Physics Electricity and Magenetism

Terry Yu

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§1 Electric Charges and Fields

§1.1 Electric Charge

We begin with the entity that causes the force of attraction/repulsion: **Electric Charges**. There are two types of electric charges.

Charges of the same sign repel each other (reffered to as **electrostatic repulsion**, and charges of opposite signs attract each ohter (aka **electrostatic attraction**.

Charges originate from the fact that everything around us is made of atoms; atoms are composed of three smaller particles, called **electrons**, **protons**, and **neutrons**. Electrons have a negative charge, and protons have a positive charge – an imbalance of these leads to a *net electric charge*.
Each object can be defined to have an *net electric charge*, commonly represented with the symbol q, with the units of in Coloumbs C. Electric charge can also be transferrred between objects, through the electrons transferring between individual atoms. It can, however, only be transferred in multiples of the elementary quantity

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

Note that while electrons are considered a fundamental particle (has no substructure), protons are not – made of *quarks*, which have fractional electric charges of $-\frac{1}{3}e$ and $\frac{2}{3}e$. A proton is made of 3 quarks such that the net charge ends up as $+e$.
Earth can be considered to have an infinite amount of electrons. When electrons can flow between an object and the Earth, it is regarded as *grounded*.

§1.2 Conductors and Insulators

Materials are often categorized based on their ability for electrons to flow through them.

Definition — A **Conductor** is an object or type of material that allows the flow of charge, whereas an **insulator** does not readily allow this flow.

What differentiates a conductor from an insulator is the atomic structure of the object; if there is a loose electron, then it is easier to knock the electron into a neighboring atom (these are called **conduction electrons**). Insulation materials lack these conduction electrons; making flow hard, or even impossible.

Definition — Bringing a charged object next to a conductor results in **polarization**, or the seperation of postiive and negative charge within an object.

An uncharged insulator is also able to be attracted to a charged body – as though the electrons don't transfer between atoms, each fall to one specific side, resulting in a net force.

Charging by Contact — Charging by contact results through the contact of an uncharged object and a charged object. The neutral object becomes being charged, due to the flow of electrons onto it through the charged object (once they are brought to contact).

Charging by Induction — When polarization is inducted into an object, one side of the object becomes charged – when the object is seperated into two pieces, or the positive side is grounded, then the individual whole object will become electrically charged.

Notice that charigng by contact generally results in a net postiive charge, whereas charging by induction (and then grounding) results in a net negative charge within an object.

§1.3 Electric Forces and Fields

Coloumb's Law — Two point charges with charge q_1 and q_2, seperated with displacement $\vec{\mathbf{r}}$, have a force between them of

$$\vec{\mathbf{F}} = k\frac{q_1 q_2}{\|\vec{\mathbf{r}}\|^2}\hat{\mathbf{r}}$$

where

$$k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$$

and ϵ_0 is the *electric constant*, or *permittivity*, with the value of

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2/\text{N m}^2$$

Each charge will have the same force, but in opposite directions, acting upon them (Newton's 3rd law).

The principal of superposition applies with Coloumb's law, with that

$$\vec{\mathbf{F}} = \vec{\mathbf{F}}_{12} + \vec{\mathbf{F}}_{13} + \vec{\mathbf{F}}_{14} + \cdots$$

Definition — A **field**, in physics, is a region where every single point has a value associated to it. Vector fields have a vector at each point, defined with a vector function; scalar fields also exist, with a scalar instead at each point.

A set of charges scattered around a region can be seen to create a vector field, where every single point has a vector as some amt of force.

Electric Field — Suppose that there are n charges $q_1, q_2, \ldots, q_n$ located at positions $\vec{\mathbf{r}}_1, \vec{\mathbf{r}}_2, \ldots, \vec{\mathbf{r}}_n$ away from a test charge Q. The total force on the test charge will be

$$\vec{\mathbf{F}} = Q\vec{\mathbf{E}}$$

where $\vec{\mathbf{E}}$ is the electric field, represented with

$$\vec{\mathbf{E}} = k\sum_{i=1}^{n} \frac{q_i}{r_i^2}\hat{\mathbf{r}}_i$$

The difference between evaluations of point charges and *continuous charge distributions*, where the charge is in a dimensional object, is minimal. If a charged object has a net charge of q, we can imagine it to be composed of many smaller elements of $\mathrm{d}q$. In different cases, charges are distributed dfiferently;

$$\begin{aligned} \mathrm{d}q &= \lambda\,\mathrm{d}x && \lambda \text{ is linear charge density} \\ \mathrm{d}q &= \sigma\,\mathrm{d}A && \sigma \text{ is surface charge density} \\ \mathrm{d}q &= \rho\,\mathrm{d}V && \rho \text{ is volume charge density} \end{aligned}$$

Evaluating such an integral is standard; just variable change the differential, and evaluate as normal.

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§2 Gauss Law

Definition — We can define the flux ϕ of an electric field $\vec{\mathbf{E}}$ to be

$$\phi_E = \oint \vec{\mathbf{E}} \cdot \mathrm{d}\vec{\mathbf{A}}$$

Notice how the surface integral is evaluated over a *closed* surface.

Gauss Law — We construct a *Gaussian surfacee* through a certain field of space, with an electric field $\vec{\mathbf{E}}$, the total flux ϕ_E through this surface is related with

$$\epsilon_0 \phi_E = \epsilon_0 \oint \vec{\mathbf{E}} \cdot \mathrm{d}\vec{\mathbf{A}} = q$$

where q is the net charge enclosed by the surface.

Theorem (Shell Theorems for Electric Field)

1. A uniform spherical shell of charge behaves, for external points, as if all its charge were concentrated at its center.
2. A uniform spherical shell of charge exerts no electrical force on a charged particle placed inside the shell.

A side note from this is that *the electric field vanishes inside a uniform shell of charge.*

An excess charged placed on an isolated conductor moves entirely to the outer surface of hte conductor. None of the excess charge is found within the body of the conductor.