Electric field

Eugenia Etkina

Links to materials for today’s workshop

All workshop materials

https://drive.google.com/drive/folders/1zaq7NcDLCOjZ2H9NqXBIKLvsMc9rNwBU

OALG file for Chapter 18

OALG Chapter 18 Final.docx

Let’s watch a movie

https://www.youtube.com/watch?v=GZxgYNnkBd0

How can a car protect us from lightning?

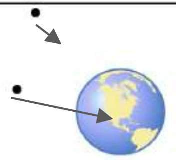
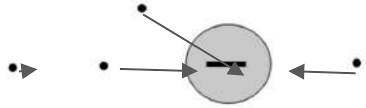
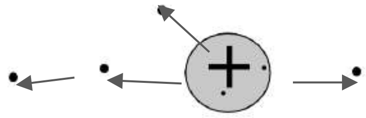
Why is this rhombus hanging there?

Let’s find out!

All together - OALG 18.1.1 and 18.1.2 OALG Chapter 18 Final.docx

http://islevideos.net/experiment.php?topicid=13&exptid=160 watch the first experiment only - charging anomalous

Team 1 OALG 18.1.3 a and b Read the activity and draw on the screenshot here using the arrow tool, answer the questions on the next slide

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.	

Team 1 18.1.3

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.

More charge will mean more force. The farther away the smaller the force.

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

Adding effects

Team 2 OALG 18.1.3 a and b Read the activity and draw on the screenshot here using the arrow tool, answer the questions on the next slide

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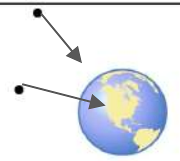
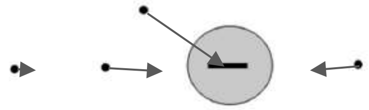
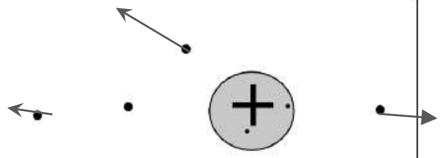
Represent with arrows the gravitational force that the Earth (the source mass) exerts on a small object (the test mass) at the points shown.	
Represent with arrows the electric force that the object with a large negative charge (the source charge) exerts on a small object that has a positive charge (called 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.	

Team 2 18.1.3

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.

For gravitational field, the larger the mass of the source object and the smaller the distance, the stronger the field. For electric field, it should depend on the amount of charge of the source object and the distance.

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

By exerting force to them. It should exist until infinity.

Team 3 OALG 18.1.3 a and b Read the activity and draw on the screenshot here using the arrow tool, answer the questions on the next slide

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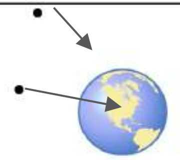
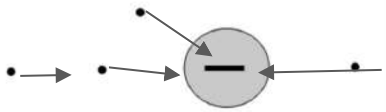
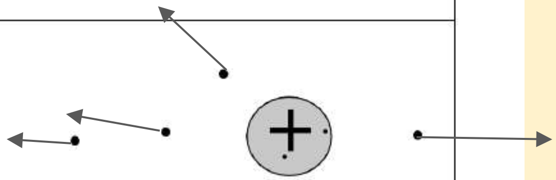
Represent with arrows the gravitational force that the Earth (the source mass) exerts on a small object (the test mass) at the points shown.	
Represent with arrows the electric force that the object with a large negative charge (the source charge) exerts on a small object that has a positive charge (called 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.	

Team 3 18.1.3

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

Team 1 18.1.3

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

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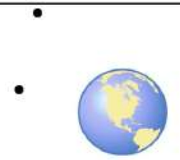
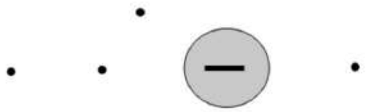
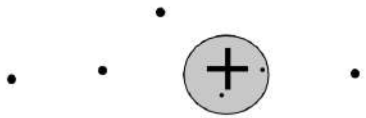
Represent with arrows the gravitational force that the Earth (the source mass) exerts on a small object (the test mass) at the points shown.	
Represent with arrows the electric force that the object with a large negative charge (the source charge) exerts on a small object that has a positive charge (called 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.	

Team 1 18.1.3

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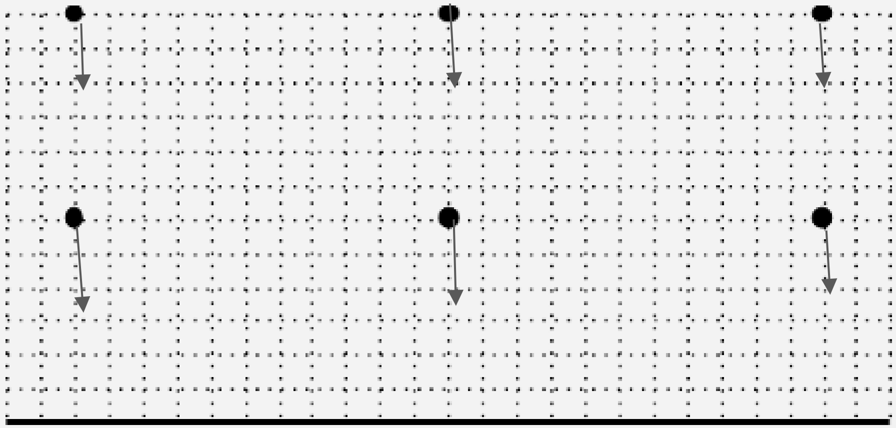
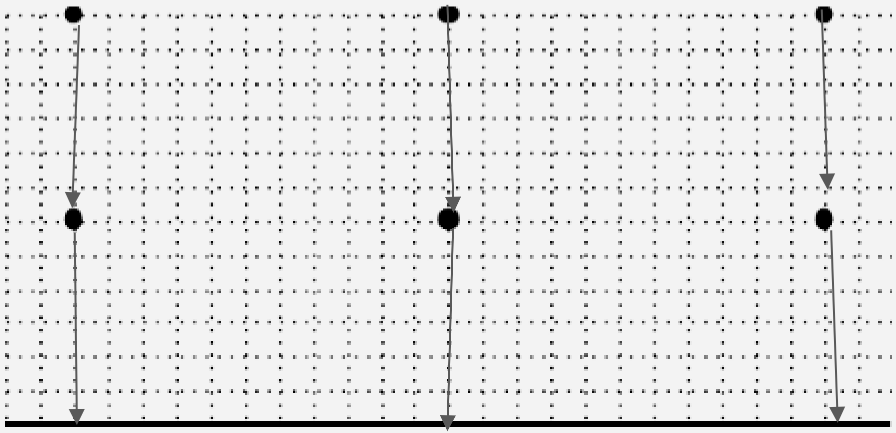
b. How does the presence of a source mass or a source charge alter the space? How far do you think this alteration extends?

Team 1 OALG 19.1.4

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.

