Description: Students use the PhET simulation "Charges and Fields" to understand the spatial distribution of the electric potential for a variety of simple charge configurations and to understand how electric field and voltage are related. In a different tutorial, "Charges and Electric Fields," students use this simulation to study the electric field.

Learning Goal:
To understand the spatial distribution of the electric potential for a variety of simple charge configurations, and to understand how the electric field and electric potential (voltage) are related.

For this problem, use the PhET simulation *Charges and Fields*. This simulation allows you to place multiple positive and negative point-charges in any configuration and look at the resulting electric field and corresponding electric potential.

Start the simulation. You can click and drag positive charges (red) or negative charges (blue) into the main screen. If you select **Electric Field** in the menu, arrows will appear, showing the direction of the electric field. Faint arrows indicate that the electric field is weaker than at locations where the arrows are brighter (this simulation does not use arrow length as a measure of field magnitude).

You can drag a positive charge into the main screen and place the cross-hairs of the electric potential (voltage) measurement tool on top of any point for which you would like to see the voltage (for this tutorial, voltage will be taken to be the same as electric potential). To move the electric potential (voltage) measurement tool, drag it by clicking and holding onto the body of the tool, and not the cross-hairs. Clicking **Plot** (the pencil icon) on this device shows an equipotential line. All points along an equipotential line have the same potential.

Feel free to play around with the simulation. When you are done, click the **Reset** button before beginning Part A.

Part A

The electric potential (voltage) at a specific location is equal to the potential energy per unit charge a charged object would have if it were at that location. If the zero point of the voltage is at infinity, the numerical value of the voltage is equal to the numerical value of work done to bring in a unit charge from infinity to that location.

Select **Values** and **Grid** in the menu, and drag one positive charge to the middle of the screen, right on top of two intersecting bold grid lines.

Using the voltage meter, you should find that 1 m away from the charge, the voltage is 9 V. What is the voltage 2 m away from the charge?

Express your answer numerically in volts to two significant figures.

ANSWER:

4.5 V

Unlike the magnitude of the electric field, the electric potential (voltage) is *not* proportional to the inverse of the distance squared.

Part B

What is the voltage 3 m away from the charge?

ANSWER:

