

Chapter 19

Electric Charges, Forces, and Fields

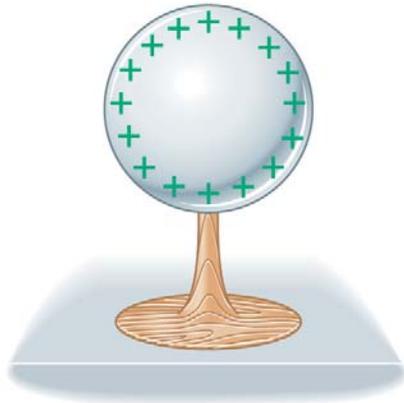
Outline

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- 19-2 Insulators and Conductors
- 19-3 Coulomb's Law
- 19-4 The Electric Field
- 19-5 Electric Field Lines
- 19-6 Shield and Charging by Induction
- 19-7 Electric Flux (and Gauss's Law)

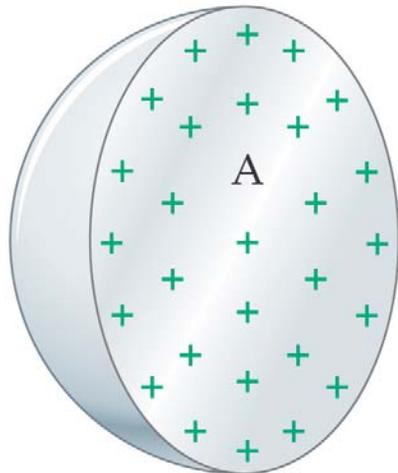
19-6 Shielding and Charging by Induction

Figure 19-18

Charge Distribution on a **Conducting** Sphere
Which one is correct?



(a)



(b)

a) Charge Distributed uniformly on the surface of a Conducting Sphere.

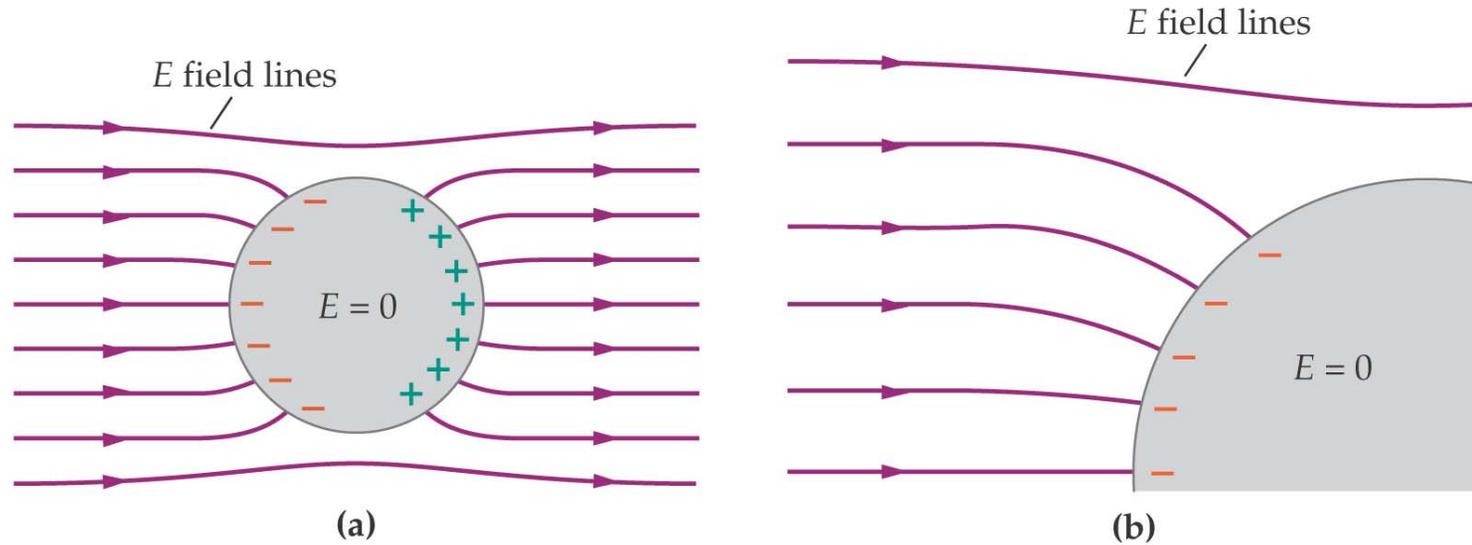
b) Charge Distributed uniformly through the volume of a Conducting Sphere.

