

Field maps, voltage and energy per unit charge

AP Physics 2 (algebra-based) · Lesson

Quick answer: An electric field $E = F/q$ is the force per unit positive charge, a vector drawn with field lines. Electric potential $V = U/q$ is the energy per unit charge, a scalar measured in volts. Equipotentials are perpendicular to field lines, and a charge moved through ΔV changes its energy by $q\Delta V$.

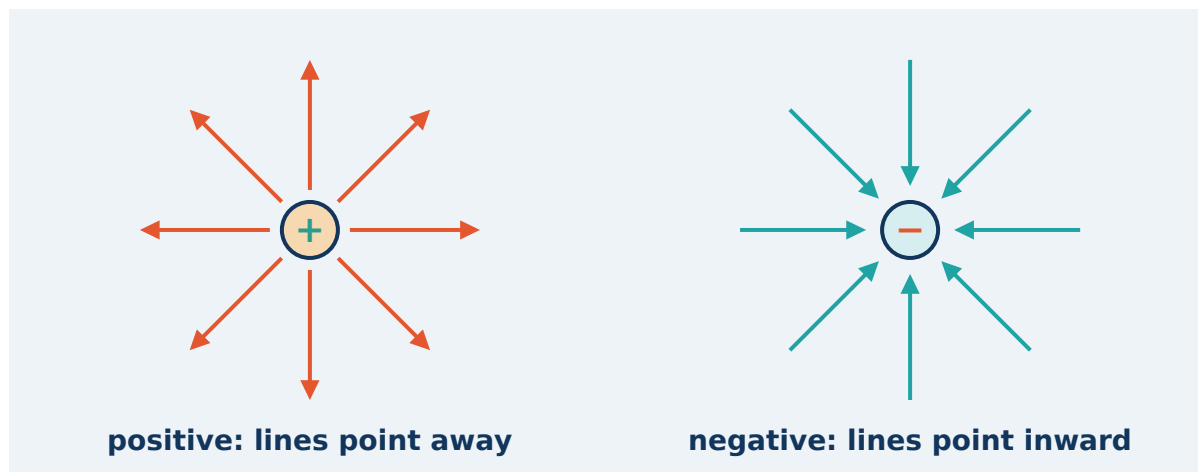
Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 10

What is an electric field?

A charge changes the space around it. Any other charge placed there feels a force, and we describe this with the electric field. The field at a point is the force that a small positive test charge would feel, divided by its charge. It is a vector, so it has a size and a direction.

Definition

The **electric field** E at a point is the force per unit positive charge, $E = F/q$, measured in N/C (equivalent to V/m). Its direction is the direction of the force on a positive test charge. For a point charge Q , $E = kQ/r^2$, pointing away from a positive Q and towards a negative Q .

