Lecture 17

Electricity (chapters 26-32)

- Introduction: charge model
- Charges at microscopic level
- understand insulators, conductors...
- Quantify force: Coulomb's law
- Concept of electric field

Introduction

- going beyond Newton's laws
- charges at rest and in motion (currents): less experience, e.g., don't see movement of charges
- electricity and magnetism connected (PHY 270)
- new concept of "field" to describe interactions (macroscopic description)
- microscopic level: relation of charges to atoms/molecules; atoms (neutral) made of charged particles (electrons and protons): can be separated and moved; atoms held by electric force...; macroscopic mechanical forces due to electric at atomic level
- this week: chapter 26 (Electric Charges and Forces) "charge model" to describe basic electric phenomena; how charges behave in insulators and conductors; calculate forces using Coulomb's law; "field model" (review properties of vectors)

Charge Model I

- Rubbing objects causes forces, e.g. plastic comb picks up paper; shock on touching metal doorknob after walking across carpet..
- understand electric phenomena in terms of charges and forces between them (without reference to atoms/electrons)
- experiments with rubbing of plastic/glass rods on wool/silk: no forces originally (neutral); both attractive and repulsive (cf. gravity), long range forces (like gravity) after rubbing (charging)
- attractive force between charged and neutral object → test for object being charged: picks up paper

Postulates of Charge Model

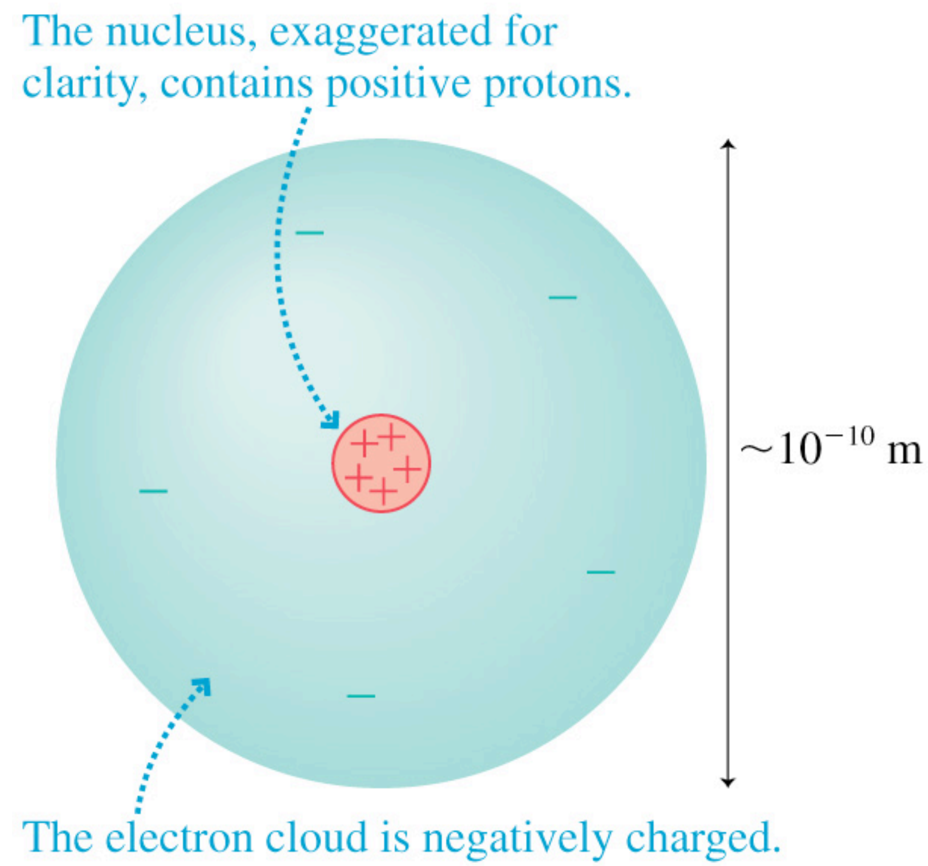
- Rubbing adds/removes charge (larger for more vigorous)
- Two kinds of charges: “plastic” and “glass” (others can be charged too: “positive” and “negative”)
- Two like charges repel, two opposite charges attract
- Force between charges is long-range; increases with quantity of charge, decreases with distance
- Neutral objects equal mixture of 2 charges: rubbing separates...

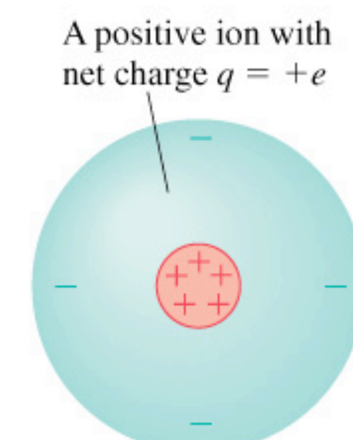
...more experiments with metal spheres...

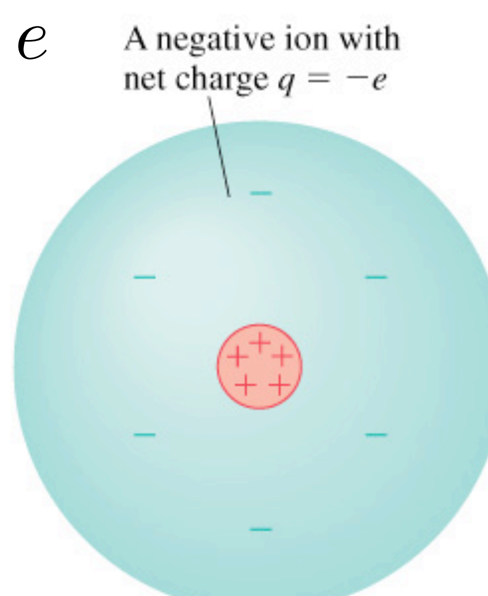
- Charge can be <u>transferred</u> by contact (removing charge: <u>discharging</u>)
- <u>Conductors</u> (charges move easily, e.g., metal) vs, <u>Insulators</u> (charges remain fixed, e.g., plastic): both can be charged

Charge at microscopic level I

- 2 types of charges behave like positive and negative numbers, e.g. metal sphere is neutral after receiving equal amounts of 2...
- which is positive is convention (Franklin): glass rod positive, electron attracted to it electron negative
- Atomic-level/fundamental unit of charge: +e for proton, -e for electron (inherent property)
- no other sources of charge: $q = N_p e - N_e e = (N_p - N_e)\, e$ (charge quantization)
- acquire positive charge by losing electron (ionization); negative ion (extra electron)

