

Open the simulation at **activities.zornscience.org/equipotential-lab/**. The board is a 60 cm × 40 cm sheet. Positions are given as (x, y) in centimeters, measured from the bottom-left corner, and the meter shows the probe position under the reading. The voltmeter reads the **electric potential** V at the red probe tip, measured against a reference of 0 V very far away. The panel under the meter also shows the **electric field** strength E at the probe, in volts per meter (1 V/m = 1 N/C).

To place the probe exactly: press Tab until the probe is selected, then use the arrow keys. Each press moves 0.5 cm, or 2 cm with Shift held down. You can also click anywhere on the grid.

Goals. By the end of this lab, I can (1) map equipotential lines and explain why the electric field crosses them at right angles and points toward lower potential, (2) measure how electric potential and electric field change with distance from a point charge and build a mathematical model from my data, and (3) use $\Delta PE = q\Delta V$ to find how a charge's energy changes as it moves through a field.

Key equations. $V = kq/r$ | $E = kq/r^2$ | $\Delta PE = q\Delta V$ | $E \approx |\Delta V|/\Delta d$ | $k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ | $1 \text{ nC} = 1 \times 10^{-9} \text{ C}$

NGSS alignment. HS-PS3-5 (develop and use a model of two objects interacting through electric fields to illustrate the forces between them and the changes in energy due to the interaction) and HS-PS2-4 (use mathematical representations of Coulomb's law to describe and predict electrostatic interactions). Science practices: developing and using models; analyzing and interpreting data; using mathematics and computational thinking.

Predict (before you touch the simulation)

1. A small positive charge sits on a sheet of paper. You slide a voltmeter probe around it so the meter always reads exactly 9 V. (a) Predict the shape of the path your probe traces. (b) If you then move the probe twice as far from the charge, will the reading stay the same, drop to half, or drop to one quarter? Explain your thinking.

Part A: Mapping a Single Charge (Questions 2 to 5)

Set **Configuration** to **Single positive charge** (+0.10 nC at (30, 20)). Uncheck **Equipotential lines** so the grid is bare. Leave **Electric field vectors** and **Potential color map** unchecked for now.

2. Find four different points where the meter reads between 8.90 V and 9.10 V. At least two points must be off the line $y = 20$ cm. For each point, calculate its distance from the charge: $r = \sqrt{(x - 30)^2 + (y - 20)^2}$.

Point	x (cm)	y (cm)	V (V)	Distance r (cm)
1				
2				
3				
4				

3. What shape do your four points make? Now set **Contour spacing** to **1 V** and check **Equipotential lines**. Does one of the lines pass through your points? What do all the points on one equipotential line have in common?
4. Check **Electric field vectors**. (a) What angle do the field arrows make with the equipotential lines they cross? (b) Do the arrows point toward higher or lower potential?
5. A +1.0 nC charge is carried once all the way around the 9 V equipotential line. Use $\Delta PE = q\Delta V$ to find the change in its electric potential energy. How much work does the electric field do on it along the way? Explain.

