Coulomb interaction does not spread instantaneously

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Abstract

The experiment is described which shows that Coulomb interaction spreads with a limit velocity and thus this kind of interaction cannot be considered as so called "instantaneous action at a distance"

I. INTRODUCTION

As shown in previous works by one of the authors of this article [1-4], instantaneous action at a distance is the direct consequence of generally accepted classical electrodynamics. Particularly in the aforementioned works it was shown that the Coulomb field (unlike a so called *free* field) is spread instantaneously. On the other hand theories exist which affirm that any kind of electric field spreads with a limited rate, but these theories require significant modification within classical electrodynamics [5]. However, one cannot choose theoretically one theory over another; it must be done through experiment. Thus, the propose of this present work is to verify experimentally if the Coulomb field is really spread instantaneously or not.

In the following section we describe an experiment which provided us with appropriate framework for verifying the instantaneous spread.

II. EXPERIMENTAL EQUIPMENT

In order to determine the velocity of the Coulomb interaction, a Coulomb electric field generator, which rapidly changes its magnitude, and antennas which can register this electric field, are necessary.

A. The generator

The generator consists of two hollow metallic spheres a and b, connected electrically by means of a plasma discharger and discharge cable (fig.1):

Fig1. Coulomb electric field generator (regular configuration)

The radius of each sphere is R, the distance between the centres of the spheres is equal to l. Let us investigate the field at point A, which is on a line which passes through the centres of both spheres and which is at a distance L from the centre of sphere b. Let us call this line the "experimental axis".

Sphere b is charged electrically with a positive charge as far as the break-down voltage of the discharger. Then, a spark flies through the discharger, a spark which is a very brief plasma cord of little electrical resistance. As we can see, both spheres are electrically connected during the spark by means of the discharge cable alone. Thus begins a process of discharge, during which a part of the electric charge initially accumulated on sphere b oscillates between sphere a and sphere b with a high frequency. The distance between this mobile part of the charge and point A changes with the same frequency. Consequently, the electric field at point A also oscillates according to the Coulomb law. This field has colinear direction at the experimental axis.

It is important to note that because of the cilindrical symmetry of the experimental construction at point A, the electric field is not perceived due to an electromagenetic transversal wave, regardless of the values of the distances l and L.

In our examinations further on we will use the quasi-stationary approximation. This approximation can be correctly applied only if the length of the discharge cable, the radius of the spheres and all distances in our experiment are less than the wavelength of the proposed field. All our calculations will be carried out supposing that "instantaneous action" exists, that is, the velocity of propagation of the Coulomb electric field is infinite. In this case the wavelength will have an infinite value. In case it turns out that the electric field is propagated with a finite velocity and if the use of the quasi-stationary approximation is not correct, our calculations can only be considered as the first aproximation in the description of the process.

From an electric point of view, both spheres a and b are condensers. Their capacitance is the sum of each sphere's own capacitance and the capacitance in common with the other sphere:

$$C = C_{own} + C_{a,b}$$

The discharge cable can be presented as an induction L_d and a resistance R_d connected in series. When the discharger is in the state of conduction it can be substituted by a short circuit. Consequently, the variable field generator can be presented as a dipole (fig.2):

Fig.2. Electric diagram equivalent to the electric field generator.

$q_a(t)$ and $q_b(t)$ are the electric charges corresponding to spheres a and b and $U_a(t)$ and $U_b(t)$ are the corresponding potentials. Applying the second law of Kirchoff for this circuit and taking into consideration that each sphere is in itself an equipotential surface, we obtain:

$$R_d i(t) + L_d \frac{di(t)}{dt} - \frac{1}{C}\left[q_a(t) - q_b(t)\right] = 0, \tag{1}$$

where $i(t)$ is the current which passes through the discharge cable.

The process begins by electrically charging sphere b as far as the break-down voltage of the discharger U_{b0}. Then, when the spark appears on the surface of sphere b a charge of

$$Q_0 = CU_{b0}$$

has accumulated.

