Some Review due to Quiz3 results

A few questions were done VERY poorly

23.9% of 109 students

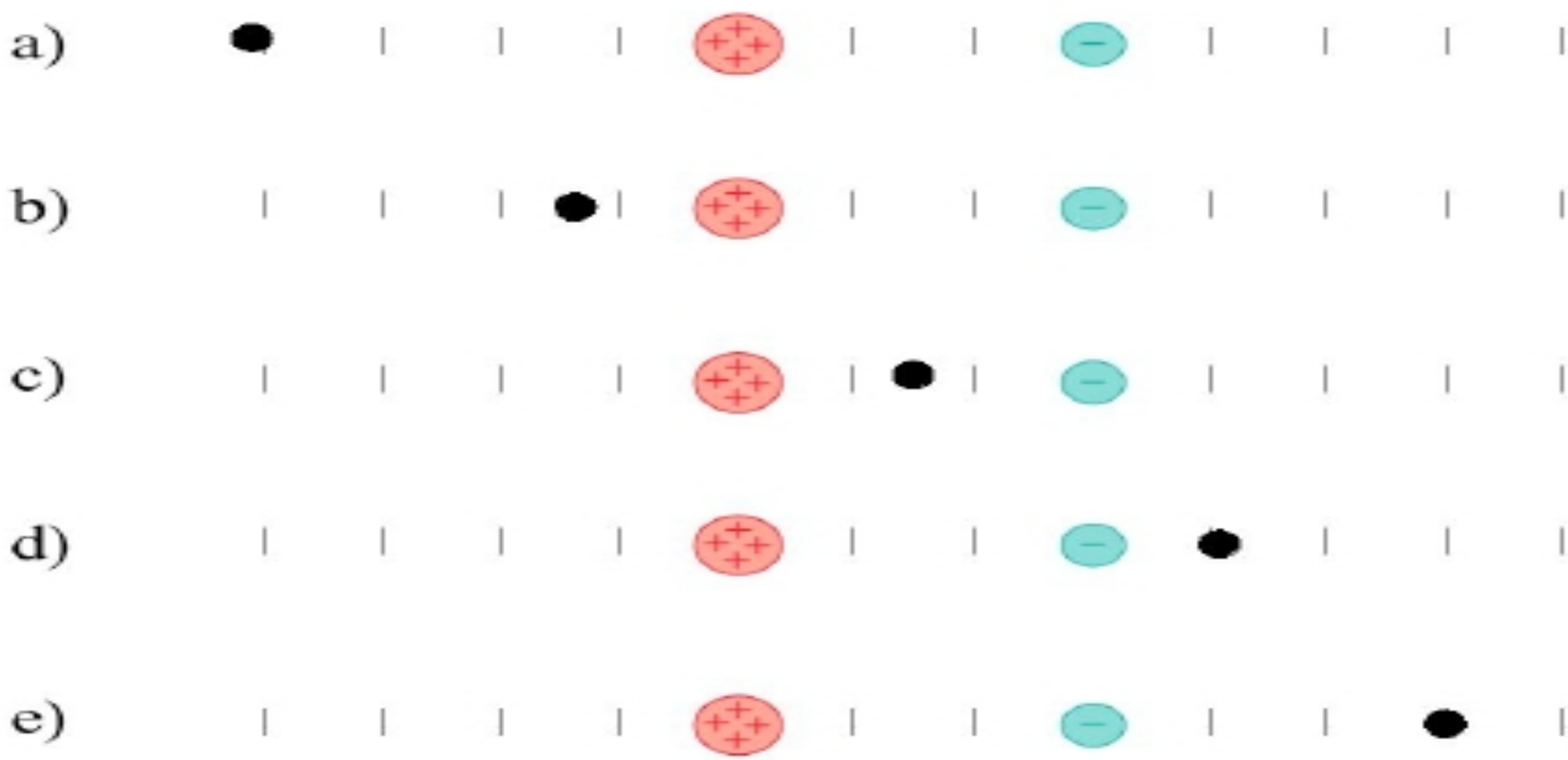
- Four charges of 6 μC are at the corners of a square, which has sides of length 10 cm. What is the magnitude of the net force on the NE charge?
- Please Answer to one decimal.

19.1% of 126 students

- A -2 μC charge is placed at the origin and a +8 μC charge is placed at x = 10 cm. At what position should a charge be placed so that the force on it is zero?
- Please answer in centimeters.

29.0% of 138

- In which of the following figures would an electron placed on the dot feel zero net force?



26.1% of 142

To determine if an object has negative charge, you need to

A. see if the object attracts a positive charged rod.
B. see if the object repels a negative charged rod.
C. Both A and B.
D. Either A or B.

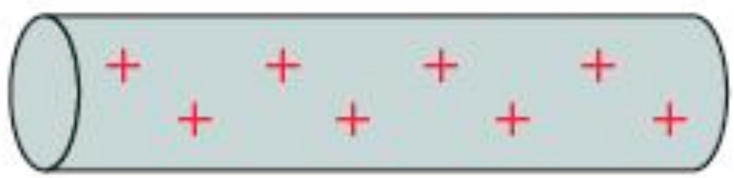
26.1% of 142

To determine if an object has negative charge, you need to

A. see if the object attracts a positive charged rod.
✔ **B. see if the object repels a negative charged rod.**
C. Both A and B.
D. Either A or B.

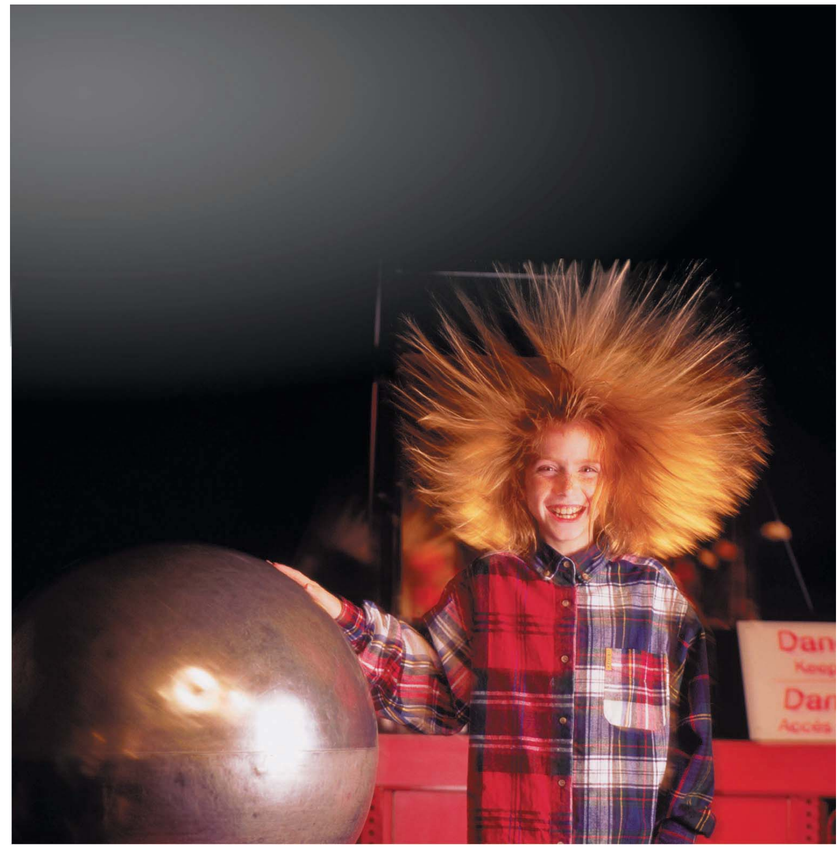
21.5% of 200

- A small segment of wire shown in the figure below contains 10 nC of charge. The segment is shrunk to one-third of its original length. A proton is very far from the wire. What is the ratio F_f/F_i of the electric force on the proton after the segment is shrunk to the force before the segment is shrunk?
- Express your answer to **one significant figure**.