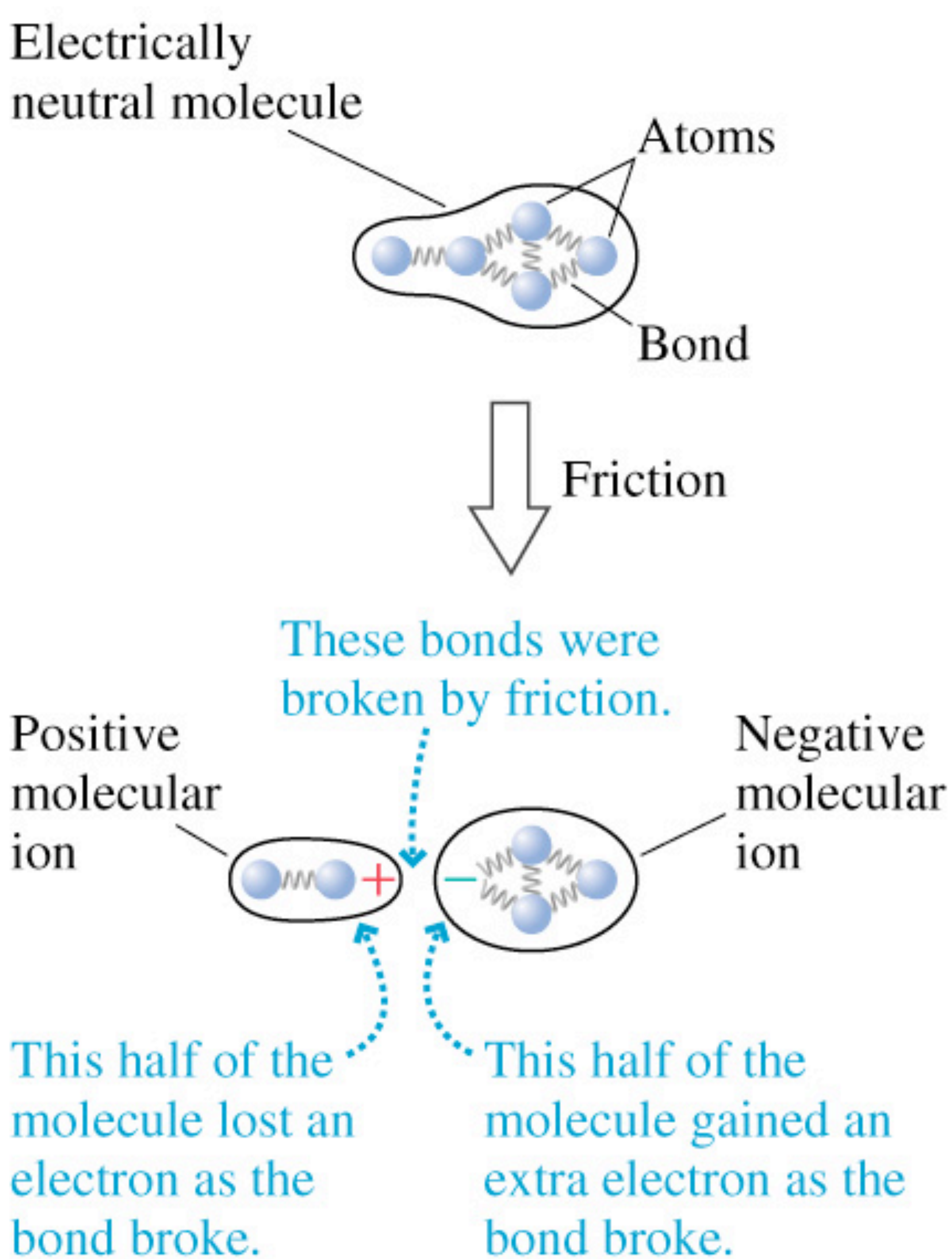


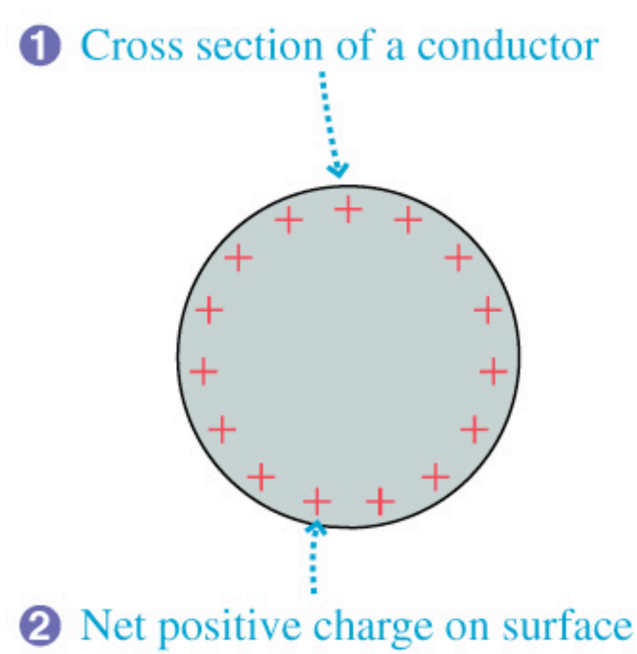


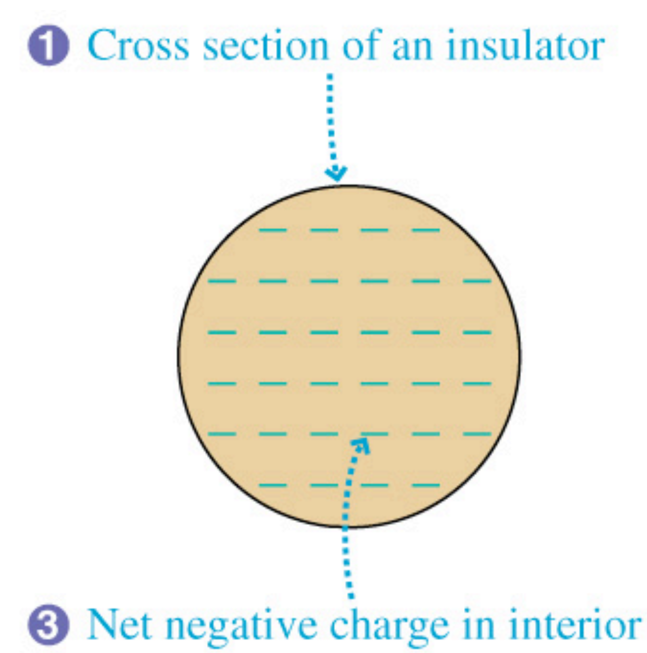


Charge at microscopic level II

- charging by rubbing: molecular ions from breaking of bonds
- charge conservation (transferred by electrons/ions): $q_{wool} = -q_{plastic}$
- charge diagrams: show net charge; conserve charge in next diagram

