

Name: _____

1225 Section: _____

Date: _____

Mapping Electric Potential

Purpose: To investigate the equipotential maps and electric field line diagrams created by different source charge configurations.

Apparatus

PhET “Charges and Fields” simulation. You can access the simulation through this link:
https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

Introduction

Electric charges change the space around them by creating an electric field. If you bring a test charge into this space, it will experience a force – the electrostatic force. The force on a positive test charge will be in the same direction as the field, and on a negative charge the force will be opposite the field.

If we view this field from the energy perspective, we say the charges change the space around them by raising or lowering the electric potential in the surrounding regions. If you bring a test charge into this space, it will have an electric potential energy, and the electrostatic force acting on it tends to lower its potential energy. The force on a positive test charge will try to move it from high potential to low potential and the force on a negative test charge will try to move it from low potential to high potential.

Electric potential and electric field are related by the formulas:

$$\Delta V = - \int \vec{E} \cdot d\vec{r}, \quad E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}$$

The difference between the “potential” and the “potential difference”

The term “potential” refers to a point, and the term “potential difference” refers to the difference between two points. The potential of any point depends on where we choose as zero, but potential difference remains the same no matter where the zero is. Take a 1.5 V battery as an example: If we choose the negative terminal to be the zero potential, then the positive terminal has a potential of 1.5 V. If we choose the positive terminal to be the zero potential, then the negative terminal has a potential of -1.5 V. But the potential difference between the two terminals is always 1.5 V. In circuits, the “potential difference” is often called voltage, and can be measured by a voltmeter.

In this lab, we will model three different charge configurations and draw the equipotential maps with a PhET simulation. Based on the equipotential lines, we can draw and calculate the electric fields.

Before working with the simulation, your lab instructor will demonstrate how to use a voltmeter to measure the potential difference between a point on the conductive paper to the zero, and the value of the voltmeter will be the potential of that point. Note that we choose the ground terminal of the power supply to be the zero potential.

The experiment set up with parallel-plates model is shown in Figure 1. A piece of conductive paper with the parallel-plates model is put on top of a piece of carbon paper. The carbon paper is on top of a piece of white paper. The three pieces of paper are fixed by the conductive push pins on a cork board.

The conductive push pins act as two electrodes of the parallel-plates and are connected to a power supply (0-20V) with two alligator-to-plug wires. A black plug-to-plug wire is used to connect the “COM” (negative, left) of the multimeter to the negative side of the parallel plate (zero potential). One end of the red plug-to-plug wire is connected to the positive terminal of the multimeter for voltage measurement. The multimeter is now ready to measure the potential relative to zero.

After turning on the power supply, use the free end of the red plug-to-plug wire to touch the positive (right) side of the parallel plate and adjust the power supply until the reading of the multimeter is 10.0V. We are now ready to map the potential.

Lightly touch the conductive paper with the free red plug and the move it around while watching the readings of the multimeter. This gives us an overall picture of the potential around the plate. When we map the equipotential lines, we move the free red plug to the desired potential value (e.g. 2.0V) and apply pressure to the plug to create a dot on the paper (due to the carbon paper). Several dots should be made for each potential value, so that we can connect the dots to form an equipotential line. Figure 2 shows the potential map inside the parallel plate.

