Chapter 24

Conductors in Electrostatic Equilibrium

Course website:
http://faculty.uml.edu/Andriy_Danylov/Teaching/PhysicsII
Today we are going to discuss:

Chapter 24:

- Section 24.6 Conductors in electrostatic equilibrium
- Skip (Example 24.8)
Now let’s look at properties of Conductors using Gauss’s law
Consider a conductor and apply an external electric field.

Conductor has tons of free electrons and under the influence of $E_{\text{ext}}$ they will run to the left surface leaving positive charges near the right surface and creating $E_{\text{internal}}$.

How many of them will move?

-The electrons will keep moving until the internal field cancels out the external field inside the conductor.

Thus, the electric field inside a conductor is zero in electrostatic situation.
Charges in a conductor

Consider a positively charged conductor

Where does this excess charge reside in the conductor?

Let’s apply Gauss’s law

Take a Gauss. surface just barely inside the surface of a conductor

\[ \Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\varepsilon_0} \]

So \( Q_{\text{in}} = 0 \) (inside the Gaussian surface)

Thus, the positive excess charge resides on the external surface of the conductor

In simple words:
They just repel each other 😊
E (outside) is \perp to the surface of a conductor

The external electric field right at the surface of a conductor must be perpendicular to that surface.

If it were to have a tangential component, it would exert a force on the surface charges and cause a surface current, and the conductor would not be in electrostatic equilibrium.\textbf{(Proof by contradiction)}
E near any conducting surface

Consider a conductor with the surface charge density \( \sigma \).

Apply Gauss's law:
\[
\oint E \cdot dA = \frac{Q_{\text{in}}}{\varepsilon_0}
\]

A small cylinder \( \perp \) to the surface is a Gaussian surface, which consists of three open surfaces, so

\[
\oint E \cdot dA = \oint E \cdot dA + \oint E \cdot dA + \oint E \cdot dA = E \cdot A = \frac{Q_{\text{in}}}{\varepsilon_0}
\]

\( Q_{\text{in}} = \sigma \cdot A \), so

\[
E \cdot A = \frac{\sigma \cdot A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{\varepsilon_0}
\]

And, as we know, it's \( \perp \) to the surface.
A point charge $q$ is located distance $r$ from the center of a neutral metal sphere. The electric field at the center of the sphere is:

A) $4\pi \varepsilon_0 r^2$

B) $4\pi \varepsilon_0 R^2$

C) $4\pi \varepsilon_0 (R-r)^2$

D) 0

E) It depends on what the metal is.
A charged conductor with a hole inside

Are there any charges on an interior surface?

Let’s apply Gauss’s law
Place a Gaussian surface around the hole.

\[ \Phi_E = \oint E \cdot d\vec{A} = \frac{Q_{\text{in}}}{\varepsilon_0} = 0 \]

The electric flux is zero through the Gaussian surface, since \( E = 0 \) inside the conductor.

So \( Q_{\text{in}} = 0 \) (inside the Gaussian surface), i.e.
there is no charge on the surface of the hole.

Any excess charge resides on the exterior surface of a conductor, not on any interior surfaces.
The use of a conducting box, or Faraday cage, to exclude electric fields from a region of space is called screening.

Sensitive instruments are often enclosed in a "Faraday cage" to shield them from unwanted radio frequencies (electromagnetic waves). The field pushes electrons toward the left, leaving a net negative charge on the left side and a net positive charge on the right side. The result is that the net electric field inside the box is zero.
Screening/Faraday cage II

Shielding essentially prevents electromagnetic pulses from interfering with the proper functioning of electronics.

- conductive fabrics
- metallic inner shields
- Vacuum metallization
- Conductive paints

A Faraday cage protects its contents by preventing electromagnetic energy from getting inside.
Let’s put a charge inside the hole

**Are there any charges on an interior surface?**

Let’s ask the same question again:

**Charged (+\(Q\)) conductor**

**Conductor**

\(E = 0\)

\(+q\)

Negative charge -\(q\)

Let’s apply Gauss’s law

Place a Gaussian surface around the hole.

\[
\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\varepsilon_0} = 0
\]

The electric flux is zero through the Gaussian surface, since \(E=0\) inside the conductor.

So \(Q_{\text{in}} = 0\) (the net charge inside the Gaussian surface)

But, we know that there is +\(q\) inside, it means that there must be -\(q\) on the interior surface (+\(q\) charge induced -\(q\) on the surface)

Let’s count all charges inside the conductor to find the amount of charge on the exterior surface

\(-q + Q_{\text{outer surface}} = +Q\)

\(Q_{\text{outer surface}} = +Q + q\)
Charge +3 nC is in a hollow cavity inside a large chunk of metal that is electrically neutral. The total charge on the exterior surface of the metal is

A) 0 nC.
B) +3 nC.
C) −3 nC
D) Can’t say without knowing the shape and location of the hollow cavity
Conductor with two cavities

An uncharged conducting sphere of radius $R$ contains two spherical cavities. Point charge $Q_1$ is placed within the first cavity (not necessarily at the center) and $Q_2$ is placed within the second one. Find the charge on the outer surface.

The conductor is uncharged but $-Q_1$ and $-Q_2$ were induced on the interior surfaces. It means $Q_1+Q_2$ must be appeared somewhere else. Charges can only be on surfaces. So the external surface must be charged with $Q_1+Q_2$. Distribution of these charges is uniform.
Thank you
Bye Bye For Now