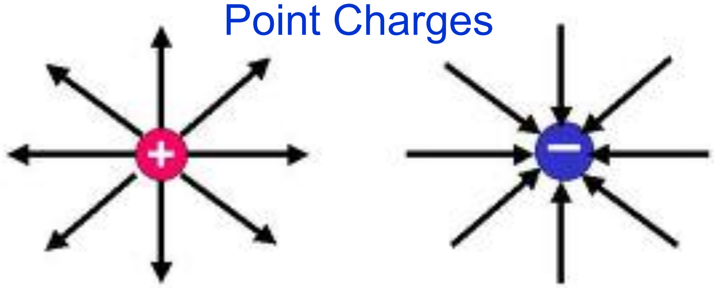
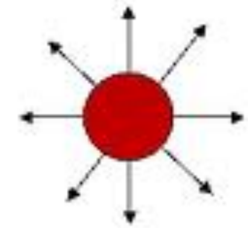
Last Time

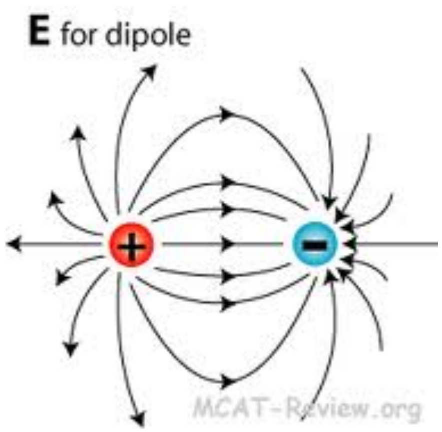
- Electric forces are stronger than gravitational forces
- Electric field of:

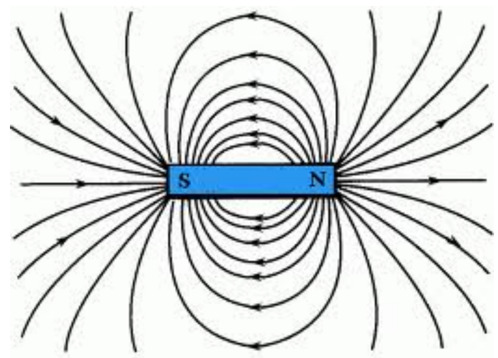
Point Charges



Charged Sphere







- Superposition Principle
  - $\mathbf{E}_{tot}$ is the sum from all charges

Today

Conservation of Charge
Fun with Scotch Tape
Polarization of Atoms
Neutral Atom and Point Charge

Conservation of Charge

The net charge of a system and its surroundings cannot change

✓ You can move charge from the system to surroundings

Example: Rub a balloon (or comb) on your hair

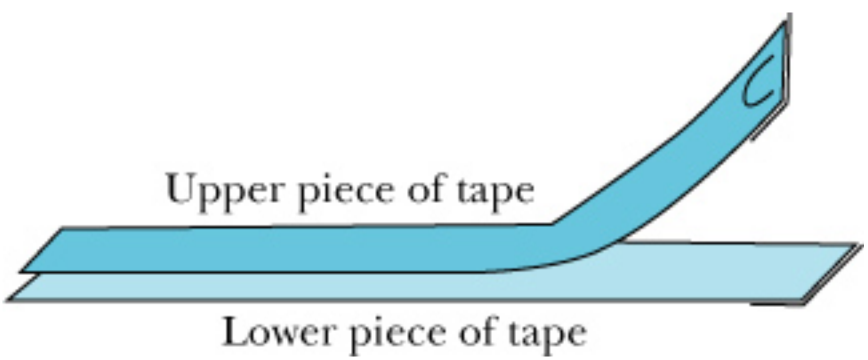
➡ Can you create or destroy charge? *Yes!*

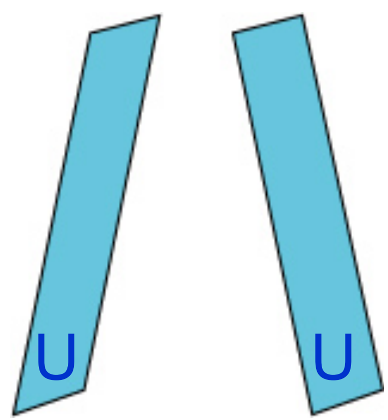
✓ Charges can be created or destroyed in (+,-) pairs

Example: electron-positron annihilation.

