

Chapter 1.13 | Electrostatics

Gauss's Law

The shortcut law connecting electric flux and enclosed charge.

The Core Statement

The total electric flux through any closed surface is exactly equal to $1/\epsilon_0$ times the net charge enclosed by that surface.

Φ (Flux): Total number of electric field lines crossing the surface.

q_{enclosed} : The net algebraic sum of all charges inside the surface.

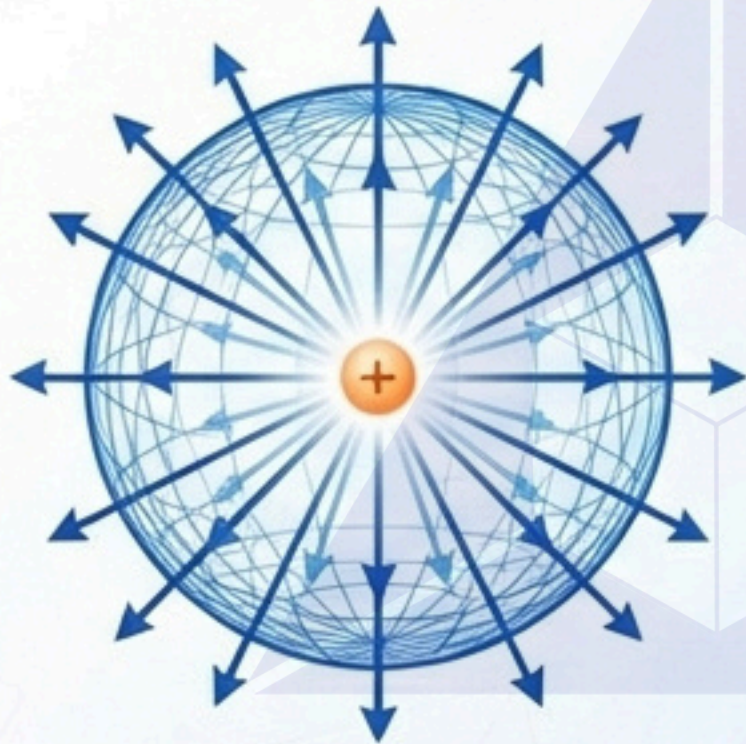
$$\Phi = \oint E \cdot dS = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

$\oint E \cdot dS$: The surface integral over a closed 3D boundary.

ϵ_0 : Permittivity of free space ($8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$).

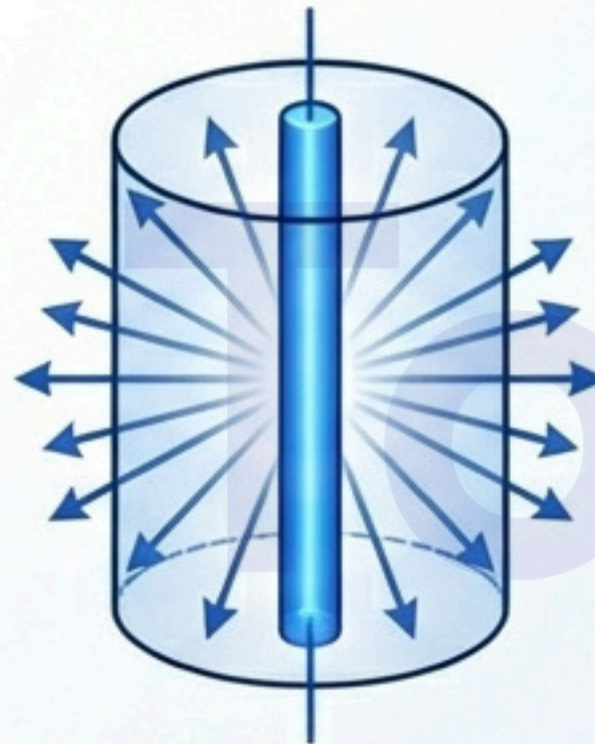
What is a Gaussian Surface?

To use Gauss's Law, we imagine a hypothetical, closed 3D boundary around our charge. We choose the shape that perfectly matches the charge's symmetry.



