Electrostatics and Electric Potential

CONCEPT EXPLORATION

You have already studied gravitational forces. You will investigate another kind of force in the following unit: electrostatic force.
What force holds the molecules of your body together? What keeps you from melting through the floor?

Engagement Question

1. What is electricity?

The Challenge

You will investigate how to produce an electrostatic charge as well as determine how different charges affect one another.

Your Ideas about the Challenge

Rub an inflated balloon on your hair.

2. How does your hair behave when you hold the rubbed part of the balloon close to the top of your head?

3. Does the "rubbed" balloon attract or repel your hair?

4. Why do you think that the balloon either attracted or repelled your hair?

At each lab station you should find the following:
two rods composed of the same substance mounted on stands, various materials for rubbing the rods

The Investigation

a. Rub one end of each of the two rods with the same material.
b. Bring the rubbed ends of the rods close together.

5. Do the two rods attract or repel each other?

When you rub each of the rods with the material you are "charging" the rods.

6. Did you give the two rods the same charge or different charges? Explain how you know.

7. In general, what do "like" charges do to each other? Do they attract or repel each other?

At each lab station you will find the following:
Two rods composed of different substances mounted on stands, various materials for rubbing the rods.

The Investigation

a. Rub one end of each of the two rods with different materials.
b. Bring the rubbed ends of the rods close together.
c. Repeat both “a” and “b” until the two rods appear to be attracted to each other.
d. Record in the table provided below which rod was rubbed with which material when the two rods were attracted to each other.

	Rod	**Material**
1		
2		

8. When the two rods were attracted to one another did they have the same charge or different charges? Explain how you know.

9. In general, what do you think “unlike” charges do to one another? Do they attract or repel one another?

10. Evaluate the following student statement about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

“If like charges repel one another, then the rods, that were attracted to one another, must have had different charges.”

Check your work with your teacher ☐

When you rubbed each rod with one of the materials you were transferring an electrical substance from one of the objects to the other. This substance was either being transferred from the material to the rod or from the rod to the material.
Scientists didn’t know what this substance was until about one hundred years ago. The electrical substance that is being transferred through the rubbing process consists of tiny particles called electrons. All electrons have the same mass and charge and they are usually attached to atoms. They are easily transferred between certain materials. Each electron has a negative charge.

11. Would two electrons attract or repel one another? Explain how you know.

Atoms also have other particles that are called protons. All protons have the same positive charge. The charge on a proton is the same size as the charge on an electron except that it is considered to be a “positive” charge while the charge on an electron is a “negative” charge.
Protons are <u>not</u> easily transferred between materials and are not usually the cause for the production of a net charge on a body.

12. Would two protons attract or repel one another? Explain how you know.

13. Would an electron be attracted or repelled by a proton? Explain how you know.

If an object has an equal number of protons and electrons, then the object is said to be electrically neutral. The equal number of “positive” and “negative” charges would balance each other so that the object has a net charge of zero.
In order to produce a net charge on a neutral object, electrons are either added to the object or they are removed from the object.

14. If you added electrons to an object that was initially electrically neutral, would the object acquire a “net” positive or a “net” negative charge? Explain how you know.

15. If you removed electrons from an object that was initially electrically neutral, would the object acquire a “net” positive or a “net” negative charge? Explain how you know.

You have seen that charged bodies either attract or repel one another without actually touching. This invisible force of attraction or repulsion is the electrostatic force. How do charged objects affect one another without touching?

The idea of an electric field was invented in order to help explain how charged objects can influence each other without actually touching. You already know how the earth’s gravity can affect you even when you aren’t touching the ground. The mass of the earth creates a gravitational field that acts on other objects that have mass.

16. What is the direction of the earth’s gravitational field? Explain how you know.

17. Evaluate the following student statements about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

Student A
“Since I feel the earth pulling on me straight down, I think that the direction of the earth’s gravitational field is straight down.”

