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Teaching Coulomb's Law through the interaction of three charged particles

Jizreel Pereira da Silva

School of Education, International University Center, Nilópolis, Brazil
jizreelsilva@yahoo.com.br
Orcid ID: https://orcid.org/0000-0002-7874-1648

Abstract: *The study of Coulomb's law was developed in the classroom with 23 students of the 3rd year of high school in a class in São Cristóvão, Rio de Janeiro, Brazil. The work begins with the theoretical discussion based on the emphasis of Coulomb's law, going through the historical factor and mathematical tools characteristic of the law for later virtual experimental activity, using the computational resource of the WOLFRAM project for the treatment of the interaction of three charged point particles, with the objective of complementing and consolidating the understanding about a part of electrostatics. The students individually developed the experiment and through the data, we raised an analysis and discussion of the graphs obtained, seeking to emphasize the relationship between theory and practice for a better understanding of the teaching-learning process of physics. By using programs such as Wolfram and for this work on charged particles, we developed in the students the ability to assimilate the content and experimental notion, even if virtually, facilitating the work in the teaching-learning process.*

Keywords: Coulomb; particle; charge; student; electrostatic interaction.

1. INTRODUCTION

In all classes, even though most of the time I use theoretical expository resources, I try to innovate in one way or another the teaching-learning process, because I know how important it is for students that in this moment of teacher-student interaction, it has some meaning and that students can feel part of this process.

We developed a work so that students had a more autonomous posture in the activities according to the belief of Moreira, where we seek to develop experimental activities, scientific skills, meaningful learning, dialogicity and criticality, with the involvement of research projects in the classroom [1].

At first, we discussed electric charges with the students, where we commented on the physics of electromagnetism such as lightning, solar energy and electronic devices that we use in everyday life, such as computers, notebooks, cell phones, televisions, etc.

We commented in an introductory way about the beginnings of the study of electromagnetism through the Greeks, rubbing a piece of amber, a kind of fossil resin with shades ranging from yellow to brown, used in the making of ornamental objects and this became known as electric force and through the studies of William Gilbert (1544-1603), concluded that the natures of a magnet and amber are different, being called electrical materials and the compass was oriented due to the magnetism of the Earth.

We went through the discussion with the students about Michael Faraday (1791-1867), where in laboratories he developed his experiments on electricity, and James Clerk Maxwell (1831-1879), seeks to mathematize Faraday's experimental works, also putting his own ideas and giving consistency to electromagnetism. We discuss the positive and negative signs of electric charges and aspects of attraction and repulsion for further virtual experimental activity [2].

Following this previous work, we followed the electrostatics work and, in this article, we present the structure of the work, commenting on the treatment of Coulomb's law and subsequent virtual experimental apparatus to consolidate learning and understand the functioning and importance of Coulomb's work and finally, we will present the analysis and discussion of the results, showing graphically how the students operated with the system determined by the teacher.

2. COUMLOMB'S LAW

Charles Augustin de Coulomb (1736-1806) invented a torsion balance to study the force exerted between two loads. He placed charged spheres, which were much smaller than the distance between them, and were treated as punctate charges. The idea is that they would be geometrically identical to ensure electrification when they are put in contact. When electrifying the spheres of the scale, they repelled each other and Coulomb noticed the proportion in the measurement of the torsion angle and the intensity of the electric force between the two charges, evaluating this whole process [3,4].

Fig. 1. The torsion scale [3].

He repeated the experiment several times with other pairs of electric charges, leading to his law in which: "*The force between two-point charges is exerted along the line between the charges. It varies with the inverse square of the distance separating the charges. The force is repulsive if the charges have the same sign and attractive if they have opposite signs*" [4].

A charged particle exerts an electrostatic force on another charged particle, where the direction of the force is that of the line connecting the particles, but the direction depends on the sign of the charges. The particles will repel each other if they have the same sign, that is, they will tend to move away from each other and if the particles have opposite signs, they will attract each other.

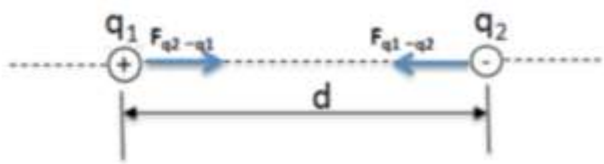

Fig. 2. Action of forces on electric charges [5].

