Chapter 17

Electric Charge, Force, and Energy

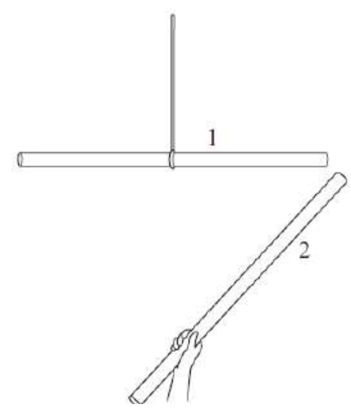
17.1 Electrostatic interactions

17.1.1 Observe and find a pattern

PIVOTAL ***Lab or class:*** *Equipment per group:* plastic gloves, foam insulation tubes, felt/wool, plastic wrap, non-conducting string + ring stand with arm (alternates: swivel stand or magnet holder), whiteboard, markers. If foam tubes are not available, use other equipment for the same purpose provided by your instructor. (Alternates: PVC pipe rod rubbed with wool or dry paper towel, and glass rod rubbed with rabbit fur).

For better results wear plastic gloves when performing the experiment. If humidity is too high, blow warm air on your equipment (using a hair dryer) before performing the experiments.

Suspend one tube from a string, as shown in the illustration at right, or place it on a swivel stand that is free to rotate. Before starting the experiments that follow, bring one end of tube 2 near one end of hanging tube 1. Is there any interaction? Now rub one end of each tube vigorously with different materials, as described below.



Caution: mark the tubes, so that you know which you rubbed with felt and which you rubbed with plastic wrap, make sure you do not switch them, remember which end of the tube you rubbed and do not touch it after rubbing; make sure only one person holds one tube and rubs it with the material described in the table. Do not pass the tubes and do not exchange the material.

a. Bring the rubbed end of tube 2 or the material doing the rubbing near the rubbed end of the suspended tube 1 and record the behavior of tube 1. Work with your group, creating a table like the one below on a whiteboard and record your observations in that table.

Object 1	**Object 2**	**Record your observation**
Tube 1 rubbed with felt	Tube 2 rubbed with felt	
Tube 1 rubbed with felt	The felt that was used to rub tube 1*	
Tube 1 rubbed with plastic wrap	Tube 2 rubbed with plastic wrap	
Tube 1 rubbed with plastic wrap	The wrap that was used to rub tube 1*	
Tube 1 rubbed with plastic wrap	Tube 2 rubbed with felt	

* The interactions in these experiments are much more pronounced if the experimenter is standing on an insulating board (such as a Styrofoam board).

b. Identify patterns in these observations and put your ideas on a whiteboard. Compare your ideas with those from another group.

17.1.2 Observe and explain

Lab: *Equipment per group:* two foam tubes, suspension set-up, rubbing material.

You have two foam tubes; one tube is suspended at the center from a string, and the other is free. Vigorously rub one end of each tube with felt. Slowly bring the rubbed end of the free tube closer and closer to the rubbed end of the hanging tube. Describe your observations. What can you infer about how the electric force depends on the separation of the objects?

17.1.3 Observe and explain

PIVOTAL Lab: *Equipment per group:* 2 plastic (PVC) pipes, 1 metal rod, 1 glass rod, a swivel stand or hanging set-up (non-conducting string and ring stand with arm), rubbing materials (dry paper towel and rabbit fur), whiteboard, markers.

Work with your group members to design and conduct experiments to examine how a neutral (un-rubbed) plastic rod and a neutral (un-rubbed) metal rod interact with rubbed/charged PVC pipes.

a. Record your results for all experiments in words and with a picture as necessary on a whiteboard. Do your results depend on the type of the rubbed object? Do your results depend on whether the neutral object is plastic or metal? Remember to describe what you see in as much detail as possible without fancy words, and without trying to explain anything.

b. What is similar in the behaviors glass rod on a swivel and a metal rod on a swivel when a charged object approaches them? What is different?

c. What can you say about interactions of charged objects with uncharged objects? (Formulate the pattern(s) you noticed.)

d. Devise a mechanistic explanation for how the interaction between the rubbed/charged rod and the un-rubbed rod (plastic or metal) works. Remember, there is *no contact* between the objects. *Hint*: Think about the internal microscopic structure of the rod. Use charge diagrams to illustrate your explanation. Put your diagram(s) on a whiteboard. Hold a brief discussion with other groups in the class. Your class should have come up with at least two competing ideas about the internal structure of materials that could explain why uncharged objects are attracted to charged objects.

e. Discuss any assumptions that you made in devising your explanation(s).

17.1.4 Test multiple explanations

PIVOTAL Lab: *Equipment:* 2 metalized Mylar foil balloons on strings hanging so that they are touching, 2 latex balloons on strings hanging so that they are touching, PVC tube and rubbing material (paper towel or fur), whiteboard and markers.

In this activity you need to collaborate with your group to use the multiple explanations you devised in Activity 17.1.4 to predict the outcome of the following two experiments:

Experiment 1: Bring a rubbed PVC rod near the pair of metalized Mylar foil balloons (the balloons are touching each other).

Experiment 2: Bring a rubbed PVC rod near one of a pair of latex balloons (the balloons are touching each other).

Use your competing ideas about the internal structure of materials to made two predictions about what will happen to each balloon in relation to the rubbed rod and then in relation to each other. Note you should have one prediction for each idea you came up with in Activity 17.1.4. To make a prediction, draw a diagram representing the behavior of charges inside the balloons as the rubbed rod is brought close to the balloons.

a. Working with your group, put predictions for each experiment on a whiteboard, including charge diagrams as needed.

b. Conduct the experiments and compare the outcomes to your predictions. What can you say about the explanations under test? Compare how the foil balloons behaved to how the latex balloons behaved. What can you conclude about the internal structure of the latex balloons versus the internal structure of foil balloons to account what occurred?

17.1.5 Reading exercise

Read Section 17.1 in the textbook and answer Review Question 17.1.

