Conductors

Conductors and insulators

1) Any material is made of positive and negative electric charges, even if it may be macroscopically neutral.
2) These electric charges will react in the presence of an electric field.
3) This reaction will produce different behaviours for conductors and insulators.

- Conductor

The external e^- are not linked to the nucleus.

They are free to move throughout the material.

They can be transferred between objects in contact.

- Insulator

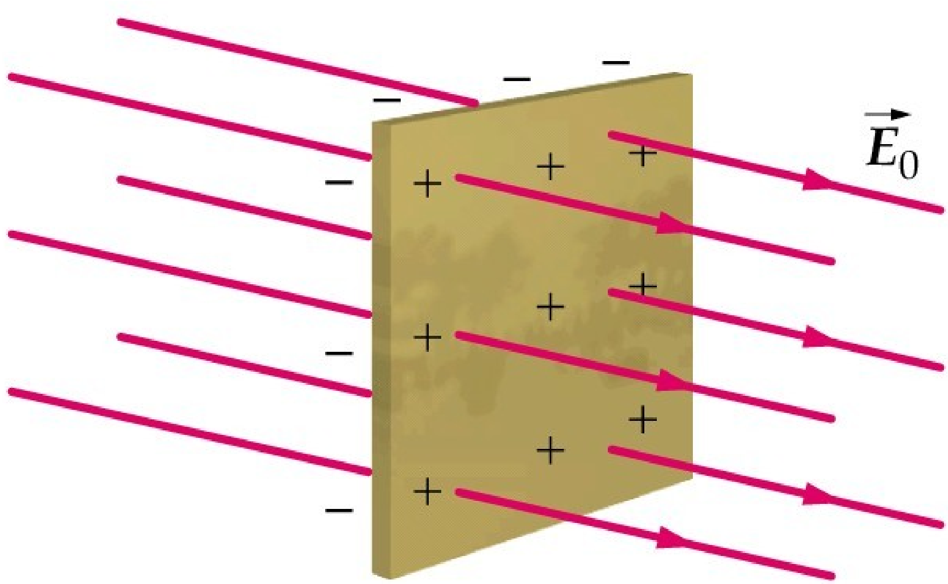
All e^- are linked to the nucleus.

They are not free to move.