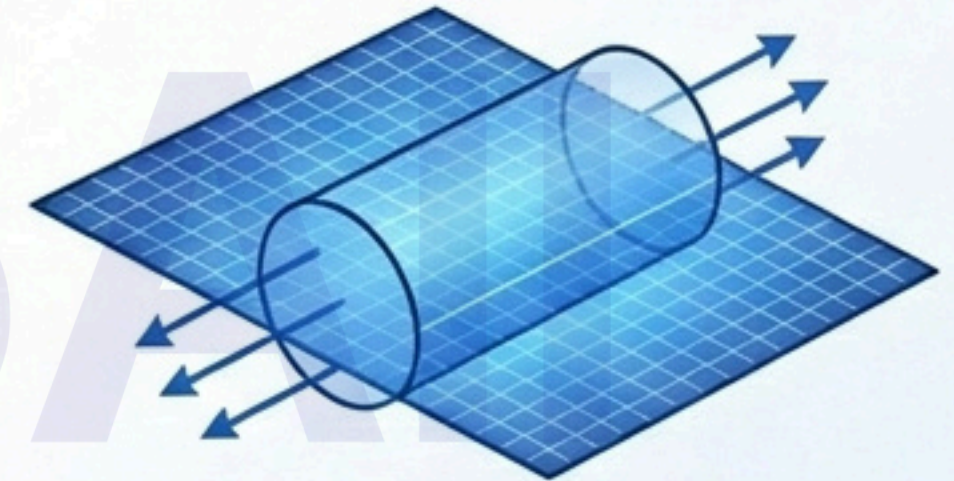
Best For: Point charges (q) or spherical shells.

Why: Electric field is perfectly radial, hitting the surface at exactly 90° .



Best For: Infinitely long lines of charge (λ).

Why: Field lines project radially outward, piercing only the curved surface.



Best For: Infinite flat sheets of charge (σ).

Why: Field lines are strictly parallel to the curved sides and only pierce the flat end-caps.

Why Symmetry Matters

Gauss's law is always true, but it is only useful when the system has perfect symmetry. Symmetry transforms complex calculus into simple algebra.

The Calculus Problem

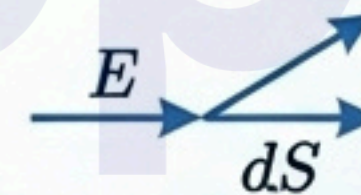
$$\Phi = \oint E \cos(\theta) dS$$

(If E and θ are changing everywhere across an irregular surface, this integral is a nightmare to solve).

The Symmetry Shortcut

If we choose a Gaussian surface where the Electric Field (E) is constant in magnitude and parallel to the area vector (dS), the math collapses beautifully:

1. $\theta = 0^\circ$, so $\cos(0) = 1$.



2. E is constant, so it pulls out of the integral:

$$E \oint dS$$

3. The integral $\oint dS$ is simply the total surface area (A).



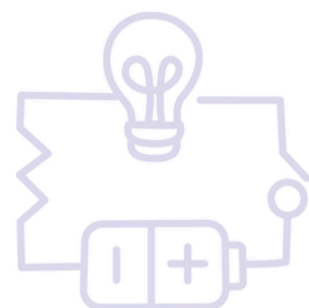
4. Final Math:

$$E \times A = \frac{q_{\text{enclosed}}}{\epsilon_0}$$



You've Learned the Theory. Let's Test Them Now.