17.2 Explanations for electrostatic interactions

17.2.1 Explain

Lab or class: *Equipment per group:* whiteboard and markers.

In Activities 17.1.1 and 17.1.2 you found a consistent pattern: Identical objects rubbed with a second material repel each other. The second material in turn attracts the objects it rubbed. Brainstorm with your group about a mechanism that might explain why rubbing objects makes them attract or repel each other. Put your group's ideas on a whiteboard and discuss with another group.

17.2.2 Test the explanation

PIVOTAL Lab: *Equipment per group:* a light magnet on a swivel, two foam tubes, felt, and plastic wrap, whiteboard, markers.

Your friend Hector says that electric interactions are the same as magnetic interactions because magnets also attract and repel each other. Consequently, he believes that when you rub objects, they become magnetized. Work with your group members to design an experiment(s) whose outcome will allow you to test Hector's idea.

a. Describe an experimental set-up to test the idea that rubbing causes materials to become magnetic (Hector's idea).

b. Predict the outcome of your experiment based on Hector's idea.

c. Perform the experiment and then describe the outcome.

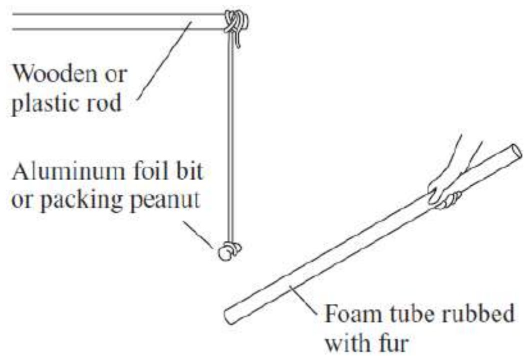
d. Make a judgment about Hector's idea based on the outcome.

17.2.3 Reading exercise

Read Section 17.2 in the textbook and answer Review Question 17.2.

17.3 Conductors and insulators (dielectrics)

17.3.1 Test your ideas



Lab or class: *Equipment per group:* A bit of aluminum foil suspended on a string, foam "peanut" (standard packing material) suspended on a string, and a foam tube rubbed with felt.

Hang a small piece of aluminum foil from a 30-cm-long piece of thread, which is tied at the top to a plastic or wooden rod (for example, a ruler).

a. Predict what happens when you bring the end of a foam tube rubbed with fur near the piece of foil. Then repeat the procedure using a foam peanut hanging from the thread.

b. Explain your prediction using a charge diagram. To learn how to draw a charge diagram consult with the Figure 17.6 in the textbook.

c. What additional assumptions about the thread did you make? Is it important from what material it is made?

d. Perform the experiment and record your observations.

e. Revise the explanation or the assumption if necessary.

17.3.2 Observe and explain

Class or lab: *Equipment per group:* Electroscope, a plastic PVC tube, rubbing material (paper towel or fur) and a rubber glove (or a plastic bag), whiteboard, markers.

An electroscope consists of a metal ball attached to a metal rod that passes from the outside through an insulating support into a glass-fronted metal enclosure. A very lightweight needle-like metal rod is connected on a pivot on the larger rod (see the photo on the right).

Work with your group to perform the experiments described below, describe what you observed and then explain the outcomes. Put your explanations on a whiteboard; include charge diagrams as needed.

a. Charge a foam tube with any material and then bring it close to the top of the electroscope without touching. Observe what happens when you are holding the tube close and explain your observations. Then remove the tube, observe what happens and explain.

b. Repeat the experiment only this time touch the electroscope with the charged foam tube and rub the top of the electroscope with it. Observe what happens and explain your observations. Then remove the tube, observe what happens and explain.

c. Touch the top of the electroscope from the previous experiment with your hand. Record your observation and explain it.

d. Rub the top of the electroscope with a rubbed foam tube, remove the tube, and then touch the top of the electroscope with your hand while wearing a plastic glove. Record your observation and explain it.

e. What do your observations and explanations suggest about the human body? Is the human body a conductor or an insulator?

17.3.3 Observe, explain, and test an explanation

Class or lab: *Equipment per group:* electroscope, a plastic PVC tube, rubbing material (paper towel or fur), whiteboard, markers.

Working with your group, conduct the following experiment with an electroscope:

In a careful sequence,

1. Bring a charged rod close to the metal ball of the electroscope without touching it.

2. While the rod is still there, touch the electroscope with your free hand so that the needle returns to “zero,” and then remove your hand.

3. Now remove the charged rod.

a. Describe what happened to the needle of the electroscope after you removed the charged rod.

b. With your group members, working on a whiteboard, devise an explanation for why the needle did what you observed. You may need to draw a sequence of charge diagrams. In particular, what should be the sign of the charge on the electroscope at the end of the charging sequence? (Same as the charged rod or opposite to the charged rod?) Compare your explanation with another group.

c. Work with your group to devise and perform an experiment to test the sign of the charge on the electroscope as you devised in part **b.** above. Is the outcome of the experiment consistent with your expectations? Revise your explanation in part **b.** if necessary.

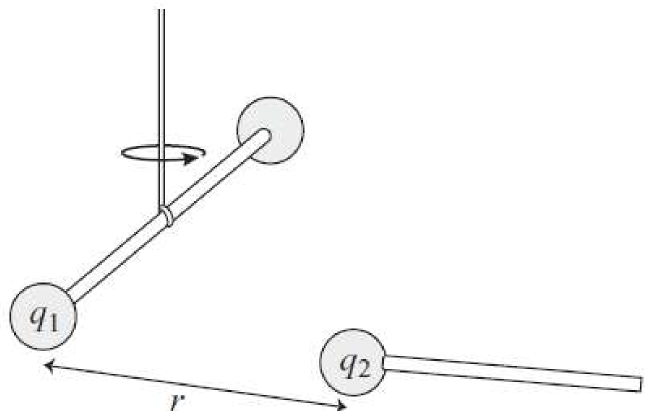
17.3.4 Reading exercise

Read Section 17.3 and answer Review Question 7.3.

