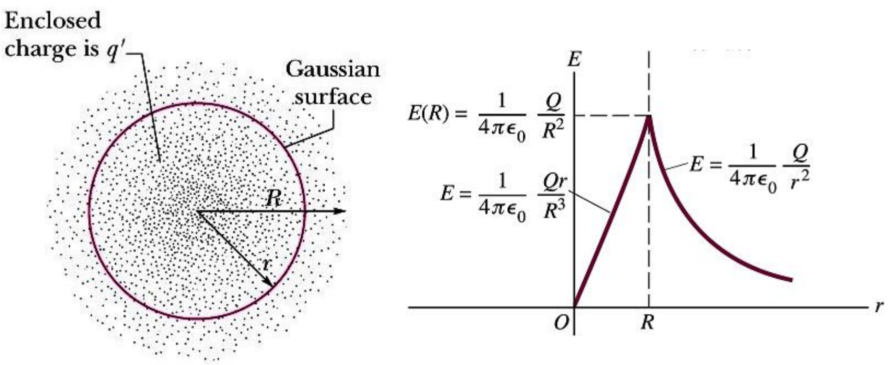
Lecture 8: Faraday cages

- Back to the uniform charged sphere
- Conductors & insulators again real quick
- What happens if our sphere is a conductor?
- Gauss' law for a charged conductor & internal fields.
- Fun with Faraday cages

Electric field in a uniform sphere of charge

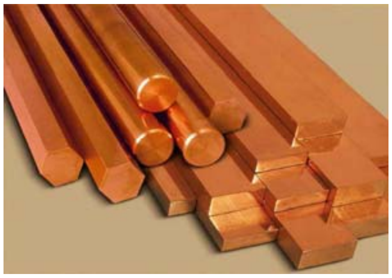
We finished with this problem last lecture…



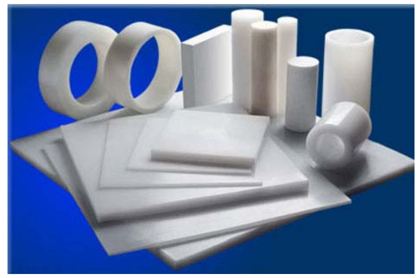
But it's a little contrived… how do we get a <u>'uniform'</u> sphere of charge? We usually don't.

Conductors & Insulators

We can broadly separate materials into two classifications.



Conductors (e.g., Copper)



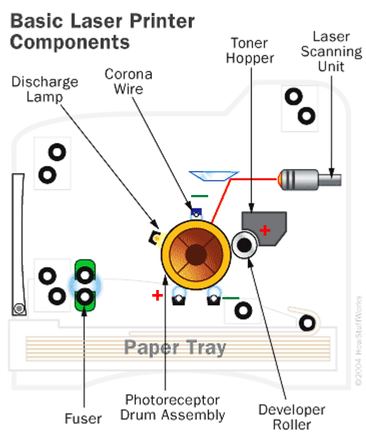
Insulators (e.g., Teflon)

In insulators, electrons can't move easily. Charge usually stays where it is put.

In conductors, electrons move easily. The net charge will redistribute to maximise its separation to minimise the 'Coulomb' repulsion energy.

Insulators

Hard to get charge anywhere but the surface, and it really does want to stay put. This can be really useful though…



Conductors & electrostatic equilibrium

Charge can freely move, and it will do so until it reaches electrostatic equilibrium.

Equilibrium is a state with no net force.

Charge in a conductor is like a liquid, it will reorganise to an equilibrium state.

Conductors & electrostatic equilibrium

Electrostatic equilibrium for a conductor means the following properties:

1. The electric field is zero everywhere inside the conductor (no net force on charges).

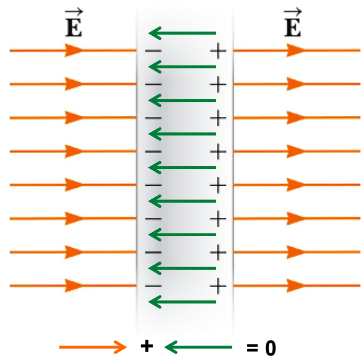
2. If it has a net charge, then all that charge resides on the surface (by Gauss' law).

3. The electric field outside is perpendicular to the surface and has magnitude σ/ε_0

4. On an irregularly shaped conductor, charge density is highest at sharpest points.

Why is the field inside the conductor zero?

Suppose we put a conducting slab in an electric field (orange)…



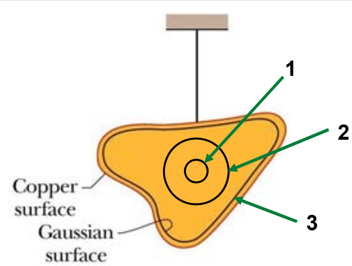
The electrons in the conductor will move left leaving the right net positive, establishing an internal opposing field (green).