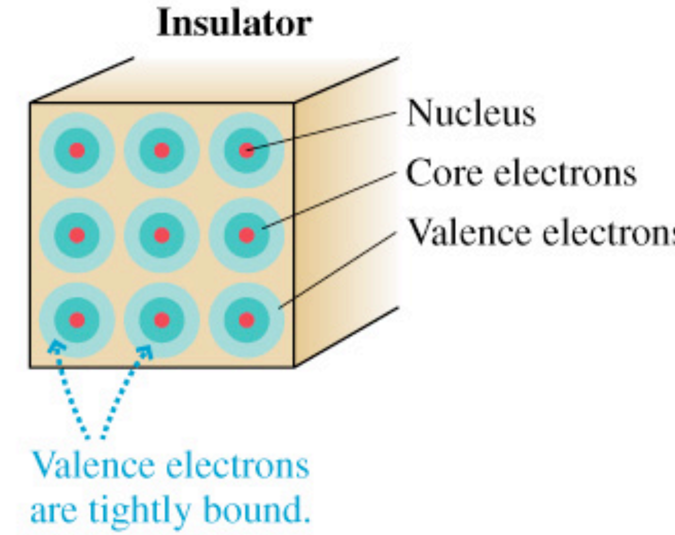






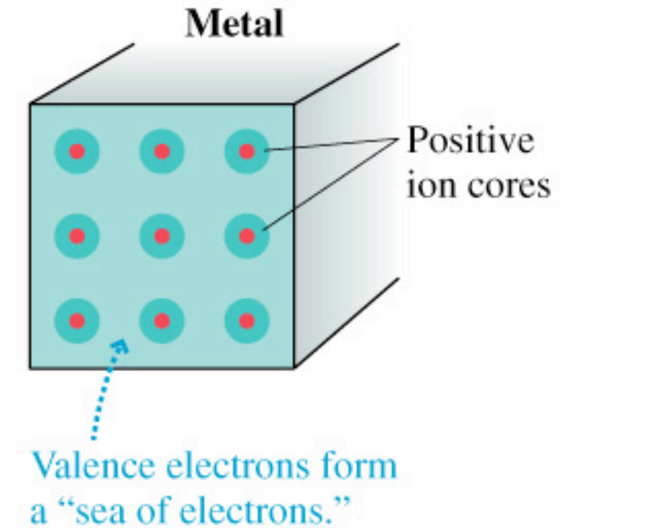
Insulators and Conductors

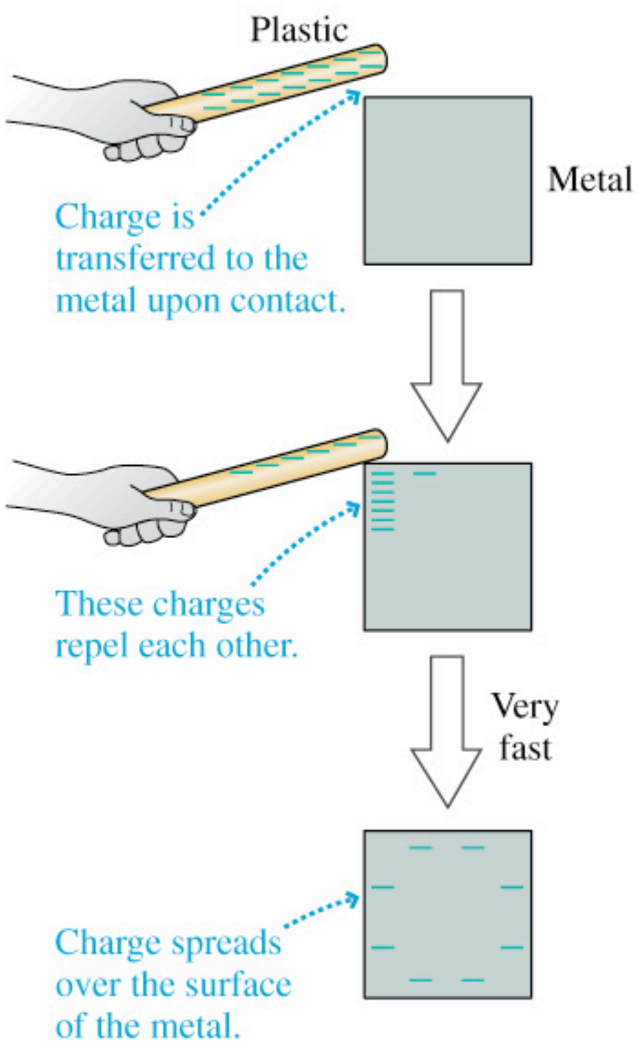
- insulators: charges immobile
- Conductors, e.g., <u>metals</u>: valence electrons weakly bound, respond to electric forces; salt water: ions...

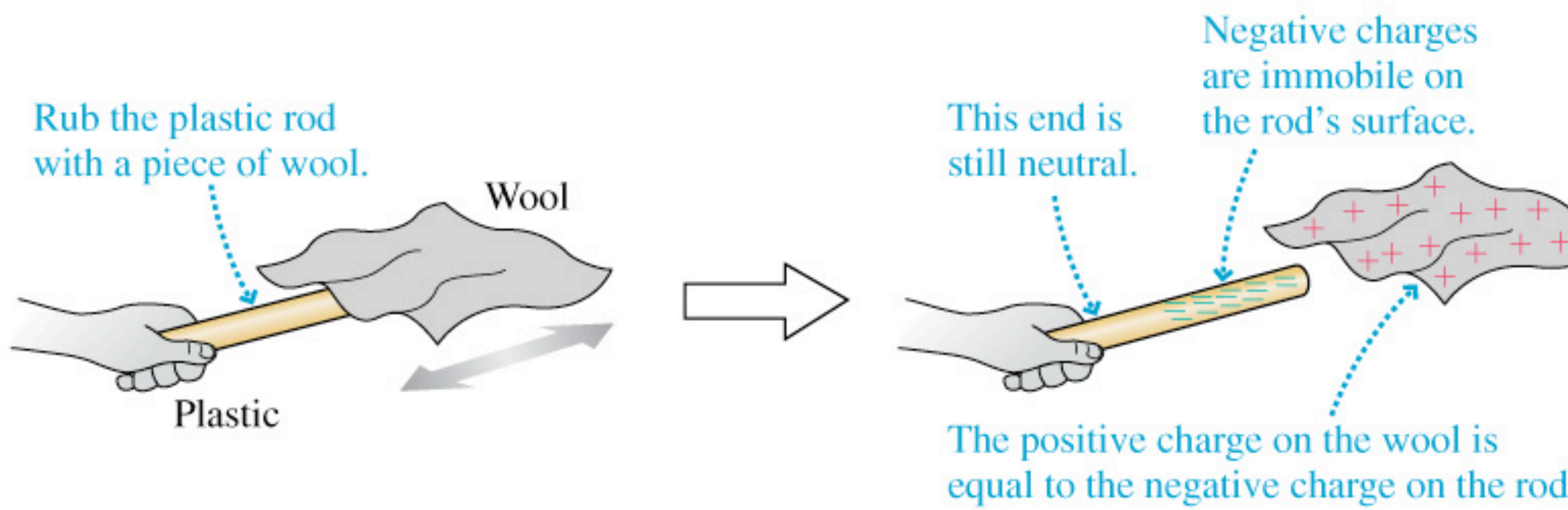


Charging

- conductors in electrostatic equilibrium: excess charge located on surface (if in interior, forces exerted causing move...)