17.4 Coulomb's force law

17.4.1 Find a pattern

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

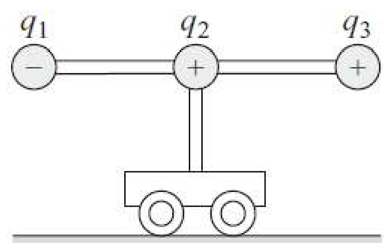


Charles Coulomb used a torsion balance (see the figure at right) to measure the force that one charged ball exerts on another charged ball to find out how the force between two electrically charged objects depends on the magnitudes of the charges and on their separation. Coulomb could not measure the absolute magnitude of the electric charge on the metal balls. However, he could divide charges in half by touching a charged metal ball with an identical uncharged ball. The table that follows provides data that resemble what Coulomb might have collected. Represent the data graphically collaborating with your group members on a whiteboard. Discuss with your group: which are the independent variables and what is the dependent variable in Coulomb's experiment? Then analyze the changes in the dependent variable as you change only *one* independent variable at a time. Use this analysis technique (controlling variables) to find patterns in the data and devise a mathematical relationship based on these observations. Put your final equation on a whiteboard and share it with another group.

Charges (q_1, q_2)	**Distance**	**Force**
1, 1 (unit)	1 (unit)	1 (unit)
1/2, 1	1	1/2
1/4, 1	1	1/4
1, 1/2	1	1/2
1, 1/4	1	1/4
1/2, 1/2	1	1/4
1/4, 1/4	1	1/16
1, 1	2	1/4
1, 1	3	1/9
1, 1	4	1/16

17.4.2 Represent and reason

PIVOTAL Class: *Equipment per group:* whiteboard and markers.



The metal balls on the cart in the figure at right have charges of equal magnitude and are very light. The rods supporting and connecting them are made of an insulating material and are also light. The cart initially rests on a smooth table. Work with your group members on the activities that follow. Present the results to the class.

a. Draw labeled arrows representing electric forces exerted on the left metal ball. Represent the ball with a dot.

b. Draw labeled arrows representing electric forces exerted on the center metal ball.

c. Draw labeled arrows representing electric forces exerted on the right metal ball.

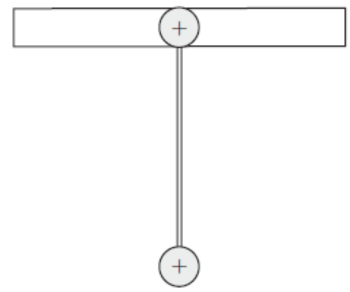
d. Draw labeled arrows representing electric forces exerted on the whole cart (a system with three charged balls).

e. Will the cart tend to accelerate either to the left or to the right? Explain your answer.

17.4.3 Represent and reason

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

A positively charged ball of mass m hangs at the end of a string. Another positively charged ball is secured at the top end of the string to a wooden support, as shown on the right. Work with your group members on the questions that follow. Present the results to the class on a whiteboard.



a. Draw a force diagram for the hanging ball if both balls are positively charged.

b. Represent the diagram mathematically using Newton's second law.

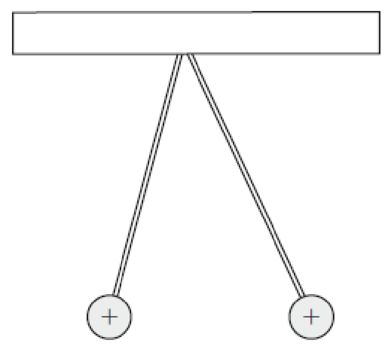
c. Draw a force diagram for the hanging ball if the top ball is negatively charged.

d. Represent the diagram mathematically using Newton's second law.

17.4.4 Represent and reason

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Two equal-mass stationary balls hang at the end of strings, as shown on the right. The ball on the left has electric charge $+5Q$, and the ball on the right has electric charge $+Q$. The strings make angles less than 45° with respect to the vertical plane. Work with your group members on the questions that follow. Present the results to the class on a whiteboard.



a. Draw a force diagram for the left ball.

b. Apply Newton's second law in component form for the right ball in both the horizontal x-direction and the vertical y-direction.

c. Draw a force diagram for the right ball.

d. Based on your analysis, rank the forces $F_{\text{S on }Q}$, $F_{5Q\text{ on }Q}$, and $F_{\text{E on }Q}$, listing the largest force first.

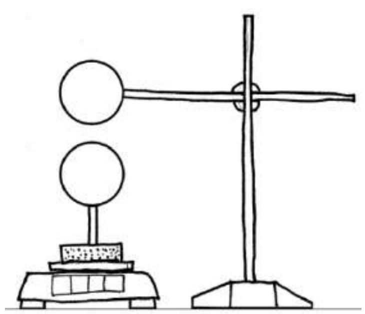
e. Explain the ranking.

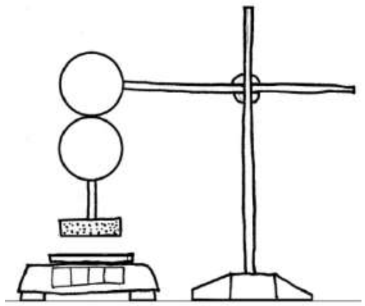
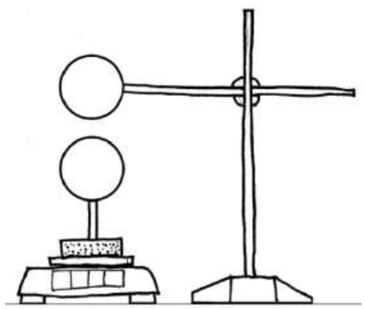
f. Decide which string makes a bigger angle with the vertical plane or if both strings make the same angle.

17.4.5 Observe and explain

Lab: *Equipment per group:* two copper spheres on insulating stands, plastic rod, fur (or felt), a digital platform scale, a ring stand to hold the sphere.

Work with your group members to fill out the cells of the table below. If the spheres discharge quickly because of humidity in the room, use a hair dryer to dry them. Perform all experiments quickly.

