

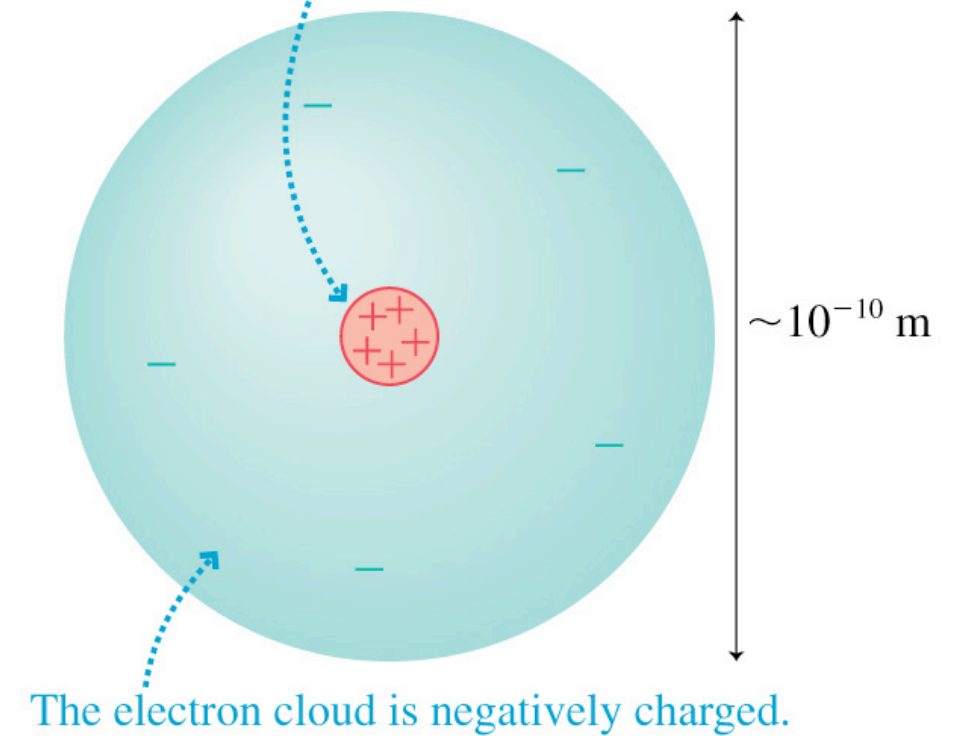
Lecture 17

- Charges at microscopic level
- understand insulators, conductors...
- Quantify force: Coulomb's law
- Concept of electric field
- Electric field due to point charge

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 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)

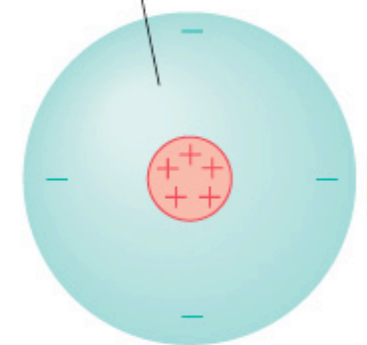
The nucleus, exaggerated for clarity, contains positive protons.



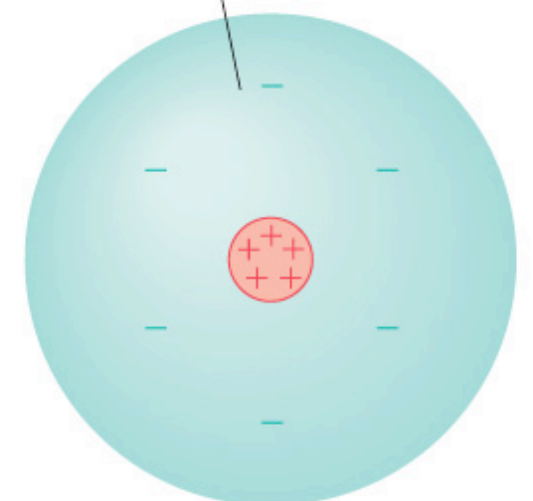
The electron cloud is negatively charged.

c

A positive ion with net charge $q = +e$



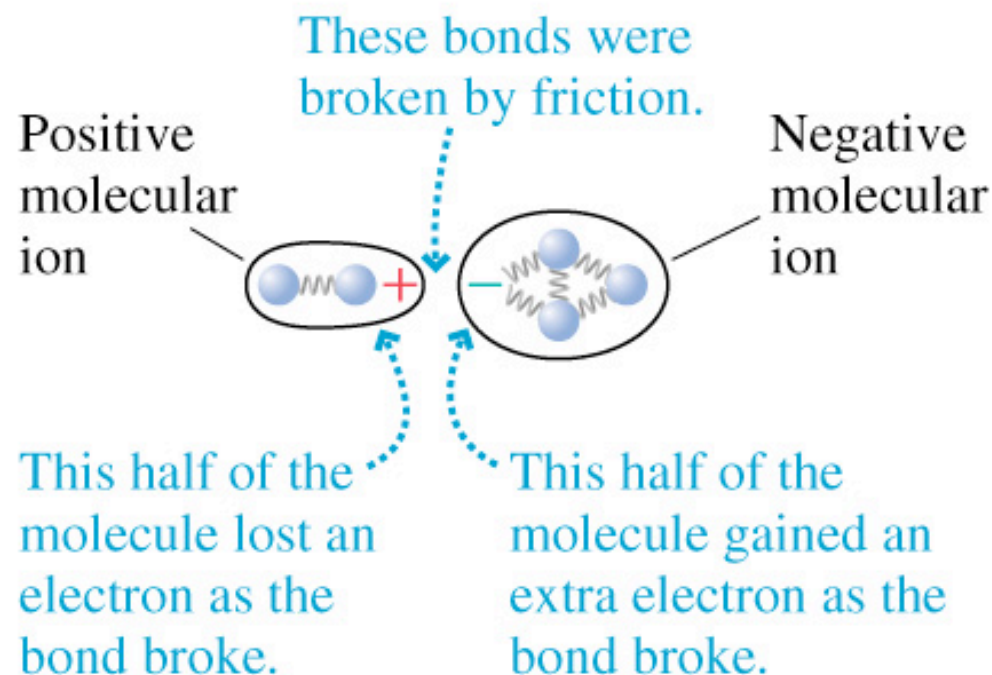
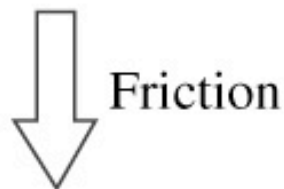
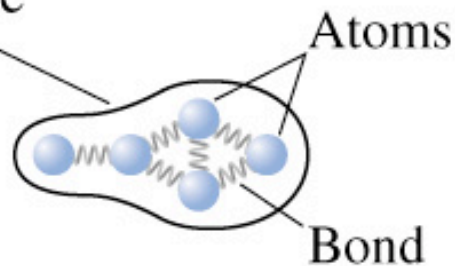
A negative ion with net charge $q = -e$



