

Phys 102 – Lecture 2

Coulomb's Law & Electric Dipoles

Today we will...

- Get practice using Coulomb's law & vector addition
- Learn about electric dipoles
- Apply these concepts!

Molecular interactions

Polar vs. nonpolar molecules

Hydrophilic vs. hydrophobic

Permanent vs. induced dipole

} Chemistry!

Recall: Coulomb's Law

Force between charges q_1 and q_2 separated a distance r :

Magnitude

Force on q_1 due to q_2

$$F_{12} = F_{21} = \frac{k |q_1| |q_2|}{r^2} \geq 0$$

“Coulomb constant”
 $k = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$

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

“Permittivity of free space”
 $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$

Direction

Opposite charges attract, like charges repel

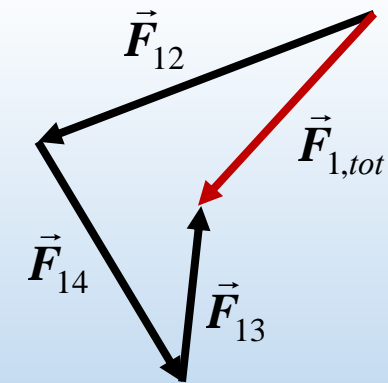
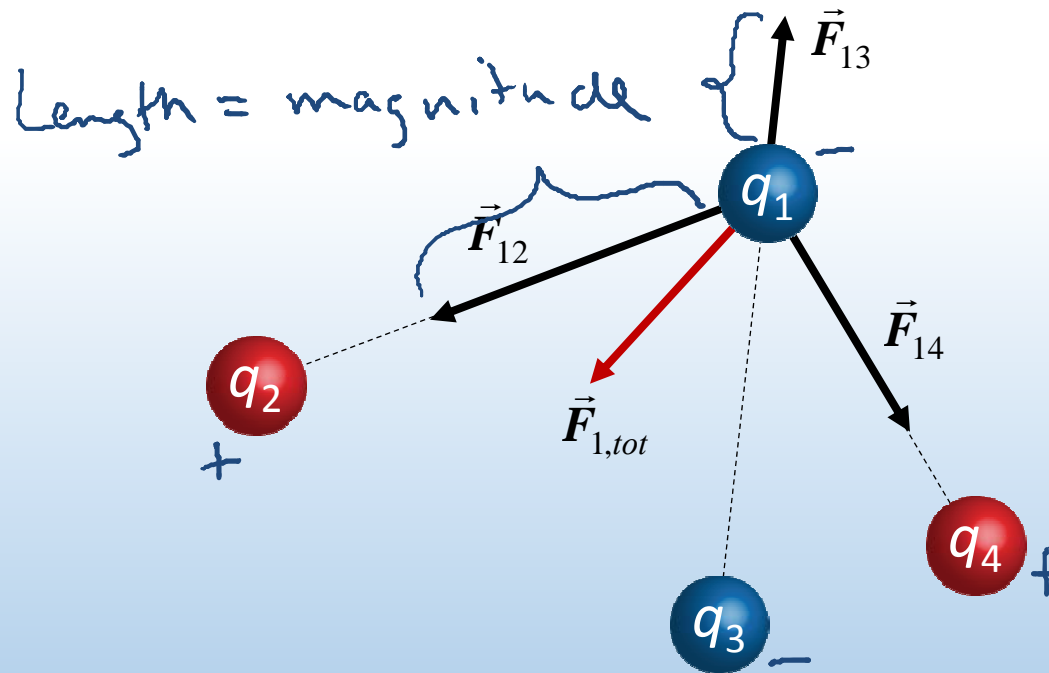
$$\vec{F}_{12} = -\vec{F}_{21}$$

Superposition principle

Total force on charge due to other charges = sum of individual forces

$$\vec{F}_{tot} = \sum \vec{F}$$

Ex: what is the force on q_1 due to q_2 , q_3 , and q_4 ?



Order does not matter!