Description of the experiment	**Charge distribution on the sphere(s)**	**Reading of the scale**	**Force diagram for the system (sphere on the stand)**	**Explanation of the reading of the scale**
1. Place a neutral sphere on the scale.				
2. Charge the sphere by rubbing it with the charged rod several times.				
3. Bring an uncharged sphere right above the sphere on the scale. Make sure the spheres do not touch!				

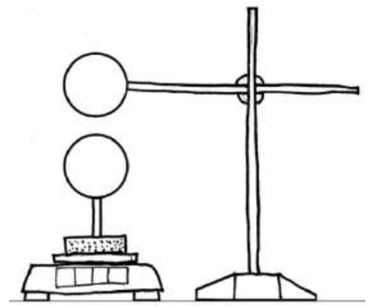
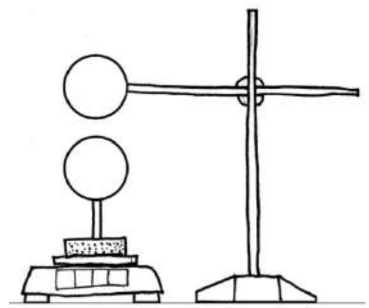
4. Lift the lower sphere by holding it by the wooden bottom (do not touch the supporting rod) and touch the upper sphere.				
5. Perform all operations QUICKLY! Put the bottom sphere back on the scale				

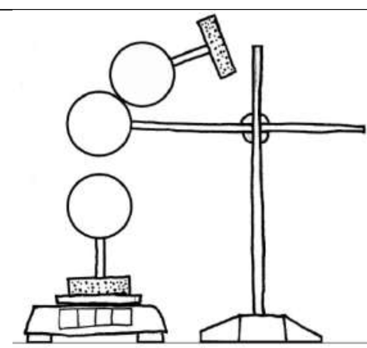
17.4.6 Test an idea

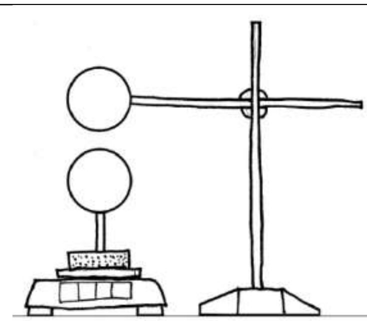
Lab: *Equipment per group:* two copper spheres on insulating stands, plastic rod, fur (or felt), a digital platform scale, a ring stand to hold the sphere.

Take a look at your findings from the previous Activity 17.4.5. Your friends Isabel and Chrisso have two different casual explanations for the observable behavior of the spheres. Isabel says: "When a charged sphere touches an uncharged sphere, the resultant charge on both spheres is equal to the initial charge q. Each sphere will have charge q." Chrisso says: "When they touch, the charge distributes equally between the two spheres because the two spheres are exactly the same. Therefore the charges on both spheres add up to the initial charge q. Each sphere will have charge $\frac{1}{2}q$." Using these explanations, make predictions of the outcome of the following experiment – one based on Isabel's explanation and the other one based on Chrisso's explanation. Remember that in a testing experiment, your goal is to disprove a proposed explanation. The experiment should produce significantly different outcomes so that you can make a judgment about the explanation.

a. Once you have predictions, perform the experiments and record the outcomes.

<table>
<tr><th>Description of the testing experiment</th><th>Charge distribution on the sphere(s)</th><th colspan="2"></th></tr>
<tr><td>1. Place one sphere on the scale and the other one right above it. Both spheres should be initially uncharged.</td><td></td><td colspan="2"></td></tr>
<tr><td>2. Now charge both spheres with the charged rod by rubbing the rod with fur and touching one sphere and then quickly repeating with the other sphere. You might need to repeat charge transfer multiple times; try to do it quickly.</td><td></td><td>Reading of the scale:</td><td>Force diagram for the system (sphere on the stand):</td></tr>
<tr><td>3. Before this step, make sure you have predictions.

Touch the top shere with the third (uncharged) sphere and remove it.</td><td></td><td colspan="2">Isabel's prediction:

Chrisso's prediction:</td></tr>
<tr><td>4. Record the reading of the scale after the third sphere was removed.</td><td></td><td colspan="2">Outcome:</td></tr>
</table>

b. Make a judgment about the explanations. Do not forget to take into account assumptions.

17.4.7 Reading exercise

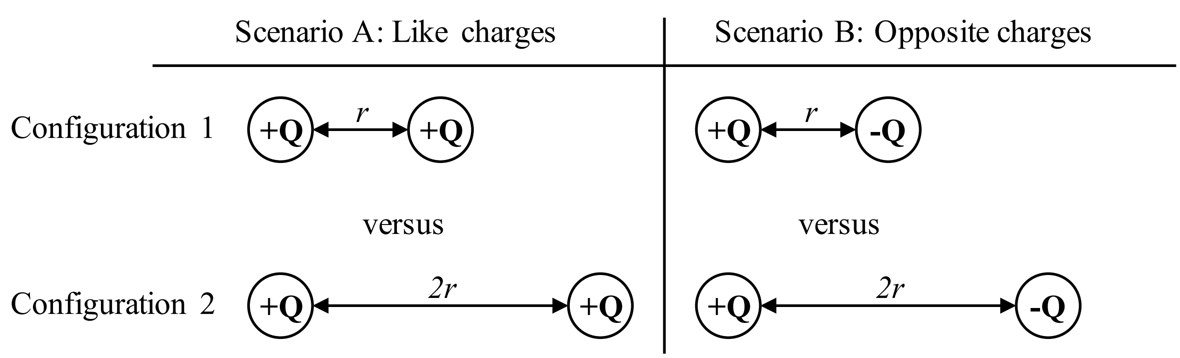
Read Section 17.4 and answer Review Question 17.4.

