



Parallel Plate Capacitor

A **parallel plate capacitor** consists of two large, flat, parallel conducting plates separated by a small distance. One plate holds a charge $+Q$, the other $-Q$. The plates each have area A and are separated by distance d .

Physical Principle

A capacitor stores electrical energy in the electric field between its plates. Bringing equal and opposite charges close together, separated by an insulating gap, requires work, which is stored as energy.

Derivation of Capacitance

Let's step through how we derive the formula for capacitance of a parallel plate capacitor:

1. Surface Charge Density

The amount of charge per unit area on either plate is:

$$\sigma = \frac{Q}{A}$$

where Q is the charge and A the area.

2. Electric Field Between Plates

The electric field E between two infinite parallel plates (ignoring edge effects) filled with vacuum (or air) is:

$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

where ϵ_0 is the **permittivity of free space** (a fundamental constant).

3. Potential Difference

The potential difference V across the plates is given by:

$$V = E \cdot d = \frac{Qd}{\epsilon_0 A}$$

where d is the separation between plates.

4. Capacitance Formula

Capacitance is defined by:

$$C = \frac{Q}{V}$$

Substitute the expression for V from above:

$$C = \frac{Q}{\frac{Qd}{\epsilon_0 A}} = \frac{\epsilon_0 A}{d}$$

Final formula:

$$C = \frac{\epsilon_0 A}{d}$$

- C : Capacitance (in Farads)
- A : Area of each plate (in square meters)
- d : Separation between plates (in meters)
- ϵ_0 : Permittivity of free space $8.85 \times 10^{-12} \text{ F/m}$

Checking Understanding

Can you explain why increasing the plate area A increases capacitance, and why increasing the separation d decreases capacitance?

Quick Recap (Mnemonic)

- **C is directly proportional to A:** Bigger plates, more capacitance.
- **C is inversely proportional to d:** Closer plates, more capacitance.

If you want to see what happens when a dielectric fills the gap, or to practice with a sample calculation, let me know! Also, if you tell me your course or grade level, I can tailor the explanation further.

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Class 12th Physics | Electrostatic Potential & Capacitance ↪ Super One Shot | By Ashu Sir -
YouTube why did he used $\sigma = \epsilon_0 E$.

Ashu Sir used $E = \sigma / 2\epsilon_0$ because this is the formula for the electric field produced by a single infinite charged plane (sheet) with uniform surface charge density σ in free space or air.

Explanation

- When you have just *one* infinite sheet of charge, the electric field it produces (on either side of the sheet) is given by:

$$E = \frac{\sigma}{2\epsilon_0}$$

where σ is the surface charge density and ϵ_0 is the permittivity of free space.^[15]

- The derivation comes from Gauss's Law, applied to a "pillbox" Gaussian surface that straddles the plane. The flux through the two flat surfaces gives $2EA$ (since field comes out both sides), and the total enclosed charge is σA . Solving, you get the above field per side.

- Why only half?**

The field from a single sheet goes outwards on both sides, so each side gets half the total field lines. If you had two plates (like in a parallel plate capacitor), the total field inside would be the *sum* of the fields due to both plates, hence $E = \sigma/\epsilon_0$ between them.

Summary Table

Situation	Field formula
Single infinite sheet	$E = \frac{\sigma}{2\epsilon_0}$
Between two oppositely charged plates	$E = \frac{\sigma}{\epsilon_0}$

This formula is foundational for explaining how the field is calculated in steps for the parallel plate capacitor derivation: first individual plate, then combined effect inside the capacitor.^[15]

If you want more details or diagrams from the exact timestamp in Ashu Sir's video, let me know!

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still don't understand what the 2 is there for

The "2" in $E = \frac{\sigma}{2\epsilon_0}$ comes from the fact that the electric field created by an infinite sheet of charge is *evenly shared on both sides* of the sheet, because of symmetry.