Chapter 28. Gauss's Law

The nearly spherical shape of the girl's head determines the electric field that causes her hair to stream outward. Using Gauss's law, we can deduce electric fields, particularly those with a high degree of symmetry, simply from the shape of the charge distribution.



Chapter Goal: To understand and apply Gauss's law.

Chapter 28. Gauss's Law

Topics:

- Symmetry
- The Concept of Flux
- Calculating Electric Flux
- Gauss's Law
- Using Gauss's Law
- Conductors in Electrostatic Equilibrium

Chapter 28. Gauss's Law

Topics:

- Symmetry
- The Concept of Flux
- Calculating Electric Flux
- Gauss's Law
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- Conductors in Electrostatic Equilibrium

Last lecture

Chapter 28. Gauss's Law

Topics:

- Symmetry
- The Concept of Flux
- Calculating Electric Flux
- Gauss's Law
- Using Gauss's Law
- Conductors in Electrostatic Equilibrium

Last lecture

Today

Chapter 28. Reading Quizzes

The amount of electric field passing through a surface is called

A. Electric flux.
B. Gauss's Law.
C. Electricity.
D. Charge surface density.
E. None of the above.

The amount of electric field passing through a surface is called

✔ **A. Electric flux.**
B. Gauss's Law.
C. Electricity.
D. Charge surface density.
E. None of the above.

Gauss’s law is useful for calculating electric fields that are

A. symmetric.
B. uniform.
C. due to point charges.
D. due to continuous charges.

Gauss's law is useful for calculating electric fields that are

✔**A. symmetric.**
B. uniform.
C. due to point charges.
D. due to continuous charges.

Gauss's law applies to

A. lines.
B. flat surfaces.
C. spheres only.
D. closed surfaces.

Gauss's law applies to

A. lines.
B. flat surfaces.
C. spheres only.
✔ **D. closed surfaces.**

The electric field inside a conductor in electrostatic equilibrium is

A. uniform.
B. zero.
C. radial.
D. symmetric.

The electric field inside a conductor in electrostatic equilibrium is

A. uniform.
✔ **B. zero.**
C. radial.
D. symmetric.

Learning Objectives

- To understand the importance of symmetry
- To calculate electric flux
- To use Gauss's law to derive electric fields of interest
- To study the properties of conductors in electrostatic equilibrium

Why this (Gauss's Law) is difficult

- Requires reasoning with the concept of symmetry
- Presupposes a basic understanding of electric fields
- Uses surface (vector) integrals

- Most students are not familiar with reasoning by symmetry, have just learned about electric fields and have not studied vector integrals

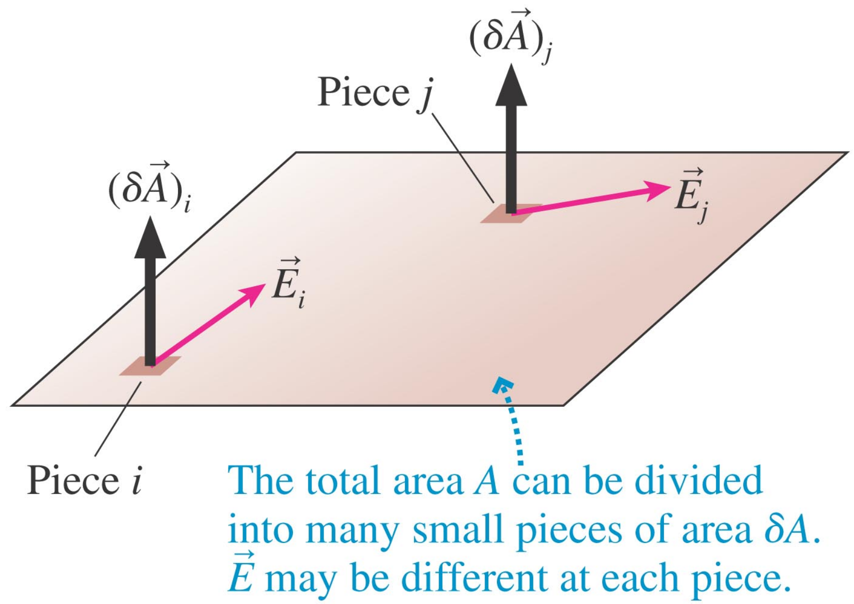
Electric Flux of a non-Uniform Field

- We just did an example of the electric flux through a surface of a uniform field

$$\Phi_e = \vec{E} \cdot \vec{A}$$

- What if the electric field is not uniform
  - Evaluate intergral over the surface

$$\Phi_e = \int_{\text{surface}} \vec{E} \cdot d\vec{A}$$



Flux Through a Curved Surface

- Electric Flux

$$\Phi_e = \int_{\text{surface}} \vec{E} \cdot d\vec{A}$$

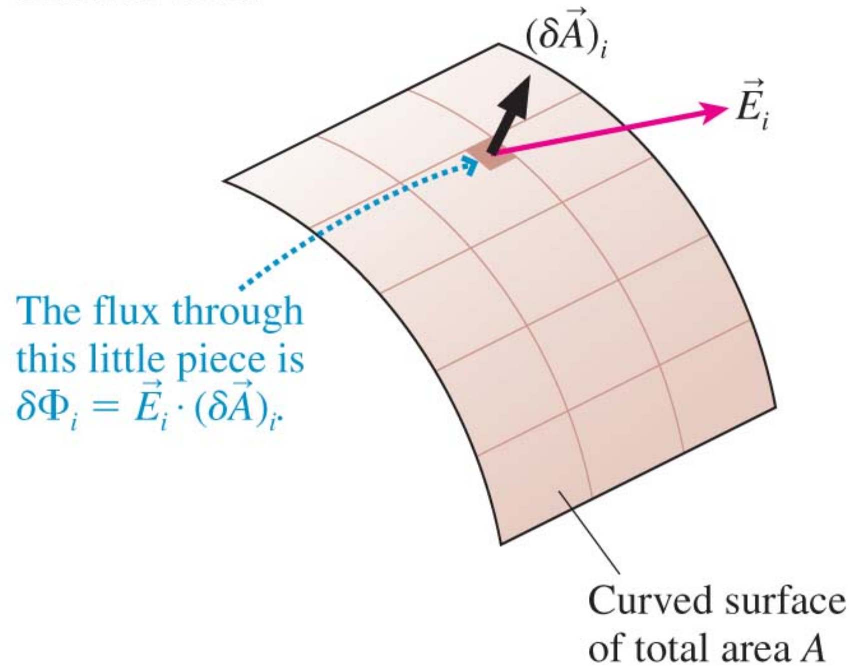
- If electric field is constant then

$$\Phi_e = \int_{surface} \vec{E} \cdot d\vec{A} = E \cos\vartheta \int_{surface} dA$$

- The last integral is just the sum of all the little areas which equals the total surface area A

$$A = \int_{surface} dA$$

FIGURE 28.15 A curved surface in an electric field.



The Electric Flux through a Closed Surface

The electric flux through a closed surface is

$$\Phi_e = \oint \vec{E} \cdot d\vec{A}$$

The electric flux is still the summation of the fluxes through a vast number of tiny pieces, pieces that now cover a closed surface.

NOTE: A closed surface has a distinct inside and outside. The area vector *dA* is defined to always point *toward the outside.* This removes an ambiguity that was present for a single surface, where *dA* could point to either side.

Gauss's Law

For any *closed* surface enclosing total charge Q_{in},the net electric flux through the surface is

$$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$$

This result for the electric flux is known as **Gauss's Law.**

Using Gauss's Law

1. Gauss's law applies only to a *closed* surface, called a Gaussian surface.
2. A Gaussian surface is not a physical surface. It need not coincide with the boundary of any physical object (although it could if we wished). It is an imaginary, mathematical surface in the space surrounding one or more charges.
3. We can't find the electric field from Gauss's law alone. We need to apply Gauss's law in situations where, from symmetry and superposition, we already can guess the *shape* of the field.