Fun With Tape

- There are two kinds of charge (+,-)
- Like Charges Repel; Opposites Attract

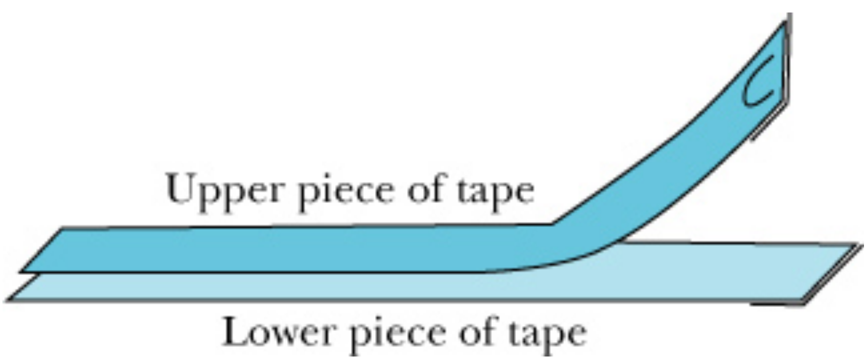


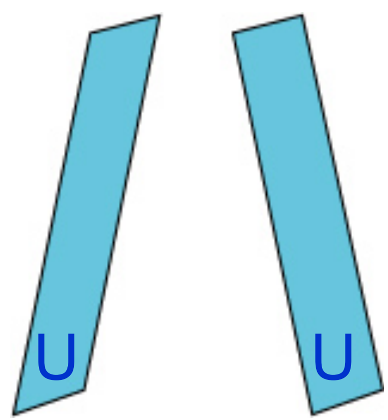


Fun With Tape

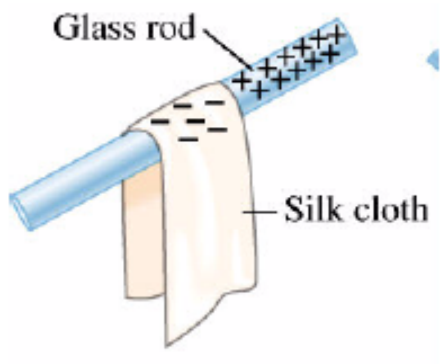
The Electric Force:

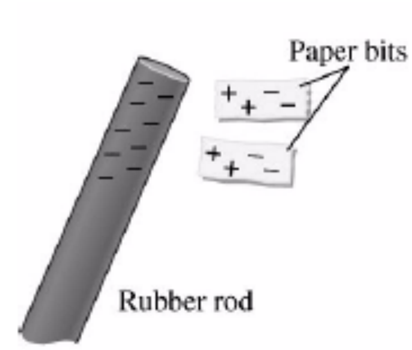
- Acts along a line between the charges
- Decreases with distance
- Proportional to amount of charge