Just as during the process of discharge there is no charge leak, and the capacitance of the discharge cable is not appreciable, it is always

$$q_a(t) + q_b(t) = Q_0. \tag{2}$$

From equations (1) and (2), for the charge $q_b(t)$ we obtain the following differential equation:

$$\frac{d^2q_b(t)}{dt}+\frac{R_d}{L_d}\,\frac{dq_b(t)}{dt}+\frac{2}{L_dC}q_b(t)=\frac{Q_0}{L_dC} \tag{3}$$

with the initial conditions in the instant $t=0$:

$$\left.\frac{dq_b(t)}{dt}\right|_{t=0}=0; \qquad q_b(t)|_{t=0}=Q_0.$$

The solution to this differential equation is:

$$q_b(t)=q_m e^{-\beta t}\cos(\omega t+\alpha)+\frac{Q_0}{2}, \tag{4}$$

where

$$\beta=\frac{R_d}{2L_d};\;\; \omega=\sqrt{\omega_0^2-\beta^2};\;\; \omega_0=\sqrt{\frac{2}{L_dC}};\;\; \tan\alpha=-\frac{\beta}{\omega};\;\; q_m=\frac{Q_0}{2\cos\alpha}.$$

For the electric charge of the sphere a we obtain:

$$q_a(t)=Q_0-q_b(t)=\frac{Q_0}{2}-q_m e^{-\beta t}\cos(\omega t+\alpha). \tag{5}$$

The electric current discharge $i(t)$ is given by the expression:

$$i(t)=-q_m\omega_0 e^{-\beta t}\sin\omega t. \tag{6}$$

The potential of the electric field at point A will be the sum of the potentials generated by the charges $q_a(t)$ and $q_b(t)$

$$\begin{aligned}\varphi_e(L,t)&=\frac{q_a(t)}{4\pi\varepsilon_0(L+l)}+\frac{q_b(t)}{4\pi\varepsilon_0 L}=\\&=\frac{Q_0}{8\pi\varepsilon_0}\,\frac{2L+l}{L(L+l)}+\frac{q_m}{4\pi\varepsilon_0}\,\frac{l}{L(L+l)}\,e^{-\beta t}\cos(\omega t+\alpha).\end{aligned} \tag{7}$$

As we pointed out earlier, in the case of the existence of a finite velocity of the propagation of the Coulomb interaction, the application of the quasi-stationary approximation can be not correct and the processes in the generator may only be described qualitatively. However, the basic conclusion of the consideration made is correct: there are rapid spatial oscillations of the electric charge along the axis of the experiment that produces a rapid change of electric field at the point A.

B. The antenna

The antenna is a metallic hollow sphere of radius r, connected by means of a cable to the earth (fig.3).

Fig.3. Electric antenna.

It is accepted that the earth has a potential equal to zero. Thus, the potential on the surface of the antenna will always be equal to 0 due to the connection to the earth. When there is no external electrical field the sphere of the antenna is not electrically charged. Let us suppose that there is an external electrical field whose source is sufficiently far away from the sphere so that we can accept that the potential of the external field is not altered considerably in the place of the sphere. Then we can talk of the potential in the region on the sphere of the antenna $\varphi_{e,a}(t)$. In this case, there is charge $q(t)$ of such magnitude on the surface of the sphere that equation (8) is fulfilled:

$$\varphi_{e,a}(t) + \varphi_{i,a}(t) = \varphi_{e,a}(t) + \frac{q(t)}{4\pi\varepsilon_0 r} = 0, \tag{8}$$

where $\varphi_{i,a}(t)$ is the potential on the surface of the antenna originated by charge $q(t)$, which comes from the earth. Therefore:

$$q(t) = -\varphi_{e,a}(t)\, 4\pi\varepsilon_0 r. \tag{9}$$

When the electric field changes, charge $q(t)$ changes. This means that the electric charge passes through the connecting cable between the antenna and the earth, in other words, electric current passes through the connecting cable:

$$i_a(t) = \frac{dq(t)}{dt} = -4\pi\varepsilon_0 r\, \frac{d\varphi_{e,a}(t)}{dt}. \tag{10}$$

The current $i_a(t)$ can be recorded.

C. Experimental configuration

The Coulomb electric field generator and two antennas are at a distance F from each other, as shown in fig. 4:

Fig.4. The main diagram of the experimental configuration.

The distance from the centre of antenna 1 to the centre of sphere b of the generator is L. In the cables, which connect the antennas to earth, small R_{50} magnitude resistors are included, which do not affect the working of the antennas. The voltage fall on these resistors is proportional to the current and is supplied at both input points to a rapid digital oscilloscope. In this way, the currents passing through the cables are recorded.