Show relationship between Coulomb’s Law and Gauss’s Law

PROBLEM-SOLVING STRATEGY 28.1 **Gauss's law**

MODEL Model the charge distribution as a distribution with symmetry.

VISUALIZE Draw a picture of the charge distribution.

- Determine the symmetry of its electric field.
- Choose and draw a Gaussian surface with the *same symmetry.*
- You need not enclose all the charge within the Gaussian surface.
- Be sure every part of the Gaussian surface is either tangent to or perpendicular to the electric field.

SOLVE The mathematical representation is based on Gauss's law

$$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$$

- Use Tactics Boxes 28.1 and 28.2 to evaluate the surface integral.

ASSESS Check that your result has the correct units, is reasonable, and answers the question.

Electric Field Outside a Sphere of Charge

- Last week (chapter 27) we asserted that the electric field outside a sphere with total charge Q is the same as the field of a point charge Q at the center of the sphere.

$$\vec{E}_{\text{sphere}} = \frac{Q}{4\pi\epsilon_0 r^2}\hat{r} \qquad \text{for } r \geq R$$

  - Now we will prove using Gauss's Law

Let us do 3 examples of Calculating Electric Field using Gauss's Law

Point Charge

Exterior to charged sphere

Uniformly charged sphere

Use Gauss's law to determine the electric field outside a sphere of total charge Q

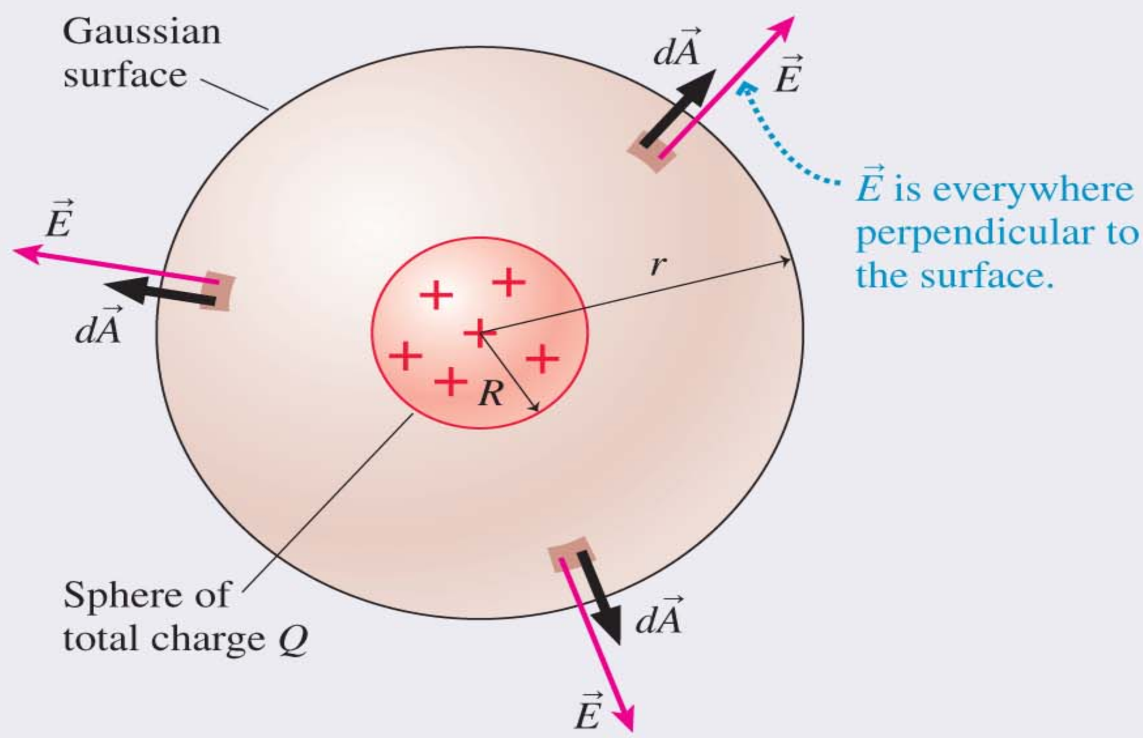
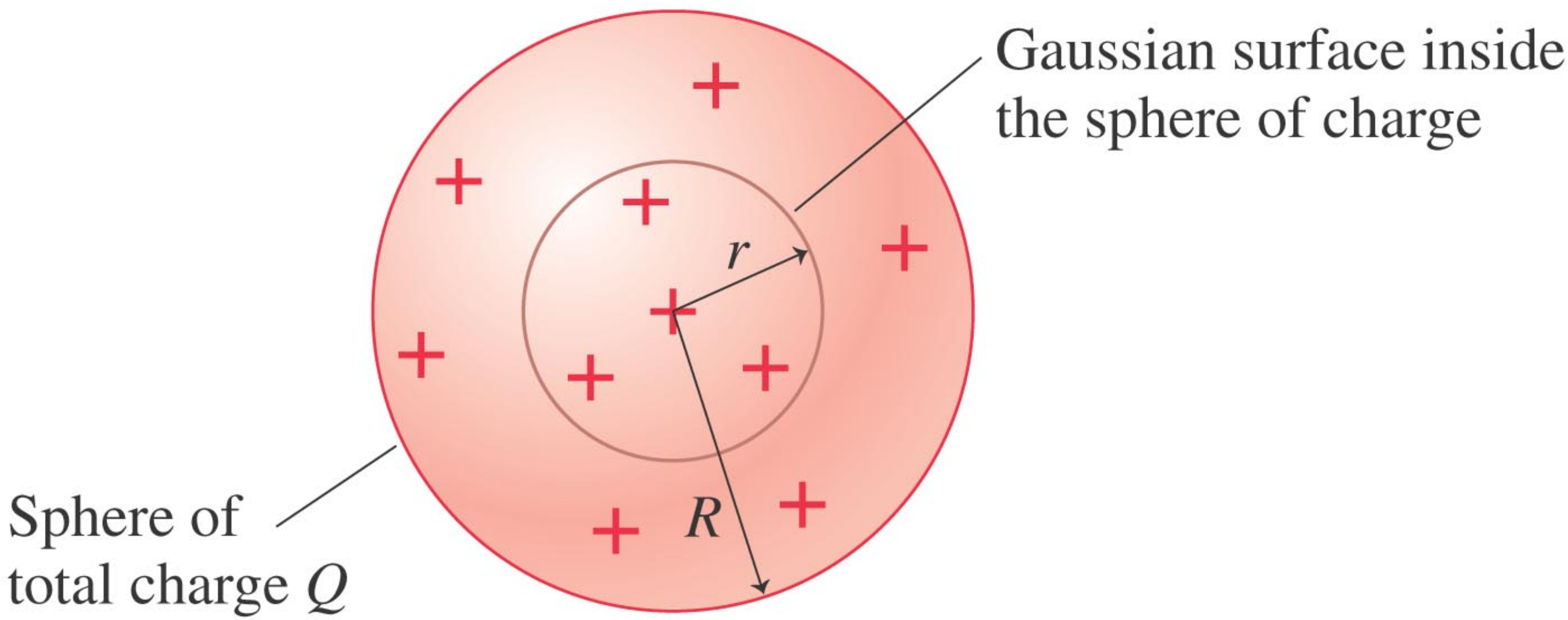
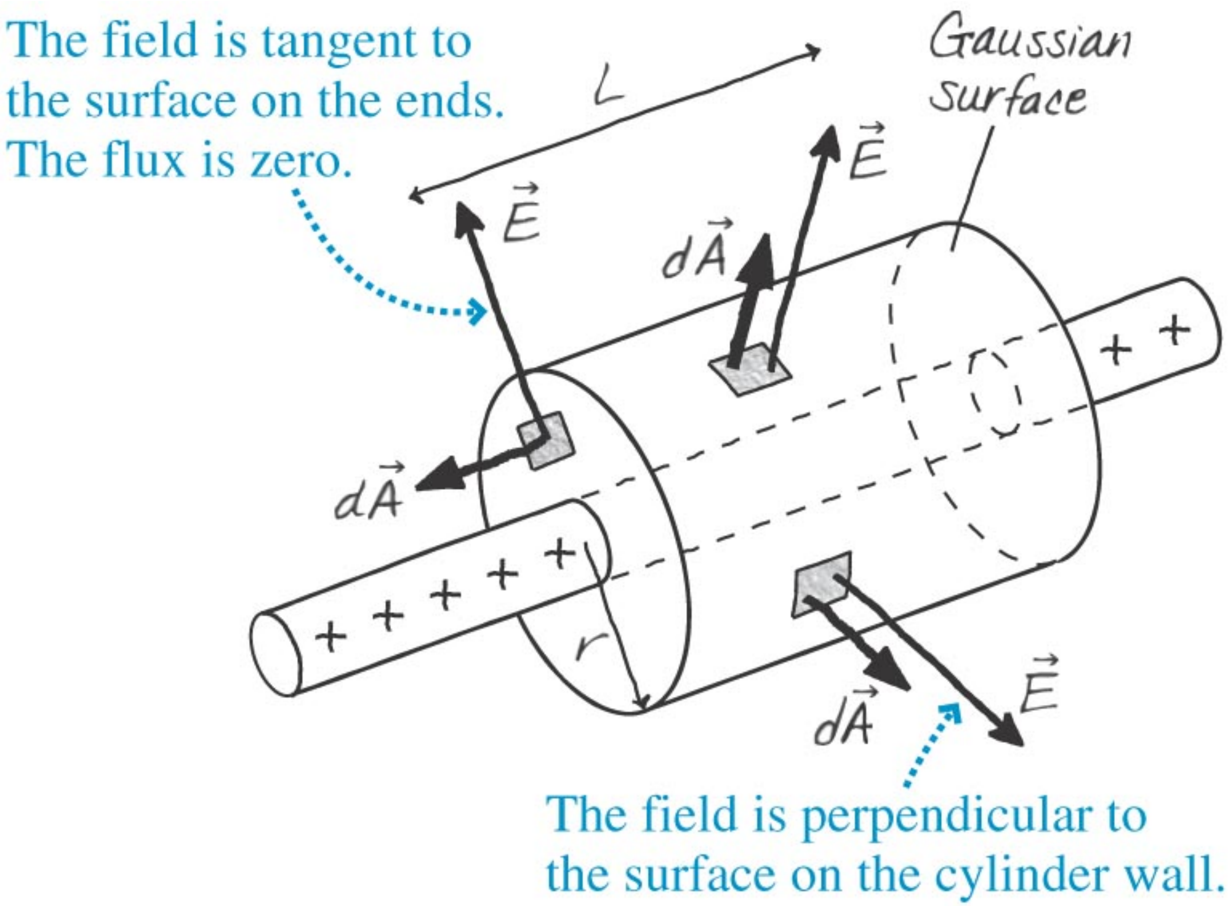


