Physics II: 1702
Gravity, Electricity, & Magnetism

Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

Announcements I

- First lab tonight!
- Be sure to complete your pre-lab questions beforehand

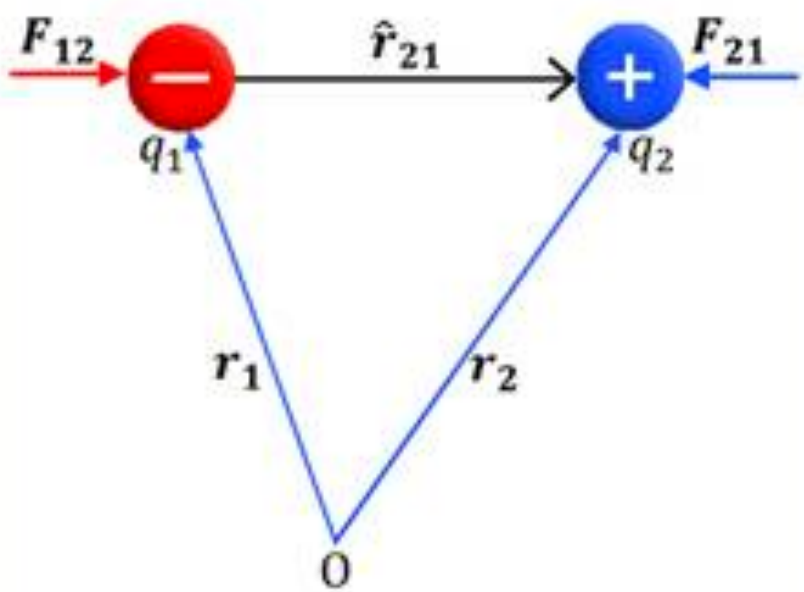
Announcements II

- Office hours canceled Tuesday and Wednesday (2/2 and 2/3)
- Prof. Baalrud will sub Wednesday 2/3
- I'll be back on Thursday for discussion
- My apologies for any inconvenience

Coulomb's Law: Vector Form

- Note that Coulomb's constant $k = 1/(4\pi\varepsilon_o)$

$\mathbf{r}_{12} = \mathbf{r}_1 - \mathbf{r}_2$



$$\boldsymbol{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{\boldsymbol{r}}_{12}$$

$$\hat{\boldsymbol{r}}_{12} = \frac{\boldsymbol{r}_{12}}{r_{12}} \quad ...(5)$$

$$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{21}^2}\hat{\boldsymbol{r}}_{21} \quad ...(6)$$

$$\hat{\boldsymbol{r}}_{21} = \frac{\boldsymbol{r}_{21}}{r_{21}} \quad ...(7)$$

$$\hat{\boldsymbol{r}}_{21} = -\hat{\boldsymbol{r}}_{12}$$

According to Newton's Third Law

$$\boldsymbol{F}_{21} = -\boldsymbol{F}_{12}$$

Inverse Square Laws

- Note something interesting

- Electrical force between two particles

$$F = kq_1q_2/r^2 = q_1q_2/(4\pi\varepsilon_0 r^2)$$

- Gravitational force between two particles

$$F = Gm_1m_2/r^2$$

Concept Check

Two protons are near each other. Each feels an electrostatic repulsion of magnitude F_{elec} and a gravitational attraction of magnitude F_{grav}, due to the other proton.