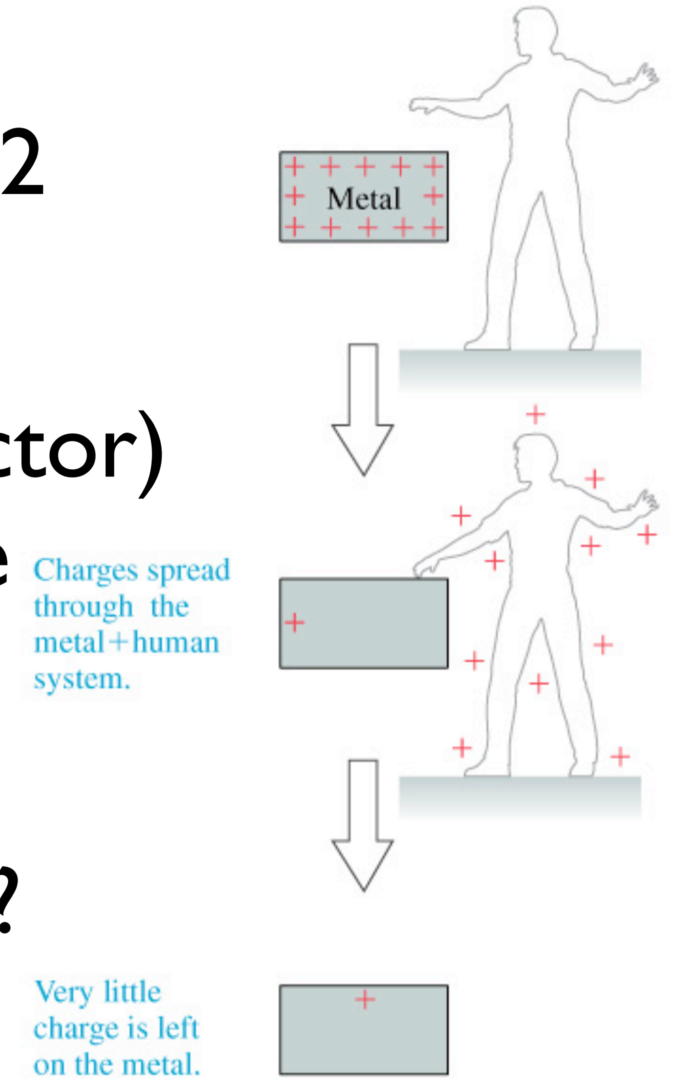






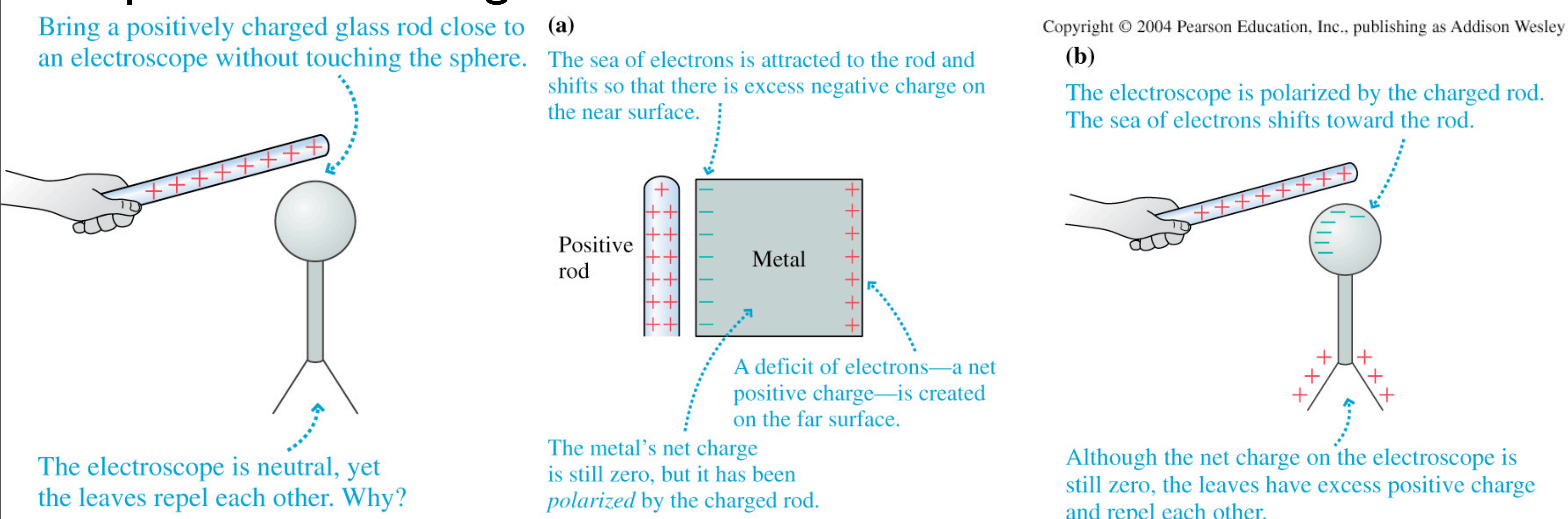
Discharging

- human body (salt water) is (large) conductor:2 conductors in contact “share” charge
- grounding: object connected to earth (conductor) thru’ conductor to prevent build-up of charge



