302L - Lecture 2

Electric Charge + Static Electricity
(Serway sections 15.1-15.2)

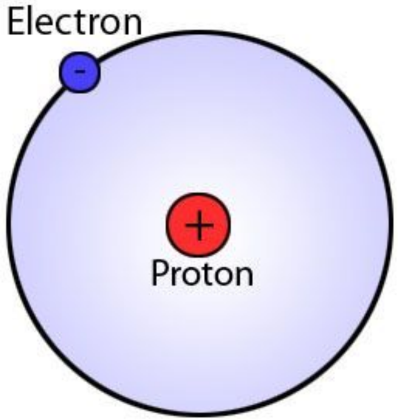
Main points: electric charge

- Matter has an additional property known as electric charge
- Charge is characterized by a number, can be positive or negative
- Like charges repel, opposite charges attract.
- On the microscopic level, positive charge is carried by protons, negative charge by electrons.
- Charge is *quantized:* All protons have the same charge, called e, and all electrons have the same charge, equal and opposite to the proton charge, i.e. $-e$.
- Charge is *conserved:* It can not be created or destroyed.

Main points: static electricity / electrostatics

- Friction between different materials results in charge being transferred from to the other (*triboelectricity*).
- Materials are separated into two categories, depending on the degree of mobility of electrons in the material:
    - Conductors, where a significant fraction of the electrons are able to move freely, and
    - Insulators, where nearly all electrons are tightly bound to individual atoms
- *Electrostatic conduction:* charge flows from one body to another in response to electrical forces.
- *Electrostatic induction*: nearby charges create charge separation in uncharged objects.

Electric charge - microscopic



All (ordinary) matter is composed of electrons, protons, and neutrons.

- electron charge: $-e$
- proton charge: $+e$
- neutron charge: 0

For instance, a hydrogen atom consists of a single electron orbiting a single proton, and a helium atom consists of two electrons orbiting a nucleus comprised of two protons and two neutrons.

aside: because the electron is 1836 times lighter than the proton, it is often (though not always!) the particle participating in the *conduction*, or transport, or charge.

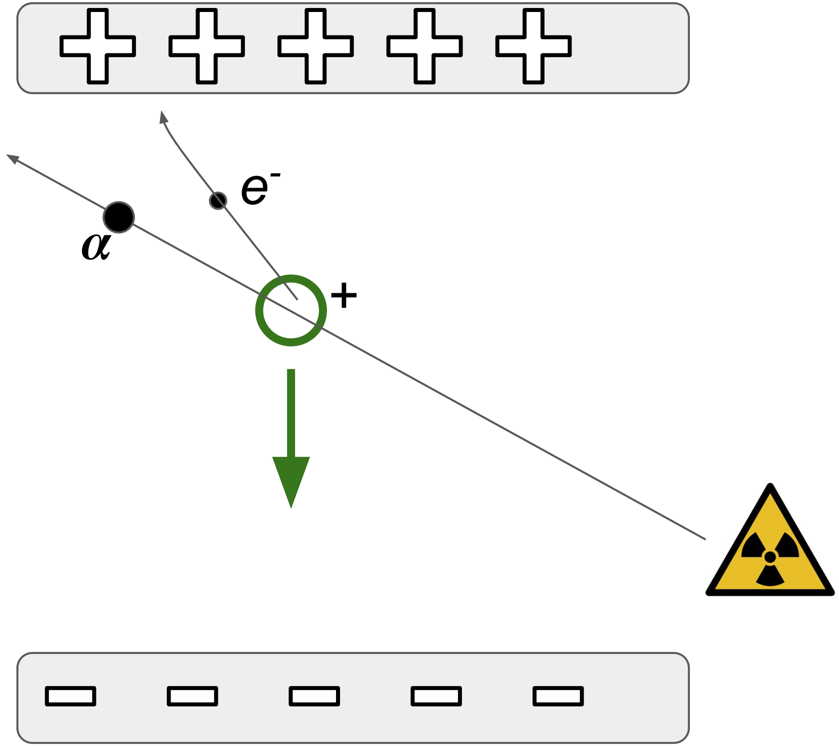
Charge quantization / Millikan oil drop experiment

Charge is ***quantized***: no object/particle has ever been detected with a charge not equal to some integer multiple of *e*

(..., -3*e*, -2*e*, -1*e*, 0*e*, +1*e*, +2*e*, +3*e*, …)

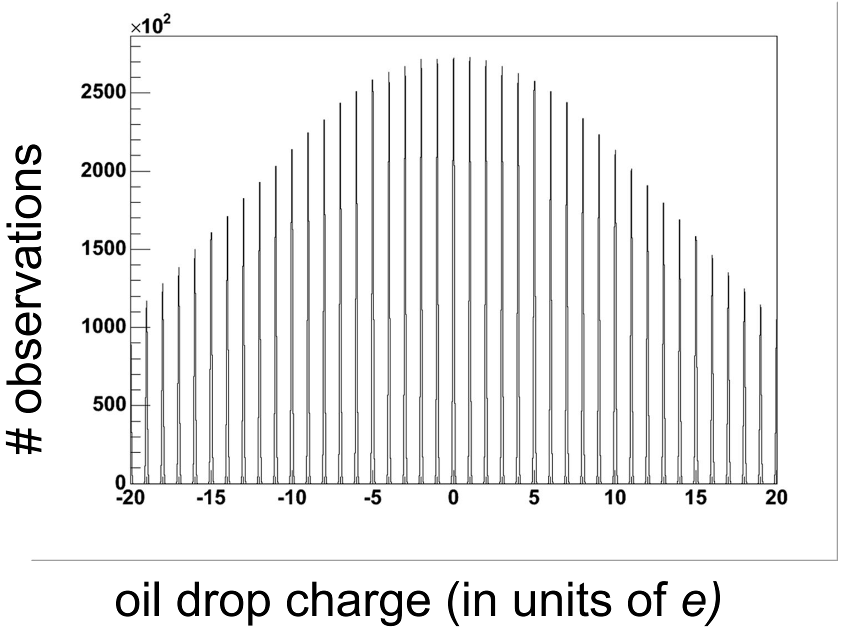
Remarkably well tested law of physics:

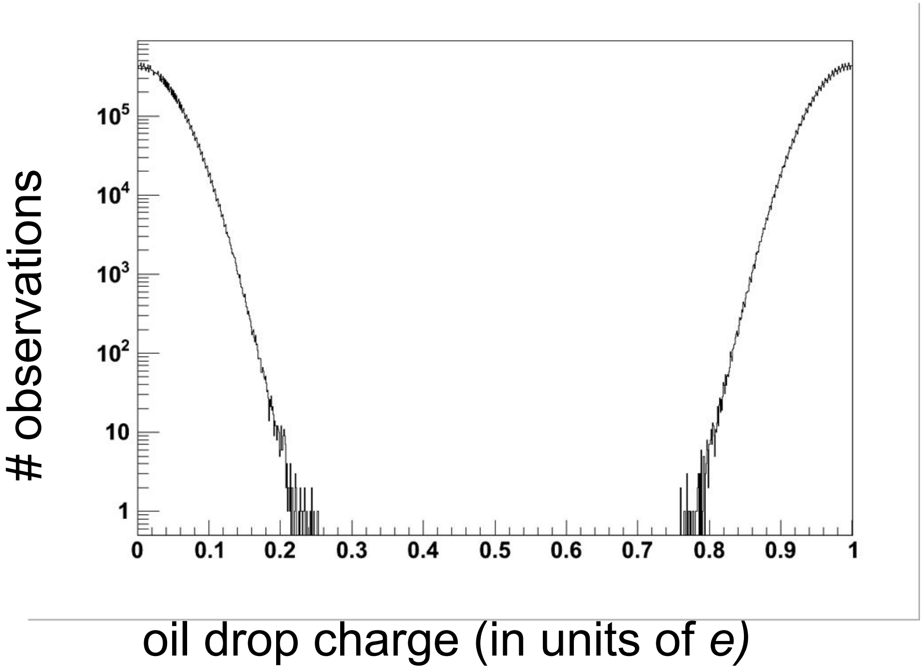
Charge tiny (~100nm) **oil drops** using radioactivity, measure velocity between two charged plates to determine charge



what about *quarks*? up-type (up, charm, top) has charge +2/3*e*, down-type (down, strange, bottom) has charge -1/3*e*.

Search for fractional charge in space rocks





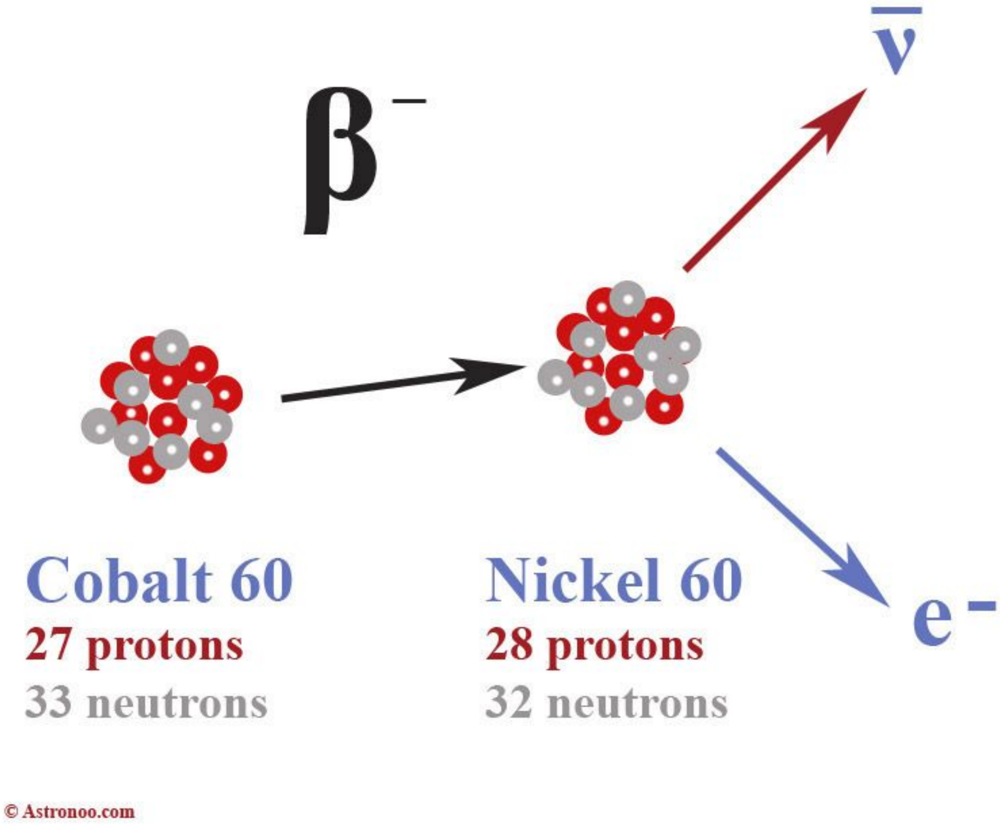
https://www.slac.stanford.edu/exp/mps/FCS/FCS_rslt.htm

Charge conservation

Charge can neither be created nor destroyed.

