for capacitance, farads (SI)

$conv_{volttoseccm2}$ = factor to convert volts to sec/cm^2

$conv_{seccm2tovolt}$ = factor to convert sec/cm^2 to volts

d_{cm} = distance between capacitor plates, cm

K = dielectric constant, dimensionless--but multiples the permittivity of free space

Q = general expression for charge (conventional theory) or energy (Reciprocal System), coulombs

Q_{coul} = total of positive "charge" on capacitor(s), coulombs, according to conventional theory

Q_{0coul} = initial "charge" on first capacitor, coulombs, according to conventional theory

Q_{0joul} = initial energy stored in first capacitor, joules, according to Reciprocal System

Q_{uc} = natural unit of charge, coulombs, according to Reciprocal System and conventional theory

$q_{convent}$ = electrical quantity, conventional theory

q_{cm} = electrical quantity, cm

q_{coul} = electrical quantity, coulombs_q

q_n = electrical quantity, number of stored electrons in first and second capacitors

s_u = natural unit of space in time-space region, cm

V = general expression for voltage across capacitor, volts

V_0= initial voltage, volts

ε_0 = permittivity of free space, s^2/t

Note: A black square in the upper right of an equation means that the equation is disabled from running in *Mathcad*. This is done because not all variables in the equation have, as yet, been given numerical values. Because of the nature of this subject, it is necessary to use a mixture of SI, cgs, and natural units in the paper, but each individual equation utitlizes just one set of units.

Unit Conversions and Physical Constants

$conv_{volttoseccm2} := 7.85794 \cdot 10^{-15}$ $conv_{seccm2tovolt} := 1.272598 \cdot 10^{14}$ (based on Ref. [2])

$Q_{uc} := 1.602062 \cdot 10^{-19}$ coulombs_Q (Ref. [2])

$q_{uc} := 1.602062 \cdot 10^{-19}$ coulombs_q $t_u := 1.520655 \cdot 10^{-16}$ sec

$s_u := 4.558816 \cdot 10^{-6}$ cm (Ref. [1])

$V_u := 9.31146 \cdot 10^{8}$ volts $C_u := \frac{q_{uc}}{V_u}$ $C_u = 1.720527 \times 10^{-28}$ farads

$R_u := 8.83834 \cdot 10^{11}$ ohms $R_u \cdot C_u = 1.52066 \times 10^{-16}$ sec ($= t_u$)

(This is a third revision of this paper; it is clear that the capacitance for capacitors has the dimensions s^3/t, rather than s; this also means that the time constant for a DC RC circuit is RC, rather than RC/(V/4.9412). The cgs unit of capacitance, cm, is incorrect--it should be cm^3/sec.)

1. The Capacitance Equations

The general capacitance equation given in the textbooks is

$$Q := C \cdot V \qquad (1a)$$

Conventional theory says that Q is the quantity of charge, in coulombs_Q, stored on either plate (positive on one, negative on the other) of a capacitor with capacitance C, in farads, with V volts applied across the plates. Charging a capacitor can be pictured as transferring Q/Q_{uc} electrons from one plate (which becomes positive) to the other plate (which becomes negative), the capacitor remaining neutral overall.

In contrast, the Reciprocal System says that a capacitor stores massless, uncharged electrons--the plates are not charged positive or negative. Eq. (1a) should therefore be modified for as follows:

$$q := C \cdot V \qquad (1b)$$

In dimensional terms, this is

$$s := \frac{s^3}{t} \cdot \frac{t}{s^2} \qquad (1c)$$

In words:

total_electric_quantity_stored = capacitance_available x electrical_force (1d)

Here we have coulombs_q, not coulombs_Q. Capacitance, C, depends solely on the geometric configuration of the capacitor and the material (dielectric) in between the conductors. The natural unit of permittivity in the Reciprocal System is unity:

$$\varepsilon_{0\_n} := 1 \qquad (2a)$$

This may be converted to cgs units as follows:

$$\varepsilon_{0\_cgs} := \frac{s_u^{\,2}}{t_u} \qquad \varepsilon_{0\_cgs} = 1.366701 \times 10^{5} \quad \text{cm}^2\text{/sec} \qquad (2b)$$

