

Unit 10: Electric Force, Field, and Potential

Unit 10 covers the physics of electric charge at rest. It starts with charge itself and Coulomb's law for the force between charges, builds the electric field as a way to describe how a charge affects the space around it, then switches to the energy picture with electric potential energy and electric potential. It ends with capacitors, which store separated charge, and with the motion of charges in electric fields.

AP Physics 2

Electric Force, Field, and Potential

About 15 minutes to read

How to use this guide

Read the sections in order the first time. The unit is built as a chain. Charge explains the force, the force motivates the field, the field sets up the energy and potential picture, and potential makes capacitors and charge motion make sense. Skipping ahead to capacitors without the field and potential sections will make the formulas feel like random algebra.

After the first read, use the trap boxes for the distinctions the exam tests most often, especially field versus potential and series versus parallel capacitors. Finish with the practice questions, then complete the recall check on the last page out loud and note any items you cannot explain yet.

What this unit is worth. Electric Force, Field, and Potential is 15 to 18 percent of the AP Physics 2 exam, which makes it one of the three heaviest units on the test, along with thermodynamics and electric circuits. It also feeds directly into Unit 11, since circuits run on the potential differences and charge motion you learn here. Time spent getting field and potential straight now pays off twice.

10.1 Electric Charge and Electric Force

There are two kinds of **electric charge**, positive and negative. Like charges repel and opposite charges attract. An object is neutral when it carries equal amounts of positive and negative charge, and it is charged when the balance is off. Charging an object does not create charge. It moves electrons from one place to another.

Charge is quantized. The smallest unit of charge that can be isolated is the **elementary charge** $e = 1.60 \times 10^{-19}$ C. Every observable charge is a whole-number multiple of e . The electron carries $-e$ and the proton carries $+e$. **Conservation of charge** says the net charge of an isolated system never changes. In any process, the total charge before equals the total charge after.

Conductors and insulators

In a **conductor**, some charges are free to move through the material. Metals are the standard example. In an **insulator**, charges stay essentially fixed where they are. Rubber, glass, and plastic are insulators. Two facts about conductors in electrostatic equilibrium come up constantly. The electric field inside a conductor is zero, and any excess charge sits on the outer surface of the conductor.

Coulomb's law

Coulomb's law gives the magnitude of the electric force between two point charges: $F = k|q_1q_2| / r^2$, where r is the separation and $k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$. The force acts along the line joining the charges, repulsive for like charges and attractive for opposite charges. The two forces form a Newton's third law pair, so they are equal in magnitude even when the charges are very different in size.

Worked example. Two charges of $+1.0 \mu\text{C}$ each are 0.50 m apart. The force magnitude is $F = (8.99 \times 10^9)(1.0 \times 10^{-6})(1.0 \times 10^{-6}) / (0.50)^2$. The numerator is 8.99×10^{-3} , the denominator is 0.25 , and the result is $3.6 \times 10^{-2} \text{ N}$, or 0.036 N , repulsive. Notice how small the force is. It takes a huge amount of charge to make an everyday-size force, because k is enormous and the coulomb is an enormous unit.

Trap. Coulomb's law needs r^2 in the denominator, not r . Doubling the separation cuts the force to one fourth, not one half. When a question changes the distance, square the ratio before you touch anything else.

10.2 The Process of Charging

Objects become charged by moving electrons, and there are three processes to know. **Charging by friction** happens when two materials are rubbed together and electrons transfer from one to the other. One object ends up positive and the other negative, with equal magnitudes, which is conservation of charge in action.

Charging by conduction means charging by direct contact. When a charged conductor touches a neutral one, charge flows until the two are at the same potential, and the total charge is conserved. If the two conductors are identical spheres, they split the total charge evenly. A sphere carrying $+6.0\ \mu\text{C}$ touched to an identical neutral sphere leaves each sphere with $+3.0\ \mu\text{C}$.

Charging by induction charges an object without ever touching it with a charged object. Bring a positively charged rod near a neutral metal sphere. The rod attracts the sphere's free electrons toward the near side, leaving the far side positive. While the rod is held in place, ground the sphere. Electrons flow up from the ground onto the sphere, attracted by the rod. Remove the ground connection first, then remove the rod, and the sphere is left with a net negative charge. The order matters. If you remove the rod before breaking the ground connection, the extra electrons flow back out and the sphere ends up neutral.