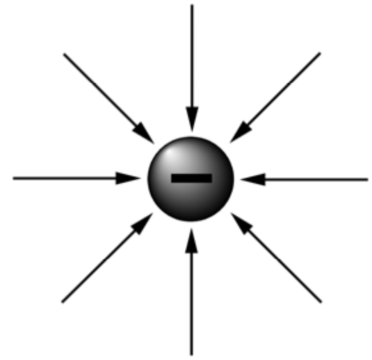
Student B
“That can’t be true since the downward direction here would be the upward direction on the other side of the planet. If that were true, objects would fall up in Australia.”

Check your work with your teacher ☐

All charged bodies create their own electric field. In addition to this, all charged bodies are influenced by the electric field created by other charged bodies.
The direction of an electric field is the direction that a positive charge would feel a force when it is exposed to the electric field created by another charge. In order to understand the traditional graphical representation for electric fields you will first investigate the electric field that surrounds a “point” charge. A **point charge** is a charged body that is spherical in shape and is very small.

18. In what direction would the positive charge on the left experience a force due to the presence of the negative charge on the right? Draw the force vector that acts on the positive charge.

The electric field created by a negative charge goes into the negative charge since this is the direction that a positive charge would experience a force due to this negative charge. The traditional way to draw electric field lines surrounding a negative charge is to show them going into the charge as seen to the right.



Notice that the electric field lines are all the same length and that they are evenly distributed around this spherical charge. However, you should also notice how the electric-field lines drawn in this diagram get more spread out as you move away from the charge. This would indicate that the strength of the field would be less as you moved farther from the charge.

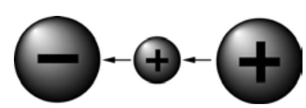
Electric fields are really a three-dimensional phenomena but the representation for the electric field about a point charge is usually drawn this way since we have to draw our diagrams on a flat piece of paper.

19. In what direction would the positive charge on the left experience a force due to the presence of the positive charge on the right? Draw the force vector that acts on the positive charge on the left.

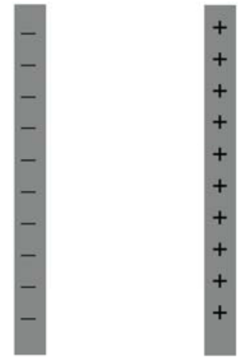
20. Draw what you think the electric field lines would look like that surround a positive charge on the diagram seen below. Remember that this would be the direction that another positive charge would experience a force due to the presence of this positive charge.

21. Draw what you think the direction would be for the electric field that exists halfway between the two charges seen below. Remember that the direction of the electric field is in the direction that a positive charge would experience a force due to the presence of the other two charges.

A positive charge located halfway between these two charges would be repelled by the positive charge on the right and attracted to the negative charge on the left.



22. The diagram seen to the right represents two metal plates that are parallel to one another. The plate on the left has an evenly-distributed negative charge and the plate on the right has an evenly-distributed positive charge that is the same size as the negative charge that is on the plate on the left. On the diagram draw what you think the electric field would look like between these two plates.



Hint: try to imagine the direction of force that positive charges would experience if they were placed in between these two plates.

23. Evaluate the following student statements about the questions that you have just answered and the diagrams that you have drawn. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

<u>Student A</u>
"The electric field between these two plates would go from the positive plate to the negative plate."

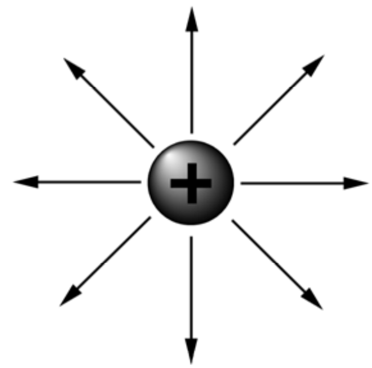
<u>Student B</u>
"The electric field between two parallel plates would be strongest close to the positive plate since the positive charge on that plate would repel a positive charge more when it was placed close to that plate."

