ELECTRIC CHARGE

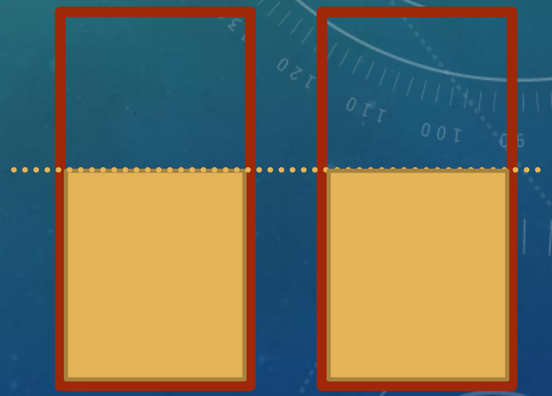
PES 1000 – PHYSICS IN EVERYDAY LIFE

PHENOMENA

- It has been known since antiquity that objects can be 'charged' by rubbing them against other objects. The substance amber is one type of material used then to observe charge. 'Amber' in Greek is 'elektros'.
  - Examples are a glass rod rubbed by silk and a rubber rod rubbed by wool.
  - The glass rod seems to gain one type of charge, which repelled other glass rods.
  - The rubber rod seems to gain another type of charge, which repelled other rubber rods.
  - Rubber rods and glass rods attracted each other.
  - Like-charges repel, unlike-charges attract.

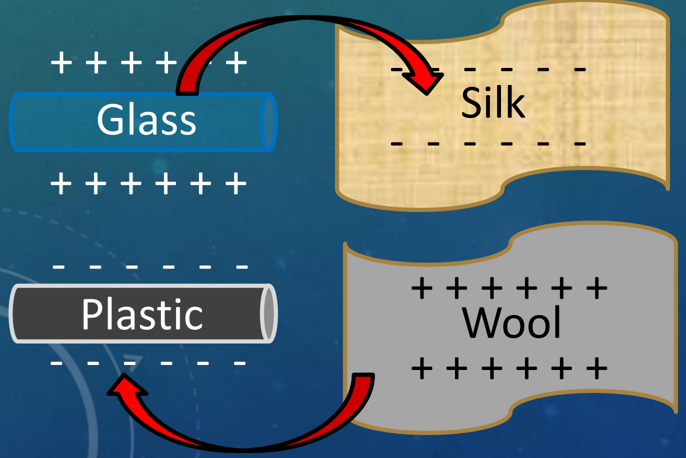
PHENOMENA

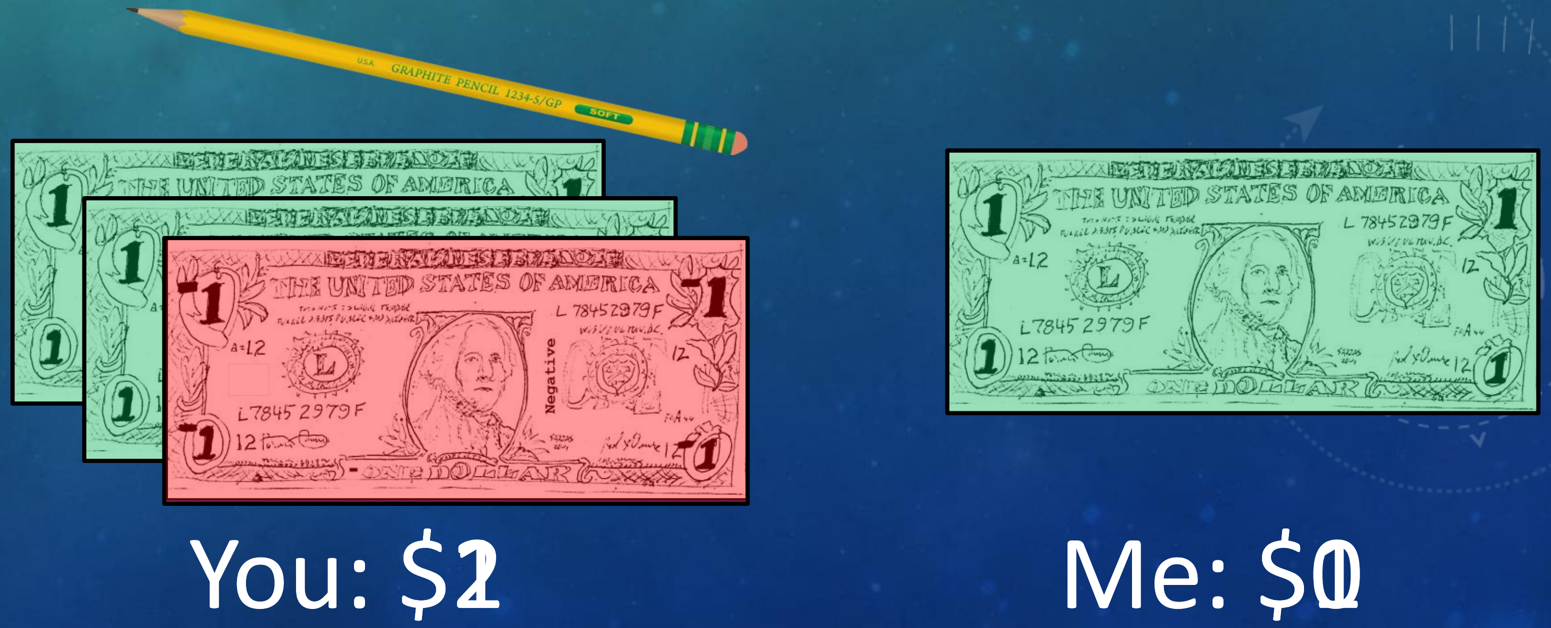
- Ben Franklin postulated that instead of two different 'fluids', the observed behavior could be explained by a single-fluid model. This fluid was transferred between objects by rubbing them together.
  - He labeled an excess of fluid as positive (+), and a scarcity of fluid as negative (-).
  - Excess repelled excess, scarcity repelled scarcity, and scarcity attracted excess.
  - The net charge on an object could now be calculated using simple arithmetic.