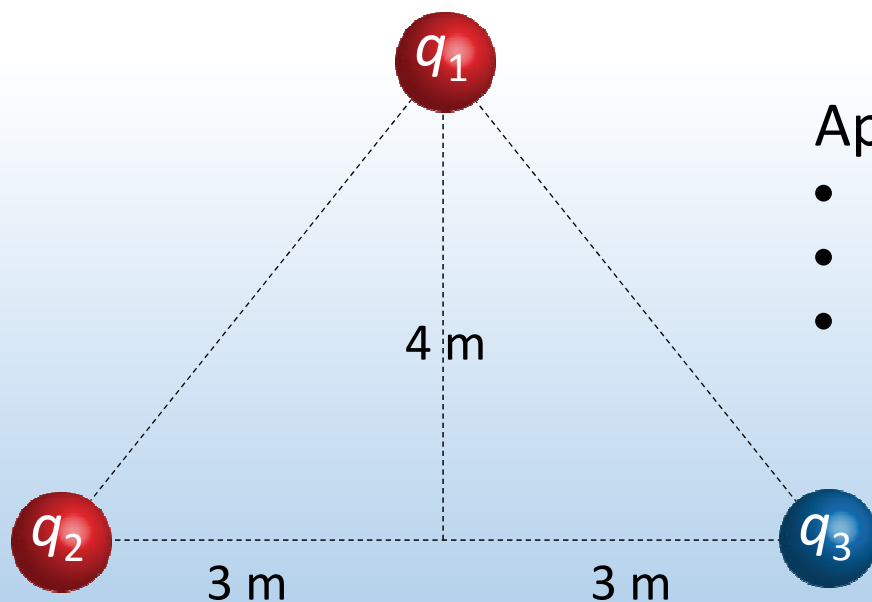
$$\vec{F}_{1,tot} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14}$$

Calculation: four charges

Calculate the total force on charge $q_1 = +2 \mu\text{C}$ due to charges $q_2 = +7 \mu\text{C}$, $q_3 = -3.5 \mu\text{C}$

Fundamental concept: Superposition

$$\vec{F}_{1tot} = \vec{F}_{12} + \vec{F}_{13}$$



Approach:

- Draw forces
- Calculate magnitudes of forces
- Add vectors

Decompose into x-, y-components

Add like components

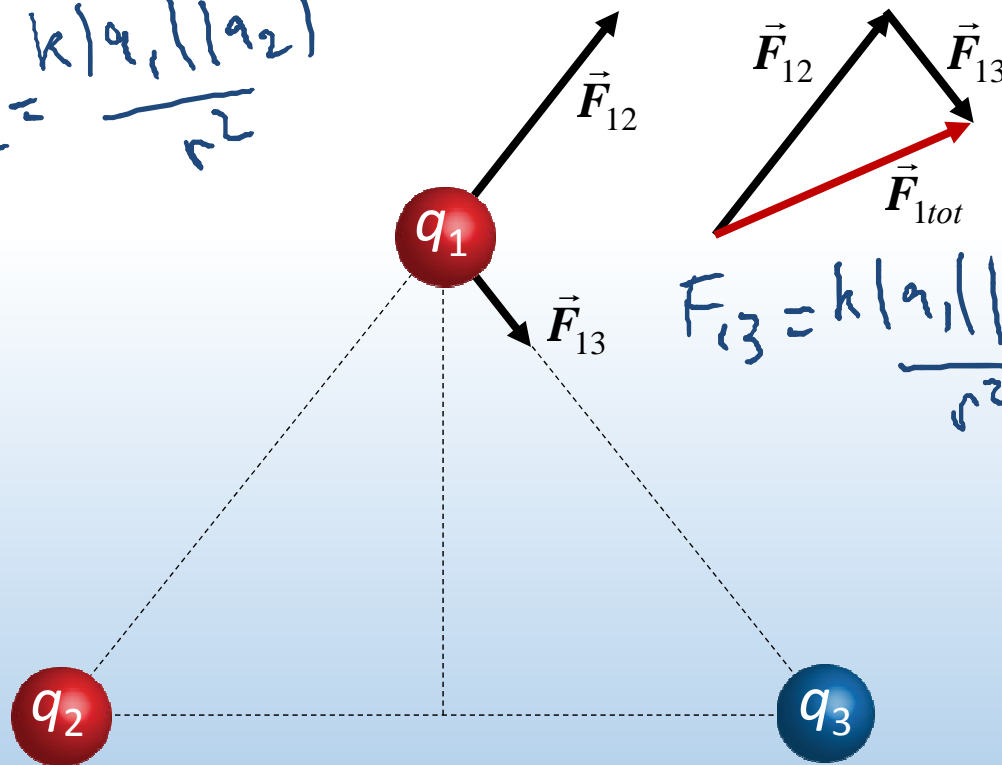
May need geometry, trigonometry



ACT: four charges

Which vector best represents the total force on charge $q_1 = +2 \mu\text{C}$ due to charges $q_2 = +7 \mu\text{C}$ and $q_3 = -3.5 \mu\text{C}$?