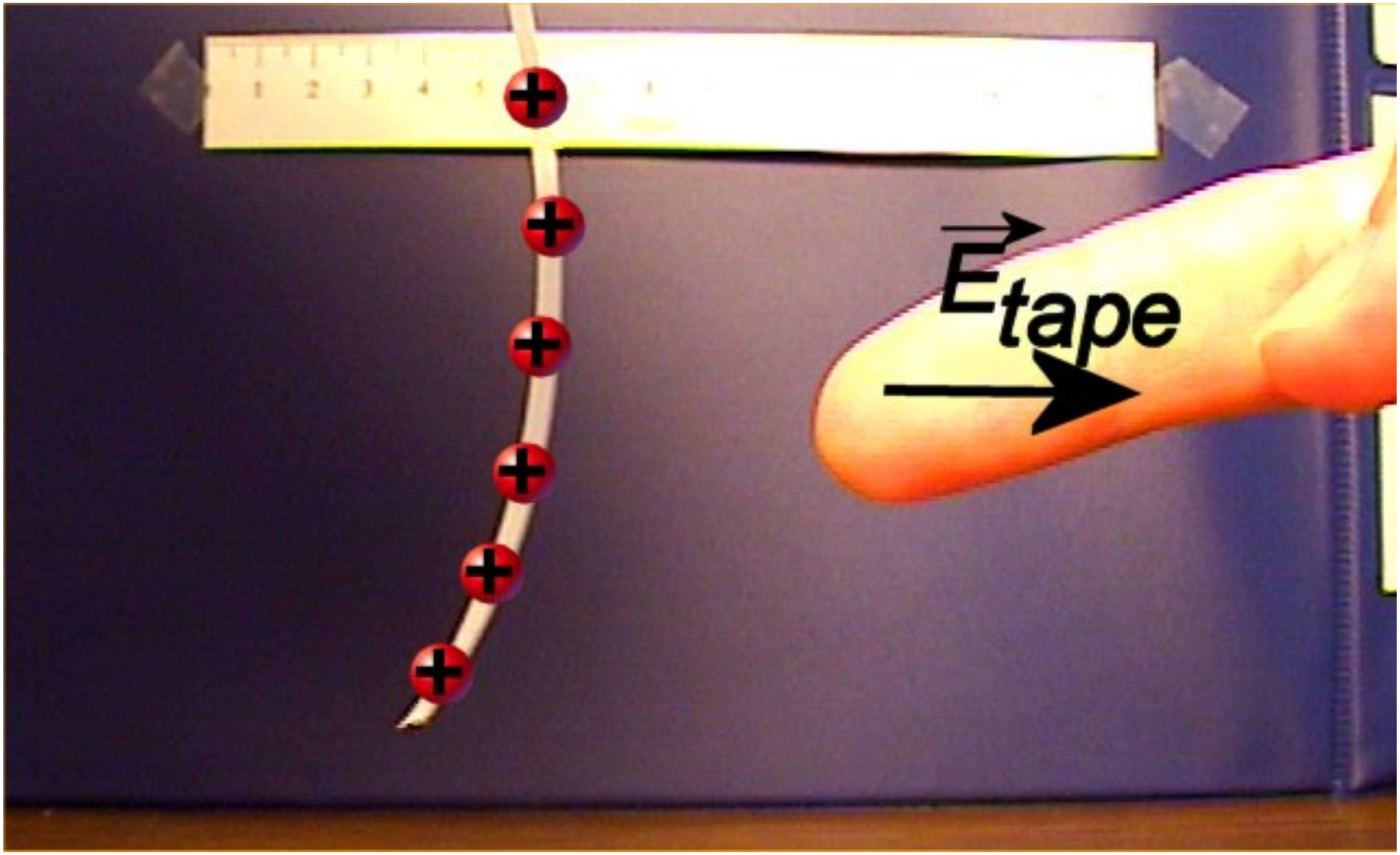
Determining Sign of the Charge



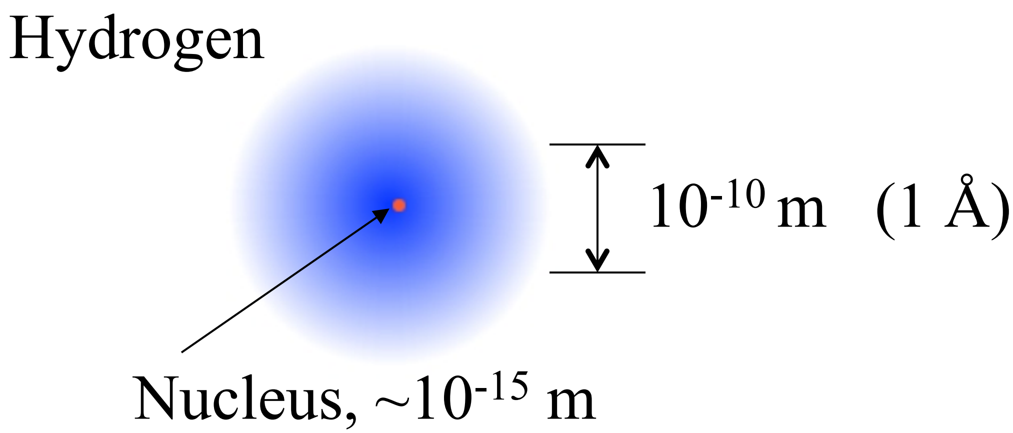


- Why get charged?
  - Breaking large molecules, transfer ions
  - Transfer electrons
- Why positive or negative?
  - We don't know - Current Topic of Research!

Why did this happen?



The Structure of an Atom



Charge of electron cloud equals that of nucleus → neutral atom.

If the electron cloud is centered on the nucleus → electric field produced by electrons exactly cancels the field produced by nucleus.