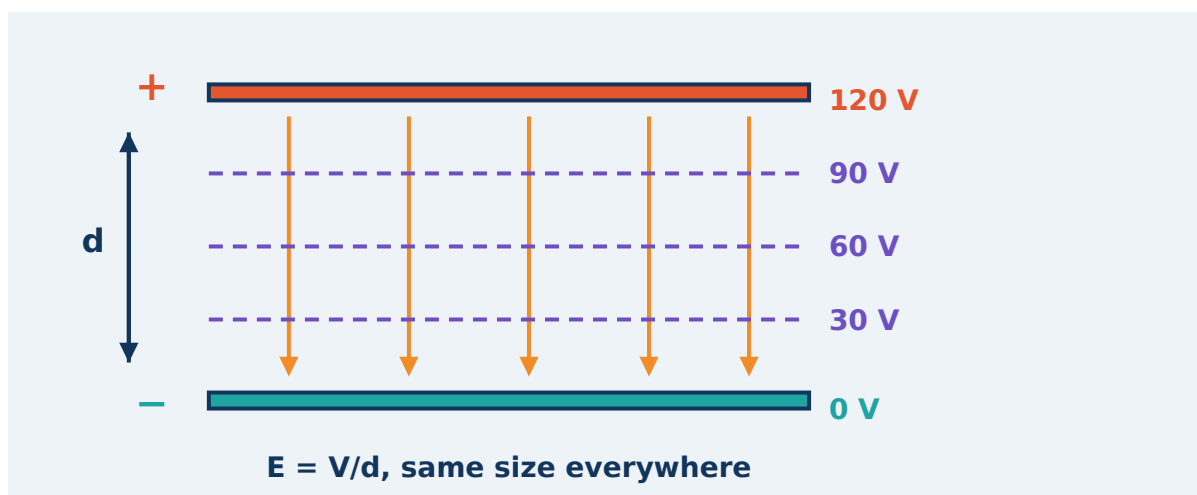


Field lines start on positive charge and end on negative charge. Where they are closer, the field is stronger.

Field lines map the field. They leave positive charges, enter negative charges and never cross. The closer the lines, the stronger the field. At any point the field is tangent to the line.

How does a uniform field behave?

Two large parallel plates with opposite charges make a uniform field between them: the same size and direction everywhere. It points from the positive plate to the negative plate, and a charge q inside feels a constant force $F = qE$.



Between parallel plates the field is uniform and the potential falls in equal steps.

What are electric potential and potential energy?

Moving a positive charge against the field needs work, just like lifting a mass against gravity. That work is stored as electric potential energy U . Dividing by the charge gives a property of the point itself, called the electric potential.

Key law

Electric potential $V = U/q$, in volts ($1 \text{ V} = 1 \text{ J/C}$). A charge q moved through a potential difference ΔV changes its potential energy by $\Delta U = q\Delta V$. In a uniform field, $E = \Delta V/d$, and for a point charge $V = kQ/r$. An electron-volt (eV) is the energy of one electron moved through 1 V: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$.

Quantity	Symbol and unit	Type	Point charge Q
Electric field	E , in N/C or V/m	vector	$E = kQ/r^2$
Electric potential	V , in volts (J/C)	scalar	$V = kQ/r$
Potential energy	U , in joules	scalar	$U = qV$

Worked example

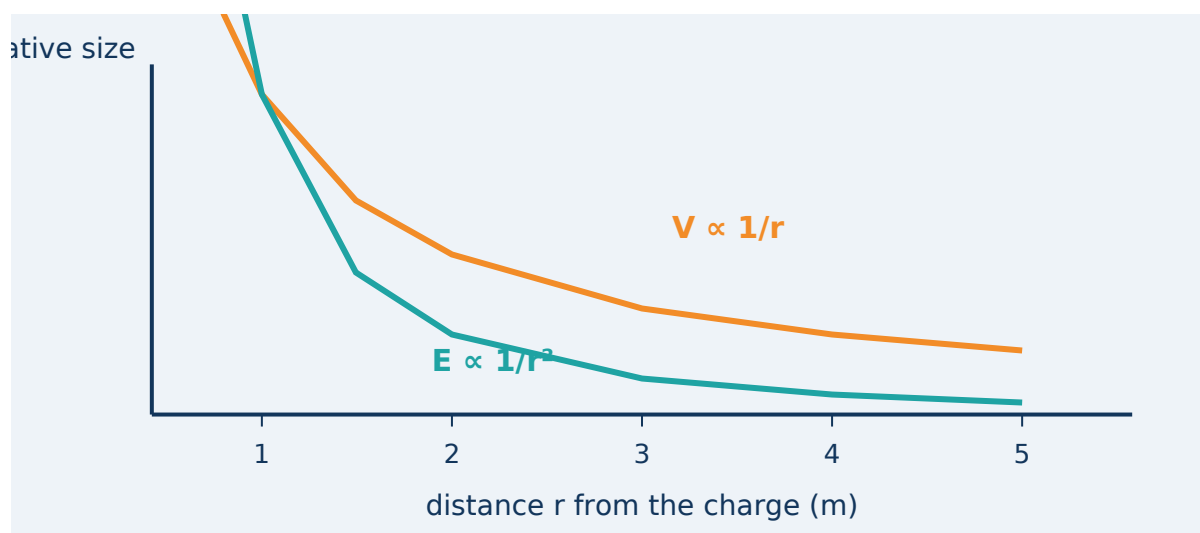
Chiamaka measures near a $+5.0 \text{ nC}$ sphere. Find E and V at 0.30 m .

