ANSWER KEY. Values match the simulation readouts for the settings in each step.

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Equipotential Lines Virtual Lab

Physics | ANSWER KEY

Open **activities.zornscience.org/equipotential-lab/** and follow each step. Use $k = 8.99 \times 10^9$ N·m^2/C^2. Show your work with units.

Objective

Map the **electric potential** (voltage) and **electric field** around point charges, and find how voltage and field strength depend on distance and on the arrangement of charges.

NGSS alignment: HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. HS-PS2-4. Use mathematical representations of Coulomb's law to describe and predict the electrostatic forces between objects.
Practices and concepts: Developing and using models; Analyzing and interpreting data; Using mathematics; Patterns; Cause and effect.

Meet the simulation

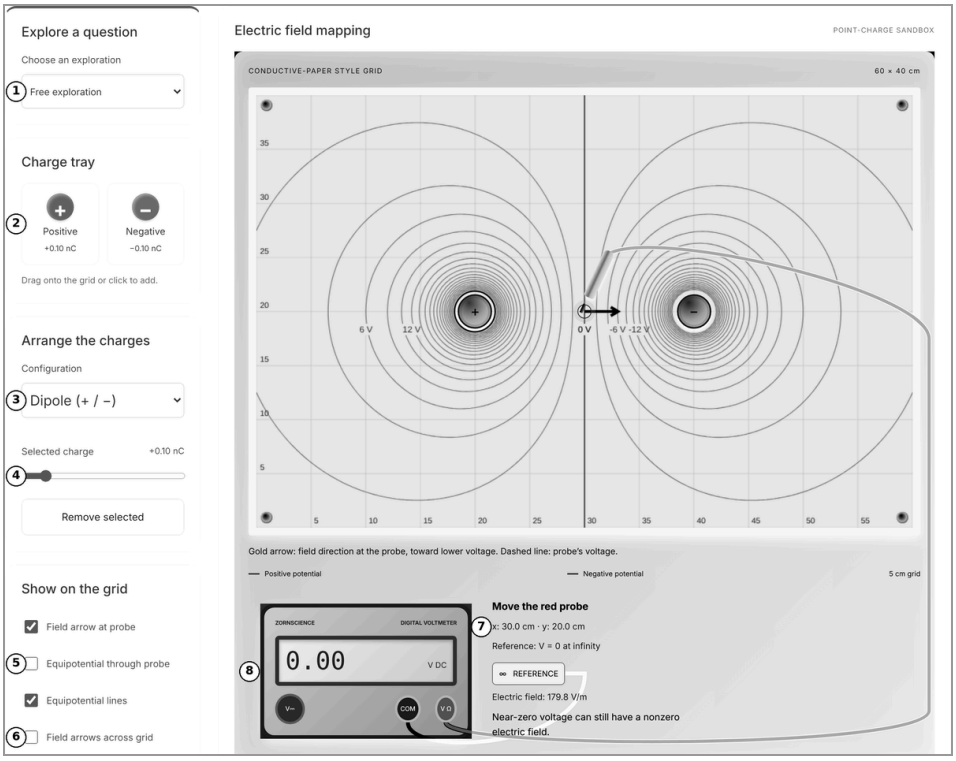


Figure 1. The lab with the dipole loaded. The dark grid is shown inverted for printing.

(1) Explore a question: optional guided explorations. Leave it on Free exploration.

(2) Charge tray: adds a +0.10 nC or −0.10 nC charge.

(3) Configuration: loads a set of charges.

(4) Selected charge: sets the size of the selected charge.

(5) Draws the equipotential line through the probe.

(6) Shows field arrows across the grid.

(7) Probe position (x and y in cm) and field strength in V/m.

(8) Voltmeter: voltage at the probe tip.

Moving the probe exactly: select **Reset lab** (probe at x 30.0 cm, y 20.0 cm). Click the probe tip once without dragging, then use the arrow keys: 0.5 cm per press, or 2 cm with Shift. Watch the position readout.

Pre-lab

1. What is an **equipotential line**? How much work does it take to move a charge along one?

A line where every point has the same voltage (electric potential). Zero work, because ΔV = 0, so W = qΔV = 0.

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2. The voltage near a point charge is V = kq/r. Calculate V at 10 cm (0.10 m) from a +0.10 nC (1.0×10^{-10} C) charge.

$V = kq/r = (8.99 \times 10^9\ N{\cdot}m^2/C^2)(1.0 \times 10^{-10}\ C) / (0.10\ m) =$ <u>9.0 V</u>

3. Predict: if you move twice as far from the charge, what happens to the voltage? To the field strength?

Any reasoned prediction. Correct result: the voltage is cut in half ($V \propto 1/r$) and the field strength drops to one fourth ($E \propto 1/r^2$).

Part A. One positive charge

1. Select **Reset lab**, then set **Configuration** to **Single positive charge**. The +0.10 nC charge sits at x = 30.0 cm, y = 20.0 cm.
2. Move the probe along y = 20.0 cm to each x below (Figure 2). Record the voltmeter reading and the electric field readout.