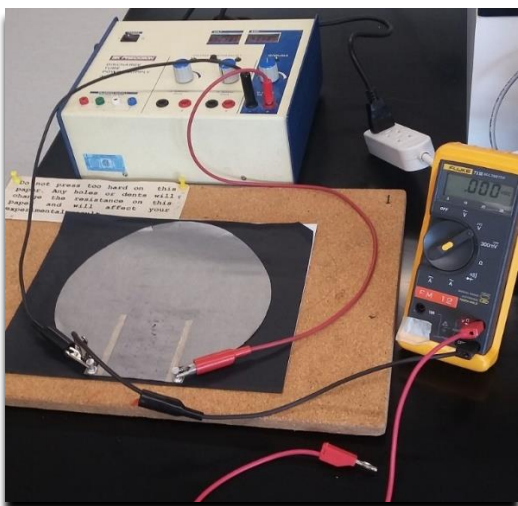


Figure 1

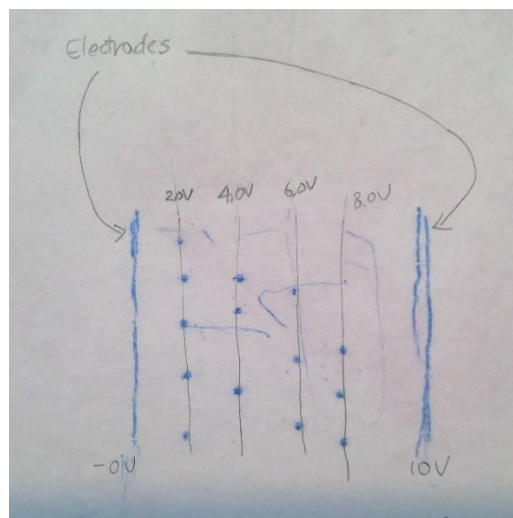
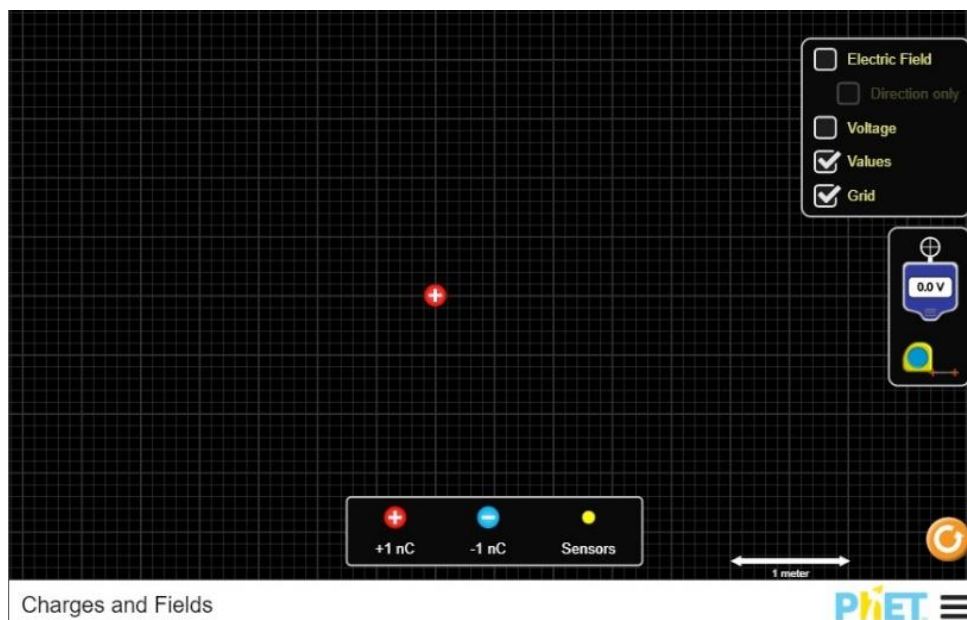



