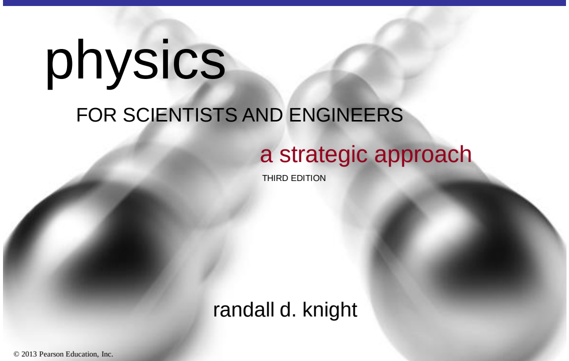
## Class 8, Sections 25.1 – 25.4 Preclass Notes





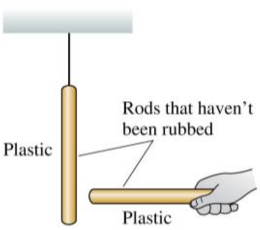

ALWAYS LEARNING PEARSON

## Chapter 25 Electric Charges and Forces

**Chapter Goal:** To describe electric phenomena in terms of charges, forces, and fields.



## Discovering Electricity: Experiment 1

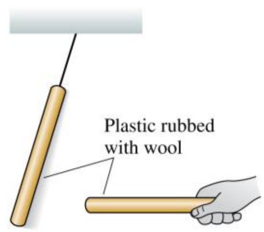



- Take a plastic rod that has been undisturbed for a long period of time and hang it by a thread.
- Pick up another undisturbed plastic rod and bring it close to the hanging rod.
- Nothing happens to either rod.

- No forces are observed.
- We will say that the original objects are **neutral**.



## Discovering Electricity: Experiment 2

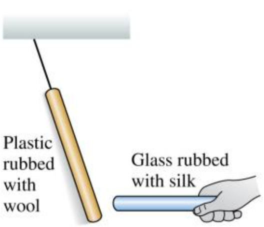



- Rub both plastic rods with wool.
- Now the hanging rod tries to move away from the handheld rod when you bring the two close together.
- Two glass rods rubbed with silk also repel each other.

There is a *long-range* ***repulsive*** *force*, requiring no contact, between two identical objects that have been charged in the ***same*** way.



## Discovering Electricity: Experiment 3

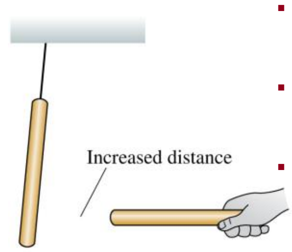



- Bring a glass rod that has been rubbed with silk close to a hanging plastic rod that has been rubbed with wool.
- These two rods *attract* each other.

These particular two types of rods are **different** materials, charged in a somewhat different way, and they ***attract*** each other rather than repel.



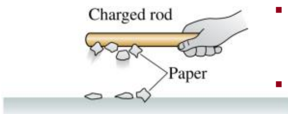
## Discovering Electricity: Experiment 4




- Rub rods with wool or silk and observe the forces between them.
- These forces are greater for rods that have been rubbed more vigorously.
- The strength of the forces decreases as the separation between the rods increases.

The force between two charged objects depends on the **distance** between them.

## Discovering Electricity: Experiment 5

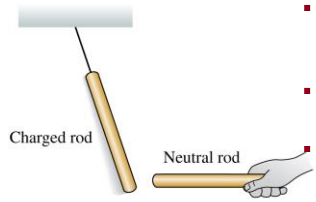



- Hold a charged (i.e., rubbed) plastic rod over small pieces of paper on the table.
- The pieces of paper leap up and stick to the rod.
- A charged glass rod does the same.
- However, a neutral rod has no effect on the pieces of paper.

There is an attractive force between a **charged** object and a ***neutral*** (uncharged) object.