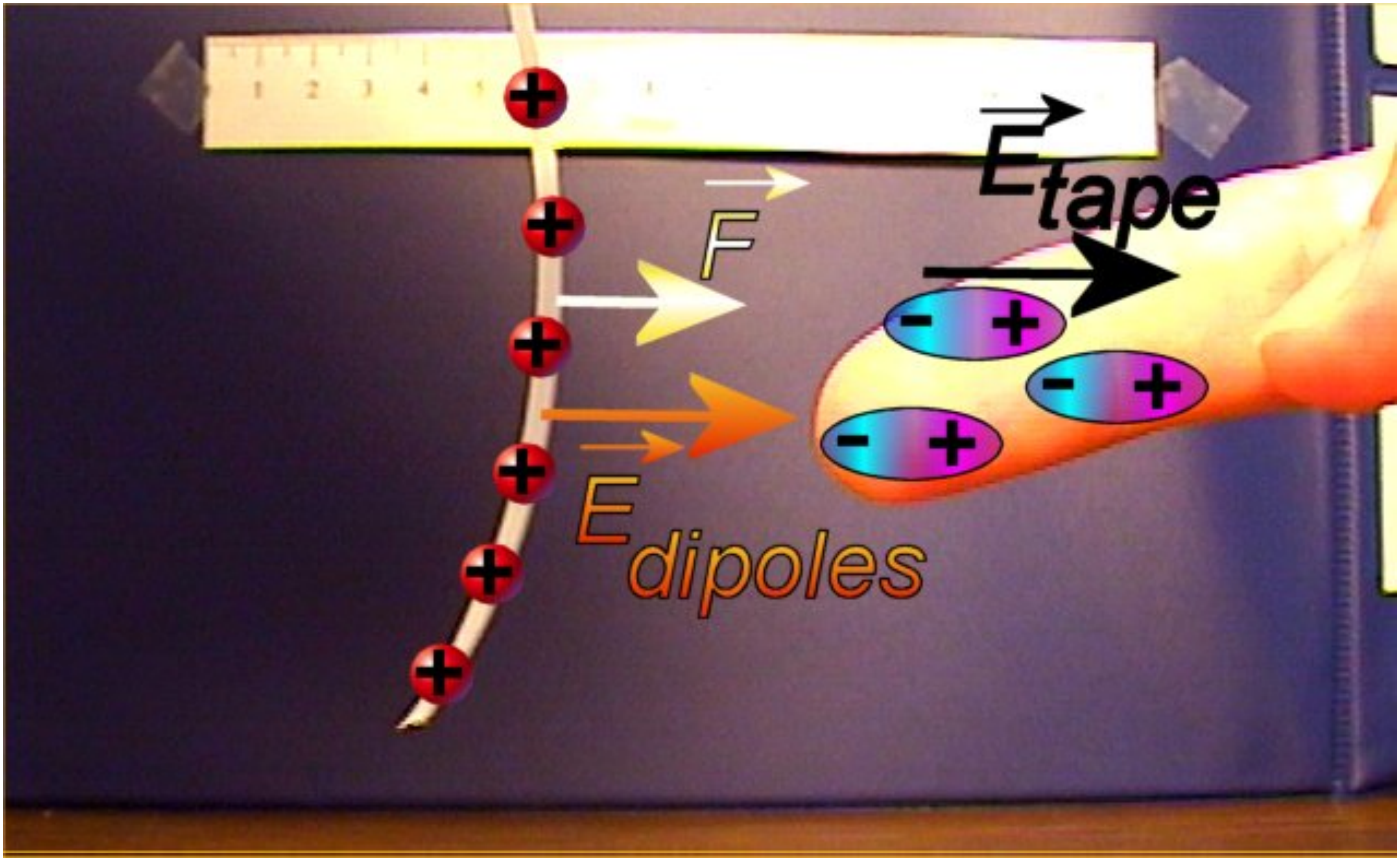
WHY?

Polarization of Atoms

Atom becomes **polarized** by Electric Field

"Induced Dipole"

Interaction of Charged Tapes and Neutral Matter



Clicker Question

Polarization

Amount of polarization = dipole moment of the atoms/molecules

$$\boxed{\vec{p} = \alpha \vec{E}}$$

POLARIZATION

α - "*polarizability*" of a material

In an induced dipole, is the distance between the charges fixed?

The distance is proportional to the strength of the applied field.

Example

A typical atomic polarizability is $\alpha = 10^{-40}$ C•m/(N/C).
If q=e (proton charge), what is the charge separation by applying a field $E = 3 \cdot 10^{6}$ N/C?

