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# Maxwell's Equations: *Gauss' Law*

EE-3321  
Electromagnetic Field Theory



## Outline



- Fields and Charges
- Field Lines
- Two Ways to Calculate Total Charge  $Q$
- Gauss' Law in Differential Form

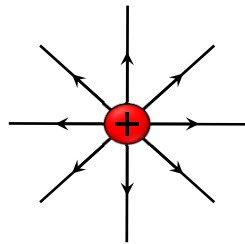
## Fields & Charges (1 of 2)



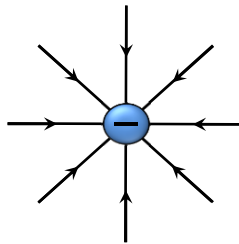
The electric field induced by charges is best described by the electric flux density  $D$  because this quantity is most closely associated with charge.

$$\vec{D} = \frac{Q}{4\pi r^2} \hat{a}_r$$

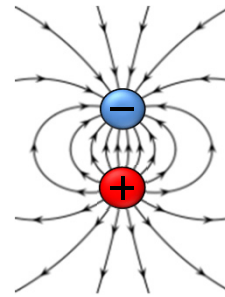
Electric field lines diverge from positive charges.



Electric field lines converge on negative charges.



...or both!



Maxwell's Equations -- Gauss' Law

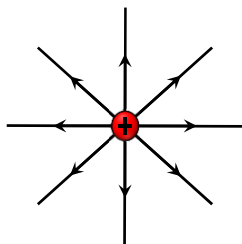
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## Fields & Charges (2 of 2)

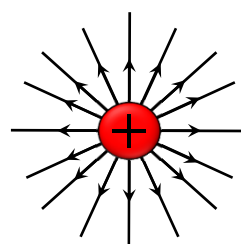


The magnitude of the charge is usually conveyed by the density of the field lines.

Small charge



Large charge



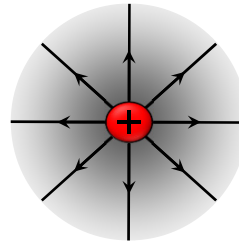
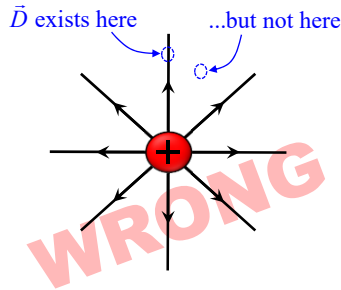
Maxwell's Equations -- Gauss' Law

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## A Note About Field Lines



It is in some ways misleading to draw electric field lines because it incorrectly implies that the field exists at some points but not others.



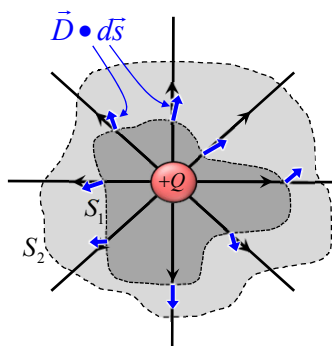
The electric field is a smooth and continuous phenomenon, but that is hard to convey in a diagram.

## How to Calculate Total Charge $Q$



### Method 1: Surface integral of electric flux

Since the density of field lines convey the amount of charge, it makes sense that we can calculate the total charge  $Q$  enclosed within a surface  $S$  by integrating the flux of the field lines at the surface.



$$Q = \oiint_{S_1} \vec{D} \cdot d\vec{s} = \oiint_{S_2} \vec{D} \cdot d\vec{s}$$

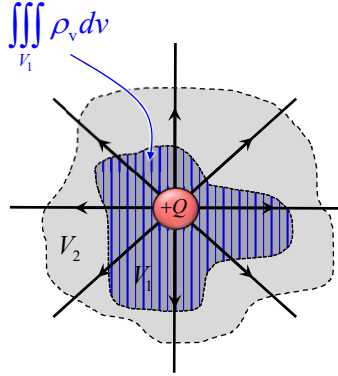
The choice of surface  $S$  does not matter as long as the surface completely encloses the charge. Usually the shape of the surface is chosen to make the math as simple as possible.

# How to Calculate Total Charge $Q$



## Method 2: Volume integral of electric charge density

The total charge  $Q$  can be calculated by integrating the electric charge density  $\rho_v$  within a volume  $V$  that completely encompasses the charge.



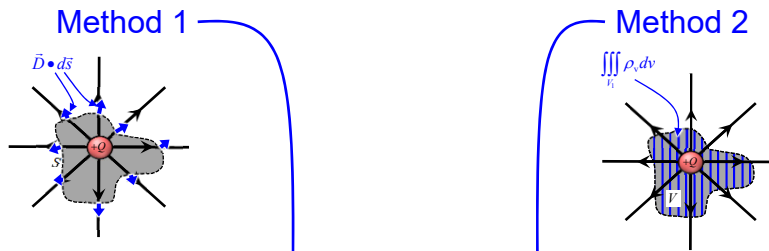
$$Q = \iiint_{V_1} \rho_v dv = \iiint_{V_2} \rho_v dv$$

The choice of volume  $V$  is the same as the choice of the surface for Method 1. the shape does not matter as long it completely encompasses the charge. It is usually chosen for mathematical convenience.

# Gauss' Law in Integral Form



Both methods calculate the same total charge so they can be set equal.



$$Q = \oiint_S \vec{D} \cdot d\vec{s} = \iiint_V \rho_v dv$$

## Apply Divergence Theorem



The *divergence theorem* allows us to write a closed-contour surface integral as a volume integral.

$$\oiint_S \vec{A} \cdot d\vec{s} = \iiint_V (\nabla \cdot \vec{A}) dv$$

Applying this to Gauss' law gives us

$$Q = \oiint_S \vec{D} \cdot d\vec{s} = \iiint_V \rho_v dv$$

↓

$$Q = \iiint_V (\nabla \cdot \vec{D}) dv = \iiint_V \rho_v dv$$

Maxwell's Equations -- Gauss' Law

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## Gauss' Law in Differential Form



If the surface  $S$  and volume  $V$  describe the same space, the argument of both integrals must be equal. Setting these arguments equal gives Gauss' law in differential form.

$$Q = \iiint_V (\nabla \cdot \vec{D}) dv = \iiint_V \rho_v dv$$

$$\nabla \cdot \vec{D} = \rho_v$$

Maxwell's Equations -- Gauss' Law

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