Chapter 18

The Electric Field

18.1 A model of the mechanism for electrostatic interactions

OALG 18.1.1 Observe and explain

Equipment: a foam tube (or a plastic rod, a plastic comb), rubbing material (felt, fur or wool), a small piece of aluminum foil on an insulating string (such as dental floss).

Conduct the following experiment: First you need to charge a foam tube and a small piece of aluminum foil on a string so they have the same charge. How will you do this? Then hold the foam tube still and slowly bring the piece of foil close to the charged foam tube. Observe what happens.

a. What happens to the piece of foil as it is brought closer to the charged foam tube? As it moves farther away?

b. Describe a possible mechanism by which the charged foam tube interacts with the charged piece of foil without touching it.

c. Read and interrogate page 536 in Section 18.1 in the textbook. What is the mechanism discussed there? How do you understand the term "electric field" and "gravitational field"?

OALG 18.1.2 Observe and explain

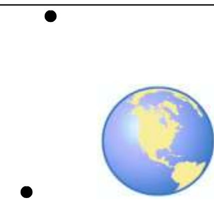
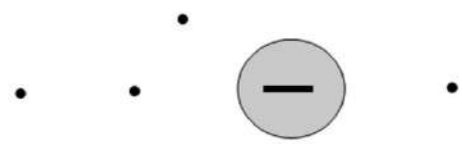
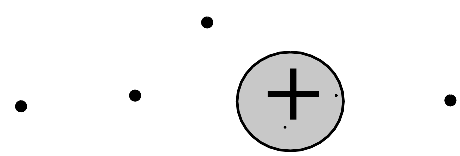
Watch experiments at http://islephysics.net/pt3/experiment.php?topicid=10&exptid=194

a. Describe what you observed.

b. Explain your observations using the concept of electric field.

OALG 18.1.3 Represent and reason

For each situation pictured in the table that follows, represent the gravitational force or the electric force that the object of source mass or source charge exerts on the object of test mass or test charge at the points shown.

Word description	**Picture description; draw the gravitational force or the electric force at the points. Draw the arrows with the correct relative lengths.**
Represent with arrows the gravitational force that the Earth (the source mass) exerts on a small object (the test mass) at the points shown.	
Represent with arrows the electric force that the object with a large negative charge (the source charge) exerts on a small object that has a positive charge (called the test charge) at the points shown.	
Represent with arrows the electric force that the object with a large positive charge (the source charge) exerts on a small positively charged object (the test charge) at the points shown.	

a. Use a field approach to explain in words how the source object can exert a force on test objects without directly touching them. For the gravitational field, discuss how the magnitude of the force may depend on the properties of the field, on the mass of the source object, and on the distance away from the source object. Consider similar factors for the electric field.

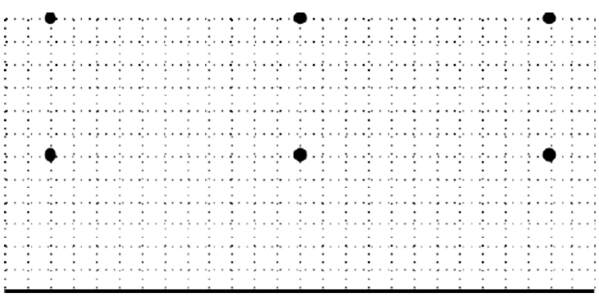
b. How does the presence of a source mass or a source charge alter the space? How far do you think this alteration extends?

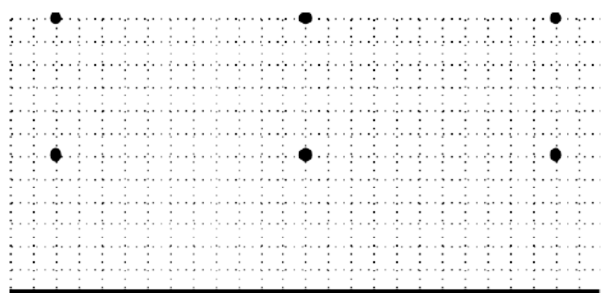
c. Does a system that includes Earth and the test object possess gravitational potential energy? Does a system that includes the source charged object and the test charged object possess electric potential energy? Does each energy depend on the source mass or the test mass? On the magnitudes of source charge or the test charge? Their signs?

OALG 18.1.4 Represent and reason

Alicia and Sammy decide to map the gravitational field created by Earth near the Earth's surface (assuming that close to Earth's surface it is flat) by measuring the force exerted by Earth on a test object at the six points shown in the diagram. Alicia uses a 1-kg test object while Sammy uses a 2-kg test object.

a. Draw Alicia's and Sammy's measured gravitational field vectors at the points shown in the diagram. Make sure you draw the vectors to scale.