Excess Charge on a Conductor

Excess charges (positive or negative) placed on a conductor should move to the exterior surface of the conductor.

A. Shielding

Figure 19-19. Electric Field Near a Conducting Surface



(a) $E=0$ in the conductor.

The charges are induced
by the outside field

(b) Electric field lines meet the surface
at right angles.

Zero Field within a Conductor

Zero Field within a Conductor

When electric charges are at rest, the electric field within a conductor is zero, $E = 0$;

Note:

The conclusion is also hold true for a hollow conductor.

Applications:

Sensitive electronic equipment can be enclosed in a metal box to isolate from the exterior electric field, since the electric field in the metal box is 0.

Electric Field at Conductor Surface

Electric field lines contact conductor surface at right angle.

B. Charging by Induction

For an electric neutral object, there are two ways to charge the object:

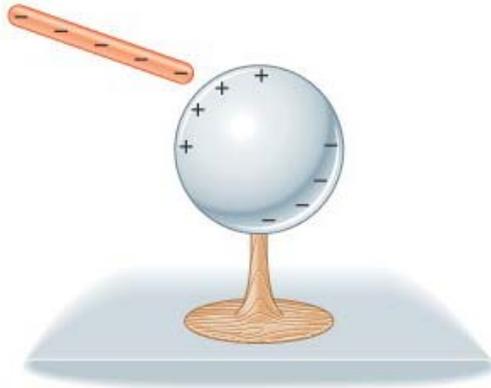
1) **By Touching**

2) No physics touching: **By induction.**

since electric field can act at a distance!

Figure 19-22 (a, b) Charging by Induction

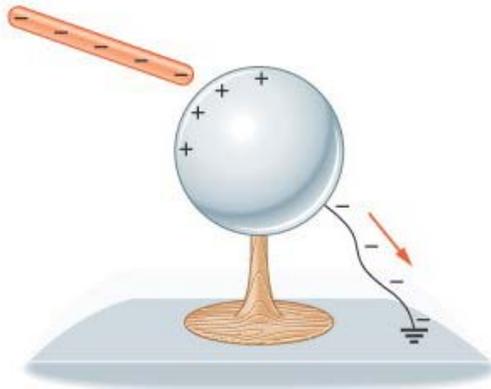
amber



(a)

a). A charged rod induces + and – charge on opposite sides of the conductor.

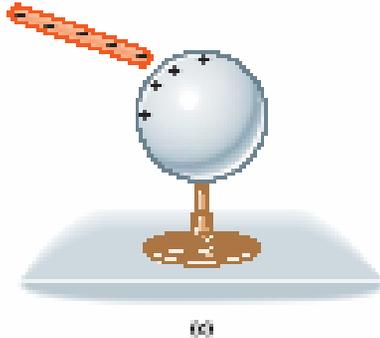
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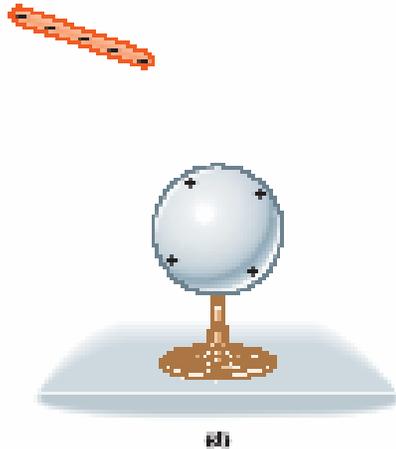
(b)

b). When the conductor is grounded, the – charges are transferred.

