The Simple AP® Physics 2 Unit 10 Cheat Sheet

10.1 Charge & Coulomb's Law

Charge Basics

Charge: + or −; smallest unit e = 1.6×10^{-19} C.
Electron −e, proton +e, neutron 0.
Point charge: its size doesn't matter.

Coulomb's Law: Ratios

$F \propto q_1q_2/r^2$: bigger charges → bigger F; farther apart → a much smaller F (inverse square).

Change	New F
$q_1 \times 2$	2F
$r \times 2$	F/4
$r \times 1/3$	9F
both $q \times 2$, $r \times 2$	F (same)

Like charges repel; opposite charges attract. Use $|q|$ for the size, then draw the direction.
Newton's 3rd law: both charges feel the SAME size force, even if one charge is bigger.
Different masses → different a = F/m.

Net Force

Superposition: find each force alone → add them as vectors using x & y components.
Symmetry: equal charges at equal distances → some force components cancel out.
Zero-force spot: between 2 like charges, closer to the smaller one; never between opposites.
Units: k = 9.0×10^{9} N·m²/C²; μC → $\times10^{-6}$ C.

⚠ Don't use signs to find direction. Use magnitudes, then attract/repel.

✓ State the pattern first: "F ∝ 1/r², so 3× r → F/9."

10.1 Electric vs. Gravity; Materials

Electric vs. Gravity

	Gravity	Electric
Source	Mass	Charge
Direction	Attract	Both ways
Distance	$\propto 1/r^2$	$\propto 1/r^2$
Strength	Very weak	Very strong
Wins at	Planets	Atoms

Gravity rules space: big objects are ~neutral, so their electric forces cancel; mass never cancels.
Tiny particles: electric force ≫ gravity → ignore gravity unless the problem says otherwise.
Two protons: electric force ≈ 10^{36} × gravity.
Contact forces (normal, friction) are really many tiny electric forces between the surface atoms.

Conductors vs. Insulators

Conductor (metals): electrons move freely.
Insulator (glass, plastic): charges stay put.
Polarization: a nearby charge shifts electrons → one side −, other +; net charge still 0.

Permittivity

Permittivity: how easily a material polarizes. Free space value: ε_0; $k = 1/(4\pi\varepsilon_0)$ relates them.
Dielectric constant κ ≥ 1: a polarized material weakens the field inside it by a factor of κ.

⚠ Electric force is stronger, but neutral objects feel ~no net electric force at a distance.

✓ Both forces ∝ 1/r², so double r → each force ÷ 4; their ratio stays exactly the same.

10.2 Charging & Conservation

Conservation of Charge

Net charge stays the same unless charge moves into or out of the system (conservation).
Electrons move, not protons. Gain e^- → negative; lose e^- → object becomes positive.
Quantized: q = ne, where n = the whole number of electrons moved on or off of it.

3 Ways to Charge

Method	Touch?	Sign
Friction	Rub	Opposite
Conduction	Yes	Same
Induction	No	Opposite

Conduction: identical metal spheres touch → share charge equally: $(q_1+q_2)/2$.
Example: +6 nC touches −2 nC → each +2 nC.
Induction: rod near → ground far side → cut ground → remove rod → opposite charge left.
Grounding: connect to Earth → electrons flow to or from it until the object is ~neutral again.

Induced Charge Separation

Neutral objects are attracted: near side gets opposite charge, and it's closer.
Electroscope: leaves spread when charged b/c the like charges on both leaves repel.

⚠ Attraction doesn't prove an object is charged. Only repulsion proves that it is.

✓ Track + and − on each object at every step; the system's total charge stays the same.

10.3 Electric Fields

Definition

$E = F_E/q$: the force per unit charge on a small positive test charge. Units: N/C = V/m.
E comes from the source charges; the test charge doesn't change the field it measures.
Direction: away from +, toward −. **+ charge pushed along E; − charge pushed opposite E.**
Point charge: $E = k|q|/r^2$ → double r → E/4.
Example: +2 μC at 0.3 m → $E = 2\times10^{5}$ N/C, pointing directly away from the charge.

Several Charges

Net E = vector sum of each field. Midpoint of 2 equal like charges: E = 0 (they cancel).
Midpoint of +q & −q: E ≠ 0; points toward −q.
Ranking E: a bigger source charge or a closer point → a stronger electric field ($E \propto |q|/r^2$).

Field Diagrams

Feature	Meaning
Lines start/end	Start +, end −
Lines close together	Strong E
Lines never cross	One E per point
Parallel, even lines	Uniform E

Suspended charge: qE = mg → floats.

⚠ Field lines aren't paths. They show the force direction on a + charge, not motion.

✓ Draw each E vector w/ its tail at the point; a longer arrow = a stronger field at that point.

10.3 Conductors & Insulators in Fields

Conductors at Equilibrium

E = 0 inside: free electrons shift until the field they create cancels the outside field there.
Extra charge sits on the surface.
E ⊥ surface just outside the conductor.
Whole conductor is at one potential (same V everywhere, inside & on the surface).
Charged sphere: outside, it acts like a point charge Q located at its center ($E = kQ/r^2$).
Shielding: E = 0 inside a closed metal box (e.g., people in a car struck by lightning stay safe).
Hollow charged sphere: E = 0 inside.
Grounded conductor near +q: near side turns −; the far-side charge flows off to Earth.