$$F_{12} = \frac{k|q_1||q_2|}{r^2}$$

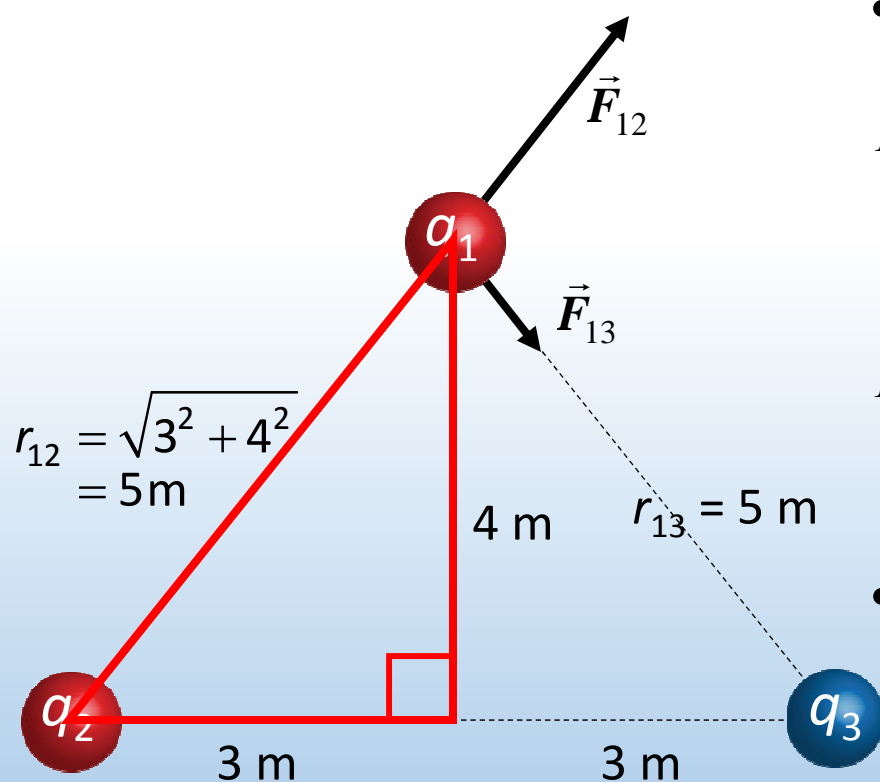


$$F_{13} = \frac{k|q_1||q_3|}{r^2}$$

- A.
- B.
- C.
- D.
- E.

Calculation: four charges

Calculate the total force on charge $q_1 = +2 \mu\text{C}$ due to charges $q_2 = +7 \mu\text{C}$ and $q_3 = -3.5 \mu\text{C}$



- Calculate magnitudes of forces

$$F_{12} = k \frac{|q_1||q_2|}{r_{12}^2} = 9 \times 10^9 \frac{|+2 \times 10^{-6}| |+7 \times 10^{-6}|}{5^2} = 5.0 \times 10^{-3} \text{ N}$$

$$F_{13} = k \frac{|q_1||q_3|}{r_{13}^2} = 9 \times 10^9 \frac{|+2 \times 10^{-6}| |-3.5 \times 10^{-6}|}{5^2} = 2.5 \times 10^{-3} \text{ N}$$

- Note: magnitudes > 0



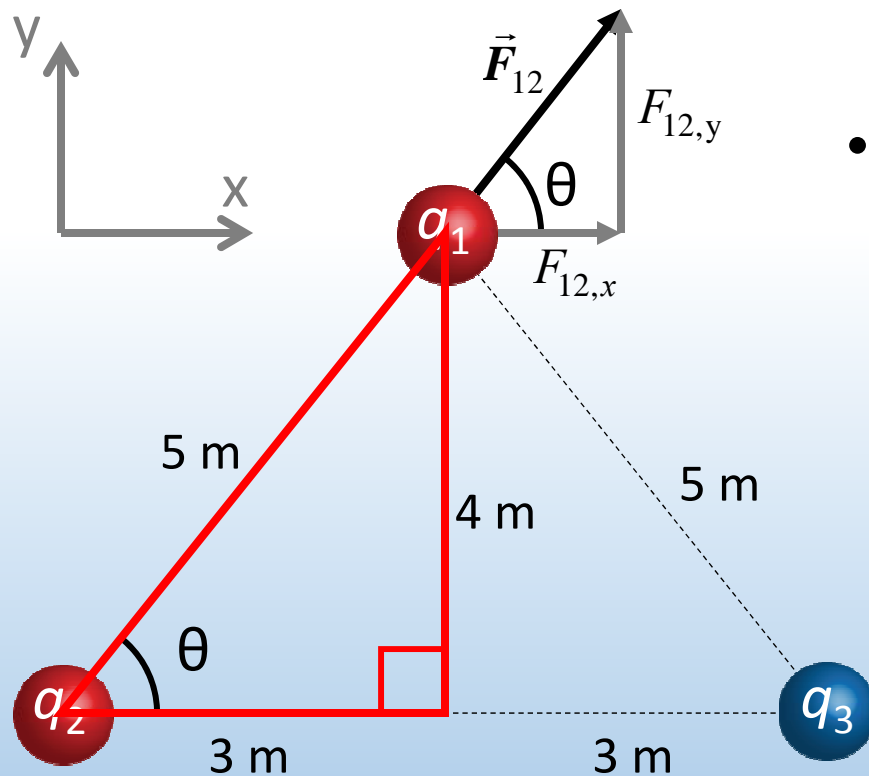
ACT: components

What is the x-component of \vec{F}_{12} , $F_{12,x}$?