Note that the cgs system itself claims that ε_0 is 1 and is dimensionless, but this is incorrect. For a parallel plate capacitor, the capacitance is defined as

$$C := \frac{K \cdot \varepsilon_{0\_cgs} \cdot A_{cm2}}{d_{cm}} \quad \text{cm}^3\text{/sec} \qquad (3)$$

And note:

$$\frac{C_u}{\varepsilon_{0\_cgs} \cdot s_u} = 2.761443 \times 10^{-28} \quad \text{farads/(cm}^3\text{/sec)}$$

Putting this expression for C into Eq. (1b), we have

$$q_{cm} := \frac{K \cdot \varepsilon_{0\_cgs} \cdot A_{cm2}}{d_{cm}} \cdot V \cdot conv_{volttoseccm2} \qquad (4a)$$

Simplifying,

$$q_{cm} := 1.073945 \cdot 10^{-9} \cdot K \cdot \frac{Acm2}{d_{cm}} \cdot V \qquad (4b)$$

This expression needs to be converted to q_{coul} for practical use.

$$q_{coul} := \frac{q_{cm}}{s_u} \cdot q_{uc} \tag{5a}$$

Simplifying,

$$q_{coul} := 3.774064 \cdot 10^{-23} \cdot K \cdot \frac{A_{cm2}}{d_{cm}} \cdot V \tag{5b}$$

But after doing all of this, the conventional farad is defined, not in terms of cm^3/sec, but in terms of cm. So, Eq. (5b) is academic. By *convention*,

$$q_{coul} := 8.854188 \cdot 10^{-14} \cdot K \cdot \frac{A_{cm2}}{d_{cm}} \cdot V \tag{5c}$$

The same numerical result would be achieved by multiplying the K in Eq. (5b) by 2.346062×10^9 . What this really means is that the ratio of farad/meter, *defined* to be 8.854188×10^{-12}, is the SI equivalent to the natural unit of *permittivity, not the definition of capacitance in terms of length*.

Larson explains what happens in a capacitor:

"...the electrons do, in fact, flow into the spatial equivalent of the time interval between the plates of the capacitor, but...these electrons are not charged and are unobservable in what is called a vacuum. Aside from being only transient, this displacement current is essentially equivalent to any other electric current.

"The additional units of space (electrons) forced into the time (equivalent space) increase the total space content.... In the storage process, units of space, uncharged electrons, are forced into the surrounding equivalent space--that is, the spatial equivalent of time (t = 1/s)--and this inverse space, 1/s, becomes one of the significant quantities with which we must deal." (Ref. [2], pp. 171-172.)

Therefore, as d_{cm} is reduced, capacitance *increases.* In effect, the electrons are stored in coordinate time units (1/s) and so, as s is reduced, the number of coordinate time units *increases*, and more electrons can be stored. In the opposite direction, as d_{cm} goes to infinity, capacitance goes to zero (which explains why electrons do not ordinarily leave a conductor). Continuing with Larson:

"[If a dielectric] is inserted between the plates of a capacitor, the capacitance is increased. The rotational motions of all non-conductors contain motion with space displacement. It is the presence of these space components that blocks the translational motion of the uncharged electrons through the time components of the atomic structure, and makes the dielectric substance a non-conductor. Nevertheless, dielectrics, like all other ordinary matter, are predominantly time structures; that is, their net total displacement is in time. This time adds to the time of the reference system, and thus increases the capacitance." (Ref. [2], p. 172.) Hence the factor K, the dielectric constant, is included in the numerator of all the equations for C.

2. Energy Equations

Conventional theory says that

$$Q_{joulconvent} := .5 \cdot Q_{coul} \cdot V \qquad \text{joules} \qquad (6a)$$

But, from the standpoint of the Reciprocal System, this equation is not dimensionally correct:

$$\frac{t}{s} := .5 \cdot \frac{t}{s} \cdot \frac{t}{s^2} \qquad \text{or} \qquad \frac{t}{s} := .5 \cdot \frac{t^2}{s^3}$$

The correct equation for energy of the capacitor is, according to the Reciprocal System, simply Eq. (5b), multiplied by the voltage

$$Q_{jouleRS} := .5 \cdot q_{coul} \cdot V \qquad \text{joules} \qquad (6b)$$

$$\frac{t}{s} := .5 \cdot s \cdot \frac{t}{s^2}$$

Also, note the coefficient of .5; this is because in charging the capacitor the voltage starts at 0.