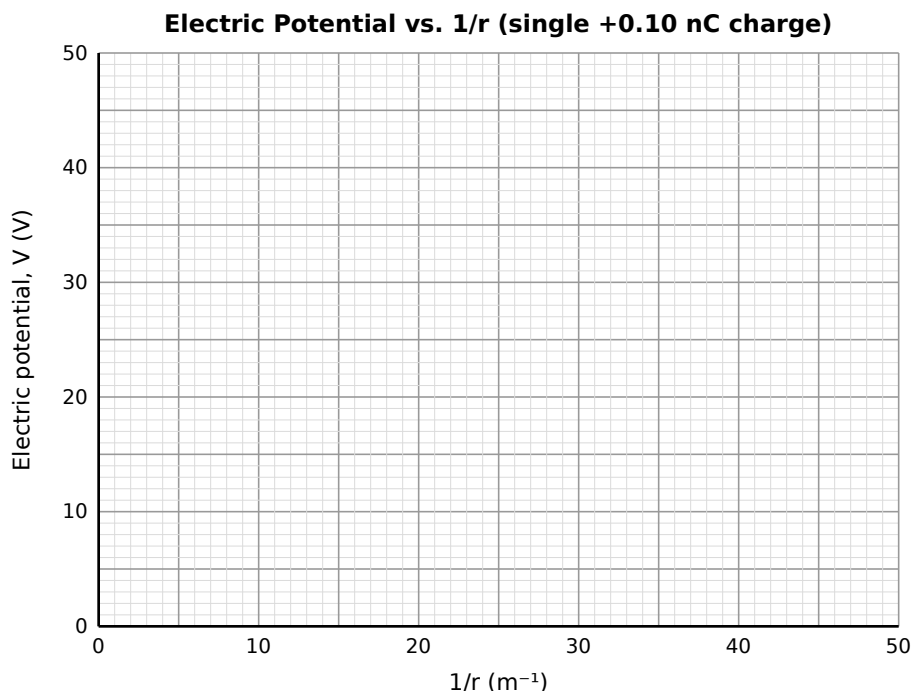
Part B: Potential and Field vs. Distance (Questions 6 to 9)

Keep the single positive charge. Uncheck the field vectors if they make the board busy. Move the probe along the line $y = 20$ cm to the right of the charge, and record V and E at each position. Then complete the calculated columns.

6. Data table. Distance from the charge: $r = x - 30$ cm.

Probe x (cm)	r (cm)	r (m)	V (V)	E (V/m)	$1/r$ (m ⁻¹)	$V \times r$ (V·m)
32	2					
34	4					
36	6					
40	10					
45	15					
50	20					
55	25					

7. Plot V (vertical axis) against $1/r$ (horizontal axis) on the grid below. Draw a best-fit line, then calculate its slope. Include units.



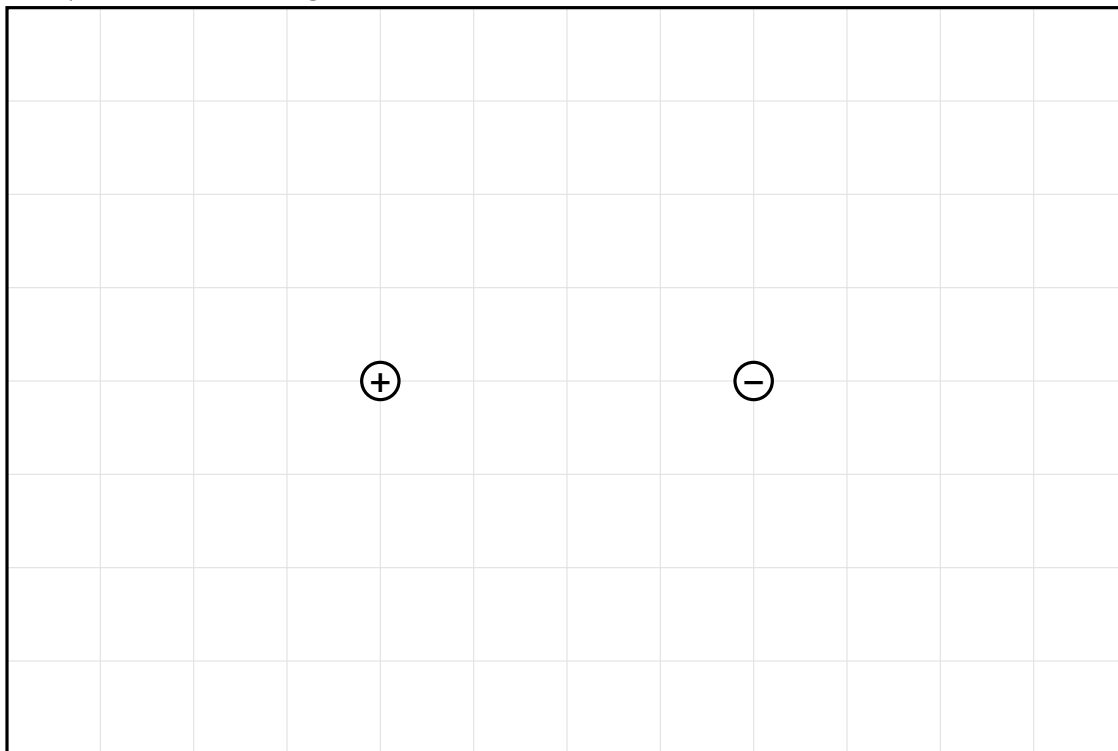
8. The model says $V = kq \times (1/r)$, so the slope of your graph equals kq . Use your slope to calculate the charge q in coulombs, then convert it to nanocoulombs. Compare your result with the charge tray value (0.10 nC) using percent error. What does the $V \times r$ column tell you?
9. Compare your readings at $r = 10 \text{ cm}$ and $r = 20 \text{ cm}$. By what factor did V change? By what factor did E change? Which quantity follows an inverse-square law, and why does that make sense given $E = F/q$ and Coulomb's law?