Matter, however, can be both created and destroyed. e.g. beta decay (see right).

In addition, charge is *locally* conserved, in that it can not teleport.



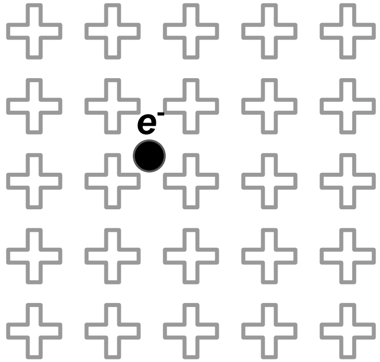
Conductors and insulators

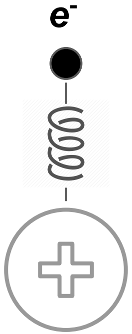
Electrical conductors are materials containing charge carriers that are free to move away from like charges / towards unlike charges.

- In metals the charge carriers are electrons.

Electrical insulators contain charge carriers that are subjected to strong binding forces and can only displace themselves from their equilibrium positions by microscopic (~10^{-10} m) distances in response to forces exerted by nearby charges.

conductor: electrons move freely





insulator: electrons bound to atoms

Generation of static electricity: *triboelectricity*

When dissimilar materials are rubbed together, electrons are transferred from one material to the other.

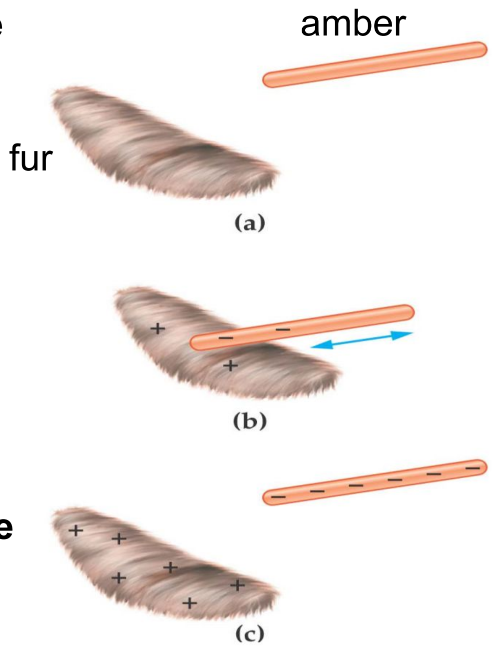
It is very complicated to determine in general which surface will lose/gain electrons, and to what extent, though certain tendencies are well established (see right).

<u>Triboelectric series (abridged)</u>

gains positive charge

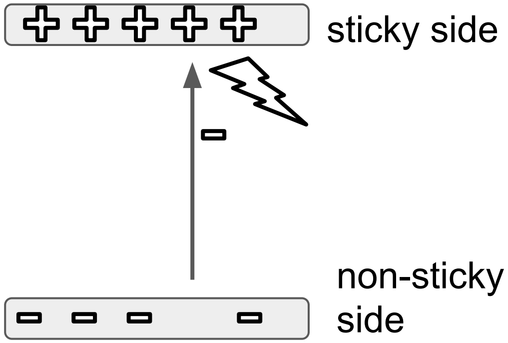
- rabbit fur
- glass
- wool
- silk
- amber
- plastic (pvc)

gains negative charge



Triboelectricity and the scotch tape x-ray generator

The electrical forces that can develop between the two surfaces during friction charging can be strong enough to generate x-rays!



Electric charge - History*

Ancients Greeks knew that rubbing amber allowed it to attract small pieces of straw.

(Demo with plastic rod and paper)

Amber in Ancient Greek = Sun (color) = hlector → electricity

Nuisance in textile manufacture: clutters up looms!

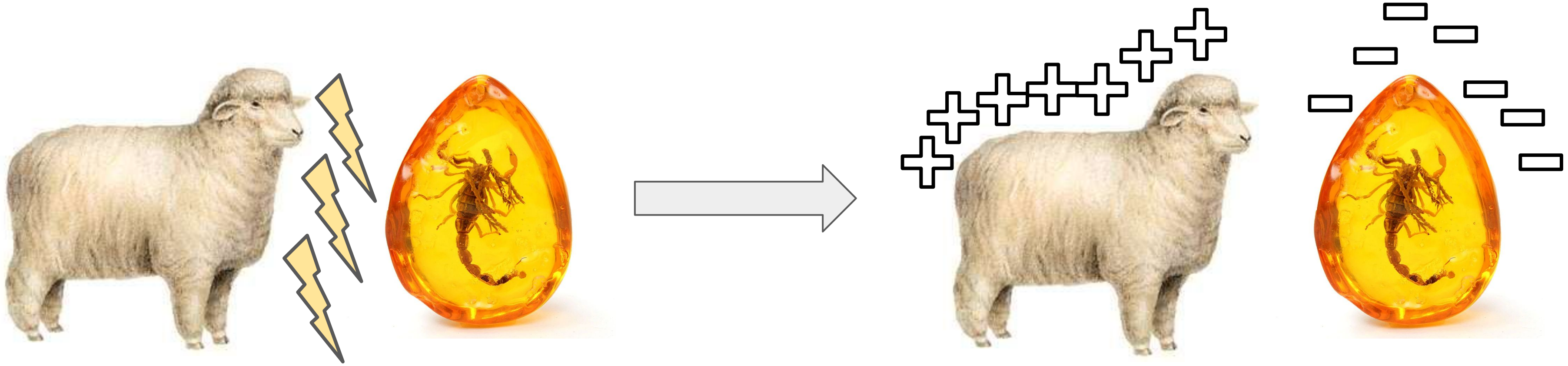
Electric *repulsion* not discovered until 1629