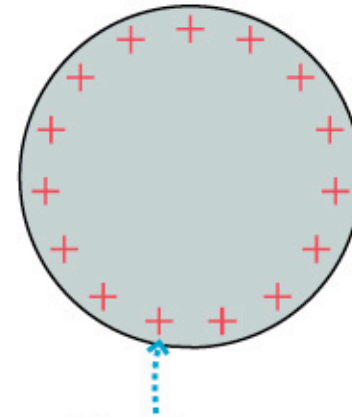
Charge at microscopic level II

- 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

Electrically neutral molecule

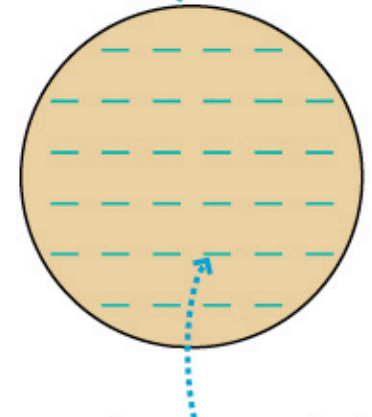


① Cross section of a conductor



② Net positive charge on surface

① Cross section of an insulator

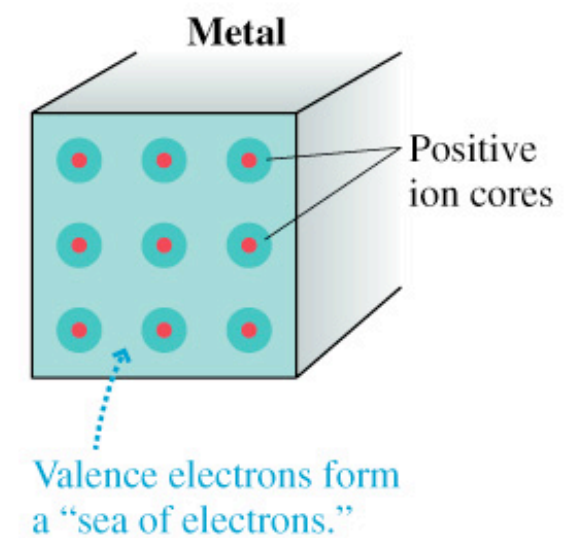
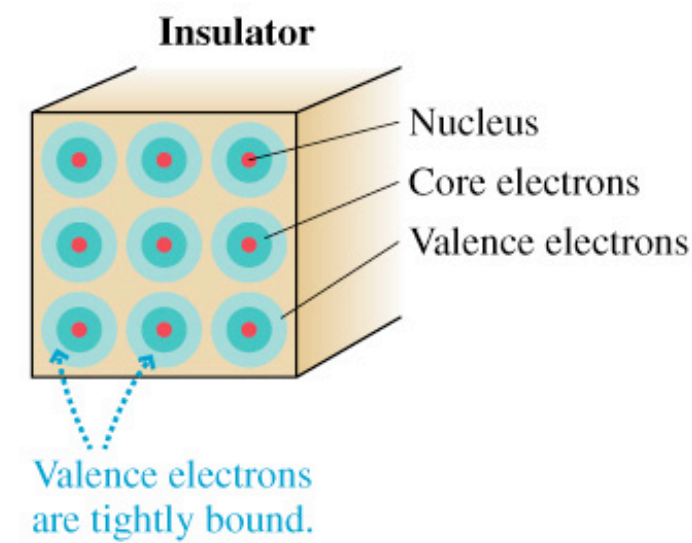
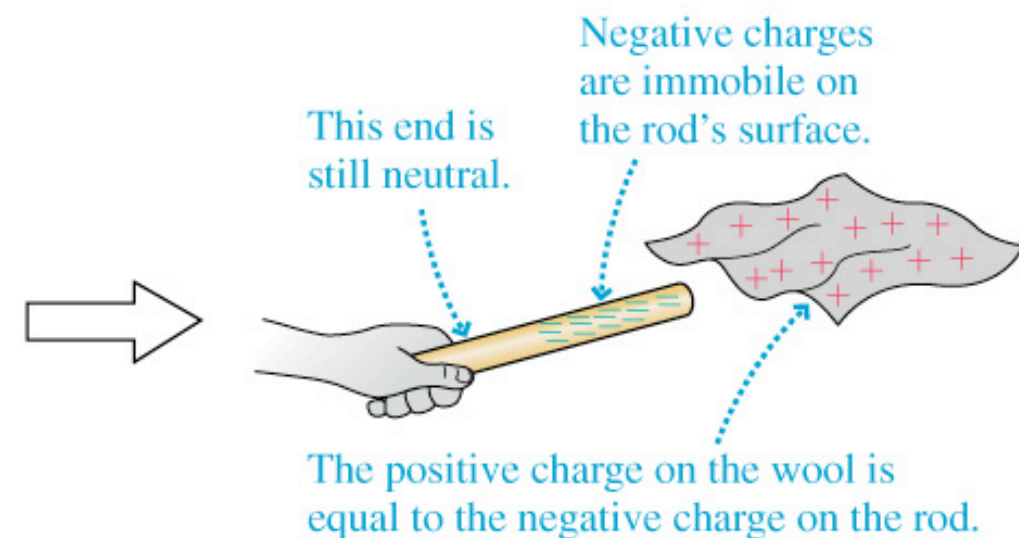
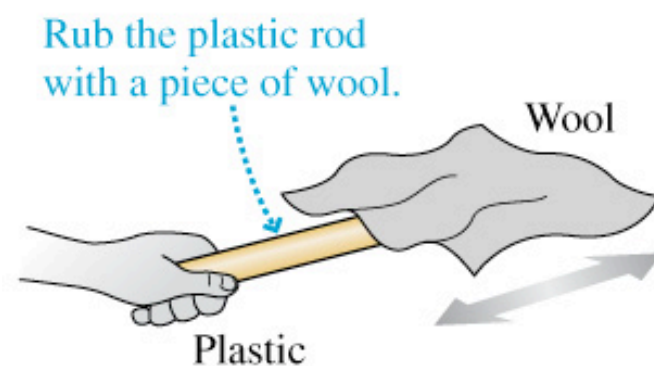
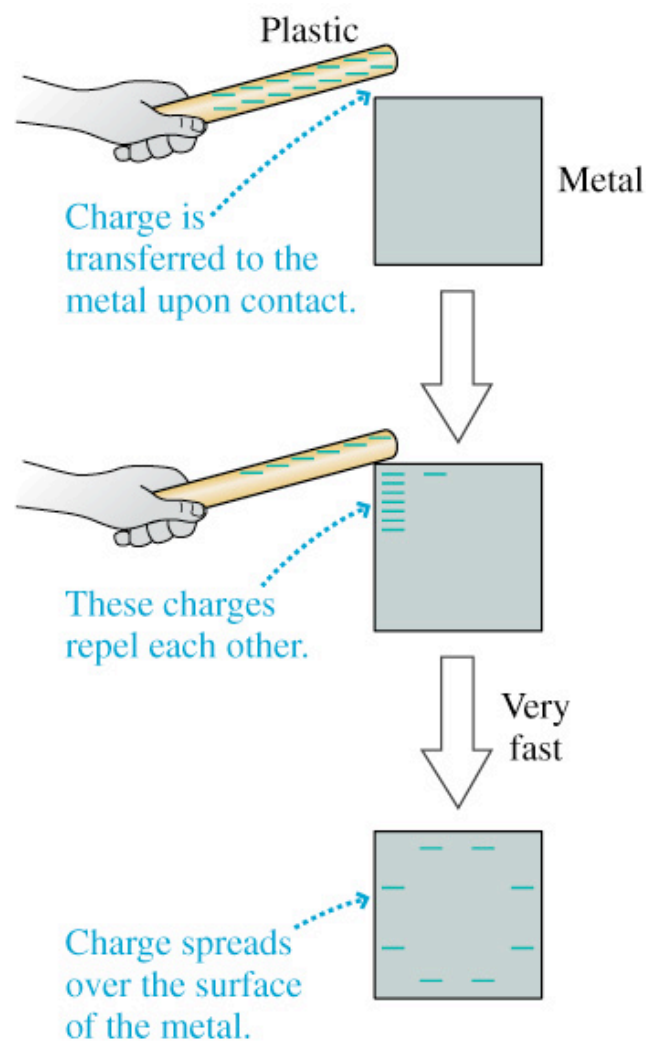


③ Net negative charge in interior

Insulators and Conductors

- insulators: charges immobile
- Conductors, e.g., metals: valence electrons weakly bound, respond to electric forces; salt water: ions...
- conductors in electrostatic equilibrium: excess charge located on surface (if in interior, forces exerted causing move...)