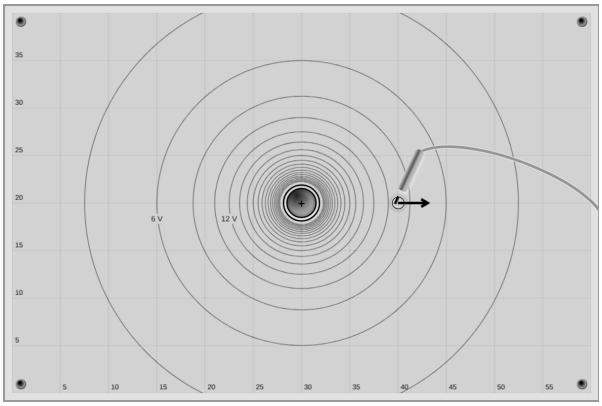
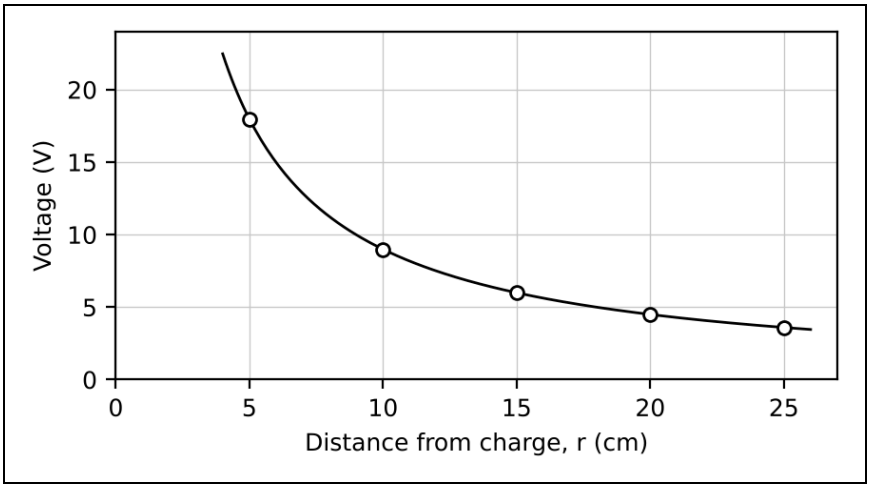


Figure 2. Probe at x = 40.0 cm, y = 20.0 cm (r = 10 cm). Inverted for printing.

Probe x (cm)	Distance r (cm)	Voltage (V)	Field (V/m)
35.0	**5**	**17.98**	**359.5**
40.0	**10**	**8.99**	**89.9**
45.0	**15**	**5.99**	**39.9**
50.0	**20**	**4.49**	**22.5**
55.0	**25**	**3.60**	**14.4**

4. Graph voltage (y-axis) against distance r (x-axis). Label both axes with units and sketch a smooth curve. Describe the shape.



A curve that drops quickly, then levels off (inverse relationship, not a straight line). V × r is constant: about 0.90 V·m.

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5. Use your data to compare r = 5 cm with r = 10 cm and r = 10 cm with r = 20 cm. When the distance doubles, by what factor does the voltage change? The field strength?

Voltage: 17.98 V → 8.99 V and 8.99 V → 4.49 V, so it is cut in half ($V \propto 1/r$). Field: 359.5 → 89.9 V/m and 89.9 → 22.5 V/m, so it drops to one fourth ($E \propto 1/r^2$).

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6. Click the charge, then set **Selected charge** to +0.20 nC. Measure at x = 40.0 cm and x = 50.0 cm (y = 20.0 cm). How do the readings compare with the 0.10 nC readings?

x = 40.0 cm: 17.98 V, 179.8 V/m. x = 50.0 cm: 8.99 V, 44.9 V/m. Both double (8.99 → 17.98 V, 89.9 → 179.8 V/m), so V and E are directly proportional to q.

Part B. Walking along an equipotential

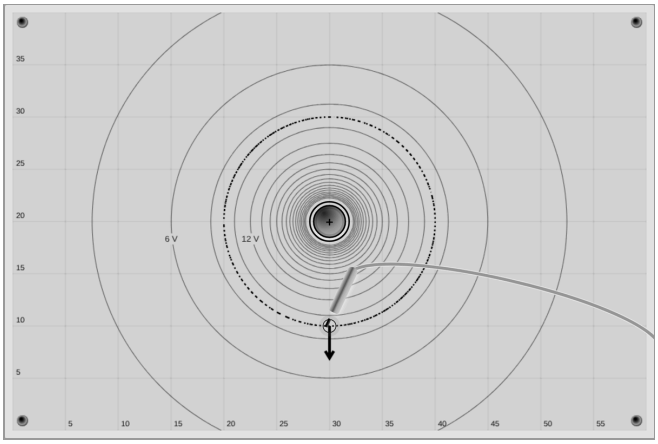


Figure 3. Equipotential through probe (dashed) at r = 10 cm. Inverted for printing.