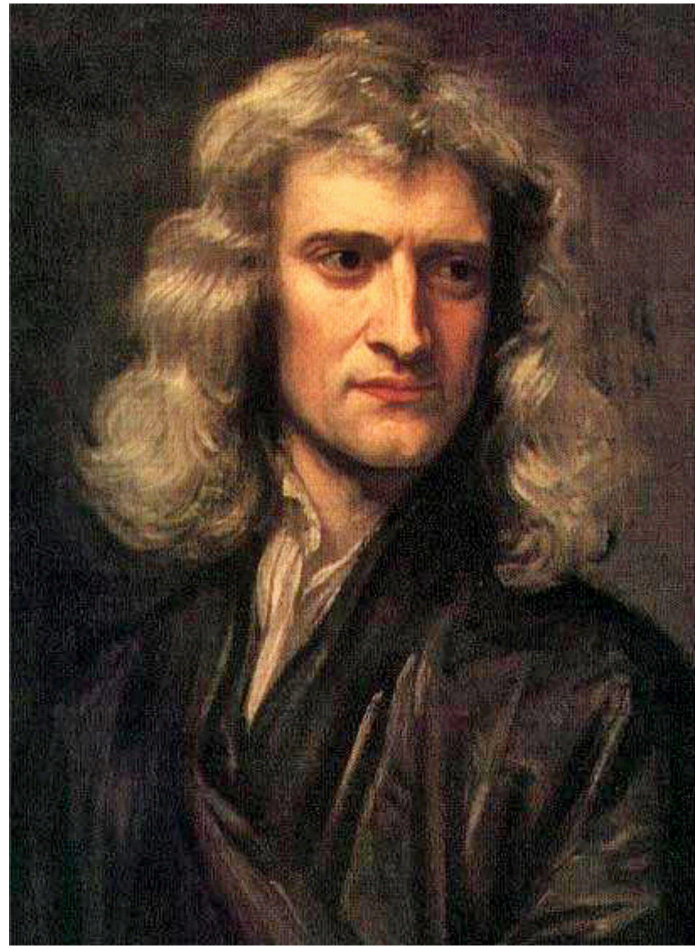
As the charges are moved apart, the ratio $$\frac{F_{elec}}{F_{grav}}$$

A) Increases
B) Decreases
C) Remains constant

Coulomb Vs. Newton

- Force between two particles $F = kq_1q_2/r^2$
- Force between two particles $F = Gm_1m_2/r^2$
- $k = 8.99 \times 10^9\ Nm^2/C^2 = 1/(4\pi\varepsilon_o)$
- $q = 1.6 \times 10^{-19}\ C$
- $G = 6.673 \times 10^{-11}\ Nm^2/kg^2$
- $m_p = 1.67 \times 10^{-27}\ kg$, $m_e = 9.1 \times 10^{-31}\ kg$
- **Who wins in a fair fight?**

Hmmm…



Say we have a proton and an electron.

$$F_g = -G\, m_p m_e / r^2 \quad \text{attracting}$$

$$F_e = k q_p q_e / r^2$$
$$= -k e^2 / r^2 \quad \text{attracting}$$

$$e = 1.6e^{-19}\,C = q_e = |q_p|$$

$$F_e / F_g = \frac{k e^2}{G m_p m_e}$$

$$= \frac{8.99 \times 10^9 \cdot (1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \cdot 1.67 \times 10^{-27} \cdot 9.1 \times 10^{-31}}$$

$$\sim \frac{10^{10} \cdot 2 \times 10^{-38}}{100 \times 10^{-69}} = \frac{2 \times 10^{-28}}{1 \times 10^{-67}}$$

$$= \boxed{2 \times 10^{39}}$$

A big number!!

- For what q/m are they equal?