A related effect is **polarization**. A charged object brought near a neutral insulator shifts each atom's electron cloud slightly, creating tiny induced dipoles. The near side of the insulator ends up with the opposite sign to the charged object, so the two attract. This is why a charged balloon sticks to a neutral wall. The wall was never given a net charge. Its charges just rearranged.

PROCESS	CONTACT?	NET CHARGE RESULT
Friction	Rubbing contact	Both objects charged, opposite signs, equal magnitudes.
Conduction	Direct touch	Charge shared. The originally charged object ends with the same sign, less of it.
Induction	No touch by the charged object (grounding contact only)	The object ends with the opposite sign to the inducing charge.

Trap. In induction, only electrons move. If a question says protons flowed onto the sphere, that answer is wrong on physics grounds, since protons are locked in nuclei. Also, a polarized insulator is still net neutral. Rearranged charge is not the same as added charge.

10.3 Electric Fields

The **electric field** E at a point is the electric force per unit charge that a charge placed there would feel: $E = F / q$. Its units are newtons per coulomb (N/C). The field describes how a source charge affects the space around it, whether or not any other charge is actually there to feel it. A single charge sitting alone still produces a field everywhere around it.

For a point charge Q , the field magnitude at distance r is $E = k|Q| / r^2$. The direction is defined by the force on a *positive* test charge: away from a positive source charge and toward a negative one. This definition is the source of the most common sign errors in the unit, so read the trap box below carefully.

Electric field lines are a visual map of the field. They start on positive charges and end on negative charges (or run to infinity). The field direction at any point is tangent to the line through that point. The line density shows the strength, with crowded lines meaning a stronger field. Field lines never cross, because the field at a point has exactly one direction.

Fields add as vectors. The **superposition** principle says the total field at a point is the vector sum of the fields from each source charge. Worked example: two $+2.0 \mu\text{C}$ charges are fixed 0.60 m apart. At the midpoint, each charge is 0.30 m away, so each contributes $E = (8.99 \times 10^9)(2.0 \times 10^{-6}) / (0.30)^2 = 2.0 \times 10^5 \text{ N/C}$. The left charge's field points away from it (to the right) and the right charge's field points away from it (to the left). Equal magnitudes in opposite directions cancel, so the net field at the midpoint is zero.

Trap. The field direction is the direction of the force on a positive test charge. A negative charge feels a force opposite to the field direction. If the field points east, a proton is pushed east and an electron is pushed west. Drawing the force arrow in the field direction for an electron is the classic sign error.

Trap. The field exists even with no test charge present. A question that asks for the field at an empty point in space is well defined. Do not answer zero just because nothing is sitting there. Zero field comes from cancellation, as in the midpoint example, not from emptiness.

10.4 Electric Potential Energy

Electric potential energy U is the stored energy of a charge configuration. For two point charges, $U = kQq / r$, with $U = 0$ defined at infinite separation. The sign carries meaning. Like charges give positive U , since work must be done to push them together against repulsion. Opposite charges give negative U , since they attract and the field would do positive work pulling them together.

More generally, moving a charge q through a potential difference ΔV changes its potential energy by $\Delta U = q\Delta V$. The work done *by the electric field* is $W = -\Delta U$. When the field does positive work, the charge's potential energy drops and its kinetic energy rises. If only electric forces act, energy is conserved: $\Delta K + \Delta U = 0$, so any loss of potential energy shows up as kinetic energy.

10.5 Electric Potential

Electric potential V is potential energy per unit charge: $V = U / q$, measured in volts ($1 \text{ V} = 1 \text{ J/C}$). For a point charge Q , $V = kQ / r$. Potential is a scalar, so it adds by ordinary arithmetic, with the sign of Q included. This makes potential calculations much easier than field calculations. You add numbers instead of adding vectors.

Worked example: the potential 0.10 m from a $+2.0 \mu\text{C}$ charge is $V = (8.99 \times 10^9)(2.0 \times 10^{-6}) / 0.10 = 1.8 \times 10^5 \text{ V}$. A $-2.0 \mu\text{C}$ charge at the same distance would give $-1.8 \times 10^5 \text{ V}$. Place a $+1.0 \mu\text{C}$ charge there and its potential energy is $U = qV = (1.0 \times 10^{-6})(1.8 \times 10^5) = 0.18 \text{ J}$.