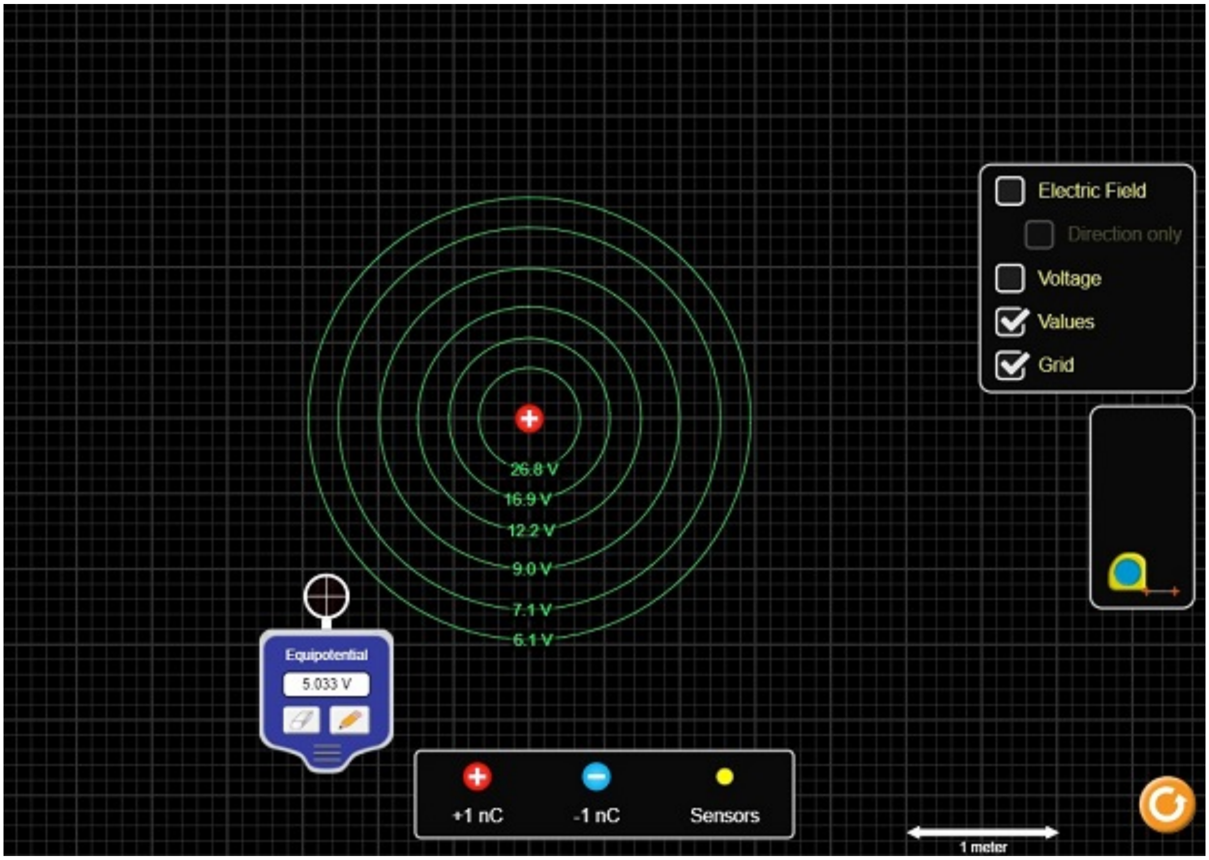
- (●) 3 V
- ( ) 9 V
- ( ) 1 V

Based on this result, and the previous question, the electric potential (voltage) *is* inversely proportional to the distance r from the charge: $V \propto 1/r$. Recall that the magnitude of the electric field $E \propto 1/r^2$.

Part C

Another way to study voltage and its relationship to electric field is by producing equipotential lines. Just like every point on a contour line has the same elevation in a topographical map, every point on an equipotential line has the same voltage.

Click plot on the voltage tool to produce an equipotential line. Produce many equipotential lines by clicking plot as you move the tool around. You should produce a graph that looks similar to the one shown below.



Place several E-Field Sensors at a few points on different equipotential lines, and look at the relationship between the electric field and the equipotential lines. Which statement is true?

ANSWER:

- ○ At any point, the electric field is perpendicular to the equipotential line at that point, and it is directed toward lines of higher voltages.
- ◉ At any point, the electric field is perpendicular to the equipotential line at that point, and it is directed toward lines of lower voltages.
- ○ At any point, the electric field is parallel to the equipotential line at that point.

All points on an equipotential line have the same voltage; thus, no work would be done in moving a test charge along an equipotential line. No work is done because the electric field, and thus the force on the test charge, is perpendicular to the displacement of the test charge being moved along the equipotential line.

Part D

Equipotential lines are usually shown in a manner similar to topographical contour lines, in which the difference in the value of consecutive lines is constant. Clear the equipotential lines using the **Erase** button on the voltage tool. Place the first equipotential line 1 m away from the charge. It should have a value of roughly 9 V. Now, produce several additional equipotential lines, increasing and decreasing by an interval of 3 V (e.g., one with 12 V, one with 15 V, and one with 6 V). Don't worry about getting these exact values. You can be off by a few tenths of a volt. Which statement best describes the distribution of the equipotential lines?

ANSWER:

- ○ The equipotential lines are equally spaced. The distance between each line is the same for all adjacent lines.
- ◉ The equipotential lines are closer together in regions where the electric field is stronger.
- ○ The equipotential lines are closer together in regions where the electric field is weaker.

Near the positive charge, where the electric field is strong, the voltage lines are close to each other. Farther from the charge, the electric field is weaker and the lines are farther apart.

Part E

Now, remove the positive charge by dragging it back to the basket, and drag one negative charge toward the middle of the screen. Determine how the voltage is different from that of the positive charge. How does the voltage differ from that of the positive charge?