A. $3/4 F_{12}$

B. $3/5 F_{12}$

C. $-4/5 F_{12}$



- Decompose vectors into components

$$F_{12,x} = F_{12} \cos \theta$$

$$= F_{12} \frac{3}{5}$$

$$= 3.0 \times 10^{-3} N$$

$$F_{12,y} = F_{12} \sin \theta$$

$$= F_{12} \frac{4}{5}$$

$$= 4.0 \times 10^{-3} N$$



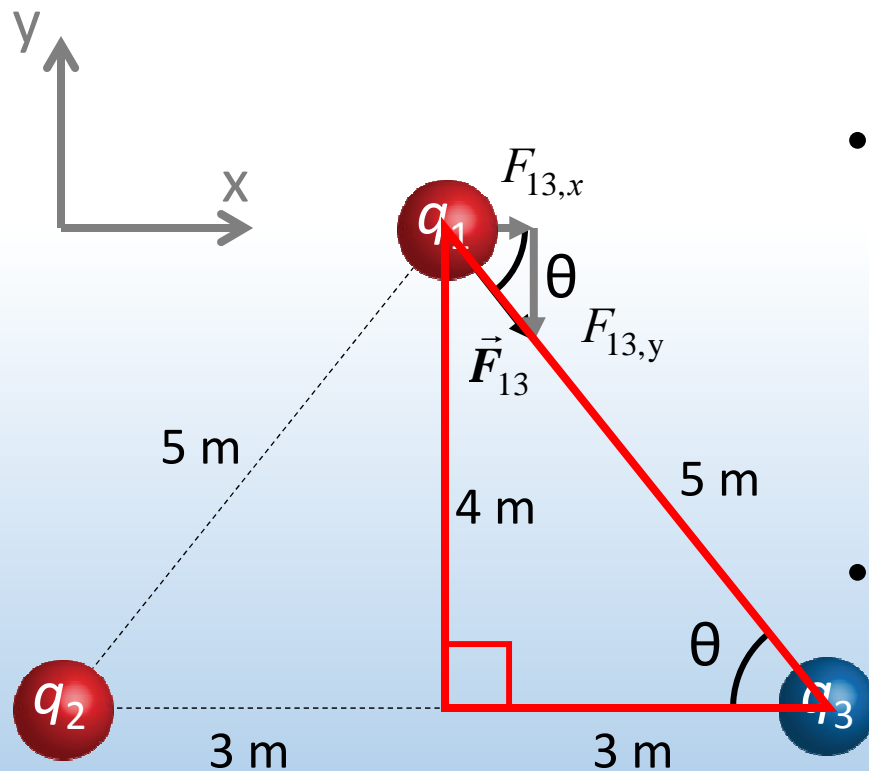
ACT: components

What is the y-component of \vec{F}_{13} , $F_{13,y}$?