Check your work with your teacher ☐

Electrostatics and Electric Potential

CONCEPT DEVELOPMENT

You should know that like charges will repel each other while unlike charges attract one another.
You should also be familiar with the concept of electric fields. This idea helps scientists to understand how charged bodies can affect one another without touching. You should know that the accepted direction for electric fields is the direction that a positive charge would experience a force due to the presence of an electric field. You should be able to picture the traditional way of representing electric fields surrounding "point" charges (either positive or negative) and the electric field that exists between two oppositely-charged parallel plates.



Engagement Question

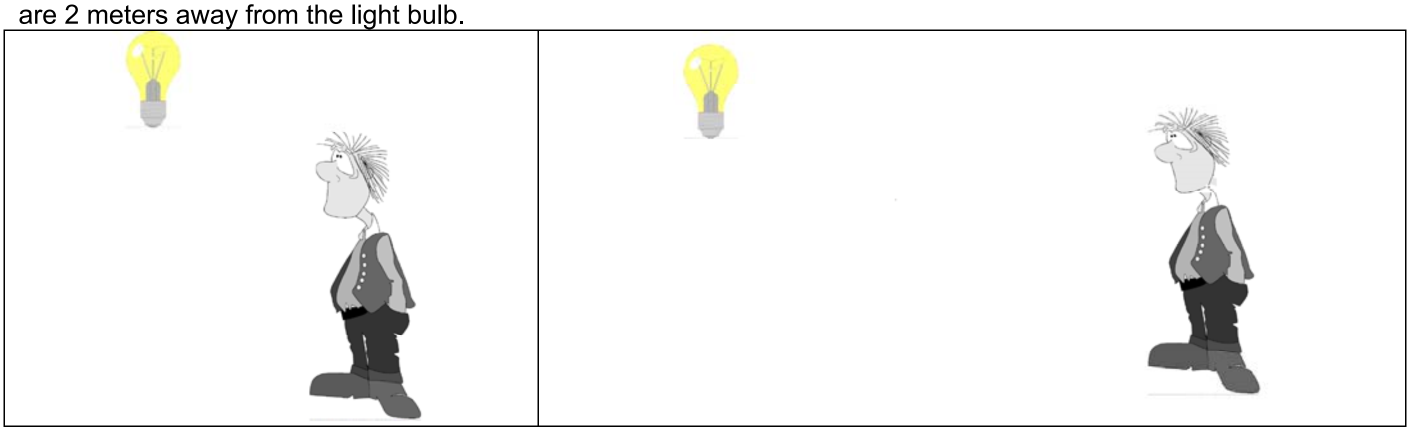
1. Where is the electric field, created by the charged sphere shown on the right, the strongest? Is it strongest close to the charge or farther away? Is the strength of the electric field created by this charge the same size everywhere? Explain your answer.

The Challenge

You will investigate how the intensity of light, produced by a *point source of light*, changes as you change the distance away from the light.

Your Ideas about the Challenge

A student stares at a light bulb from a distance of 1 meter. The student then backs away from the light so that they are 2 meters away from the light bulb.



2. How does the intensity of the light that the student receives at the 2-meter location compare to the intensity when they were closer? Does the intensity seem to be more, less, or about the same as before? Explain your answer.

At each lab station you should find the following materials:
a flashlight with the lens removed, a light probe along with a computer and a computer interface, a meter stick

The Investigation

a. Start the computer program so that it collects light intensity data.
b. Turn on the flashlight and place it so that the bulb is unobstructed.
c. Hold the light probe 10 cm away from the light bulb on the flashlight.
d. Record, in the table provided below, the intensity reading that you receive from the computer as you hold the probe at this position.
e. Repeat steps "c" and "d" for distances of 20, 30, 40, and 50 cm.