ELECTRONS AS A 'NEGATIVE FLUID'

- We now know that the 'fluid' that is usually transferred is a large number of tiny charged particles called 'electrons'.
- Unfortunately, the convention established by Franklin means that the electron has a negative charge.
- This is like having positive and negative money. To buy a pencil, instead of giving you a positive dollar, you could give me a negative dollar with the pencil, leaving me \$1 poorer and you \$1 richer.





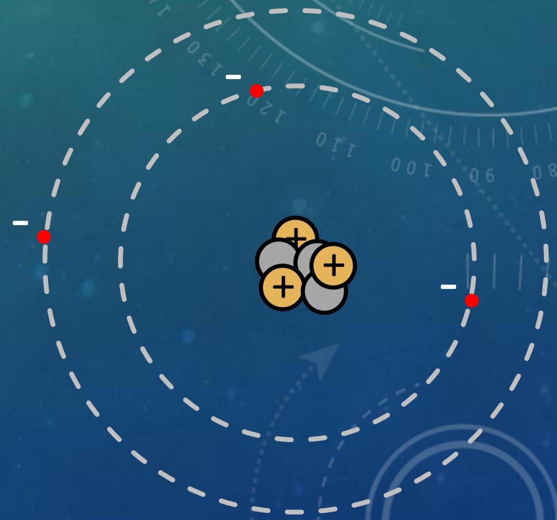
FUNDAMENTAL UNIT OF CHARGE

- Here is a simplified model of an atom – Protons and neutrons reside in a cluster at the nucleus, and electrons occupy shells around the nucleus.
  - These ‘electron shells’ represent possible locations that electrons will occupy according to a set of rules.
  - They are also called ‘energy levels’, with the lowest energy being nearest the nucleus.

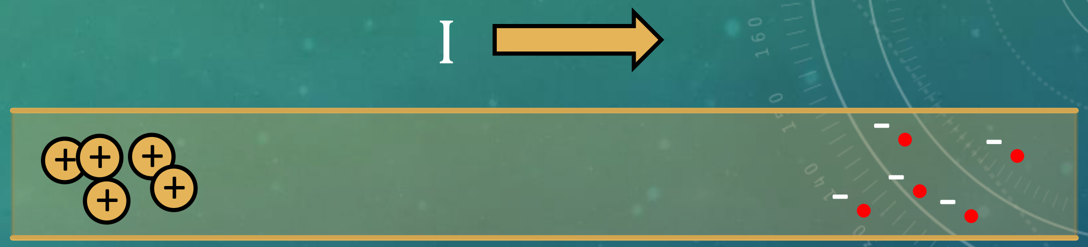
- These parts of an atom may hold a fundamental (quantized) unit of charge:
  - Proton – Holds the smallest possible unit of positive charge
  - Electron – Holds the smallest possible unit of negative charge. The unit of charge is the same as for the proton, but has opposite sign.
  - Neutron – Has no net charge.