Charging



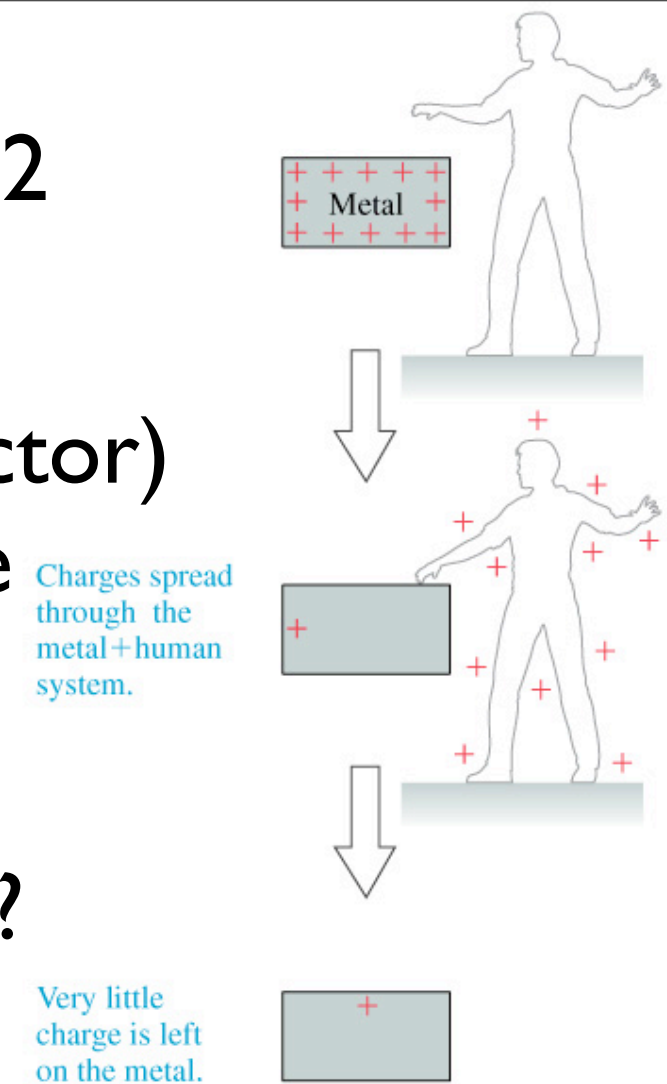
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Discharging

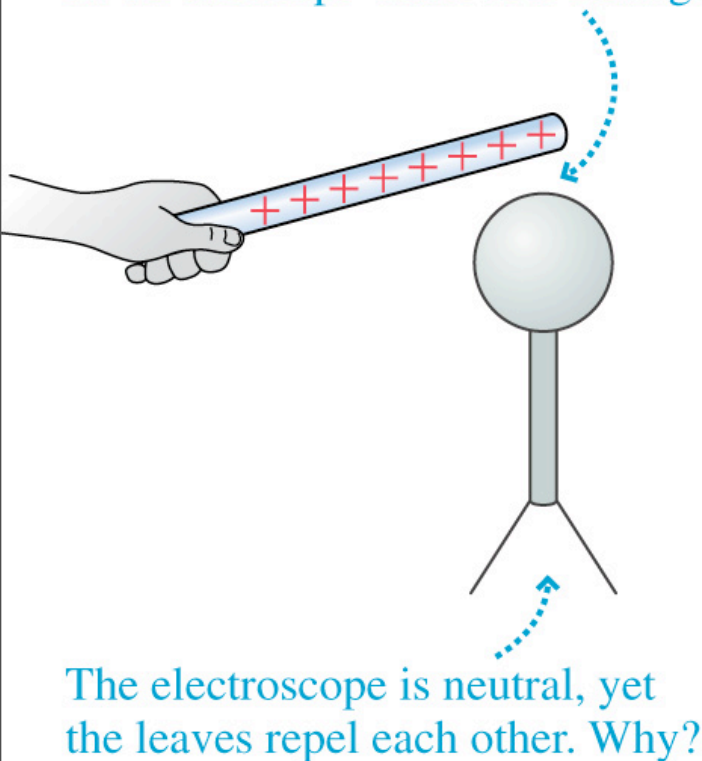
- human body (salt water) is (large) conductor: 2 conductors in contact “share” charge
- grounding: object connected to earth (conductor) thru’ conductor to prevent build-up of charge

Charge polarization

- charged objects (either sign) force on neutral?
- separation of charges in neutral

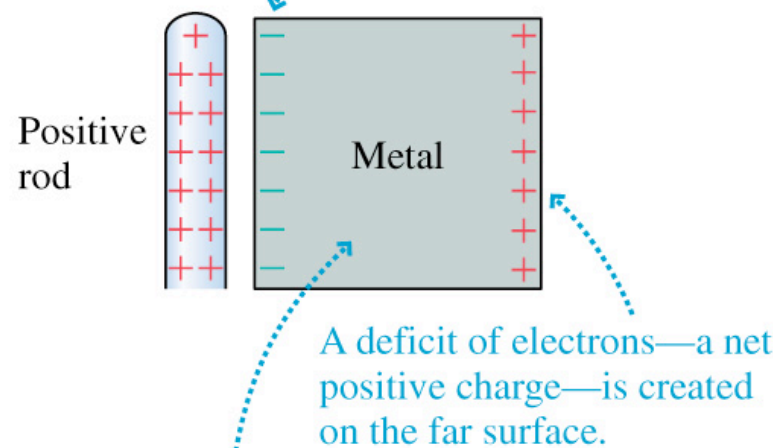


Bring a positively charged glass rod close to an electroscope without touching the sphere.



(a)

The sea of electrons is attracted to the rod and shifts so that there is excess negative charge on the near surface.