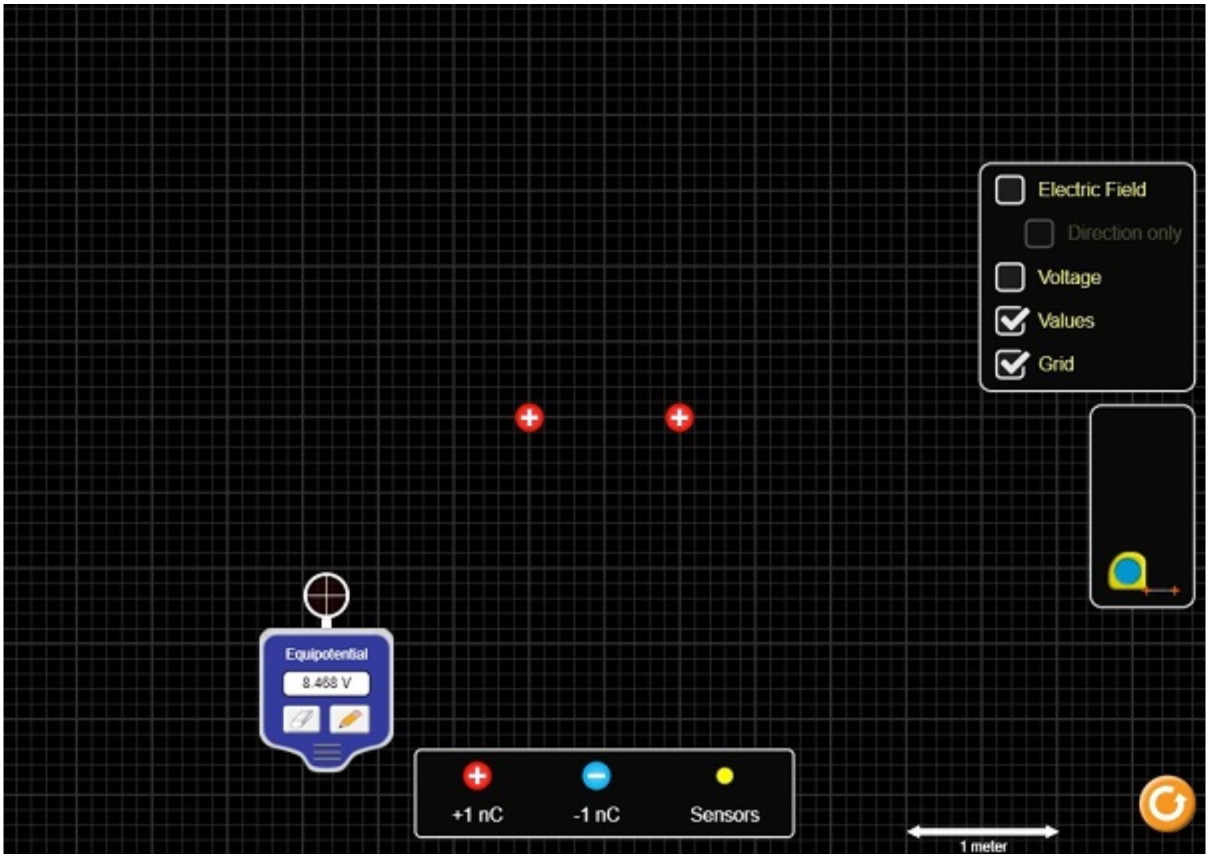
ANSWER:

- ○ The voltage distribution does not change.
- ◉ The voltages become negative instead of positive and keep the same magnitudes.
- ○ The voltages are positive, but the magnitude increases with increasing distance.

The voltage is still inversely proportional to the distance from the charge, but the voltage is negative everywhere rather than positive.

Part F

Now, remove the negative charge, and drag two positive charges, placing them 1 m apart, as shown below.



What is the voltage at the midpoint of the two charges?