* http://galileoandeinstein.physics.virginia.edu/more_stuff/E&M_Hist.html,

Binnie, A. Using the History of Electricity and Magnetism to Enhance Teaching. *Science & Education* 10, 379–389 (2001). https://doi.org/10.1023/A:1011213519899

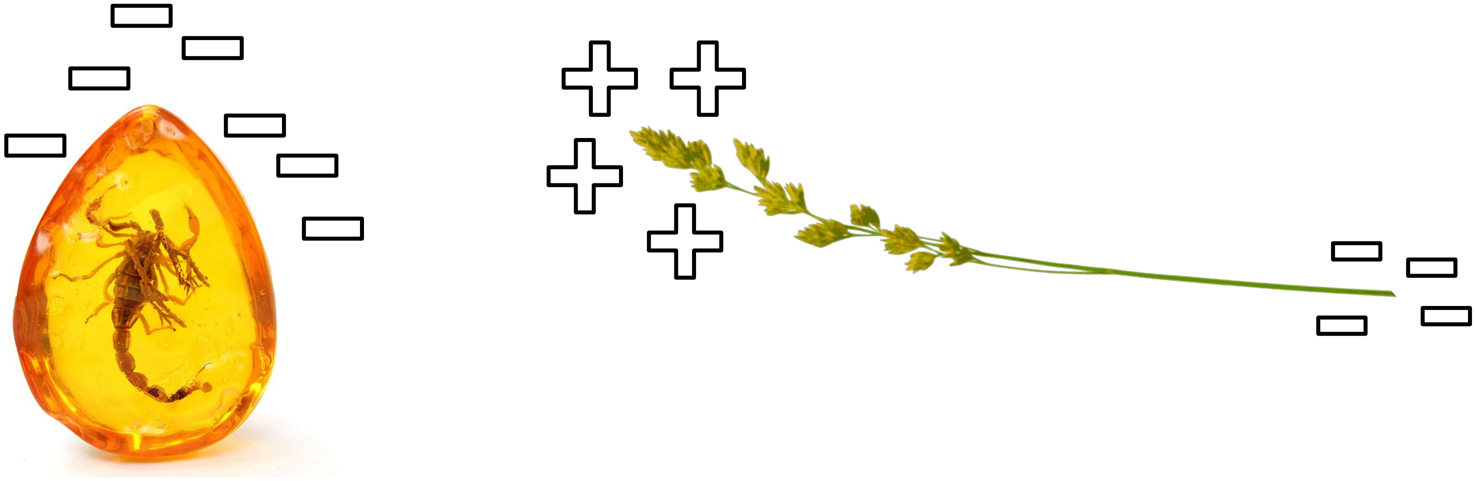
Electrostatic attraction & induction

Step 1: rub wool + amber, transfer electrons to wool



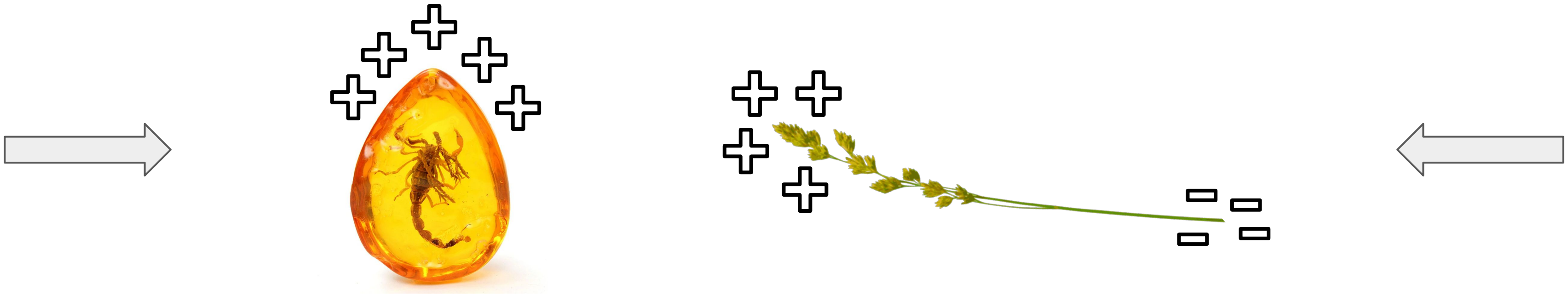
Electrostatic attraction & induction

Step 2: induce charge separation in uncharged straw



Electrostatic attraction & induction

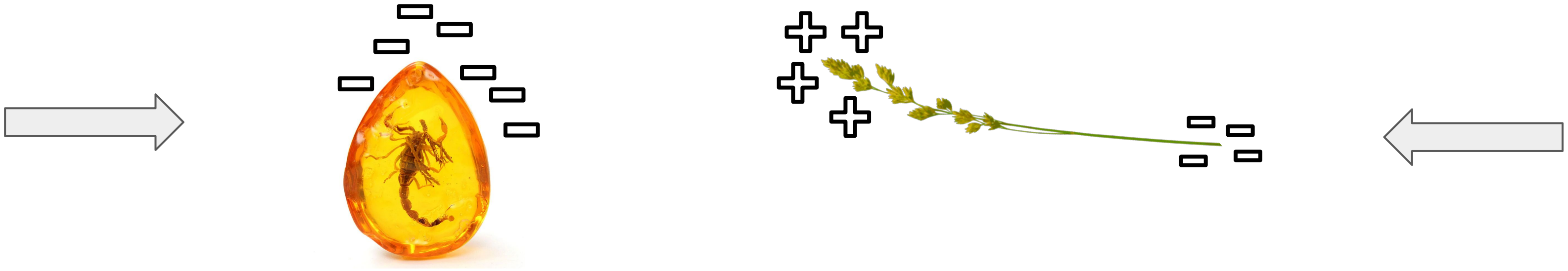
Step 3: amber and straw attract (move towards) each other.



