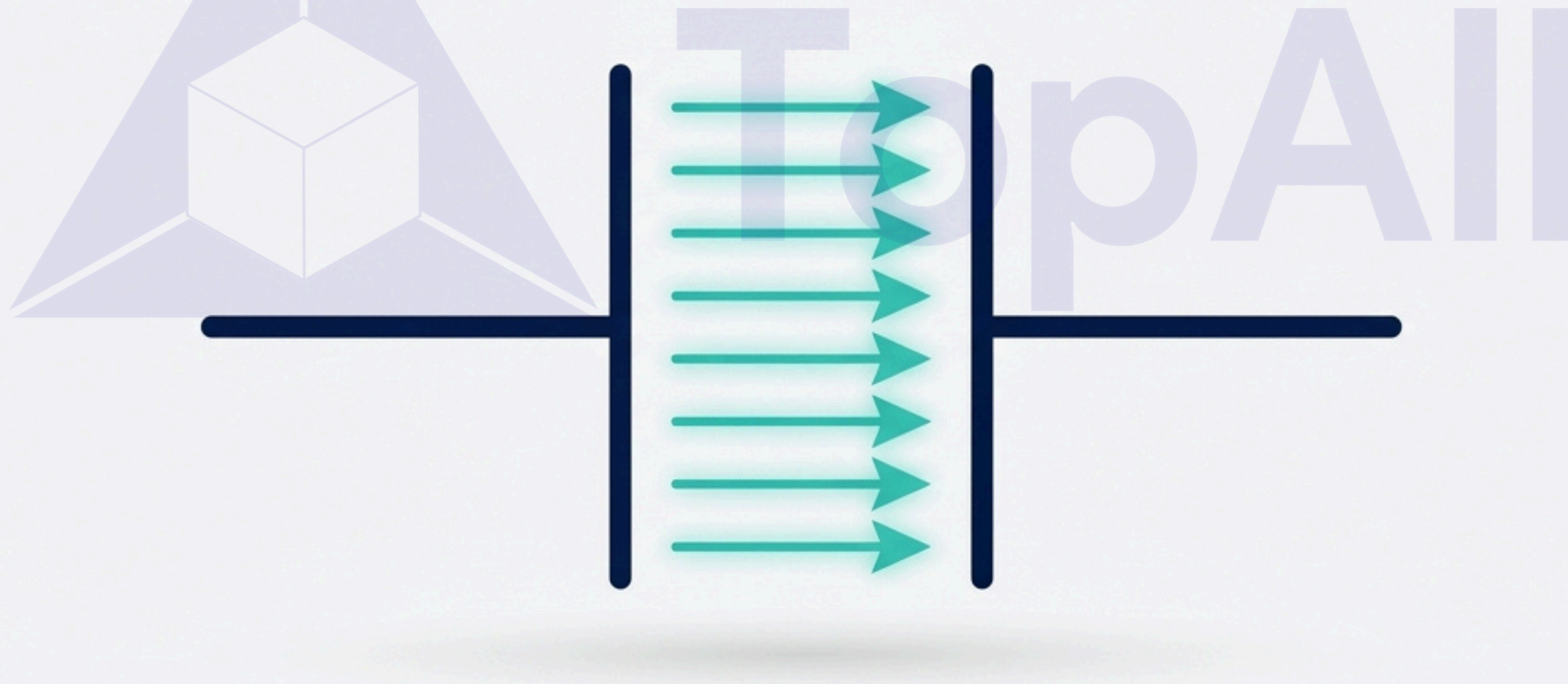


The Missing Current Inside a Capacitor

How Maxwell fixed Ampere's Law and completed the circuit.