17.5 Electric potential energy

17.5.1 Represent and reason

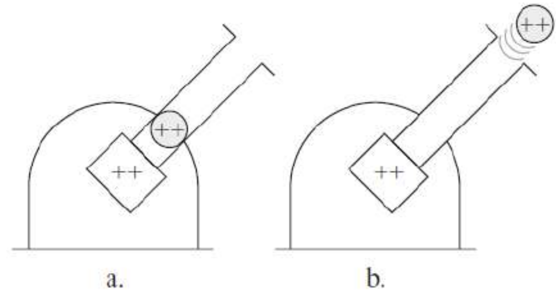
***PIVOTAL* Lab or class:** *Equipment per group:* whiteboard, markers.

In the diagram below, two different configurations of charged objects for two different scenarios are shown. In configuration 2, the two objects are further apart than in configuration 1. Scenario A involves 2 objects carrying the same charge, and scenario B involves 2 objects with opposite charge. If we consider the two charged objects as a system together, which configuration (1 or 2) has more electrical potential energy? Study scenario A and B separately from each other, i.e., compare configuration. 1 to configuration. 2 in scenario A, then *separately* compare configuration. 1 to configuration. 2 in scenario B. Work with your group. Draw diagrams and energy bar charts as needed on your whiteboard and justify your reasoning by using physics you already understand.



17.5.2 Represent and reason

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

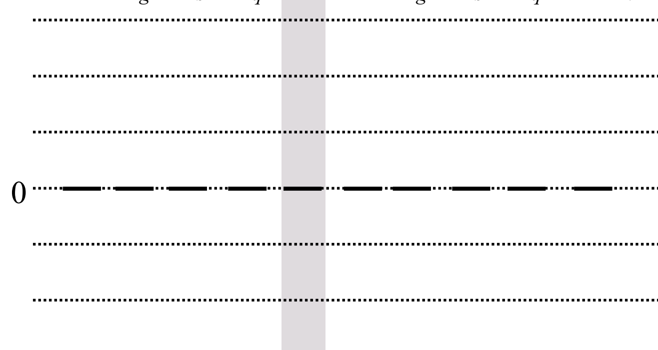


Two positively charged objects are held near each other in the muzzle of a cannon (see part (a) of the figure at right). When the “trigger” holding the cannonball is released, the positively charged cannonball flies out the end of the muzzle, as shown in part (b). Certain types of energy have increased. Describe a type of energy decrease that you think might compensate for the increase in these other energies. *Note:* The situation shown in part (a) of the illustration is similar to that of a compressed spring; instead of the coils of the spring being squeezed together, two like charges are squeezed or pushed together. In part (b) of the illustration, this compressed electric “spring” is more relaxed.

a. Using the language of energy, explain in words the described process, going from the initial state to the final state. Indicate your system choice.

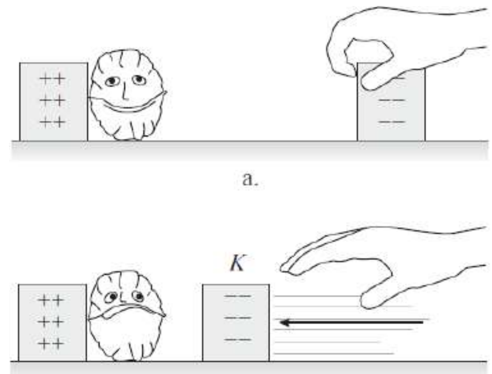
b. Draw an energy bar chart representing the initial and final states.

$$K_i + U_{gi} + U_{si} + U_{qi} + W = K_f + U_{gf} + U_{sf} + U_{qf} + \Delta U_{int}$$



17.5.3 Represent and reason

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

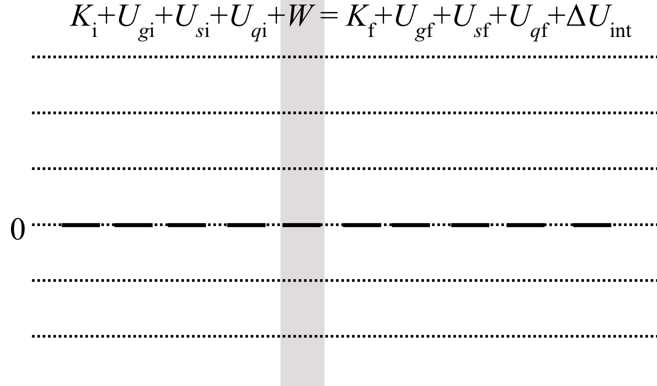


Imagine the energy changes of two opposite-sign charged objects used as a nutcracker, as illustrated in the figure to the right. What happens when the negatively charged block shown in part (a) is released and moves near the nut, as shown in part (b)? What type of energy decreases to make up for the increase in kinetic energy? *Note:* The situation shown in part (a) is similar to that of a stretched spring. Instead of the coils of a spring being stretched, the two opposite charges are pulled apart—like stretching a spring. In part (b), this electric stretched "spring" is in the process of relaxing.

a. Using the language of energy, explain in words the process described above going from the initial state to the final state. Indicate your system choice.

b. Draw an energy bar chart representing the initial and final states.

$$K_i + U_{gi} + U_{si} + U_{qi} + W = K_f + U_{gf} + U_{sf} + U_{qf} + \Delta U_{int}$$



17.5.4 Reason

Class: *Equipment per group:* whiteboard, markers.

a. Discuss with your group members whether the analogy of a compressed spring for a system consisting of two similarly charged objects pushed close to each other makes sense. Explain your opinion.

b. Discuss with your group members whether the analogy of a stretched spring for a system consisting of two oppositely charged objects pulled apart makes sense. Explain your opinion.

c. Discuss the limitations of both analogies.

17.5.5 Reading exercise

PIVOTAL

Read Section 17.5 in the textbook.

a. Compare and contrast graphs for the electric potential energy of interaction U_q of two charged objects (q_1 and q_2) as a function of the distance between them and for electric force between them. Consider both like-charged objects and oppositely-charged objects.

b. Evaluate the equation for U_q derived on page 519 of the textbook: Consider case 1: $r = \infty$ and then let r decrease for the case where q_1 and q_2 are both + or both –. Does the equation for U_q behave the way you think it should – consistent with Activity 17.5.1? Discuss. Next, consider case 2: $r = \infty$ and then let r decrease for the case where q_1 is + and q_2 is –. Does the equation for U_q behave the way you think it should – consistent with Activity 17.5.1? Discuss.

c. Answer Review Question 17.5.