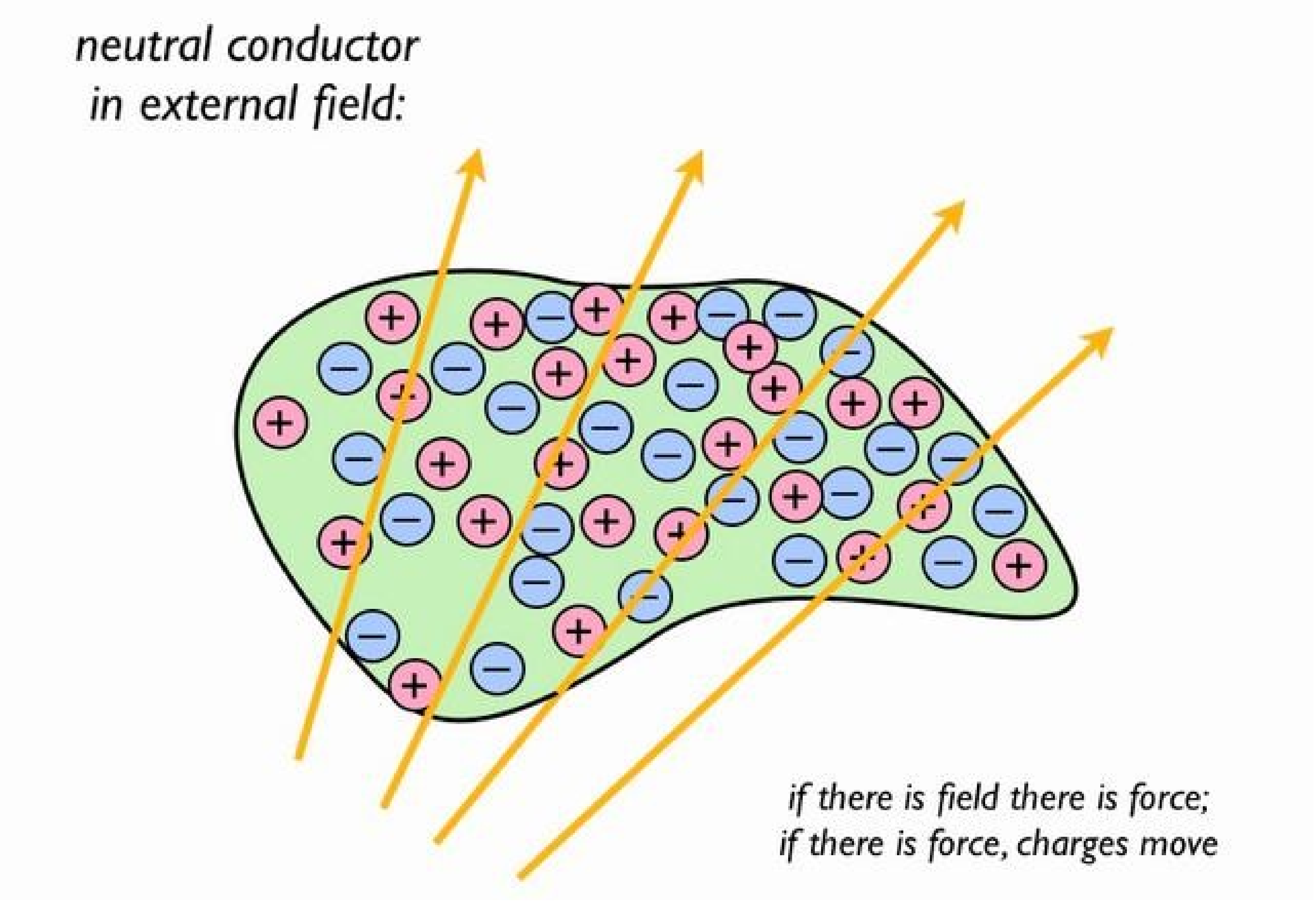
Conductors in electrostatic equilibrium

When an **E** goes through a conductor, the electrons in the conductor redistribute <u>until the field cancels inside</u>.