FIGURE 28.23 A spherical Gaussian surface surrounding a sphere of charge.

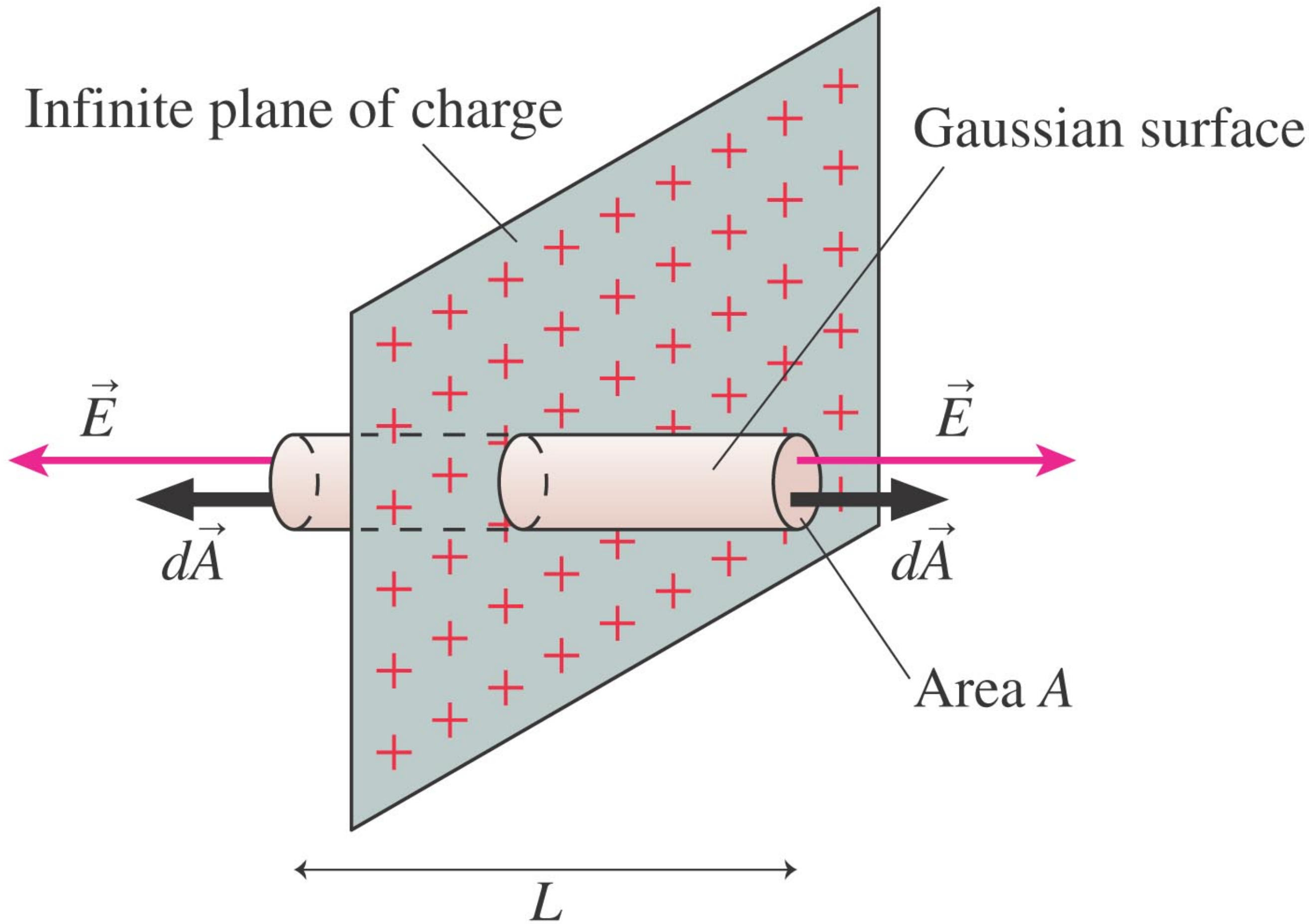
What is the electric field inside a UNIFORMLY charged sphere?