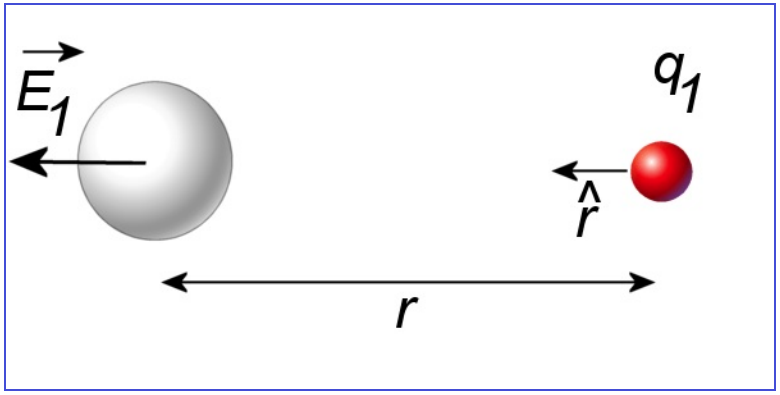
$$p = \alpha E = 10^{-40} \times 3 \times 10^{6} (\mathrm{C} \cdot \mathrm{m}) = 3 \times 10^{-34}\, \mathrm{C} \cdot \mathrm{m}$$

$$p = qs$$

$$s = \frac{p}{q} = \frac{3 \times 10^{-34}}{1.6 \times 10^{-19}}\, \mathrm{m} \approx 2 \times 10^{-15}\, \mathrm{m}$$

Shift is five orders of magnitude smaller than the atom itself!

A Neutral Atom and a Point Charge

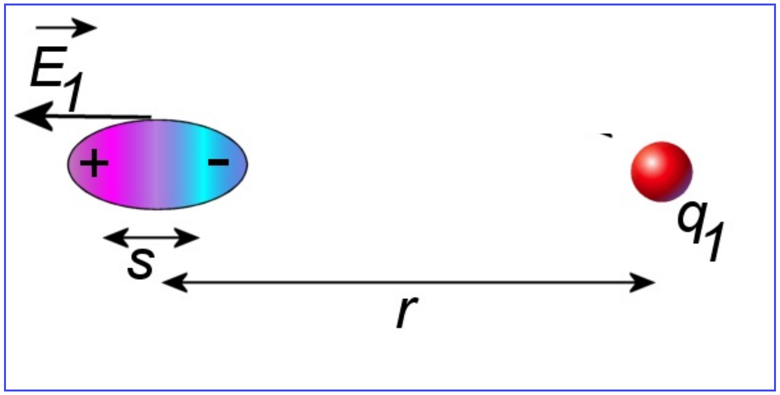


1. Charge q_1 creates field E_1 at the location of the atom

$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r^2}\hat{r}$$

A Neutral Atom and a Point Charge

1) $\boxed{\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r^2}\hat{r}}$



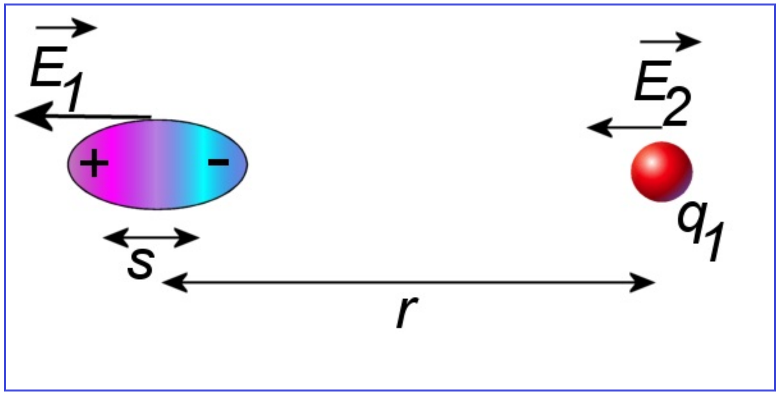
2. Field E_1 polarizes the atom creating a dipole

$$\vec{p} = \alpha\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{\alpha q_1}{r^2}\hat{r}$$

A Neutral Atom and a Point Charge

1) $\vec{E}_1 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1}{r^2}\hat{r}$

2) $\vec{p} = \alpha\vec{E}_1 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{\alpha q_1}{r^2}\hat{r}$



