Electric Charge

Physics

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Welcome to Electricity and Magnetism. We will be looking mainly at the characteristics and notions behind **charge** in this document.

§1 Charge

First off, it is worth noting that the world is made up of matter. Matter is made up of individual atoms. Inside these atoms are **particles**: **protons (+), neutrons,** and, **electrons (−)**. Charge comes from protons and electrons since neutrons are of neutral charge. You can think of charge as a force since that is how we will be studying it.

There are two important characteristics of charge which are included in the definition box for charge below.

> **Charge**: Electric charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field [1]. There are two types of charges; namely, positive and negative. The SI unit for charge is called a Coulumb and is denoted by a C. Though, it is common to denote charge with a q. Two important characteristics of charge: charge is **quantized** and charge is **conserved**.

§1.1 Conservation and quantization

So... what does quantized and conserved even mean? The simpler characteristic is that charge is conserved. What this means is that the net charge (total positive charge − total negative charge) cannot change in an isolated system. That is, the charge is determined by the number of protons and the number of electrons in an isolated system and that is it. No altering possible. However, as opposed to the ever so common conservation of momentum principle, the conservation of charge means that charge **can** be created or destroyed in an isolated system. More on this when we discuss conductors and induction (see section below).

Now onto quantization. I think a good mental framework to have about quantization is that it is similar to the idea behind the unit vector. We are essentially defining a new fundamental unit called the **elementary charge (e)**. So from now on, we can talk about charge in relation to the elementary charge (so in an exact sense, we talk about charge in discrete quantities instead of continious quantities). That is, "charges are quantized because the charge of any object are multiples of a fundamental quantity" [2]. So we now have a fundamental unit which relates all charges together since each charge can be defined in terms of e. Mathematically, the elementary charge defined in terms of Coulumb's is:

$$e = (1.602 \times 10^{-19})C$$

Another interesting note is that the elementary charge is equivalent to the charge carried by one proton. Thus, we denote that the charge of one proton is $1e$. So, not only are we standardizing all charges in relation to one fundamental charge, we are relating all charges to the charge of a singular proton (so you can think in terms of a proton charge if you'd like). Even more intrigueing, is that that the charge of one electron is $-1e$ which is exactly the negative of the charge of the proton. This fact has been experimentally confirmed.

§2 Charge as a force

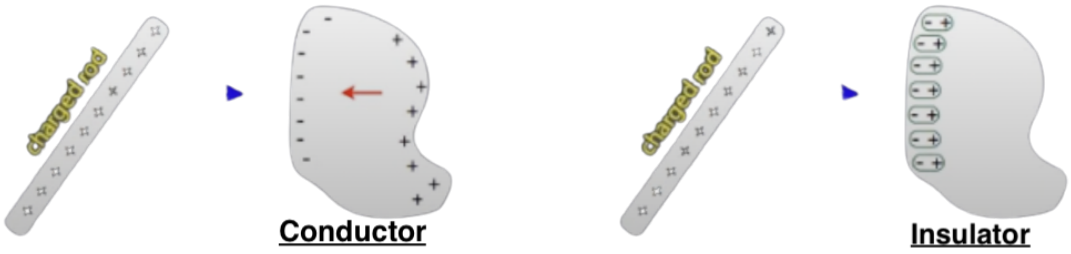
When dealing with physics problems in this quarter, we'll be performing calculations of various kinds of charges in isolated systems. Moreover, we will consider objects that do have some non-neutral charge (for the most part) such that interesting reactions will occur. Thus, you should be thinking of effects on charges as *forces*. More formally, we begin the study of the electric force, which acts on all objects with a property called charge [3].

The main thing you should know here is this:

> Two like charges (same polarity) repel each other while two unlike charges attract each other.

§2.1 Induction

Before we move on, it is worth mentioning this: how can you get something that isn't of static charge if you obey the conservation of charge principle? The answer is that you can transfer charge from one object to another via electron movement. And by obeying by the conservation of charge principle, if you transfer electrons from one object to another, not only does the recipient object become more negatively charged, the giving object becomes more positively charged. This movement of electrons is called **induction**, where charged is "induced" from one object to another. **Conductors** allow induction to happen easily since they contain electrons that aren't bound to any specific atoms. As such, they can easily move from object to object. Interestingly though, induction cannot quite occur via non-conductors (called **insulators**) because all electrons are bound to atoms. However, atoms themselves can become **polarized** meaning electrons can move around to certain sides of the atom itself which creates attraction or repulsion (but not induction). Another way of putting it is that "induction is the process and polarization is one of the means to do it" [7]. A good visual of this is shown below (diagram adapted from [4]).



§2.2 Coulumb's Law

As with all physical phenomena we have studied, we must be able to quantify electric force. That is exactly what Coulumb's Law does.

Coulumb's Law: Coulumb's Law quantifies the amount of force between two stationary, electrically charged particles [5].

Example:

$$\vec{F}_{12} = k\frac{q_1 q_2 \hat{r}_{12}}{r^2}$$

§2.3 Superposition

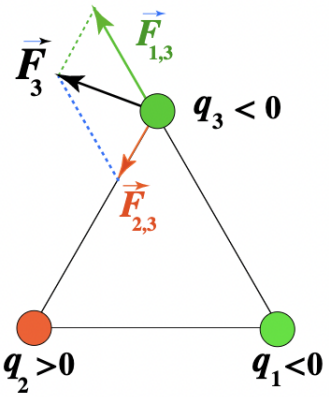
We have an intuitive understanding of how charges interact if there are two charges in the scenario, but what happens if there are more?

Principle of superposition: When there are more than two charges present, the vector sum of the forces exerted on one charge by the other charges represents the total force on that charge [6].

Mathematically, for $\vec{F}_3$ in some three charge system:

$$\vec{F}_3 = \vec{F}_{1,3} + \vec{F}_{2,3}$$

Visually (recall how to add vectors in space):



References

[1] *Electric charge - Wikipedia*. https://en.wikipedia.org/wiki/Electric_charge.

[2] *What is the meaning of statement, "charges are quantized"*. https://www.enotes.com/homework-help/what-meaning-statement-charges-quantized-gt-443833#:~:text=Charges%20are%20quantized%20because%20the,charge%20%2D%20or%20the%20elementary%20charge..

[3] *University Physics Volume 2 - OpenStax*. https://openstax.org/details/books/university-physics-volume-2.

[4] *AP Physics C - Charges and Coulomb's Law - YouTube*. https://www.youtube.com/watch?v=SeaW8nvIoMA&list=PLd2HWlWc-MswIOwpFIAkoPgmWXQichduW&ab_channel=DanFullerton.

[5] *Coulomb's law - Wikipedia*. https://en.wikipedia.org/wiki/Coulomb%27s_law.

[6] *Textbook Links — Lesson 1: Charge and Electric Forces — 8.02.1x Courseware — MIT Open Learning Library*. https://openlearninglibrary.mit.edu/courses/course-v1:MITx+8.02.1x+1T2019/courseware/802x_week01/802x_lesson_01/?activate_block_id=block-v1%3AMITx%2B8.02.1x%2B1T2019%2Btype%40sequential%2Bblock%40802x_lesson_01.

[7] *What is the difference between an induction and a polarization? - Quora*. https://www.quora.com/What-is-the-difference-between-an-induction-and-a-polarization.