Step-by-Step Reason

- When you apply **Gauss's Law** to an infinite plane, you usually pick a cylindrical "pillbox" Gaussian surface cutting through the sheet. The field points perpendicularly away from both sides of the sheet.^{[18] [19]}
- The total electric flux is the sum of the field going out through **both faces** of the pillbox. If each face has area A , the total flux is:

$$\text{Total flux} = E \times A + E \times A = 2EA$$

- Gauss's law says:

$$\text{Total flux} = \frac{\text{enclosed charge}}{\epsilon_0} = \frac{\sigma A}{\epsilon_0}$$

- Therefore:

$$2EA = \frac{\sigma A}{\epsilon_0}$$

$$E = \frac{\sigma}{2\epsilon_0}$$

- **Physical meaning:** The field produced by an infinite charged sheet is divided equally; half of it goes to one side, half to the other. That's why you see a "2" in the denominator.

Summary: The "2" means the field lines go out on both sides of the sheet, so each side gets only half of the total field that the charge creates. [\[20\]](#) [\[19\]](#) [\[18\]](#)

If you put two such sheets with charges (like in a capacitor), the fields add up in the region between them, resulting in $E = \sigma/\epsilon_0$ there. For a single sheet, each side gets $\sigma/2\epsilon_0$.

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whats flux

Electric flux is a measure of how much electric field "flows" through a given surface area. Imagine electric field lines passing through a surface: the electric flux quantifies the total number of these lines crossing that area.

Mathematically, for a uniform electric field \mathbf{E} passing through a flat surface of area A , the electric flux Φ is given by:

$$\Phi = \mathbf{E} \cdot \mathbf{A} = EA \cos \theta$$

where:

- E is the magnitude of the electric field,
- A is the area of the surface,
- θ is the angle between the electric field direction and the perpendicular (normal) to the surface.

If the surface is perpendicular to the field ($\theta = 0^\circ$), then $\cos \theta = 1$ and flux is maximized. If the surface is parallel to the field ($\theta = 90^\circ$), no field lines go through the surface so flux is zero.

Electric flux helps us understand how electric fields interact with surfaces and is a key concept in Gauss's Law, which relates flux through closed surfaces to the charge enclosed. It is a scalar quantity measured in units of Newton-meter squared per Coulomb ($N \cdot m^2/C$). [\[28\]](#) [\[29\]](#) [\[30\]](#) [\[31\]](#)

In simple terms, it tells how much of the electric field "passes through" or "pierces" a surface—a bit like how much water flows through a net or how much sunlight hits a solar panel.

This concept is fundamental to calculating electric fields of charge distributions, like in the parallel plate capacitor derivation discussed earlier.

combination of capacitors series combination

Class 12th Physics | Electrostatic Potential & Capacitance ↪ Super One Shot | By Ashu Sir - YouTube

A **series combination of capacitors** is when capacitors are connected end-to-end such that the same charge flows through each capacitor, but the voltage across each may be different. Ashu Sir explains and derives the formula for the equivalent capacitance for capacitors in series as follows:

Key Points for Series Combination

- When \$ C_1, C_2, C_3 \$ are in series, they are connected one after another, so the same charge (\$ Q \$) passes through each, but the voltages add up:

$$V_{\text{net}} = V_1 + V_2 + V_3$$

- Using \$ Q = CV \$ for each capacitor:

$$V_1 = Q/C_1, \quad V_2 = Q/C_2, \quad V_3 = Q/C_3$$

- The equivalent capacitance (\$ C_{\text{net}} \$) is such that:

$$V_{\text{net}} = Q/C_{\text{net}}$$

- Substitute and add voltages:

$$Q/C_{\text{net}} = Q/C_1 + Q/C_2 + Q/C_3$$

$$\frac{1}{C_{\text{net}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Series Combination Formula

$$\boxed{\frac{1}{C_{\text{net}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots}$$

- The equivalent capacitance in series is **always less than** the smallest individual capacitor in the series. [38]

Quick Recap

- **Charge is same** on all capacitors in series.
- **Voltages add up:** total voltage across the series equals the sum of voltages across each capacitor.
- The formula is **opposite to resistors in series** (for resistors, you just add the resistances).

Example (from Ashu Sir's notes)

If $C_1 = 6 \mu F$ and $C_2 = 3 \mu F$ are in series:

$$\frac{1}{C_{\text{net}}} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{3}{6} = \frac{1}{2}$$

So,

$$C_{\text{net}} = 2 \mu F$$

[38]

Let me know if you need the parallel formula or a visual explanation!