$$\kappa q^2 = G m^2$$

$$q/m = \sqrt{G/\kappa} = \sqrt{\frac{6.7\times10^{-11}}{9\times10^{9}}}$$

$$\cong \sqrt{10^{-20}}$$

$$= 10^{-10}\ C/kg$$

$$= 10^{-10}/1.6\times10^{-19}\ e^-/kg$$

$$= \boxed{6\times10^{8}\ e^-/kg}$$

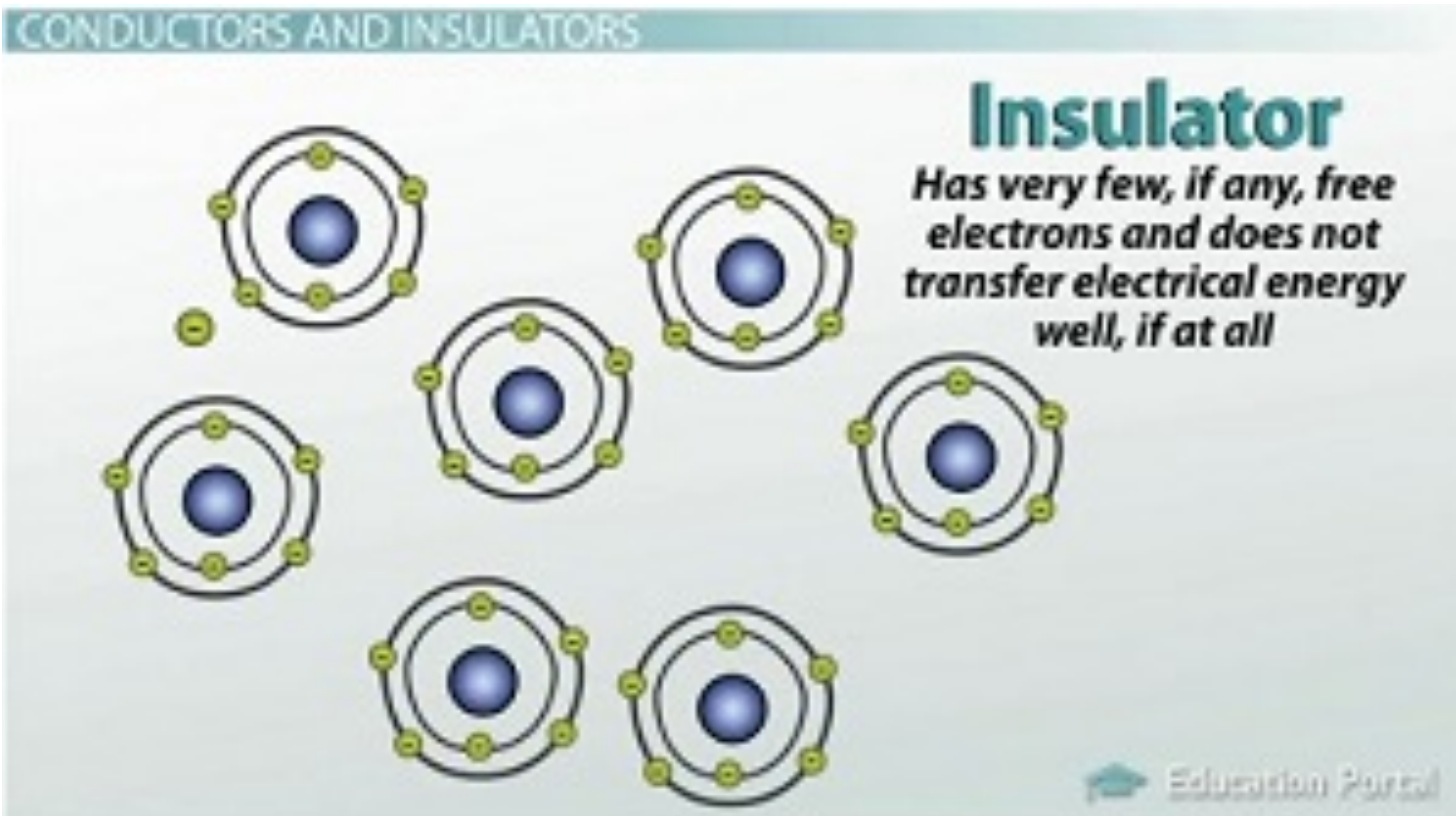
Sounds like a lot but there are around

$$N_A \cdot 1000 = 6\times10^{26} \text{ atoms}$$

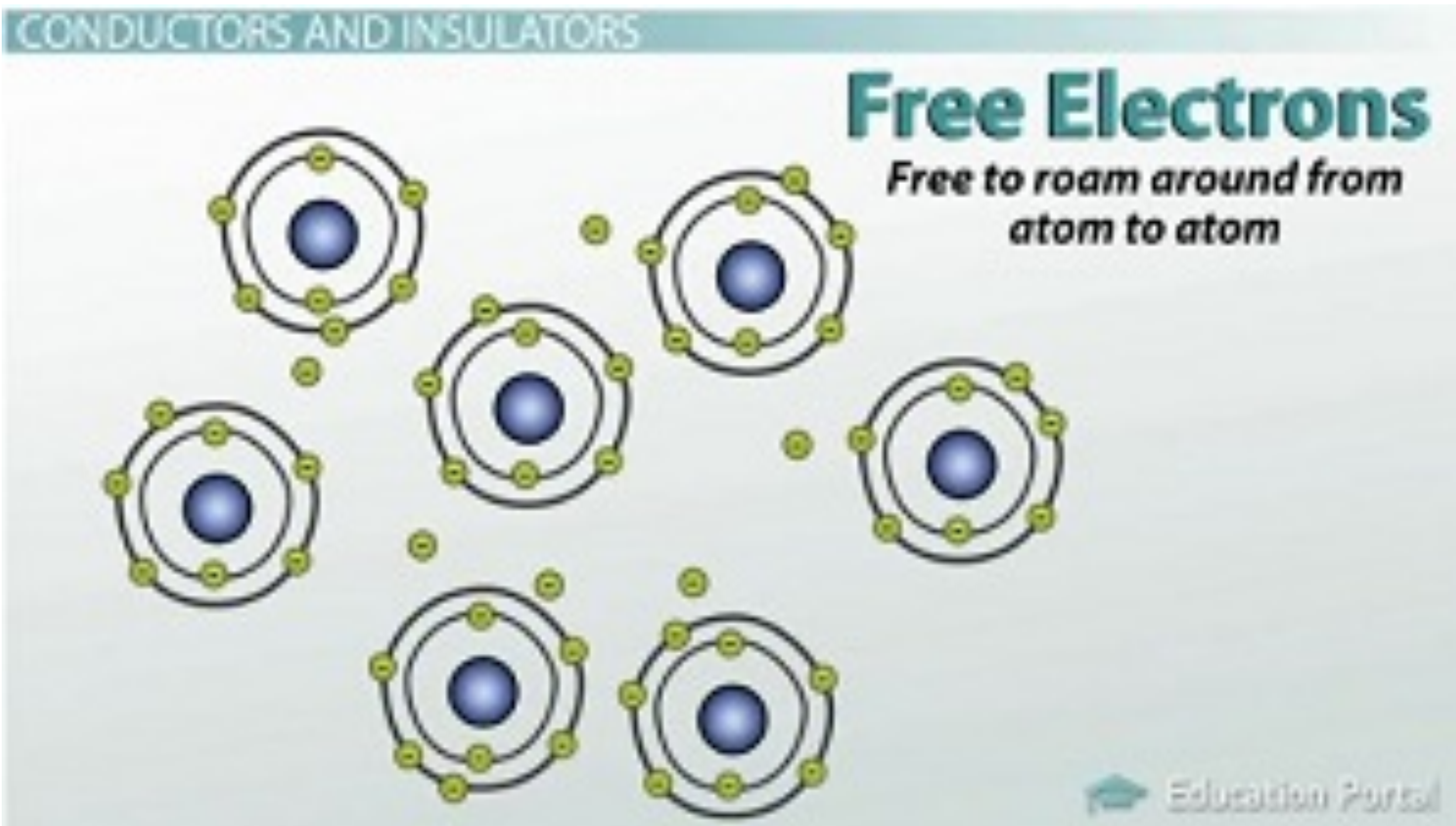
in a kg

- So you only need to ionize one out of every 10^{18} = one billion billion atoms to have electrical forces be important

Insulators


CONDUCTORS AND INSULATORS
Insulator
Has very few, if any, free electrons and does not transfer electrical energy well, if at all
Education Portal

Conductors


CONDUCTORS AND INSULATORS
Free Electrons
Free to roam around from atom to atom
Education Portal