Figure 2

Part 1 A single point charge model

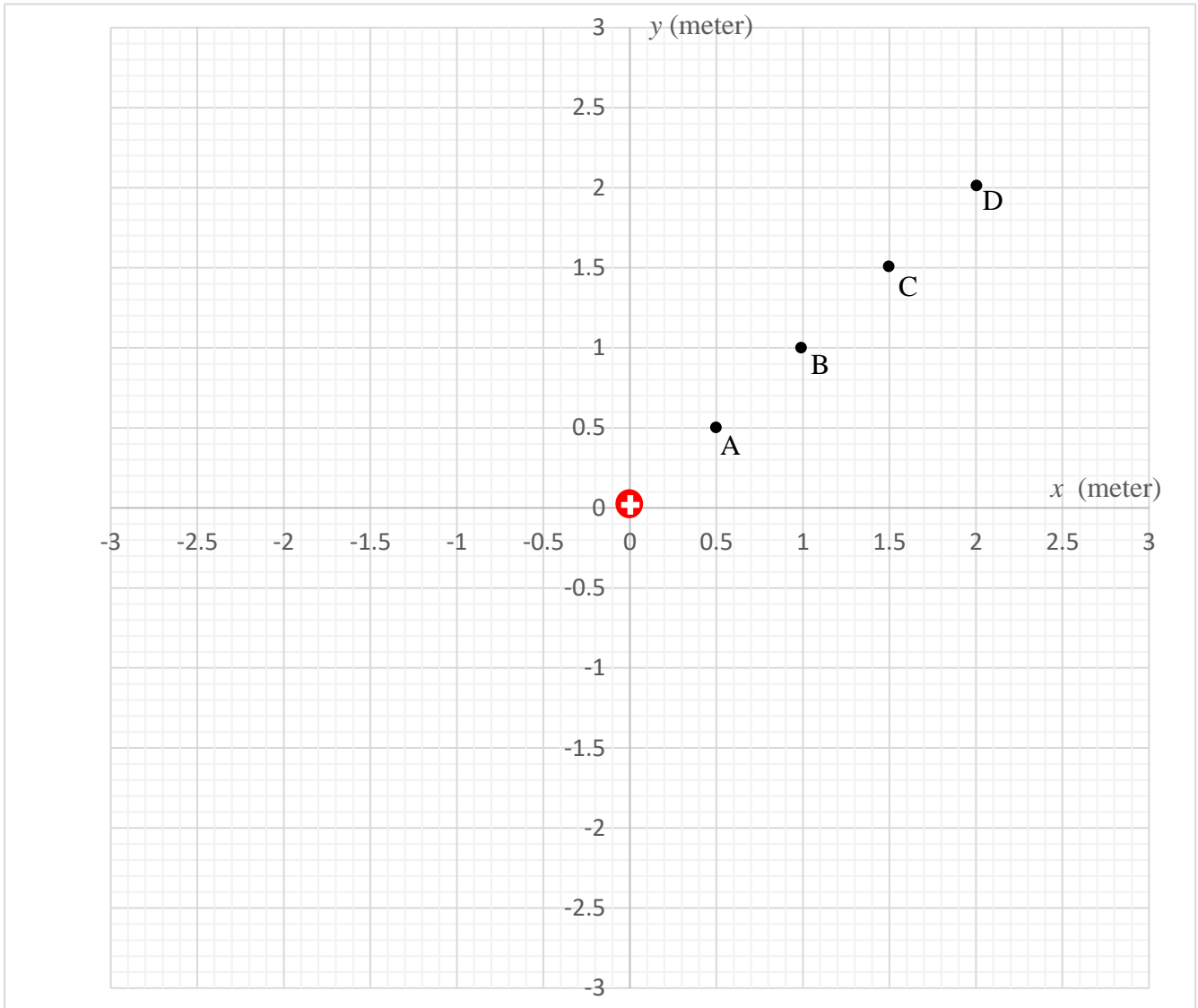
1) Mapping the electric potential

1. Drag a single, single positive charge from the box at the bottom to the middle of the simulation.
2. In the box at the right hand corner, unclick the box for “Electric Field” and click the boxes for “Values” and “Grids”. You should have a screen that looks like the following picture.



3. You can move the charge and place it at the intersection of any two lines on the grid. Each small grid space represents 0.1 meter and each large grid space represents 0.5 meter.
4. Drag the blue “equipotential tool” out of the right hand side panel. The reading on the equipotential tool tells you the value of the electric potential at the point where the white cross is located. If you move the equipotential tool away from the positive charge, you will see that the reading decreases. 
5. Move the equipotential tool to a point where the reading is 19.0V (any value between 18.9V to 19.1V is fine). Click on the “pencil” button on the equipotential tool. An equipotential line of electric potential equal to 19.0V will be drawn on the screen.
6. Use the equipotential tool to find the equipotential lines with the values of electric potential from 17.0V to 3.0V with equal steps of 2.0V, again to within 0.1V.
7. Sketch your equipotential map on the graph in the next page (with the same distance scale as in the simulation). Don’t forget to label the equipotential lines with the correct electric potential values. Ignore the points A, B, C, D for now. We will calculate the magnitude of the electric field (or the electric field strength) at those points later in the lab.

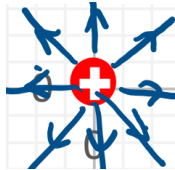
A single charge equipotential map



2) Investigating the electric fields from the potential map

1. Draw the electric field lines on your equipotential map, following the rules below:


- A point charge of a certain size should have a certain number of electric field lines pointing to or pointing away from the point charge. For this map, we will have 8 electric field lines pointing away from the positive point charge, as shown:

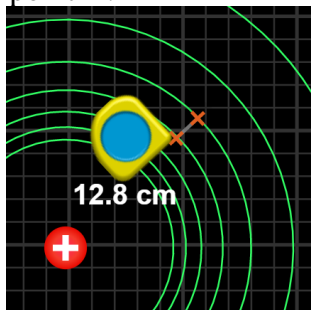


- When they cross, electric field lines must be perpendicular to the equipotential lines. (To see why it is so, think whether the electrostatic force can have a component parallel to the equipotential line.)
- The direction of the electric field is pointing from high potential to low potential. (To see why it is so, think of the direction of the electrostatic force on a positive test charge.)
- The density of electric field lines is proportional to the density of equipotential lines. (Assume equal intervals of the potential.) The next activity will illustrate why it is so.