Instapoll: *why?*

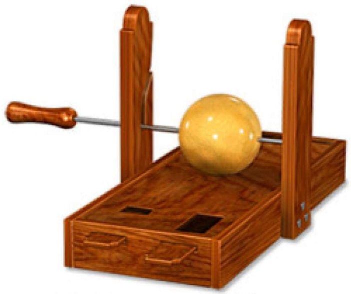
Electrostatic attraction & induction

Step 3: amber and straw attract (move towards) each other.



Instapoll: *why?* attraction between (+) charge on amber and (-) charge on straw stronger than repulsion between (+) charge on amber and (+) charge on straw because (-) charge on straw is closer.

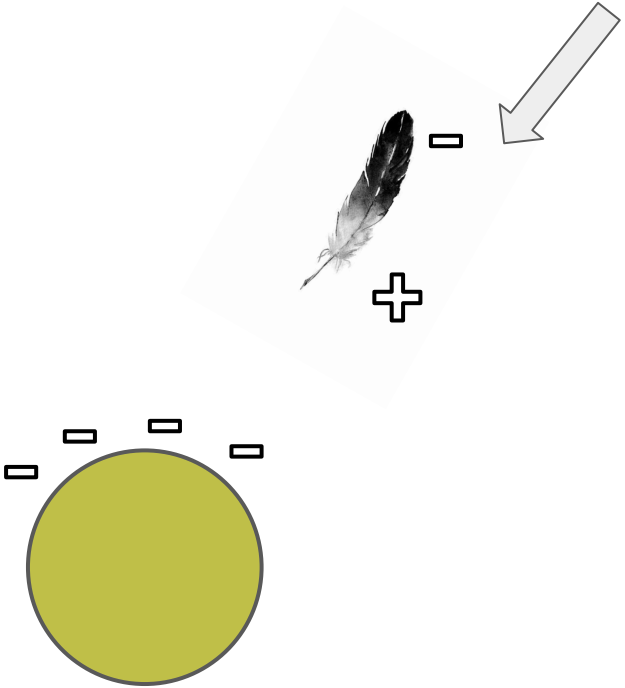
Electric repulsion - historical account



"...von Guericke made (in 1663) a … sphere of sulphur (about the size of a child's head, he says) with a wooden rod through the middle, the ends of the rod resting on supports so that the sphere is easily rotated. If it is then rotated and rubbed, it is found to attract chaff, feathers, etc. He also found that once a feather had touched the globe, it was repelled, and he lifted the globe by the rod through its middle and chased a charged feather around the room, keeping it aloft by repulsion, and, suitably guiding it, was able to get it to land on a pointed object, such as a nose."

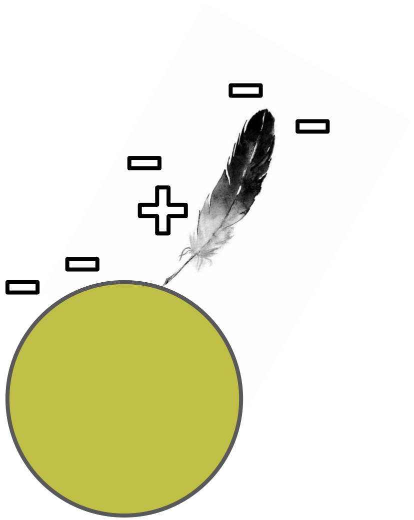
* http://galileoandeinstein.physics.virginia.edu/more_stuff/E&M_Hist.html,

Electrostatic repulsion & conduction



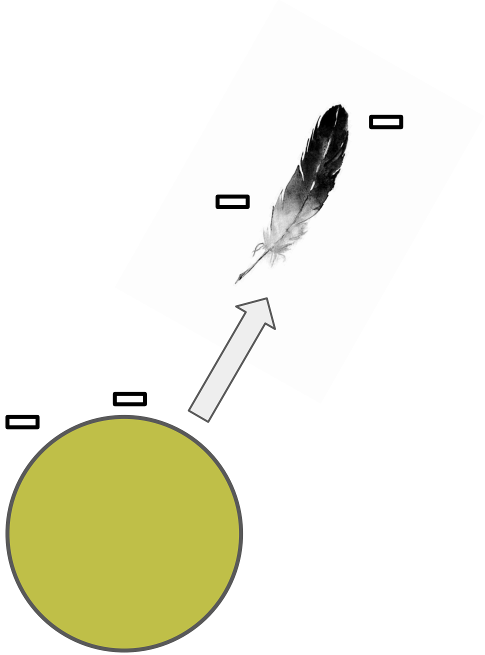
Step 1: charged sulfur sphere induces charge separation on feather. Feather is attracted to sphere