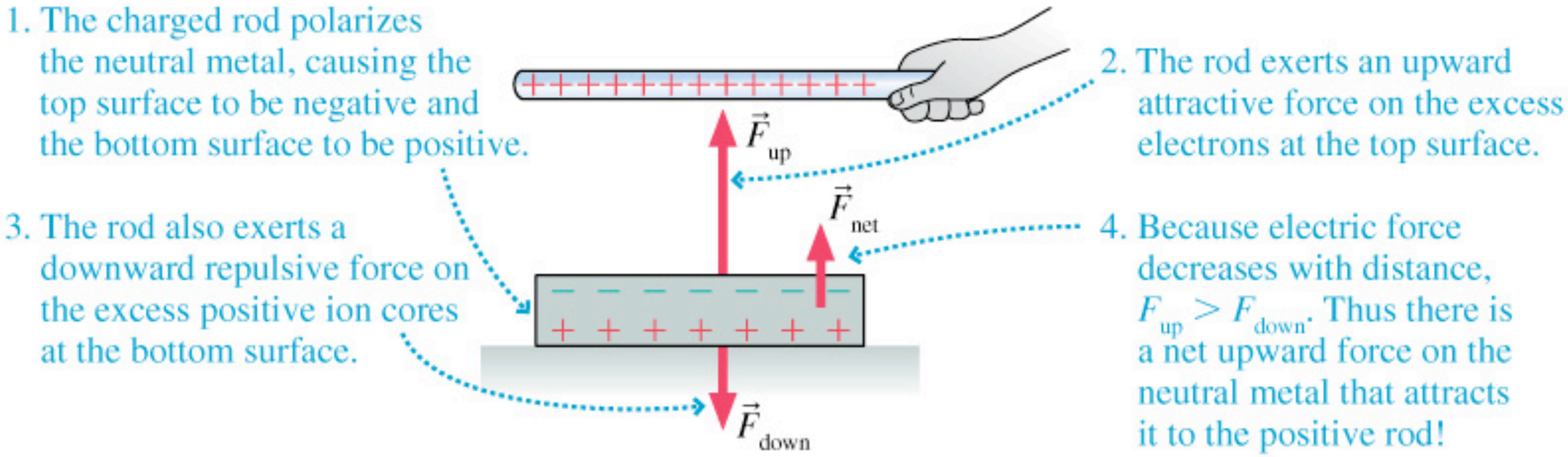
Charge polarization

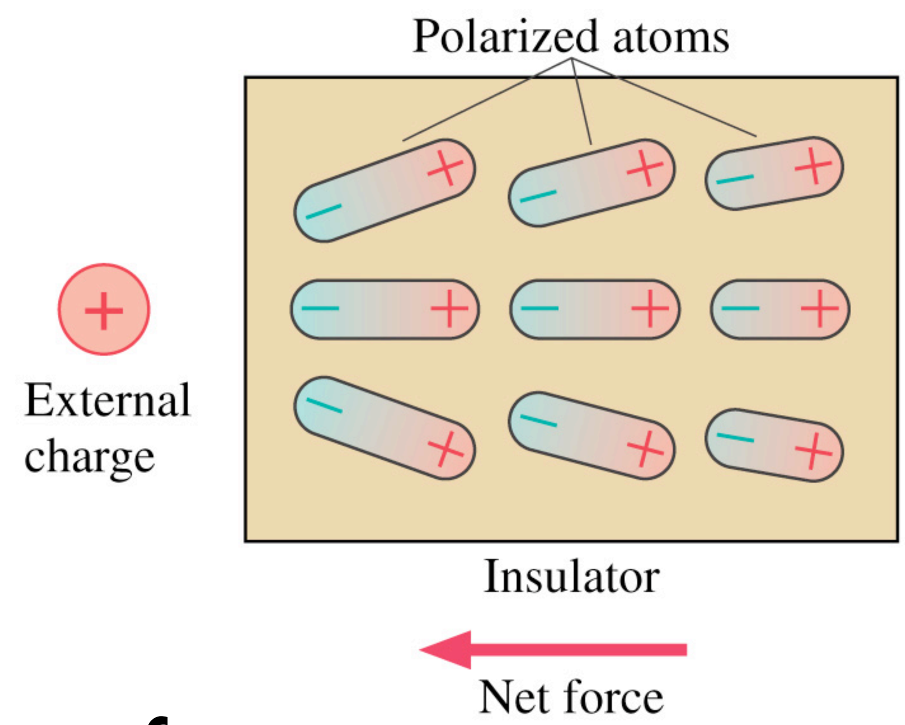
- charged objects (either sign) force on <u>neutral</u>?
- <u>separation</u> of charges in neutral