2. Calculate the average magnitude of electric field at points A through D in the potential map. The average magnitudes of the electric field between two equipotential lines can be calculated by $E = \Delta V / \Delta s$, where ΔV and Δs are the potential difference and the perpendicular distance between two adjacent equipotential lines. Because ΔV should be the same, the closer the potential lines, the higher the electric field. This reflects on your map as the denser the equipotential lines, the denser the electric field lines. Summarize your results in the table on the next page. We will not track uncertainty for these calculations, but will keep the answers to 2 significant figures.

Note:

You can use the measuring tool  to measure the distance Δs between two adjacent equipotential lines. For example, for point A:




Point	ΔV	Δs	E (calculation and result)
Unit	V	cm	V/m or N/C
A	$13 - 11 = 2$	12.8	$E = \frac{\Delta V}{\Delta s} = \frac{2V}{12.8\text{cm}} = \frac{2V}{0.128\text{m}} = 15.625 \text{ V/m} \approx 16 \text{ V/m}$
B			
C			
D			

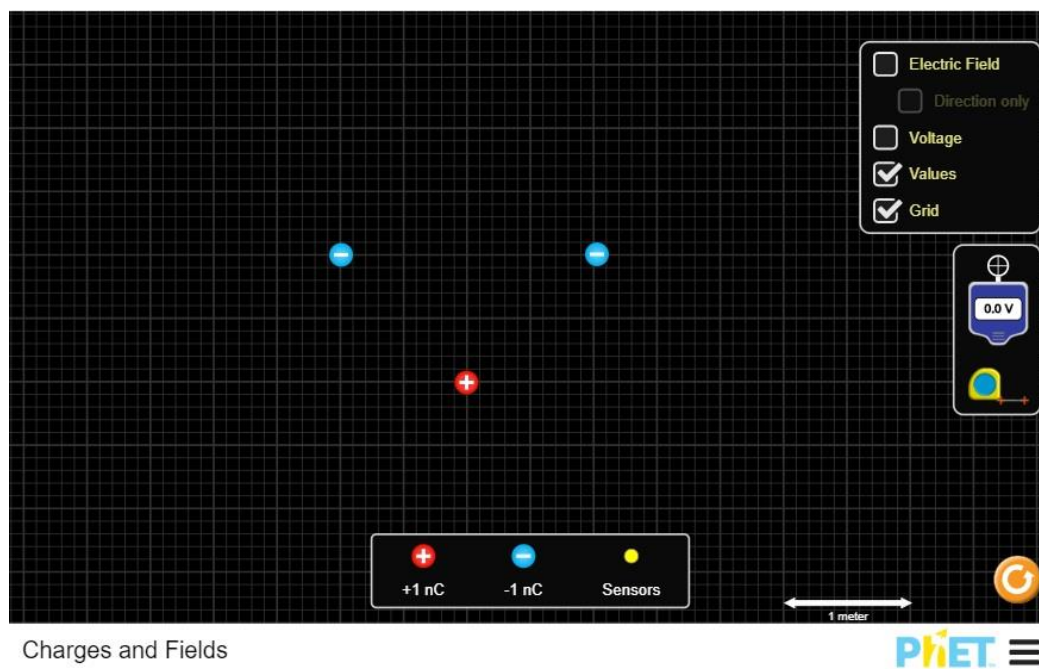
3) Discussions

1. Explain in your own words why electric field lines must be perpendicular to the equipotential lines when they cross.
2. Do your results correspond to the idea of “the density of electric field lines is proportional to the density of equipotential lines”?
3. (Bonus) When we calculated the average magnitude of the electric field, we are limited by our choice of equipotential lines. For this simple case, we can calculate the electric field exactly using Coulomb’s law. By what percentage does each of our result differ from the exact answer?