Electrostatic repulsion & conduction



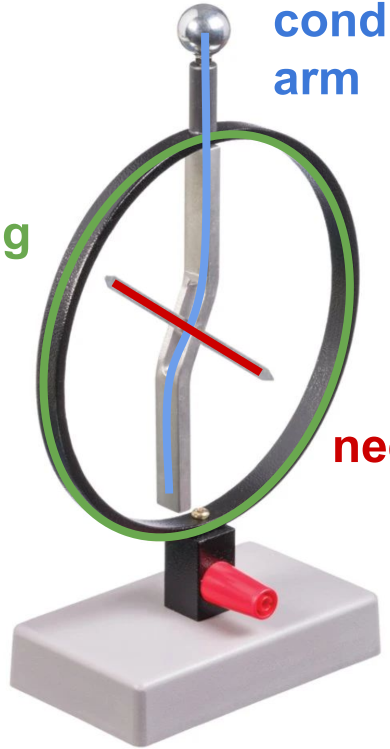
Step 2: Feather contacts sphere, providing means for negative charge on sphere to reduce their mutual repulsion by increasing their separation

Electrostatic repulsion & conduction



Step 3: Repulsion between negative charges on sphere and feather overcomes attraction due to induction, causing feather to detach from sphere.

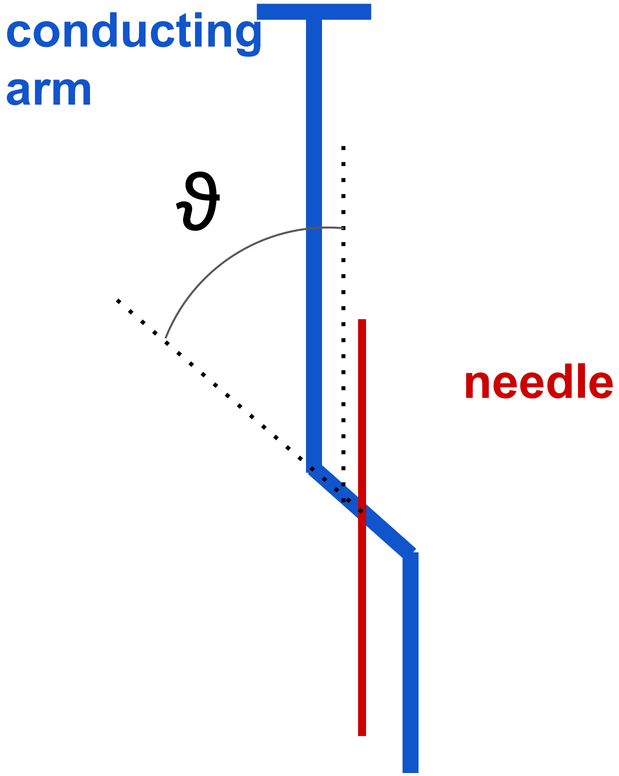
Electroscope



Device for detecting the presence and polarity (+ or -) of electric charge.

A thin needle is electrically connected to and allowed to swivel about a conducting arm

Electroscope - Charging by conduction

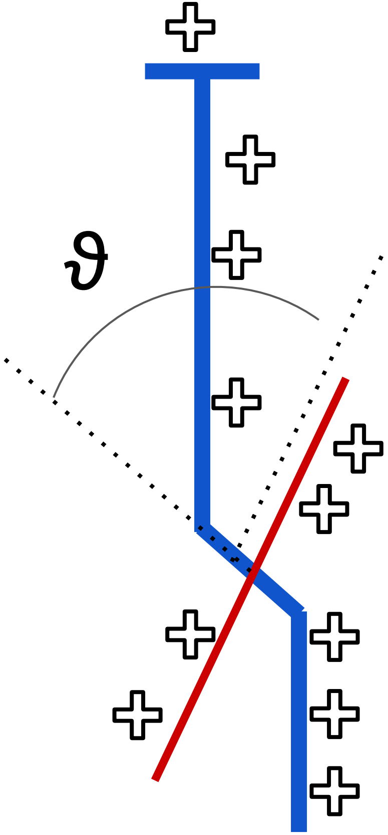


The electroscope (conducting arm + needle) is initially uncharged.

Some positive charge is placed on the conducting arm.

Instapoll: What will happen to the needle?

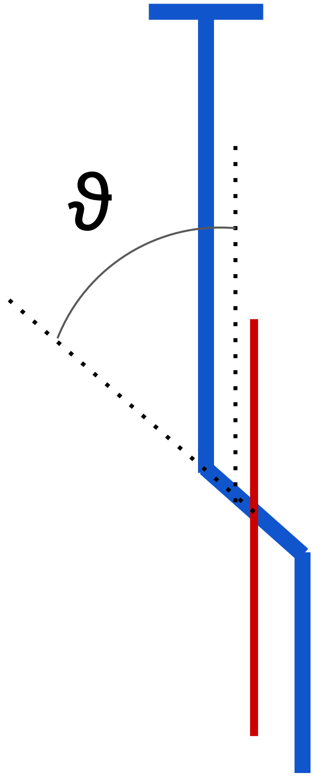
Electroscope - Charging by conduction



Instapoll: What will happen to the needle?