A. $3/4 F_{13}$

B. $3/5 F_{13}$

C. $-4/5 F_{13}$



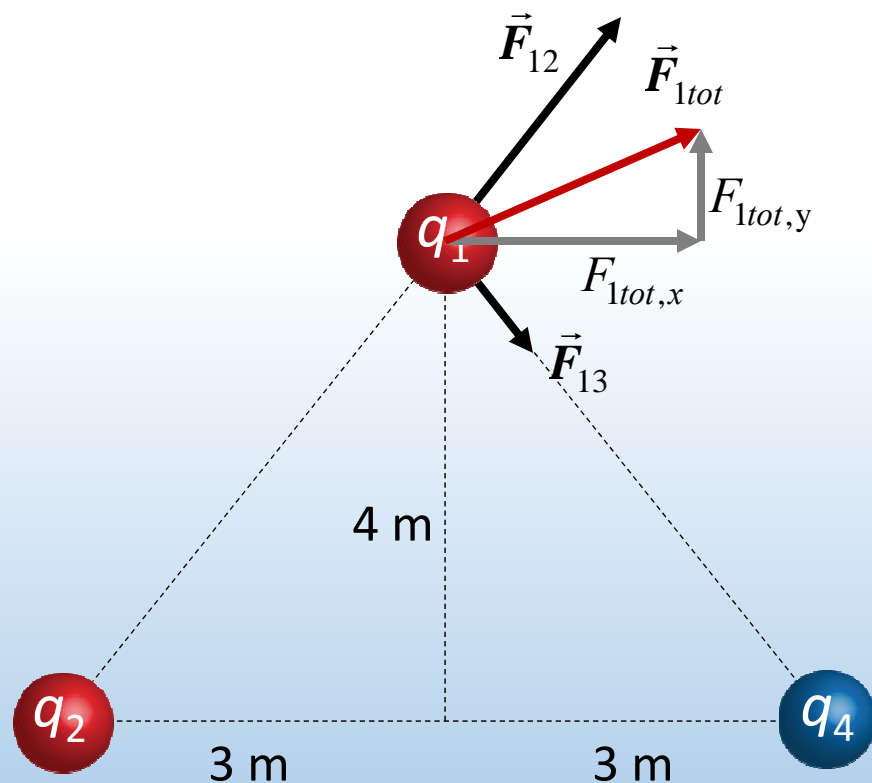
- Decompose vectors into components

$$\begin{aligned} F_{13,x} &= F_{13} \cos \theta & F_{13,y} &= -F_{13} \sin \theta \\ &= F_{13} \frac{3}{5} & &= -F_{13} \frac{4}{5} \\ &= 1.5 \times 10^{-3} \text{ N} & &= -2.0 \times 10^{-3} \text{ N} \end{aligned}$$

- Note: components can be positive or negative

Calculation: four charges

Calculate the total force on charge $q_1 = +2 \mu\text{C}$ due to charges $q_2 = +7 \mu\text{C}$ and $q_3 = -3.5 \mu\text{C}$



- Add like components

$$F_{12,x} = 3 \times 10^{-3} \text{ N} \quad F_{12,y} = 4 \times 10^{-3} \text{ N}$$

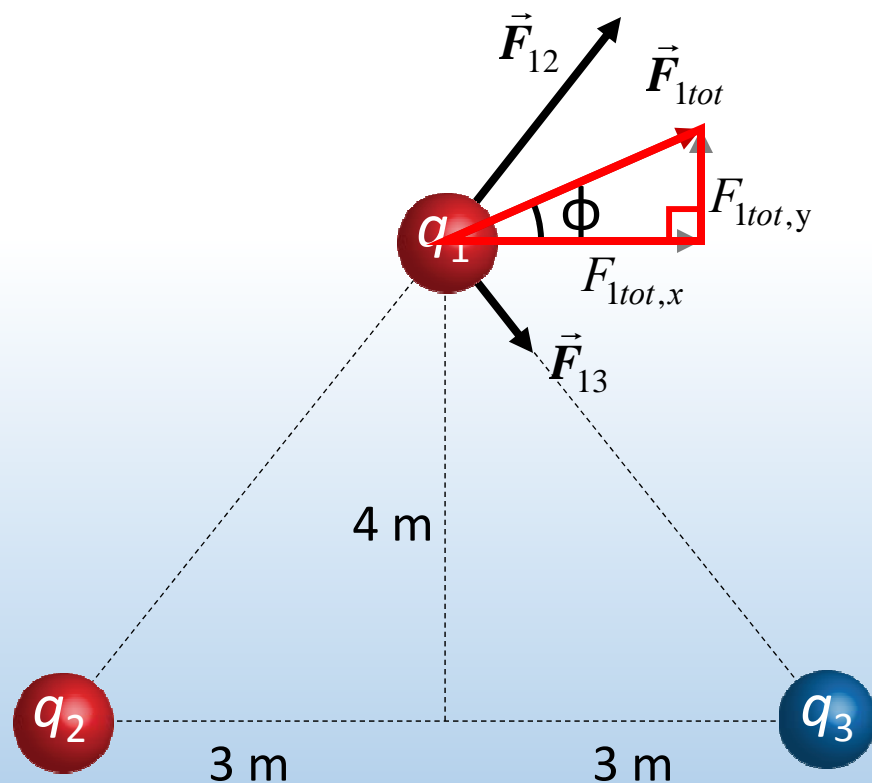
$$F_{13,x} = 1.5 \times 10^{-3} \text{ N} \quad F_{13,y} = -2 \times 10^{-3} \text{ N}$$

$$F_{1tot,x} = 4.5 \times 10^{-3} \text{ N} \quad F_{1tot,y} = 2 \times 10^{-3} \text{ N}$$

✓ Compare to drawing

Calculation: four charges

Calculate the total force on charge $q_1 = +2 \mu\text{C}$ due to charges $q_2 = +7 \mu\text{C}$ and $q_3 = -3.5 \mu\text{C}$



- Magnitude of total force

$$F_{1tot} = \sqrt{F_{1tot,x}^2 + F_{1tot,y}^2} = 4.9 \times 10^{-3} \text{ N} \quad \checkmark$$

- Direction of total force

$$\phi = \tan^{-1} \frac{F_{1tot,y}}{F_{1tot,x}} = 24^\circ \quad \checkmark$$

DONE!



