Charge Conservation

When rub glass rod with silk
- positive charge transferred onto rod
- negative charge on silk (e^-'s stripped from atoms)

→ total charge conserved

"in a closed system, one can never make or destroy net charge."

At fundamental particle level

$$\begin{array}{lccc} \text{charge} & 0 & & 0 \\ & \gamma & \rightarrow & e^+ e^- \end{array}$$

↳ positive electron = "positron"

- No cases of change in net electric charge have ever been observed (+ we're looking!)

Charging Objects by Induction

conductors

copper, silver

→ free electrons ~~form~~ occur when many many metal atoms together

– not bound to atoms + move easily in material

insulators

rubber, glass

→ all electrons bound to atoms

→ can't move

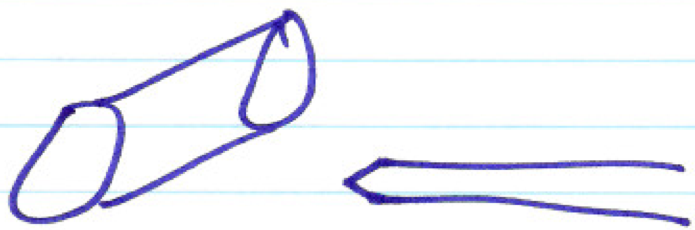
semiconductors

silicon

→ properties between C + I

→ conductivity sensitive to (intentional) addition of other types of atoms to material

Demo: Electrification by Induction



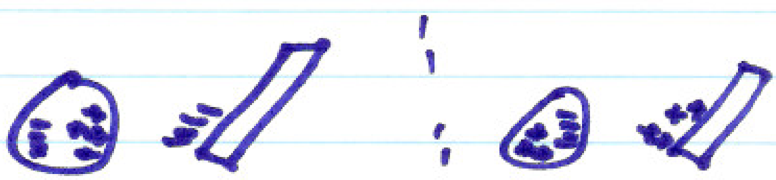
can attracted to electrified rod

→ what charge is can?

rubber rod → attracts

glass rod → " "

what's going on?



electron pushed from or pulled to rod side of can

Coulomb's Law

Coulomb used a torsion balance
→ rotating rod under tension → indicates strength of force
- repulsion causes
  - twisting which can be adjusted ⇒ strength of force

$F_e \propto 1/r^2$

$F_e \propto q_1 q_2$

$$\Rightarrow \boxed{F = k\frac{q_1 q_2}{r^{2}}}$$ **Coulomb's Law**

"n"

- for point charges (i.e. size << distance)
- know "n" to 1 part in 10^{16}

$k = \frac{1}{4\pi\epsilon_0} = 9\times10^{9}\,Nm^2/C^2$

$\epsilon_0 = 8.85\times10^{-12}\,C^2/Nm^2$

electron charge, $e = 1.6\times10^{-19}C$ (very tiny)

Units of charge ("coulomb")

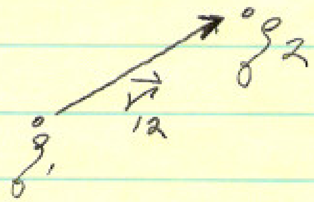
- define in terms of current ("ampère") "A"
  - unit of flowing charge (charge per time)

"amount of charge that flows thru any cross section of a wire in 1s if there's a steady current of 1A"

in a 100W lightbulb, 10^{19} e's in 1 sec!

Vector form of Coulomb's Law

$$\vec{F}_{12} = k\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12}$$



unit vector
in direction from q_1 to q_2

- if q_1 + q_2 samesign: positive product + repulsive force

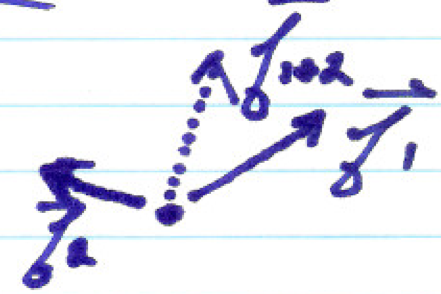
If > 2 particles, use superposition

$$\vec{F}_1 = \vec{F}_{21} + \vec{F}_{31} + \vec{F}_{41} \ldots$$

- resultant force is sum of forces from all particles

Vector Addition + Angles + Force Diagrams

a) Adding 2 vectors:

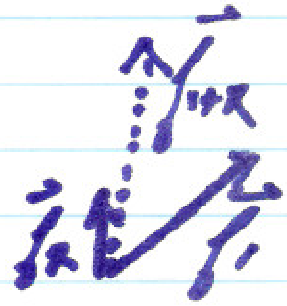


$$\vec{f}_1 = 4\hat{i} + 3\hat{j}$$
$$\vec{f}_2 = -3\hat{i} + 1\hat{j}$$

→ add in each ⊥ direction

$$\vec{f}_1 + \vec{f}_2 = (4-3)\hat{i} + (3+1)\hat{j}$$
$$= \boxed{1\hat{i} + 4\hat{j}}$$