Based on this premise, Coulomb's law is the equation used to calculate the electrostatic force exerted between charged particles. If we consider particle 1 with charge *q1* and particle 2 with charge *q2* (independent of the charge sign), then this equation is expressed in the form

$$F = k_0 \frac{q_1 q_2}{r^2} \quad (1)$$

Being k_0 the constant related to the medium in which the charges are, in this case in vacuum, with a value of $k_0 = 9.0.10^9 \frac{N.m^2}{C^2}$, called the electrostatic constant of the vacuum, in the International System of Units.

Coulomb found that the intensity of the electric force depended on the modulus of the two electric charges, the distance separating the two particles, and the environment in which the electric charges are found.

Since the Coulomb equation was developed only for two charged particles, then we must work out an equation that can present the interaction force for three or more particles. In this case, we must analyze the pairs of particles, determining the electrical force on each pair. In the case of this work, we developed a study for the treatment of three particles A, B and C.

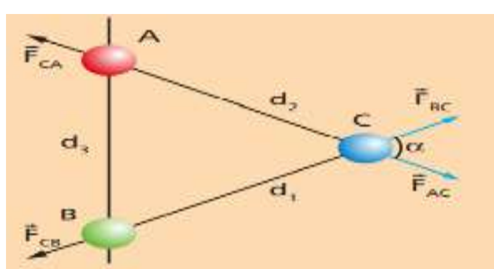

Fig. 3. Interaction of the electric force in the three charged particles [3].

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According to figure 3, we analyze the electrical force in each pair and for the pair AB, we have the force in the form

$$F_{AB} = k\frac{q_A q_B}{d_3^2}\ , with\ q_A = q_B = q,$$

$$F_{AB} = k\frac{q^2}{d_3^2} \tag{2}$$

$$F_{BC} = k\frac{q^2}{d_1^2}\ , F_{AC} = k\frac{q^2}{d_2^2} \tag{3}$$

With k for any dielectric medium. Similarly, for other pairs in this case, the equation is similar. Since the force vectors $\overrightarrow{F_{AC}}$ and $\overrightarrow{F_{BC}}$, form an angle with each other α, then we can find the modulus of the net force in C, for example, using the parallelogram rule, so we have the net force in the form,

$$F_{RC} = \sqrt{{F_{AC}}^2 + {F_{BC}}^2 + 2.F_{AC}.F_{BC}\cos\alpha} \tag{4}$$

3. Research Method

In the first meeting, the study of Coulomb's law was carried out in a theoretical way with 23 students from a school in São Cristóvão, Rio de Janeiro, Brazil. The students were identified by the alphabet from *A* to *W*.

In the second meeting, we carried out the virtual experimental resource for the theme treatment, through the WOLFRAM demonstration project [6].

The demonstration aims to analyze the interaction of three-point loads. The "student" operator can control the distance between load 1 and load 2 and from load 1 to load 3 ranging from 20 to 70 meters. The angle in radians between charges 2 and 3 ranges from 0.5 to 3.14 and the charges of particles ranges from -1.10^{-3} to 2.10^{-3} for charges 1 and 2, and 0 to 1.10^{-3} for particle 3.