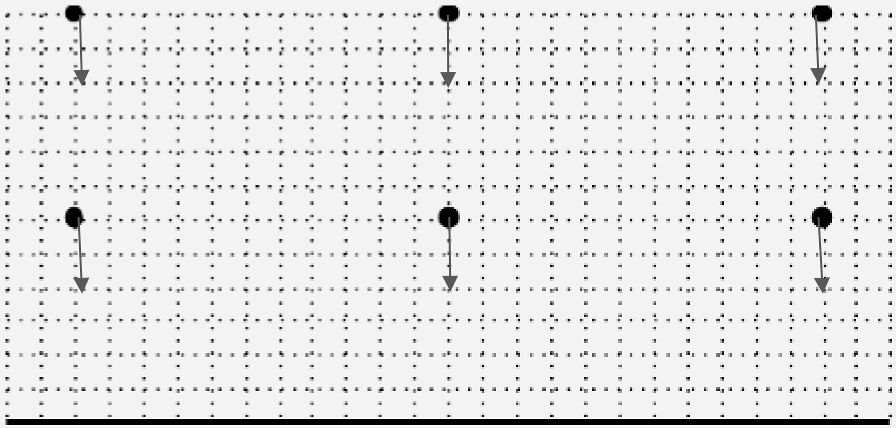


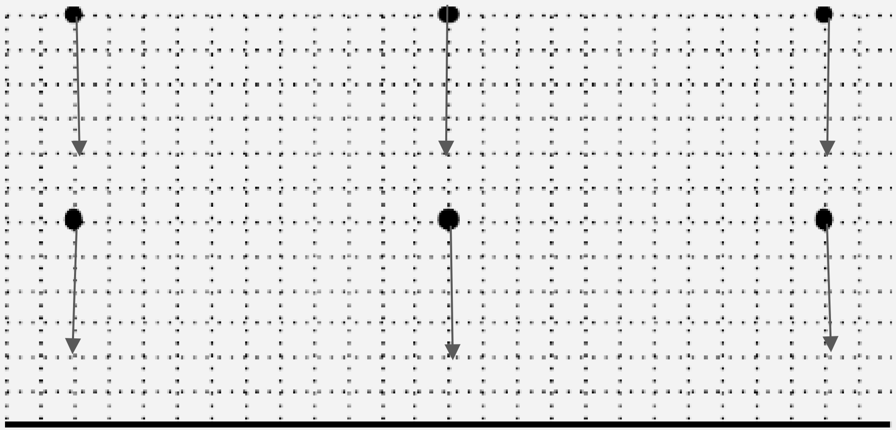


Team 2 OALG 19.1.4

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' *(using FORCE measurements)* at the points shown in the diagram. Make sure you draw the vectors to scale.





Team 3 OALG 19.1.4

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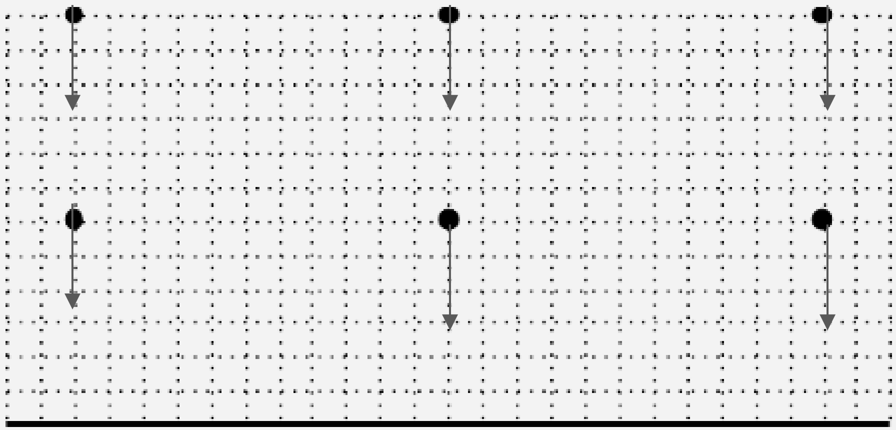
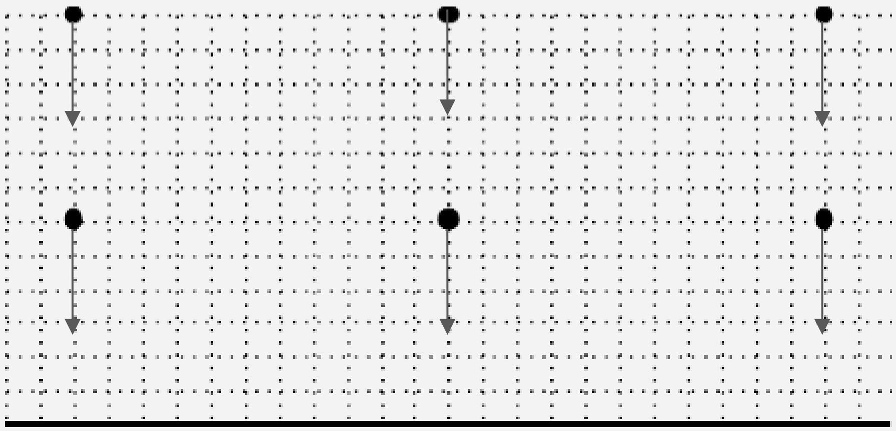
a. Draw Alicia's and Sammy's measured gravitational field vectors at the points shown in the diagram. Make sure you draw the vectors to scale.

Intensity of gravitational field is uniform near the Earth, it not depends on the test mass



Alicia



Sammy

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 field) that will be independent of the mass of the test object used to measure it (we will call this test object test-mass).

(Fsource on test object/m test object)=$m_o g/m_o$=g

Fsource on test charge/charge test object= F/q_{test}= E_{field}

All together

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 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.

Let's develop a gravitational field approach for the gravitational force that one object with mass exerts on another. In the region near Earth, Earth's contribution to the gravitational field is the dominant one. Imagine Earth and one of three small objects A, B, or C. We call these objects *test objects*, because we use them as detectors to probe the field (**Figure 18.3a**). We place the test objects one at a time at the same location near Earth. The masses of these test objects are $m_A = m$, $m_B = 2m$, and $m_C = 3m$. Consider the gravitational force that Earth exerts on each test object (Figure 18.3b).

$$F_{\text{E on A}} = G\frac{m_E}{r^2}m_A = m_A\left(G\frac{m_E}{r^2}\right)$$

$$F_{\text{E on B}} = G\frac{m_E}{r^2}m_B = m_B\left(G\frac{m_E}{r^2}\right) = 2F_{\text{E on A}}$$

$$F_{\text{E on C}} = G\frac{m_E}{r^2}m_C = m_C\left(G\frac{m_E}{r^2}\right) = 3F_{\text{E on A}}$$

The directions of these forces are all toward the center of Earth. However, the magnitudes of the forces differ: they are proportional to the masses of the test objects. Despite the differences in magnitude, however, the ratio of the magnitude of the force exerted on each object and the mass of that object is identical for all three objects:

$$\frac{F_{\text{E on A}}}{m_A} = \frac{F_{\text{E on B}}}{m_B} = \frac{F_{\text{E on C}}}{m_C} = G\frac{m_E}{r^2}$$