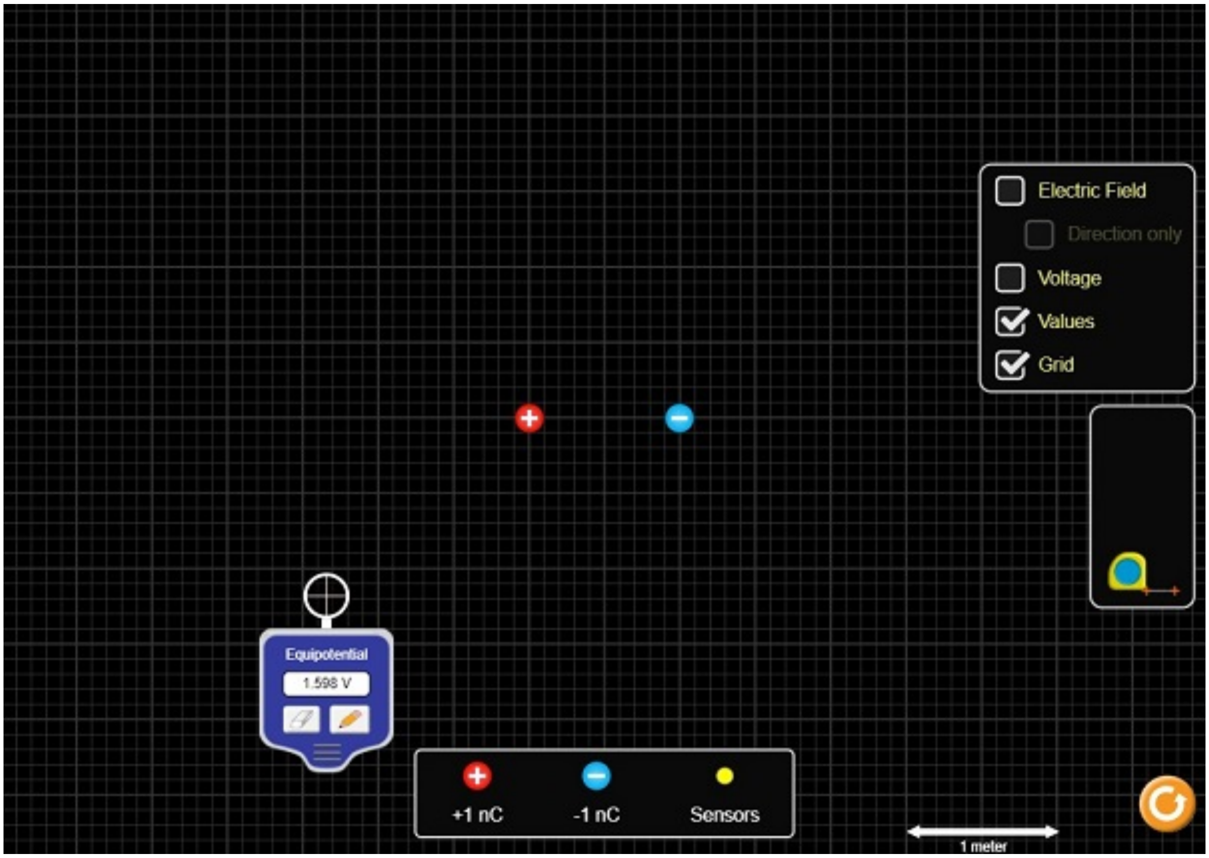
ANSWER:

- ○ Greater than zero, but less than twice the voltage produced by only one of the charges at the same point
- ○ Zero
- ◉ Exactly twice the voltage produced by only one of the charges at the same point

Because voltage is a scalar quantity, there are no vector components with opposite directions canceling out, as for electric fields. The voltage is simply the sum of the voltages due to each of the individual charges. Since both charges are positive, the voltage due to each charge (at all locations) is positive.

Part G

Now, make an electric dipole by replacing one of the positive charges with a negative charge, so the final configuration looks like the figure shown below. What is the voltage at the midpoint of the dipole?