The discharge in the discharger gives rise to an oscillatory displacement of electric charge along the experimental axis. For this reason, a change in the Coulomb electric field will be emitted from the generator through the same axis. This change, reaching antennas 1 and 2 will cause the current to flow through the R_{50} resistors and thus, a U_R voltage fall upon them. In the case of "instananeous action", when the Coulomb electric field appears simultaneously in the whole space, this $U_{R1}(t)$ voltage fall for antenna 1 satisfies the following differential equation:

$$\frac{dU_{R,1}(t)}{dt} + \frac{1}{4\pi\varepsilon_0 r R_{50}} U_{R,1}(t) = \frac{d\varphi_{e,1}(t)}{dt}, \tag{11}$$

where $\frac{d\varphi_{e,1}(t)}{dt}$ is the first derivate of the potential of the Coulomb electric field in the region of antenna 1, originated by the generator. The inicial condition $U_{R,1}(0) = 0$ gives us the following solution of this equation:

$$U_{R,1}(t) = \frac{D}{(\beta - B)^2 + \omega^2} \left[-\omega e^{-Bt} + \omega e^{-\beta t} \cos \omega t + (\beta - B) e^{-\beta t} \sin \omega t \right], \tag{12}$$

where

$$D = \frac{q_m \omega_0}{4\pi\varepsilon_0} \frac{l}{L(L+l)}; \qquad B = \frac{1}{4\pi\varepsilon_0 r R_{50}}.$$

The voltage fall $U_{R,2}(t)$ corresponding to antenna 2 obeys the same law and the difference is only in the value of the coefficient D. For antenna 2:

$$D = \frac{q_m \omega_0}{4\pi\varepsilon_0} \frac{l}{(L+F)(L+F+l)}.$$

The tension $U_{R,1}(t)$ has been supplied to channel 1 of the oscilloscope by means of a coaxial cable, and the tension $U_{R,2}(t)$ - at channel 2. Consequently, **if "instantaneous action" exists, two impulses of equal form and different amplitude should be**

visible on the display of the oscilloscope, which appear simultaneously and develop in a parallel fashion in time. We assume that the air and coaxial cable are linear structures which possess no noticeable dispersion for the frequencies used. The other possibility is that the change in the Coulomb electric field is propagated at a finite velocity, that is, a wave exists. So, the front of the wave produced by the Coulomb electric field will arrive at antenna 1 first and then at antenna 2 after a certain interval of time Δt. Consequently, two impulses displaced in time Δt will be seen on the display of the oscilloscope, which will obey the equation:

$$\Delta t = \frac{F}{v},$$

where v is the velocity of propagation of the wave. The interval can be measured experimentally and the velocity of the front of the wave v can be obtained, which by its essence, is group velocity.

III. PRACTICAL EXPERIMENTAL EQUIPMENT

The Coulomb electric field generator consists of two standard Van de Graaf generators with the radius of the balls equal to 10 cm. One of the generators becomes electrically charged during the experiment, and we shall call it “active”. The other, which is only used for receiving a part of the charge of the active generator through the discharger and the discharge cable, we shall call “passive”. The generators are elevated on insulating supports until the centre of the balls reaches a height of 1.7m with reference to the earth’s surface. The distance between the centres of both balls is 3 m. The antennas are spheres of a radius of 9.5 cm, whose centres can be found 1.7 m from the earth’s surface. The centre of antenna 1 is to be found at a fixed distance of 0.5 m from the centre of the ball of the Van de Graaf active generator, and the distance between the centres of both antennas varies. Fig. 5 gives an overview of the practical experimental equipment:

Fig.5. Practical experimental equipment (overview).