Consider the objects to be near Earth's surface. When we substitute the values of G, m_E, and Earth's radius r_E, we find that

$$G\frac{m_E}{r_E^2} = \left(6.67 \times 10^{-11}\,\frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)\frac{(5.97 \times 10^{24}\,\text{kg})}{(6.37 \times 10^6\,\text{m})^2} = 9.8\ \text{N/kg}$$

Since this value does not depend on the mass of any test object, we speculate that this value might be a mathematical description of the "strength" of Earth's gravitational field at a particular location. Since the gravitational force has direction, we say that the gravitational field close to Earth's surface at a particular location has a magnitude of 9.8 N/kg and points directly toward the center of Earth. Until now, we have called this quantity free-fall acceleration. Now we characterize the gravitational field using the quantity $\vec{g}$ field. We define the **$\vec{g}$ field** at any location as the gravitational force exerted by the field on a test object at that location, divided by the mass of that object:

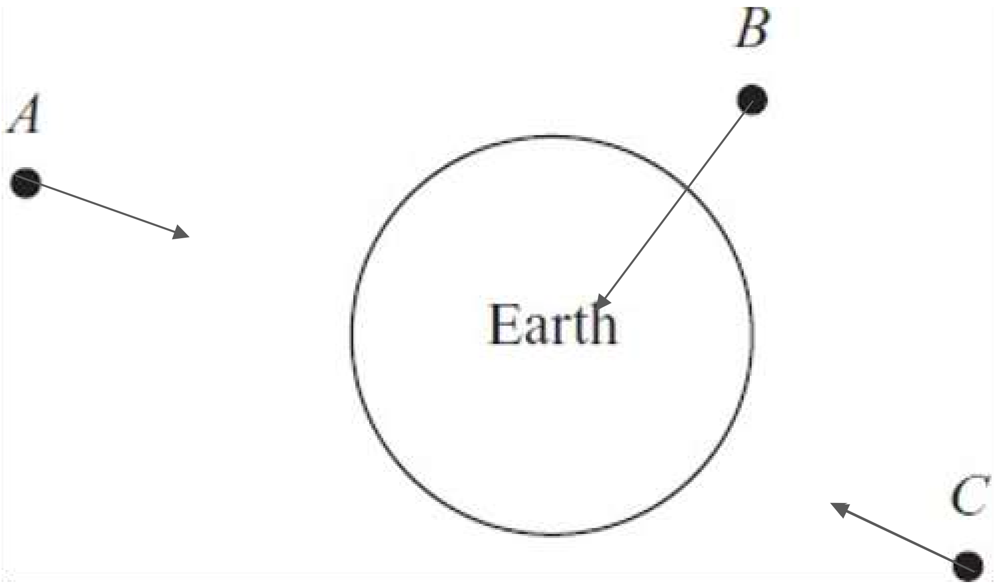
$$\vec{g} = \frac{\vec{F}_{\text{Field on Object}}}{m_{\text{Object}}} \tag{18.1}$$

FIGURE 18.3 Earth exerts a gravitational force on each of the three test objects placed at the same location.

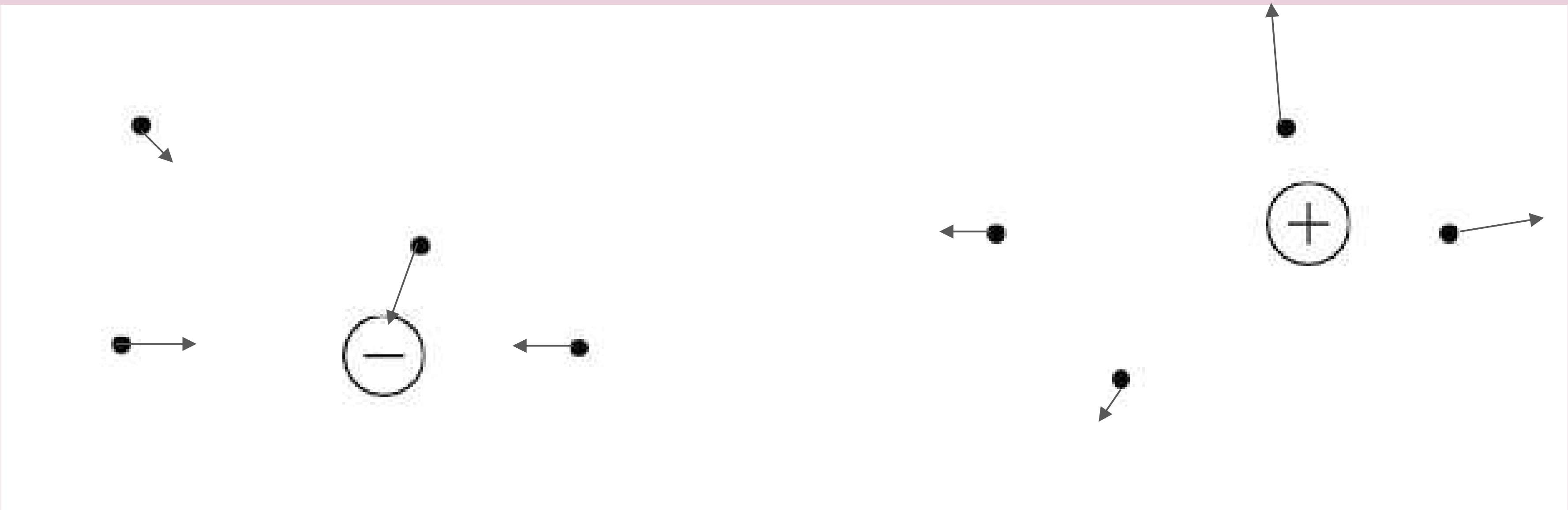
(a)

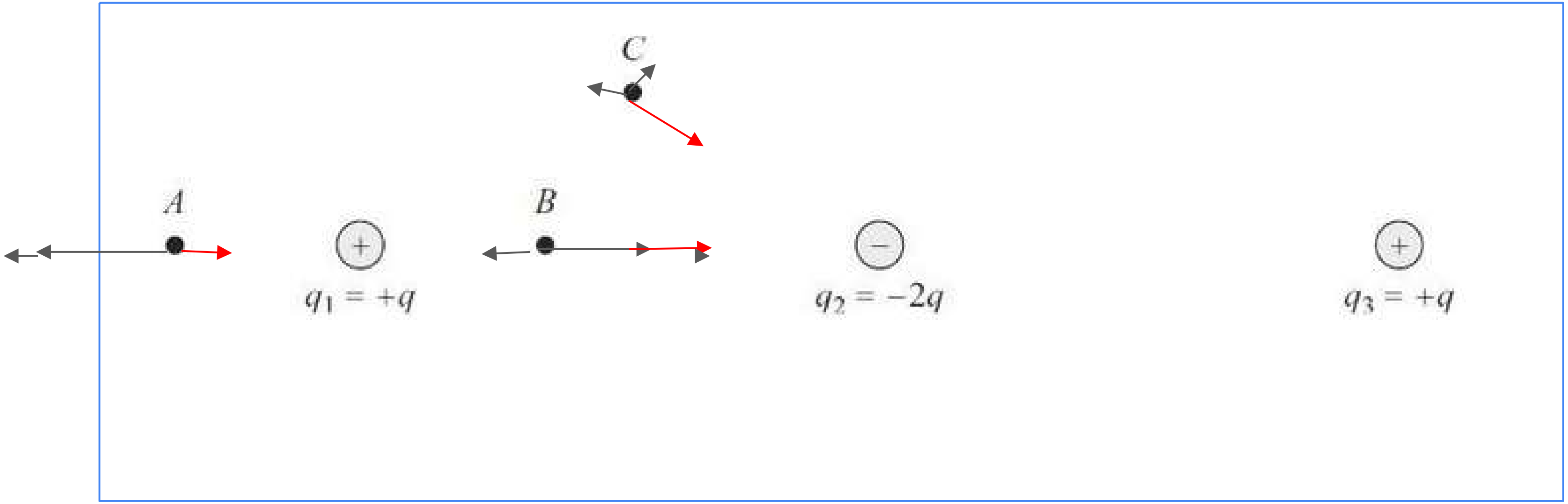
(b)