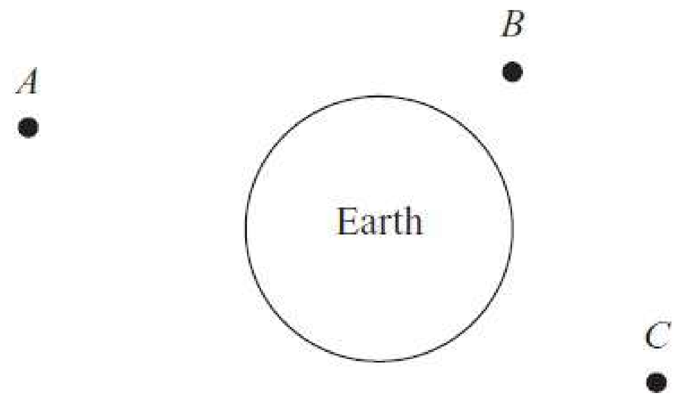


b. You may notice that in the previous activity, Alicia's and Sammy's fields look different. This is a problem because, conceptually, the field is created by Earth and should be the same no matter what mass the test object used to measure it has. Invent a new physical quantity (the $\vec{g}$ **field**) that will be independent of the mass of the test object used to measure it (we will call this test object test-mass).

c. Compare the physical quantity that you invented with the quantity defined in Equation 18.1 on page 537 in the textbook. Then think how you can devise a similar quantity to characterize electric field. Then compare the physical quantity you invented with the one defined by Equation 18.2 on page 538 in the textbook.

OALG 18.1.5 Represent and reason

Estimate and draw the Earth's $\vec{g}$ field at the points shown in the figure.



a. What would you choose as the source-mass object? What would you use as the test-mass object?

b. Draw $\vec{g}$ field vectors at points *A, B,* and *C*.

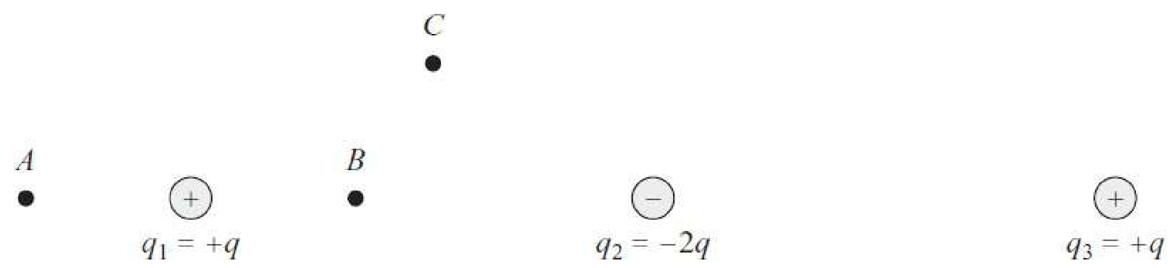
c. Discuss how the magnitude and direction of the $\vec{g}$ field are related to the acceleration of free-falling objects placed at these points.

OALG 18.1.6 Represent and reason

Draw $\vec{E}$ field vectors around the source charged objects shown in the two diagrams below. Remember that (by agreement) the $\vec{E}$ field is mapped by a positive test charge. Pay attention to the length of the arrows.

OALG 18.1.7 Represent and reason

Estimate the direction and the magnitude of the $\vec{E}$ field at points A, B, and C in the figure that follows. The field is created by all three charges.



OALG 18.1.8 Represent

Read and interrogate subsection "$\vec{E}$ field lines" on page 540 in the textbook. Then answer the questions below.

a. Below you see several examples of charged object creating electric fields. Draw the objects and for each situation draw $\vec{E}$ field vectors and $\vec{E}$ field lines.

1. A point-like positively charged object.

2. A point-like positively charged object with twice the magnitude of charge as in part 1.

3. A point-like negatively charged object.

4. A point-like negatively charged object with twice the magnitude of charge as in part 3.

5. Two positively charged point-like objects of equal-magnitude charge, separated by a distance *r*.

6. Two negatively charged point-like objects of equal-magnitude charge, separated by a distance *s*.

7. A small positively charged object and a small negatively charged object of equal-magnitude charge, separated by a distance *s*.

8. A small positively changed object and a small negatively charged object with twice the magnitude of electric charge, separated by a distance *s*.

After you have drawn the vectors and lines, answer the following questions.

Can electric field lines cross? Explain.

b. What is the direction of the $\vec{E}$ field line at a point midway between two equal-magnitude, positively charged objects? How do you know?

c. What is the direction of the $\vec{E}$ field line at a point midway between two equal-magnitude, oppositely charged objects? How do you know?

d. Pick 3 of the situations in part **a**. Use household objects to represent the source charges.

Take a video of yourself showing what the E field looks like around the source charges in 3D. Be creative in how you physically represent both field strength and field direction at various positions in space around the source charges.