Part 2 Three point charges model

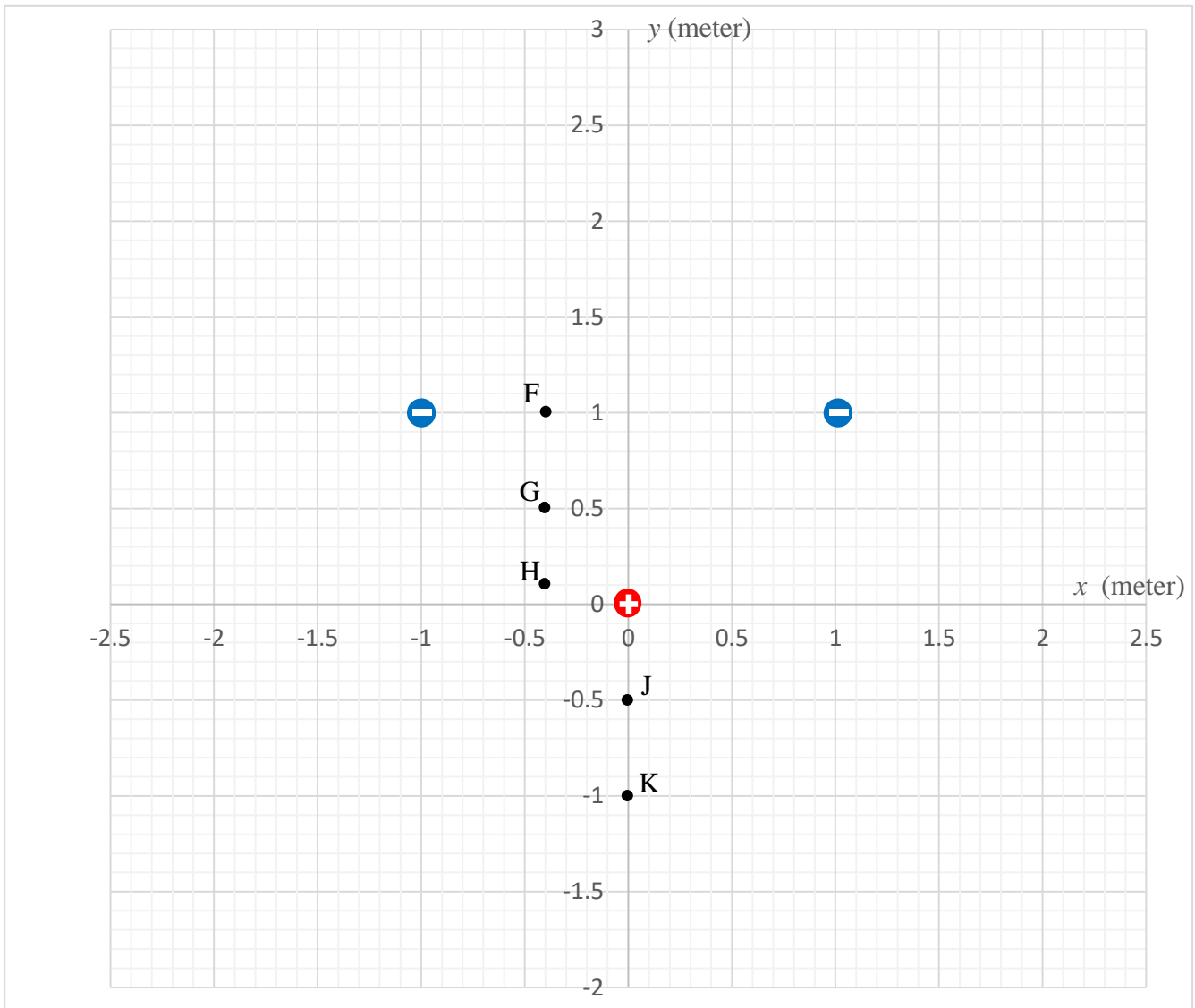
1) Mapping the electric potential

1. Press the reset button  at the lower right corner.
2. Drag two negative charges and one positive charge to the centre of the screen. The negative charges are at the same distance from the bottom of the screen, but they are 2.0m apart horizontally. The positive charge is 1.0m down from the midpoint of the two negative charges. The three point charges should be configured as in the following picture:



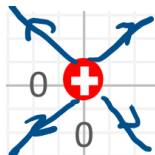
3. Follow same procedure as the single point charge model to create an equipotential map with the values of electric potential from -20.0V to 20.0V with equal steps of 5.0V. (Hint: Be sure to get the equipotential lines around each of the negative charges.)
4. Sketch your equipotential map on the graph in the next page (with the same distance scale as in the simulation).

Three charges equipotential map



2) Investigating the electric fields from the potential map

1. Draw the electric field lines on your equipotential map, following the same rules as for the single charge case. However, with three point charges (each with a magnitude of 1 nC), to avoid overcrowding the diagram, we will only draw 4 electric field lines pointing to or pointing away from each point charge, as shown:



2. Calculate the average magnitude of electric field at points A through E. Again, summarize your result in the table below, giving your result to 2 significant figures.