b) Considering Angles



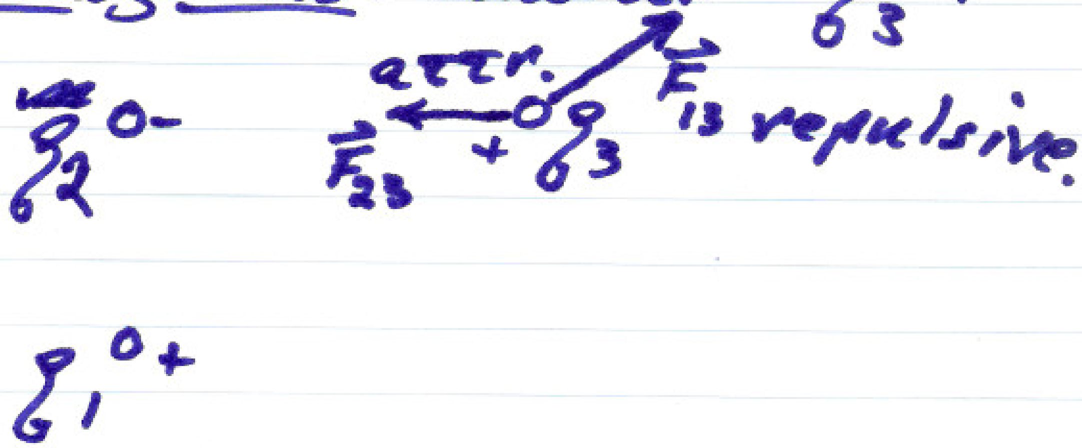
$$\vec{f}_1 = 30N \text{ @ } \theta = 45°$$
$$\vec{f}_2 = 10N \text{ @ } \theta = 90°$$

$$\vec{f}_1 = f_{1x}\hat{i} + f_{1y}\hat{j} = |\vec{f}_1|\cos\theta\,\hat{i} + |\vec{f}_1|\sin\theta\,\hat{i}$$
$$= 21.2\hat{i} + 21.2\hat{j}$$

$$\vec{f}_2 = \cancel{f_{2x}\hat{i}} + f_{2y}\hat{j} = |\vec{f}_2|\sin 90°\,\hat{j}$$
$$= 10\hat{j}$$

$$\therefore \vec{f}_1 + \vec{f}_2 = \boxed{21.2\hat{i} + 31.2\hat{j}}$$

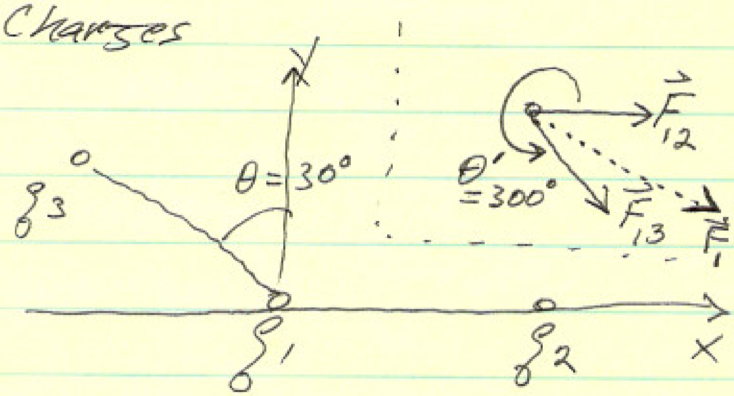
Force Diagrams: Consider q_3:



when multiple forces act on point charge, it's useful to draw magnitude + dir.

Example: Multiple Point Charges

$q_1 = -1.0\times10^{-6}\,C$
$q_2 = +3.0\times10^{-6}\,C$
$q_3 = -2.0\times10^{-6}\,C$



$r_{12} = 15cm$; $r_{13} = 10cm$

What is resultant force + direction?

$$|F_{12}| = k\,q_1 q_2 / r_{12}^2$$
$$= 9\times10^9\,Nm^2/C^2 \,\frac{(+1.0\times10^{-6}C)(+3.0\times10^{-6}C)}{(0.15m)^2}$$
$$= \underline{\underline{1.2N}}$$

$$|F_{13}| = k\,q_1 q_3 / r_{13}^2$$
$$= 9\times10^9\,Nm^2/C^2 \,\frac{(-1.0\times10^{-6}C)(-2.0\times10^{-6}C)}{(0.1m)^2}$$
$$= \underline{\underline{1.8N}}$$

Adding vectors

$$F_{1x} = F_{12x} + F_{13x} = |F_{12}| + |F_{13}|\cos\theta'$$
$$= \underline{\underline{2.1N}}$$

$$F_{1y} = F_{12y} + F_{13y} = \cancel{|F_{12}|} + |F_{13}|\sin\theta'$$
$$= \underline{\underline{1.6N}}$$

$$\underline{\underline{|F_1|}} = \sqrt{(2.1N)^2 + (1.6N)^2}$$
$$= \boxed{2.6N}$$

$$\underline{\underline{\phi}} = \tan^{-1}\left(\frac{-1.6}{2.1}\right)$$
$$= \boxed{-37°}$$