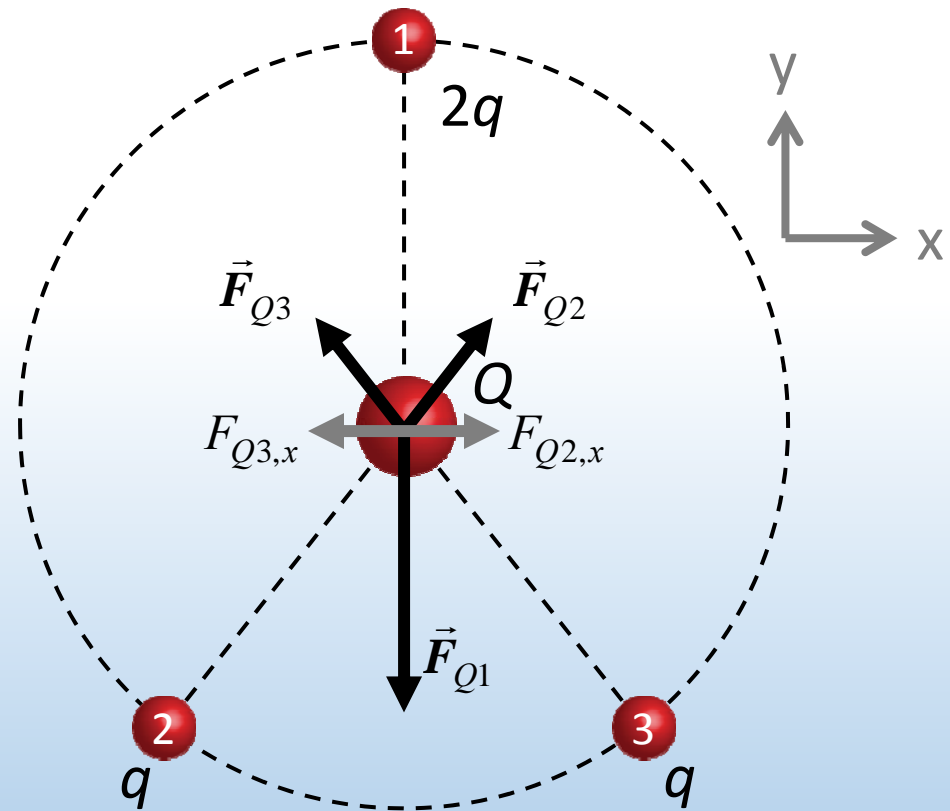
ACT: CheckPoint 1.1

Consider three charges on a circular ring, $q_1 = +2q$, $q_2 = q_3 = +q$. A charge $+Q$ is placed at the center of the circle.

What is the x-component of the total force on Q ?

- A. $F_x > 0$ 6%
- B. $F_x = 0$ 92%**
- C. $F_x < 0$ 2%

All x-components cancel by symmetry





ACT: CheckPoint 1.2

Consider three charges on a circular ring, $q_1 = +2q$, $q_2 = q_3 = +q$. A charge $+Q$ is placed at the center of the circle.

What is the y-component of the total force on Q ?