Insulators and Conductors

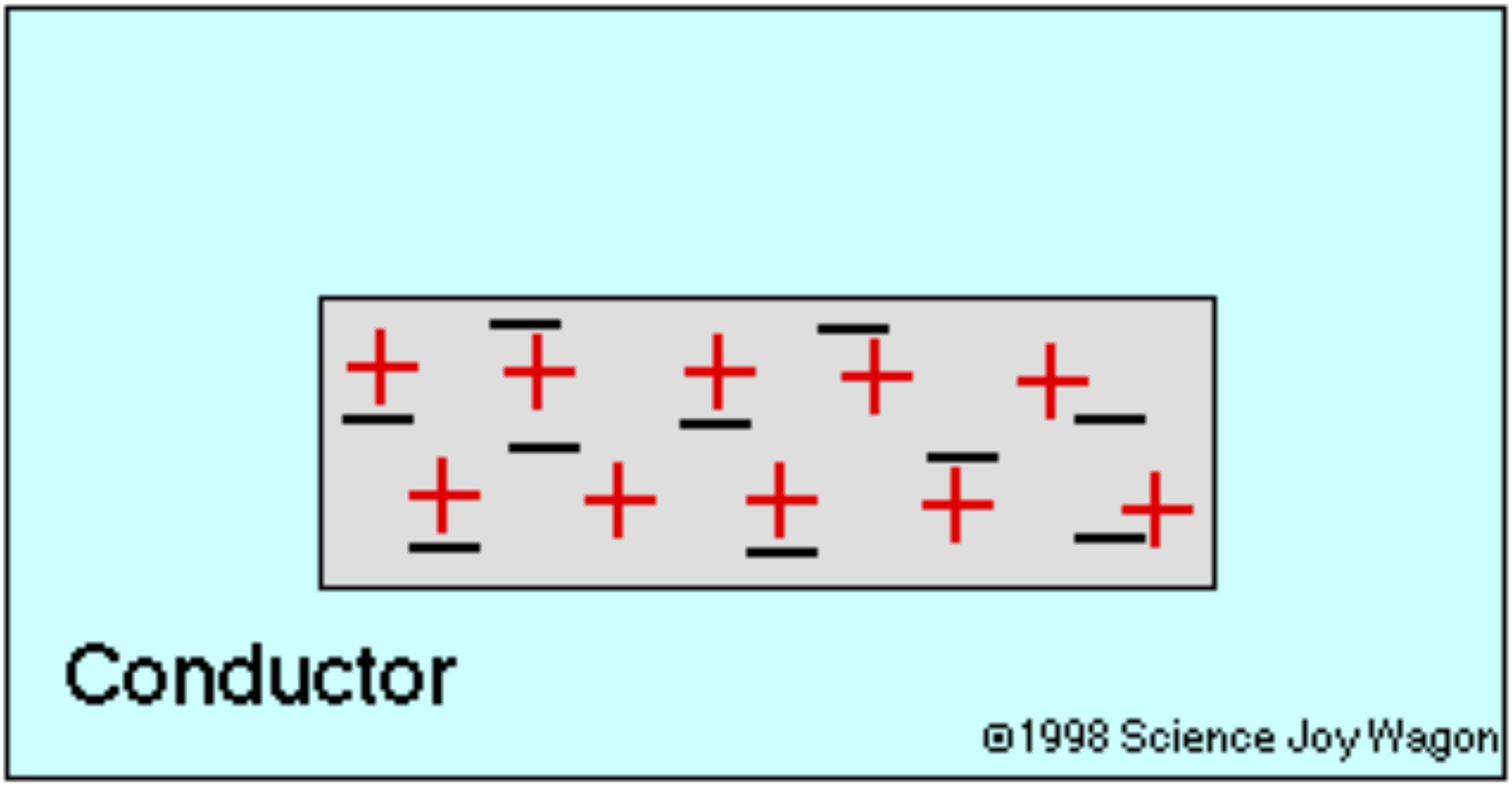
- Are both net neutral by default
  - Unless you transfer extra charge to them
- Under the influence of an external charge, they behave similarly in some ways, differently in others
- Only conductors will allow charge to flow across them (current)

The Confusing Part

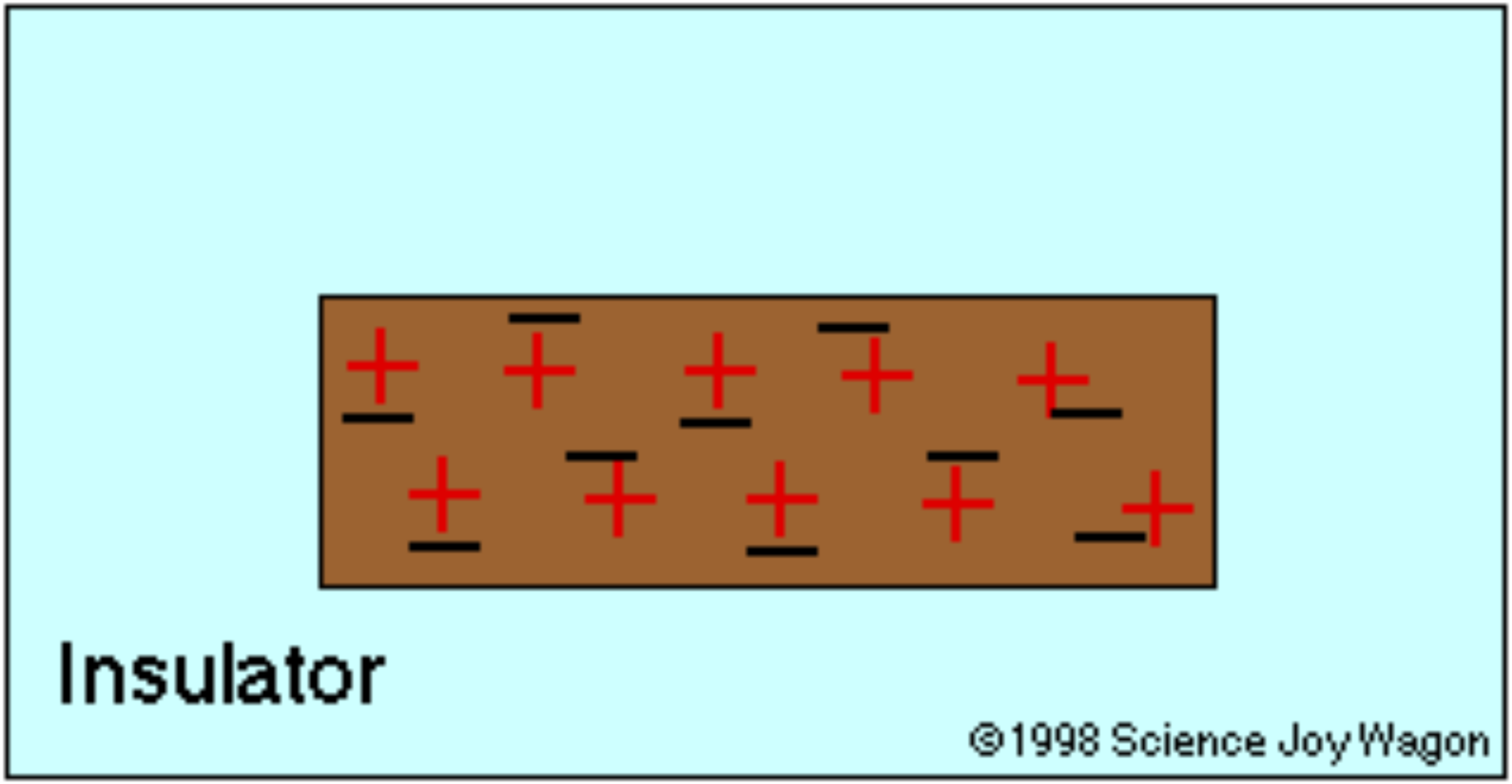
- Both conductors and insulators will be attracted to a nearby charge, even if they have no net charge on them