Antenna 1 is slightly displaced from the experimental axis so as not to obstruct the direct visibility between the Van de Graaf and antenna 2 generators. If this does not happen, antenna 1 will behave like a screen and the signal from antenna 2 decreases drastically. Both antennas are connected at the input of the oscilloscope by means of two high frequency coaxial cables with the characteristic resistance of 50 Ohms. Antenna 1 is connected to channel 1 and antenna 2 to channel 2. Each cable is impedance balanced on both sides. The lengths of the cables are equal, with an uncertainty of 5 mm. The noise at the input of the oscilloscope has a value of 10 mV_{p-p}. The measurement sensitivity of the temporal intervals is 0.3 ns. The signals which are due to the effects of the apparatus (signal penetration from one of the channels of the oscilloscope to the other, bad earth contact, signal penetration through the power supply cables, etc.) and inductions in the coaxial cables have already been measured. With this purpose, an experiment has been carried out, in which antenna 1 has approached to a maximum the active Van de Graaf generator maintaining constant the other variables of the experiment; the sphere of antenna 2 has been disconnected from the coaxial cable. The signal in channel 2 of the oscilloscope in the case of various distances bewteen the end of the coaxial cable corresponding to antenna 2 and the active Van de Graaf generator has been measured. The result is that in all cases, the signal obtained has a value below 0.5% of the useful signal (with the sphere of antenna 2 connected). An analogous experiment has been done with antenna 1, commuting the exploration of the oscilloscope to antenna 2. The result was similar. This allows us to exclude corrections in order to avoid apparatus effects.

The temporal symmetry of the antennas of the experimental equipment has been verified. The defect of the aforementioned symmetry can be obtained from a different length of the coaxial cables or an assymetry of both channels of the oscilloscope. With this end, both antennas are disposed symmetrically side-by-side at a distance equal to that of the active Van de Graaf generator. The delay of the front flank of the impulse of channel 1 with reference to the front flank of the impulse of channel 2 in the case of various combinations of the sensitivity of the vertical amplifiers of the oscilloscope has been determined. The result is that the delay in all cases is below 0.3 ns. For this reason we have considered that, in the following measurements and calculations, the assymetry shown in time is equal to 0.3 ns.

The experiments were carried out in the following manner: Antenna 2 is placed at a certain distance F from antenna 1. The oscilloscope is put to work in the framework of the exploration of single firing with a sinchronization along the negative front flank of the impulse of channel 1. One waits until the moment of the spontaneous jump of the spark between the electrodes of the discharger. The information of the impulses of antennas 1 and 2 is recorded in the memory of the oscilloscope. Then the analysis of the information begins.

It has been predicted theoretically and demonstrated experimentally that the first flanks of impulses from antennas 1 and 2 are negative and have the same form. For this reason, by means of an adjustment of the sensitivity of the vertical amplifiers of both channels of the oscilloscope, its parallelism is reached (fig.6) and then the delay Δt of the impulse flank of antenna 2 with reference to the impulse flank of antenna 1 is measured.

Fig.6. Disposition of the antennas' impulses on the display of the oscilloscope.

This investigation has been repeated for different distances between antennas 1 and 2 in the interval of 0.50 m to 1.50 m spaced uniformly 0.10 m. For each value of distance the measurement has been reiterated 20 times. With the purpose of proving what influence the power supply cables and the oscillations (which are gradually propagated along them) have, a complete cycle of investigations has been carried out, with the configuration shown in fig.7:

Fig.7. Coulomb electric field generator (configuration with a turn of 180°).

The Coulomb electric field generator is turned 180° on the horizontal plane, and with this the passive and active Van de Graaf generators have changed places. At the same time, the disposition of the power supply cables and the block of antennas is unalterable.

