Course Overview

Your one stop shop: Login to myWPI at https://my.wpi.edu and click on course GEN. PHYSICS-ELEC-MAGNET to do labs, track your grades and follow the link to the course webpage.

You may also reach the course webpage directly by going to www.wpi.edu\+physics . Once there click on Student Resources, PH1120 B11 and read the syllabus, schedule, study guides, lab and homework assignments and due dates, and exam dates, and most importantly, instructions for setting up your MasteringPhysics account.

Setup a Mastering Physics account at www.masteringphysics.com for online homework.

Direct questions about Mastering Physics, add/drops and special needs to Prof. P.K. Aravind.

Direct lab questions to your lab instructors.

Direct physics questions to your conference instructors.

Direct questions about lecture capture to me.

What is E&M?

Start with mechanics, the study of bodies engaging in contact forces and the gravitational force. Then include two new forces between bodies: the electric force and the magnetic force.

Why do we love E&M? We get to study invisible force fields.

Why do we hate E&M? We have to study invisible force fields.

To demonstrate the electric force we need a volunteer… You know about atoms, how they have positively charged nuclei surrounded by negatively charged electrons. The pluses and minuses balance, and each atom is electrically neutral as a whole.

You also know that physical bodies are collections of atoms, and are prefer to be electrically neutral. If everything around us is neutral, how do we experience electricity?

You have seen lightning and experienced static electricity yourselves when you pet a cat, or brush your hair in dry weather. As shown in Y&F 21.1, people have long known that we can wake the dragon; we can cause the electric force to reveal itself by stealing electrons from atoms.

Two neutral Styrofoam cups hanging from strings do nothing. But rub the cups with fur to charge the cups, and now the cups repel one another across empty space, like gravity acting between two masses.

How is that possible? We do not know. Like gravity, that's how the electric force works.

Same cup, same fur, so the cups have the same type of charge, so we conclude that like charges repel.

The fur attracts the cup. We surmise that the cup has a different kind of charge. We say it is the opposite kind since attraction is the opposite of repulsion. We conclude that opposites attract.

Two pieces of fur repel one another. Good, for this kind of charge, again we see that like charges repel.

Long ago, before Styrofoam cups existed, someone decided the charge on the fur is positive $+$, and the charge on the Styrofoam cup is negative $-$.

Rub a glass rod against a silk cloth and charge the rod; the rod will attract the cups.

The presence of both attractive and repulsive forces is evidence of two types of charge.

What is electric charge? Like gravitation, it is an ability possessed by some particles (electrons and protons, but not neutrons) to push and pull one another across empty space.

Did we say "push" and "pull"? We must be talking about forces…

Electrostatics. Through experiments, Coulomb found that the force is proportional to the charges, and inversely proportional to the distance between the charges. Coulomb's Law describes the electric force (a non-contact force) between two <u>point charges</u>

$$\vec{F} = F\hat{r} = k\frac{q_1 q_2}{r^2}\hat{r}\,, \qquad k = \frac{1}{4\pi\epsilon_0}\,, \qquad \epsilon_0 = 8.854 \times 10^{-12}\,\frac{C^2}{Nm^2}\,, \qquad k = 9.00 \times 10^9\,\frac{Nm^2}{C^2}$$

The constant of proportionality depends on choice of units for length, mass and charge. Two charges of 1C each, at a distance of 1 m apart, exert forces of 9 billion newtons!

The forces lie along the line joining the charges, are either attractive or repulsive, and are equal and opposite (consistent with classical mechanics)

$$\vec{F}_{12} = -\vec{F}_{21}$$

To obtain a unit vector that lies along the line, use the charge coordinates

$$\hat{r} = \frac{\vec{r}}{r}\,, \qquad \vec{r} = \Delta x\,\hat{x} + \Delta y\,\hat{y}\,, \qquad \Delta x = x_2 - x_1\,, \qquad \Delta y = y_2 - y_1\,, \qquad r = \sqrt{\Delta x^2 + \Delta y^2}$$

Recall from mechanics that forces are additive, use component form to add (sketch graphical addition)

$$\sum \vec{F}_n = \vec{F}_1 + \vec{F}_2 + \cdots = kq\left[\frac{q_1}{r_1^2}\hat{r}_1 + \frac{q_2}{r_2^2}\hat{r}_2 + \cdots\right]$$

Let's review some Mechanics. In mechanics we studied the equal and opposite forces that two bodies exert on one another

$$\vec{F}_{12} = -\vec{F}_{21}$$

We looked at contact forces and non-contact (gravitational) forces (which are attractive).

