# Electricity and Magnetism
# Implications of Gauss's Law
# Electric Potential Energy

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# Last time

- using Gauss's law

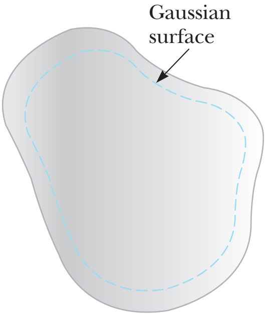
# Overview

- implications of Gauss' law
- electric potential energy

# Some Implications of Gauss's Law

## Excess Charge on a Conductor

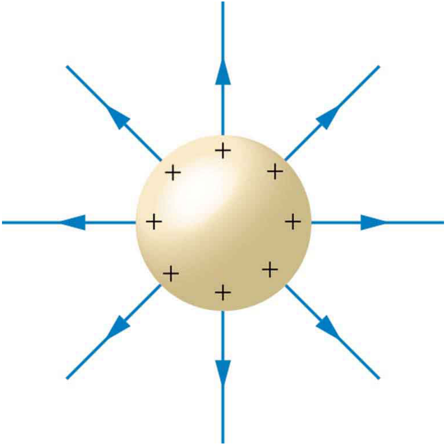
We can argue that if an excess charge is placed on an isolated conductor, that amount of charge will move entirely to the surface of the conductor. None of the excess charge will be found within the body of the conductor.




$\mathbf{E} = 0$ inside the conductor, so the Gaussian surface shown cannot enclose a net charge. $\Rightarrow$ All excess charge is on the surface.

# Charges and Conductors

Excess charge sits on the outside surface of a conductor.

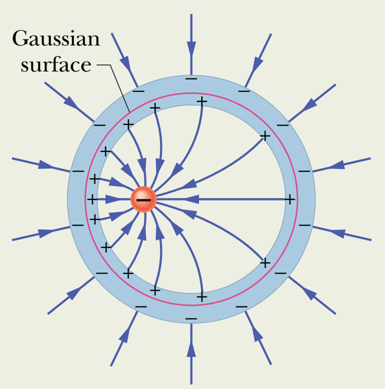



Close to the surface, the electric field lines are perpendicular to the surface.

[1]Figure from OpenStax College Physics.

# Some Implications of Gauss's Law

## Faraday Ice Pail




A charge placed inside a conducting shell appears on the outside of the conductor.

($\mathbf{E} = 0$ for the Gaussian surface shown.)

# Questions about applying Gauss's law

What shape would you pick for the Gaussian surface if you wanted to find the electric field at a perpendicular distance $r$ from a line charge of uniform charge density $\lambda$?

**(A)** cube

**(B)** rectangle

**(C)** sphere

**(D)** cylinder

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# Questions about applying Gauss's law

What shape would you pick for the Gaussian surface if you wanted to find the electric field at a distance $r$ from the center of a spherical conductor carrying a net charge?

**(A)** cube

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# Questions about applying Gauss's law

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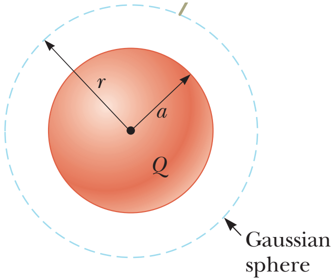
# Some Implications of Gauss's Law

## Uniform Shell of Charge

- A shell of uniform charge attracts or repels a charged particle that is outside the shell as if all the shell's charge were concentrated at the center of the shell.
- If a charged particle is located inside a shell of uniform charge, there is no electrostatic force on the particle from the shell.

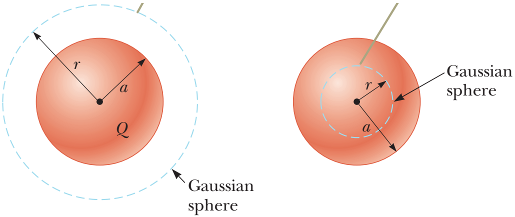
# Uniform Sphere of Charge




Consider a uniform insulating sphere of charge, radius $a$, charge density $\rho$, total charge $Q$.

How does the electric field strength change with distance from the center?