## Discovering Electricity: Experiment 6

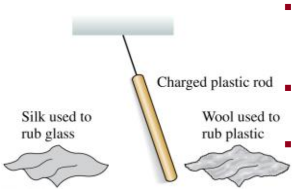



- Rub a plastic rod with wool and a glass rod with silk.
- Hang both by threads, some distance apart.
- Both rods are attracted to a *neutral* object that is held close.

There is an attractive force between a **charged** object and a ***neutral*** (uncharged) object.



## Discovering Electricity: Experiment 7

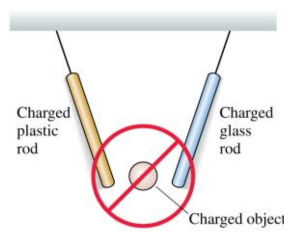



- Rub a hanging plastic rod with wool and then hold the wool close to the rod.
- The rod is weakly attracted to the wool.
- The plastic rod is repelled by a piece of silk that has been used to rub glass.

The silk starts out with equal amounts of "glass charge" and "plastic charge" and the rubbing somehow **transfers** "glass charge" from the silk to the rod.



## Discovering Electricity: Experiment 8




- Other objects, after being rubbed, attract one of the hanging charged rods (plastic or glass) and repel the other.
- These objects always pick up small pieces of paper.
- There appear to be *no* objects that, after being rubbed, pick up pieces of paper and attract both the charged plastic and glass rods.

There are only two types of charge: "like plastic" and "like glass"; there is **no third kind of charge**.



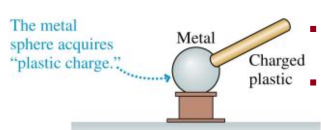
## Charge Model, Part I

Recap, so far:

- Electric **charge** can be added or removed from an object by rubbing it (kinetic friction).
- There are exactly two kinds of charge (+ and −)
- Like charges repel, opposite charges attract.
- The size of the forces between two objects increases as amount of charge increases.
- The size of the force between two objects decreases as the distance between the objects increases.
- Neutral objects have an equal mixture of + and – charges.



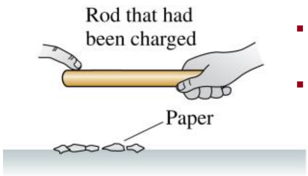
## Discovering Electricity: Experiment 9




- Charge a plastic rod by rubbing it with wool.
- Touch a neutral metal sphere with the rubbed area of the rod.
- The metal sphere then picks up small pieces of paper and repels a charged, hanging plastic rod.
- The metal sphere appears to have acquired "plastic charge".

Charge can be *transferred* from one object to another, but only when the objects *touch*.

## Discovering Electricity: Experiment 10

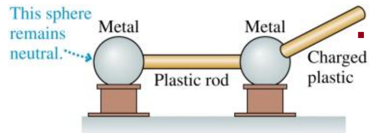



- Charge a plastic rod, then run your finger along it.
- After you've done so, the rod no longer picks up small pieces of paper or repels a charged, hanging plastic rod.
- Similarly, the metal sphere of Experiment 9 no longer repels the plastic rod after you touch it with your finger.

Removing charge from an object, which you can do by touching it, is called **discharging.**



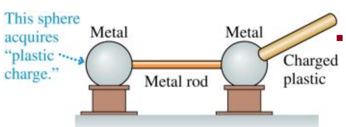
## Discovering Electricity: Experiment 11




- Place two metal spheres close together with a plastic rod connecting them.
- Charge a second plastic rod, by rubbing, and touch it to one of the metal spheres.
- Afterward, the metal sphere that was touched picks up small pieces of paper and repels a charged, hanging plastic rod.
- The other metal sphere does neither.



## Discovering Electricity: Experiment 12




- Repeat Experiment 11 with a metal rod connecting the two metal spheres.
- Touch one metal sphere with a charged plastic rod.
- Afterward, *both* metal spheres pick up small pieces of paper and repel a charged, hanging plastic rod.

Metal is a **conductor**: Charge moves easily through it.
Glass and plastic are **insulators**: Charges remain immobile.