An **equipotential surface** is a surface on which V is constant. No work is done moving a charge along an equipotential, since $\Delta V = 0$ there. Field lines are always perpendicular to equipotential surfaces, and the field points from higher potential toward lower potential, which is the direction of steepest decrease of V . For parallel plates, the equipotentials are planes parallel to the plates and the field between the plates is uniform, with magnitude $E = \Delta V / d$.

Trap. Electric field is a vector in N/C. Electric potential is a scalar in volts. They are not two names for the same thing. A point can have zero potential and nonzero field, and the two obey completely different addition rules. When a question mixes them up, sort out which quantity it is actually asking about first.

Trap. $V = 0$ does not mean $E = 0$. At the midpoint between equal and opposite charges, the potentials cancel as scalars ($V = 0$) while the fields point the same way and add. Zero potential tells you nothing about the field by itself.

10.6 Capacitors

A **capacitor** stores separated charge on two conducting plates with an insulating gap between them.

Capacitance C is defined by $C = Q / \Delta V$, where Q is the magnitude of charge on one plate and ΔV is the potential difference between the plates. The unit is the farad (F).

For a **parallel-plate capacitor**, $C = \epsilon_0 A / d$, where A is the plate area, d is the plate separation, and $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$ is the permittivity of free space. Larger plates facing each other store more charge, and plates closer together store more charge. The field between ideal parallel plates is uniform: $E = \Delta V / d = Q / (\epsilon_0 A)$.

Worked example: plates of area 0.020 m^2 separated by 1.0 mm . $C = (8.85 \times 10^{-12})(0.020) / (1.0 \times 10^{-3}) = 1.8 \times 10^{-10} \text{ F}$, about 180 pF . Real capacitors are small in farads, so expect microfarads and picofarads in problems.

Combinations of capacitors

Capacitors in **parallel** all share the same voltage, and their charges add, so $C_{\text{eq}} = C_1 + C_2 + \dots$.

Capacitors in **series** all carry the same charge, and their voltages add, so $1/C_{\text{eq}} = 1/C_1 + 1/C_2 + \dots$.

Example: $2.0 \text{ }\mu\text{F}$ and $4.0 \text{ }\mu\text{F}$ in parallel give $6.0 \text{ }\mu\text{F}$. In series, $1/C_{\text{eq}} = 1/2.0 + 1/4.0 = 0.75 \text{ }\mu\text{F}^{-1}$, so $C_{\text{eq}} = 1.3 \text{ }\mu\text{F}$. The series equivalent is always smaller than the smallest individual capacitor.

Trap. Capacitor combinations work the opposite way from resistor combinations. Series capacitors use the reciprocal sum, which is the rule series resistors do not use. If you memorized the resistor rules, flip them for capacitors: parallel adds directly, series adds reciprocally.

Trap. Capacitance depends only on geometry (and the dielectric), not on Q or V . Charging a capacitor to a higher voltage puts more charge on the plates, but the ratio $Q/\Delta V$ stays fixed. A question that asks what happens to C when the voltage doubles is testing whether you know C was never about the charge in the first place.

Energy stored in a capacitor

Separating the charges takes work, and that work is stored as electric potential energy: $U = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2 = Q^2 / 2C$. All three forms are equivalent, so pick whichever matches the quantities you know. Example: a $4.0 \mu\text{F}$ capacitor charged to 12 V stores $U = \frac{1}{2}(4.0 \times 10^{-6})(12)^2 = 2.9 \times 10^{-4} \text{ J}$.

Dielectrics

A **dielectric** is an insulating material placed between the plates. It polarizes in the plates' field, and the induced field partially cancels the original field, which lets the plates hold more charge at the same voltage. Capacitance increases by the **dielectric constant** κ : $C = \kappa\epsilon_0 A / d$. Two cases matter. If the capacitor stays connected to a battery, the voltage is fixed, so inserting the dielectric increases the charge and the stored energy. If the capacitor is isolated (disconnected, charge fixed), inserting the dielectric lowers the voltage and lowers the stored energy. Name which case you are in before you predict anything.