3. Example Calculations

Let's consider an example problem from a well-known physics textbook, Ref. [5]. The situation is shown in the following figure.

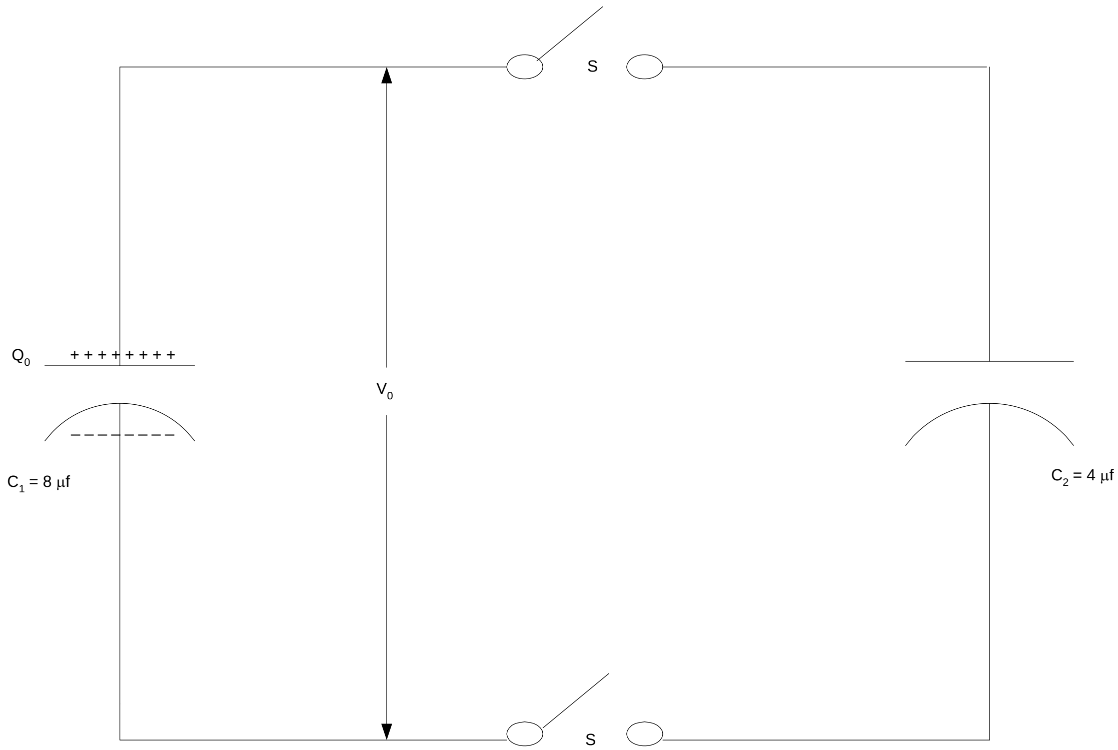

Figure 1. Two capacitor problem.

In this problem:

$C_1 := 8 \cdot 10^{-6}$ farads

$C_2 := 4 \cdot 10^{-6}$ farads

$V_0 := 120$ volts

The initial "charge" on C_1 due to V_0 is

$Q_0 := C_1 \cdot V_0$ $Q_0 = 9.6 \times 10^{-4}$ coulombs_Q, conventional theory

$q_0 := C_1 \cdot V_0$ $q_0 := 9.6 \cdot 10^{-4}$ coulombs_q, Reciprocal System

Both conventional theory and the Reciprocal System would agree that, although the dimensions are different, the initial energy of the capacitor is

$.5 \cdot Q_0 \cdot V_0 = 0.0576$ joules or $.5 \cdot q_0 \cdot V_0 = 0.0576$ joules