All together OALG 18.1.5 [OALG Chapter 18 Final.docx]



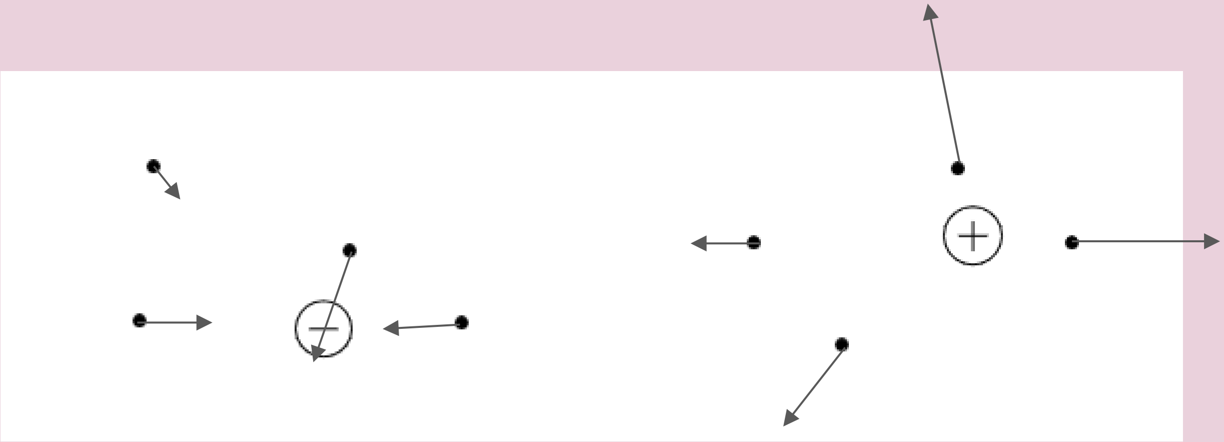
Team 1 OALG 18.1.6 and 18.1.7 add an additional slide if needed





C
A
B
$q_1 = +q$
$q_2 = -2q$
$q_3 = +q$

Team 2 OALG 18.1.6 and 18.1.7 add an additional slide if needed



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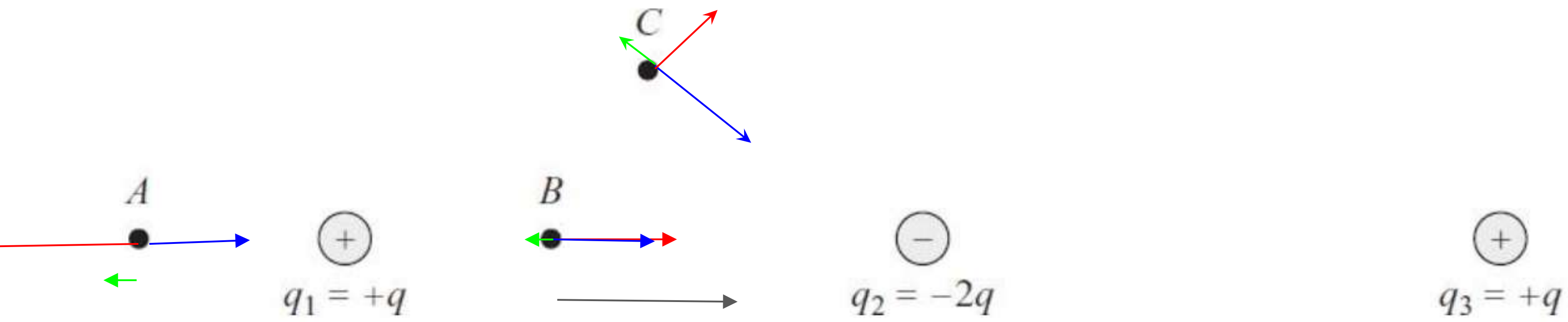
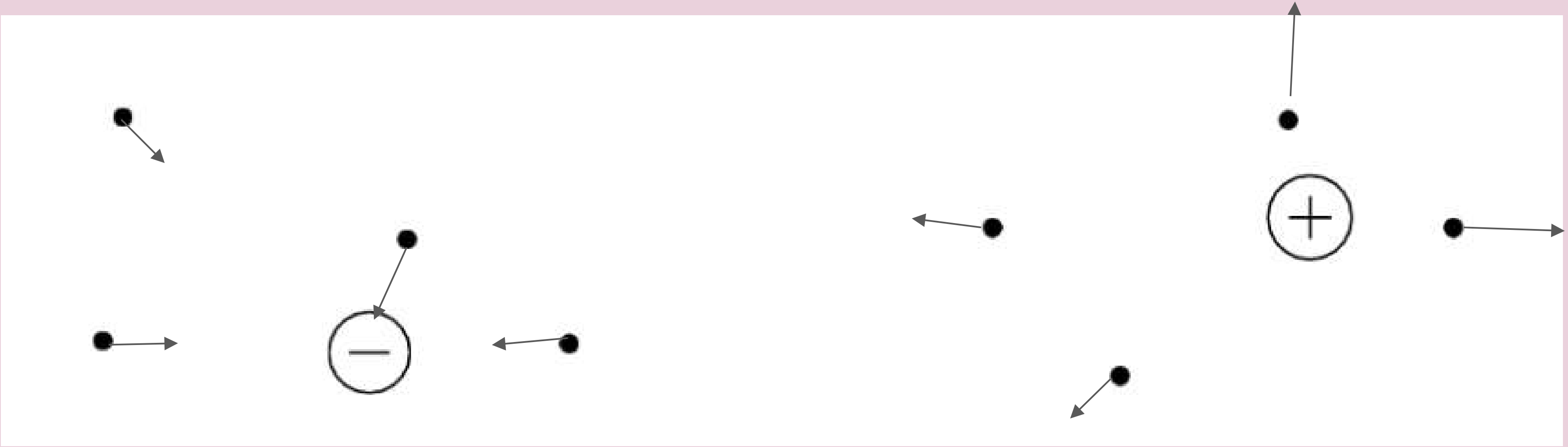