These balance at equilibrium (no net force) giving a net field of zero by superposition inside the conductor.

Why must all the net charge be on the surface?

This is where Gauss' law comes in.

Gauss law: $$\varepsilon_0 \oint \vec{E}.d\vec{A} = q_{enc}$$



We know $E = 0$ inside a conductor at equilibrium.

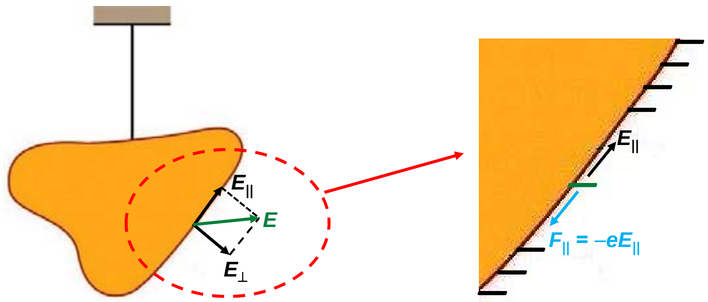
Start with surface 1. If $E = 0$, we require the <u>net</u> charge enclosed $q_{enc} = 0$.

Can expand Gaussian surface until it's just inside the surface, even then $q_{enc} = 0$.

Therefore, any <u>net</u> charge must be right at the surface of the conductor.

Why must field lines be ⊥ to the surface?

Imagine we had a line that *isn't* ⊥ at the surface…

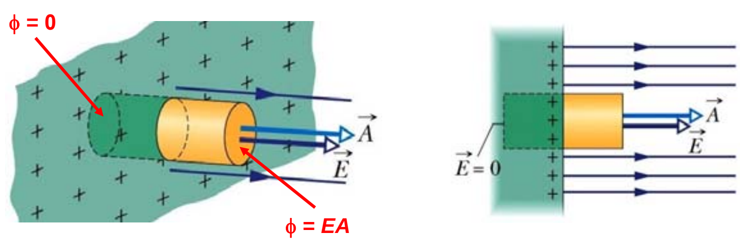


…surface charge would be subject to a force along the surface! Violates initial premise that the system was at equilibrium.

This perpendicularity requirement has an important implication, but first...

Electric field at the surface of a conductor.

We now apply Gauss' law right at the surface: $\varepsilon_0 \oint \vec{E}.d\vec{A} = q_{enc}$



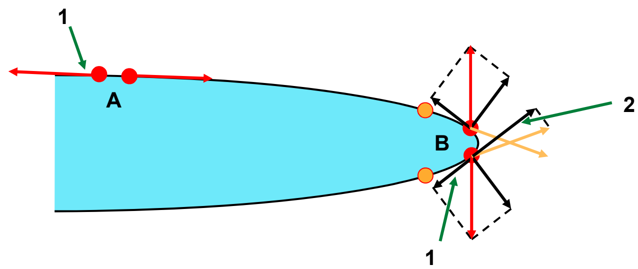
Crucial difference: flux through inner end-cap is zero as $E = 0$ inside the conductor.

Do the maths, and what you find is that $E = \sigma/\varepsilon_0$ outside the conductor.

This is double the result for an infinitely thin sheet with infinite extent: requirement for $E = 0$ inside forces that field to appear outside the conductor.

Why does charge concentrate at sharp points?

Consider the repulsive forces for charges in two locations on an irregular surface.



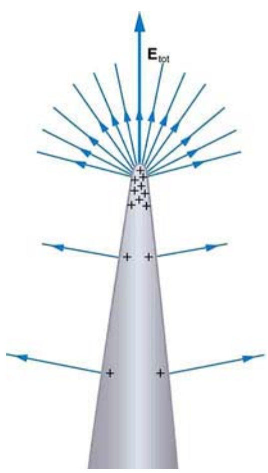
At A, repulsive forces along surface. At B, partly along & partly out. Repulsive forces along surface proportionally stronger at A (see 1.).

You also get charge nearer to A ‘backing the charge at B into the corner’ (see 2.).

Net result: charge will accumulate where radius of curvature is highest at equilibrium.

And the electric field at sharp points?

The electric field is also more intense where the radius of curvature is smallest.