Point	ΔV	Δs	E (calculation and result)
Unit			
F			
G			
H			
J			
K			

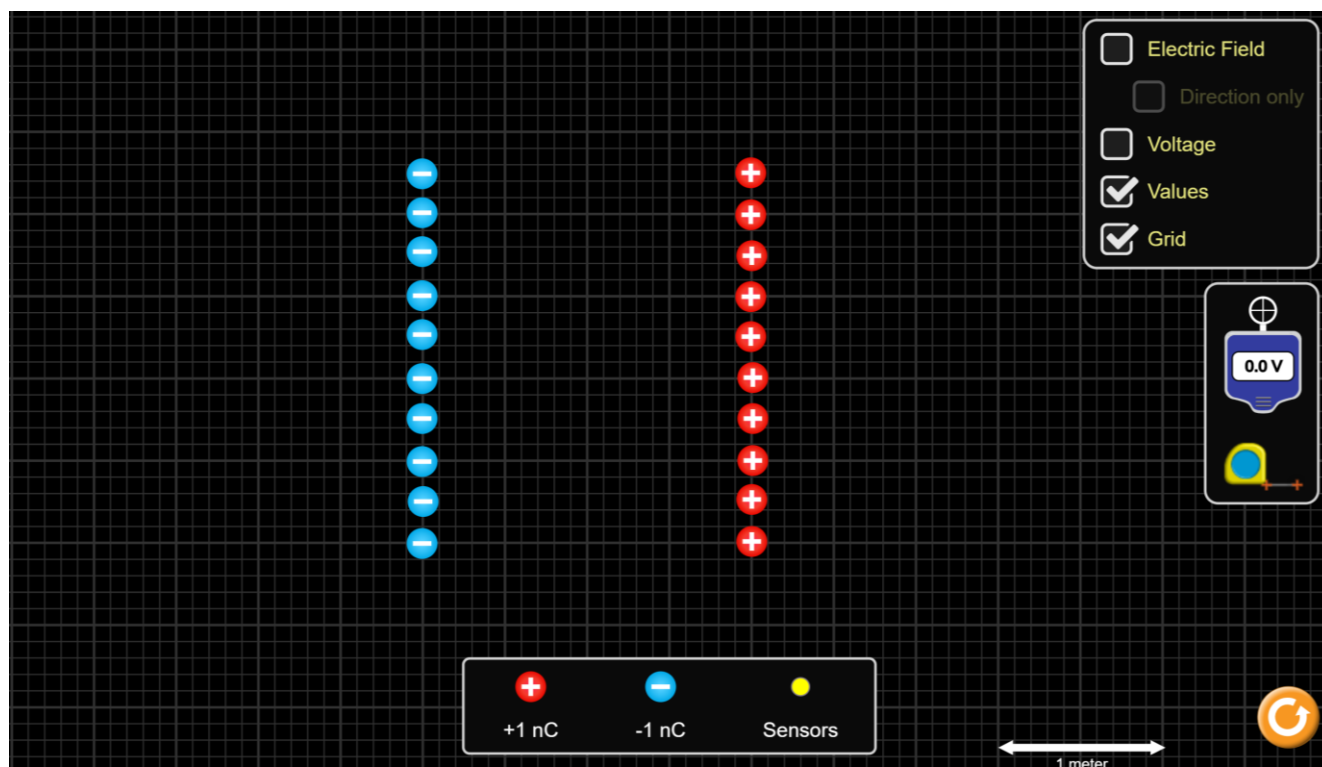
3) Discussions

1. (Bonus) Using Coulomb's law, calculate the exact electric field at point A. Compare the magnitude and direction of the electric field with those you got using the equipotential map.

Part 3 The “parallel-plates” model

1) Mapping the electric potential

1. Press the reset button  at the lower right corner.
2. Drag 10 negative charges and 10 positive charges to the centre of the screen. The negative charges are lined up vertically on one side with 0.25m apart. The positive charges are 2.0m horizontally away from the negative charges and they are also lined up vertically with 0.25m apart. The negative charges act like a negative charged plate and the positive charges represent a positively charged plate. The point charges should be configured as in the following picture:

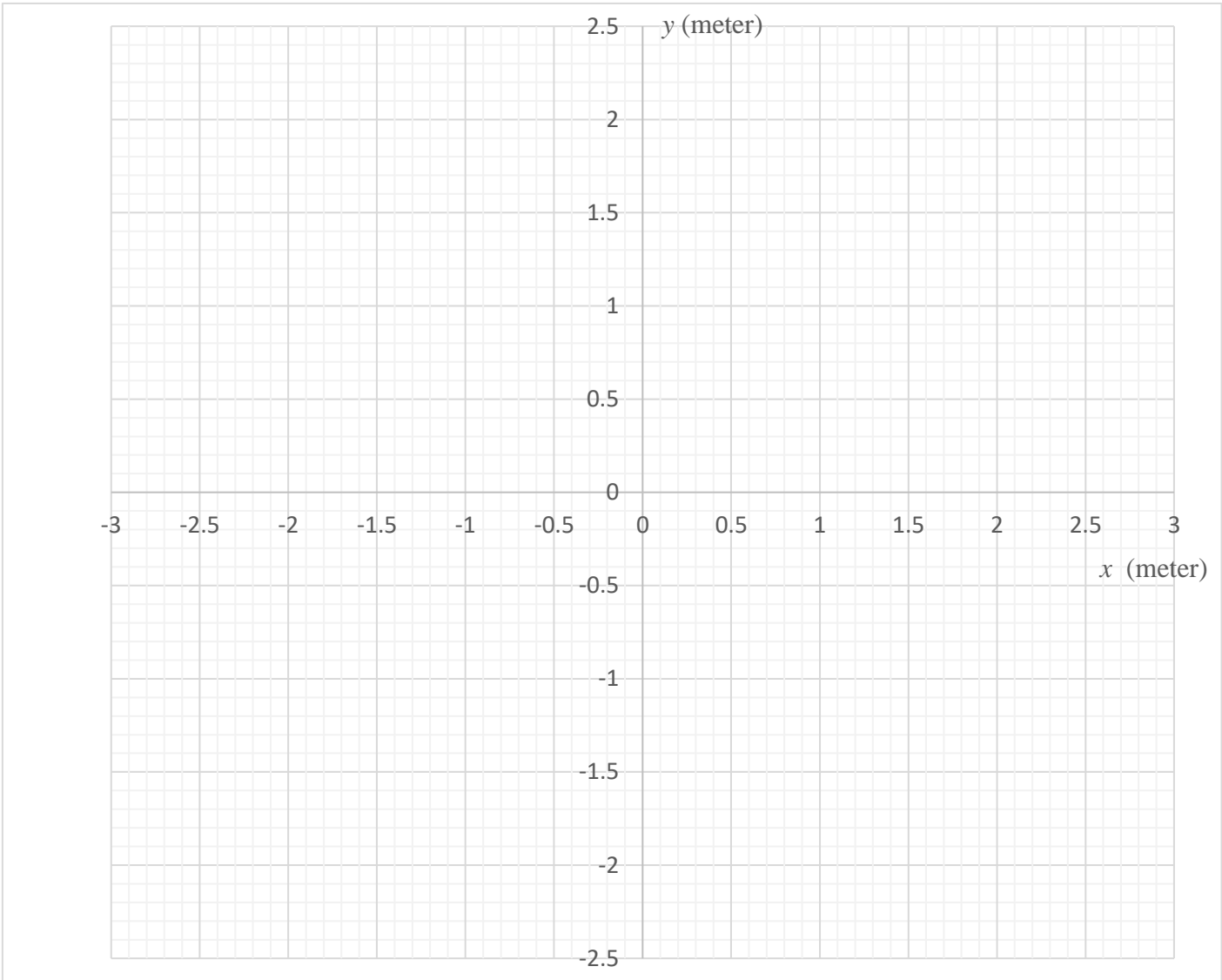


Charges and Fields



3. Follow same procedure as the single point charge model to create an equipotential map with the values of electric potential from -60V to 60V with equal steps of 15V.
4. Sketch your point charges and equipotential map on the graph in the next page (with the same distance scale as in the simulation).

Parallel Plates equipotential map



2) Investigating the electric fields from the potential map

1. Draw the electric field lines on your equipotential map, following the same rules as for the single charge case. Draw an appropriate number of lines to sufficiently represent the situation.
2. Choose and label four points to find the magnitude of the electric field near the middle between the parallel plates, to show that the electric field is approximately uniform in that region.