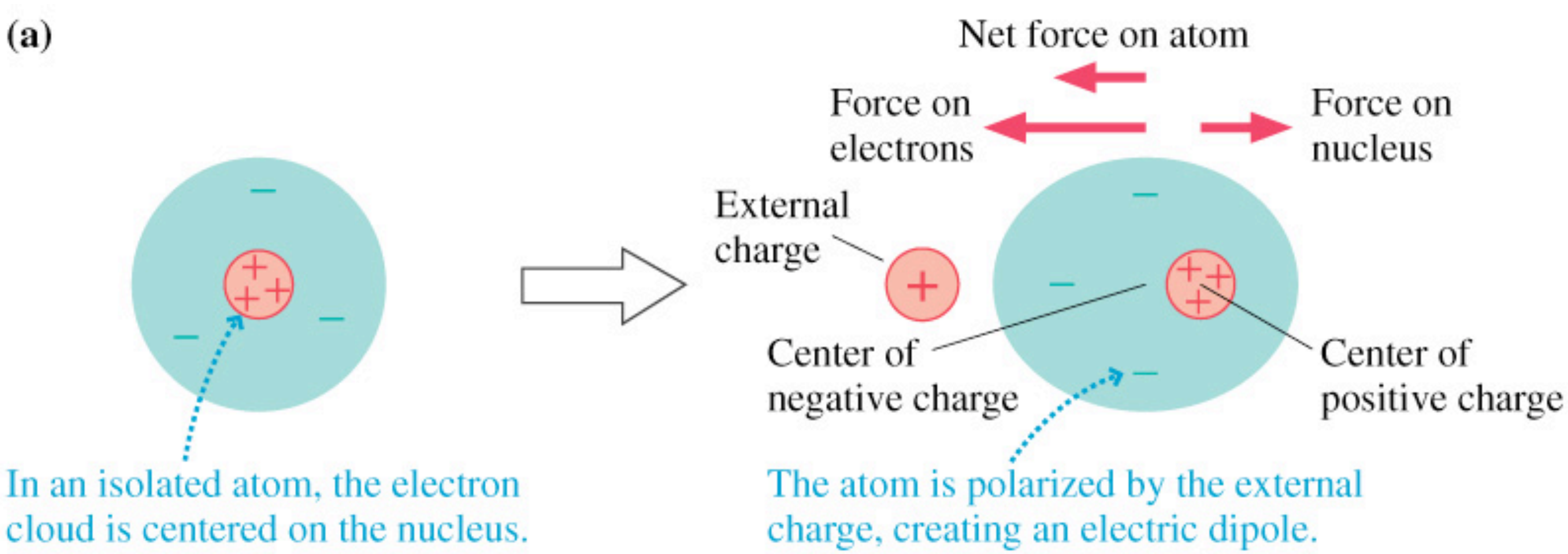
Electric Dipole

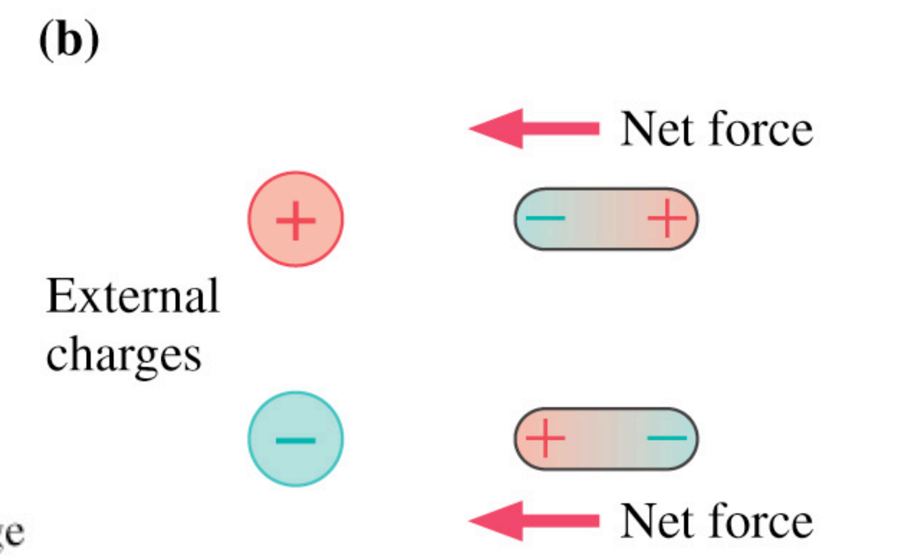
- Polarization force <u>attractive</u> (both signs of charged rods)





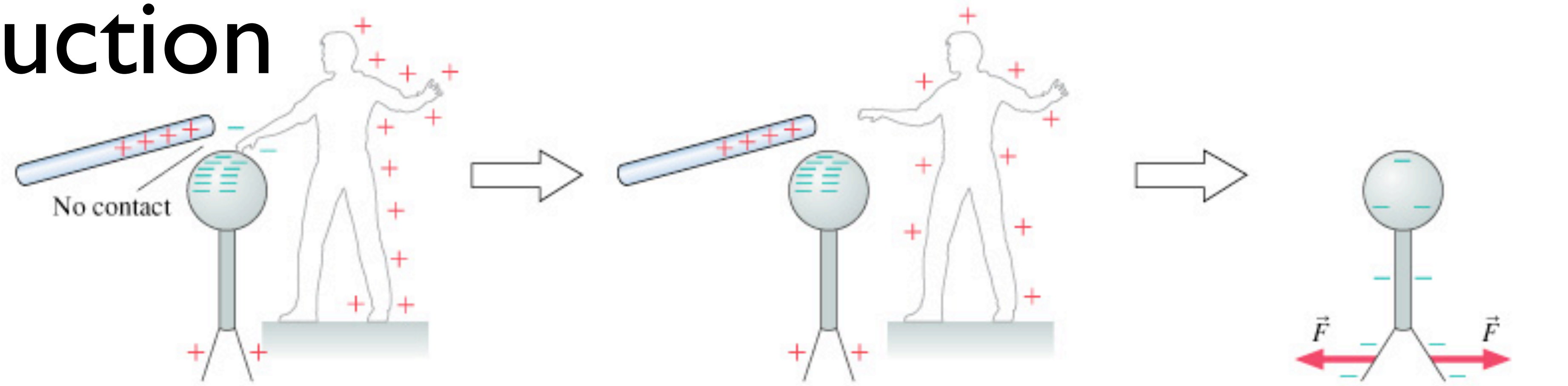
- charged rod picks up paper (<u>insulator</u>)?
- atoms polarized (electrons still bound)...net force... <u>electric dipole</u>: two charges with separation





Electric dipoles can be created by either positive or negative charges. In both cases, there is an attractive net force toward the external charge.

Charging by Induction



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

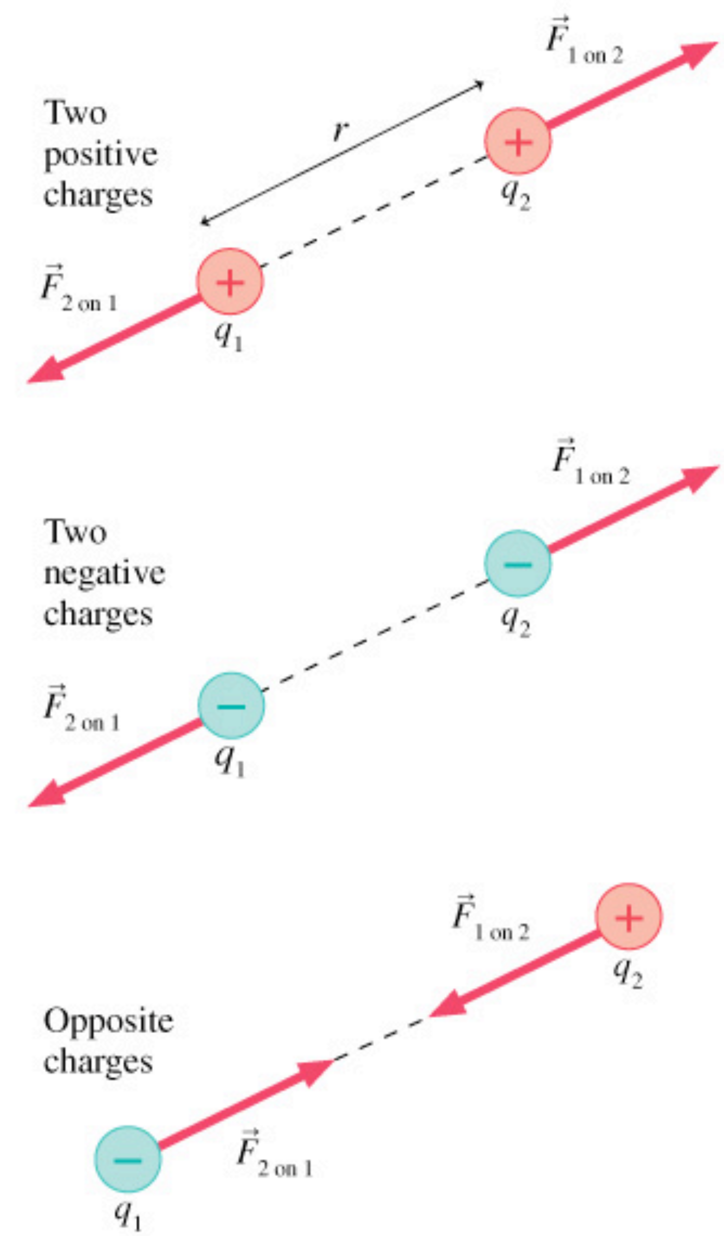
2. The negative charge on the electroscope is isolated when contact is broken.