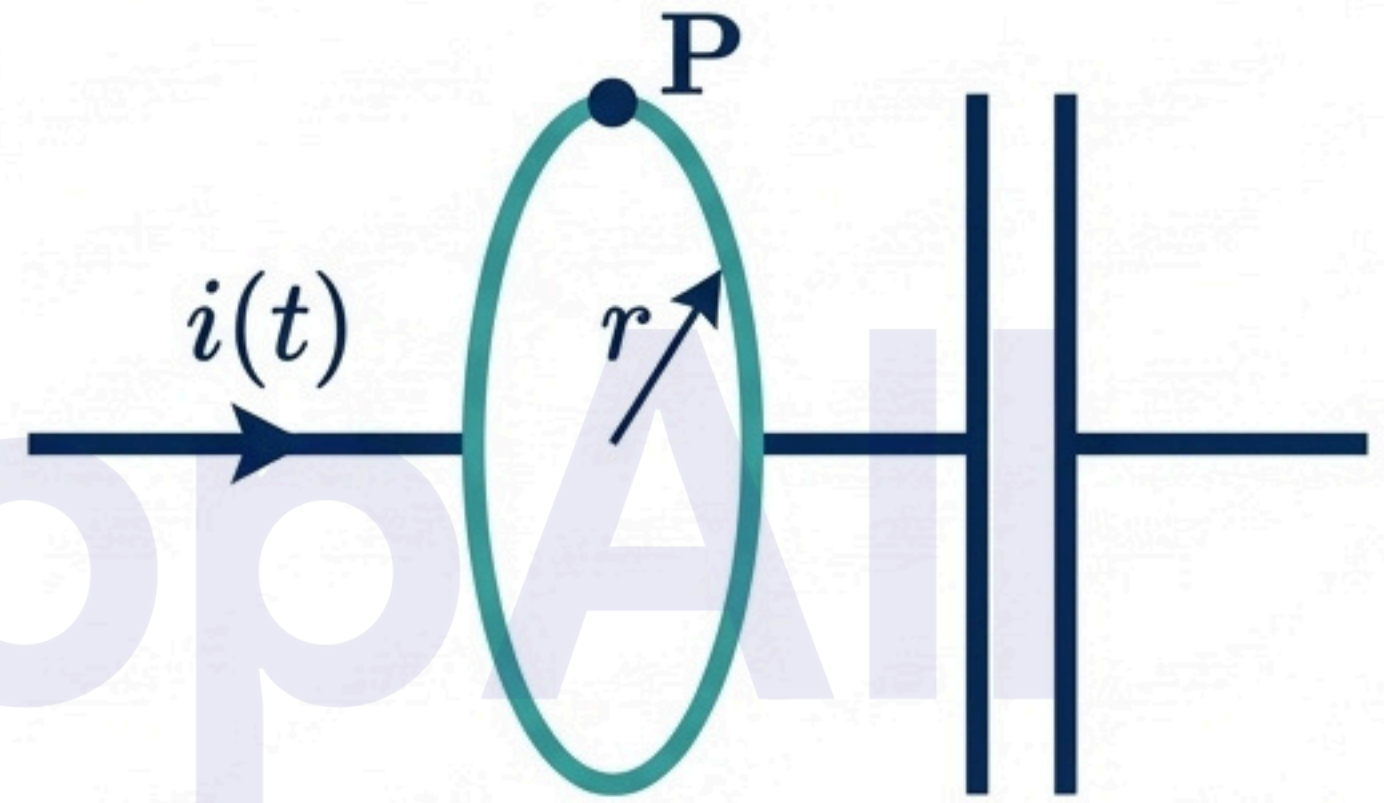
Applying Ampere's Law to a Circuit

Consider a parallel plate capacitor C being charged by a time-dependent current $i(t)$. We want to find the magnetic field $\mathbf{B}$ at point P on a circular loop of radius r outside the capacitor.

