PHYS 260 Electromagnetism

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Chapters 21-22

1 Electrostatics Basics

1.1 Introduction

1. As you may know, matter is made of atoms. Atoms have a nucleus, which is made up of protons (positive) and neutrons (neutral), and electrons (negative). Opposite charges are attracted to one another with a inverse square force, and like charges are similarly repelled.
2. The electrons[1] in conductors are able to move freely, while in insulators they cannot unless they come off entirely
3. Some materials tend to give off electrons (e.g. fur) and some tend to attract them (e.g. plastic)
4. Not all metals are conductors
5. A neutral object can be attracted to a charged object via inducted polarity. In a conductor, this means the electrons move through the entire object to create a dipole. In an insulator, the electrons of the atoms realign to create billions of of tiny dipoles. This makes a difference due to the inverse square law, which will be discussed further later. The former creates a strong attraction, while the latter creates a weak attraction.

1.2 Electrical Grounding

An object can be "grounded" by connecting it to a big conductor, which serves as a resevoir for charge, e.g. you can ground the wall outlet by sticking a fork into it. The gruond in this case is you body and the ground. The electricity from the wall will flow through your body and into the ground

[1] Not *all* of the electrons in a conductor can move, it's just that the ones that don't move can be ignored because they do not contribute to the net charge of a material

2 Coulomb's Law

The magnitude of the force between two point charges q_1 and q_2 C, with distance r m is equal to the following

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 \cdot q_2|}{r^2}$$

- where ϵ_0 is vacuum permittivity, the value of the absolute dielectric permittivity of classical vacuum, or also just "the electric constant".
- $\epsilon_0 \approx 8.854189 \cdot 10^{-12}$
- the Coulomb constant $k = \frac{1}{4\pi\epsilon_0}$
- electric forces add as vectors, which is called the "Superposition Principle"

3 Electric Fields

- Electric Fields are best represented by vector fields
- For the electric field of a point charge $\vec{F} = q\vec{E} \rightarrow E = \frac{F}{q} \rightarrow E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2} = \frac{kq}{r^2}\ \frac{N}{C}$
- Field lines do not indicate the trajectory of a test charge, but rather are lines tangent to the electric field at a given point

3.1 Electric Field Integrations

As it turns out, it is unrealistic to use Coulomb's Law just by itself to calculate the electric field at a point. This would require knowing the location and charge of every charge in an object. One way this problem can be simplified is with the use of charge density and calculus.

- Linear density: $\lambda = \frac{Q}{L}$
- Area density: $\sigma = \frac{Q}{A}$
- Volumetric density: $\rho = \frac{Q}{V}$

Basically, what you do is find the ds/dA/dV and you multiply it times the charge density to get the dQ. You then usually use the point charge electric field formula and integrate it over the relevant domain. When the differential is a point charge, you usually need to make sure you aren't summing magnitudes. However, if the differential you are given is an area, this has probably already been taken care of.

Infinite Sheet of Charge

$$|\vec{E}| = \frac{\sigma}{2\epsilon_0}$$

[2]**Near the Surface of a Conductor**

$$|\vec{E}| = \frac{\sigma}{\epsilon_0}$$

4 Gauss' Law

$$\Phi = \oint \vec{E} \cdot d\vec{A} = \oint \vec{E} \cdot \hat{n}\ dA = \frac{Q_{net}}{\epsilon_0}$$

The above equation is Gauss' Law, which states that the flux through a surface is a measure of how orthogonally an electric field passes through a surface. Positive flux means that the passing it outward, while negative flux means that it is inward (overall). Finding flux is useful because it is proportional to the net charge of within the surface of the integral. The surface used in the integral typically is not a real surface, but a contrived one, used for determining the net charge of what it encloses. It is called a Gaussian Surface and is usually a rectangular prism, cylinder, or sphere, depending on what is most convienient.