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

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

- equal in magnitude, opposite in direction, along line joining
- attractive for opposite, repulsive for like (vectors)
- point charges: size $\ll$ separation between..
- static charges ($\ll$ speed of light)



Using Coulomb's law

- Units of charge (derived from current):

$$e = 1.6 \times 10^{-19}\ \mathrm{C} \quad \Longrightarrow \quad K = 9 \times 10^{9}\ \mathrm{N\ m^2/C^2}$$

- Rewrite in terms of $\epsilon_0 = \frac{1}{4\pi K} = 8.85 \times 10^{-12}\ \mathrm{C^2/N\ m^2}$

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

- Superposition: multiple charges 1,2, 3...

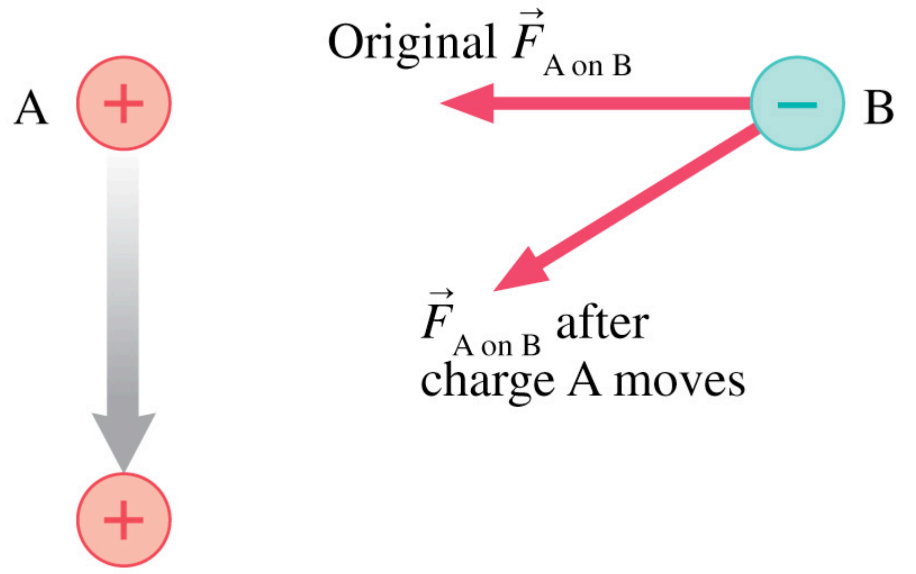
$$\bar{F}_{net\ \mathrm{on}\ j} = \bar{F}_{1\ \mathrm{on}\ j} + \bar{F}_{2\ \mathrm{on}\ j} + \ldots$$

- Strategy: pictorial representation (show charges, forces vectors...); graphical vector addition; x-and y-components

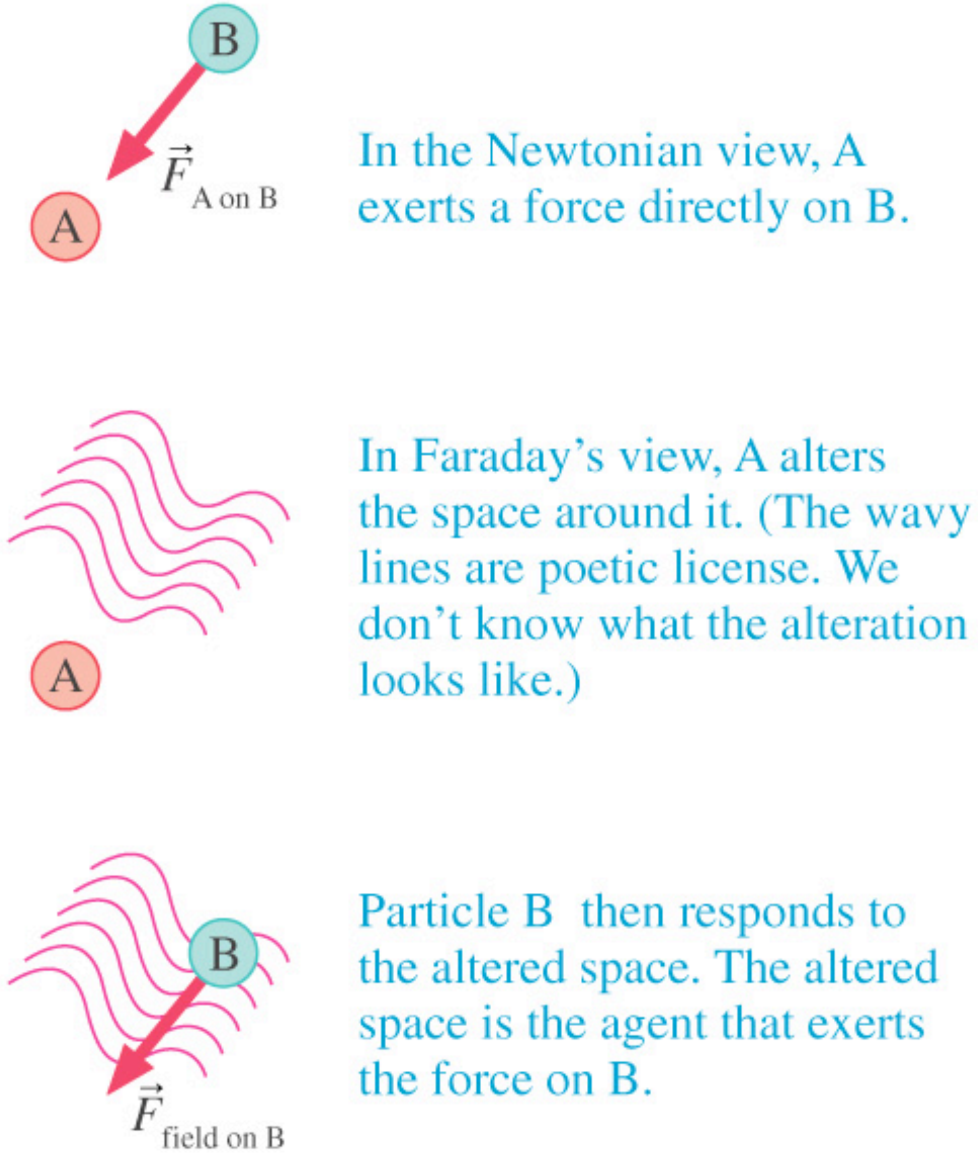
Example

- Two 1.0 g spheres are charged equally and placed 2.0 cm. apart. When released, they begin to accelerate at 150 meter per second squared. What is the magnitude of the charge on each sphere?