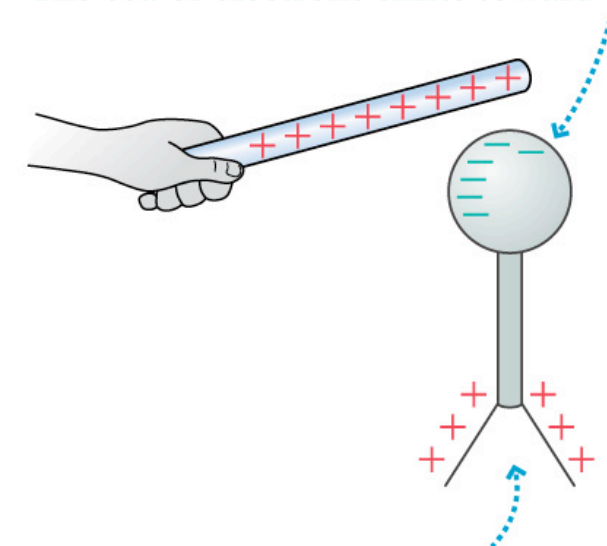


The metal's net charge is still zero, but it has been *polarized* by the charged rod.

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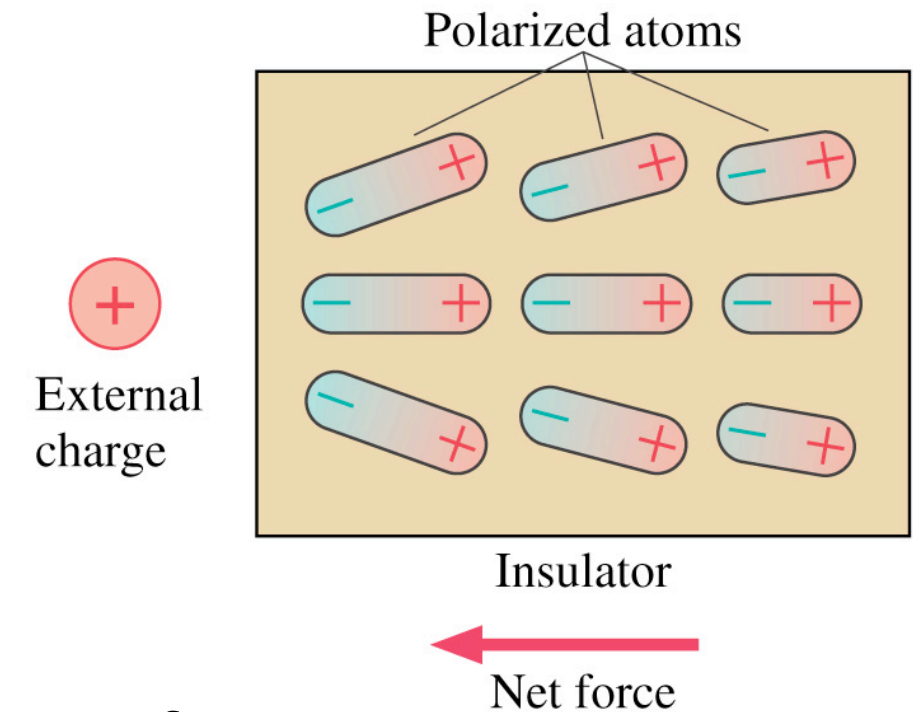
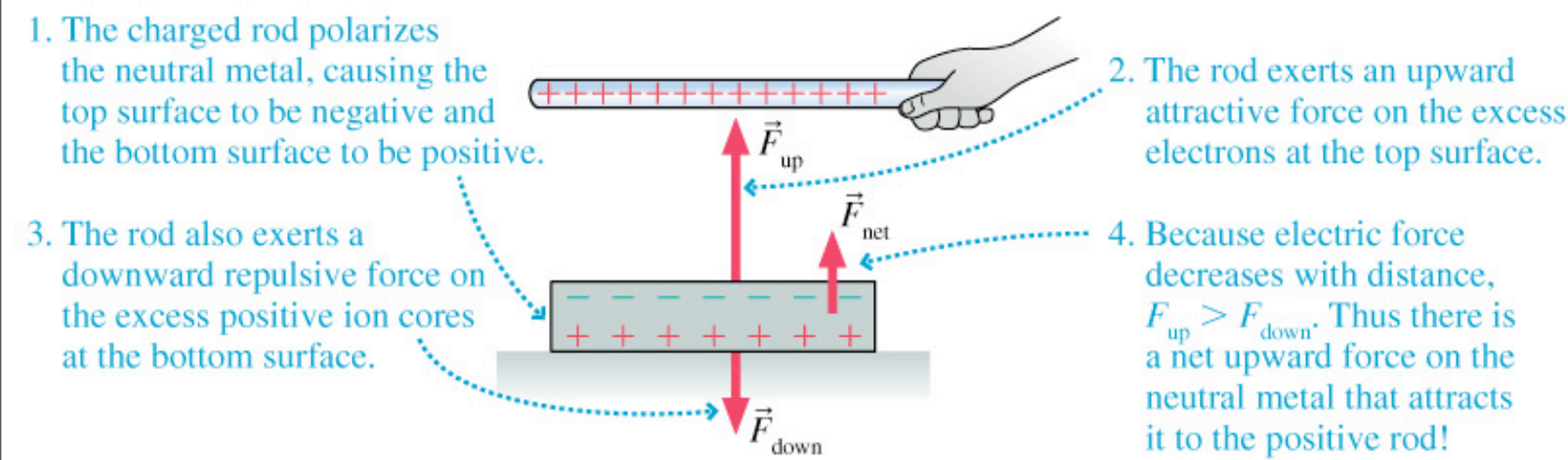
(b)

The electroscope is polarized by the charged rod. The sea of electrons shifts toward the rod.