Team 3 OALG 18.1.6 and 18.1.7 add an additional slide if needed

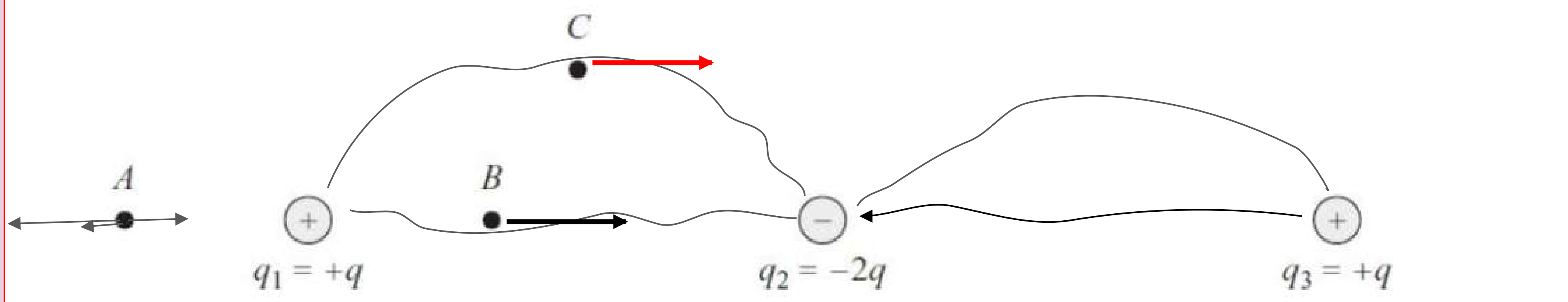
18.1.6 Considering as two separate diagrams, with no relation



Team 3 OALG 18.1.6 and 18.1.7 add an additional slide if needed

18.1.7

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.



Operational definition vs cause-effect relationship, superposition principle

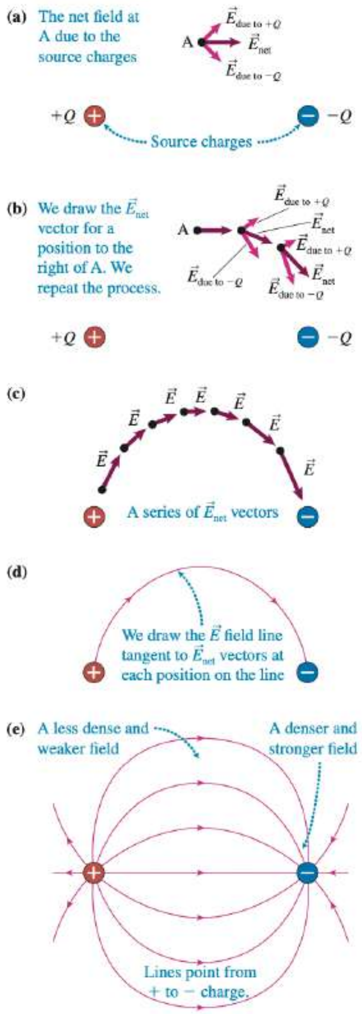
E=F/q test OD

E=kQsource/r^2 CE relationship

E=E1+E2+....E3 SP

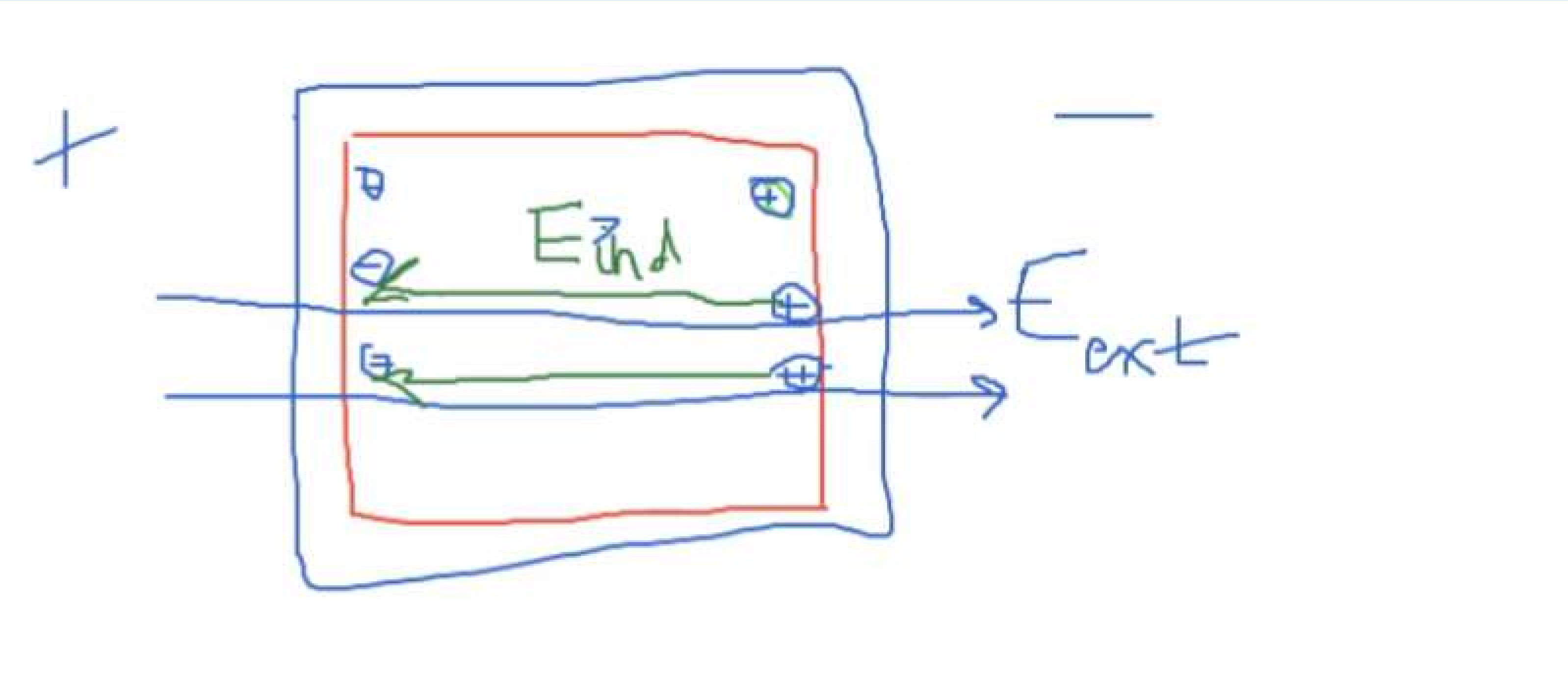
Constructing E field lines

FIGURE 18.5 Constructing $\vec{E}$ field lines.



Team 1 OALG 18.5.3

Team 2 OALG 18.5.3



Team 3 OALG 18.5.3

How did the metal cover shield the electroscope?

How does a car shield you from lightning?

All together 18.3.1 (some parts)

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 E field characterizes the field from the force-type perspective.