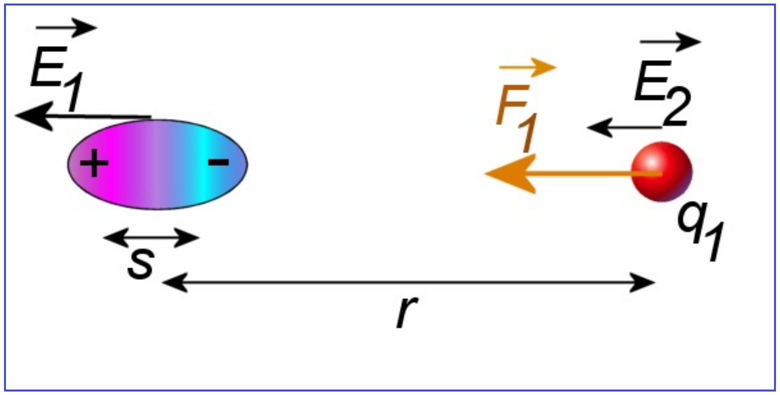
3. Dipole creates field E_2 at the location of q_1

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3} = \frac{1}{4\pi\varepsilon_0}\frac{2\alpha}{r^3}\vec{E}_1 = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1}{r^5}\hat{r}$$

A Neutral Atom and a Point Charge

1) $\vec{E}_1 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1}{r^2}\hat{r}$

2) $\vec{p} = \alpha\vec{E}_1 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{\alpha q_1}{r^2}\hat{r}$



3) $\vec{E}_2 = \left(\dfrac{1}{4\pi\varepsilon_0}\right)^2\dfrac{2\alpha q_1}{r^5}\hat{r}$

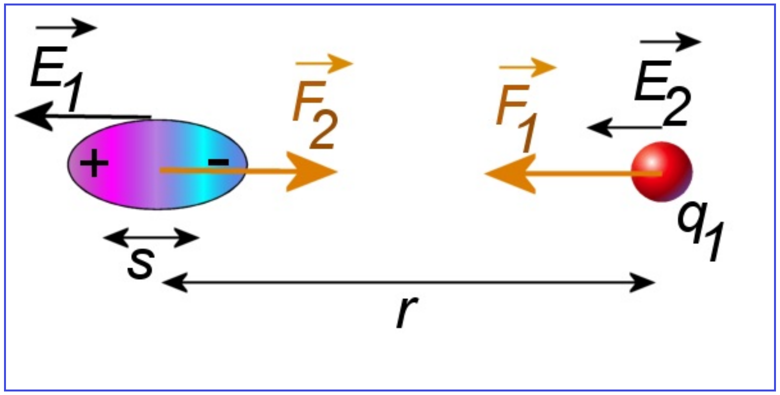
4. Induced dipole exerts force F_1 on the charge:

$$\vec{F}_1 = q_1\vec{E}_2 = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1^2}{r^5}\hat{r}$$

A Neutral Atom and a Point Charge

1) $\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r^2}\hat{r}$

2) $\vec{p} = \alpha\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{\alpha q_1}{r^2}\hat{r}$



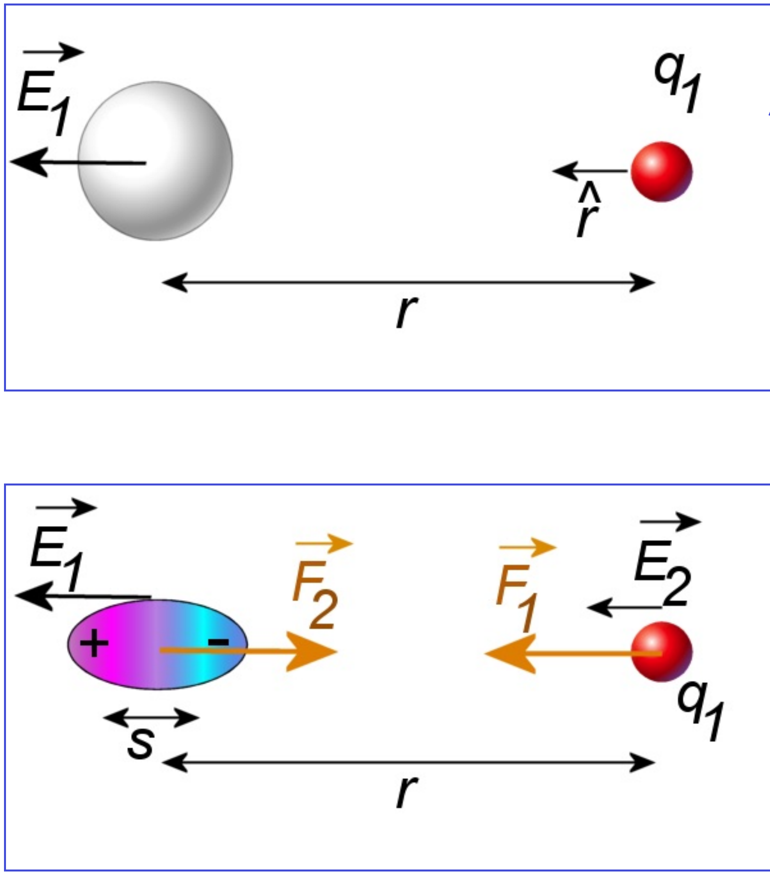
3) $\vec{E}_2 = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1}{r^5}\hat{r}$