Figure 19-22 (c, d) Charging by Induction



c). Removing the ground line, the conductor has net + charges



d). The charges are uniformly distributed on the conductor, and the charges are opposite in sign to that of the rod.

Charging by Induction

A electric charge can create a local opposite charge **on a conductor** at some distance away, without contacting the conductor (since the electric charge create an electric field).

19-7 Electric Flux and Gauss's Law

Electric Flux

Definition of Electric Flux, Φ

$$\Phi = EA \cos \theta \quad (19-11)$$

SI unit: $\text{N}\cdot\text{M}^2/\text{C}$

Where,

E is (uniform) electric field.

A is the area.

θ is the angle between \vec{E} and the normal of the area A .

19-23. Definition of Electric Flux

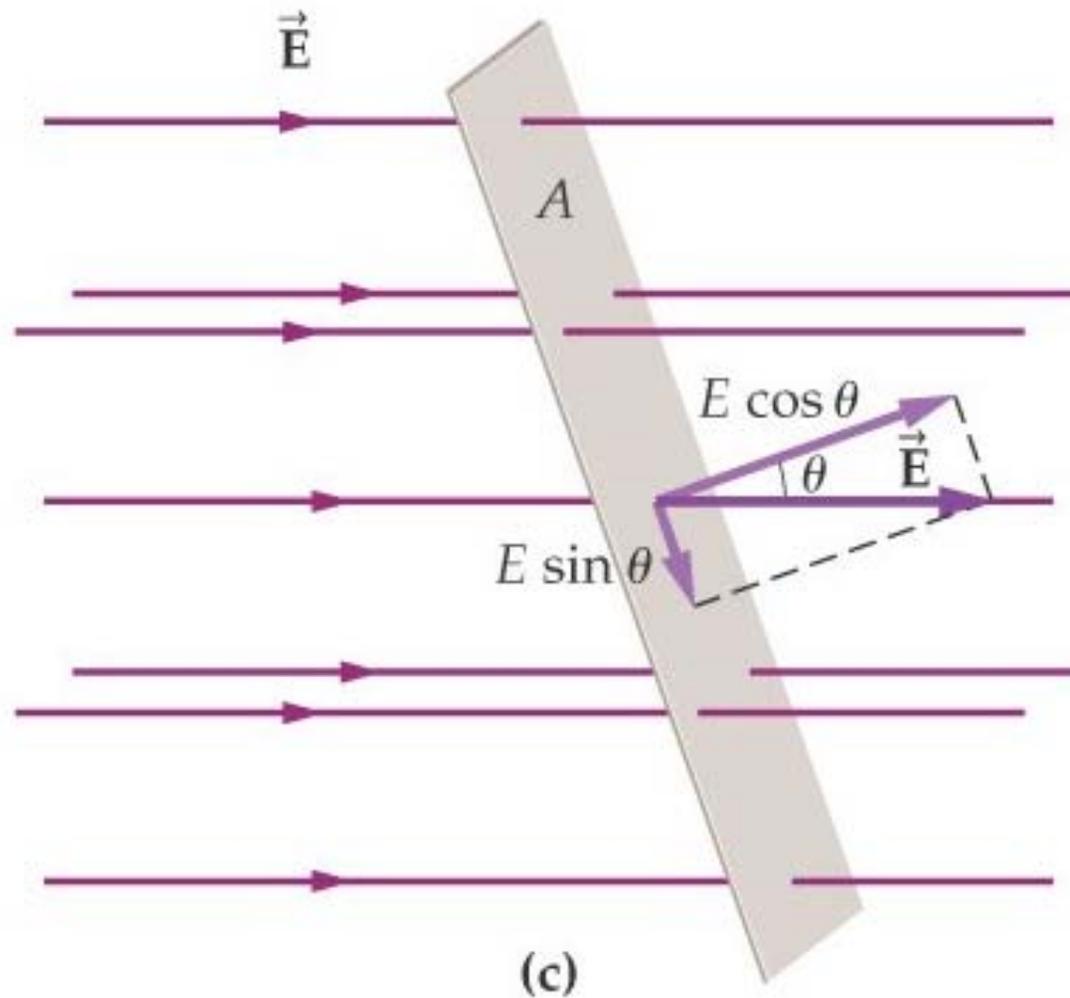
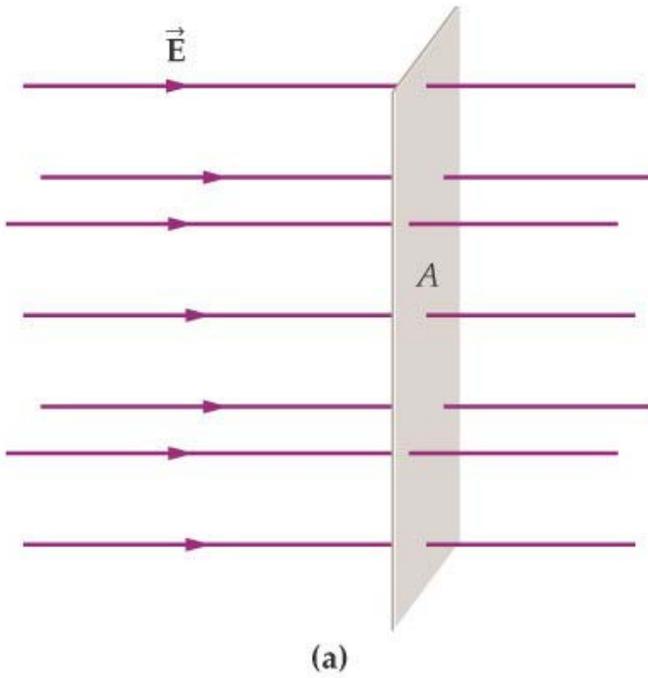
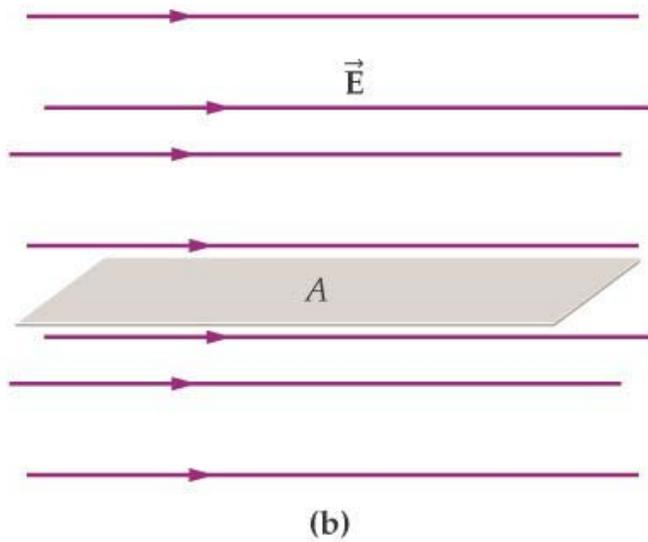