The same isolated-versus-connected logic applies to changing the geometry. Take an isolated parallel-plate capacitor and double the plate separation. The charge cannot leave, so Q is fixed. Capacitance halves ($C = \epsilon_0 A/d$), the voltage doubles ($\Delta V = Q/C$), and the field between the plates stays the same ($E = Q/(\epsilon_0 A)$ has no d in it).

10.7 Conservation of Electric Energy

A charge released in an electric field converts potential energy to kinetic energy according to $\Delta K = -\Delta U = -q\Delta V$. A positive charge speeds up moving toward lower potential. A negative charge speeds up moving toward higher potential. The sign of q decides everything, so write it explicitly.

In a uniform field the force qE is constant, so the acceleration $a = qE/m$ is constant and the kinematics from AP Physics 1 apply directly. A charge entering the field between parallel plates perpendicular to the field follows a parabolic path, exactly like projectile motion with gravity replaced by qE/m .

The **electron volt** is a convenient energy unit: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$, the energy an elementary charge gains crossing 1 V . Worked example: an electron starts from rest and accelerates through 200 V . Its kinetic energy is $200 \text{ eV} = (200)(1.60 \times 10^{-19}) = 3.20 \times 10^{-17} \text{ J}$. Setting $\frac{1}{2}mv^2$ equal to that, with $m = 9.11 \times 10^{-31} \text{ kg}$, gives $v = \sqrt{(2 \times 3.20 \times 10^{-17} / 9.11 \times 10^{-31})} = 8.4 \times 10^6 \text{ m/s}$.

Confusions That Cost Points

PAIR	HOW TO KEEP THEM STRAIGHT
Electric field E vs electric potential V	E is a vector in N/C and adds by vector superposition. V is a scalar in volts and adds by ordinary arithmetic. They are different quantities with different units and different addition rules.
Field direction vs force direction	The field points in the direction a positive charge would be pushed. A negative charge is pushed opposite the field. Always check the sign of the charge before drawing a force arrow.
$V = 0$ vs $E = 0$	Zero potential does not imply zero field. Between equal and opposite charges, the potentials cancel while the fields add. Judge each quantity on its own.
Series vs parallel capacitors	Parallel adds directly ($C_{eq} = \Sigma C$). Series adds reciprocally ($1/C_{eq} = \Sigma 1/C$). This is the opposite of the resistor rules. Series equivalent is always smaller than the smallest capacitor.
$C = Q/\Delta V$ vs what sets C	The ratio defines capacitance, but geometry sets it. Doubling the voltage doubles the charge and leaves C unchanged. Only A , d , or the dielectric change C .
Charging by conduction vs induction	Conduction needs contact and leaves the same sign. Induction needs no contact with the charged object, uses grounding, and leaves the opposite sign. Grounding must be broken before the inducing charge is removed.
Work by the field vs ΔU	$W_{field} = -\Delta U$. Positive work by the field means potential energy went down. A positive charge moving to lower V and a negative charge moving to higher V both gain kinetic energy.
Isolated vs battery-connected capacitor	Isolated means Q is fixed. Battery-connected means ΔV is fixed. Inserting a dielectric or changing the geometry does opposite things to the energy in the two cases. Name the case first.

Practice Questions

Original questions written for this guide in the style of the AP exam. Answers and explanations are on the next page, so complete the questions before checking them.

1. Two point charges, $+2.0\ \mu\text{C}$ and $-3.0\ \mu\text{C}$, are held $0.40\ \text{m}$ apart. What is the magnitude of the electric force that each exerts on the other, and is it attractive or repulsive?

1. $0.34\ \text{N}$, repulsive
2. $0.034\ \text{N}$, attractive
3. $0.34\ \text{N}$, attractive
4. $0.13\ \text{N}$, attractive

2. A neutral metal sphere on an insulating stand is brought near a positively charged rod without touching it. While the rod is held in place, the sphere is momentarily grounded, the ground connection is removed, and then the rod is taken away. What is the net charge on the sphere at the end?

1. Positive
2. Negative
3. Zero
4. It cannot be determined without knowing the charge on the rod

3. Two identical $+1.0\ \mu\text{C}$ charges are fixed $1.0\ \text{m}$ apart. What is the electric field at the midpoint between them?