All together: Operational definition of the V field vs cause-effect relationship, superposition principle

V=Uq/qtest

V=kQ/r

Q

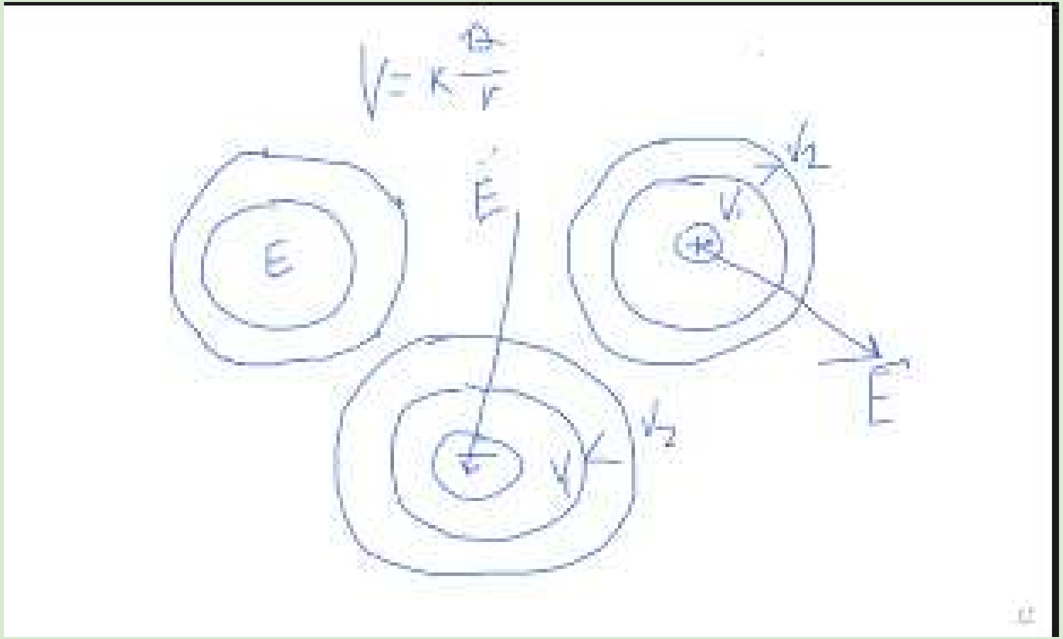
q

$$V = U_q/q = K\frac{Qq_t}{r}\Big/q_t$$

$$E = \frac{F}{q_t}$$

$$V = \frac{U_q}{q_t}$$

Team 1 OALG 19.3.6

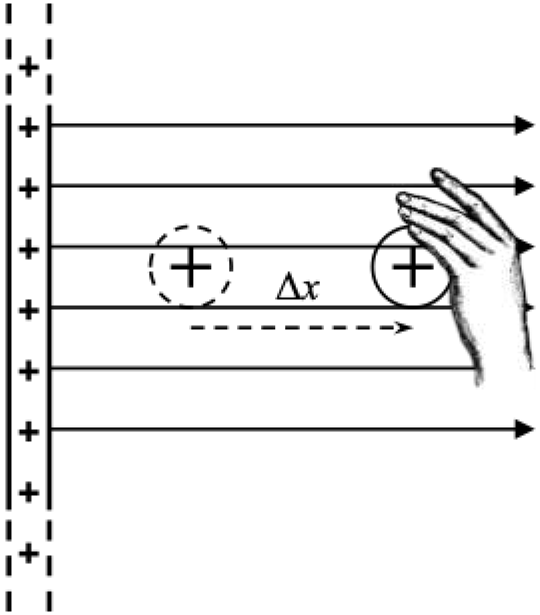


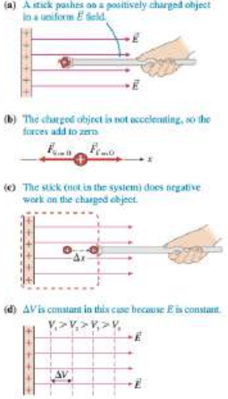
Team 2 OALG 19.3.6

Team 3 OALG 19.3.6

All together: Draw lines of equal potential for single point like charges and for a charged metal plate. Then add E filed lines to the drawings.

All together OALG 18.4.2





18.4 Relating the E field and the V field

We know qualitatively that the V field varies most rapidly with position where the $\vec{E}$ field is strongest. We can also examine this idea quantitatively.

Deriving a relation between the $\vec{E}$ field and ΔV

Consider the uniform $\vec{E}$ field produced by an electrically charged infinitely large glass plate. We attach a small object with charge $+q$ to the end of a wooden stick and place the charged object and stick in the electric field produced by the plate (**Figure 18.12a**). The electric field exerts a force on the charged object in the positive x-direction $F_{\vec{E}\text{ on O}\,x} = +qE_x$. The stick exerts a force on the charged object with an x-component $F_{\text{S on O}\,x} = -F_{\text{S on O}}$ pointing toward the plate (Figure 18.12b) in the negative x-direction. If the charged object does not move or moves slowly with zero acceleration, the x-component form of Newton's second law applied to the charged object is $\Sigma F_x = F_{\vec{E}\text{ on O}\,x} + F_{\text{S on O}\,x} = +qE_x - F_{\text{S on O}} = 0$, or

$$F_{\text{S on O}} = qE_x$$

Now, let's do a work-energy analysis for a process in which the charged object (still attached to the stick) is moved slowly a small distance Δx farther from the plate (Figure 18.12c). For our system we choose the charged object and the electric field, but not the stick, which is part of the environment and does work on the system. The stick exerts a force on the charged object opposite its displacement and does negative work on the system:

$$W = F_{\text{S on O}}\,\Delta x \cos(180°) = -F_{\text{S on O}}\,\Delta x = -qE_x\,\Delta x$$

The only energy change is the system's electric potential energy because the positively charged object moves farther away from the positively charged plate. Applying the generalized work-energy principle, we get $U_{qi} + W = U_{qf}$, or

$$W = \Delta U_q = q\Delta V$$

Setting these two expressions for work equal to each other and canceling the common q, we get

$$\Delta V = -E_x\,\Delta x \tag{18.9}$$

Equivalently, the component of the $\vec{E}$ field along the line connecting two points on the x-axis is the negative change of the V field divided by the distance between those two points:

$$E_x = -\frac{\Delta V}{\Delta x} \tag{18.10}$$

TIP Equation (18.10) suggests that another unit for the $\vec{E}$ field is V/m.

The magnitude of the $\vec{E}$ field component in a particular direction indicates how fast the V field (electric potential) changes in that direction (Figure 18.12d). The $\vec{E}$ field vector points in the direction in which the V field decreases fastest with position, hence the minus sign in Eq. (18.10). Similar equations apply for other directions if the situation is in two or three dimensions. Although we derived Eqs. (18.9) and (18.10) using the example of a uniform $\vec{E}$ field, the equations represent a general result that relates the component of the $\vec{E}$ field in the chosen direction to the rate of change of the V field in that direction. The relation between the $\vec{E}$ field and V field tells us two things: (1) in a region where the V field is constant, the $\vec{E}$ field is zero, and (2) if you have two points at different potentials, the closer those points are, the stronger the $\vec{E}$ field between them will be.