## Charge Model, Part II

Recap:

- There are two main types of materials: Conductors are ones through which electric charge moves easily. Insulators are ones in which charge remains fixed in place.
- Charge can be transferred from one object to another by contact.



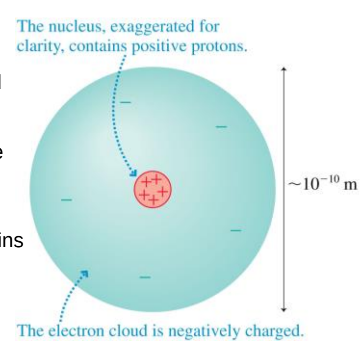
## Charge

- The modern names for the two types of charge, coined by Benjamin Franklin, are *positive charge* and *negative charge.*
- Franklin established the convention that **a glass rod that has been rubbed with silk is *positively* charged**.
- Any other object that repels a charged glass rod is also positively charged, and any charged object that attracts a charged glass rod is negatively charged.
- Thus **a plastic rod rubbed with wool is negative**.
- This convention was established long before the discovery of electrons and protons.



## Atoms and Electricity

- An atom consists of a very small and dense *nucleus*, surrounded by much less massive orbiting *electrons.*
- The nucleus contains both *protons* and *neutrons.*



## Atoms and Electricity

- The atom is held together by the attractive electric force between the positive nucleus and the negative electrons.
- Electrons and protons have charges of opposite sign but *exactly* equal magnitude.
- This atomic-level unit of charge, called the **fundamental unit of charge,** is represented by the symbol $e$.

**TABLE 25.1** Protons and electrons

| Particle | Mass (kg) | Charge |
|---|---|---|
| Proton | $1.67 \times 10^{-27}$ | $+e$ |
| Electron | $9.11 \times 10^{-31}$ | $-e$ |



## Charge Quantization

- A macroscopic object has net charge:

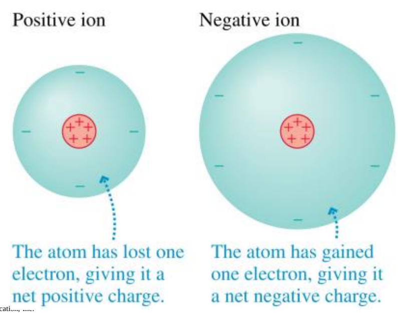
$$q = N_p e - N_e e = (N_p - N_e)e$$

- Where $N_p$ and $N_e$ are the number of protons and electrons contained in the object.
- Most macroscopic objects have an *equal number* of protons and electrons and therefore have $q = 0$.
- A charged object has an unequal number of protons and electrons.
- Notice that an object's charge is always an integer multiple of $e$.
- This is called **charge quantization**.



## Atoms and Electricity

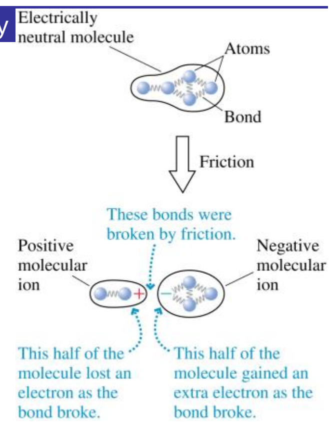
The process of removing an electron from the electron cloud of an atom, or adding an electron to it, is called **ionization.**






## Atoms and Electricity

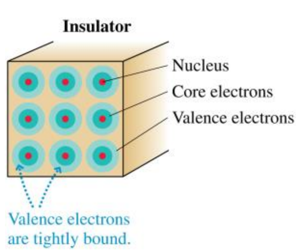
- *Molecular ions* can be created when one of the bonds in a large molecule is broken.
- This is the way in which a plastic rod is charged by rubbing with wool or a comb is charged by passing through your hair.