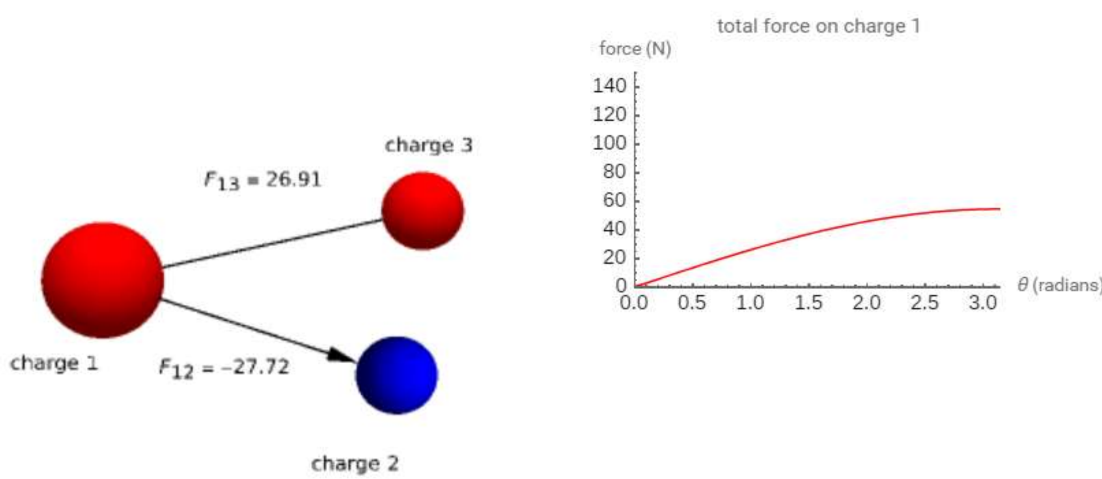

Fig. 4. Interaction of the electric force on the left-hand particles of charge 1 ($1.9.10^{-3}$), charge 2 (-8.10^{-4}), and charge 3 (9.10^{-4}). On the right side, the graph of the total force on particle 1 with respect to the angle between particles 2 and 3.

The 23 students individually performed the experiment presented by the teacher in the classroom, using a notebook and projecting the image so that all students could observe the activities being carried out. The students, as student-researchers, developed the activities and were supervised by the teacher to achieve the proposed objective.

4. Results and Discussion

Also analyzing the data of student *L*, for the purpose of example in the discussion, we talked to the students to discuss graphically the result of the data of student L, in relation to Coulomb's Law, observing the forces between particles 1 and 2 and between particles 1 and 3, as well as the relationship with distance.

Since the Coulomb equation was developed only for two charged particles, then we must work out an equation that can present the interaction force for three or more particles. In this case, we must analyze the pairs of particles, determining the electrical force on each pair. In the case of this work, we developed a study for the treatment of three particles A, B and C.

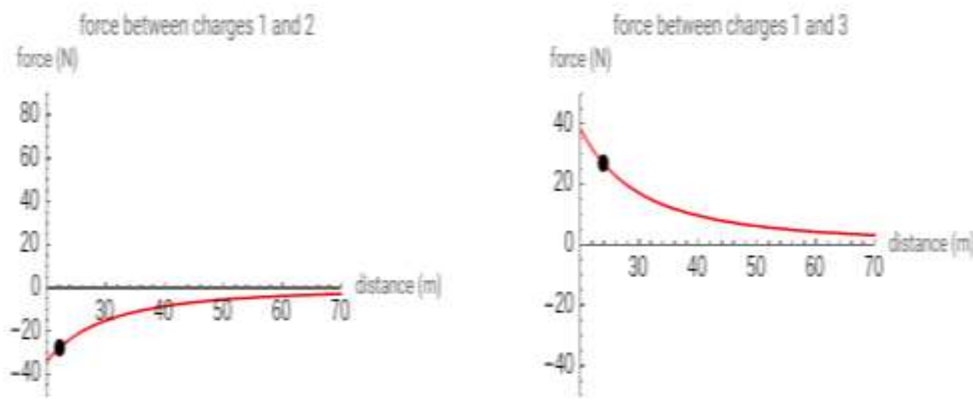

Fig. 5. Graph relating the distance and electrostatic force between particles 1 and 2 (left). Graph relating the distance and electrostatic force between particles 1 and 3 (right).

The students realized that the graphs obey the calculations performed, as well as Coulomb's law. They realized that if the particles interact in a linear way, the mathematical treatment will be different, because the rule of the parallelogram is when a kind of "geometry" is observed in the positions of the three particles, giving the visibility of a triangular shape, that is, each particle at the vertex of the triangle.

For this case, the students understood the use of the parallelogram rule, in view of the angular, natural appearance of the vertex.

classroom, because there are many open questions in science and even survey of questions on the part of the students about the universe and its daily life, where it is observed the posture of a researcher as a problem solver.

5. Final Considerations

All the mathematical tools used in the work are accessible to students. We discuss theoretically, develop exercises and finally carry out an experimental activity to consolidate the teaching-learning process, about the treatment of Coulomb's law with the application in the interaction of three charged particles.

The activity developed by the student's provided richness in individual educational knowledge and continued the motivation of the studies of physics, on electrostatics.

The experiment of the interaction of three charged particles developed the students' ability to assimilate and understand Coulomb's law and how the process takes place according to the data of each particle, such as charge and distance between them.

As usual, the discussion together with the students, analyzing the graphs and understanding the behavior, makes it solidly add meaning and stimulus for further studies in various segments of physics.

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