Figure 19-23 (a, b)
Electric Flux



(a) $\Phi = EA$



(b) $\Phi = 0$

The sign of the Flux is defined as

- 1) The flux is *positive* for field lines that leave the enclosed volume of the surface.
- 2) The flux is *negative* for field lines that enter the enclosed volume of the surface.

Example 19-49

Plane Surface Flux

A uniform electric field of magnitude 25,000 N/C makes an angle of 27° with a plane surface of area 0.133m. What is the electric flux through this surface?

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Plane Surface Flux

A uniform electric field of magnitude 25,000 N/C makes an angle of 27° with a plane surface of area 0.0133m. What is the electric flux through this surface?

Solution:

$$\Phi = EA \cos \theta$$

$$= 25,000 \times 0.0133 \times \cos(90^\circ - 27^\circ)$$

$$= 1.51 \times 10^2 \quad \text{N.M}^2/\text{C}$$

Gauss's Law

If a charge q is enclosed by an arbitrary surface, the electric flux, Φ , is

$$\Phi = \frac{q}{\epsilon_0} \quad (19-13)$$

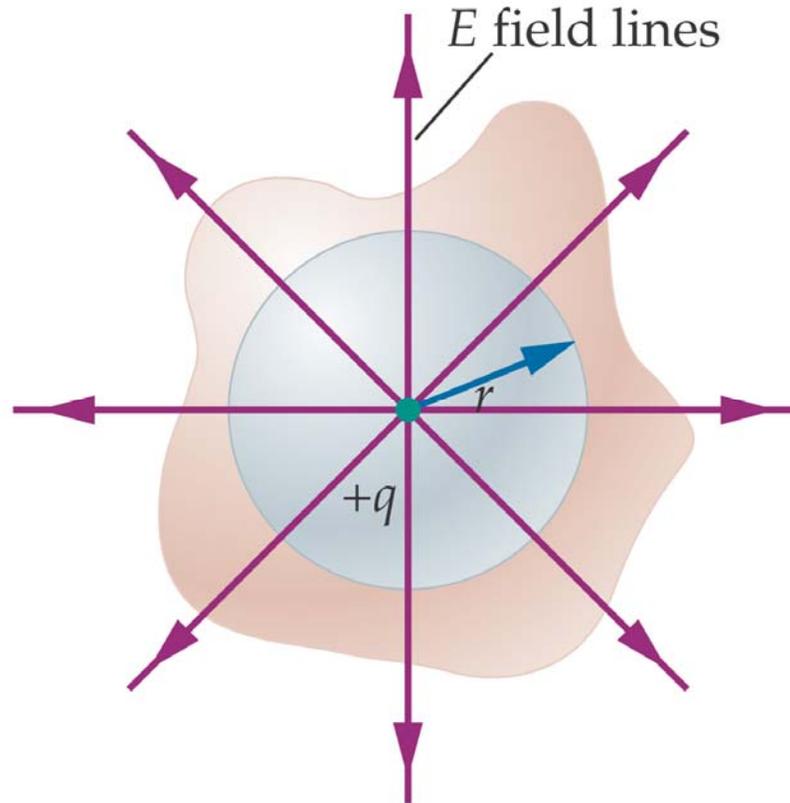
Where $\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C/N.m}^2$

is the permittivity of free space.

Note:

Gauss's law holds true for any arbitrary surface.

Figure 19-24 Electric Flux for a Point Charge



The electric flux through a spherical surface surrounding a positive point charge q . The electric flux for arbitrary surface is the same as for the sphere.

Deriving Gauss's Law

- 1) For a positive point source charge q , as shown in 19-24, the surface of a sphere has a constant magnitude

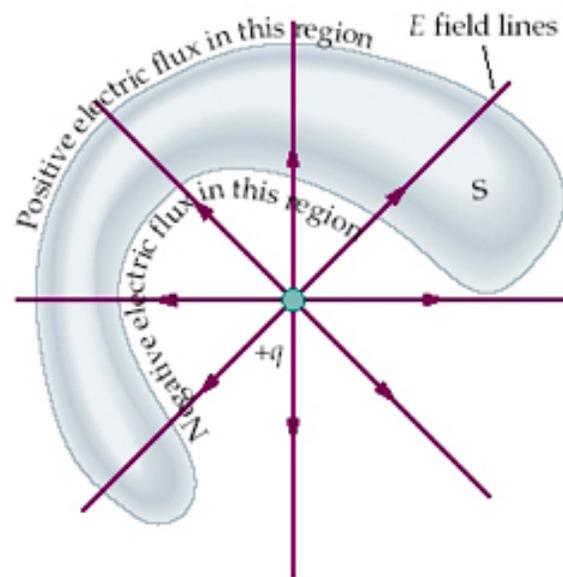
$$E = k \frac{q}{r^2}$$

- 2) Since the electric field is perpendicular to the spherical surface, the flux is simple the E times the area A

$$\begin{aligned}\Phi &= EA = \left(k \frac{q}{r^2}\right)(4\pi r^2) = 4\pi kq \\ &= \frac{q}{\epsilon_0}\end{aligned}$$

CONCEPTUAL CHECKPOINT 19–6

Consider the surface S shown in the sketch. Is the electric flux through this surface **(a)** negative, **(b)** positive, or **(c)** zero?