Use Gauss's law to determine Electric field of uniformly charged wire



Use Gauss's law to determine electric field of infinite plane



Conductors in Electrostatic Equilibrium

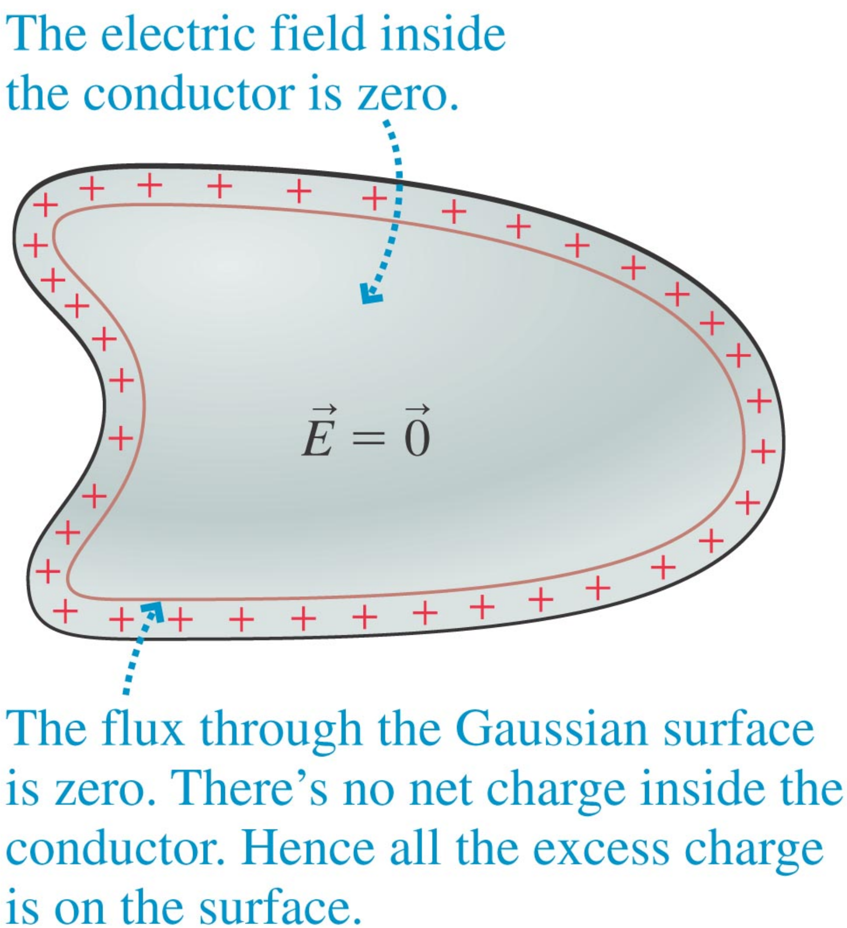
The electric field is zero at all points within a conductor in electrostatic equilibrium.

If this weren't true, the electric field would cause the charge carriers to move and thus violate the assumption that all the charges are at rest.

The electric field at the surface of a charge carrier is

$$\vec{E}_{\text{surface}} = \left(\frac{\eta}{\epsilon_0}, \text{ perpendicular to surface} \right)$$

where η is the surface charge density of the conductor.


The electric field inside the conductor is zero.
$\vec{E} = \vec{0}$
The flux through the Gaussian surface is zero. There's no net charge inside the conductor. Hence all the excess charge is on the surface.

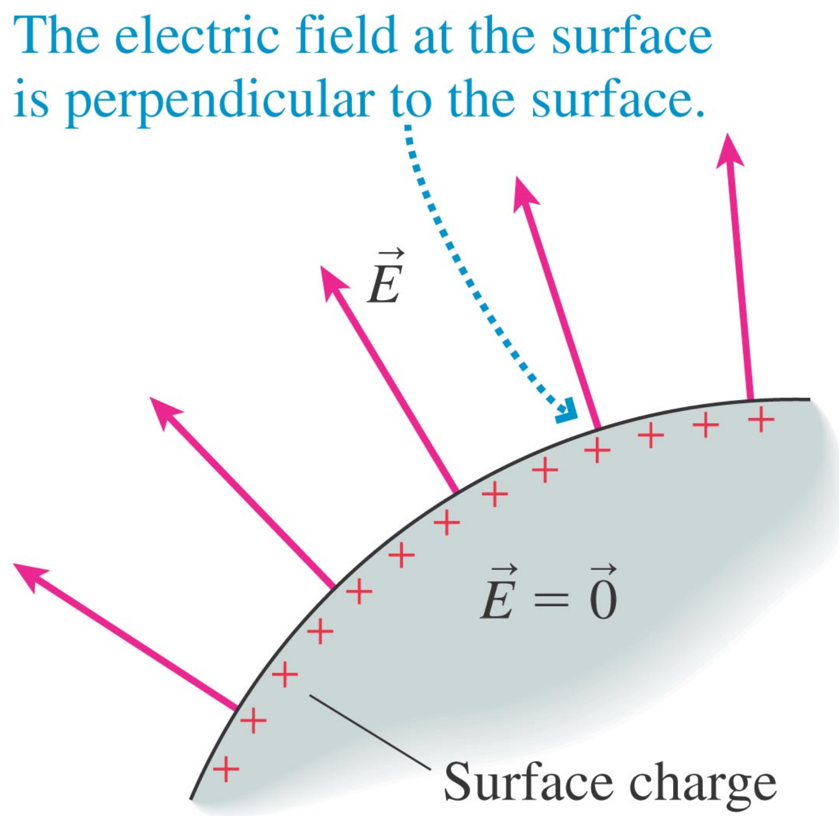
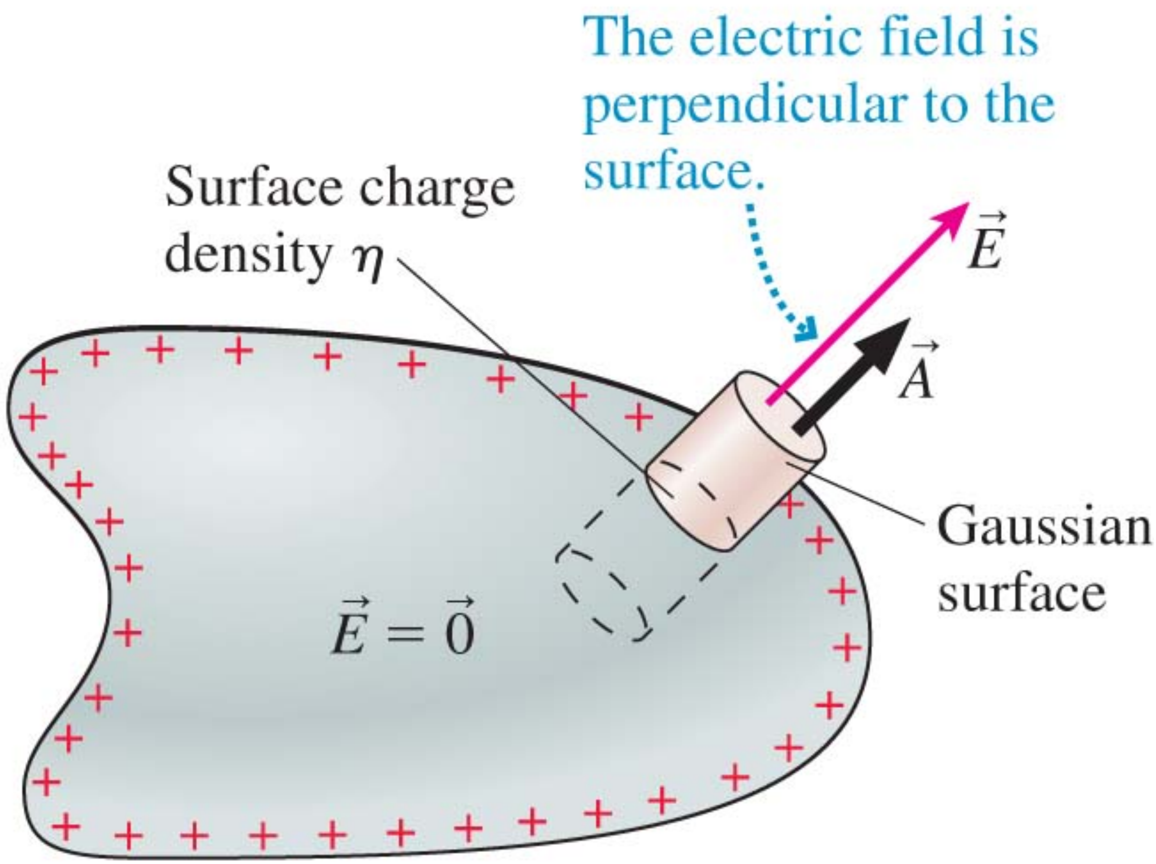

The electric field at the surface is perpendicular to the surface.
$\vec{E}$
$\vec{E} = \vec{0}$
Surface charge

FIGURE 28.30 A Gaussian surface extending through the surface of the conductor has a flux only through the outer face.