$$E=mc^2$$



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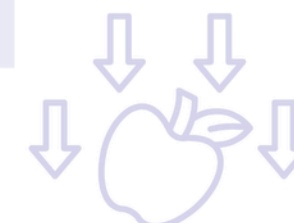
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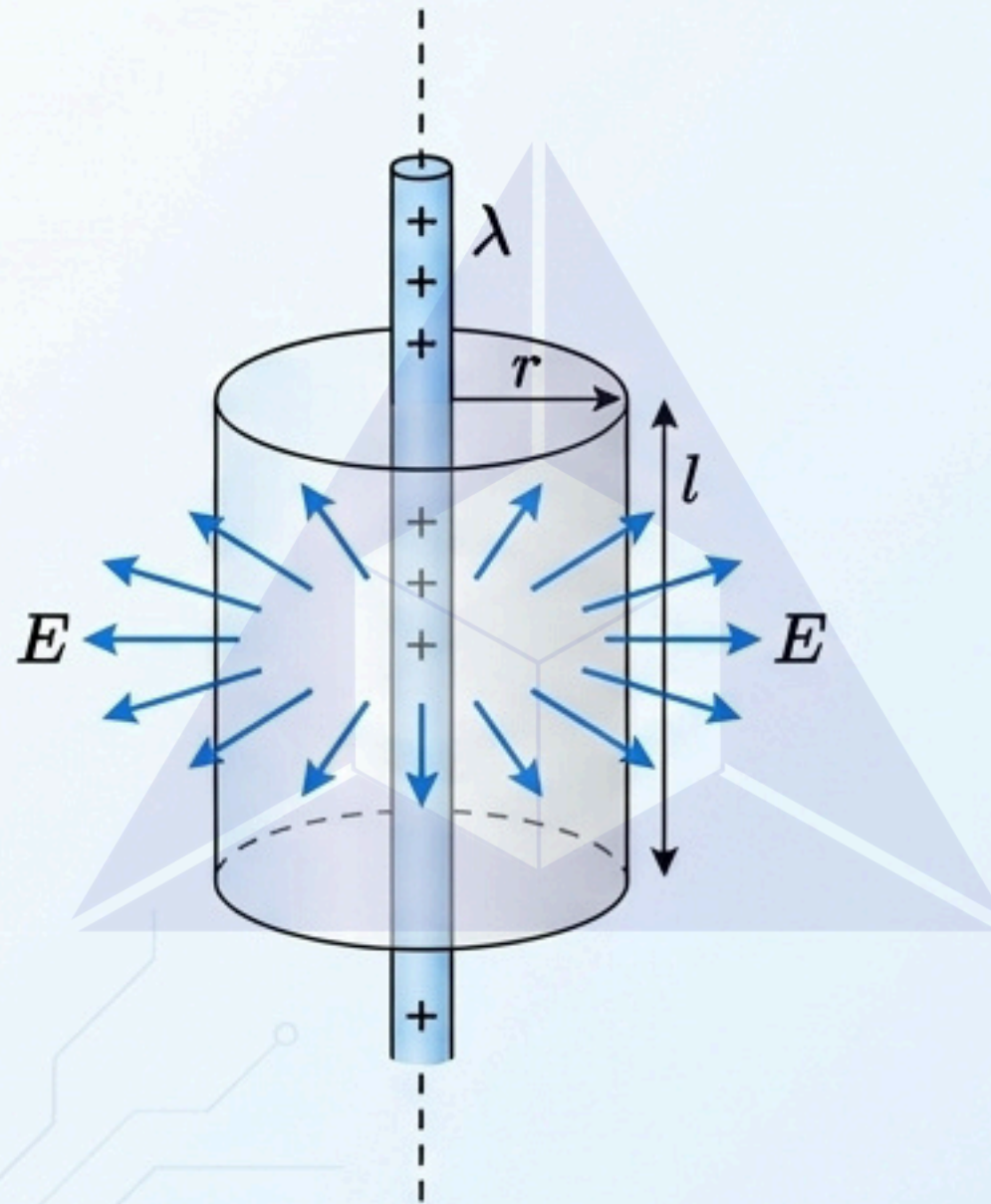
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Application 1: Infinite Straight Wire

Finding the electric field around a long, uniformly charged wire.



Charge type:
Linear charge density (λ)

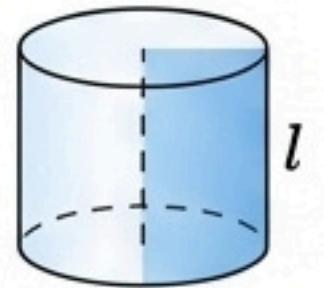


Enclosed charge:
 $q = \lambda l$

Derivation

1. **Apply Gauss's Law:** $\Phi = E \times \text{Area} = \frac{q}{\epsilon_0}$

2. **Identify Area:** Flux only passes through the curved part of the cylinder. Area = $2\pi r l$.