## Insulators

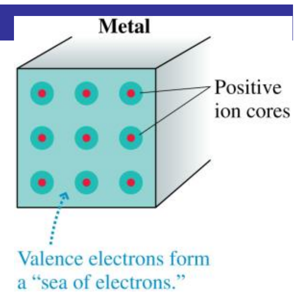
- The electrons in an **insulator** are all tightly bound to the positive nuclei and not free to move around.
- Charging an insulator by friction leaves patches of molecular ions on the surface, but these patches are immobile.





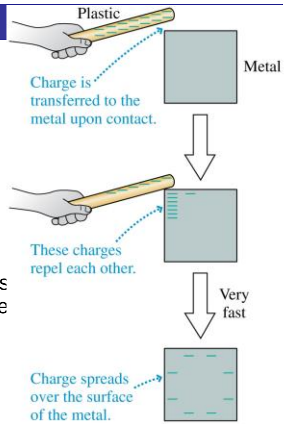

## Conductors

- In metals, the outer atomic electrons are only weakly bound to the nuclei.
- These outer electrons become detached from their parent nuclei and are free to wander about through the entire solid.
- The solid *as a whole* remains electrically neutral, but the electrons are now like a negatively charged liquid permeating an array of positively charged **ion cores**.



## Charging

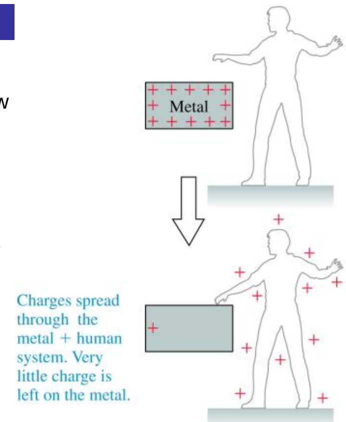
- The figure shows how a conductor is charged by contact with a charged plastic rod.
- Electrons in a conductor are free to move.
- Once charge is transferred to the metal, repulsive forces between the electrons cause them to move apart from each other.






## Discharging

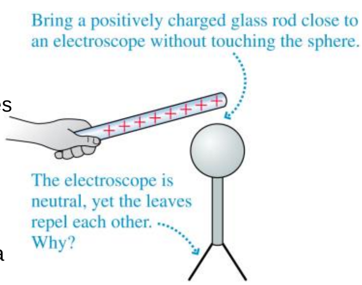
- The figure shows how touching a charged metal discharges it.
- Any excess charge that was initially confined to the metal can now spread over the larger metal + human conductor.






## Charge Polarization

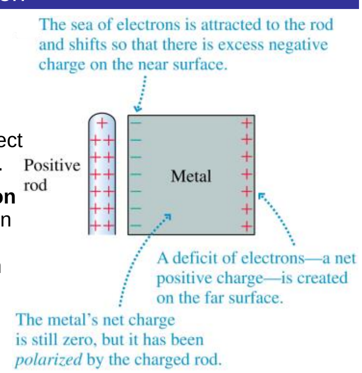
- The figure shows how a charged rod held close to an electroscope causes the leaves to repel each other.
- How do charged objects of either sign exert an attractive force on a *neutral* object?






## Charge Polarization

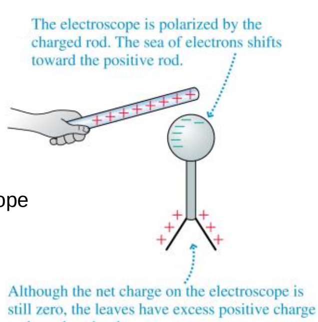
- Although the metal as a whole is still electrically neutral, we say that the object has been *polarized*.
- **Charge polarization** is a slight separation of the positive and negative charges in a neutral object.






## Charge Polarization

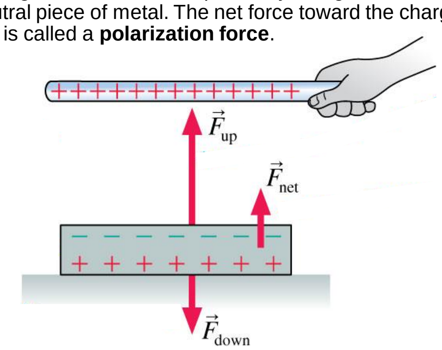
- Charge polarization produces an excess positive charge on the leaves of the electroscope, so they repel each other.
- Because the electroscope has no *net* charge, the electron sea quickly readjusts once the rod is removed.





