



explane energy stored per unit volume in a parallel plate capacitor Class 12th Physics | Electrostatic Potential & Capacitance ✂ Super One Shot | By Ashu Sir - YouTube

The energy stored per unit volume in a parallel plate capacitor is given by the formula $\frac{1}{2}\epsilon_0 E^2$, where ϵ_0 is the permittivity of free space and E is the electric field between the plates.^[1]

Energy Stored in a Capacitor

When a capacitor is charged, it stores energy in the electric field created between the plates. The total energy stored (U) in a capacitor can be written in three equivalent ways:

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

Where:

- C is capacitance,
- V is potential difference,
- Q is the charge.

For a parallel plate capacitor, the capacitance is $C = \epsilon_0 \frac{A}{d}$ with area A and plate separation d .^[1]

Derivation for Energy Per Unit Volume

First, recall that the electric field between the plates is $E = \frac{V}{d}$. The volume between the plates is Ad , so energy per unit volume is:

$$\text{Energy per unit volume} = \frac{U}{Ad}$$

Substitute $U = \frac{1}{2}CV^2$ and $C = \epsilon_0 \frac{A}{d}$:

$$U = \frac{1}{2} \left(\epsilon_0 \frac{A}{d} \right) V^2$$

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

But since $E = \frac{V}{d}$, we get:

$$\frac{U}{Ad} = \frac{1}{2} \epsilon_0 E^2$$

Physical Meaning

- This formula expresses that the energy is not just stored overall, but actually distributed in the electric field filling the space between the plates.
- The energy density increases with a stronger electric field.
- This result also applies generally to uniform electric fields in free space, not just to parallel plate capacitors.^[1]

Final Formula

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

Where ϵ_0 is approximately 8.85×10^{-12} F/m, and E is measured in volts per meter.^[1]

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from where $c = e.a/d$

The formula $C = \epsilon_0 \frac{A}{d}$ for the capacitance of a parallel plate capacitor comes from the relationship between electric field, potential difference, and the definition of capacitance. When two large plates of area A are separated by a distance d , the capacitance is derived using these steps:

- The charge on each plate is Q and the plates have opposite signs.
- The electric field between the plates is $E = \frac{\sigma}{\epsilon_0}$, where $\sigma = Q/A$.
- The potential difference is $V = Ed = \frac{Qd}{\epsilon_0 A}$.
- Capacitance is defined as $C = \frac{Q}{V}$.
- Substituting, $C = \frac{\epsilon_0 A}{d}$.^{[3] [4] [5]}

This formula assumes the plates are large and closely spaced, and the space between them is filled with air or vacuum.

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Capacitance of Parallel Plate Capacitor With Dielectric Slab

When a **dielectric slab** is inserted between the plates of a parallel plate capacitor, the capacitance changes because the slab reduces the effective electric field (and potential difference) inside.

Step-by-Step Derivation

1. Without Dielectric: Basic Capacitance

For plates of area A and separation d :

$$C_0 = \epsilon_0 \frac{A}{d}$$

where ϵ_0 is the permittivity of free space.

2. With Dielectric Slab (Thickness t , Dielectric Constant K)

- The region between plates is split into two:
 - Region 1:** Air/vacuum of thickness $d - t$
 - Region 2:** Dielectric slab of thickness t
- Electric field in region 1: E_0 .
- Electric field inside dielectric (region 2): $E = \frac{E_0}{K}$, because dielectric reduces field by K .
- Total potential difference between plates:**

$$V = E_0(d - t) + Et = E_0(d - t) + \frac{E_0}{K}t = E_0 \left[(d - t) + \frac{t}{K} \right]$$

- Substitute $E_0 = \frac{Q}{A\epsilon_0}$:

$$V = \frac{Q}{A\epsilon_0} \left[(d - t) + \frac{t}{K} \right]$$

- Capacitance (definition):** $C = \frac{Q}{V}$

$$C = \frac{Q}{\frac{Q}{A\epsilon_0} \left[(d - t) + \frac{t}{K} \right]} = \frac{A\epsilon_0}{(d - t) + t/K}$$

3. Special Cases

- If the slab completely fills the space ($t = d$):

$$C = \epsilon_0 \frac{A}{d} K = KC_0$$

4. Physical Meaning

- **Dielectric increases capacitance:** The slab allows the capacitor to store more charge for the same potential difference, thanks to its property $K > 1$.
- The more space the slab occupies, or the higher its dielectric constant, the higher the capacitance.

Quick Summary:

- The capacitance increases when a dielectric slab is introduced.
- Final formula with slab of thickness t :

$$C = \frac{A\epsilon_0}{(d - t) + \frac{t}{K}}$$

- If the dielectric fills the entire gap ($t = d$), then $C = KC_0$.

If you want a visual, or have a specific case (say, multiple slabs), let me know! Could you restate the final formula now, or tell me what changes if $t = d$?

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whats d-t

In the formula for a parallel plate capacitor with a dielectric slab, $d - t$ refers to the thickness of the region between the plates that is *not* filled by the slab. ^[23] ^[24]

- d : the total distance (separation) between the plates of the capacitor.
- t : the thickness of the dielectric slab inserted between the plates, where $t < d$.

So, $d - t$ gives the remaining distance between the plates that still has air (or vacuum), not the dielectric. For example, if the plates are 4 mm apart ($d = 4 \text{ mm}$) and the inserted slab is 3 mm thick ($t = 3 \text{ mm}$), then $d - t = 1 \text{ mm}$ of the gap will be air and $t = 3 \text{ mm}$ will be dielectric slab. ^[25]

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from where the k came

The \$ K \$ in the formula is called the **dielectric constant** (also known as relative permittivity). It measures how much a material increases the capacitance of a capacitor compared to air or vacuum. ^[33] ^[34] ^[35]

- **Definition:** $K = \frac{C_{\text{material}}}{C_{\text{vacuum}}}$, where C_{material} is the capacitance with the dielectric slab, and C_{vacuum} is the capacitance with air or vacuum.
- Alternatively: $K = \frac{\epsilon}{\epsilon_0}$, where ϵ is the permittivity of the dielectric, and ϵ_0 is the permittivity of free space.

- ϵ_r is always greater than or equal to 1 and is a **property of the material** used as the dielectric.

A dielectric constant greater than 1 means the material increases the capacitor's ability to store charge compared to air. ^[35] ^[33]

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whats C_0 there in the end

In the context of the capacitor formulas, C_0 stands for the capacitance of a parallel plate capacitor when there is **no dielectric** between the plates—meaning the space is filled only with air or vacuum. ^[43] ^[44] ^[45]

- Its formula is $C_0 = \epsilon_0 \frac{A}{d}$.
 - ϵ_0 : permittivity of free space
 - A : area of each plate
 - d : distance between plates

When a dielectric is added, the capacitance increases, and C_0 is used as the reference or "original" capacitance (without the dielectric) for comparison. ^[45] ^[43]

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