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now parallel combination

A **parallel combination of capacitors** is when the capacitors are connected so that all their positive plates are joined at one point, and all their negative plates at another, meaning each capacitor is directly across the same voltage source.

Key Points for Parallel Combination

- In this arrangement, **the voltage across each capacitor is the same** as the voltage of the source.
- The **total charge** stored in the circuit is the sum of the charges stored on each capacitor.

Derivation and Formula

Let C_1, C_2, C_3 be the capacitors in parallel, all connected to a voltage V :

- Charge on each: $Q_1 = C_1 V$, $Q_2 = C_2 V$, $Q_3 = C_3 V$.
- Total charge supplied by the battery: $Q = Q_1 + Q_2 + Q_3$
- Equivalent capacitance C_{eq} is defined by $Q = C_{\text{eq}} V$.

So, substituting:

$$C_{\text{eq}} V = C_1 V + C_2 V + C_3 V$$

$$C_{\text{eq}} = C_1 + C_2 + C_3$$

General formula:

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \dots$$

Recap Table

Series Combination	Parallel Combination
$\frac{1}{C_{\text{net}}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$	$C_{\text{eq}} = C_1 + C_2 + \dots$
Charge same	Voltage same
Voltage divides	Charge divides

- Equivalent capacitance in parallel is always greater than the largest value in the group.
[\[40\]](#) [\[41\]](#) [\[42\]](#)

Let me know if you need worked examples or circuit diagrams for clarity!

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now parallel combination Class 12th Physics | Electrostatic Potential & Capacitance ↪ Super One Shot | By Ashu Sir - YouTube

For the **parallel combination of capacitors** (as explained by Ashu Sir in the referenced video):

Parallel Combination – Key Points

- In the parallel arrangement, all capacitors are connected such that both of their terminals are connected to the same two points, meaning each capacitor gets the **same voltage** across it.[\[50\]](#)
- The **total charge** stored by the network is the sum of the charges stored on each capacitor.

Formula Derivation

- If you have capacitors C_1 , C_2 , and C_3 connected in parallel to a voltage V ...
- Charge on each: $Q_1 = C_1 V$, $Q_2 = C_2 V$, $Q_3 = C_3 V$.
- Total charge supplied by the battery/source is $Q = Q_1 + Q_2 + Q_3$.
- The equivalent/single capacitance C_{eq} is such that $Q = C_{\text{eq}} V$.
- Substitute the values: $C_{\text{eq}} V = (C_1 + C_2 + C_3) V$ so,
- $C_{\text{eq}} = C_1 + C_2 + C_3$

Final Formula

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \dots$$

- This means in parallel, you **just add** all the capacitances.[\[50\]](#)
- The **voltage** across every capacitor is the same.

- The **charge** divides between the capacitors based on their capacitance values.

Fast Facts (from Ashu Sir's revision):

- Parallel: C_{eq} **increases** (sum); **voltage is equal** on all; **charges add up**.
- Series: $1/C_{\text{eq}}$ (reciprocal sum); **charge is equal** for all; **voltages add up**.

Ashu Sir also warns not to confuse the formula with series and resistors—here, it's the same as resistors-in-parallel, but for capacitance you *add directly* in parallel.^[50]

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Energy Stored in a Capacitor

When you charge a capacitor by connecting it to a voltage source, work is done to move charge from one plate to the other. This work gets stored in the capacitor as **electrostatic potential energy**.

Why is Energy Stored?

To move small bits of charge, you have to work against the electric field that grows across the plates as more charge builds up. This work accumulates as stored energy.