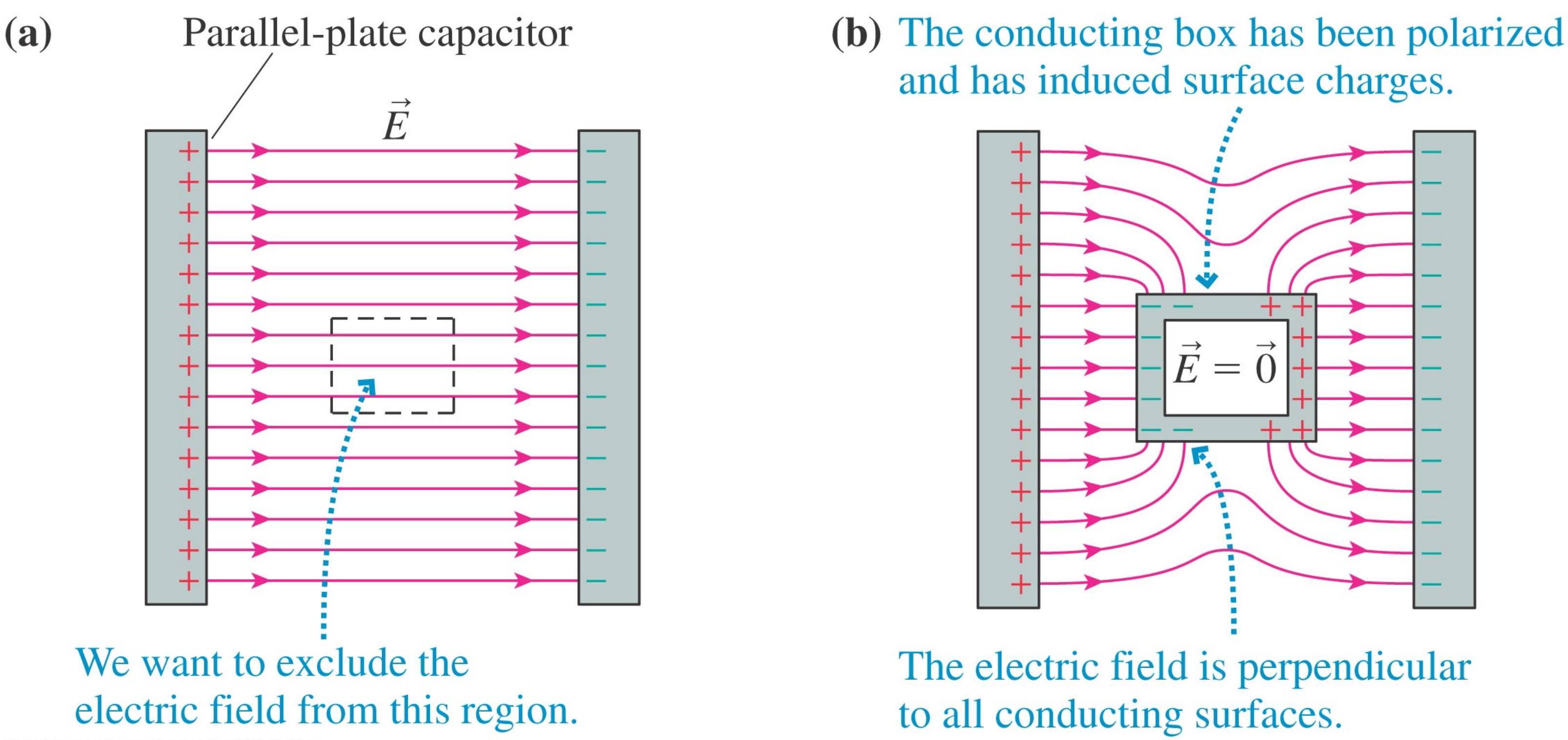
Tactics: Finding the electric field of a conductor in electrostatic equilibrium

TACTICS BOX 28.3 **Finding the electric field of a conductor in electrostatic equilibrium**

1. The electric field is zero at all points within the volume of the conductor.
2. Any excess charge resides entirely on the *exterior* surface.
3. The external electric field at the surface of a charged conductor is perpendicular to the surface and of magnitude η/ϵ_0, where η is the surface charge density at that point.
4. The electric field is zero inside any hole within a conductor unless there is a charge in the hole.