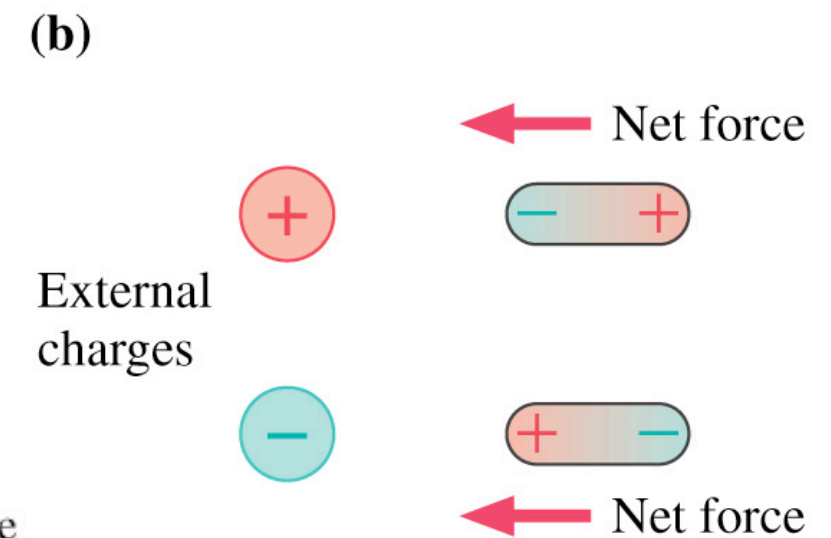
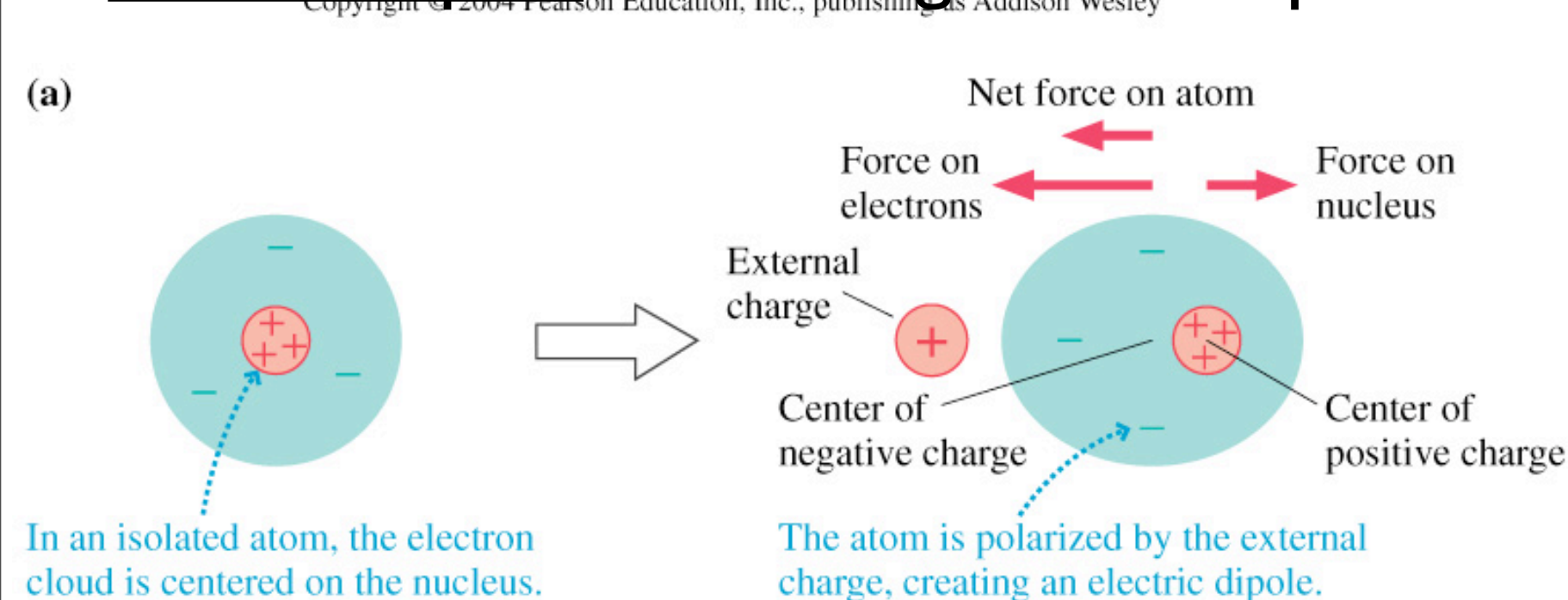
Electric Dipole

- Polarization force attractive (both signs of charged rods)



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

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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

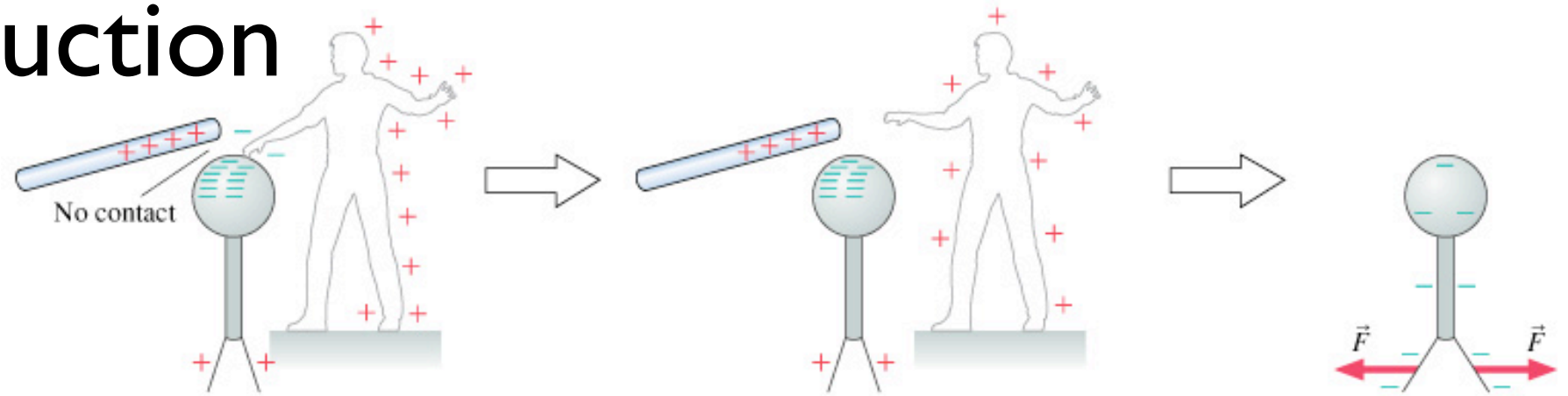
Coulomb's law

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

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.

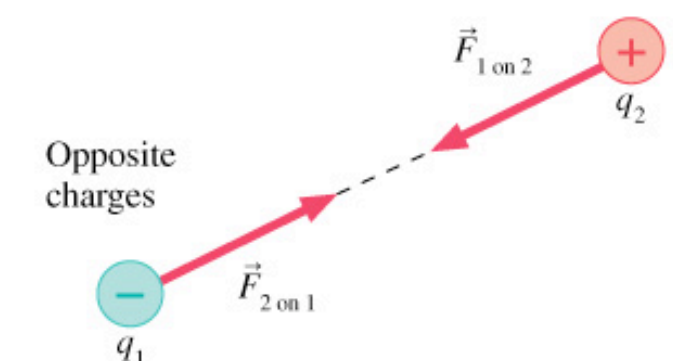
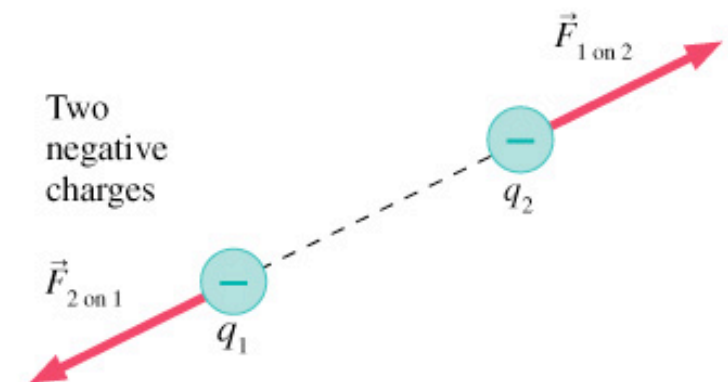
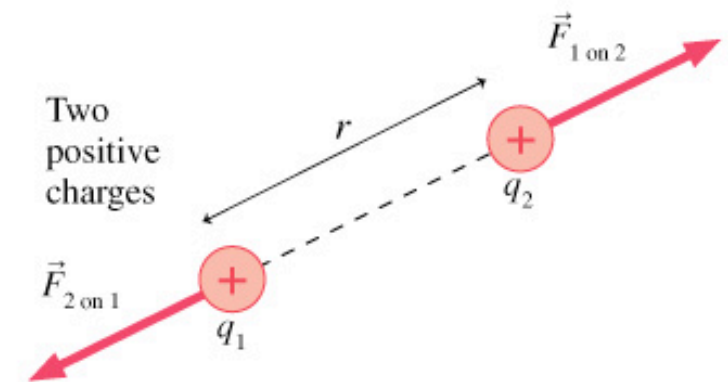
2. The negative charge on the electroscope is isolated when contact is broken.