- The reason is essentially the same, but the details are different

Conductor Response to Charge



Insulator Response to Charge



Concept Check

Two socks are observed to attract each other. Which, if any, of the first 3 statements MUST be true? (emphasis on MUST)

A) The socks both have a non-zero net charge of the same sign.
B) The socks both have a non-zero net charge of opposite sign.
C) Only one sock is charged; the other is neutral.
D) None of the preceding statements MUST be true.

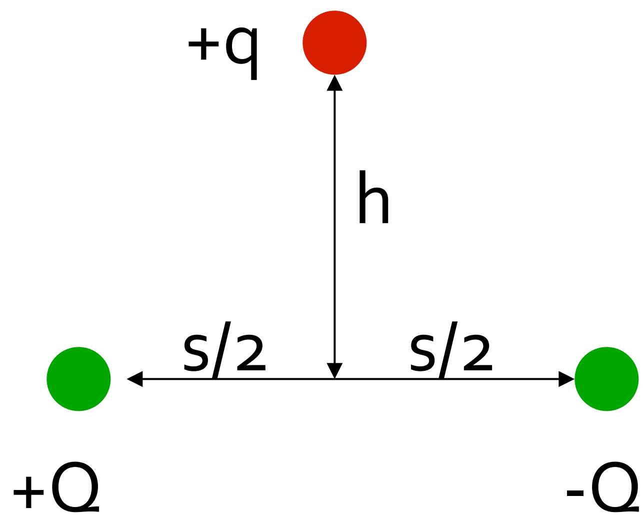
Superposition of Forces

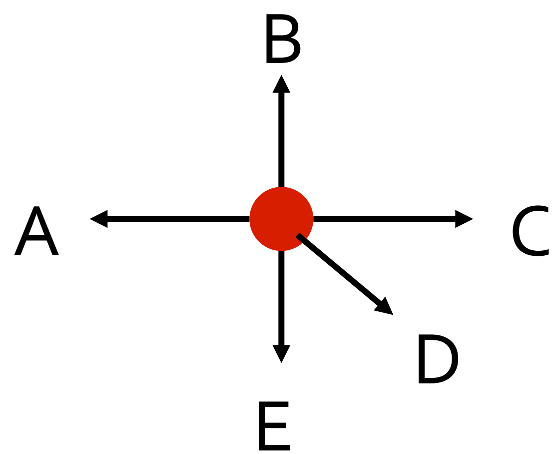
- Force on a point charge is the superposition of forces due to all other point charges
  - In the universe!
  - Thanks to $1/r^2$ and neutrality on large scales, really just those nearby