Insulators

Extra charge spreads through the inside & surface; E inside can be ≠ 0 (it stays put).
Insulators polarize too: their molecules stretch → they're still attracted to nearby charges.

Compare

	Conductor	Insulator
Charge moves?	Freely	Barely
Extra charge	Surface	Throughout
E inside	0	Can be ≠ 0

⚠ E = 0 inside a conductor ≠ V = 0. V is constant inside, the same as the surface V.

✓ Sketch: charge on the surface, field lines ⊥ to it outside, & none inside the metal.

10.4–10.5 Potential Energy & Potential

Electric Potential Energy (U_E)

$U_E = kq_1q_2/r$, U = 0 at ∞. **Keep the signs.**
U > 0: like charges (they'd fly apart). U < 0: opposite charges (bound together, need work).
Many charges: add U for every pair. 3 charges → 3 pairs; 4 charges → 6 pairs in total.
Example: +1 μC & −1 μC, 0.1 m apart → U = −0.09 J (a bound pair; +0.09 J to separate).

Electric Potential (V)

V = U/q: potential energy per unit charge at a point in space. Units: volts (1 V = 1 J/C).
ΔV = ΔU/q: energy change per charge between 2 points. Batteries maintain a fixed ΔV.
Point charge: V = kq/r → double r → V/2.
V vs. r graph: +q → positive, ∝ 1/r, → 0 far away.
Add V as plain numbers (w/ signs); no x & y parts.

Compare

Qty	Vector?	Formula	r × 2
F_E	Yes	kq_1q_2/r^2	÷ 4
E	Yes	kq/r^2	÷ 4
U_E	No	kq_1q_2/r	÷ 2
V	No	kq/r	÷ 2

Midpoint of +q & −q: V = 0 but E ≠ 0.
Midpoint of +q & +q: E = 0 but V ≠ 0.

⚠ Add E as vectors, V as signed numbers.

✓ Negative total U = bound system: outside work is needed to pull all the charges apart.

10.5 Equipotentials & the E–V Link

E from V

$|E| = |\Delta V|/\Delta r$: V changes fast → strong E.
E points toward lower V ("downhill").
Uniform field: ΔV = Ed along the field. E.g., 200 V/m × 0.05 m = 10 V between the points.
Work: $W_{field} = -q\Delta V$; outside work = $+q\Delta V$.

Equipotential Lines

Equipotential: a line or surface of points at the same V. Always ⊥ to the electric field lines.
Close lines → strong E. Point charge → circles that spread out farther away from the charge.
Uniform field: evenly spaced, parallel equipotentials, all ⊥ to the E field lines.
Dipole (+q, −q): the V = 0 line runs halfway between them, ⊥ to the line joining them.
No work to move a charge along an equipotential.
Convert: field map → draw lines ⊥ to arrows; equipotential map → draw E ⊥, high V → low V.

Which Way Do Charges Move?

Charge	Moves to	U_E
+ (free)	Lower V	Decreases
− (free)	Higher V	Decreases

Touching conductors: electrons move until both are at the same V (not the same charge).
Electron volt: 1 eV = 1.6×10^{-19} J.

⚠ Electrons move to higher V but still lose potential energy b/c their q < 0.

✓ Draw equipotentials ⊥ to field lines, always closer together where E is strongest.

10.6–10.7 Capacitors & Energy

Parallel-Plate Capacitor

$C = Q/\Delta V$; $C = \kappa\varepsilon_0 A/d$: set by the plate area, gap & material only, not set by Q or ΔV.
Uniform E between the plates (ignore edges): $E = \Delta V/d$, from the + plate to the − plate.
Energy: $U_C = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2$.
Dielectric between plates → C × κ.
Example: 4 μF at 12 V → Q = 48 μC.
Q vs. ΔV graph: straight line; slope = C; area = U_C.

Battery On vs. Off

Change	Battery on	Isolated
d × 2	C, Q, E ÷ 2	ΔV × 2; E same
Add κ	C, Q × κ	ΔV, E ÷ κ

Charges Moving in Fields

$\Delta U = q\Delta V$; energy conserved → $\Delta K = -q\Delta V$.
From rest: $\frac{1}{2}mv^2 = |q|\Delta V$ → solve for v.
Proton across 1,000 V: gains 1.6×10^{-16} J of KE.
Between the plates: constant force → a curved, parabolic path like a thrown ball's path.
Electron vs. proton between the same plates: same size force, opposite directions; the lighter electron accelerates ~1,840× more than the proton.
Pulling plates apart (isolated): plates attract → it takes work → U_C ↑ by that amount.
Lab: plot C vs. 1/d → straight line; slope = $\kappa\varepsilon_0 A$.

⚠ C doesn't depend on Q or ΔV. A bigger battery puts more Q on the plates, not more C.

✓ First ask: is the battery still connected?