Answer: Positive charge spreads evenly over the conducting arm and needle. The needle swivels *away* from the arm in response to the electrostatic repulsion. ϑ *increases.*

Electroscope - Charging by conduction

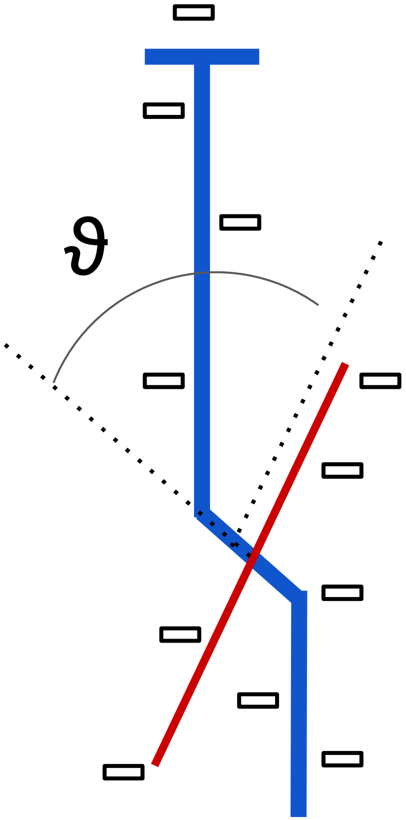


The electroscope (conducting arm + needle) is initially uncharged.

Some ***negative*** charge is now placed on the conducting arm.

Instapoll: What will happen to the needle now?

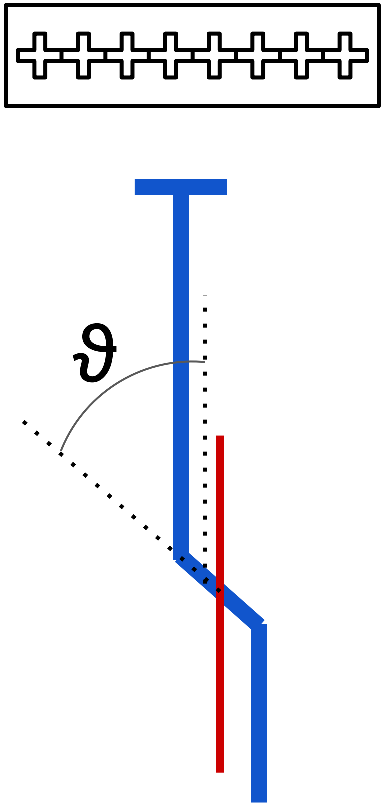
Electroscope - Charging by conduction



Instapoll: What will happen to the needle now?

Answer: The argument is the same. Electrostatic repulsion will cause ϑ to *increase.*

Electroscope - Charging by induction

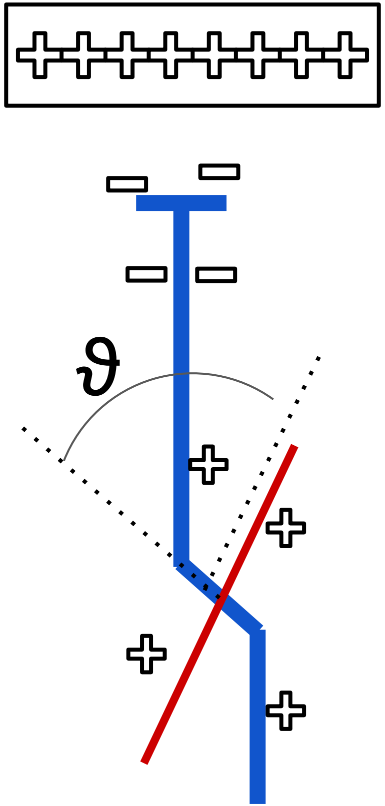


The electroscope (conducting arm + needle) is initially uncharged.

A positively charged object is brought close to (but does not touch!) the top of the electroscope.

Instapoll: What happens to the needle?