4) $\vec{F}_1 = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1^2}{r^5}\hat{r}$

5. The charge q_1 exerts force F_2 on the dipole (reciprocity):

$$\vec{F}_2 = -\vec{F}_1 = -\left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1^2}{r^5}\hat{r}$$

A Neutral Atom and a Point Charge



1) $\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r^2}\hat{r}$

2) $\vec{p} = \alpha\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{\alpha q_1}{r^2}\hat{r}$

3) $\vec{E}_2 = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1}{r^5}\hat{r}$

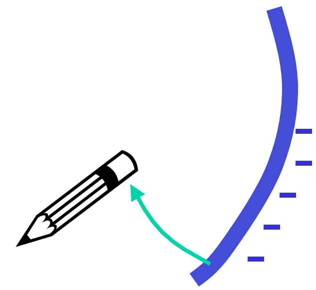
4) $\vec{F}_1 = \left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1^2}{r^5}\hat{r}$

5) $\vec{F}_2 = -\left(\frac{1}{4\pi\varepsilon_0}\right)^2\frac{2\alpha q_1^2}{r^5}\hat{r}$

Neutral atoms are attracted by charges!
Interaction strength ~ 1/r^5

Determining the Charge of an Object

Suppose tape is negatively charged, and you rub a wooden pencil on a wool sweater and bring it near the tape.



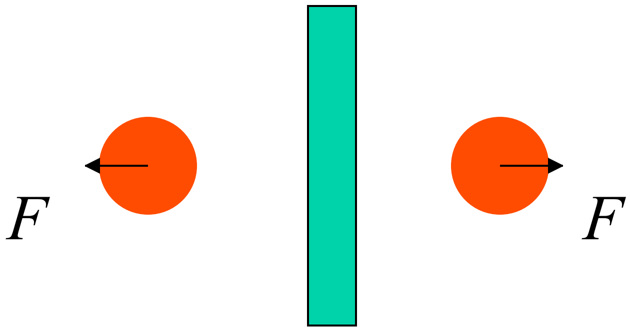
If tape swings toward the pencil, does it show that the pencil had been charged positively?

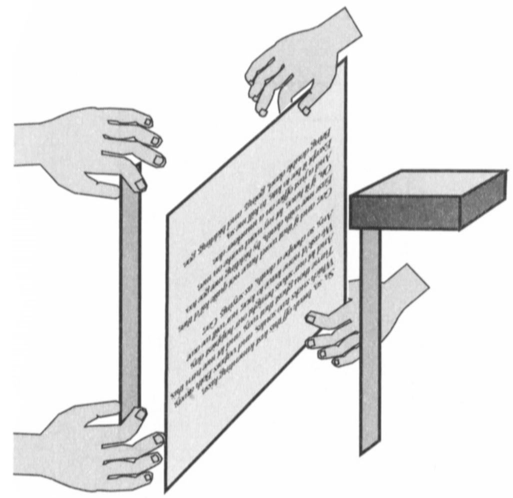
NOT NECESSARILY!

Attraction: can happen for like-charged objects!

Repulsion: can happen **only** for like-charged objects!

Electric Field Through Intervening Matter





The field appears to be weaker in presence of intervening (polarizable) object.

Superposition principle: *the presence of matter does not affect the electric field produced by a charged object*.

Intervening matter ***does not*** "block" the E field

The resulting field is a ***superposition*** of two fields:
Field of the other charge plus the field of induced dipoles.

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