We used vectors to describe the forces, and used Newton's laws to obtain the equations of motion

$$\vec{F} = m\vec{a}\,, \qquad \rightarrow \quad EOMs$$

$$x = x_0 + v_{0x}t + \frac{a_x t^2}{2}\,, \qquad v_x = v_{0x} + a_x t\,, \qquad v_{fx}^2 - v_{ix}^2 = 2a_x\left(x_f - x_i\right)$$

Recall from mechanics the form of vectors is in 3D (sketch), we prefer component form (the last one)

$$\boldsymbol{A} = \vec{A} = A\hat{A} = A\measuredangle\theta, \varphi = A_x\hat{x} + A_y\hat{y} + A_z\hat{z}$$

Much of what we do can be done in a plane, in 2D (sketch)

$$\hat{A} = \frac{\vec{A}}{A}\,, \qquad A = \sqrt{A_x^2 + A_y^2}, \qquad \theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)$$

In mechanics we did not consider electric and magnetic forces. Now we do, and we use Coulomb's law the calculate the electric force.

Calculate the forces on the two cups, and their charges. Treat the cups as equal point charges $q_1 = q_2 = q$, and equal masses $m = 0.002\ kg$. Let string length $L = 1.0\ m$, and suppose the cup separation is $r = 2d = 0.2\ m$. From the free body diagram

$$\theta = \sin^{-1}\left(\frac{d}{L}\right), \qquad T\cos\theta = mg, \qquad T\sin\theta = F, \qquad \rightarrow F = mg\ \tan\theta = 1.972\ mN$$

By measuring the angle, we determined the electric force. Coulomb's law helps us find the charges

$$F = k\frac{q^2}{r^2}\,, \qquad q = \sqrt{\frac{r^2 F}{k}} = 0.468\ \mu C \times \frac{6.24 \times 10^{18} e}{1C} = 2.92 \times 10^{12} e$$

Let me remind you to give answers to 3 significant digits.

Here we introduce the SI unit of charge, the Coulomb (1 Ampere of electric current flowing for 1 second delivers 1C of charge)

$$1C = 6.24 \times 10^{18} e, \qquad e = 1.602 \times 10^{-19} C$$

where e is the charge of a single electron or proton. How would you write the vector $\vec{F}_{12}$? That depends on how you orient your coordinate system…

Find the force on a point charge located at the origin $q_1 = -1\mu C$ exerted by 2 other charges $q_2 = 2nC$, $q_3 = -5nC$, whose locations are $(x_2, y_2) = (2m, 3m)$ and $(x_3, y_3) = (-1m, 4m)$, so that

$$\vec{r}_{21} = -2\hat{x} - 3\hat{y}\ m\,, \qquad \vec{r}_{31} = 1\hat{x} - 4\hat{y}\ m$$

This is a straightforward application of our formulas. The force $\vec{F}_{2on1} = \vec{F}_{21}$ is attractive (why?) while $\vec{F}_{31}$ is repulsive. We sketch our coordinate system and plot the charges, draw the lines passing through the charges, then sketch the two force vectors along the lines, in the appropriate direction depending on whether the force is attractive (a pull) or repulsive (a push). From the sketch, we see immediately which unit vectors $\hat{r}_{21}$ and $\hat{r}_{31}$ are required.

$$r_{21} = \sqrt{2^2 + 3^2} = \sqrt{13}\, m\,, \qquad \hat{r}_{21} = \frac{\vec{r}_{21}}{r_{21}} = \frac{-2}{\sqrt{13}}\hat{x} + \frac{-3}{\sqrt{13}}\hat{y}$$

$$\vec{F}_{21} = k\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21} = 0.768\hat{x} + 1.152\hat{y}\ \mu N$$

$$r_{31} = \sqrt{1^2 + 4^2} = \sqrt{17}\, m\,, \qquad \hat{r}_{31} = \frac{\vec{r}_{31}}{r_{31}} = \frac{1}{\sqrt{17}}\hat{x} - \frac{4}{\sqrt{17}}\hat{y}$$

$$\vec{F}_{31} = k\frac{q_1 q_3}{r_{31}^2}\hat{r}_{31} = 0.642\hat{x} - 2.57\hat{y}\ \mu N$$

$$\vec{F} = \vec{F}_{21} + \vec{F}_{31} = 1.410\hat{x} - 1.418\hat{y}\ \mu N$$

Our method is: sketch the charges and the force vectors, then draw displacement vectors from source charges to the target charge, find the corresponding unit vectors, then plug everything into Coulomb's Law.

Summary. We have seen how to determine the vector forces between two "point" charges and write the vectors in component form. For three or more bodies, we simply add the forces to obtain the total force. Know how to do this. You will be tested on your ability to calculate electric forces.

Make sure to read Y&F 21.1 thru 21.3 and the examples to learn more about units of charge, the electrical nature of atoms, and more about types of materials: conductors and insulators. By the way, what is a semi-conductor?