General Physics - E&M (PHY 1308) Lecture Notes

Lecture 002: Electric Charge and Coulomb's Law (Wolfson 20.1-20.2)

SteveSekula, 24 January 2011 (created 19 August 2010)

no tags

Main Goals of this Lecture

- Define basic concepts in electricity: charge, units of charge, and force
- Define the mathematical relationship between charge and force exerted by one charge on another (Coulomb's Law)

Activities in this Lecture

1. Demonstrations of the electric force
2. The origin of electric force: electric charge
    a. Student Discussion: what is electric charge? See if they have any answers. (2 minutes)
3. Description of electric charge: fundamental measure, units, conventions for signs, examples of charges (electron, proton), conservation of charge
4. Interactive Effort: using the atomic theory of matter, predict what should happen to a candle flame in the presence of an electric field?

Electric Charge

- What is "electric charge"?
    - fundamentally, nobody really knows the answer to that yet
    - don't lose heart! Fundamentally, nobody really know what "mass" is either - however, we are familiar with mass because we spend our

lives pushing things around.
  - we understand "electric charge" in the same way that we understand "mass" - through observations of the natural world, careful measurement, and the use of the language of mathematics to express observations, develop frameworks to describe the world and make predictions about the outcomes of experiments

- Here are some things we DO know about electric charge
  - It comes in two varieties - positive and negative
    - Benjamin Franklin - yes, one of the Founders of the United States - is credited with devising this naming scheme
    - this naming scheme is VERY useful, because it connects directly to an observation: the total charge in any system is *THE ALGEBRAIC SUM OF THE INDIVIDUAL CHARGES IN THE SYSTEM*. For instance,

$$q_{total} = q_1 + q_2 + q_3 + ... = \sum_{i=1}^{N} q_i$$

  - It is a property that is "carried" by particles like electrons and protons

  - Total electric charge in a defined system (e.g. an enclosed region) is CONSERVED - that is, no matter what happens to the system the total charge cannot change. Charged particles may be created, or they may be annihilated, in various physical processes, but those processes cannot change the total electric charge.

Electric Charge Demonstrations

- Van de Graaf generator - sparks and lightning and shocks
- Capacitor + candle: demonstrate the behavior of ions in an electric force field
- Balloon simulator

Quantities of Charge

All electrons carry the same charge. All protons carry the same charge. The proton's charge has exactly the same MAGNITUDE as, but the opposite sign of, the electron's charge.

Given that the electron and proton are so different in many other ways (e.g. mass, radius, etc.) this is a remarkable fact.

The magnitude of the electron or proton charge is the **elementary charge**, e. Electrons have charge $-e$, and protons have charge $+e$. Electric charge is *quantized* - that is, there is a smallest unit below which you can no longer subdivide a system of electric charge. Charge only comes in discrete amounts.

And what is e? The Standard International (SI) unit of electric charge is the *Coulomb*, named after Charles-Augustin de Coulomb and denoted by a capital letter *C*. It is convention to define:

$$1C = 6.25 \times 10^{18} \text{ elementary charges}$$

Making the elementary charge:

$$1e = 1.60 \times 10^{-19} C$$

Exploring Charge

See the supplementary slides for Lecture 002 for movies and images that illustrate electric charge:

- The charged balloon demonstration and simulation
- The charged plastic comb water-deflection demo
- The beam tree as an example of charge and aesthetics
- Arc flash injury simulation using a dummy
- Fluffy carpet and the danger of touching grounded metal objects

Electric Force

As some of these demonstrations indicate, electric charge is able to exert a force. We tend not to notice this force most of the time because the electrons and protons in our bodies, and in the work around us, are largely paired up and thus electrically neutral (zero electric charge) on a human scale.

As the balloon demonstration and the funny video of the electric shock from the carpet illustrate, electric charge and force go hand-in-hand. Many observations and measurements of the relationship between:

- The magnitude of the charges involved
- the distance between the charges (it's direction AND magnitude)
- the sign of the charges
- the force exerted between charges

have been carefully studied. The result is mathematical statement that has been upheld by thousands upon thousands of repeated experiments carried out over hundreds of years - a LAW. This law is known as "Coulomb's Law":

$$\vec{F_{12}} = \frac{k \cdot q_1 \cdot q_2}{r^2} \hat{r}$$

where $\vec{F_{12}}$ is the force VECTOR (magnitude and direction) that charge 1 exerts on charge 2. k is a constant, determined from repeated experimentation, whose value is:

$$k = 9.0 \times 10^9 \mathrm{N} \cdot \mathrm{m}^2/\mathrm{C}^2$$

Let's draw a picture of this and illustrate the pieces of this formula. It combines two key areas of mathematics: standard algebra and vector algebra. The picture will help us to parse the meaning of this formula, considering two cases: a pair of like-signed charged, and a pair of opposite-signed charges.