OALG 18.1.9 Represent

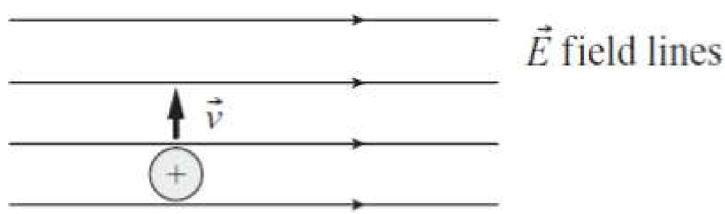
Draw $\vec{E}$ field lines for a uniformly positively charged, infinitely large glass plate. Use these guiding questions to help you figure this out:

a. Redraw the plate in your notes. Pick a position of interest to one side of the plate and figure out the direction of the $\vec{E}$ field at that point. Think about the direction of the $\vec{E}$ field created by each small segment of the glass plate. Are there any components of the $\vec{E}$ field that cancel out? What direction should the overall $\vec{E}$ field point?

b. Now draw $\vec{E}$ field lines emanating from the plate. In what direction do they point? Why? How should the $\vec{E}$ field lines be spaced? Why? Compare your drawing with the answer for Conceptual Exercise 18.2 in the textbook on page 542.

OALG 18.1.10 Represent and reason

Imagine that a small, positively charged object moving toward the top of the page enters an electric field with the lines shown below.



a. Sketch on the illustration an approximate trajectory of the object as it moves through the field. The direction of the initial velocity of the object as it enters the field is shown in the figure.

b. Do the lines represent the trajectories that a charged object follows after it enters the field?

OALG 18.1.11 Read and Interrogate

Read and interrogate Section 18.1 in the textbook and answer Review Question 18.1.

OALG 18.1.12 Practice

Answer Questions 1, 7, 9, 10, and 11 on page 566 and solve Problems 1, 3 and 6 on page 567 in the textbook.

18.2 *Skills for determining $\vec{E}$ fields and analyzing processes involving $\vec{E}$ fields*

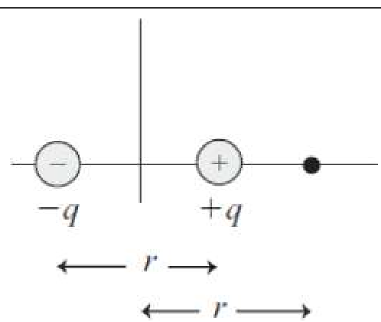
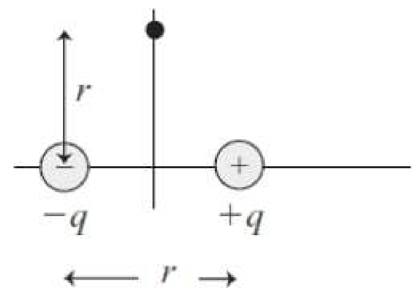
OALG 18.2.1 Represent and reason

A small aluminum ball is charged with $+1.0\times10^{-9}$ C. Represent the $\vec{E}$ field at each point using an arrow. Determine the magnitude of the $\vec{E}$ field due to this source charge at the four points shown below.

5 cm to the right of the ball	**7 cm to the left of the ball**	**1 cm above the ball**	**10 cm below the ball**
			

OALG 18.2.2 Represent and reason

Two charged objects with charges $+q$ and $-q$ respectively are separated by a distance r, as shown in the figures below. Determine an expression for the magnitude of the E field at points $(r, 0)$ and $(0, r)$ due to these two charges. Examine both cases.

Case 1:	Case 2:
	

a. Draw an $\vec{E}$ field vector diagram.

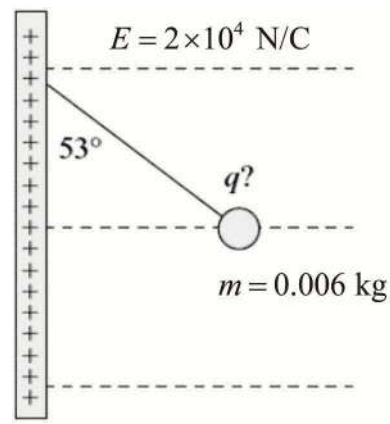
b. Determine the component fields, E_x and E_y .

c. Determine the magnitude of the net $\vec{E}$ field.

OALG 18.2.3 Read and interrogate

Read and interrogate Section 18.2 in the textbook, work through Examples 18.3-18.5, and answer Review Question 18.2.

OALG 18.2.4 Represent and reason



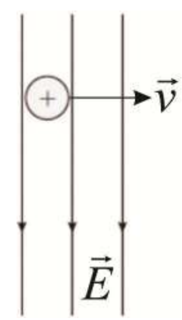
A 0.006-kg electrically charged ball hangs at the end of a string oriented 53° outward from a charged vertical plate. The $\vec{E}$ field produced by the plate at the position of the ball is 2.0×10^4 N/C and points away from the plate. Assume that the gravitational constant is 10 N/kg.

a. Draw a force diagram for the hanging ball.