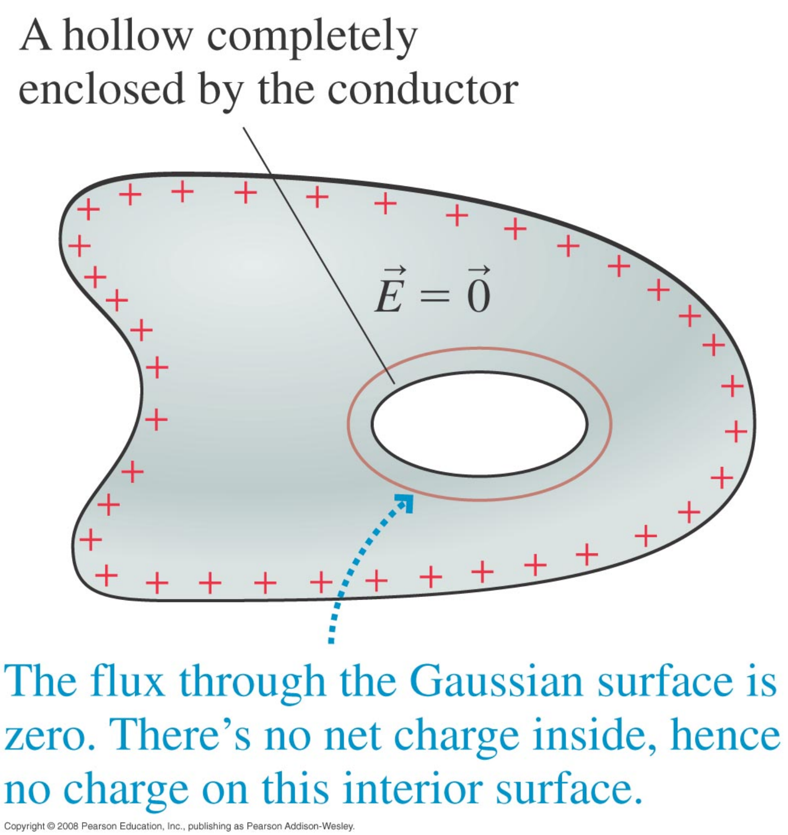
Exercises 20–24

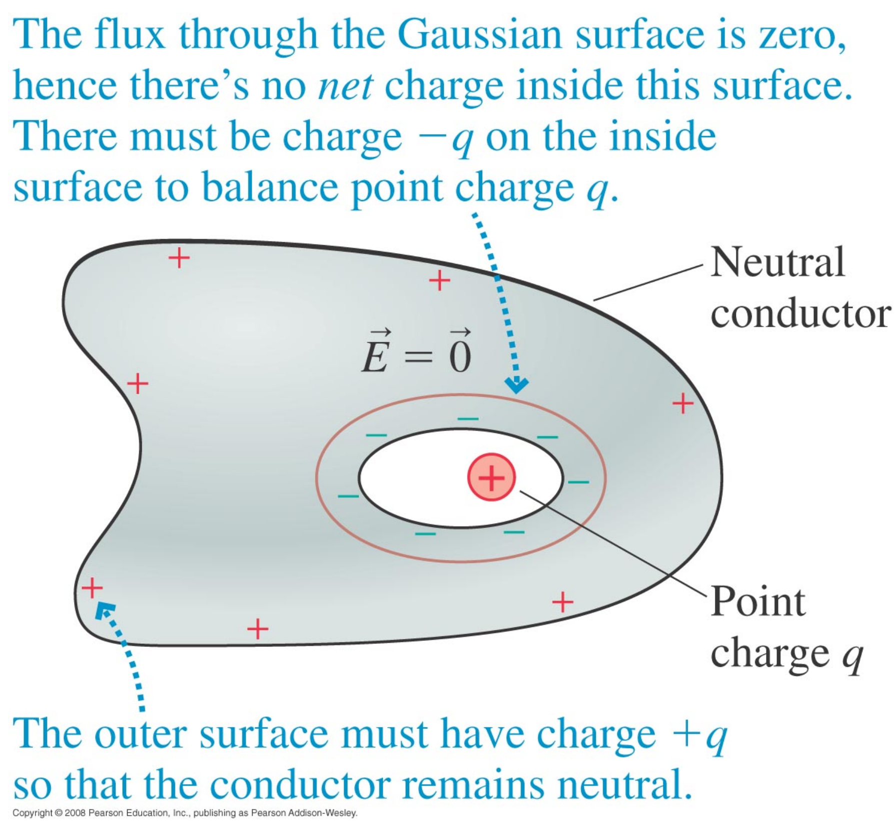
“Screening” of Electric Field



- Electric Field can be excluded from a region of space by surrounding it with a conducting box

Conductor in Electrostatic Equilbrium with hole





EXAMPLE 28.7 The electric field at the surface of a charged metal sphere

QUESTION:

EXAMPLE 28.7 The electric field at the surface of a charged metal sphere

A 2.0-cm-diameter brass sphere has been given a charge of 2.0 nC. What is the electric field strength at the surface?

Chapter 28. Summary Slides

General Principles

Gauss's Law

For any *closed* surface enclosing net charge Q_{in}, the net electric flux through the surface is

$$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$$

The electric flux Φ_e is the same for *any* closed surface enclosing charge Q_{in}.

General Principles

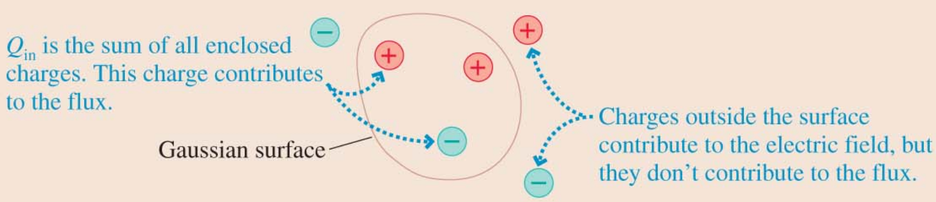
Symmetry

The symmetry of the electric field must match the symmetry of the charge distribution.

In practice, Φ_e is computable only if the symmetry of the Gaussian surface matches the symmetry of the charge distribution.

Important Concepts

Charge creates the electric field that is responsible for the electric flux.

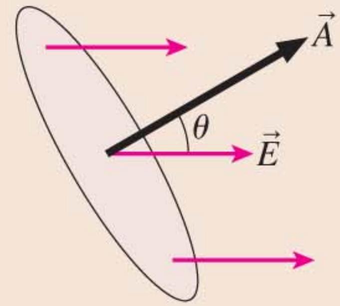


Important Concepts

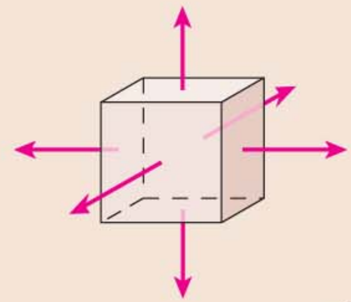
Flux is the amount of electric field passing through a surface of area A:

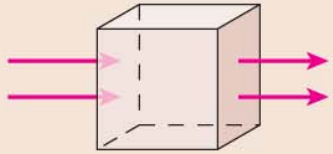
$$\Phi_e = \vec{E} \cdot \vec{A}$$

where $\vec{A}$ is the **area vector.**



For closed surfaces:
A net flux in or out indicates that the surface encloses a net charge. Field lines through but with no *net* flux mean that the surface encloses no *net* charge.



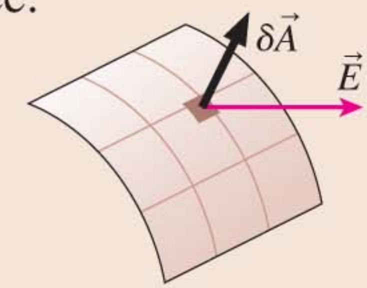


Important Concepts

Surface integrals calculate the flux by summing the fluxes through many small pieces of the surface:

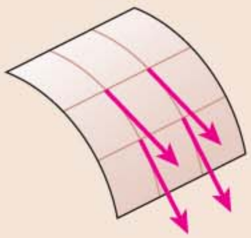
$$\Phi_e = \sum \vec{E} \cdot \delta\vec{A}$$

$$\rightarrow \int \vec{E} \cdot d\vec{A}$$



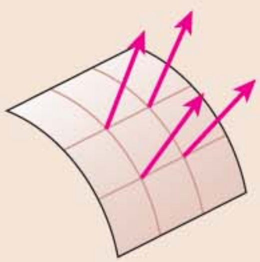
Two important situations:
If the electric field is everywhere tangent to the surface, then

$$\Phi_e = 0$$



If the electric field is everywhere perpendicular to the surface *and* has the same strength E at all points, then

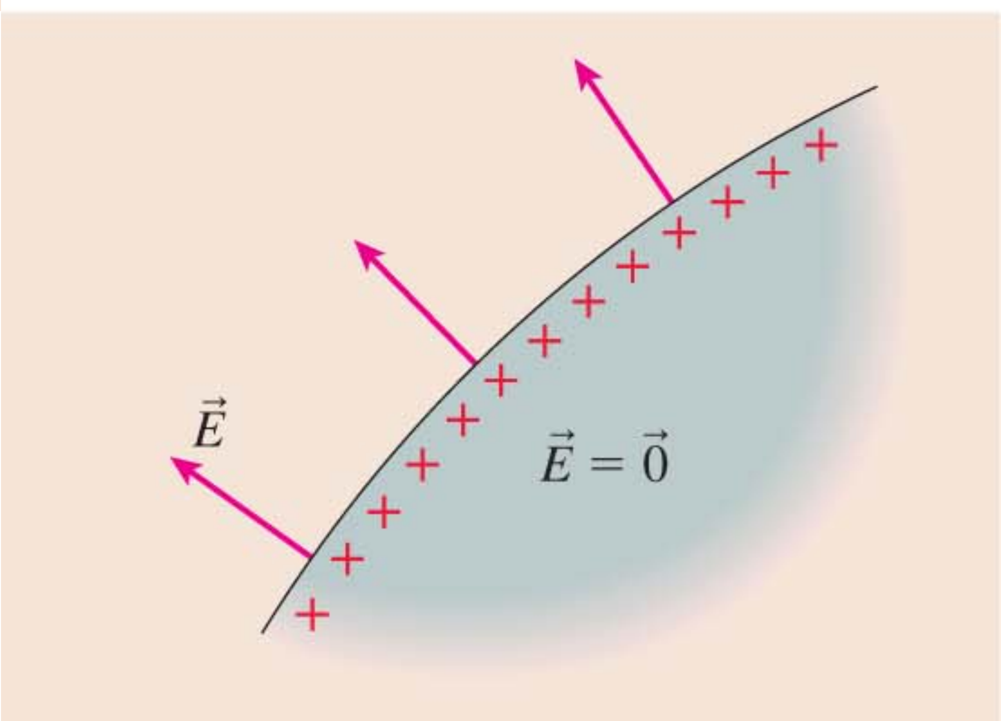
$$\Phi_e = EA$$



Applications

Conductors in electrostatic equilibrium

- The electric field is zero at all points within the conductor.
- Any excess charge resides entirely on the exterior surface.
- The external electric field is perpendicular to the surface and of magnitude η/ϵ_0, where η is the surface charge density.
- The electric field is zero inside any hole within a conductor unless there is a charge in the hole.