1. Set the charge back to **+0.10 nC**.
2. Move the probe to each point below, all 10 cm from the charge. Record the voltage.
3. Check **Equipotential through probe** to see the line (Figure 3).

Probe (x, y) in cm	Voltage (V)
(30.0, 30.0)	**8.99**
(20.0, 20.0)	**8.99**
(30.0, 10.0)	**8.99**

7. What shape are the equipotential lines around one charge? Which way does the field arrow at the probe point compared with the equipotential line?

Circles centered on the charge. The field arrow is perpendicular to the equipotential line and points away from the + charge, toward lower voltage.

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8. The lines are drawn every 2 V. Where are they closest together? What does that tell you about the field there?

Closest together near the charge. Close lines mean the voltage changes quickly over a short distance, so the field is strongest there.

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9. A real lab uses conductive paper with two metal electrodes held at fixed voltages, and the voltmeter's black lead touches one electrode. Give one way the real readings would differ from this simulation.

Any one: the voltages are measured from an electrode, not from infinity, so the numbers shift (for example, 0 V to the battery voltage); the paper is a flat sheet with edges, so lines bend near the edges; the paper is not perfectly uniform; probe placement is less precise.

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Part C. Two charges

1. Select **Reset lab** (dipole: +0.10 nC at x = 20.0 cm and −0.10 nC at x = 40.0 cm, both at y = 20.0 cm). Check **Field arrows across grid** (Figure 4).
2. Record the dipole readings below. Then set **Configuration** to **Like charges (+ / +)** (+0.10 nC at x = 20.0 cm and 40.0 cm) and record the last row.

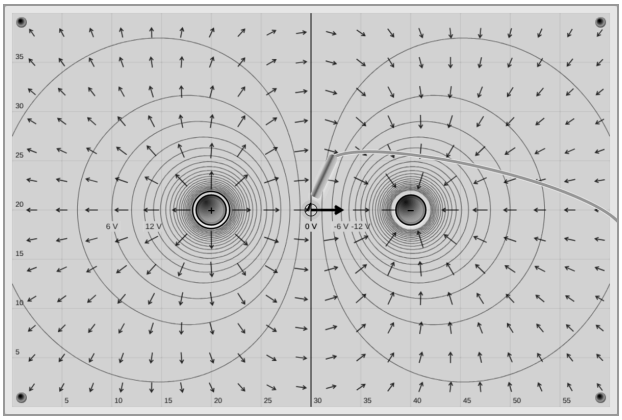


Figure 4. Dipole, probe at the midpoint.

Arrangement	Probe (x, y) in cm	Voltage (V)	Field (V/m)
Dipole	(30.0, 20.0) midpoint	**0.00**	**179.8**
Dipole	(30.0, 30.0)	**0.00**	**63.6**
Dipole	(25.0, 20.0)	**11.98**	**399.4**
Dipole	(35.0, 20.0)	**−11.98**	**399.4**
Like charges	(30.0, 20.0) midpoint	**17.98**	**0.0**

10. At the dipole midpoint the voltage is zero, but at the like-charge midpoint the field is zero. Explain each result. Does zero voltage mean zero field?

Dipole: +8.99 V and −8.99 V add to 0 V (all along the center line), but both fields point the same way (toward the − charge), so they add: 89.9 + 89.9 = 179.8 V/m. Like charges: the voltages add (8.99 + 8.99 = 17.98 V), but the fields point in opposite directions and cancel. No: V = 0 does not mean E = 0, and E = 0 does not mean V = 0.

11. A +2.0 nC test charge moves from (25.0, 20.0) to (35.0, 20.0) in the dipole field. Calculate its change in electric potential energy with $\Delta U = q\Delta V$. Does it gain or lose potential energy?

$\Delta V = -11.98\ V - 11.98\ V = -23.96\ V$. $\Delta U = q\Delta V = (2.0 \times 10^{-9}\ C)(-23.96\ V) = \underline{-4.8 \times 10^{-8}\ J}$. It loses potential energy (the field does positive work, like a ball rolling downhill).

Conclusion

12. Write a claim that describes how voltage and field strength change with distance from a point charge and how equipotential lines relate to the field. Support it with evidence from Parts A and B, then explain your reasoning.

Claim: Voltage falls as 1/r and field strength as $1/r^2$. Equipotential lines are perpendicular to the field, and they crowd together where the field is strong.
Evidence: Doubling r from 10 to 20 cm halved V (8.99 to 4.49 V) and cut E to one fourth (89.9 to 22.5 V/m). All points 10 cm away read 8.99 V, and the field arrow crossed that circle at a right angle.
Reasoning: $V = kq/r$ and $E = kq/r^2$. The field points in the direction voltage decreases fastest, so it must cross lines of equal voltage at right angles, and no work is done moving along them.

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