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

c. Determine the charge on the ball.

OALG 18.2.5 Represent and reason



A 0.0010-g dust particle charged to $+2 \times 10^{-9}$ C moving horizontally encounters a uniform 1.0×10^4 N/C electric field, as shown at right. Determine the change in the magnitude of its vertical velocity component after it moves a vertical distance of 1.0 m. Follow problem-solving strategy 18.1 .

OALG 18.2.6 Practice

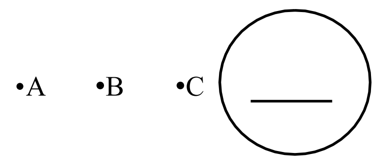
Answer Question 6 on page 566 and solve Problems 8, 12, 13, and 19 on pages 567-568.

18.3 The V field: Electric potential

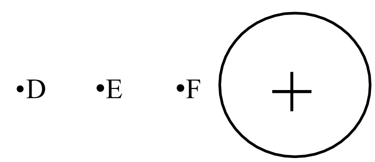
OALG 18.3.1 Represent and reason

A positive test charged object is placed at each of the following points (A through F) near a source charged object. Answer the following questions:

a. Rank the potential energies for the system test-charge-source-charge from greatest to least (for points A-C). (Remember: a large negative number is less than a small negative number.) Show at least one additional point where you can place a test charge so that the electrical potential energy is the same as for the configuration for point C.



b. Rank from greatest to least the potential energies of the system test-charge-source-charge shown below (D-F). Show at least one additional point where you can place a test charge so that the electrical potential energy is the same as for the configuration for point E.



c. How might the magnitude of the potential energy of the system test-charge-source-charge depend on the magnitude of the source charge? How is the magnitude dependent on the distance from the source?

d. Does a system that consists of a single electron have an electric potential energy?

e. Recall and write down the mathematical model for electrical potential energy. How does electric potential energy depend on the source charge? On the test charge?

f. Think of how you can define an energy-type physical quantity that will characterize the electric field from the energy perspective similar to how the quantity of $\vec{E}$ field characterizes the field from the force-type perspective.

g. Compare and contrast the physical quantity you defined with the physical quantity defined by Equation 18.6 in the textbook.

OALG 18.3.2 Reason

a. Why is the test charge present in the definition of the *V* field even though the value of the *V* field does not depend on the test object?

b. Compare and contrast operational definitions for $\vec{E}$ and *V* fields.

c. Think of the analogy of the *V* field quantity in the gravitational field. Then look around the classroom and find three locations with the largest gravitational potential and three locations with the smallest. Where did you choose the gravitational potential to be zero?

d. Explain how you can relate the surface of a desk and three shelves of bookshelves in the classroom to the concept of gravitational potential.

e. Explain how topographical maps might be related to the physical quantity of gravitational potential.

OALG 18.3.3 Represent and reason

a. Draw a positive charge of 9 nC at the center of your notes and find locations of 5 points at different locations such that: $V_A = V_B = V_C > V_D > V_E$.

b. Then measure the distance to those points with a ruler and calculate the actual values of the potential at those locations. Where did you choose the zero potential to be?

c. Draw two graphs, one under the other, for the 9 nC charge: *E*-versus-*r* and *V*-versus-*r*. How are the graphs similar? How are they different?

OALG 18.3.4 Read and interrogate

Read and interrogate Section 18.3 in the textbook, and answer Review Question 18.3.

OALG 18.3.5 Reason

Answer the following questions:

Compare the electric potentials at points *A*, *B*, and *C* due to the positive source charge, the largest potential listed first. Show at least one other point at which electric potential is the same as at point *A*.  	Compare the electric potentials at points *D*, *E*, and *F*, the largest potential listed first. (*Note:* A large negative number is less than a small negative number.) Show at least one other point at which electric potential is the same as at point *E*. 

OALG 18.3.6 Represent and reason

Draw lines of equal gravitational potential caused by Earth, a mass source for the gravitational potential. Think of how you can write an expression for the gravitational potential that is analogous to the expression for the electric potential in following cases:

a. Far away from the surface of Earth, when Earth is modeled as a sphere.

b. Close to the surface of Earth, when the surface of Earth can be modeled as a plane.

c. Read and interrogate subsection "Equipotential surfaces – representing the *V* field" on page 549 in the textbook.