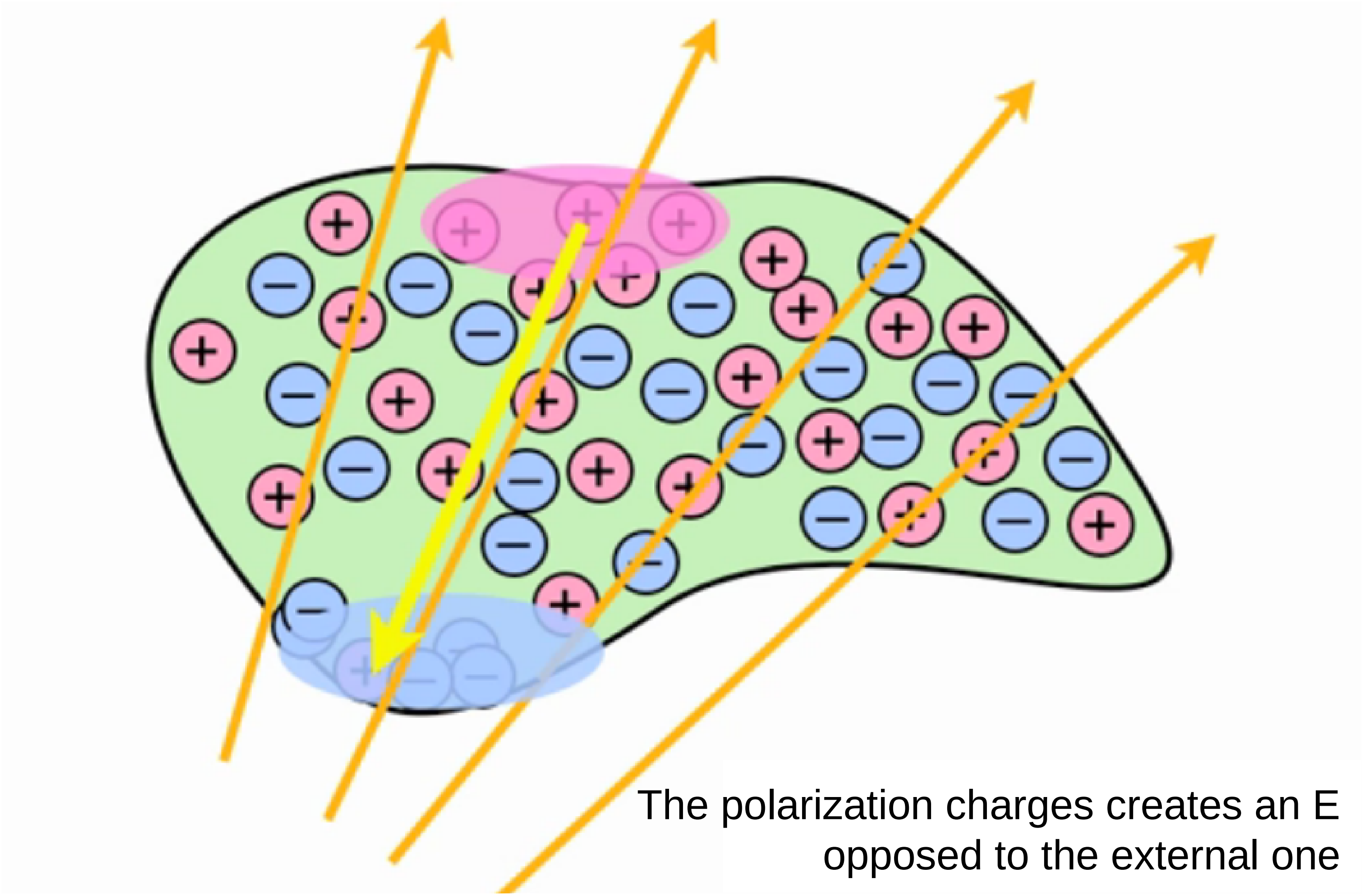
When equilibrium is reached (charges do not move any more), the conductor is said to be in electrostatic equilibrium.