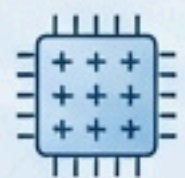
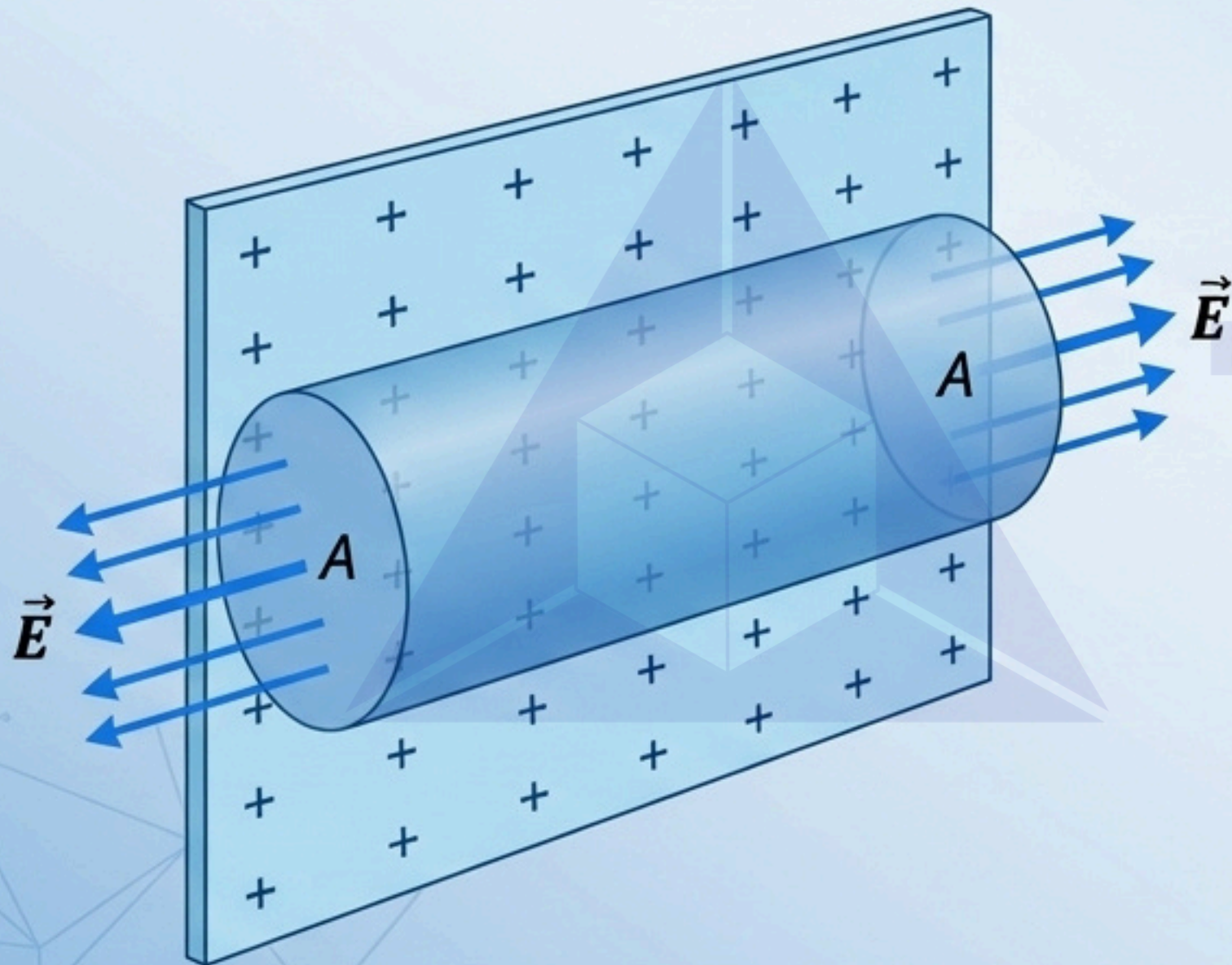
3. **Substitute:** $E \times (2\pi r l) = \frac{\lambda l}{\epsilon_0}$

4. **Solve for E:** $E = \frac{\lambda}{2\pi\epsilon_0 r}$

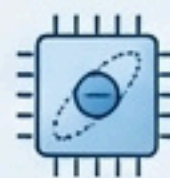
Insight: The electric field decreases strictly as $1/r$, not $1/r^2$.

Application 2: Infinite Plane Sheet

Finding the electric field generated by a massive, uniformly charged flat plane.