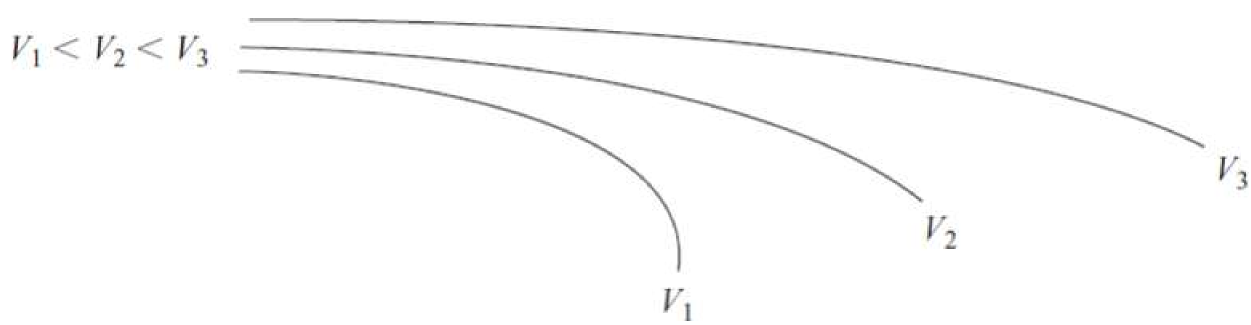
OALG 18.3.7 Explain

Sometimes physicists use the analogy between lines of equal electric potential and lines of equal altitude on topographical maps.

a. Explain how this analogy works and why it is useful. Find limitations (or problematic aspects) of this analogy.

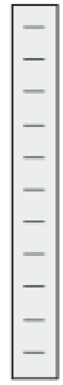
b. Describe how the closeness of the equal-altitude lines relates to the steepness of a mountain.

c. Use this analogy to draw electric field lines for the electric field whose equipotential surfaces look as follows. Explain.



OALG 18.3.8 Reason

Draw equal potential surfaces and $\vec{E}$ field lines for a negatively charged, infinitely large metal plate. For help, complete the activities in the table that follows.

Sketch the plate with electric charges (shown below).	**Draw lines of equal electric potential. Indicate where the potential is higher.**	**Draw $\vec{E}$ field lines.**
		

a. Why are the $\vec{E}$ field lines perpendicular to the surface of the plate? Explain.

b. Are both the $\vec{E}$ field lines and equal potential surfaces equally spaced? Explain.

c. Examine the locations of the $\vec{E}$ field lines and the equal potential surfaces with respect to each other. Discuss any patterns that you find. Explain.

OALG 18.3.9 Practice

Answer Questions 5 and 19 on pages 566-567 and solve Problems 23, 24, and 25 on page 568 in the textbook.

18.4 Relating the E field and the Vfield

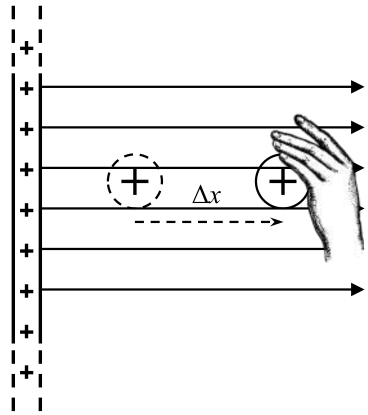
OALG 18.4.1 Represent and reason

Using the same source charges as in Activity 18.1.8 part **a.** examples 1-4 and the $\vec{E}$ field lines that you drew there, draw the surfaces of equal potential. Find a pattern between the direction of the lines and the change of electric potential (whether the electric field lines point in the direction of increasing or decreasing potential).

OALG 18.4.2 Derive

Consider a uniform $\vec{E}$ field produced by an electrically charged infinitely large glass plate. We will place a small object with charge $+q$ at some initial point in the field and move it (by hand) at a *constant* speed to some final point, through a displacement Δx, as shown in the diagram below.

Calculate the work done by the hand and use that to estimate the difference in potential between the initial and final points in order to find a relationship between the $\vec{E}$ field and the potential difference ΔV. Use the guiding questions below to help structure your derivation.



a. Draw a force diagram showing forces exerted on the charged object by other objects. How are those forces related to each other? Remember, we move the charged object at a constant speed through the field.

b. Calculate how much work is done by the hand in moving the charged object through a displacement Δx.

c. Use the generalized work-energy principle to relate the work done by the hand to the change in potential energy of the charged-object-glass-plate system.

d. Set your work equations equal to find an expression for the $\vec{E}$ field in terms of ΔV and Δx. Does the equation you derived make physical sense? In what way? Come up with specific examples to justify your reasoning.

e. Read and interrogate Section 18.4 in the textbook and find the matching steps in the derivation in the textbook to parts **a-d** that you did. Compare your answer to part **d** to the Equation 18.10 on page 551. Do you need to revise anything?