Conductors in electrostatic equilibrium

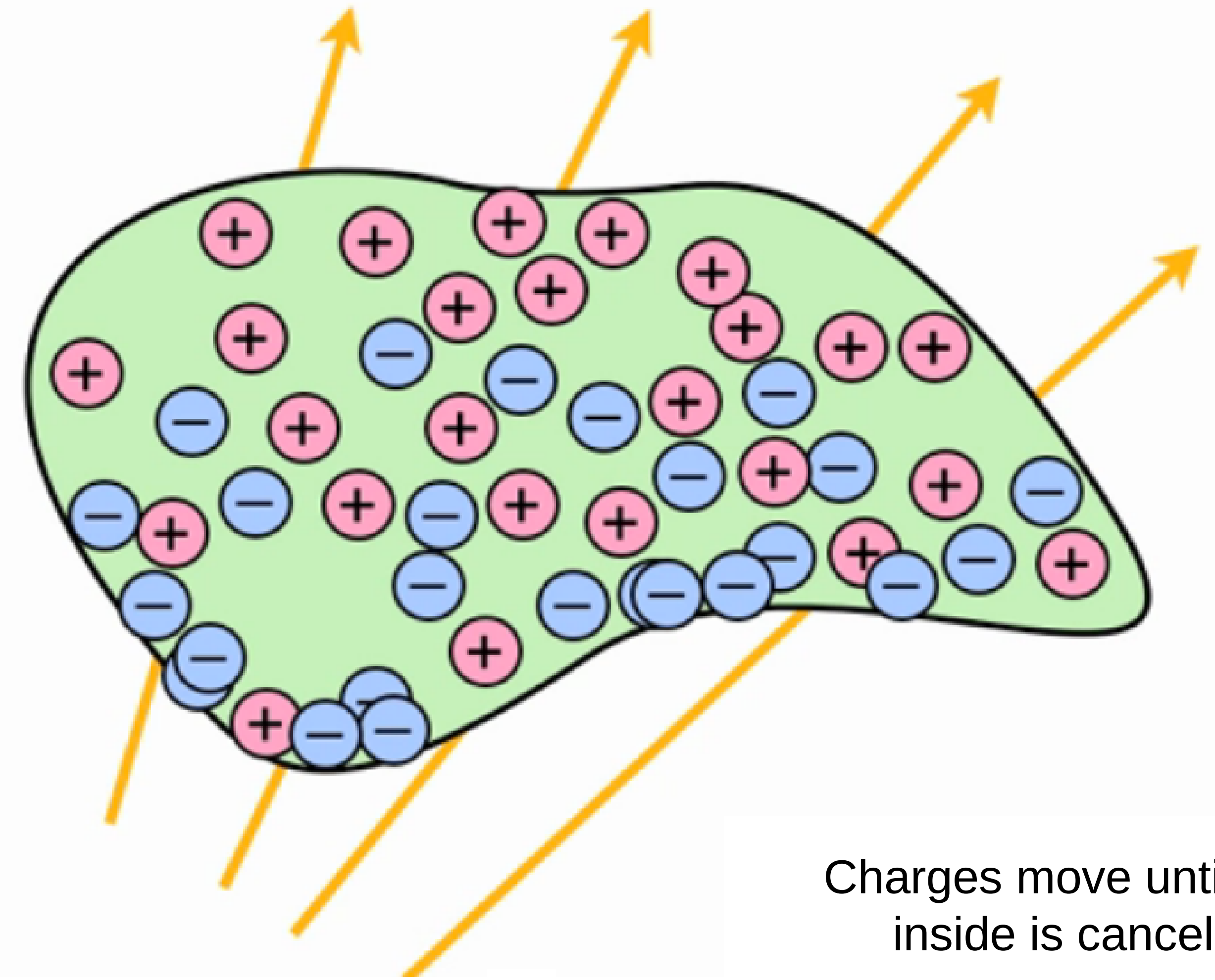


Conductors in electrostatic equilibrium



The polarization charges creates an E
opposed to the external one

Conductors in electrostatic equilibrium



Charges move until the E
inside is cancelled out

Conductors in electrostatic equilibrium

Characteristics of conductors in electrostatic equilibrium:

- The electric field inside the conductor is 0.
- The electric potential inside the conductor is constant.
- The excess charge is located at the surface ($E_{ins} = 0 \rightarrow Q_{ins} = 0$).
- At the surface of the conductor, E is perpendicular to the surface and its magnitude at each point of the surface is σ/ε_0.