A. $F_y > 0$ 30%

B. $F_y = 0$ 36%

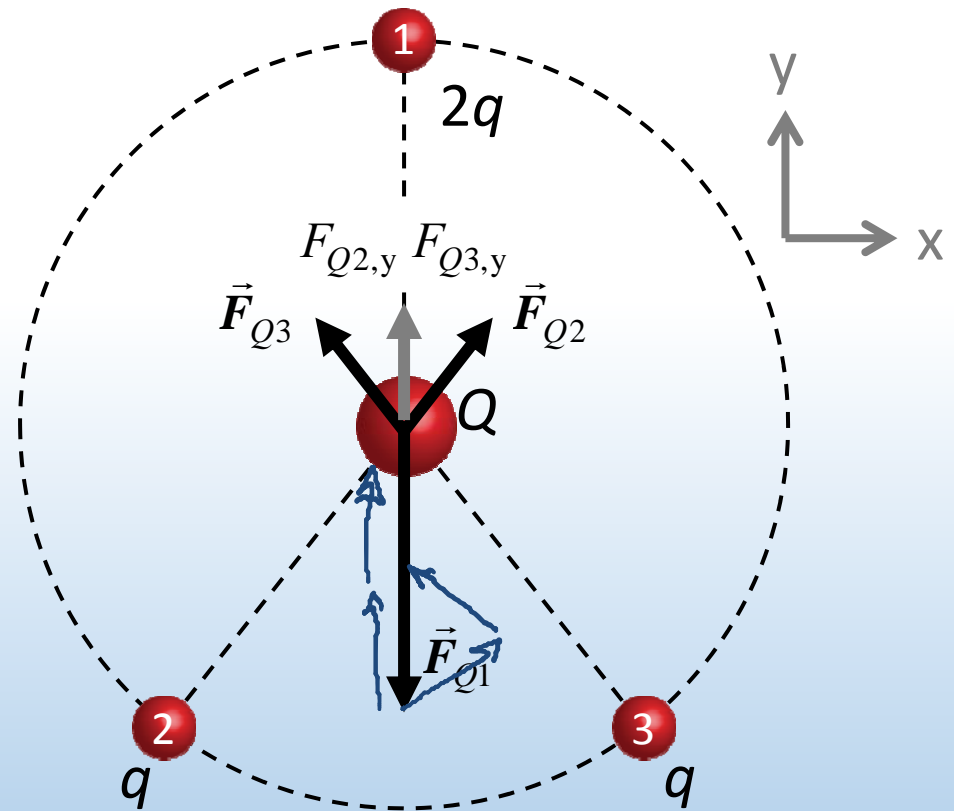
C. $F_y < 0$ 34%

Compare magnitudes:

$$F_{Q2} = F_{Q3} = F_{Q1}/2$$

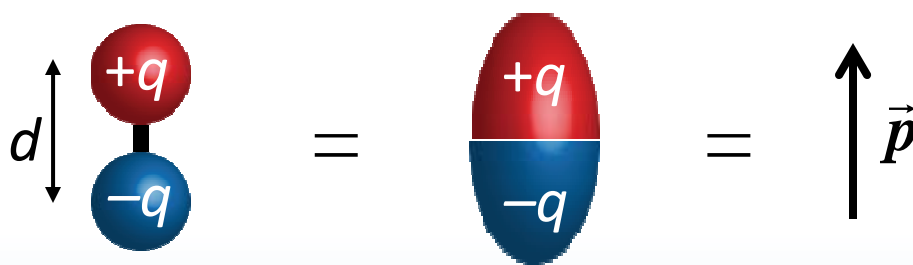
Compare y-components:

$$F_{Q2,y} = F_{Q3,y} < F_{Q1,y}/2$$



Electric dipole & dipole moment

A positive and negative charge of equal magnitude q separated by a (usually small) distance d ^{rigidly}



Dipole moment is measure of separated + and – charges

Magnitude

$$p \equiv qd$$

↑
definition

Direction

From – to + charge (by convention)

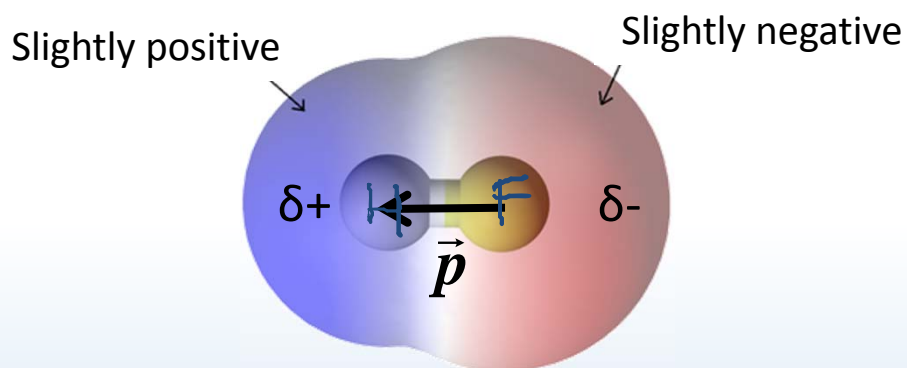
Note: opposite from Lewis notation (Chemistry)

What are examples of electric dipoles?