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ANSWER:

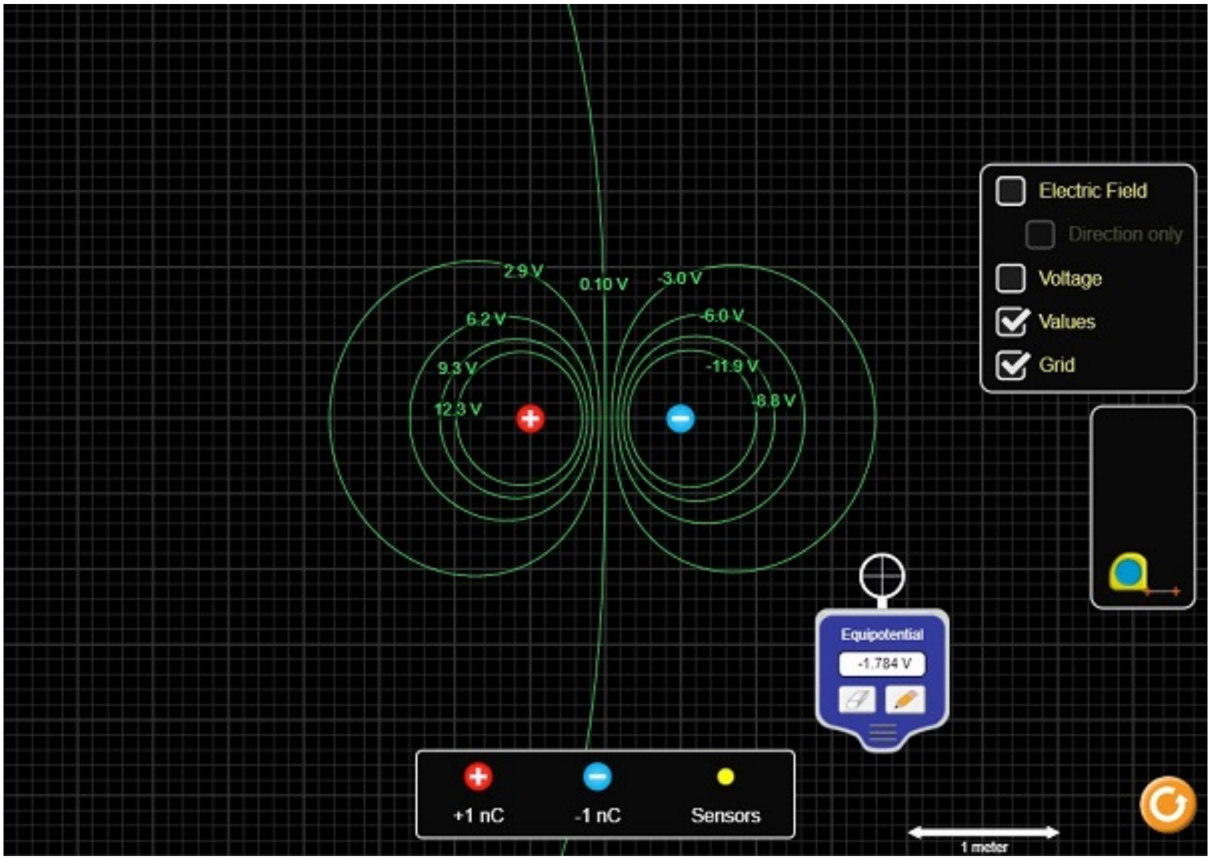
The voltage at the midpoint of the dipole is

- ○ positive.
- ◉ zero.
- ○ negative.

Because the voltage due to the negative charge has the opposite sign of the voltage due to the positive charge at the midpoint, the net voltage is zero. The electric field, however, is *not* zero here!

Part H

Make several equipotential lines similar to the figure below.



Try to have the equipotential lines equally spaced in voltage. Then, use an E-Field Sensor to measure the electric field at a few points while looking at the relationship between the electric field and the equipotential lines.

Which of the following statements is true?

ANSWER:

- ○ The electric field strength is greatest where the voltage is the smallest.
- ◉ The electric field strength is greatest where the equipotential lines are very close to each other.
- ○ The electric field strength is greatest where the voltage is the greatest.

Locations where the voltage is changing steeply are locations with a strong electric field. The magnitude of the electric field is equal to the rate the voltage is changing with distance. Mathematically, this idea is conveyed by $|E_s| = dV/ds$, where E_s is the component of the electric field in the direction of a small displacement ds. (As you learned earlier, the electric field is directed in the direction where the voltage decreases.)