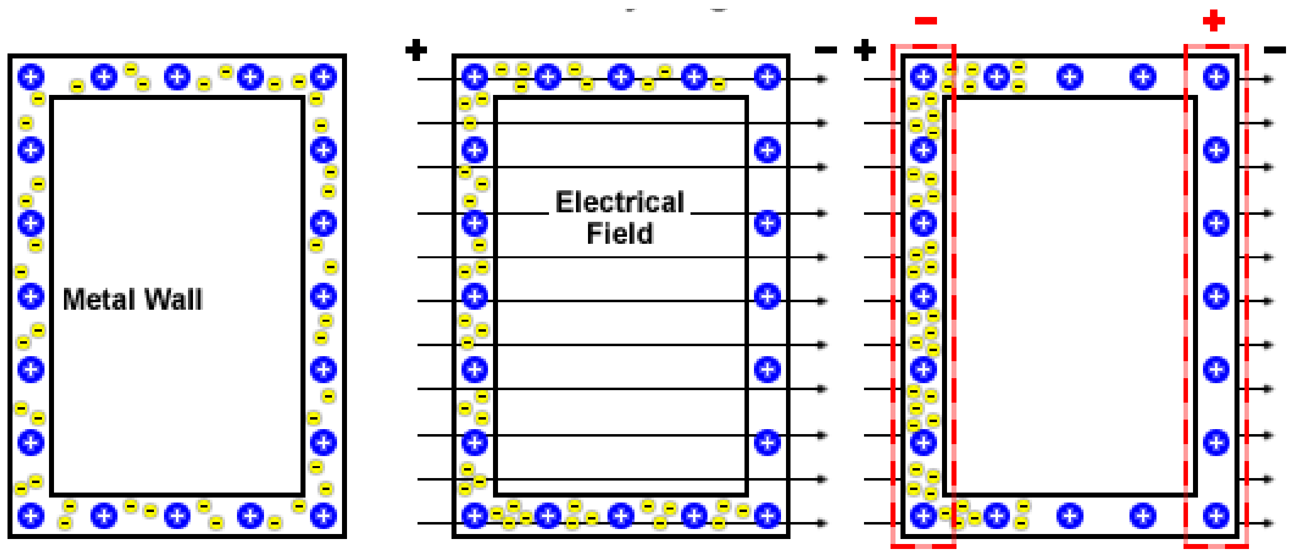
NOTE THAT if σ is not constant along the surface, E will not be constant.

- The surface of the conductor is equipotential.

Conductors in electrostatic equilibrium

EXAMPLES: a) Faraday Cage: Uncharged hollow conductor in the presence of an external field:

Structure that protects what is inside from an external field (or the outside from an internal field).



Faraday Cage in the absence of an electrical field.

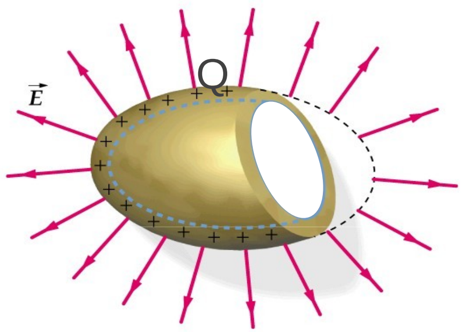
The charged particles in the wall of the Faraday cage respond to an applied electrical field.

Electrical fields generated inside the wall cancel out the applied field, neutralizing the interior of the cage.

The cavity is shielded from the external field.

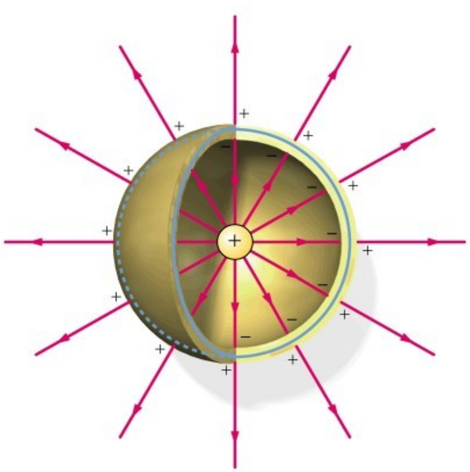
Conductors in electrostatic equilibrium

EXAMPLES: b) Hollow conductor with charge Q



- The charge on the external surface is Q
- The charge on the internal surface is 0
- E=0 both in the cavity and inside the conductor
- V=constant inside

c) Hollow uncharged conductor with a charge (q) inside the hole



- The charge in the cavity (+ q) induces a charge – q on the internal surface of the conductor.
- The charge on the external surface is + q.
- E is NOT zero inside the cavity.
- E = 0 inside the conductor.
- E outside is due to q.
- V=Const. in the conductor.