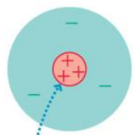

## Polarization Force

- The figure below shows a positively charged rod near a neutral piece of metal. The net force toward the charged rod is called a **polarization force**.



## The Electric Dipole

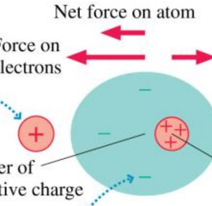
The figure below shows how a neutral atom is polarized by an external charge, forming an **electric dipole**.





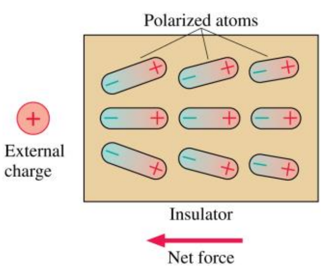

## The Electric Dipole

The figure below shows how a neutral atom is polarized by an external charge, forming an **electric dipole**.





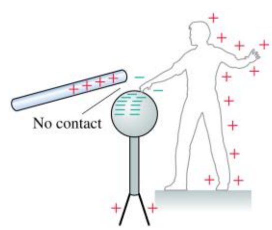

## The Electric Dipole




- When an insulator is brought near an external charge, all the individual atoms inside the insulator become polarized.
- The polarization force acting *on each atom* produces a net polarization force toward the external charge.



## Charging by Induction, Step 1




1. The charged rod polarizes the electroscope + person conductor. The leaves repel slightly due to polarization, but overall the electroscope has an excess of electrons and the person has a deficit of electrons.

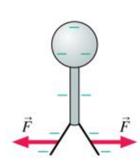


## Charging by Induction, Step 2

2. The negative charge on the electroscope is isolated when contact is broken.



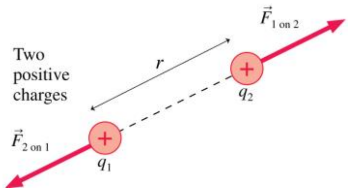
## Charging by Induction, Step 3



3. When the rod is removed, the leaves first collapse as the polarization vanishes, then repel as the excess negative charge spreads out. The electroscope has been *negatively* charged.

## Coulomb's Law

When two positively charged particles are a distance, $r$, apart, they each experience a repulsive force.



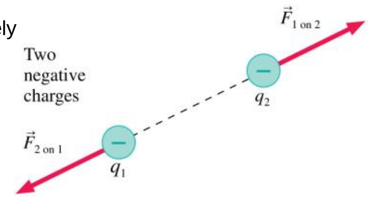

$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2}$$

In SI units $K = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$.



## Coulomb's Law

When two negatively charged particles are a distance, $r$, apart, they each experience a repulsive force.



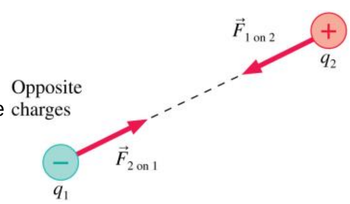

$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2}$$

In SI units $K = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$.



## Coulomb's Law

When two oppositely charged particles are a distance, $r$, apart, they each experience an attractive force.




$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2}$$

In SI units $K = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$.



## The Permittivity Constant

- We can make many future equations easier to use if we rewrite Coulomb's law in a somewhat more complicated way.
- Let's define a new constant, called the **permittivity constant** $\epsilon_0$:

$$\epsilon_0 = \frac{1}{4\pi K} = 8.85 \times 10^{-12} \text{ C}^2/\text{N m}^2$$

- Rewriting Coulomb's law in terms of $\epsilon_0$ gives us:

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1||q_2|}{r^2}$$