According to the theoretical description, the front flanks of the impulses of channels 1 and 2 in this case should invert their sign from negative to positive and the impulses of both channels should maintain sameness of form. This is observed in practice and the results of the investigation for Δt do not differ significantly from the results obtained using the basic configuration. A basic parasite factor is the transversal electromagnetic wave which is emitted from the Coulomb interaction generator and is reflected on the earth's surface. It is slightly different from the Coulomb interaction by the sign of its first front and by the sign of the flank of the first impulse which can be seen on the oscilloscope's display respectively. In the case of the basic configuration (fig.5), the first front of the Coulomb interaction is always negative, while the first front of the transversal electromagnetic wave is positive. This can be explained using the Electrodynamic theory in the case of the construction shown of the Coulomb electric field generator [6]. In order to separate the Coulomb interaction from the signal originated by the transversal electromagnetic wave, the delay observed from the first front of the transversal electromagnetic wave with respect to the first front of the Coulomb interaction is of assistance. This additional time is that needed by the transversal electromagnetic wave in order to arrive at the earth's surface and then to the antenna, while the Coulomb interaction is propagated along a straight line. With the purpose of decreasing additively the amplitude of the transversal electromagnetic wave, the discharge cable was electrically and magnetically screened. The aformentioned experimental facts oblige us, in order to avoid the influence of the transversal electromagnetic wave on the experimental results, to work with a maximum distance of 1.5 m between the antennas. In the absence of "instantaneous action", it is necessary to determine which part of our measuring signal is due to the transversal electromagnetic wave and which part is due to the lonitudinal component of the electric field. Our antennas react to the potential of the electric field and for this reason cannot distinguish both components from the electric field. With the purpose of separating them, screens have been used which considerably decrease the intensity of the transversal electromagnetic wave without altering to a relevant degree the amplitude of the longitudinal component. Two types of screens have been used: a metallic mesh and a thin layer of aluminium. In order to reject the influence of the waves reflected in the varying objects, the antenna was placed in a thick aluminium cylinder with one end sealed and the other open, connected to the earth. The opening of the cylinder was directed towards the Coulomb interaction generator. The screens were placed covering this opening. The metallic mesh is made of iron wire with a diameter of 1mm and the mesh measures 5 mm $\times$ 5 mm. Its effectiveness as armour for the transversal electromagnetic wave with the frequency obtained by us for 9.2 MHz is greater than 50 dB[7]. This means that the signal due to this wave decreases considerably and now barely affects the results of the experiment. In this case, we register a decrease of our signal of just 0.5 dB. Because of this, we can conclude the practically all of our signal comes from the logitudinal component of the electric field generated by the Coulomb interaction generator. We repeated the same experiment using a 0.02 mm thick aluminium sheet as a screen. Its effectiveness as armour for the transversal electromagnetic wave of the aformentioned frequency is greater than 80 dB[7]. The decrease in the signal is just 1 dB, and this result confirms the previous conclusion that our signal from the antenna is only due to the longitudinal component of the electric field.

IV. EXPERIMENTAL RESULTS

The results of the experiment are presented in fig.8.

Fig.8. Relation between the delay Δt between the impulses of both antennas and the distance F between the antennas.

The distance F between antenna 1 and antenna 2 has been traced along the horizontal axis. The delay Δt of the signal of antenna 2 with reference to antenna 1 has been traced on the vertical axis. The uncertainties of the measurement results have also been marked on the distance axis and the time axis.

The straight line, which is presented in the drawing, expresses the empirical linear relation, which relates distance F to the delay Δt. This has been determined by means of the minimum square method. The line, which corresponds the the speed of light $c = 3.00 \times 10^8$ m/s cannot be differentiated from the line shown by the limited exactness of the representation on the drawing.

Following a statistical treatment one obtains, that with a reliable probability $P = 0.95$ the group velocity of the propagation of the Coulomb interaction is found in the interval [8]:

$$v = (3.03 \pm 0.07) \times 10^8 \text{ m/s}$$

We would like to call this type of field propagation "*Coulomb waves*", which, of course, has no analogy with the usual electromagnetic waves.

V. CONCLUSIONS

P.A.M. Dirac wrote ([9], p. 32): "*As long as we are dealing only with transverse waves, we cannot bring in the Coulomb interactions between particles. To bring them in, we have to introduce longitudinal electromagnetic waves and include them in the potentials* A_μ." It is known, however, that generally accepted Maxwellian electrodynamics forbids the spreading of *any* longitudinal electro-magnetic perturbation in vacuum. So Dirac writes ([9], p. 32): "*The longitudinal waves can be eliminated by means of a mathematical transformation...*". But after this transformation one gets the theory in which a charge is *always* accompanied by the Coulomb field around it, i.e. ([9], p. 32) "*Whenever an electron is emitted, the Coulomb field around it is* `simultaneously` *emitted, forming a kind of* `dressing` *for the electron. Similarly, when an electron is absorbed, the Coulomb field around it is* `simultaneously` *absorbed*".

In accord with the above it was shown [1-4] that the Coulomb interaction "works" *instantaneously*, if one accepts that basic equations of classical electrodynamics are right. On the other hand our experiment shows that the Coulomb interaction, at least, does not spread instantaneously. The proper inference from this experiment is that the Coulomb interaction cannot be considered as so called "instantaneous action at a distance" and, in turn, the basic equations of classical electrodynamics *can be incomplete* and moreover, their application is even limited in classical electrodynamics.

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