1. $0\ \text{N/C}$
2. $3.6 \times 10^4\ \text{N/C}$, pointing toward one of the charges
3. $7.2 \times 10^4\ \text{N/C}$, pointing away from both charges
4. $9.0 \times 10^3\ \text{N/C}$, pointing perpendicular to the line joining the charges

4. Point P lies exactly midway between a $+4.0\ \text{nC}$ charge and a $-4.0\ \text{nC}$ charge that are $0.20\ \text{m}$ apart. Which of the following is true at point P?

1. The electric potential is nonzero and the electric field is zero
2. The electric potential is nonzero and the electric field is nonzero
3. The electric potential is zero and the electric field is zero
4. The electric potential is zero and the electric field is nonzero

- 5.** An electron starts from rest and is accelerated through a potential difference of 200 V. What is the speed of the electron afterward? (electron mass = 9.11×10^{-31} kg)
1. 8.4×10^6 m/s
 2. 5.9×10^6 m/s
 3. 4.2×10^6 m/s
 4. 0 m/s, because the electron moves toward higher potential and therefore loses energy
- 6.** A 2.0 μF capacitor and a 4.0 μF capacitor are connected in series. What is the equivalent capacitance of the combination?
1. 6.0 μF
 2. 1.3 μF
 3. 3.0 μF
 4. 0.75 μF
- 7.** An isolated parallel-plate capacitor (not connected to a battery) has its plate separation doubled. What happens to its capacitance C and the voltage ΔV across it?
1. C is halved and ΔV stays the same
 2. C is doubled and ΔV is halved
 3. C is halved and ΔV is doubled
 4. C stays the same and ΔV is doubled
- 8.** A 4.0 μF capacitor is charged to a potential difference of 12 V. How much energy is stored in the capacitor?
1. 5.8×10^{-4} J
 2. 2.4×10^{-5} J
 3. 2.9×10^{-3} J
 4. 2.9×10^{-4} J

Answer Key

- 1. C.** $F = k|q_1q_2|/r^2 = (8.99 \times 10^9)(2.0 \times 10^{-6})(3.0 \times 10^{-6})/(0.40)^2 = 0.34 \text{ N}$. Opposite signs attract. D forgot to square the separation (divided by 0.40 instead of 0.16). A got the magnitude right but the direction wrong: opposite charges attract, never repel. B slipped a decimal place.
- 2. B.** The rod attracts electrons to the near side of the sphere. Grounding lets extra electrons flow up from the ground, and removing the ground before the rod traps them there, so the sphere ends negative. A is wrong because protons do not move in a metal; only electrons flow. C confuses induction with polarization of an ungrounded object, which leaves the net charge at zero. D is wrong because the sign of the result follows from the process alone; the rod's exact charge is irrelevant.
- 3. A.** Each charge produces $E = kQ/r^2 = (8.99 \times 10^9)(1.0 \times 10^{-6})/(0.50)^2 = 3.6 \times 10^4 \text{ N/C}$ at the midpoint, but the two vectors point in opposite directions (each points away from its own source charge), so they cancel to zero. B computed only one charge's contribution and stopped. C added the two magnitudes as scalars, ignoring that fields are vectors. D used the full 1.0 m separation as r instead of the 0.50 m distance from each charge to the midpoint.
- 4. D.** Potential adds as a scalar: $V = k(+4.0 \text{ nC})/0.10 + k(-4.0 \text{ nC})/0.10 = 0$. The fields are vectors and both point the same way at P (away from the positive charge and toward the negative charge, i.e., from the positive charge toward the negative one), so they add to a nonzero net field of about $7.2 \times 10^3 \text{ N/C}$. C assumes zero potential means zero field. A assumes the fields cancel as if the charges had the same sign. B fails to do the scalar addition for V .
- 5. A.** The electron gains $KE = q\Delta V = (1.60 \times 10^{-19} \text{ C})(200 \text{ V}) = 3.20 \times 10^{-17} \text{ J}$. From $\frac{1}{2}mv^2 = 3.20 \times 10^{-17} \text{ J}$, $v = \sqrt{(2 \times 3.20 \times 10^{-17} / 9.11 \times 10^{-31})} = 8.4 \times 10^6 \text{ m/s}$. B is the speed for 100 V, from halving the potential difference. C comes from an extra factor of 2 in the denominator, a slip in handling the one-half in $\frac{1}{2}mv^2$. D confuses potential with potential energy: the electron moves toward higher V , which for a negative charge means lower potential energy and therefore a gain, not a loss, of kinetic energy.
- 6. B.** Series capacitors add reciprocally: $1/C_{\text{eq}} = 1/2.0 + 1/4.0 = 0.75 \mu\text{F}^{-1}$, so $C_{\text{eq}} = 1/0.75 = 1.3 \mu\text{F}$. A applied the parallel rule to a series combination. C averaged the two capacitances, which is not a combination rule at all. D computed the reciprocal sum 0.75 and forgot to invert it back, which is the most common arithmetic slip on this problem type.
- 7. C.** Isolated means Q is fixed. $C = \epsilon_0 A/d$, so doubling d halves C . With Q fixed, $\Delta V = Q/C$ doubles. A is wrong because the voltage cannot stay the same when C changes with Q fixed. B has the capacitance change backwards and treats the capacitor as battery-connected. D assumes capacitance depends on the charge, which it does not; C is set by geometry alone.
- 8. D.** $U = \frac{1}{2}C(\Delta V)^2 = \frac{1}{2}(4.0 \times 10^{-6})(12)^2 = 2.9 \times 10^{-4} \text{ J}$. A dropped the one-half, computing $B(\Delta V)^2$. B used ΔV instead of $(\Delta V)^2$. C slipped a decimal place, a factor of 10 too large.