Furthermore, if the electric field is uniform and the angle between the field and the surface is constant, then the following applies.

$$\Phi = \vec{E} \cdot \vec{A} = EAcos(\theta) = \frac{Q_{net}}{\epsilon_0}$$

where θ is the angle between the electric field and the normal vector $\hat{n}$

4.1 Flux

Based on the previous simplified equation, it becomes obvious that the units of flux are $\frac{N}{C} \cdot m^2$. If you think about the electric field as the flowing of water, in a river perhaps, then flux is like a measure of that flow times an area, i.e. a rate of volume. Obviously, an electric field is, in fact, not flowing water, but this analogy is useful.

[2]The field due to *everything*

5 Dipoles

$\vec{p} = q\vec{d}$
$\vec{\tau} = \vec{p} \times \vec{E}$
$|\vec{\tau}| = pEsin(\theta)$
$W = \int_{\phi_1}^{\phi_2} (-pEsin(\phi))d\phi = pE(cos(\phi_2) - cos(\phi_1))$
$U(\phi) = -\vec{p} \cdot \vec{E} = -pEcos(\phi)$

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6 Electric Potential Energy

Recall: Work done by a conservative force is equal to the following

$$W_{a \to b} = -\Delta U$$

Recall: Electrostatic force

$$F_e = qE$$

Therefore, in a uniform electric field between parallel plates

$$U = (qE)y$$

$$W_{a \to b} = F_e d = (qE)\delta y$$

For a point charge

$$F = \frac{1}{4\pi\epsilon_0}\frac{qq_0}{r^2}$$

$$U = \frac{1}{4\pi\epsilon_0}\frac{qq_0}{r}$$

Superposition applies

$$U = \frac{q_0}{4\pi\epsilon_0}\Sigma_i \frac{q_i}{r_i}$$

7 Electric Potential

Potential is just potential energy per unit charge

$$V = \frac{U}{q_0}$$

$$U = q_0 V$$

The units are volts (V, $\frac{J}{C}$) The potential difference ΔV is also called voltage. It is equal to the work in joules that must be done to move a 1 couloumb charge from a to b against the electric force.

$$\frac{W_{a \to b}}{q_0} = \frac{-\Delta U}{q_0} = -\Delta V$$

Usually since a and b are arbitrary, the voltage is usually given as an absolute value
A 9V battery has a potential difference or voltage of 9V which means that the difference between the positive and negative terminals is 9V
The electric potential due to a point charge:

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r} = \frac{U}{q_0}$$

Accordingly:

$$V = \frac{1}{4\pi\epsilon_0}\Sigma_i \frac{q_i}{r_i}$$

$$V = \frac{1}{4\pi\epsilon_0}\int \frac{dq}{r}$$

The electric potential due to a field $\vec{E}$

$$W_{a\to b} = \int_a^b \vec{F}\cdot d\vec{l} = \int_a^b q_0\vec{E}\cdot d\vec{l}$$

Divide by q_0

$$-\Delta V = \int_a^b \vec{E}\cdot d\vec{l} = \int_a^b E cos\phi \; dl$$

ito $\vec{E}$ we get:

$$\vec{E} = -\nabla V$$

Think of just

$$-\Delta V = \int_a^b E_x dx$$

$$-\int_a^b dV = \int_a^b E_x dx$$

$$-dV = E_x dx$$

$$-\frac{dV}{dx} = E_x$$

If you do for y, z then you get negative gradient

8 Capacitors and Capacitance

Any two conductors separated by an insulator (or [3]i.e. not a conductor)

9 Capitors in Series and Parallel

10 Energy in a Capacitor

11 Dielectrics

12 Current & Current Density

13 Resistivity

14 Resistors

15 Circuits and EMF

16 Energy & Power in Circuits

17 Conduction in Metals

18 Resistors in Series and Parallel

19 Kirchhoff's Rules

20 Electrical Measuring Instruments

21 R-C Circuits

22 Power Distribution Systems

[3] vaccuum