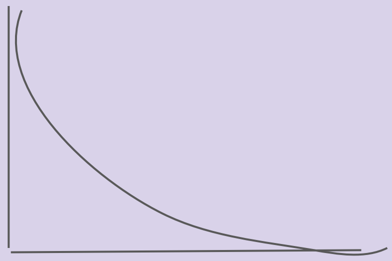
Team 1 OALG 18.4.4

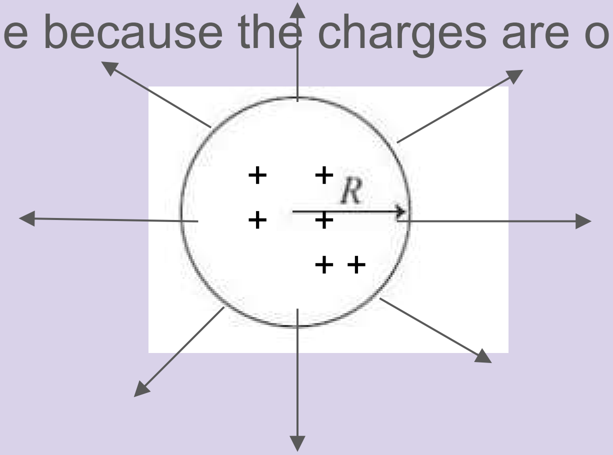
Team 2 OALG 18.4.4

Team 3 OALG 18.4.4

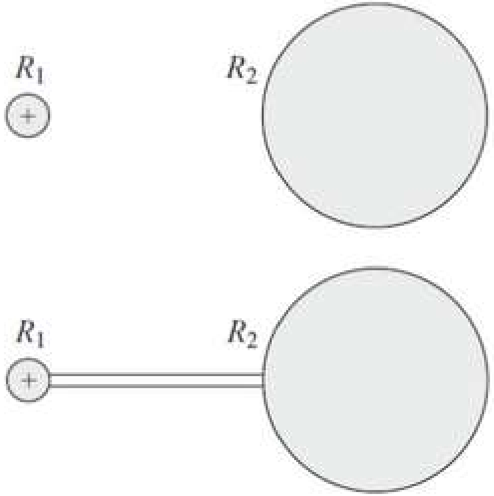
Team 1 OALG 18.5.1 and 18.5.2 Add an additional slide if needed

The charges should be evenly distributed across the surface. There wouldn't be any field lines on the inside because the charges are on the outside

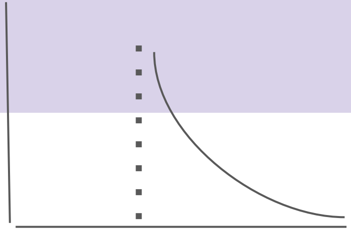




The sphere on the left will have will have an electric potential the sphere on the right would not. After they are connected the charge will now be distributed. They should have the same potential.

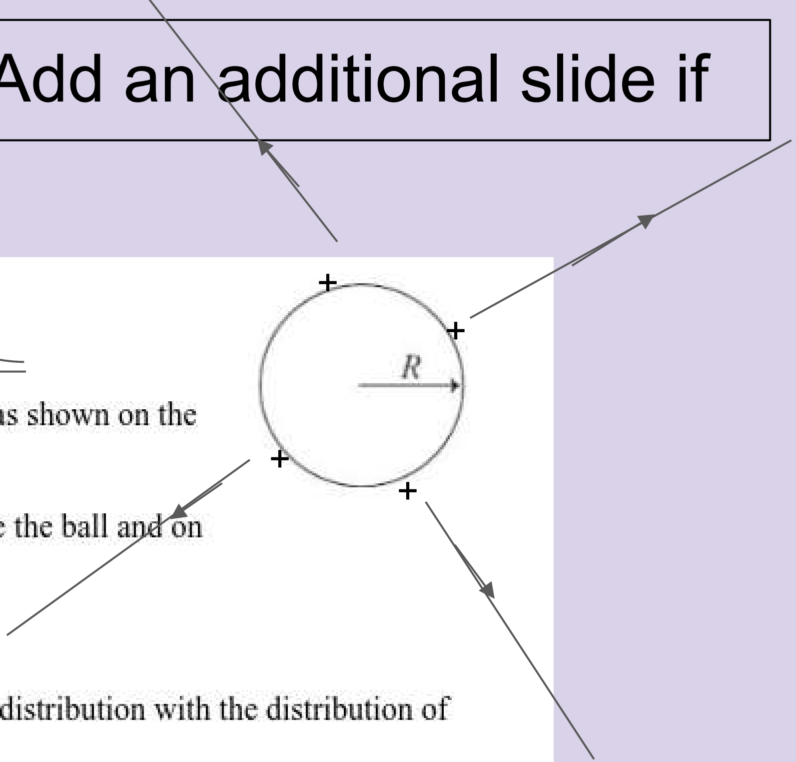


Team 2 OALG 18.5.1 and 18.5.2 Add an additional slide if needed



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.

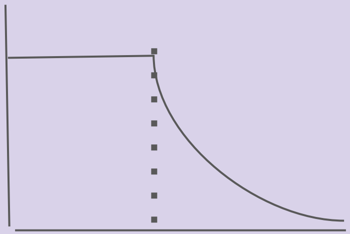
b. Draw electric field lines inside the ball (if any). Explain.

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.

a. Excess positive charges will move to the surface because they are repelled from each other.
b. No electric field lines inside the ball because they would all cancel each other (know there should be no electric field in a conductor)
c. Same distribution as a point-like charged object.

Team 2 OALG 18.5.1 and 18.5.2 Add an additional slide if needed



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

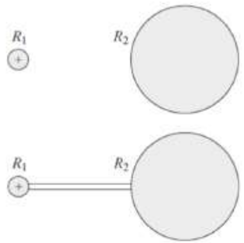
Similar to E-field one (just 1/r instead of 1/r^2)

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.

Inside the conductor.

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?

