

### The Electrostatic Force; and the Electric Field

*Let's consider an example of charges in one dimension, and then introduce the concept of the electric field.*

Coulomb determined that when two objects of charge  $q$  and  $Q$  are separated by a distance  $r$  the magnitude of the electrostatic force exerted on one object by the other is:

$$F_E = \frac{kqQ}{r^2} \qquad \text{Coulomb's Law}$$

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Three charges are equally spaced along a line. The distance between neighboring charges is  $a$ . From left to right the charges are:

$$\begin{aligned} q_1 &= -Q && \text{Draw this situation here.} \\ q_2 &= +Q \\ q_3 &= +Q \end{aligned}$$

What is the magnitude of the force experienced by  $q_2$ , the charge in the center? Express your answer in terms of  $k$ ,  $Q$ , and  $a$ . Hint on handling signs: don't bother putting signs into Coulomb's Law. Define a positive direction, determine which forces are in the positive direction and which are in the negative direction, and base your signs on that.

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Rank the charges, from largest to smallest, based on the magnitude of the net force each charge experiences.

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Find the magnitude and direction of the electrostatic force experienced by  $q_1$ .

Find the magnitude and direction of the electrostatic force experienced by  $q_3$ .

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Three charged balls are placed in a line. The charge on ball 1 has an unknown magnitude and sign, but we know that ball 1 is a distance  $2r$  to the left of ball 2.

Ball 2 is positive, with a charge of  $+Q$ .

Ball 3 has an unknown charge and sign, but it is a distance  $r$  to the right of ball 2.

Ball 3 is in equilibrium - it feels no net force due to the other two balls.

What is the sign of the charge on ball 1?

+       -       We can't tell unless we know the sign of the charge on ball 3.

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If possible, find the magnitude of the charge on ball 1.

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Now we're going to talk about electric field. What is a field, anyway? Did we talk about anything previously that fits the definition of a field?

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Draw a uniform field. Draw the field from a positive point charge. What on the diagram tells you where the field is strongest?

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You throw a positive point charge into a uniform electric field that is directed straight down. The initial velocity of the charge is horizontal. Describe the path followed by the charge.

You repeat the above with a negative point charge instead. Describe the path followed by the charge.

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## The Electric Field

*Let's do some more examples with electric field.*

The electric field from a single charge  $Q$  has a magnitude of  $E = \frac{kQ}{r^2}$  and is directed away from the charge if the charge is positive, and toward the charge if the charge is negative.

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Locations where the net electric field is zero are special, because we can put any charge we want at that location and it will feel no net force. Let's find the place(s) where the net electric field is zero near two charges that are placed on the x-axis.

Two charges,  $+3Q$  and  $-Q$ , are separated by 4 cm. Draw this above, with the negative charge 4 cm to the right of the positive charge. Is there a point along the line passing through them (and a finite distance from the charges) where the net electric field is zero? If so, where?

Let's first be qualitative about this. Is there a point to the left of the  $+3Q$  charge where the field is zero? Why or why not?

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Is there a point in between the charges where the net field is zero? Why or why not?

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Is there a point to the right of the  $-Q$  charge where the field is zero? Why or why not?

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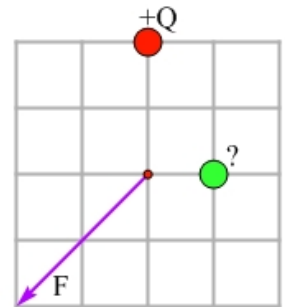
Set up the equation(s) you would use to solve for the location of any points where the field is zero, and go as far as you can toward solving for the location.

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A test charge is a small positive charge we can use to sample the electric field at various locations. The charge on a test charge is sufficiently small that the test charge has negligible impact on the existing electric field. Using the equation  $\vec{F} = q\vec{E}$ , we can see that the force experienced by a positive test charge  $+q$  is in the same direction as the electric field at the location of the test charge, and proportional to that field.

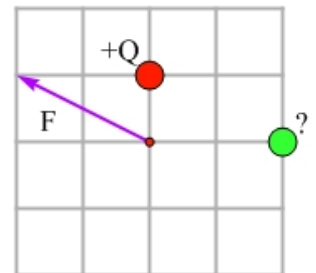
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The diagram shows the net force experienced by a positive test charge located at the center of the diagram. The force comes from two nearby charged balls, one with a charge of  $+Q$  and one with an unknown charge. What is the sign and magnitude of the charge on the second ball?



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## Simulation Worksheet: Electric Force – Three Charges

On the <http://physics.bu.edu/~duffy/NS543.html> site, find the first simulation, and carry out these activities.

1. Your challenge is to rank the three objects based on the magnitude of their charges, from largest to smallest. You should be able to do this without doing any calculations. First, drag the charges around the screen, putting them into whatever position you wish, to determine the ranking. Select the correct ranking from the list of six options at the bottom of the screen, and press the "Check Answer" button in the menu at the right to see if you are correct.
2. Figure out a system for determining the ranking that works for you every time (note that pressing the "Get new charges" button gives you a different set of charges with, most likely, a different ranking). Write a short description of how your system works.
3. Now, un-check the "Charges are draggable" checkbox at the top right so that the charges are fixed in position at the corners of an equilateral triangle. Check the "Show helpful lines" button to view lines that connect the corners of the triangle, as well as lines that run from the center of the triangle to each corner. Your goal now is to determine a new system of ranking the charges that does not involve moving them around the screen.
4. First, keep pressing the "Get new charges" button until you get a system of three like charges at the corners. Figure out a system for ranking the objects based on the magnitudes of their charges when the objects all have positive charges (all the objects are red), and when they all have negative charges (all the objects are blue).
5. Finally, see if you can come up with a system for ranking the objects based on the magnitude of their charges when the charges do not all have the same sign. Briefly describe the system you come up with when the objects are fixed in place at the corners of the equilateral triangle.

Do you have any comments about, or suggestions to improve, this simulation or this worksheet? If so, please provide them here.

## Simulation Worksheet: Electric Field – One Dimension

On the <http://physics.bu.edu/~duffy/NS543.html> site, find the second simulation, and carry out these activities.

1. Start with one charged particle only. Move the test charge (the small red ball) left and right to measure the field at various locations along the line. You can also leave the test charge in one location and change the sign and magnitude of the charge on the charged particle to see what effect that has on the electric field.
2. Still using a single charge, look at the graph of the electric field as a function of position. Move the test charge around to make sure that the information on the graph is consistent with the field as measured by the test charge. What does a positive field indicate? What does a negative field indicate?
3. Turn on the second charged particle, and set its charge. Once again, move the test charge left and right to measure the electric field at various locations along the line, and adjust the values of the charges on the particles and/or the positions of the two particles to see the effect on the electric field. In particular, see if you can find any locations where the net electric field is zero.
4. Using two charged particles, look at the graph of the electric field as a function of position. Again, move the test charge around to make sure that the information on the graph matches the electric field that is measured by the test charge.
5. Locations where the net electric field is equal to zero, because a charged object placed where the net field is zero experiences no electrostatic force. Using two charged particles, under what conditions is there a point in between the charged particles where the net electric field is zero? Using two charged particles, under what conditions is there a point to the right or left of the charged particles where the net electric field is zero? For two charged particles, is there a general rule for how many locations there are in the vicinity of the charged particles where the net electric field is zero? If so, what is it?

Do you have any comments about, or suggestions to improve, this simulation or this worksheet? If so, please provide them here.