17.6 Skills for analyzing processes involving electric charge

17.6.1 Regular problem

PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers.

Solve the following problem with your group members, using the problem-solving steps outlined below and then compare your group's solution to the solution in Example 17.7 in the textbook.

Two electrically charged objects with charges $q_1 = +1.0 \times 10^{-9}$ C and $q_2 = +2.0 \times 10^{-9}$ C are separated by 1.0 m. Where should you place a third electrically charged object so that the net electric force exerted on it by the first two objects is zero?

Sketch and translate • Sketch the process described in the problem statement. Label the physical quantities. • Identify the unknowns. • Choose an appropriate system.	
Simplify and diagram • Decide whether you can consider the charged objects to be point-like. Decide what other interactions you will consider and what interactions you can ignore. • Construct a force diagram for the system. Choose appropriate coordinate axes. • If you are using the work-energy principle, construct an energy bar chart. Decide where the zeros for potential energies are.	
Represent mathematically • Use the force diagram to apply the component form of Newton's second law to the process (or use the energy bar chart to apply the generalized work-energy equation). • If necessary, use kinematics equations to describe the motion of the object.	
Solve and evaluate • Rearrange the equation and solve for the unknown quantity. • Verify that your answer is reasonable with respect to sign, unit, and magnitude. • Also make sure the equation applies for limiting cases, such as objects having very small or very large charge.	

17.6.2 Apply

Class: *Equipment per group:* whiteboard, markers.

Work with your group to solve this problem: Two small metal spheres with a mass of 15 g each are hung by very light (e.g. silk) threads whose lengths are both 1.2 m from a common point. When the spheres are given equal quantities of positive charge (so each has a charge $+q$), each thread makes an angle of 25° from the vertical (i.e., the angle between the two threads is 50°).

a. Draw a diagram to illustrate the situation. Draw a force diagram for one sphere. (Remember to include a coordinate system.)

b. Apply Newton's second law in the x- and y-directions to find the charge q on the sphere. (Don't forget that Earth also exerts a force on the sphere.)

c. Evaluate your answer any way you like (this is a good opportunity to use a limiting/special case.)

17.6.3 Equation Jeopardy

Class: *Equipment per group:* whiteboard and markers.

The application of Newton's second law for a positively charged object at one instant of time is shown in the equation that follows. Other charged objects are along a horizontal line. Work with your group members on the activities that follow. Present the results to the class.

$$(4.0\text{ g})a_x = (9.0\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left[-\frac{(200.0\times 10^{-9}\ \text{C})(30.0\times 10^{-9}\ \text{C})}{(0.2\ \text{m})^2}-\frac{(900.0\times 10^{-9}\ \text{C})(30.0\times 10^{-9}\ \text{C})}{(0.3\ \text{m})^2}\right]$$

a. Draw a force diagram for the object at the instant the equation applies.

b. Sketch a situation the equation might describe at that particular instant.

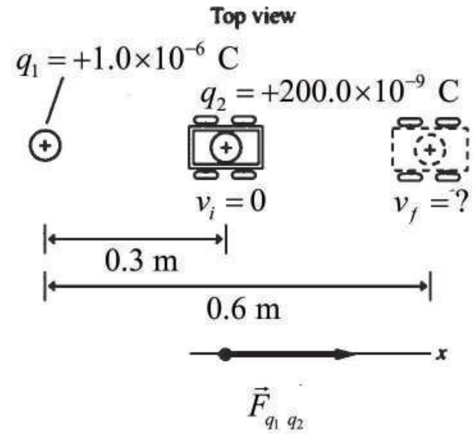
c. Write in words a problem for which the equation is a solution (it applies at only one instant in time).

d. Determine one change that could be made in the situation so that the net force exerted on the object of interest is zero.

17.6.4 Evaluate the solution

PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers.

The problem: A 20.0-g cart with a $+200.0\times10^{-9}$ C charge on it sits at rest 0.3 m to the right of a fixed dome with charge $+1.0\times10^{-6}$ C. The cart is released. Determine how fast it is moving when it is 0.6 m from the fixed-charged dome.



Proposed solution: The situation is shown at the right.

Simplify and diagram

We assume that the dome and cart are point-like particles.

See the force diagram to the right.

Represent mathematically and solve

$$a_x = \Sigma F_x/m = kq_1q_2/rm$$

$$= \left(9\times10^9\,\mathrm{N\cdot m^2/C^2}\right)\left(200.0\times10^{-9}\,\mathrm{C}\right)\left(1.0\times10^{-6}\,\mathrm{C}\right)/\left(0.3\,\mathrm{m}\right)\left(0.020\,\mathrm{kg}\right) = 0.3\,\mathrm{m/s^2}$$

$$v^2 = 0^2 + 2\left(0.3\,\mathrm{m/s^2}\right)\left[\left(0.6\,\mathrm{m}\right) - \left(0.3\,\mathrm{m}\right)\right] \quad \text{or} \quad v = 0.42\,\mathrm{m/s}$$

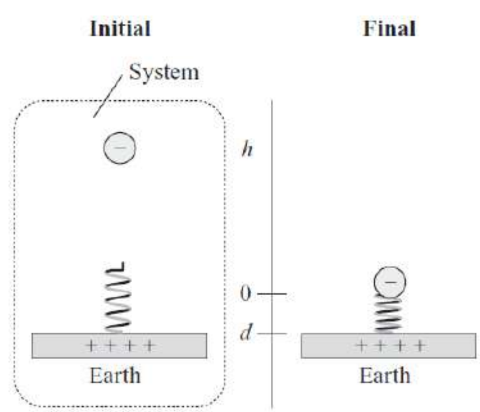
a. Identify any missing elements or errors in the solution.

b. If there are errors, provide a corrected solution or the missing elements.