CONCEPTUAL CHECKPOINT 19–6

Consider the surface S shown in the sketch. Is the electric flux through this surface (a) negative, (b) positive, or (c) zero?

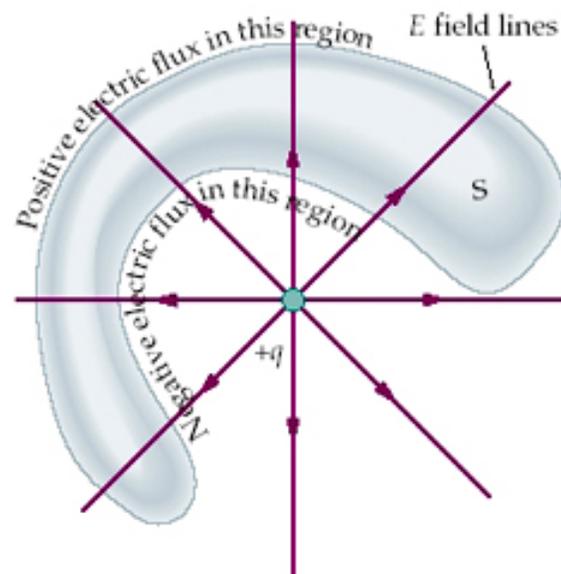
Reasoning and Discussion

Because the surface S encloses no charge, the net electric flux through it must be zero, by Gauss's law. The fact that a charge $+q$ is nearby is irrelevant, because it is outside the volume enclosed by the surface.

We can explain why the flux vanishes in another way. Notice that the flux on portions of S near the charge is negative, since field lines enter the enclosed volume there. On the other hand, the flux is positive on the outer portions of S where field lines exit the volume. The combination of these positive and negative contributions is a net flux of zero.

Answer

(c) The electric flux through the surface S is zero.



Gauss's Law applied to a metal spherical shell

A case with three Gaussian surfaces.

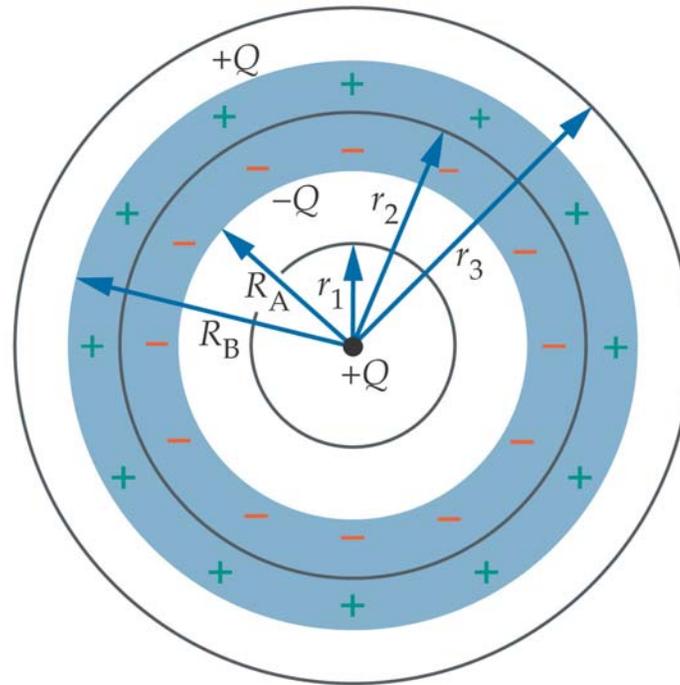


Figure 19-25
Gauss's Law Applied to a Spherical Shell

Case 1 at $r_1 < R_A$ Gaussian surface:

what is the electric flux and the magnitude of the electric field ?

The electric flux at r_1 is

$$\Phi = E(4\pi r_1^2) = Q / \epsilon_0$$

Therefore, the magnitude of the electric field is

$$E = \frac{Q}{4\pi\epsilon_0 r^2} = k \frac{Q}{r^2}$$

The charges on the shell do not affect the electric flux of this Gaussian surface!