OALG 18.4.3 Observe and explain

In the following video https://youtu.be/YO9j51QavmE you see two metal plates connected to a device called a *voltmeter* that allows you to measure the potential difference between two points. Watch the video and explain what you observe. Answer the following questions:

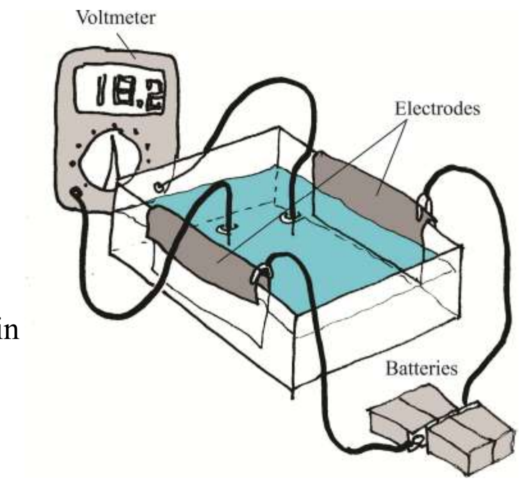
a. How is it possible for the voltmeter to read positive potential difference if the experimenter only charged one plate? Hint: Note that the yellow wire in the experiment is connected to Earth.

b. Why does the experimenter move the plate using a plastic holder?

c. Why does the reading of the voltmeter increase as the plate is moved to the right although no more charges were added to it? Use an energy bar chart for help. Consider the system to be the two plates and the hand to be a part of the environment. After you draw the bar chart and explain the outcome of the experiment, think of how you could have explained it using the relationship between the *E* field and the *V* field.

OALG 18.4.4 Test your ideas

In the following video https://youtu.be/YfhJJYVVBDs we use a digital *voltmeter* (in Activity 18.4.3 we used an analogue voltmeter) to measure the potential difference between two points. We also use a battery that creates a constant potential difference between two metal strips connected to it.



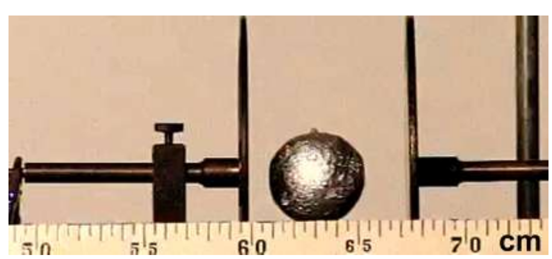
We filled the container with tap water and placed metal strips (electrodes) as shown in the figure on the right. It is possible to measure potential difference between two points by touching them with the voltmeter leads. These points can be the on the electrodes anywhere in the water.

a. Watch the video and describe in words what happens in the experiment. Then explain how you can predict the results of the experiment using your knowledge of potential difference. Discuss any additional assumptions you need to make.

b. The experiment is then modified so that the distance between the electrodes is fixed. Use your knowledge of electric potential to predict what will happen to the reading of the voltmeter when (1) the two electrodes are oriented along the line perpendicular to the metal strips and are moved along this line; (2) the two electrodes are oriented along the line parallel to the metal strips and are moved along this line, first closer to one of the strips and then closer to the middle of the container. Explain how you made your prediction.

c. Watch the experiment https://youtu.be/SI72nmsfC3A and record the outcome. Did your prediction match the outcome? If not, how do you need to modify the reasoning that led you to the prediction (or some additional assumptions) to account for the outcome?

OALG 18.4.5 Observe and explain



Watch the high-speed video of a conducting sphere vibrating between two charged plates connected to a device called a high-voltage source that creates a constant potential difference between the plates [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-18-4-4]. The sphere is hanging on a nonconducting (insulating) string. The video is recorded at 600 frames per second. *Note*: if some charges are removed from the plate, the high-voltage source replaces these charges with new ones, so the potential difference between the plates remains constant.

a. Describe your observations as fully as possible (you can use the video to collect data).

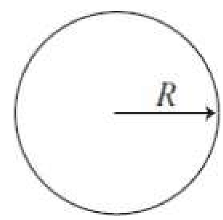
b. Explain your observations using your knowledge of forces, and the relationship between the $\vec{E}$ and V fields. Provide qualitative and quantitative explanations.

OALG 18.4.6 Practice

Answer Questions 8, 26 and 27 on pages 566-567 and solve Problems 30, 31, 32, 33, 57 and 58, on page 568-570 in the textbook.

18.5 Conductors in electric fields

OALG 18.5.1 Reason



Imagine that you have a positively charged, solid metal ball, as shown on the right. Answer the following questions.

a. Indicate on the drawing how the charge is distributed inside the ball and on the ball's surface, and explain your drawing.

b. Draw electric field lines inside the ball (if any). Explain.

c. Draw electric field lines outside the ball and compare their distribution with the distribution of electric field lines of a point-like charged object.