Conductors in electrostatic equilibrium

Problem:

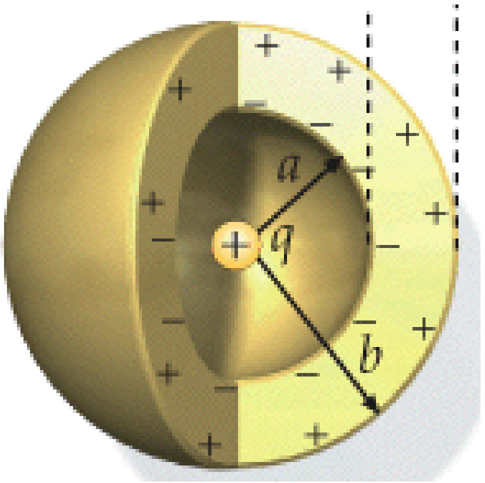
1. A discharged spherical conductor has an inner radius a and an outer radius b. A positive point charge q is placed in the cavity at the centre of the sphere.

a) Is the hollow conductor charged? Is it polarized?

b) Find the charge on the internal and external surfaces of the conductor.

c) Find the charge densities at each surface.

d) Find the electric field and the electric potential outside the sphere, inside the sphere and in the cavity (suppose V=0 when $r \rightarrow \infty$).



Conductors in electrostatic equilibrium

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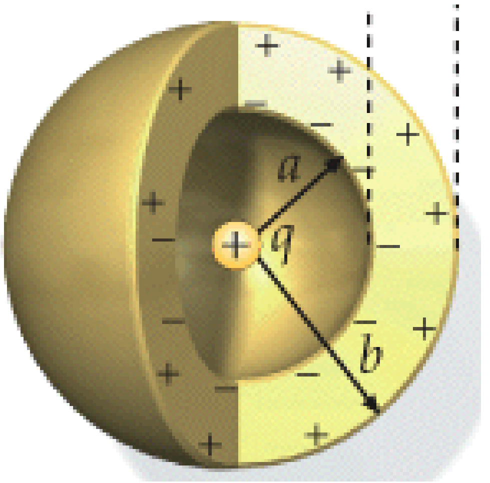
a) It is not charged as Qnet = 0, but it is polarized.

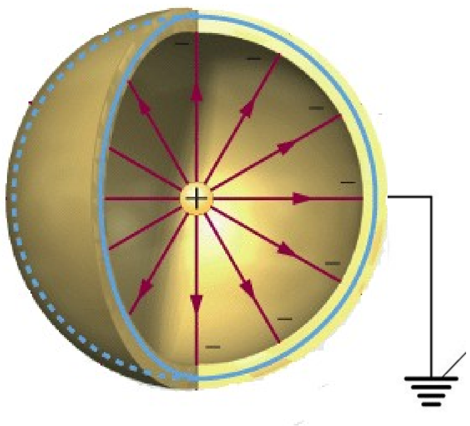
b) $Q_{int} = -q$, $Q_{ext} = q$, c) $\sigma_{int} = \frac{-q}{4\pi a^2}$, $\sigma_{ext} = \frac{q}{4\pi b^2}$ d) $r < a$ $\vec{E} = k\frac{q}{r^2}\vec{u}_r$

$V = k\frac{q}{r} + kq\left(\frac{1}{b} - \frac{1}{a}\right)$, $a < r < b$ $\vec{E} = 0$ $V = k\frac{q}{b}$, $r > b$ $\vec{E} = k\frac{q}{r^2}\vec{u}_r$ $V = k\frac{q}{r}$



Conductors in electrostatic equilibrium

EXAMPLES: d) Same system as example c) after being grounded:



- The charge in the cavity (Q) induces a charge – Q on the internal surface of the conductor.
- The charge on the external surface is 0.
- E is NOT zero inside the cavity.
- E = 0 inside the conductor.
- E = 0 in the external region.

- There is a transference of electrons from the ground to the conductor <u>until their potentials equal</u> (in this particular case, at the end of the process V=0).
- The external region is shielded from the E inside (microwaves behave this way).