Point	ΔV	Δs	E (<i>calculation and result</i>)
Unit			

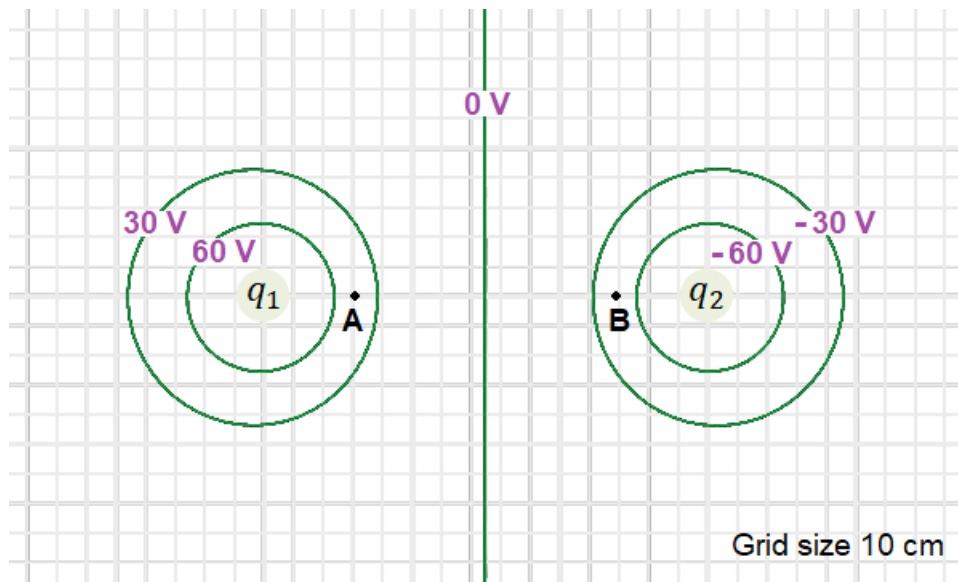
3) Discussions

1. How is a uniform electric field represented with equipotential lines?
2. How is a uniform electric field represented with electric field lines?
3. Is the electric field uniform in the entire region between the two plates?

Part 4 Final Exercise

For the potential maps below, do the following:

- Calculate the approximate electric field at the specified points.
- Give the location and sign of the electric charges, and calculate the amount the electric charges (you can use Coulomb law).
- Draw electric field lines. Do not forget the arrows on the lines.

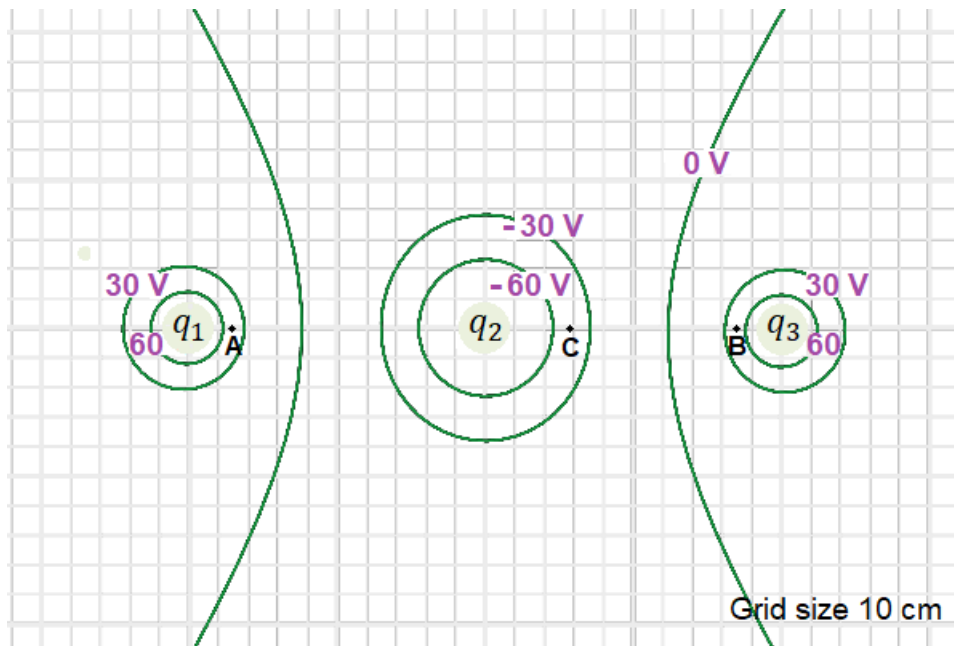


$$E_A =$$

$$E_B =$$

$$q_1 =$$

$$q_2 =$$



$$E_A =$$

$$E_B =$$

$$E_C =$$

$$q_1 =$$

$$q_2 =$$

$$q_3 =$$