The textbook continues: "When the switch S is closed, the terminals of the charged capacitor are connected to those of a 4-μf capacitor, initially uncharged. The capacitors are then in *parallel* and their equivalent capacitance is

$C := C_1 + C_2$ $C = 1.2 \times 10^{-5}$ farads

"The original charge Q_0 becomes the total charge on the equivalent capacitor. The potential difference V (the same for both capacitors) is

$$V := \frac{Q_0}{C} \qquad V = 80 \quad \text{volts}$$

"The charges on the individual capacitors are now

$$Q_1 := C_1 \cdot V \qquad Q_1 = 6.4 \times 10^{-4} \quad \text{coulombs\_Q}$$

$$Q_2 := C_2 \cdot V \qquad Q_2 = 3.2 \times 10^{-4} \quad \text{coulombs\_Q}$$

"The final energy of the system is

$$.5 \cdot Q_0 \cdot V = 0.0384 \quad \text{joules}$$

"This is less than the original energy of .0576 joules, the difference being converted to energy of some other form." Of course, this is nonsense, and shows that existing theory is wrong. For the Reciprocal System, there must be *energy conservation*:

$$q_f := \sqrt{\frac{C}{.5} \cdot \left(.5 \cdot q_0 \cdot V_0\right)} \qquad q_f = 0.001176 \quad \text{coulombs\_q} \qquad V := \frac{.0576}{.5 \cdot q_f} \qquad V = 97.97959 \quad \text{volts}$$

This electrical quantity must be apportioned between the capacitors based on their capacitance:

$q_1 := C_1 \cdot V$ $\qquad q_1 = 7.838367 \times 10^{-4}$ coulombs_q

$q_2 := C_2 \cdot V$ $\qquad q_2 = 3.919184 \times 10^{-4}$ coulombs_q $\qquad q_1 + q_2 = 0.001176$ (checks)

Therefore the first capacitor loses *some* of its electrons, and it loses some energy per electron (voltage), which is given up to the electrons electrically forced into the second capacitor. The second capacitor gains electrons (some of which, though not all, come from the first capacitor), and these end up having the same energy (voltage) as those remaining in the first capacitor. Electric charge plays no role here; *the error in conventional theory is in applying charge conservation to this problem!*

Therefore, *energy is conserved* in this action, according to the Reciprocal System. There is no need for some spurious explanation like that from the textbook: "If the resistance of the connecting wires was large, most of the energy was converted to heat. If the resistance was small, most of the energy was radiated in the form of electromagnetic waves." No one has ever measured this alleged radiation!

4. Quantity Relations

Now we turn to the issue of quantity. How many electrons are in the capacitor(s)? According to conventional theory:

$$q_{convent} := \frac{Q_0}{Q_{uc}} \quad \text{electrons} \tag{7}$$

For the sample problem: $q_{convent} = 5.992277 \times 10^{15}$ electrons

According to the Reciprocal System,

$$q_{n\_0} := \frac{q_0}{q_{uc}} \quad \text{electrons} \tag{8}$$

For the sample problem, initially: $q_{n\_0} = 5.992277 \times 10^{15}$ electrons

At the end: $q_{n\_f} := \frac{q_f}{q_{uc}}$ $q_{n\_f} = 7.339011 \times 10^{15}$ electrons

$$q_{n\_f} - q_{n\_0} = 1.346734 \times 10^{15} \qquad \frac{q_{n\_f} - q_{n\_0}}{q_{n\_f}} = 0.183503$$

The *difference* in quantity represents the number of *other* (massless, chargeless) electrons moving into the second capacitor, the so-called *displacement current*. These electrons were already *in the connecting wires or the plates* at the start of the process; they just needed a *push* (voltage) to get them into the second capacitor. In this problem, 18.35% of the total number of electrons come form the connecting wires.

The author has conducted numerous experiments with many different capacitors and has verified *energy conservation*.

References

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[2] D. Larson, *Basic Properties of Matter* (Salt Lake City, UT: International Society of Unified Science, 1988).

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[4] R. Satz, "Permittivity, Permeability, and the Speed of Light in the Reciprocal System," *Reciprocity*, Vol. XVIII, No. 1, Winter 1988-1989.

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