Ampere's Circuital Law

$$\oint \mathbf{B} \cdot d\vec{l} = \mu_0 i(t)$$

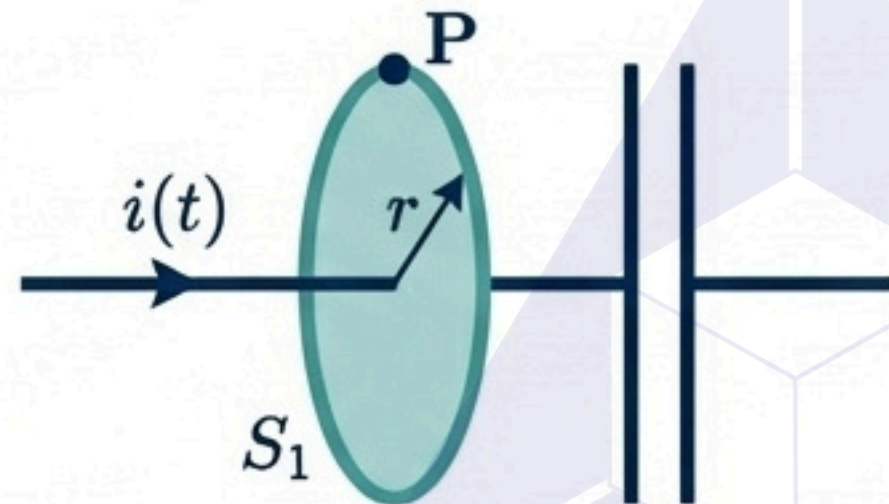
$$B(2\pi r) = \mu_0 i(t)$$



The Surface Paradox

Ampere's law must hold true for ANY surface bounded by the exact same loop. But observe what happens when we change the surface geometry:

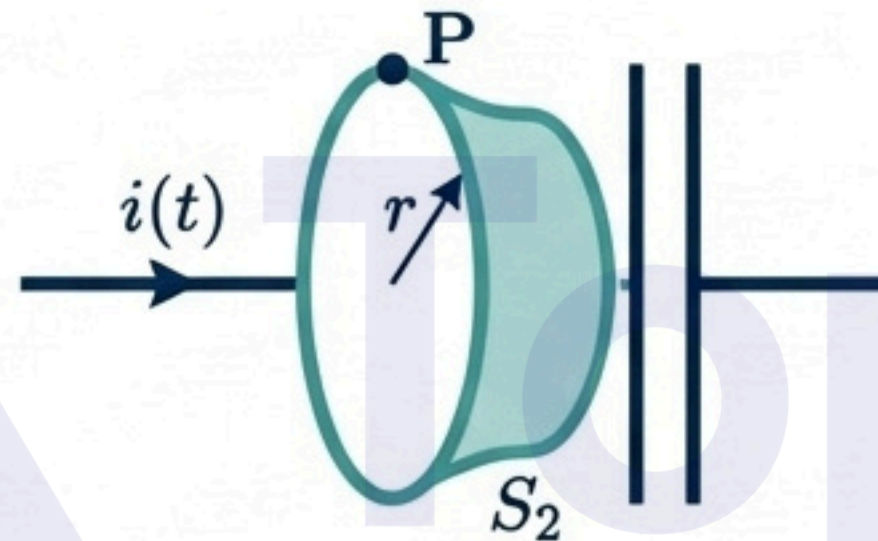
Flat Surface



Current i physically pierces the flat surface.