17.6.5 Represent and reason

Class: *Equipment per group:* whiteboard and markers.

A negatively charged ball, initially at rest, falls until it hits a massless spring, which it compresses while stopping. The bottom of the spring rests on a positively charged block.

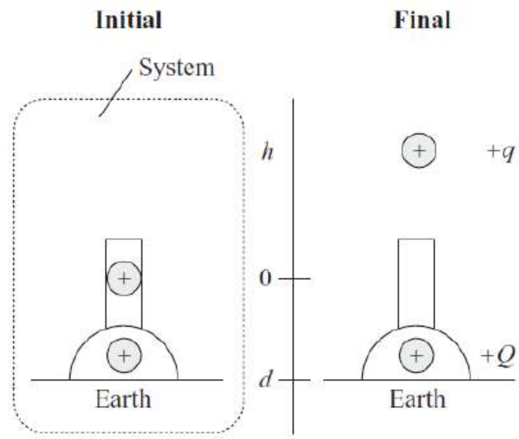


a. Draw a bar chart consistent with the process.

b. Apply the generalized work–energy equation to the process.

17.6.6 Represent and reason

Class: *Equipment per group:* whiteboard and markers.



a. Chris releases the trigger on an electric cannon. The cannonball with charge $+q$ and mass m fires vertically upward due to its repulsion from the stationary ball with a charge $+Q$. The cannonball reaches the apex of its flight at distance h above its starting position. Working with your group on a whiteboard, represent the process physically with a bar chart and mathematically.

b. Now suppose that the charge $+Q$ is reduced to $+Q/2$. Working with your group on a whiteboard, represent this process with a bar chart and mathematically. Describe in words how reducing the charge affects the process. Present your work to another group.

17.6.7 Bar–chart Jeopardy

Class: *Equipment per group:* whiteboard and markers.

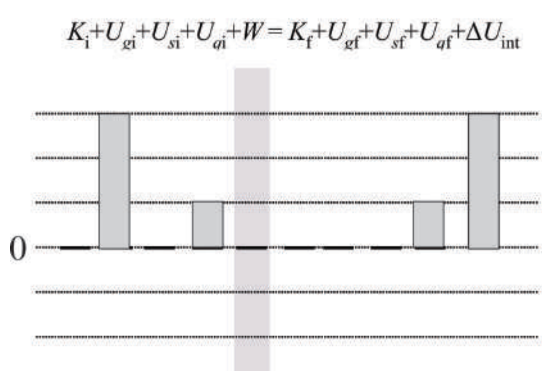
The bar charts below could represent many processes. For each bar chart:

a. Draw an initial–final sketch of one possible process described by the bar chart on your whiteboard.

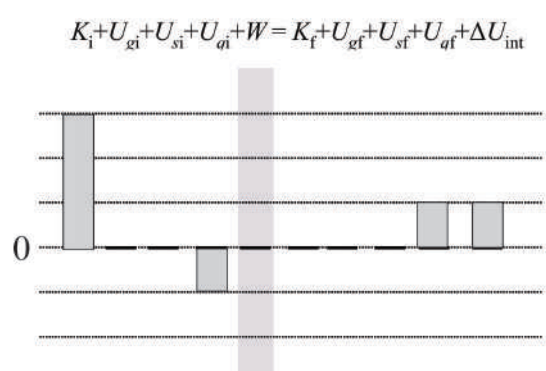
b. Working with your group, describe the process in words.

c. Convert the bar chart into the work–energy relationship as applied to this process and put it on your whiteboard.

1.



2.



17.6.8 Regular problem

Class: *Equipment per group:* whiteboard and markers.

Consider a simplified version of a real situation that occurs in the center of our Sun. A proton of charge $+e$ moves directly toward a stationary deuterium nucleus, also of charge $+e$. (We assume that the deuterium does not move.) Work with your group to answer the following questions.

a. Determine the speed that the proton must move toward the deuterium when far from it so that it is able to get within 1.0×10^{-15} m before stopping. (At this distance, there is a good chance that the proton and deuterium will fuse to form a helium nucleus. The fusion releases considerable energy.) Follow the problem-solving strategy.

b. Estimate the temperature of deuterium when this fusion can occur with good probability. The proton mass is 1.67×10^{-27} kg. What assumptions did you make?

17.6.9 Equation Jeopardy

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

The equation below describes one or more physical processes.

$$\frac{1}{2}\left(1.67\times10^{-27}\,\text{kg}\right)v_{\text{i}}^{2}+\frac{1}{2}\left(1.67\times10^{-27}\,\text{kg}\right)v_{\text{i}}^{2}=\frac{\left(9.0\times10^{9}\,\text{N}\cdot\text{m}^{2}/\text{C}^{2}\right)\left(1.6\times10^{-19}\,\text{C}\right)^{2}}{1.0\times10^{-15}\,\text{m}}$$

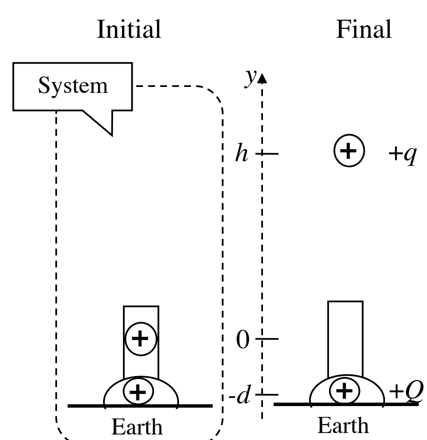
a. Draw a bar chart that is consistent with the equation.

b. Sketch the initial–final states that the equation might describe.

c. Write in words a problem for which the equation could be a solution.

17.6.10 Regular problem

PIVOTAL Class: *Equipment per group:* whiteboard, markers.

