Notes for PHYS 27200 - Electric And Magnetic Interactions

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These are lecture notes for fall 2023 PHYS 27200 at Purdue. Modify, use, and distribute as you please.

Contents

Course Introduction

This is a calculus-based physics course using concepts of electric and magnetic fields and an atomic description of matter to describe polarization, fields produced by charge distributions, potential, electrical circuits, magnetic forces, induction, and related topics, leading to Maxwell's equations and electromagnetic radiation and an introduction to waves and interference. 3-D graphical simulations and numerical problem solving by computer are employed throughout. For more information, consult the syllabus.

Equations

1. Coulomb's Law: $\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$
2. $\vec{E_1} = \frac{1}{4\pi\epsilon_0}\frac{q_1}{r^2}\hat{r}$
3. $\vec{F_2} = E_1 q_2$
4. Dipole moment between charges $-q$ and q separated by $\vec{s}$: $\vec{p} = q\vec{s}$

Eletric field

We can represent eletric fields as lines emenating from a point charge. The greater the density of the lines, the greater the strength of the electric field. Note that at the origin, the force is undefined (infinite), since $|r| = 0$.

Consider the relative strengths of the electric and gravitational fields. The gravitational force is given by $F_g = G\frac{m_1 m_2}{r^2}\hat{r}$, with $m_{electron} =$

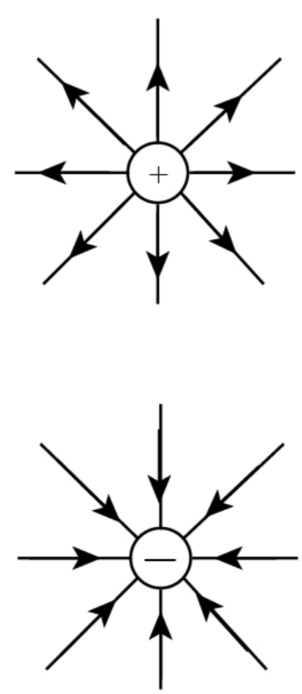

Figure 1: An eletric field coming from

$9 \times 10^{-31} kg$ and $m_{proton} = 1.7 \times 10^{-27} kg$. If we consider a hydrogen atom, then $r = 5.3 \times 10^{-11} m$. With $G = 6.7 \times 10^{-11}$, we have

$$F_g = \frac{(1.7 \times 10^{-27})(9 \times 10^{-31})(6.7 \times 10^{-11})}{(5.3 \times 10^{-11})^2} \approx O(10^{-46})N$$

Now, the eletric force is given by $\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$. The charge of a proton and eletric are $q_1 \approx q_2 \approx 1.6 \times 10^{-19} C$. Ergo, since $\frac{1}{4\pi\epsilon_0} \approx 8.99 \times 10^9 \frac{Nm^2}{C^2}$,

$$F_e = \frac{(8.99 \times 10^9 \frac{Nm^2}{C^2})(1.60 \times 10^{-19} C)^2}{(5.3 \times 10^{-11} m)^2} \approx O(10^-17)N$$

This means that $\frac{F_e}{F_g} \approx 2.27 \times 10^{39}$, meaning the eletric force is much stronger for these masses and charges than gravity. On scales as large as humans and planets, gravity is the dominant force because gravity is strictly additive.

For sufficient distances, the eletric field of a uniformly charged spherical shell resembles the eletric field of a point charge.

That means for $r >> R$, $\vec{E_{sphere}} = \frac{1}{4\pi\epsilon_0}\frac{q_1}{r^2}\hat{r}$ This holds only for outside the sphere. Inside, it can be shown that the electric field is zero.

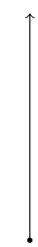

Figure 2: Notice how a circle resembles a point from a great distance.

Superposition Principle: The net electric field at a location in space is a vector sum of the individual electric fields contributed by all charged particles located elsewhere.

To introduce systems with multiple sources of electric field lines, consider the particle pair known as a dipole. Dipoles consist of one negatively charged and one positively charged particle, like so:

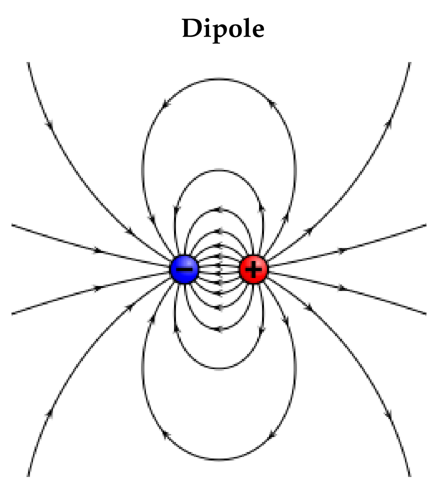

Figure 3: Two oppositely charged particles distanced from one another

Dipole Moment: The dipole moment is a way of expressing asymmetrical charge distribution. It is a vector quantity, i.e. it has magnitude as well as definite directions.

On the axis of the dipole (i.e. the lines formed by the two particles), the electric field is

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{2sq}{r^3}\hat{p}$$

On the bisecting plane (i.e., the plane exactly halfway from each point) the field is given by

$$\vec{E} = \frac{-1}{4\pi\epsilon_0}\frac{sq}{r^3}\hat{p}$$