- To add forces, you have to add vectors, not scalars

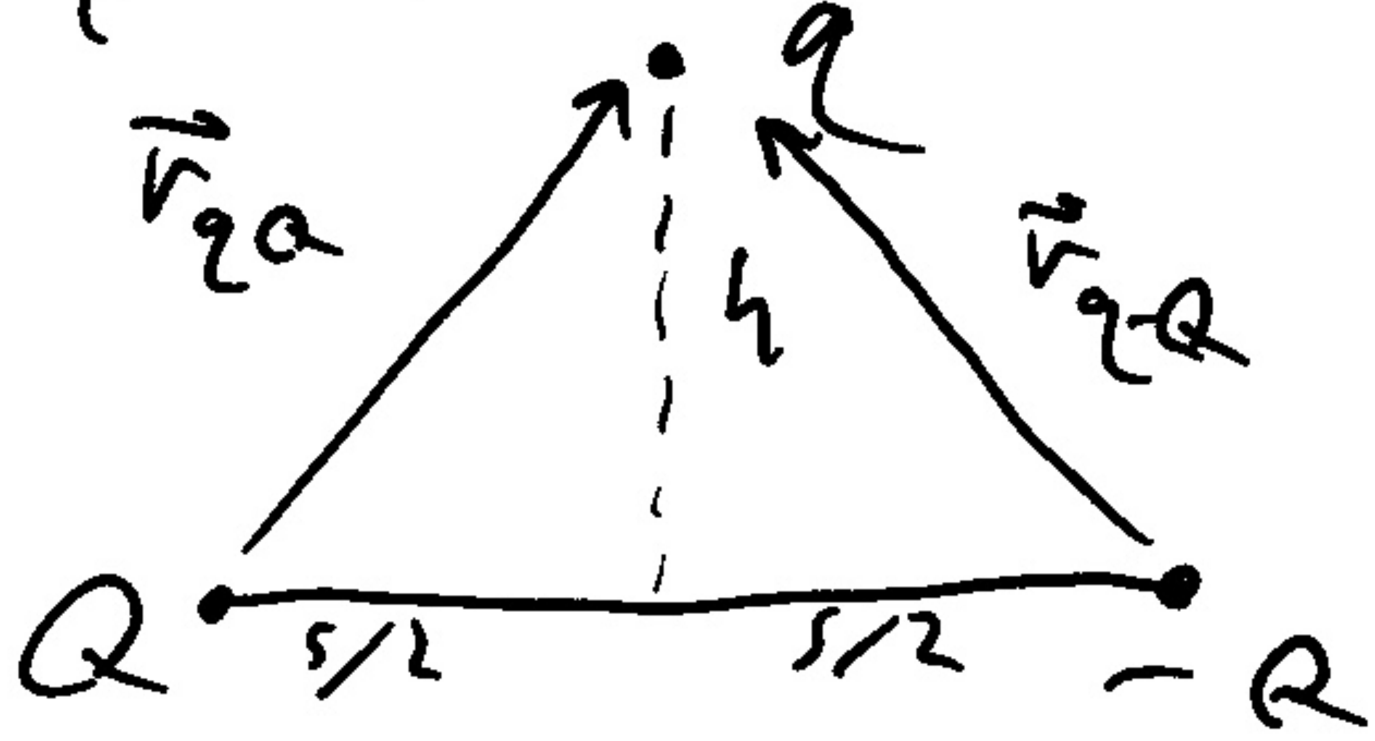
Concept Check

Consider the charge configuration shown below.
What is the direction of the net force on the +q charge?





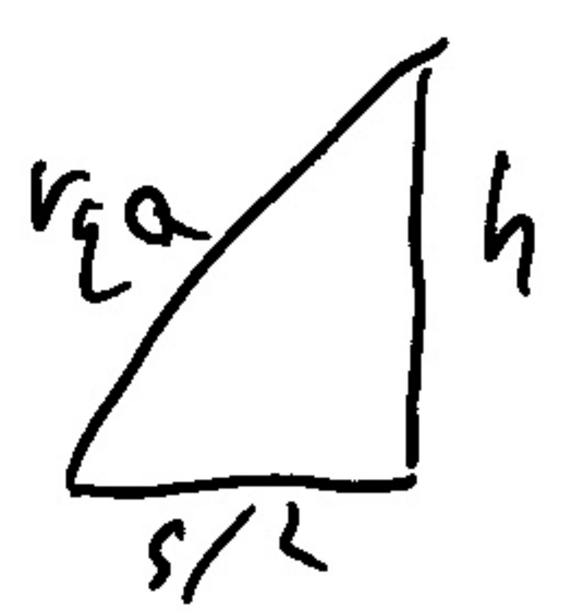
Example:



$$\vec{F}_{qQ} = \frac{k\,q\,Q\,\hat{r}_{qQ}}{|\vec{r}_{qQ}|^2}$$

$$\vec{F}_{q-Q} = \frac{k\,q\,(-Q)\,\hat{r}_{q-Q}}{|\vec{r}_{q-Q}|^2} = \frac{-kqQ\,\hat{r}_{q-Q}}{|\vec{r}_{q-Q}|^2}$$

What is $|\vec{r}_{qQ}|^2$?

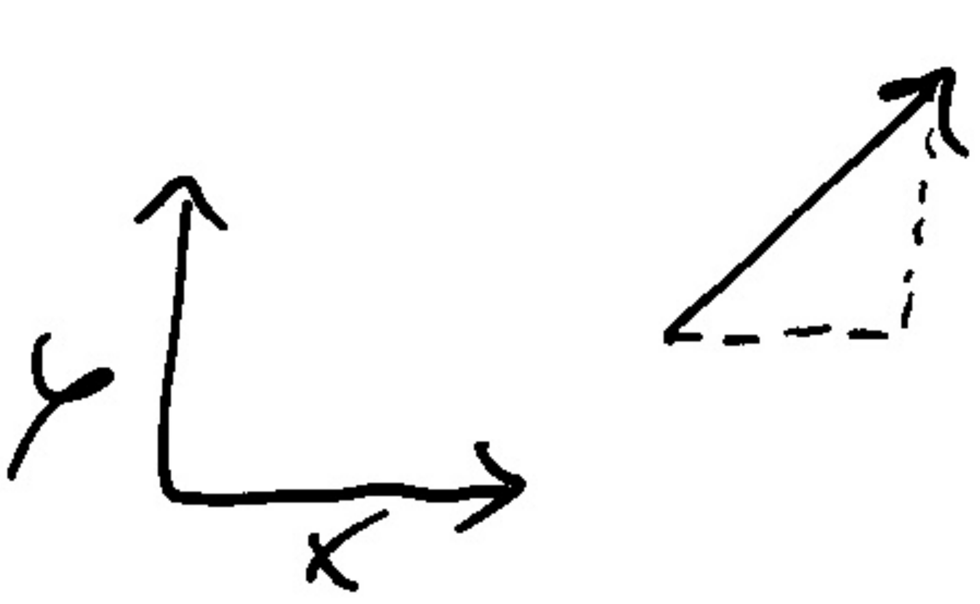


$$|\vec{r}_{qQ}|^2 = h^2 + (s/2)^2$$
$$= h^2 + s^2/4$$

also $|\vec{r}_{q-Q}|^2 = h^2 + s^2/4$

How about $\hat{r}_{qQ}$?

$$\hat{r}_{qQ} = \left(s/2\,\hat{i} + h\,\hat{j}\right) / \sqrt{h^2 + s^2/4}$$



$\hat{r}_{qQ}$  $= \left(-\frac{s}{2}\hat{i} + h\hat{j}\right) / \sqrt{h^2 + s^2/4}$

So $\vec{F}_{qQ} = \dfrac{kqQ \left(\frac{s}{2}\hat{i} + h\hat{j}\right) / \sqrt{h^2 + s^2/4}}{h^2 + s^2/4}$

$$= \frac{kqQ}{\left(h^2 + s^2/4\right)^{3/2}} \left(\frac{s}{2}\hat{i} + h\hat{j}\right)$$

Similarly:

$$\vec{F}_{q-Q} = \frac{-kqQ\left(-\frac{s}{2}\hat{i} + h\hat{j}\right)}{\left(h^2 + s^2/4\right)^{3/2}}$$

$\vec{F}$ total on q:

$$\vec{F}_q = \vec{F}_{qQ} + \vec{F}_{q-Q}$$

$$= \frac{kqQ}{\left(h^2 + s^2/4\right)^{3/2}} \left(\left(\frac{s}{2}\hat{i} + h\hat{j}\right) - \left(-\frac{s}{2}\hat{i} + h\hat{j}\right)\right)$$

$$= \boxed{\frac{kqQs}{\left(h^2 + s^2/4\right)^{3/2}}\,\hat{i} \quad \longrightarrow}$$