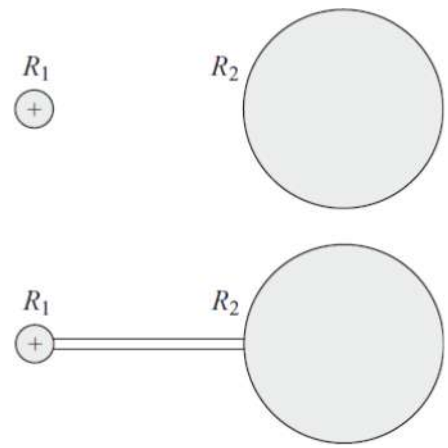
d. Draw a graph of the magnitude of the E field versus the distance r from the center of the ball.

e. Draw a graph of the V field versus the distance r from the center of the ball.

f. How can you have a situation in which the electric field at some location is zero but the electric potential is not? Does this seem reasonable? Explain.

OALG 18.5.2 Reason

You have two metal spheres of radii R_1 and $R_2 = 10R_1$ that are far apart (the figure below is not to scale). The sphere on the left has a charge $+q_1$, and the sphere on the right is not charged. They are then connected by a metal wire.



a. Explain whether the electric potential on the surfaces of the spheres will be the same or different before they are connected with a metal rod.

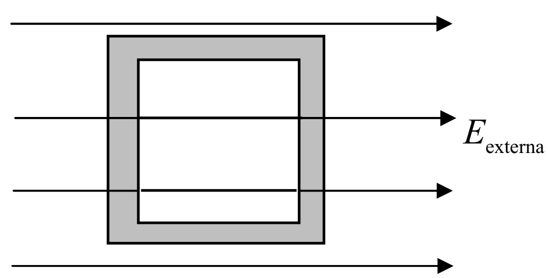
b. Will the electric potential on the surfaces be the same or different after they are connected?

c. What will be the charges of the spheres in fractions of q_1 after connection? How does the total charge of the two spheres after the connection compare to the initial charge of the left sphere?

d. Discuss how the situation in parts **a.–c.** is related to the method of discharging objects by connecting them to Earth—so-called *grounding*. Earth is a huge conductor, like a huge metal sphere.

OALG 18.5.3 Represent and Reason

A hollow metal box is placed in a uniform electric field. Negatively charged electrons in the metal can move freely.



a. Indicate the electric charge distribution in the metal due to the external electric field. *Note:* If electrons move from one part of the box to another, the part with a deficiency of negatively charged electrons is now positively charged, and the part with an excess of electrons is negatively charged.

b. Draw electric field lines caused by this induced-charge distribution on the surface of the box and discuss the magnitude of the total $\vec{E}$ field inside the box.

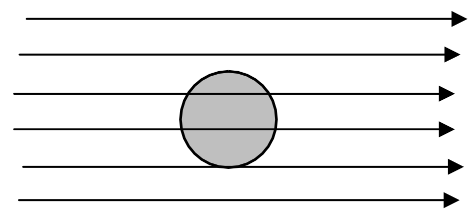
c. Discuss how your reasoning in parts **a**. and **b**. helps explain why it is safe to sit in a car during a lightning storm.

d. Draw the new shape of the field lines outside the box. How does the redistribution of electrons inside the box affect the electric field outside?

e. Compare your drawings to Figure 18.17 on page 555 in the textbook. Why do we use the term "shielding" to explain why it is safe to be in a car in a lightning storm?

OALG 18.5.4 Reason

You place a metal ball in a uniform electric field (the field lines are shown below). Draw the new orientation of the electric field outside the ball and the field lines inside the ball. *Hint*: $\vec{E}$ field lines outside the conductor are always perpendicular to the surface of the conductor.



OALG 18.5.5 Read and interrogate

Read and interrogate Section 18.5 in the textbook, and answer Review Question 18.5.

OALG 18.5.6 Practice

Answer Questions 2, 3, 20 and 21 on pages 566 and 567 and solve Problems 34, 37 and 38 on pages 568-569 in the textbook.

18.6 Dielectric materials in an electric field

OALG 18.6.1 Read and interrogate

Read and interrogate Section 18.6 in the textbook and answer Review Question 18.6.

OALG 18.6.2 Reason

a. What is the meaning of the physical quantity the dielectric constant, κ? What does it characterize? Can κ of some material be equal to 1? To zero? To infinity?

b. How does the presence of a dielectric in space between two charged metal plates affect their electric interaction? Answer the question conceptually macroscopically and microscopically, and quantitatively. Draw diagrams as appropriate in your notes.

OALG 18.6.3 Observe and explain

a. Watch the following experiment https://youtu.be/cwZ0ezi1sr8 and describe what you observe.