$$\oint \mathbf{B} \cdot d\vec{l} = \mu_0 i$$

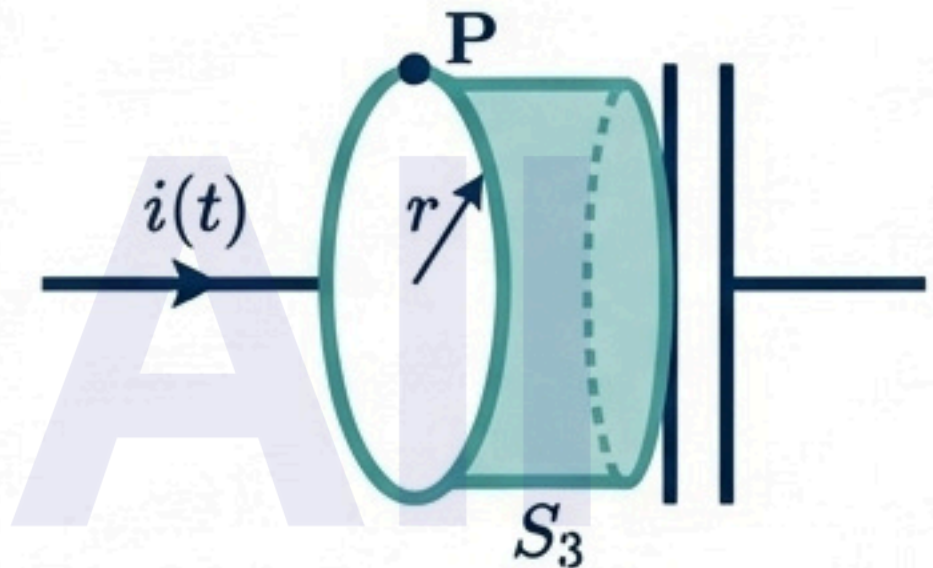
Pot Surface



Surface passes between plates. No wire touches it.

$$\oint \mathbf{B} \cdot d\vec{l} = 0$$

Tiffin Surface



Flat bottom $\mathbf{S}$ rests entirely between plates.

$$\oint \mathbf{B} \cdot d\vec{l} = 0$$

CONTRADICTION: Is the magnetic field $\mathbf{B}$ at point $\mathbf{P}$ zero or not?



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$$E=mc^2$$



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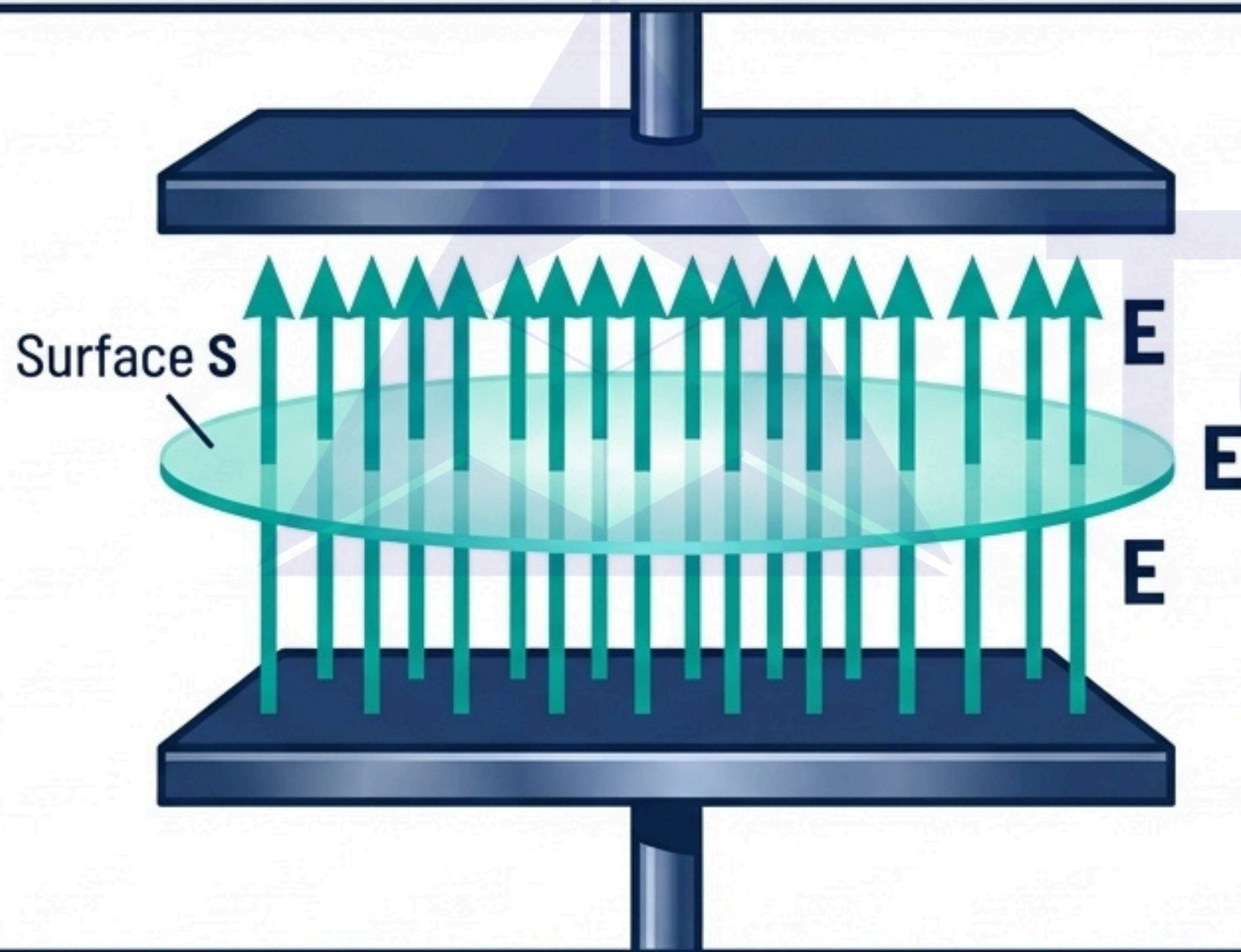
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What is passing through the gap?