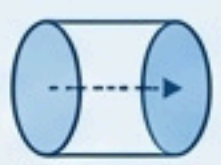


Charge type: **Surface charge density (σ)**



Enclosed charge:
 $q = \sigma A$

Derivation

1. **Apply Gauss's Law:** $\oint \vec{E} \times Area_{total} = \frac{q}{\epsilon_0}$
2. **Identify Area:** Flux passes through both end caps of area A . Total flux area = $2A$. 
3. **Substitute:** $E \times (2A) = \frac{\sigma A}{\epsilon_0}$
4. **Solve for E:**

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



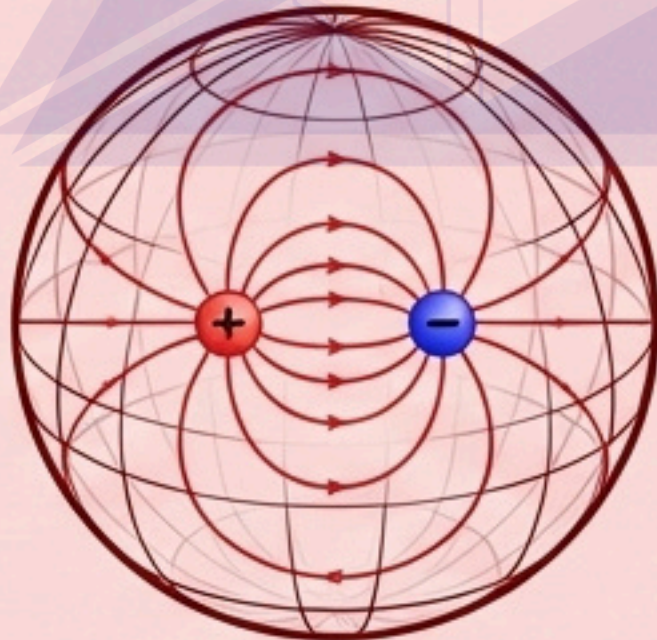
Insight: The E-field is perfectly uniform. It does not depend on distance (x) from the sheet!

The Net Flux Illusion

Clarifying the strict mathematical meaning of q_{enclosed}

Exam Trap: "Zero flux means empty space."

False. If the net flux through a closed surface is zero ($\Phi = 0$), it does not automatically mean the enclosure is empty. It only means the net algebraic sum of charges is zero.



Total charge = 0

The "Inside vs. Outside" Rule

$$\oint \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

- **The Left Side ($\vec{E}$):** The electric field vector at the surface is created by ALL charges, both inside and outside the boundary.
- **The Right Side (q_{enclosed}):** The charge term only cares about the charges strictly INSIDE the boundary. Outside charges contribute zero net flux.

Chapter Synthesis

- ✓ The Shortcut: **Gauss's law** ($\Phi = q_{\text{enclosed}}/\epsilon_0$) connects electric flux through a closed 3D surface to the net charge trapped inside it.
- ✓ **Gaussian Surfaces:** Always choose a hypothetical surface (Sphere, Cylinder, Pillbox) that perfectly matches the spatial symmetry of the charge distribution.
- ✓ **Infinite Wire:** Electric field equals $E = \lambda/(2\pi\epsilon_0 r)$. It relies on cylindrical symmetry and is inversely proportional to distance r .
- ✓ **Infinite Sheet:** Electric field equals $E = \sigma/(2\epsilon_0)$. It is completely uniform and independent of distance.
- ✓ **The Golden Rule:** External charges may alter the local Electric Field at specific points on a surface, but they can never change the net flux through that closed boundary.

Check Your Understanding

Q1: Symmetry Choice: You need to find the electric field of a uniformly charged solid sphere. What is the appropriate Gaussian surface, and why?

(Hint: Think about where the E-field magnitude is completely constant.)

Reveal 

Q2: Enclosed Charge: A box encloses three charges: $+5\mu\text{C}$, $-2\mu\text{C}$, and $+2\mu\text{C}$. A massive $+100\mu\text{C}$ charge is placed just outside the box. What is the net electric flux leaving the box?

(Hint: Focus strictly on the q_{enclosed} rule.)

Reveal 

Q3: Distance Dependence: How does the electric field behave as you move further away from a point charge, an infinite wire, and an infinite plane sheet, respectively?

(Hint: Recall the formulas: $1/r^2$ vs. $1/r$ vs. Constant)

Reveal 

 **Chapter 1.13 & 1.14 Complete. You are ready for the Chapter 1 Test.**



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