FUNDAMENTAL UNIT OF CHARGE

- (Proton mass) = 1000*(Electron mass)
  - Who moves? Usually the electron.
  - Franklin didn’t know this; that’s why his arbitrary guess on assigning a positive sign to the ‘excess’ of fluid turned out to be exactly backwards.



CHARGE AND CURRENT



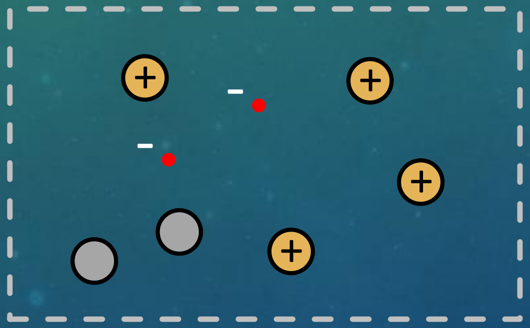
- Working with quantities of charge:
  - Variable: q or Q
  - Units: Coulomb (C)
- When charge moves, we call this ‘current’.
  - By definition, current is the direction of motion of positive charge. Thus, it is <u>opposite</u> the direction of motion of negative charge, and it is electrons that usually move.
  - We usually ignore this detail and model current as some positive charge moving in the opposite direction of the electrons. This conceptual swap amounts to the same effect.
  - Variable: i or I
  - Units: Ampere (A) 1 A = 1 C/s

CHARGE AND CURRENT

- Charge and mass of protons and electrons:
  - Proton: Charge = 1.602×10^{-19} C Mass = 1.673×10^{-27} kg +
  - Electron: Charge = -1.602×10^{-19} C Mass = 9.11×10^{-31} kg -
  - How many electrons for 1 nano-Coulomb (nC) of charge? (nano- means 1 billionth)
  - Answer: 6.24 billion (but with a mass of only 6×10^{-21} kg)

CONSERVATION OF CHARGE

- Charge obeys a fundamental conservation rule:
  - The net charge in an isolated region is constant.
  - Rephrased: Charge cannot be created or destroyed unless it is done so in equal quantities of positive and negative charge.