There is no physical charge flowing between the plates, but there IS a changing Electric Field (**E**) piercing the empty space.



Electric Field & Flux

Electric Field between plates:

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

Electric Flux (Φ_E) through surface **S**:

$$\Phi_E = E \times A$$

$$\Phi_E = \frac{Q}{\epsilon_0} \quad \text{Eq. 8.3}$$

Introducing Displacement Current

If the charge Q on the plates changes with time, there is a current $i = dQ/dt$. By differentiating our flux equation, Maxwell derived a revolutionary new mathematical term:

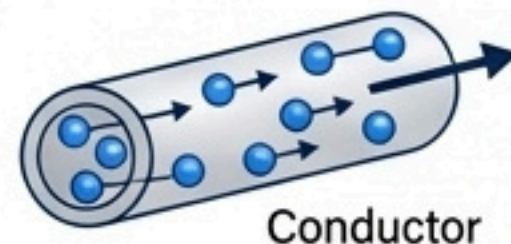
Maxwell's Displacement Current

$$i_d = \epsilon_0 \frac{d\Phi_E}{dt}$$

OUTSIDE PLATES

Conduction Current (i_c)

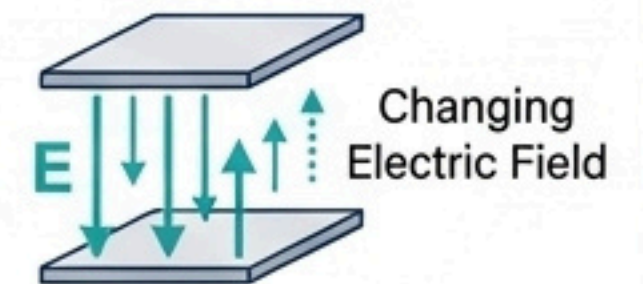
Driven by the physical flow of charges (electrons) through a solid conductor.



INSIDE PLATES

Displacement Current (i_d)

Driven by the time-rate of change of the electric field in a vacuum or dielectric.



The Generalized Ampere-Maxwell Law

Total current is continuous across any circuit. It is the unbroken sum of conduction and displacement currents: $i = i_c + i_d$. This perfectly resolves the surface paradox.

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 \left(i_c + \epsilon_0 \left[\frac{d\Phi_E}{dt} \right] \right)$$



PROFOUND RESULT: A magnetic field exists between the capacitor plates too! A changing electric field in empty space produces a magnetic field just like a physical wire does.

Key Takeaways

- ✓ **The Problem:** Ampere's original law failed (resulting in $B=0$) when applied to a surface passing between charging capacitor plates.
- ✓ **The Missing Term:** Maxwell introduced Displacement Current (i_d) to restore logical and mathematical consistency.
- ✓ **The Formula:** $i_d = \epsilon_0 (d\Phi_E/dt)$
- ✓ **The Concept:** A changing electric field in space acts exactly like a current, thereby producing a magnetic field.
- ✓ **The New Law:** The Ampere-Maxwell Law ensures total current ($i = i_c + i_d$) is perfectly continuous across any electrical circuit.



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