Data Table

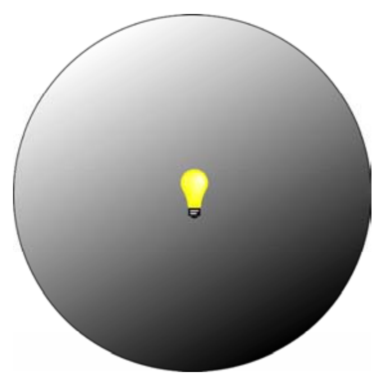
Distance from the light source (cm)	**Intensity of the light**
10	
20	
30	
40	
50	

3. Did the intensity of the light increase, decrease, or stay the same as you moved the light probe away from the light source?

4. When you doubled the distance away from the light source (moved the probe from 10 cm to 20 cm), was the intensity of the light half as much, one-third as much, one- quarter as much, . . . ?

Check your work with your teacher

Phenomena, that are produced by point sources, such as light, sound, or electric fields, spread out evenly in all directions. You can imagine these kinds of phenomena radiating outwards from the point source like an expanding sphere. Since the phenomena spreads out over a surface area you can begin to understand how the intensity of the phenomena decreases as you move away from the source.



5. Give an example of units that could be used to measure area.

The electric field that is produced by a point charge spreads out evenly in all directions. Electric fields produced by point charges obey what is known as the **inverse-square law.** As you move farther away from a point charge the intensity of the electric field decreases in proportion to the square of the distance away from the point charge.

6. Is the relationship, between the intensity of an electric field produced by a point charge and the distance away from this point charge, a direct proportion or an inverse proportion? Explain how you know this.

7. The charge on a charged body is doubled. Would the intensity of the electric field, produced by this increased charge, increase or decrease?

8. Is the relationship, between the size of a charge on a body and the intensity of the electric field produced by this charge, a direct proportion or an inverse proportion? Explain how you know this.

The relationship between the size of a charge (q) and the size of the electric field (E) that it produces is a direct proportion.	$E \propto q$
The relationship between the distance away from a charge (d) and the size of the electric field is an inverse relationship. The size of the electric field also changes with the square of the distance from the charge.	$E \propto \frac{1}{d^2}$
If you put the two proportions together you would get the relationship you see to the right.	$E \propto \frac{q}{d^2}$
In order to produce an equation you would need a constant of proportionality (k).	$E = k\frac{q}{d^2}$

The unit of charge is the Coulomb (C). It is a large unit of charge. It takes 6.25 x 10^{18} electrons to make a single Coulomb of charge.

9. What is the charge on a single electron (measured in Coulombs)?

Electric fields are defined as the force per unit charge that a charged body would experience if it were in the presence of an electric field. Therefore the definition equation for electric fields is $E = \frac{F}{q_0}$. The charge that appears in this equation (q_0) is the charge that "experiences" the electric field, <u>not</u> the charge that creates the electric field.

10. What are the units for electric field? Hint: look at the electric field definition equation.

A +2 C charge experiences a force of repulsion of 8 N when is it close to another positive charge.

11. What must be the strength of the electric field at that position?

Now we will revisit the first electric field equation that you received, $E = k\frac{q}{d^2}$. If you solve this equation for the electrical constant (k) you would get the equation $k = \frac{E \cdot d^2}{q}$.

12. What are the units for the electrical constant (k)?

The value for the electrical constant is approximately $9 \text{ x } 10^9 \ \frac{N \cdot m^2}{C^2}$. This is a giant number (9 billion) and this should give you an idea as to the size of the standard unit of charge, the Coulomb.

Check your work with your teacher ☐

Electrostatics and Electric Potential

CONCEPT REFINEMENT

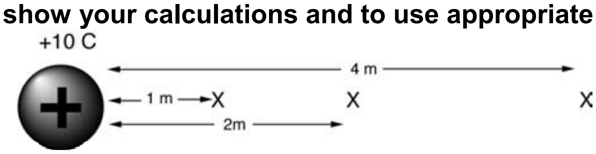
Review

Net charges can be given to neutral objects by either adding electrons or by removing electrons from the neutral bodies.