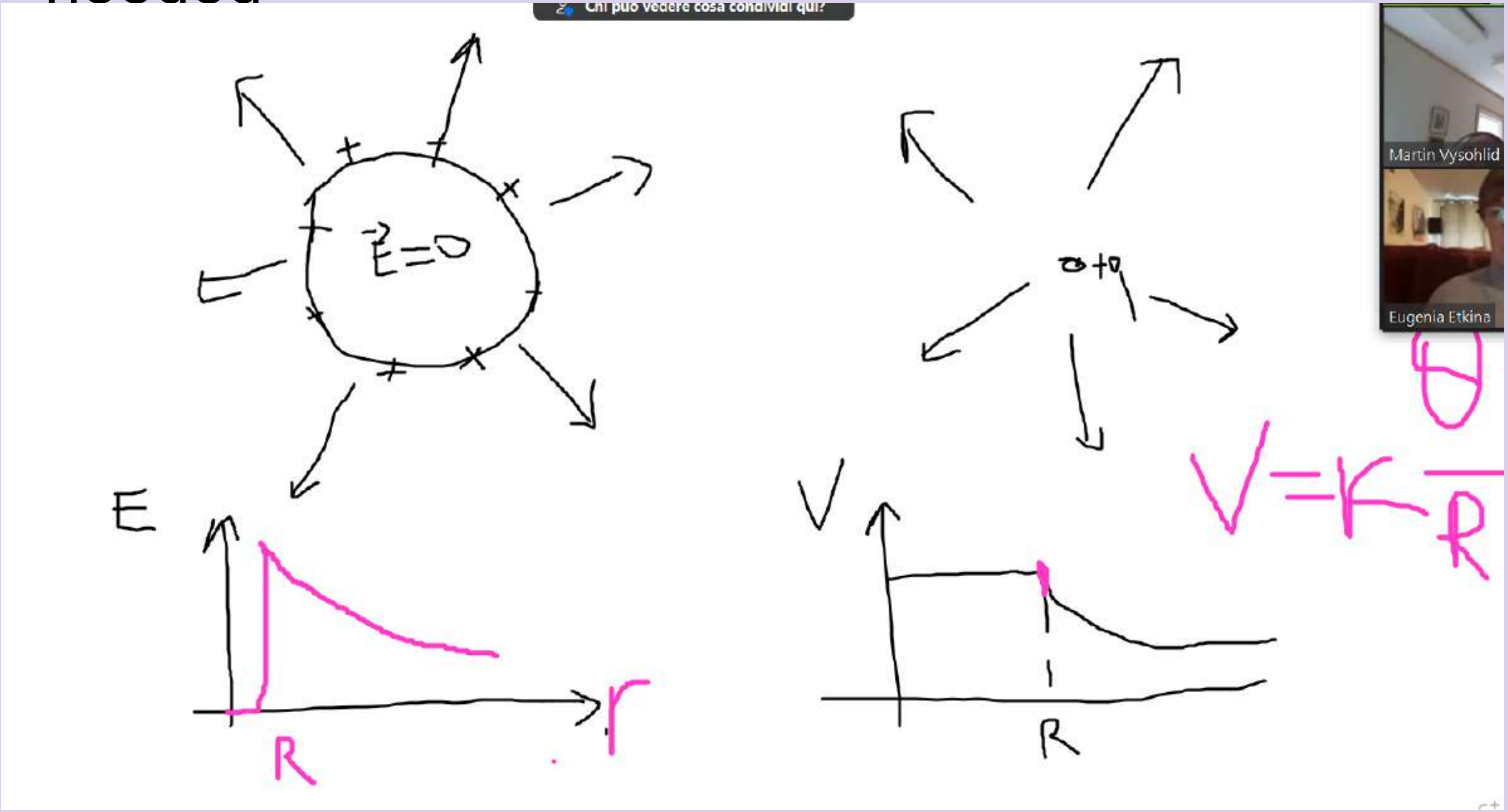
c. What will be the charges of the spheres in fractions of q_1 after connection? How does the total charge of the two spheres after the connection compare to the initial charge of the left sphere?

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.

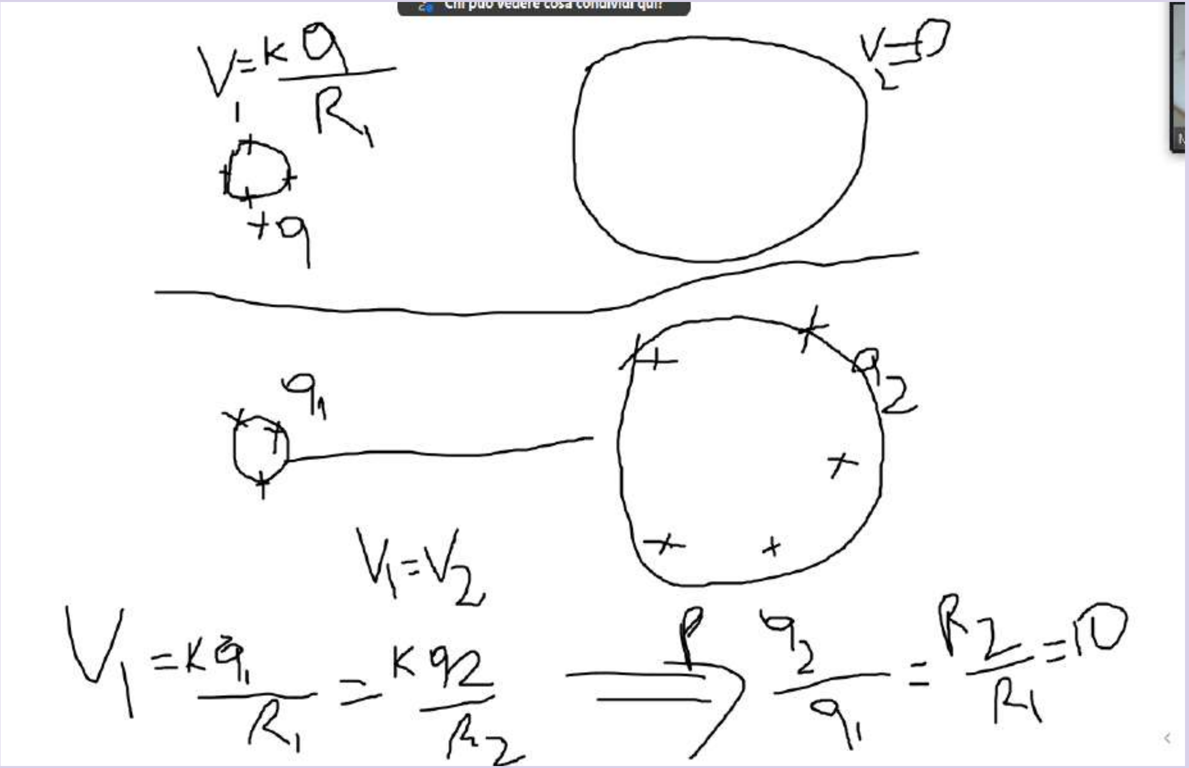
a) No, because 1 has positive charge and 2 no net charge
b) YES! Same because now one continuous conductor.
c) The ratio is 10:1 (R2:R1) and the larger sphere will have 10 times more than the small because the potential is the same so kq1/r1 = kq2/r2 => q1/q2 = r1/r2
d)

The charge density of R1 is 10 times more than R2 because area is proportional to r^2. The discharge is more likely to happen where the largest charge density is.

Team 3 OALG 18.5.1 and 18.5.2 Add an additional slide if needed



Team 3 OALG 18.5.1 and 18.5.2 Add an additional slide if needed



We can calculate the density of charge, that will be much greater (10 times because of area) on the smaller sphere

How does this explain the hanging rhombus in the video?

List the most important ideas that you learned today

Intensity of E field is dependent on how big the source charge is and how far the point of interest is from it.

Still stuck on a better way to get from $E = F/q$ to $V = U/q$.
Will do even more with gravity beforehand.
Doing very similar stuff for E and superposition.

When distributing charges, it is fair in potential not fair in charge density

Gravity is a good way to conceptualize.

Good motivation by lightning to car.

Importance of clarifying operational definitions versus cause-effect relations.

All the process visible and tangible from the need to know to its solution.

Using gravity is a great introduction to electric field. It is a more intuitive way to explain how to draw field lines.