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.



- 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)

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Using Coulomb's law

- Units of charge (derived from current):

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

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

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

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

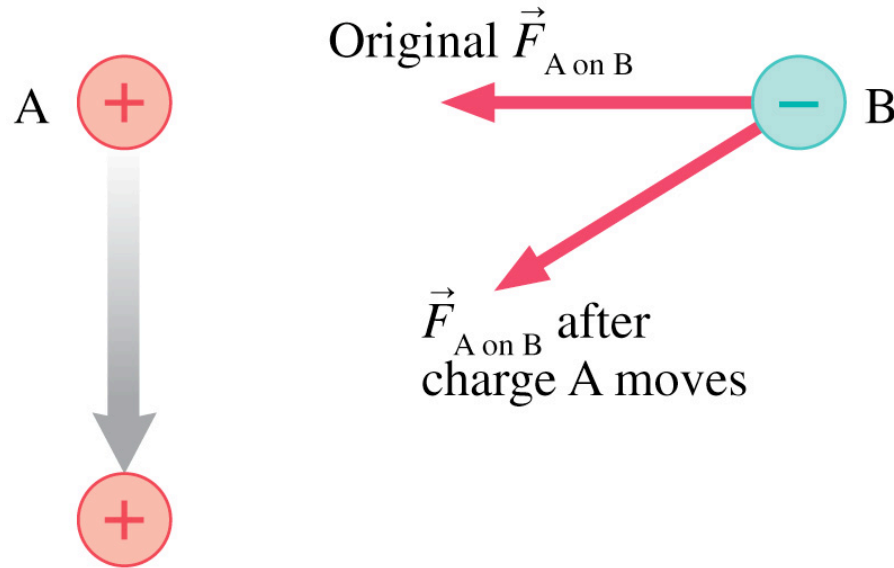
$$\bar{F}_{net \text{ on } j} = \bar{F}_1 \text{ on } j + \bar{F}_2 \text{ on } j + \dots$$

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

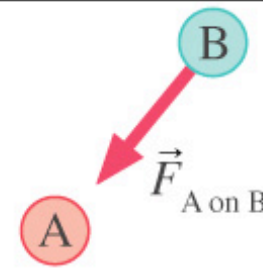
Example

- 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?

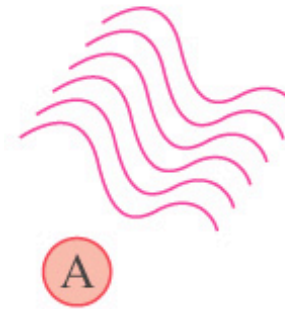
Concept of a Field



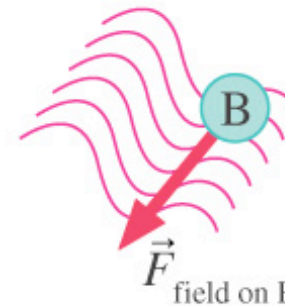
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In the Newtonian view, A exerts a force directly on B.



In Faraday's view, A alters the space around it. (The wavy lines are poetic license. We don't know what the alteration looks like.)

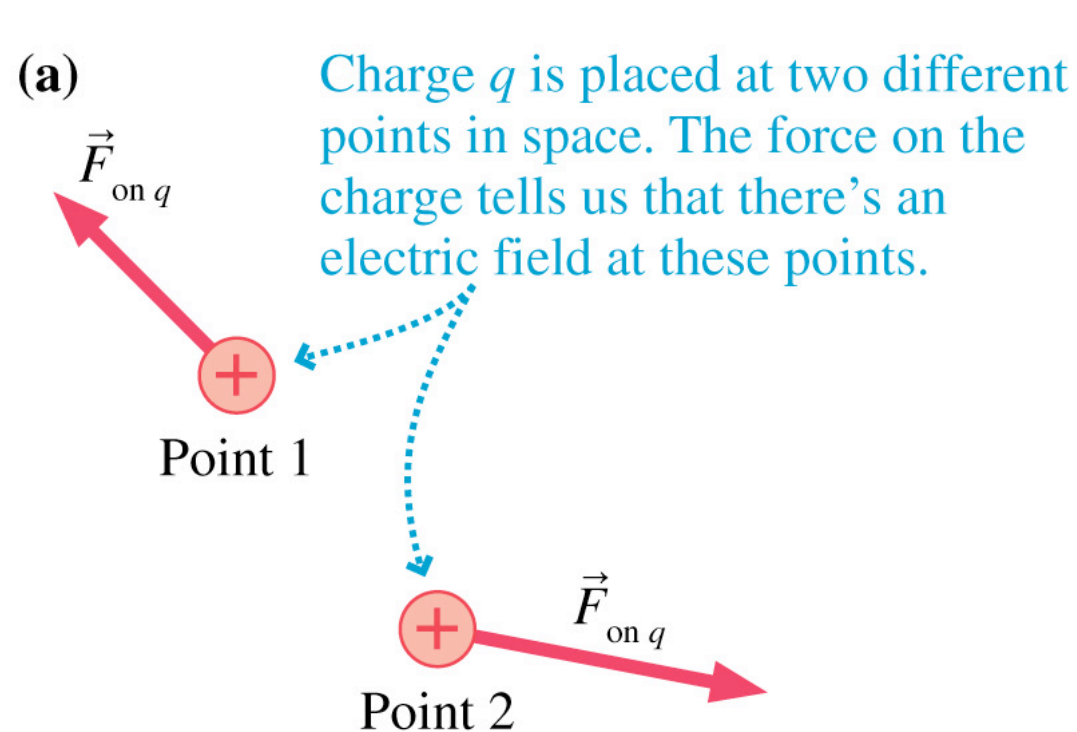


Particle B then responds to the altered space. The altered space is the agent that exerts the force on B.