Brief Preview of Chapter 29. The Electric Potential

Topics:

- Electric Potential Energy
- The Potential Energy of Point Charges
- The Potential Energy of a Dipole
- The Electric Potential
- The Electric Potential Inside a Parallel-Plate Capacitor
- The Electric Potential of a Point Charge
- The Electric Potential of Many Charges

FIGURE 29.3 Potential energy is transformed into kinetic energy as a particle moves in a gravitational field.

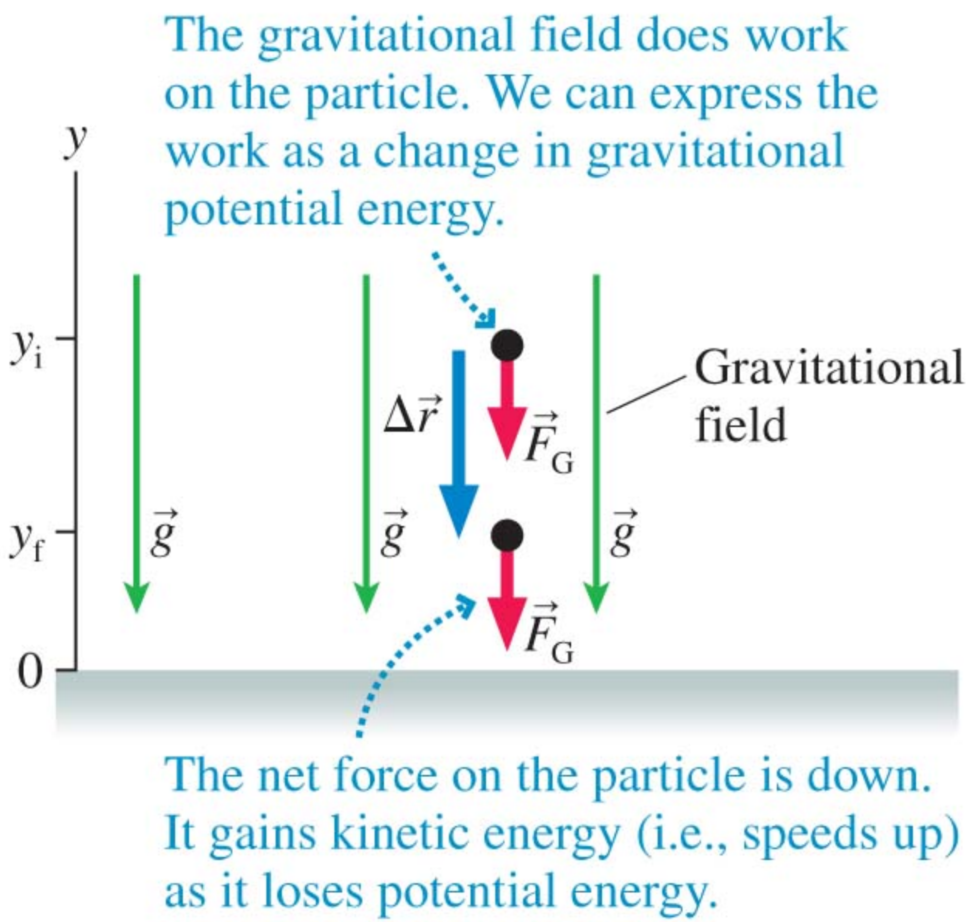
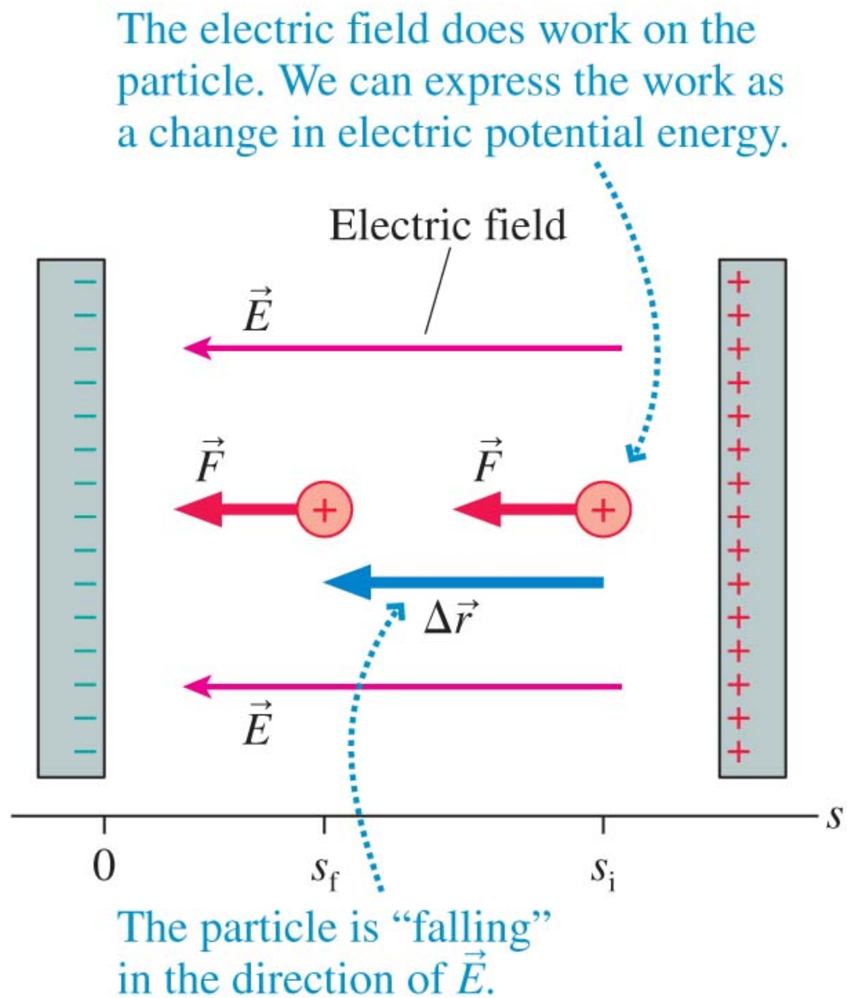


FIGURE 29.4 The electric field does work on the charged particle.



Electric Potential Energy

The **electric potential energy** of charge q in a uniform electric field is

$$U_{\text{elec}} = U_0 + qEs$$

where s is measured from the negative plate and U_0 is the potential energy at the negative plate ($s = 0$). It will often be convenient to choose $U_0 = 0$, but the choice has no physical consequences because it doesn't affect ΔU_{elec}, the *change* in the electric potential energy. Only the *change* is significant.

The Potential Energy of Point Charges

Consider two point charges, q_1 and q_2, separated by a distance r. The electric potential energy is

$$U_{\text{elec}} = \frac{Kq_1q_2}{r} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r} \qquad \text{(two point charges)}$$

This is explicitly the energy of *the system*, not the energy of just q_1 or q_2.

Note that the potential energy of two charged particles approaches zero as $r \to \infty$.