Part C: Mapping a Dipole (Questions 10 to 13)

Press **Reset lab**. This loads a dipole: $+0.10\text{ nC}$ at $(20, 20)$ and -0.10 nC at $(40, 20)$. Check **Equipotential lines** (contour spacing 2 V) and **Electric field vectors**.

- 10.** Sketch the dipole. Draw at least three equipotential lines around each charge, the 0 V line (dashed), and at least eight field arrows. Label at least one line on each side with its voltage.

Grid squares are 5 cm . The charges are at $(20, 20)$ and $(40, 20)$.



- 11.** Where are the equipotential lines closest together? Move the probe there and to a place where the lines are far apart, and compare the field readings. Write a rule that connects line spacing to field strength.
- 12.** Measure V at $(28, 20)$ and at $(32, 20)$. Find ΔV , then estimate the field between them with $E \approx |\Delta V|/\Delta d$ (Δd in meters). Now read E at the midpoint, $(30, 20)$. Find the percent difference. Why is the estimate not exactly the same as the reading?
- V at $(28, 20) =$ _____ V at $(32, 20) =$ _____ E reading at $(30, 20) =$ _____

- 13.** Find the 0 V equipotential line. Describe where it is. Is the electric field zero anywhere on that line? Explain how the potential can be zero at a point where the field is not.

Part D: Energy in the Field (Questions 14 to 16)

Keep the dipole. Point A is (24, 20), near the positive charge. Point B is (36, 20), near the negative charge.

- 14.** Measure the potential at A and B. A small +2.0 nC charge moves from A to B. Calculate $\Delta V = V_B - V_A$ and $\Delta PE = q\Delta V$. Does the charge's potential energy increase or decrease? Would it speed up on its own, or would something have to push it?

$$V_A = \underline{\hspace{2cm}} \quad V_B = \underline{\hspace{2cm}}$$

- 15.** An electron ($q = -1.6 \times 10^{-19}$ C) makes the same trip from A to B. Calculate ΔPE . Would the electron move from A to B on its own? Explain.

- 16.** Change the configuration to **Like charges (+ / +)**. Read V and E at the midpoint, (30, 20). Compare them with your dipole midpoint readings. Use the words *scalar* and *vector* to explain why V and E behave so differently.

$$\text{Like charges: } V = \underline{\hspace{2cm}} \quad E = \underline{\hspace{2cm}} \quad \text{Dipole: } V = \underline{\hspace{2cm}} \quad E = \underline{\hspace{2cm}}$$

Conclusion (Questions 17 and 18)

- 17. Claim, evidence, reasoning.** How is the direction of the electric field related to the equipotential lines, and how can you tell from an equipotential map where the field is strongest? Support your claim with specific data from Parts A through C.
- 18.** A hiking map uses contour lines that connect points at the same height. Compare a contour map of a hill and a valley to your dipole map. What plays the role of the equipotential lines? Where would a ball roll fastest, and in what direction? Which charge is the hill, and which is the valley?