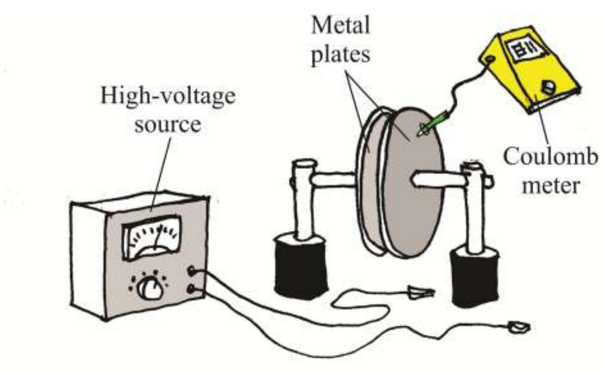
b. Explain why moving the metal plates away from each other led to the spark between two needles. Carefully observe how the plates and needles are connected. Note that the long yellow wire serves the purpose of grounding.

OALG 18.6.4 Practice

Answer Questions 4, 22 and 23 on pages 566-567 and solve Problem 41 on page 569.

18.7 Capacitors

OALG 18.7.1 Observe and find a pattern



You have two neutral metal plates on nonconducting stands. You connect the plates to a high-voltage source, a device that provides constant potential difference between the plates. One plate becomes positively charged and the other one negatively charged (the high-voltage source moves some electrons from one plate to the other plate). You disconnect the plates from the voltage source and touch one plate with a device called a coulomb meter (see figure on the right). This device allows you to measure the excess charge on the plate. You repeat the experiment several times, varying the potential difference between the plates and measuring the charge on one of the plates. The data obtained in five measurements are in the table below.

Potential difference V (V)	**Charge on one plate q (nC)**
20	4
40	8
80	15
120	25
160	31

a. What pattern can you infer from these data?

b. What physical quantity can you invent to represent this pattern?

OALG 18.7.2 Explain

In Activity 18.7.1 you found that the charge of each plate is proportional to the potential difference across the plates. Explain why such a relation makes sense using your knowledge of electric fields.

OALG 18.7.3 Test your explanation

a. Use the explanation you invented in Activity 18.7.2 to predict what will happen to the charge on the plates if you increase the distance between the plates while keeping the potential difference between the plates constant (you do this by keeping the plates connected to the high-voltage source).

b. Analyze the data from the experiment described below and check whether your prediction matches the outcome of the experiment.

Experiment: The plates are initially 3 mm apart. You connect the plates to a high-voltage source (100 V). Then you disconnect the voltage source and measure the charge on the plates using the coulomb meter. Then you again connect the plates to a 100 V potential difference, increase the separation between the plates by 1 mm, disconnect the voltage source, and again measure the charge on the plates. You repeat these steps until the separation between the plates is 8 mm. You obtain the data shown below:

Distance between the plates (mm)	**Charge on one plate (nC)**
3	84
4	63
5	50
6	42
7	35
8	32

OALG 18.7.4 Read and interrogate

a. Read the first part of Section 18.7 in the textbook (before the subsection Energy of a charged capacitor) and explain how Activities 18.7.1-18.7.2 relate to the operational definition of capacitance $C = \frac{Q}{|\Delta V|}$ and Activity 18.7.3 to the cause-effect relationship for the capacitance of a parallel plate capacitor $C = \frac{\kappa A}{4\pi k_C d}$.

b. Explain why increasing the dielectric constant increases the capacitance of a parallel plate capacitor.

c. Read and interrogate subsection "Energy of a charged capacitor" in the textbook and explain how it is possible that the energy is simultaneously directly proportional to the capacitance and inversely proportional. (See Equation 18.15).

OALG 18.7.5 Practice

Solve Problems 43-45 and 49 on page 569 in the textbook.

18.8 Electrocardiography

OALG 18.8.1 Regular problem

a. To cleanse the air of dust and pollen, some homes have electrostatic precipitators in their heating and air-conditioning systems. These units work by moving particle-laden air through an ionizing area, in which the particles acquire a charge, and then into an area in which an electric field is present. Because the particles are charged, they experience a force and are attracted to a collector that homeowners need to clean from time to time. Such units are also used on a larger scale as industrial scrubbers in smokestacks, where particle-laden air rises through the stack, acquires a charge by an industrial ionizing source, and is filtered via electrostatic attraction. Imagine that you are a member of a team from the Environmental Protection Agency that is trying to determine whether the school's heating smokestack is effective in removing most particulate matter. You find that the smoke particles move up the 20-m-high stack at a constant 5-m/s speed. By checking the ionizing equipment, you deduce that the specific charge (charge per unit mass)

imparted to each particle is 1×10^{-5} C/kg. Most particles have a mass of $1\mu\text{g}\left(10^{-6}\,\text{g}\right)$, but some are as large as 100 mg. You see that two plates separated by 0.30 m are on opposite sides of the chimney, with a 3000-*V*/m E field between them. Will you recommend that the operating license for the smokestack be renewed? Support your ruling with a careful analysis.

b. Could such a system also work to help prevent the spread of COVID-19 via aerosols? Justify your answer.