When you check your answers, note which distinction each miss came from. Make a flashcard for that distinction and drill it spaced out over the next few days instead of rereading the whole section. If you missed one of these questions, the same distinction is worth practicing again in Rycal, where the Electric Force, Field, and Potential deck has flashcards for it and more practice questions use the same kinds of traps.

One-Page Recall Check

Say each answer out loud before you look back, and mark the ones you cannot finish. Anything you cannot say out loud yet belongs in your flashcard deck. In Rycal, add those items to the Electric Force, Field, and Potential deck and let spaced review bring them back over the next few days.

- State the two kinds of charge, what a neutral object is, and the value of the elementary charge.
- State conservation of charge and explain what moves when an object is charged.
- Explain the difference between a conductor and an insulator, and state where excess charge sits on a conductor.
- Write Coulomb's law, define every symbol, and compute the force between two $1.0\ \mu\text{C}$ charges $0.50\ \text{m}$ apart.
- Describe charging by conduction and charging by induction, including the role of grounding and the order of steps.
- Explain polarization and why a charged object attracts a neutral insulator.
- Define the electric field, give its units, and state the field of a point charge with its direction rule.
- List the field line rules and explain what superposition means for fields.
- Explain why the force on a negative charge points opposite the field direction.
- Write the potential energy of two point charges, and relate ΔU to $q\Delta V$ and to the work done by the field.
- Define electric potential, give its units, and explain why it adds as a scalar.
- Describe equipotential surfaces and their geometric relationship to field lines.
- Explain why $V = 0$ at a point does not imply $E = 0$ there, with an example.
- Define capacitance, write the parallel-plate formula, and compute C for $A = 0.020\ \text{m}^2$ and $d = 1.0\ \text{mm}$.
- State the series and parallel combination rules for capacitors and say how they differ from the resistor rules.
- Write the three forms of the stored energy and compute the energy in a $4.0\ \mu\text{F}$ capacitor at $12\ \text{V}$.
- Explain what a dielectric does, and contrast the isolated and battery-connected cases.
- Describe the motion of a charge released in a uniform field, and define the electron volt.

Where to go next. Turn every missed item above into flashcards and drill them spaced out over several days rather than in one sitting. In Rycal, open the Electric Force, Field, and Potential deck under AP Physics 2. The deck covers the terms in this guide, and its practice questions target the same traps named here. If you have a test date, add it in the Test Planner. You can also start your next review with a Brain Dump, then check what you missed against this guide.

Key terms for this unit

Electric charge, Elementary charge, Conservation of charge, Conductor, Insulator, Charging by friction, Charging by conduction, Charging by induction, Grounding, Polarization, Coulomb's law, Electric field, Electric field lines, Superposition, Electric potential energy, Electric potential, Volt, Equipotential surface, Capacitance, Farad, Parallel-plate capacitor, Permittivity of free space, Dielectric, Dielectric constant, Series combination, Parallel combination, Electron volt, Test charge.

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