# Uniform Sphere of Charge




$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{q_{enc}}{\epsilon_0}$$

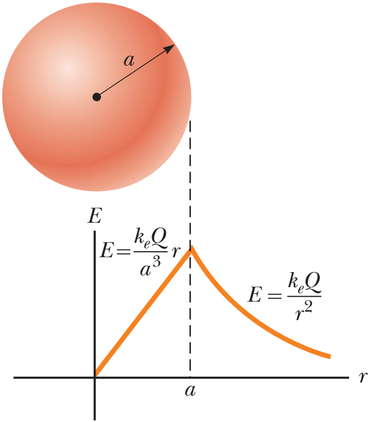
Outside sphere (for $r > a$):

$$\begin{aligned} 4\pi r^2 E &= \frac{1}{\epsilon_0} Q \\ E &= \frac{Q}{4\pi\epsilon_0 r^2} \\ E &= \frac{k_e Q}{r^2} \end{aligned}$$

Inside sphere (for $r < a$):

$$\begin{aligned} 4\pi r^2 E &= \frac{1}{\epsilon_0} \left( \frac{4}{3} \pi r^3 \rho \right) \\ E &= \frac{\rho r}{3\epsilon_0} \\ &= \frac{k_e Q r}{a^3} \end{aligned}$$

# Uniform Sphere of Charge

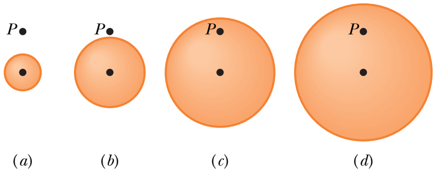



Outside the sphere, the electric field is the same as for a point charge, strength $Q$, located at the center of the sphere.

Inside the sphere, field varies linearly in the distance from the center and all charge outside the distance $r$ cancels out!

# Question

The figure shows four solid spheres, each with charge $Q$ uniformly distributed through its volume.




Rank the spheres according to their volume charge density, greatest first. The figure also shows a point $P$ for each sphere, all at the same distance from the center of the sphere.

**(A)** a, b, c, d

**(B)** d, c, b, a

**(C)** a and b, c, d

**(D)** a, b, c and d

[1] Halliday, Resnik, Walker

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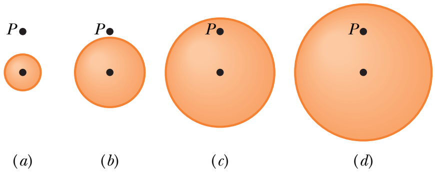


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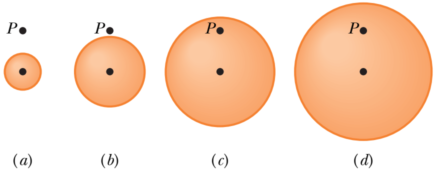


Rank the spheres according to the magnitude of the electric field they produce at point $P$, greatest first.

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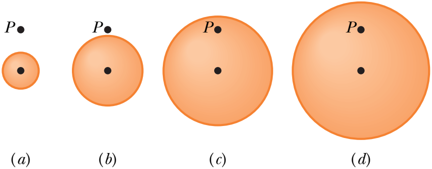


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# Potential Energy

What is the potential energy that a charge has due to the electric field of other charges in its vicinity?

# Potential Energy

Recall from 4A, there are many kinds of potential or stored energy:

- gravitational ($U = mgh$, or $U = -\frac{GMm}{r}$)
- elastic ($U = \frac{1}{2}kx^2$)

**potential energy**

energy that a system has as a result of its configuration; stored energy; this always results from the action of a *conservative force*

**mechanical energy**

the sum of a system's kinetic and potential energies, $E_{\text{mech}} = K + U$

# Conservative Forces

**Conservative force**

acts on a part of the system such that following any *closed path* (one that ends back at the starting point) the work done on the system by the force is **zero**.

Conservative forces are forces that do not dissipate energy.

They *conserve* mechanical energy.

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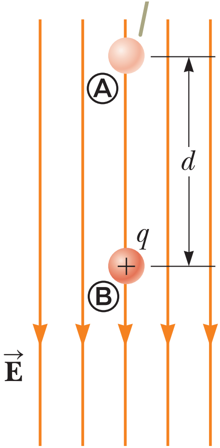
For conservative forces, it is possible to define a potential energy function.

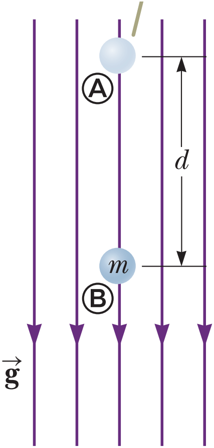
$$W_{\text{int}} = -\Delta U$$

where $W_{\text{int}}$ is the work done *by* the conservative force internal to the system and $\Delta U$ is the change in the potential energy of the system.

# Example: Potential Energy in a Uniform Field

Potential energy change of a charge $q$ moving a distance $d$?
(Similar to lifting/lowering a mass.)




$|\Delta U_E| = |q|Ed$

$|\Delta U_g| = mgd$

# Summary

- implications of Gauss's law
- Faraday ice pail
- electric potential energy

**Homework** Serway & Jewett:

- PREVIOUS: Ch 24, Section Qs: 25, 29, 31, 33, 39, 41, 43, 55, 61, 65
- NEW: Ch 25, onward from page 767. Obj. Qs: 5, 9, 11; Concep. Qs: 3; Problems: 31, 33, 35, 55, 57