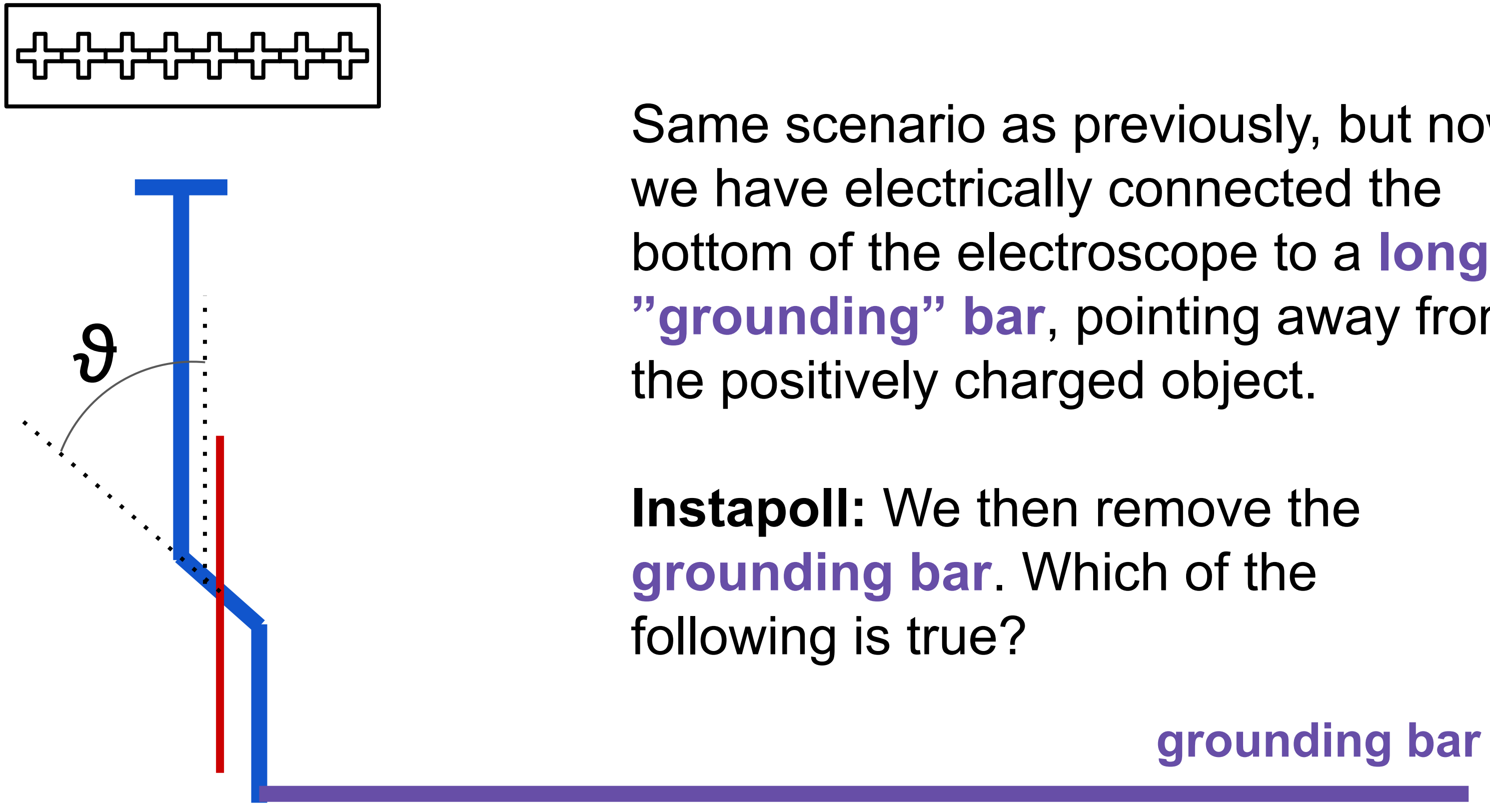
Electroscope - Charging by induction



Instapoll: What will happen to the needle?

Answer: The charged object induces charge separation, leaving the bottom half of the electroscope positively charged. For the same reason then as the earlier scenarios, ϑ *increases.*

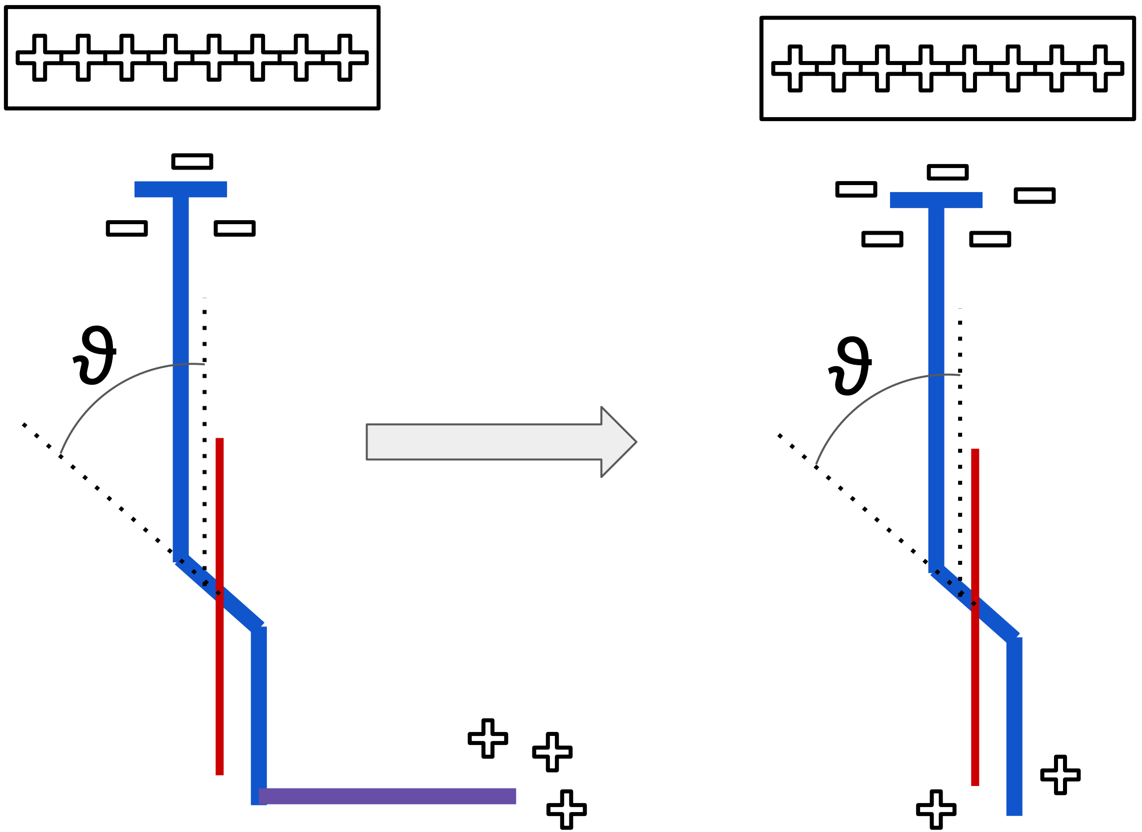
Electroscope - Charging by induction



Same scenario as previously, but now we have electrically connected the bottom of the electroscope to a **long ”grounding” bar**, pointing away from the positively charged object.

Instapoll: We then remove the **grounding bar**. Which of the following is true?

Electroscope - Charging by induction



Answer: Charge separation induced by charged object results in negative charge on the electroscope and positive charge on the grounding bar. Removing the bar leaves the negative charge on the electroscope.

Note now that if we remove the charged object from the electroscope's vicinity the needle will still deflect. Would this be the case if we *reversed* the order of removal?