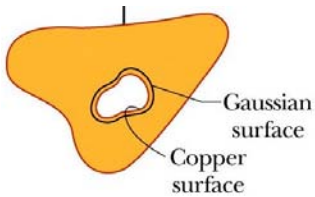


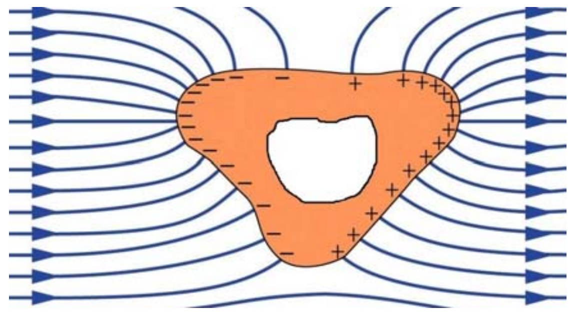
n.b.: our earlier σ/ε_0 result was only for flat surfaces.

Explains why lightning likes high, sharp objects…

The physics of the Faraday cage

Back to our metal object for a second…





In either case, in the void inside the conducting shell, there is no electric field!

The physics of the Faraday cage

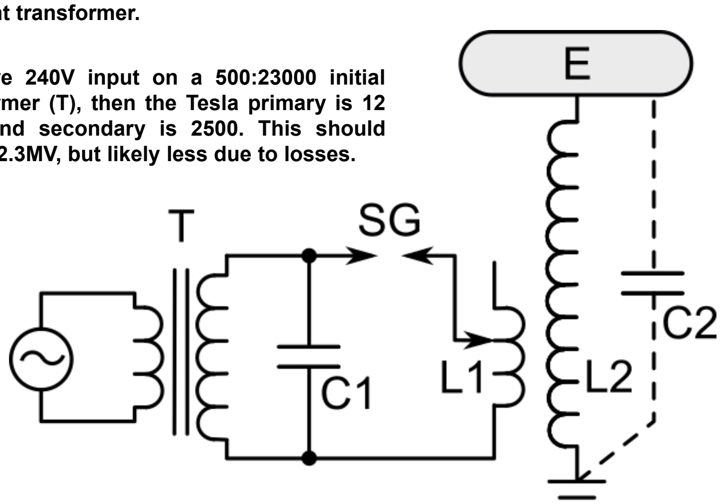
The physics of the Faraday cage

If you're a little more brave you can try…

The Tesla coil

Is really just a two-stage step-up transformer with the second-stage being a tuned, resonant transformer.

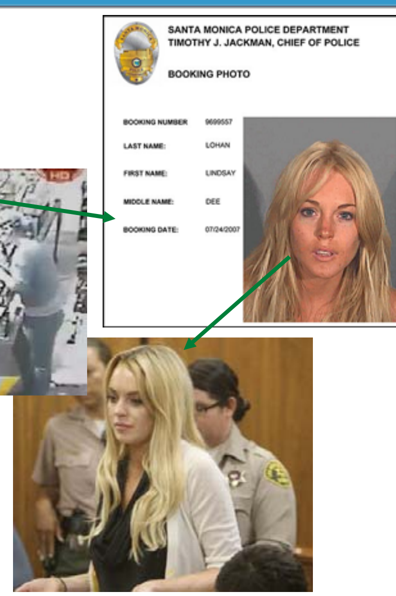
We have 240V input on a 500:23000 initial transformer (T), then the Tesla primary is 12 turns and secondary is 2500. This should step to 2.3MV, but likely less due to losses.



The physics of the Faraday cage

And if you're particularly crazy, you should try…

Amateur Resource Procurement

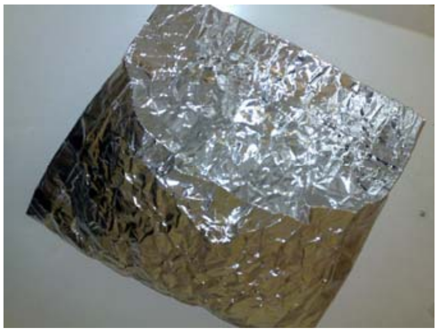


Look, if you just walk out of a store with stuff like Lindsay did, you're gonna get in trouble.

If something's worth doing, it's worth doing right!

Advanced Resource Procurement

Electrons move very fast in metals, so Faraday cages work for a.c. electric fields also!



See also: http://commonthiefebook.typepad.com/blog/diy-booster-bag/

Disclaimer: Please don't try this, despite the obvious humour I don't endorse theft. Be responsible with your knowledge. If you do try & get busted (e.g, surveillance cameras, etc). don't expect me to bail you out or blame me, ok. ☺

Better a job than a jail cell…

As a friend of mine says: "It's lucky most smart people have figured out that they can make more money risk free by just getting a job."

Next lecture: Potential, and I mean the electric kind, not the human kind.