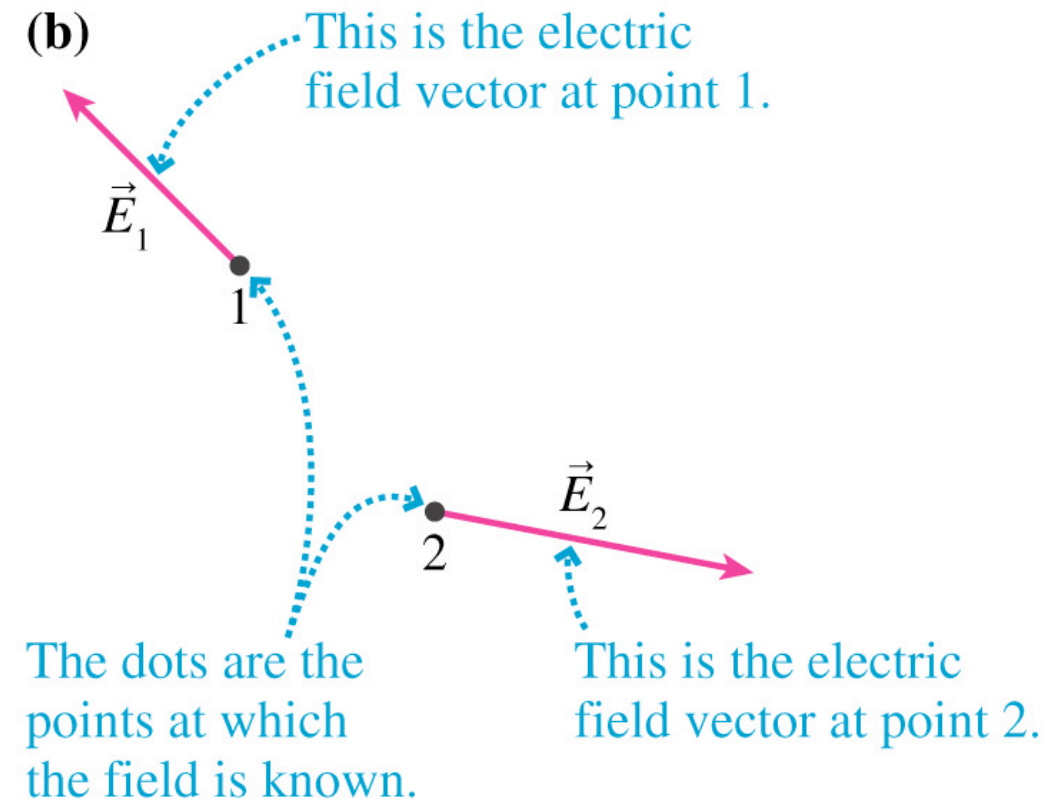
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- gravity, electric forces long range (action at a distance): mechanism?
- force changes instantly?
- Faraday (and Maxwell): **other** masses/charges respond to field, $f(x, y, z)$ cf. particle exists at 1 point
- alteration of space around a **mass/charge**: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

Electric Field Model



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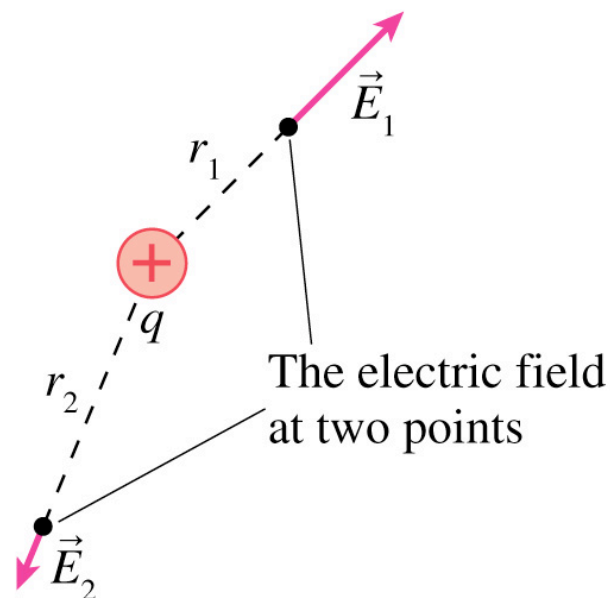
- more complex: 2 types of charges, forces, materials...
- source charge create electric field \vec{E} , probe charge experiences \vec{F} exerted by \vec{E}

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

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

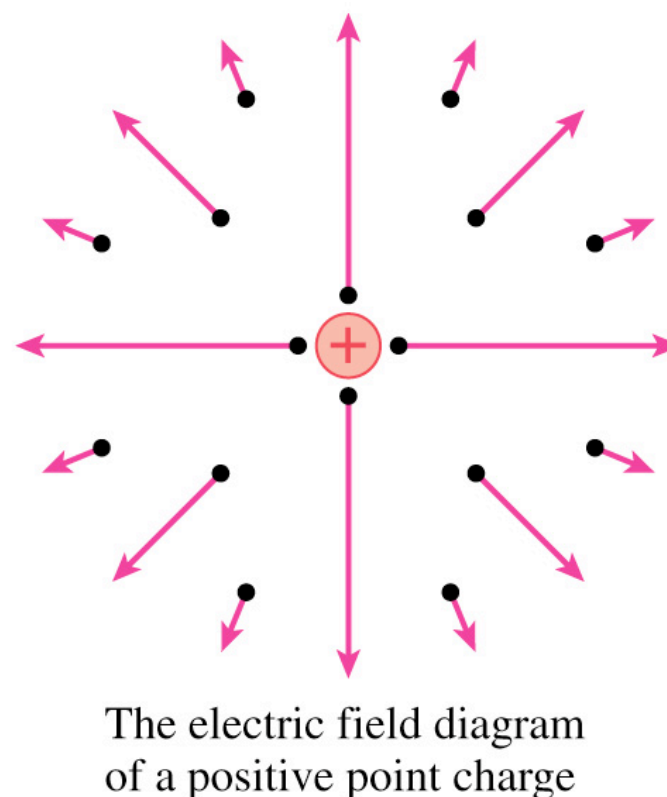
Electric Field of Point Charge

(a)



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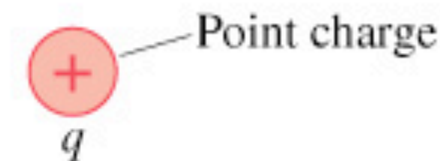
(b)



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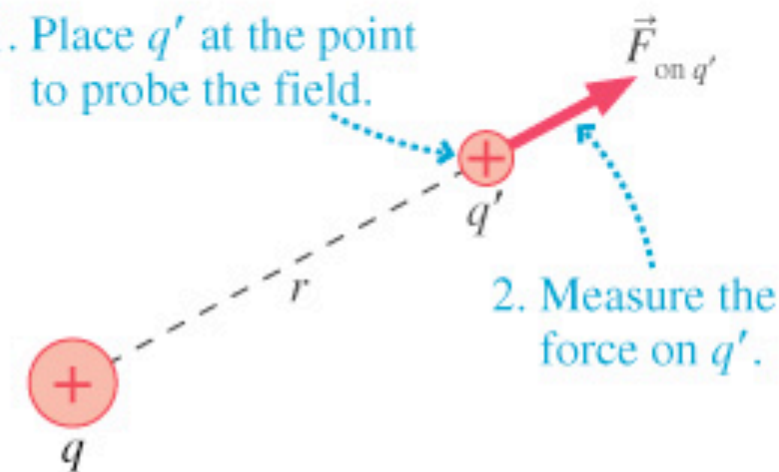
(a)

What is the electric field of q at this point?