Derivation (Step by Step)

- Let a capacitor have capacitance C , and be charged up to a final charge Q and voltage V .
- To move a small amount of charge dq onto the capacitor when the potential difference is v at that moment, the work done is:

$$dW = v \, dq$$

- Since $q = 0$ at the start and $q = Q$ at the end, but voltage is related by $v = q/C$, integrate:

$$W = \int_0^Q \frac{q}{C} dq = \frac{1}{C} \int_0^Q q \, dq = \frac{1}{C} \cdot \frac{Q^2}{2} = \frac{Q^2}{2C}$$

- This work is the energy stored in the capacitor:

$$U = \frac{1}{2} CV^2 = \frac{1}{2} QV = \frac{Q^2}{2C}$$

Here:

- U = Energy stored in the capacitor (in joules)
- C = Capacitance (in farads)
- V = Voltage across capacitor (in volts)
- Q = Total charge on one plate (in coulombs)

All Usable Forms

You can use any of these equivalent forms depending on which values you know:

- $U = \frac{1}{2}CV^2$
- $U = \frac{1}{2}QV$
- $U = \frac{Q^2}{2C}$

Physically:

- This energy is stored in the **electric field** between the plates. If you disconnect the capacitor from the battery, it keeps the energy until it is discharged.

To check your understanding: Why do we use $\frac{1}{2}$ in these formulas? What would happen if you doubled the voltage across a capacitor—how would the stored energy change?

If you'd like, I can guide you through some practice questions or show a sample calculation!

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from where did the 2 came

The factor of $\frac{1}{2}$ in the energy formula for a capacitor comes from the fact that, as you charge a capacitor, the voltage across its plates increases gradually from \$ 0 \$ to \$ V \$, not instantly to \$ V \$.

Step-by-Step Reason

- At the start, with no charge, the voltage across the capacitor is \$ 0 \$.
- As you add charge \$ dq \$, the voltage increases as \$ v = q/C \$.
- The work done to bring each small charge \$ dq \$ is not always at the full battery voltage \$ V \$, but at whatever voltage is already across the plates.
- The **average voltage** over the charging process is \$ \frac{V}{2} \$ (since it goes from 0 to \$ V \$).
- Therefore, the total work done (energy stored) is:

$$U = Q \times \text{average voltage} = Q \times \frac{V}{2} = \frac{1}{2}QV$$

- Substituting for \$ Q \$ or \$ V \$ using \$ Q = CV \$ gives the other equivalent forms with the same \$ \frac{1}{2} \$ factor.

Physical Meaning

The \$ \frac{1}{2} \$ appears because, when adding charge, not every bit of charge "feels" the full voltage. The very first bit of charge sees zero voltage; the last one sees the full voltage \$ V \$; overall, the average is \$ V/2 \$.

Summary:

The "2" in the denominator comes from averaging the voltage from 0 to V during the charging process, so the energy is actually $\frac{1}{2} CV^2$, not CV^2 .^[54] [55]

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Energy Stored per Unit Volume in a Parallel Plate Capacitor

Let's break down this important concept step by step!

1. Energy Stored in a Capacitor

For a capacitor charged to voltage V , total energy stored:

$$U = \frac{1}{2} CV^2$$

For a parallel plate capacitor (area A , separation d):

$$C = \frac{\epsilon_0 A}{d}$$

So,

$$U = \frac{1}{2} \frac{\epsilon_0 A}{d} V^2$$

2. Volume of the Space Between Plates

Total volume between plates:

$$V_{\text{ol}} = A \times d$$

3. Energy Stored per Unit Volume

Energy density (energy per unit volume):

$$\text{Energy density} = \frac{U}{Ad}$$

Substitute U and Ad :

$$\text{Energy density} = \frac{1}{2} \frac{\epsilon_0 A}{d} V^2 \div (Ad) = \frac{1}{2} \epsilon_0 \frac{V^2}{d^2}$$

But, $\frac{V}{d}$ is the electric field E between the plates:

$$E = \frac{V}{d}$$

So,

$$\text{Energy per unit volume} = \frac{1}{2} \epsilon_0 E^2$$

4. Physical Meaning

This means the energy is actually stored in the **electric field** between the plates, not just the plates themselves.

- ϵ_0 = permittivity of free space
- E = electric field between plates (V/d)

Check Your Understanding

Can you substitute V/d for E in the general capacitor energy formula and get the energy density expression? Try writing each step to reinforce the concept.

If you want a sample calculation or clarification about the meaning, let me know! Or, if you share your grade level, I'll adjust my explanation for you.

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