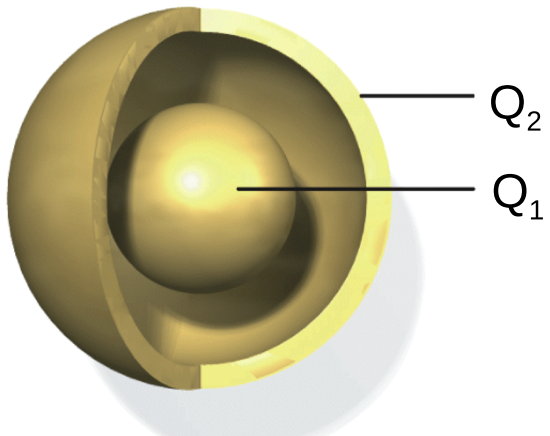
WHEN TWO CONDUCTORS ARE CONNECTED, THERE IS A TRANSFERENCE OF CHARGE BETWEEN THEM <u>UNTIL THEY ARE AT THE SAME POTENTIAL</u>.

THE EARTH BEHAVES AS AN ENORMOUS CONDUCTOR WHERE THE POTENTIAL IS TAKEN TO BE ZERO.

Conductors in electrostatic equilibrium

Two metallic spheres are located one inside the other, as shown in the figure. The inner sphere (radius R_1) is charged with Q_1. The outer sphere has as inner radius R_2 and outer radius R_3, and is charged with Q_2.

1) How is the charge distributed on each surface?
2) Find the electric field and the potential in all regions of space (suppose V=0 when $r \rightarrow \infty$).
3) What happens if the outer sphere is grounded?



Conductors in electrostatic equilibrium

8. Two uncharged spherical conductors have radii R_1=6 cm and R_2=2 cm. They are separated by a distance much greater than 6 cm and connected by a conducting wire. A charge Q=80 nC is placed on the first sphere and the system is allowed to reach electrostatic equilibrium.

a) Find the charge on each sphere.

b) Find the charge density σ on each sphere.

c) What is the magnitude of E at the surface of each sphere?

Conductors in electrostatic equilibrium

8. Two uncharged spherical conductors have radii R_1=6 cm and R_2=2 cm. They are separated by a distance much greater than 6 cm and connected by a conducting wire. A charge Q=80 nC is placed on the first sphere and the system is allowed to reach electrostatic equilibrium.

a) Find the charge on each sphere.

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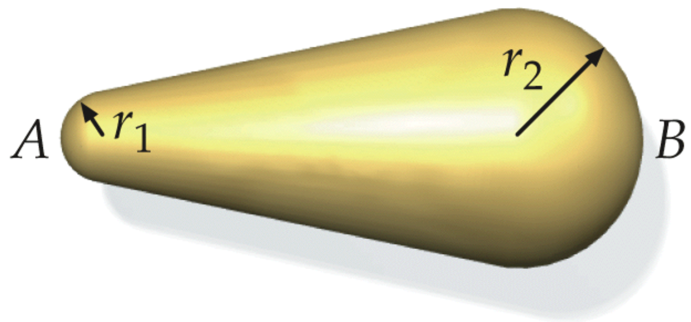
c) What is the magnitude of E at the surface of each sphere?

Answer:
a) Q_1=60 nC, Q_2=20 nC
b)σ_1=1326 nC/m^2, σ_2=3979 nC/m^2
c)E_1=149.9 kN/C , E_2=449.6 kN/C

Conductors in electrostatic equilibrium

EXAMPLES: e) Conductor with non-spherical shape:



The surface of the conductor is equipotential, but the surface charge density and the electric field at the surface will vary from point to point.

$$\sigma = \frac{V\varepsilon_o}{R} \qquad E = \frac{\sigma}{\varepsilon_o}$$

Tip effect: The electric field will be stronger at points in which the radius of curvature is small (as those points have a higher charge density).

Conductors in electrostatic equilibrium

The electrostatic potential energy of conductor is the work done by an external agent to charge the conductor.

Example: Conducting sphere of radius R. The work to bring an additional amount of charge dq from infinity to the conductor is:

$$dW_{ext} = dU = V dq = k\frac{q}{R} dq \longrightarrow U = \int_0^Q V dq = \frac{1}{2} QV$$

The expression holds for ANY conductor (any shape).

For a system of conductors: $U_{system} = \frac{1}{2}\sum_{i=1}^{n} Q_i V_i$