Initial net charge=0

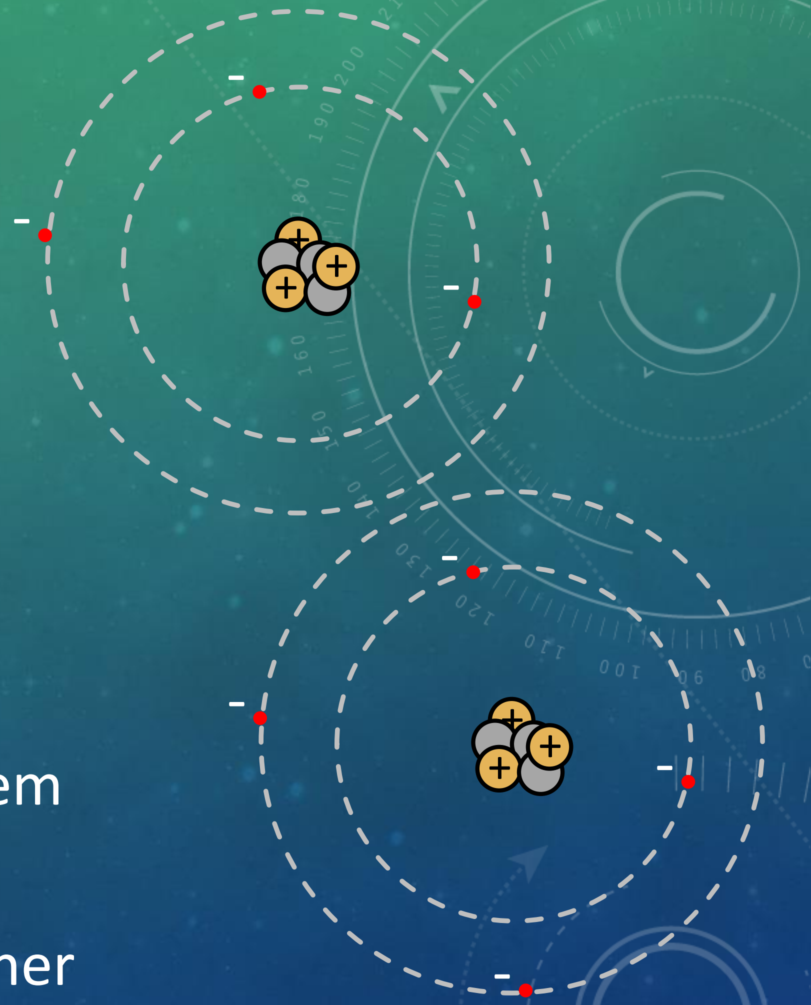
Final net charge=0

Initial net charge=0

Final net charge=0

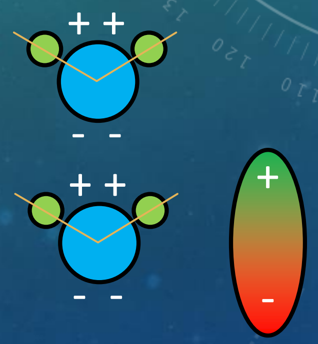
IONIZATION

- Ionization – An atom or molecule can have an unbalanced amount of charge.
  - Positive ions lack one or more electrons, leaving them positive.
  - Negative ions have an extra electron or two, leaving them negative.
  - Ions have a net charge, so they tend to attract/repel other electrons in an attempt to balance the charge.
  - This can lead to neutralization and also molecular bonding.



POLARIZATION

- Polarization – An atom or molecule can be neutral, but have an uneven distribution of charge.
  - Example: H_2O
  - Water molecules have a charge effect on each other. This leads to some of the unique properties of water.
    - Water can be used to neutralize hair that is statically charged.
    - When ice forms, it expands, unlike most other materials, and so ice floats.



CONDUCTORS AND INSULATORS

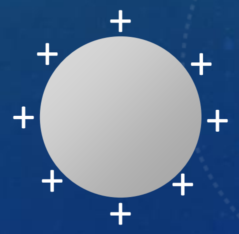
- Conductors
  - Outer electron in each atom is near the energy level required to remove it
  - Result: Electrons can easily move from atom to atom within the material
  - Charge can flow through the material (usually a metal)
- Insulators
  - Outer electron is far from the energy level required to remove it
  - Charge can't move easily through the material

CONDUCTORS AND INSULATORS

- Semi-conductors
  - The material is an insulator under some conditions, and a conductor under other conditions
  - Examples
    - Photo conductor – Conducts when light hits it
    - Semi-conductor – Conducts when a voltage is applied (it becomes a tiny switch, or bit.)