Case 2 at $R_A < r_1 < R_B$ Gaussian surface:

what is the electric flux and the magnitude of the electric field ?

Since E is zero ($E=0$) in a conductor, the electric flux at r_1 is

$$\Phi = EA = 0$$

The net charge in this Gaussian surface is zero;
This also means that the induced charge on the inner surface of the shell is $-Q$.

Case 3 at $r_1 > R_B$ Gaussian surface:

what is the electric flux and the magnitude of the electric field ?

The electric flux at r_1 is

$$\begin{aligned}\Phi &= E(4\pi r_1^2) = (\text{enclosed charge}) / \epsilon_0 \\ &= Q / \epsilon_0\end{aligned}$$

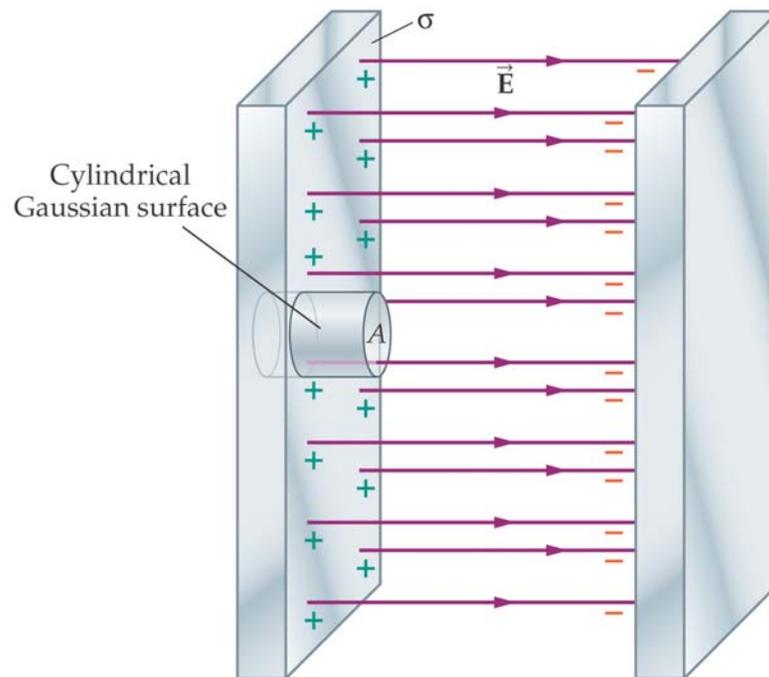
$$E = \frac{Q}{4\pi\epsilon_0 r_3^2} = k \frac{Q}{r_3^2}$$

The electric field outside the shell is the same as if the shell were not present;

The conducting shelling does not shield the extend world from charges within it.

Active Example 19-3 Find the Electric Field

Use the cylindrical Gaussian surface shown in the figure to calculate the electric field between two metal plates of the capacitor. Each plate has a charge per area of magnitude σ



Active Example 19-3
Find the Electric Field

Solution

- 1) Calculate the electric flux through the curved surface of the cylinder

$$\Phi_1 = 0$$

- 2) Calculate the electric flux through the two end caps of the cylinder

$$\Phi_2 = 0 + EA$$

- 3) The total electric flux is

$$\Phi = \Phi_1 + \Phi_2 = EA$$

- 4) The charge enclosed by the cylinder is σA

- 5) Applied Gauss's law $\Phi = \frac{q}{\epsilon_0} = \frac{\sigma A}{\epsilon_0}$

- 6) With 3) and 5), we have

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

Summary

Shield and Charging by Induction

Excess charge: **any excess charge move to conductor's exterior surface, at right angle**

Zero field is a conductor: The electric field within a conductor is in equilibrium zero.

Shielding: A conductor shields a cavity within it from the external electric field;

Electric Flux and Gauss's Law

$$\Phi = EA \cos \theta \quad (19-11)$$

$$\Phi = \frac{q}{\epsilon_0} \quad (19-13)$$