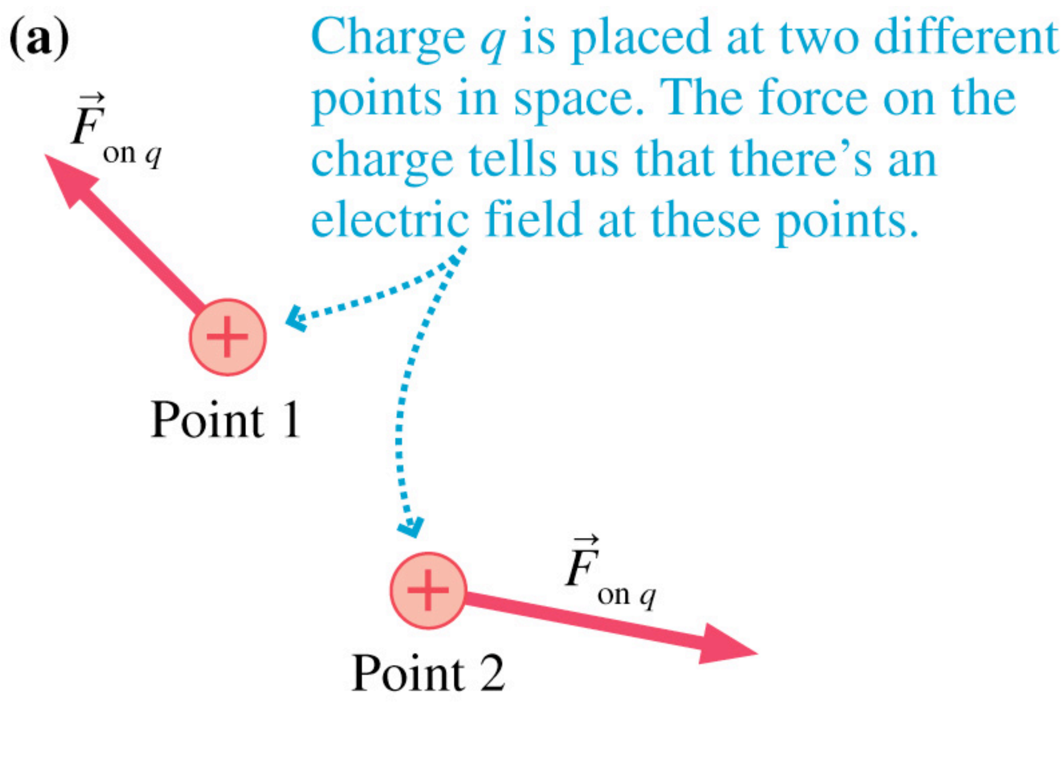
Concept of a Field

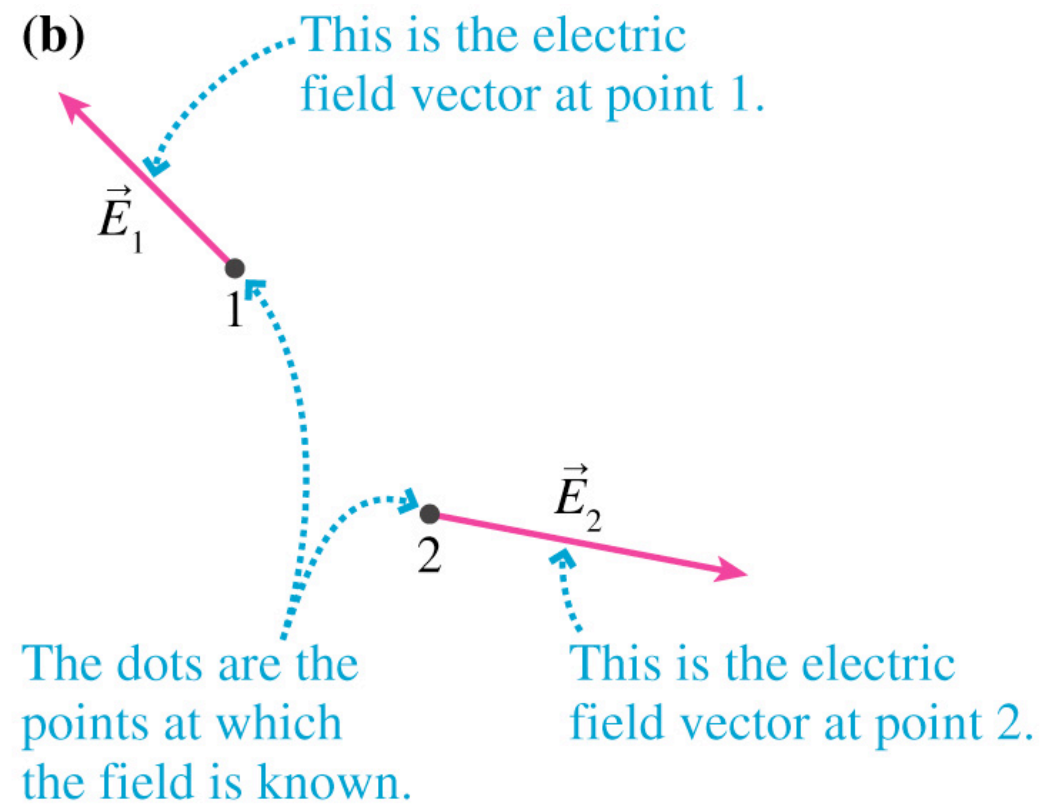


- gravity, electric forces long range (action at a distance): mechanism?
- force changes instantly?
- Faraday (and Maxwell): other masses/charges respond to field, f(x, y, z) cf. particle exits at 1 point
- alteration of space around a mass/ charge: gravitational/electric field



Electric Field Model





- more complex: 2 types of charges, forces, materials...
- source charge create electric field $\bar{E}$, probe charge experiences $\bar{F}$ exerted by $\bar{E}$

$$\vec{E}(x, y, z) = \frac{\vec{F}_{\text{on } q} \text{ at } (x, y, z)}{q}$$

- field is agent exerting force ($\bar{F} = q\bar{E}$): vector at every point; same direction as $\bar{F}$ for q > 0; independent of q (since $\bar{F}_{\text{on } q} \propto q$)