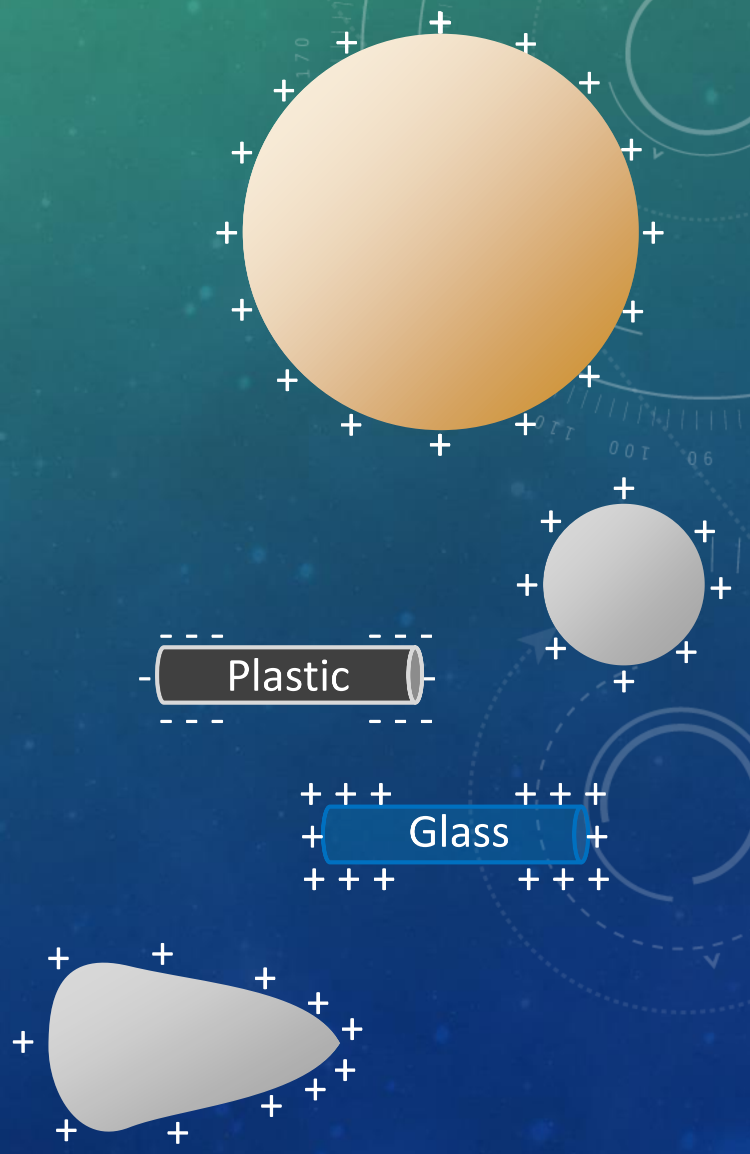
CHARGE DISTRIBUTION

- We have been placing excess charge on insulators (plastic, glass, etc.) Where does this charge reside?
  - The extra charge sits just at the surface of the material.
  - The charge can't flow through the material, but it can easily flow along the surface.
  - Like charge repels, so the charge attempts to distribute itself around the surface.
- What happens to excess charge on a conductor?
  - Exactly the same thing, except the charge can travel through the metal. But it still collects at the surface, where it is able to maximize its distance from the other charges.



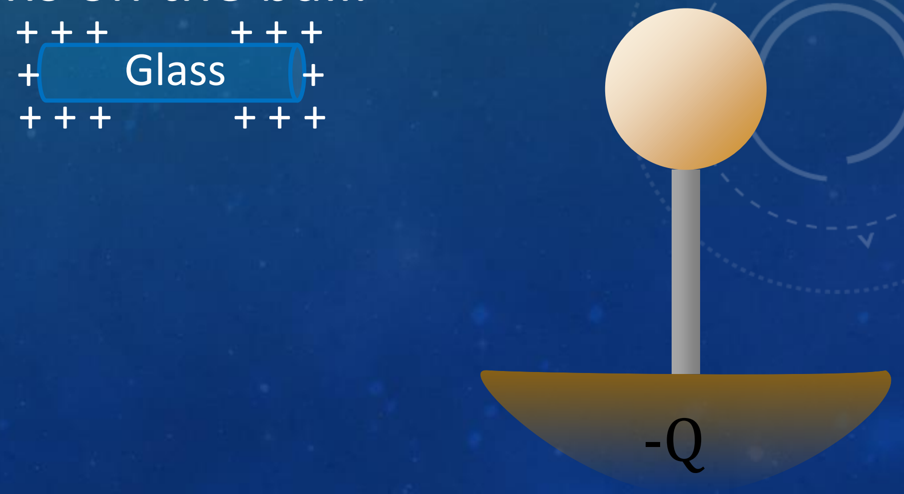
CHARGE DISTRIBUTION

- For a sphere, the charge spreads uniformly around the surface.
- For other shapes, it depends on the shape.
  - Charge tends to cluster near sharp points.



CHARGING AN INSULATOR

- Ground - A source or sink for as much positive or negative charge as needed.
- Charging by induction
  - Charge a glass rod by rubbing it with silk, then bring it near a grounded insulator.
  - Negative charge flows from the ground onto the ball.
  - Isolate the ball, and now the excess charge remains on the ball.



CHARGING AN INSULATOR

- Charging by contact
  - Bring a charged ball near an identical, but uncharged ball.
  - Upon contact, half of the charge transfers to the uncharged ball.
  - One can continue this procedure to get other fractions of charge, and works for both positive and negative charges.
  - This method is how Charles-Augustin de Coulomb (1736-1806) explored the relationship between different charges, and derived Coulomb’s Law.

STATIC CHARGE SIMULATION

- Link to simulation: https://phet.colorado.edu/en/simulation/legacy/travoltage

- Things to do:
  - Rub John's foot on the carpet 2-3 times to collect a little charge.
  - See the charge spread out on John's body.
  - Bring his finger near the grounded door until the charge jumps from his body to the doorknob.
  - Move his finger back.
  - Now rub his foot until enough charge builds up that it jumps to the door even though his finger is far from the doorknob.

CONCLUSION

- Charge is an intrinsic property of matter, independent of its mass.
  - A macroscopic quantity of charge is made from the contribution of the charge on many microscopic particles.
  - Electrons have a fundamental quantity of negative charge.
  - Protons have a fundamental quantity of positive charge.
  - The net charge on an object is the arithmetic sum of the charges of its constituent particles.
  - Like charges repel, unlike charges attract.
- Conductors allow charge to flow through them easily. Charge does not flow through insulators easily.
- Static charge spreads out on the surface of both insulators and conductors, clustering near sharp points.