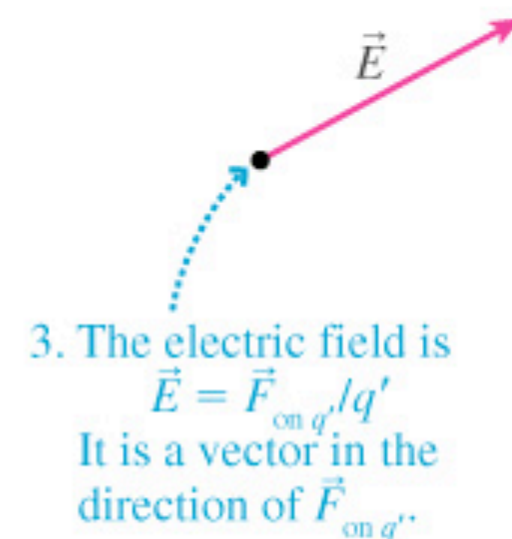


(b)

1. Place q' at the point to probe the field.



(c)

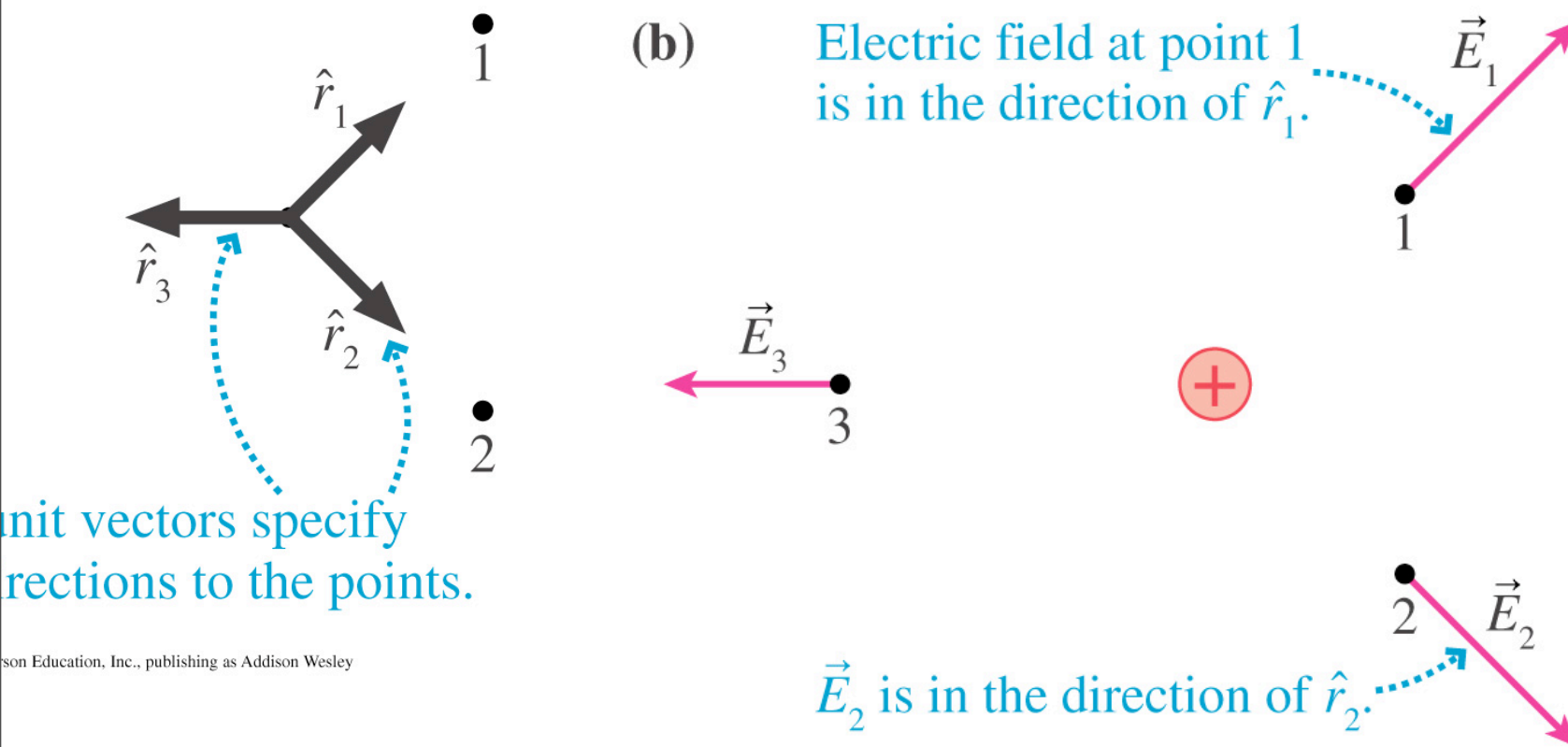


- Use Coulomb's law:

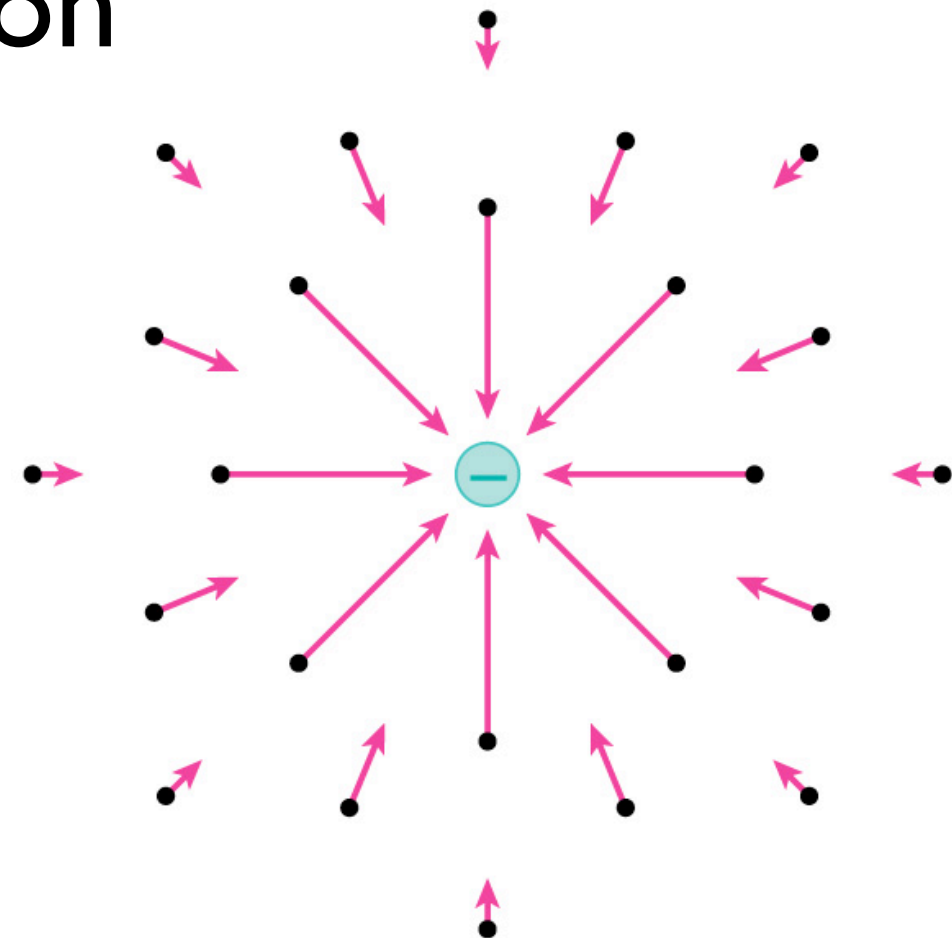
$$\vec{E} = \frac{\vec{F}_{\text{on } q'}}{q'} = \left(\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}, \text{away from } q \right)$$

- field diagram (sample vectors): at tail of vector; does not stretch...

Unit Vector Notation



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- mathematical notation for “away from q”
- \hat{i} , \hat{j} , \hat{k} : magnitude 1 (no units), purely directional information
- \hat{r} : unit vector pointing from origin to point (“straight outward from point” like \vec{E})

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r} \quad (\text{electric field of a point charge})$$

- applies to $q < 0$ ($-\hat{r}$ points towards charge)