Minds•On Physics Activity

FF·13

Using a Mathematical Model for the Electric Force

Purpose and Expected Outcome

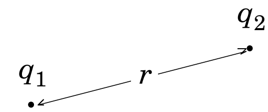
In this activity you will learn about the electric force law. This law was determined empirically and is called Coulomb's Law. You will be applying this law to a variety of simple situations. After completing this activity you will be able to estimate the size of electric interactions between *point* charges.

Prior Experience / Knowledge Needed

You should be familiar with the qualitative model for electric interactions presented earlier in FF·2 and FF·3. You should be able to distinguish electric interactions from gravitational and magnetic interactions. Finally, you should study the mathematical model of electric interactions presented on the following page.

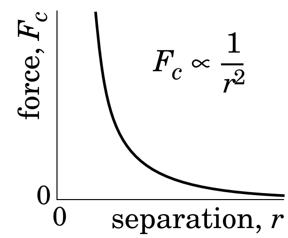
CHARACTERISTICS OF ELECTRIC FORCES (COULOMB'S LAW)

The electric forces that two point charges (shown as small dots in the diagram below) exert on each other is found to depend on only three features of the situation. They are: the *separation* r, and the two amounts of charge q_1 and q_2. This mathematical model of the electric force is called *Coulomb's Law*.



Dependence on the separation r

The magnitude of the electric force F_{12} that charge q_2 exerts on charge q_1 gets smaller as the two charges are moved apart. The Coulomb force is found to be inversely proportional to the square of the separation r between the two point charges, as shown in the graph to the right.



Dependence on the charges q_1 and q_2

The size of the Coulomb force increases as the size of <u>each</u> of the two charges increases. The force is proportional to the product of the two charges, q_1 and q_2.

$$F_c \propto q_1 q_2$$

Coulomb's Law

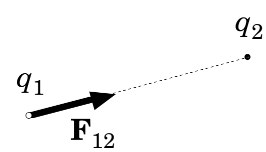
The Coulomb force depends on a proportionality constant k. In a vacuum, k has a value of about $8.99 \times 10^9 \,\text{N·m}^2/\text{C}^2$, where the standard MKS unit of charge is the *Coulomb* (C). (The size of the charge on an electron or proton is about $1.6 \times 10^{-19}\,\text{C}$.) In air, the value of k is slightly smaller, but we usually ignore this difference.

$$F_c = k\,\frac{q_1 q_2}{r^2}$$

(Coulomb's Law)

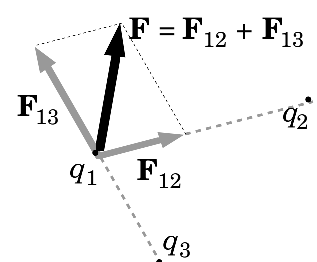
Finding the direction

The electric force always points parallel to the line that connects the two charges. When the product of the two charges is positive, the interaction is repulsive, and the force points directly <u>away from</u> the other charge (not shown). When the product is negative, the interaction is attractive, and the force points directly <u>toward</u> the other charge (shown).



Dependence on multiple charges

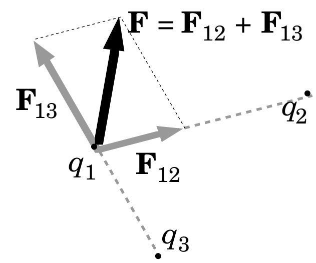
Electric forces obey the *Superposition Principle*. This means that the total electric force on any one charge is the vector sum of all the interactions between that charge and all other charges. In this example, there are three point charges, and therefore, two electric forces on charge q_1. Their vector sum is labeled $\mathbf{F}$.



Explanation of Activity

Below you will be asked questions about situations involving point charges. Use the mathematical model presented on the previous page as much as possible, but also use common sense, the qualitative model presented earlier, and any other concepts and principles you think you need. Be prepared to explain your answers.

A1. Consider the arrangement of three point charges used earlier as an example.



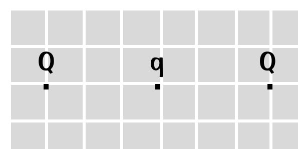
(a) Are the <u>types</u> of charge (positive or negative) on q_1 and q_2 the same or different? How do you know? Explain using both the qualitative model and the mathematical model.

(b) Are the types of charge on q_2 and q_3 the same or different? How do you know? Explain using both the qualitative model and the mathematical model.

(c) Which do you think is larger (in magnitude), the charge on q_2 or the charge on q_3? Explain.

(d) On a copy of this diagram, draw as many of the forces as you can.

A2. Three point charges are arranged as shown. Two have the same charge Q on them.

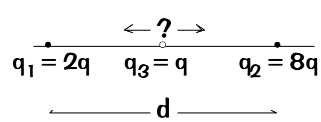


(a) What is the total electric force on charge q?

(b) Which charges are positively charged? Which are negatively charged? How do you know? Does your answer to part (a) depend on the signs of the charges?

(c) What can you say about the <u>directions</u> of the total electric forces on the two point charges labeled Q?

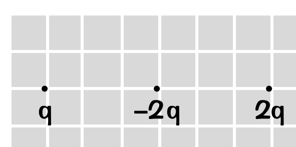
A3. Two point charges, q_1 and q_2, are held fixed a distance d apart as shown. A third point charge q_3 is placed between them and is free to slide along a wire having very low friction. (The amount of charge on each is shown in the diagram.)



(a) If released from the position shown, which direction will q_3 move? Explain.

(b) After a very long time, q_3 finally comes to rest. Approximately where is q_3 located at this time? Explain.

A4. Three point charges are arranged as shown. If the middle point charge is changed from $-2q$ to $2q$, would the force on charge q increase, decrease, or stay the same? Explain.



Reflection and Integration of Ideas

R1. Is the dependence of the electric force on the separation r consistent with our qualitative model for electric interactions? Explain.

R2. (a) How far apart do you suppose two point charges must be for the electric force to be zero? Explain.

(b) What is the maximum value of the electric force exerted by a point charge on another point charge? Explain.

R3. (a) Is the dependence of the electric force on the amounts of charge on q_1 and q_2 consistent with our qualitative model for electric interaction? Explain.

(b) Is the dependence on the types of charge (positive or negative) on q_1 and q_2 consistent with our qualitative model? Explain.

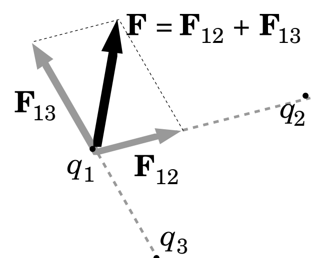
R4. In a 1g piece of material, there are about 3×10^{23} protons (assuming there is an equal number of protons and neutrons).

(a) What is the total charge on the protons in this 1g piece of material?

(b) If two identical 1g pieces are placed 2m apart, what will be the total electric force on the protons in one piece due to the protons in the other piece? (You may treat the pieces as being point charges.) What if they are 2cm apart?

(c) Why do you suppose we do not usually observe any electric interaction between two neutral objects?

R5. Reconsider situation A1, in which the forces on point charge q_1 due to point charges q_2 and q_3 are shown.



(a) How does $\mathbf{F}_{21}$ (not shown) compare in magnitude to $\mathbf{F}_{12}$? How does it compare in direction?

(b) Is the interaction between charges q_2 and q_3 attractive or repulsive? How do you know?

(c) Were you able to draw the force vectors showing the interaction between q_2 and q_3? Why or why not?

(d) What other forces did you draw, other than electric forces? What keeps the charges at rest?