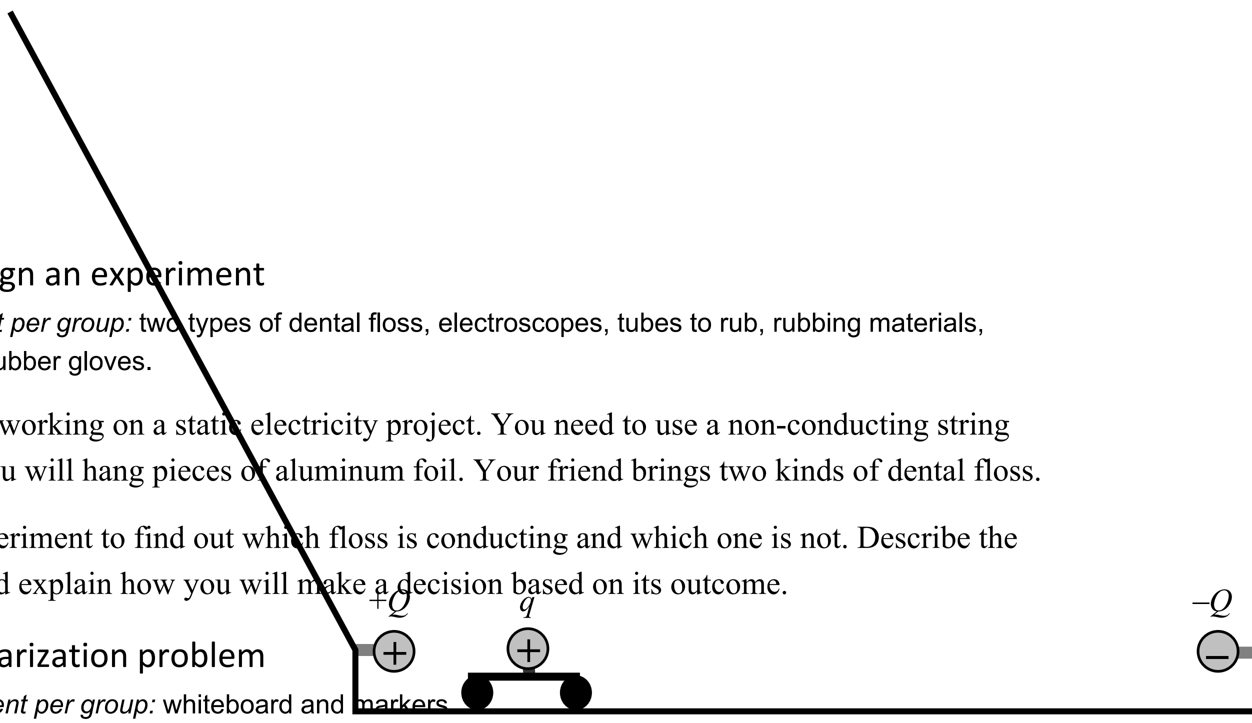


Work with your group members to solve this problem using the problem-solving strategy: Chris releases the trigger on an electric cannon. The cannon ball with charge $+q = 1.0\times10^{-8}$ C and mass $m = 0.5$ kg fires vertically upward due to its repulsion from the stationary ball with a charge $+Q = 1.0\times10^{-7}$ C. They are initially $d = 0.2$ m apart. The cannon ball reaches the top of its flight a distance *h* above its starting position. Assume g =10 N/kg. Represent the process physically with a bar chart and mathematically, then find the max height *h*. Remember to evaluate your answer.

17.6.11 Regular problem

Class: *Equipment per group:* whiteboard, markers.

Work on this problem with your group using the problem-solving strategy. A 0.50-kg cart with a metal ball with electric charge $q = +2.0 \times 10^{-8}$ C starts at rest with its metal ball 0.1 m to the right of a fixed sphere with a positive charge $Q = +3.0 \times 10^{-7}$ C. When released, the cart travels toward a fixed sphere to the right with charge $-Q$. The fixed charges are separated by 1.0 m. How fast is the cart moving when its charged metal ball gets 0.1 m from the fixed sphere with negative charge?



17.6.12 Design an experiment

Lab: *Equipment per group:* two types of dental floss, electroscopes, tubes to rub, rubbing materials, aluminum foil, rubber gloves.

Your group is working on a static electricity project. You need to use a non-conducting string from which you will hang pieces of aluminum foil. Your friend brings two kinds of dental floss.

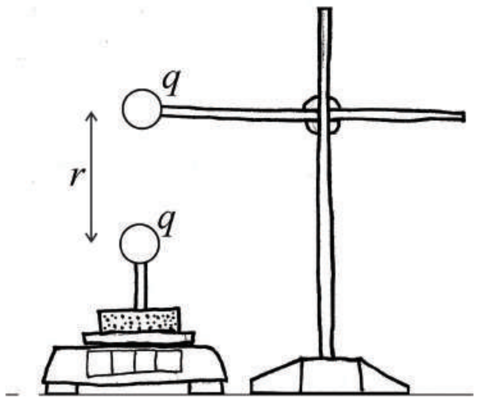
Design an experiment to find out which floss is conducting and which one is not. Describe the experiment and explain how you will make a decision based on its outcome.

17.6.13 Linearization problem

Class: *Equipment per group:* whiteboard and markers.

You have a set-up that consists of two metal spheres, stands and an electronic scale. You charge both spheres with equal charges *q*. You zeroed the scale when no object was on it. You change distance *r* and record the corresponding scale readings. Your data are in the table below.

r (cm)	*m* (g)



5.0	132
6.0	118
7.0	105
8.0	100
9.0	95
10.0	90

Make a list of quantities that you can determine from your data, and determine their values.

17.6.14 Apply

Class: *Equipment per group: balloon, woolen glove, baking soda*

You "write" a letter G with your finger on a rubber balloon using a glove made of wool. Then you bring the balloon close to a plate covered with uncharged baking soda powder. Some powder jumps from the plate and sticks to the balloon at the places rubbed with wool (see the photo on the right).

a. Explain why the neutral powder jumps onto the balloon and why it remains there. Compare and contrast the outcome of this experiment with how a photocopier works.