1. What is the net charge on an object that has more electrons than protons? Is it a positive charge or is it a negative charge. Explain how you know.

Charged bodies influence the space around them with their electric fields. These electric fields can exert forces on other charged bodies.

2. Calculate the magnitude of the electric field created by a +10 C charge at the positions marked by an "x" in the table below. Be sure to show your calculations and to use appropriate units.



Distance from Charge	1 m	2 m	4 m
Electric field strength			

3. How much bigger is the electric field at the 1-meter position compared to the 2-meter position? Is it twice as big, three times as big, four times as big . . . ?

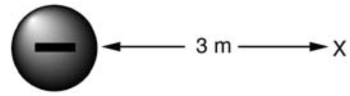
4. How much bigger is the electric field at the 1-meter position compared to the 4-meter position?

5. A student who was standing 1 meter away from a charged body senses an electric field of 9,000,000 N/C. She then takes two steps back so that she is now 3 meters away from the charge. What is the magnitude of the electric field at her new location?

A. 18,000,000 N/C **B. 9,000,000 N/C** **C. 4,500,000 N/C** **D. 1,000,000 N/C**

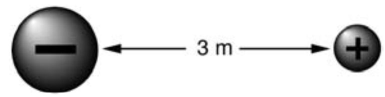
6. For the +10 C charge, shown in question 2, what is the direction of the electric field at each of the three locations marked by an "x"? Is the electric field directed to the right or to the left at each of these locations? Explain how you know.

7. Calculate the magnitude of the electric field created by the -4mC (-4×10^{-3} C) charge, shown below, at a distance of 3 meters from this charge.



A +2mC charge is now placed at the location marked by an "x" in the diagram above.

8. Calculate the magnitude of the force that this charge would experience when it is placed at this position, 3 meters away from the negative charge.



9. What is the direction of the force exerted on the +2mC charge shown above? Is it to the right or to the left? Explain how you know.

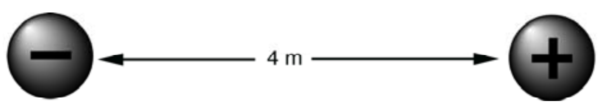
10. What would be the direction of the force that would be exerted on a negative charge if it were switched with the positive charge shown in question 8 above?

If you solve the electric-field definition equation for force you would receive the equation $F = Eq_0$.
By substituting the other equation for electric field ($E = k\frac{q}{d^2}$) for "E", in the equation shown above, you would get the following:

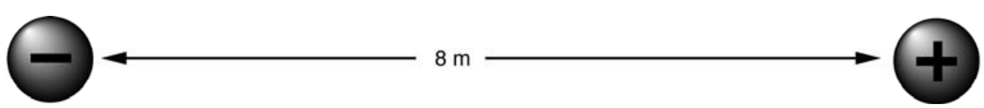
$$F = k\frac{q}{d^2} \cdot q_0 = k\frac{qq_0}{d^2}$$

This last equation is called Coulomb's Law in honor of the scientist who experimentally determined a decent value for the electrical constant "k". This equation can be used to determine the magnitude of the force of either attraction or repulsion that exists between two charged bodies. As you can see this equation also follows the inverse-square law.

11. Calculate the force of attraction between a -2 C charge and a +32C charge that are 4 meters apart.



12. Calculate the force of attraction between these two charges if the distance of separation was increased to 8 meters.



13. How much smaller is the force of attraction when the charges are 8 meters apart compared to the size of the force when they were 4 meters apart? Is it half as big? . . . one quarter as big?

14. What would be the force of attraction between these two charges if the distance between them was increased to 12 meters (three times the original distance of separation?