$E = (8.99 \times 10^9)(5.0 \times 10^{-9}) / (0.30)^2 = \mathbf{5.0 \times 10^2 \text{ N/C}}$, directed away. $V = (8.99 \times 10^9)(5.0 \times 10^{-9}) / 0.30 = \mathbf{1.5 \times 10^2 \text{ V}}$.

Worked example

A proton starts from rest and is accelerated through 500 V . Find its final speed ($m = 1.67 \times 10^{-27} \text{ kg}$).

The kinetic energy gained is $q\Delta V = 1.60 \times 10^{-19} \times 500 = 8.0 \times 10^{-17} \text{ J}$, or 500 eV . Then $v = \sqrt{2K/m} = \sqrt{(2 \times 8.0 \times 10^{-17}) / 1.67 \times 10^{-27}} = \mathbf{3.1 \times 10^5 \text{ m/s}}$.



Both fall with distance, but the field E drops much faster than the potential V .

What are equipotential lines?

An equipotential is a line or surface where the potential has the same value. Moving a charge along it takes no work, because $\Delta V = 0$. For that reason the field is always perpendicular to equipotentials, and it points from high potential to low potential. Equipotentials packed closely together mean a strong field.

Worked example

Plates 5.0 cm apart have a potential difference of 200 V. Find the potential 2.0 cm from the negative plate, and the work to move +3.0 nC from there to the positive plate.

$E = 200 / 0.050 = 4000 \text{ V/m}$, so $V = 4000 \times 0.020 = \mathbf{80 \text{ V}}$. The remaining difference is 120 V, so $W = q\Delta V = 3.0 \times 10^{-9} \times 120 = \mathbf{3.6 \times 10^{-7} \text{ J}}$.

Common mistake

Do not confuse a high potential with a strong field. A large V can have a tiny E if it changes slowly, and a field can be strong where V equals zero. The field depends on how fast V changes with distance, not on V itself.

Lina's tip

Remember: E is a vector like force, V is a scalar like height. For several charges, add the potentials as plain numbers with signs, but add the fields as arrows.

Key points to remember

- Electric field $E = F/q$ in N/C; point charge $E = kQ/r^2$
- Uniform field between plates: $E = \Delta V/d$ in V/m
- Electric potential $V = U/q$ in volts; point charge $V = kQ/r$
- Energy change $\Delta U = q\Delta V$; $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$
- Equipotentials are perpendicular to field lines; no work is done moving along one

Field maps, voltage and energy per unit charge: frequently asked questions

What is the difference between electric field and electric potential?

The electric field is a vector giving force per unit charge, in N/C. Electric potential is a scalar giving energy per unit charge, in volts. The field is the rate at which the potential changes with distance.

Why are field lines always perpendicular to equipotentials?

If the field had a component along an equipotential, it would push a charge along it and do work. But the potential is the same everywhere on the line, so no work is done and the field must be perpendicular.

Why is the field zero inside a conductor in equilibrium?

Free charges would move if any field existed inside. They keep moving until the field cancels, so in equilibrium $E = 0$ inside and any excess charge sits on the surface.

What is an electron-volt?

An electron-volt is the energy gained by an electron moved through a potential difference of 1 volt, equal to 1.60×10^{-19} J. It is a convenient unit for particles and atoms.

Does a positive charge move towards high or low potential?

If released from rest, a positive charge moves toward lower potential, in the direction of the field, and loses potential energy. A negative charge moves toward higher potential.