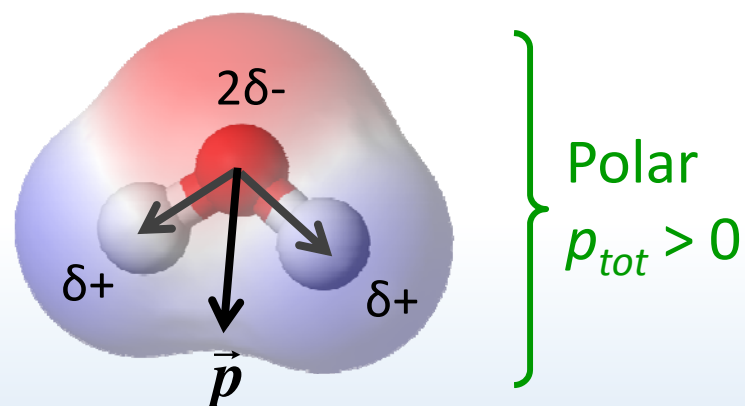
Molecular dipole

Electrons are not shared equally between chemically bonded atoms
Charge imbalance creates a bond dipole

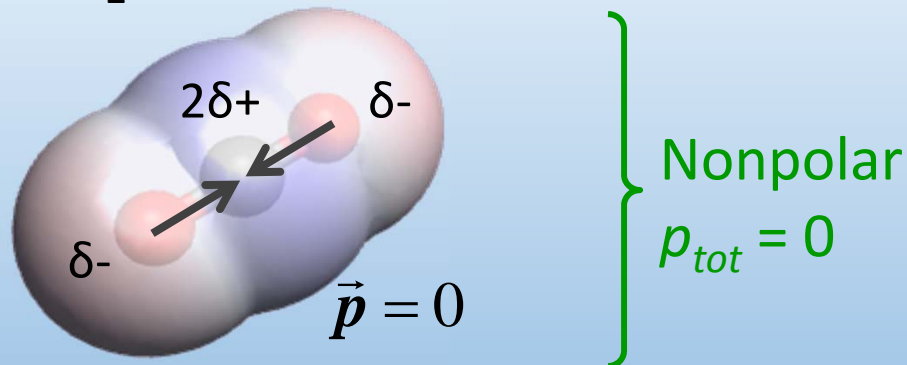
Ex: HF (hydrofluoric acid)



Ex: H₂O (water)



Ex: CO₂ (carbon dioxide)





ACT: CheckPoint 2.1

An electric dipole is placed near a large positive charge $+Q$.
In what direction is the net force on the dipole?

A. Left

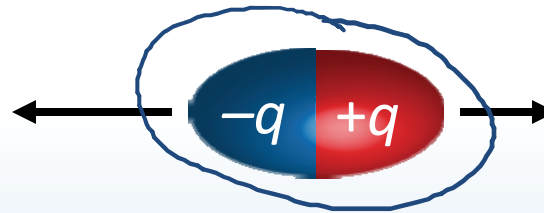
65%

B. Zero

22%

C. Right

13%



1. $+q$ is repelled (force to right)
2. $-q$ is attracted (force to left)
3. $-q$ is closer to $+Q$ so force to left is larger

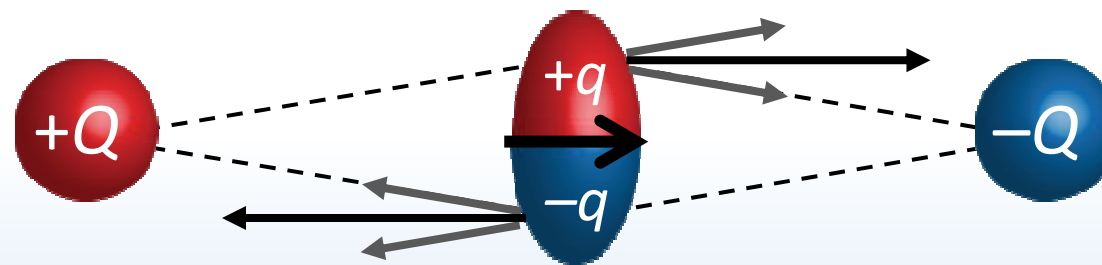
“...I really do not understand why a dipole isn't considered as having one neutral charge at the center”

$$F = \frac{k|q||Q|}{r^2}$$



ACT: Dipole & 2 charges

Consider an electric dipole placed an equal distance from a $+Q$ and a $-Q$ charge. Does the dipole move?



A. Yes

B. No

Total force = 0
Dipole does not translate

BUT...

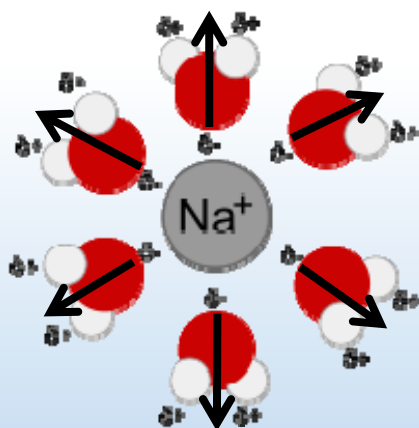
Total torque > 0 !
Dipole spins!

Ion-dipole interactions

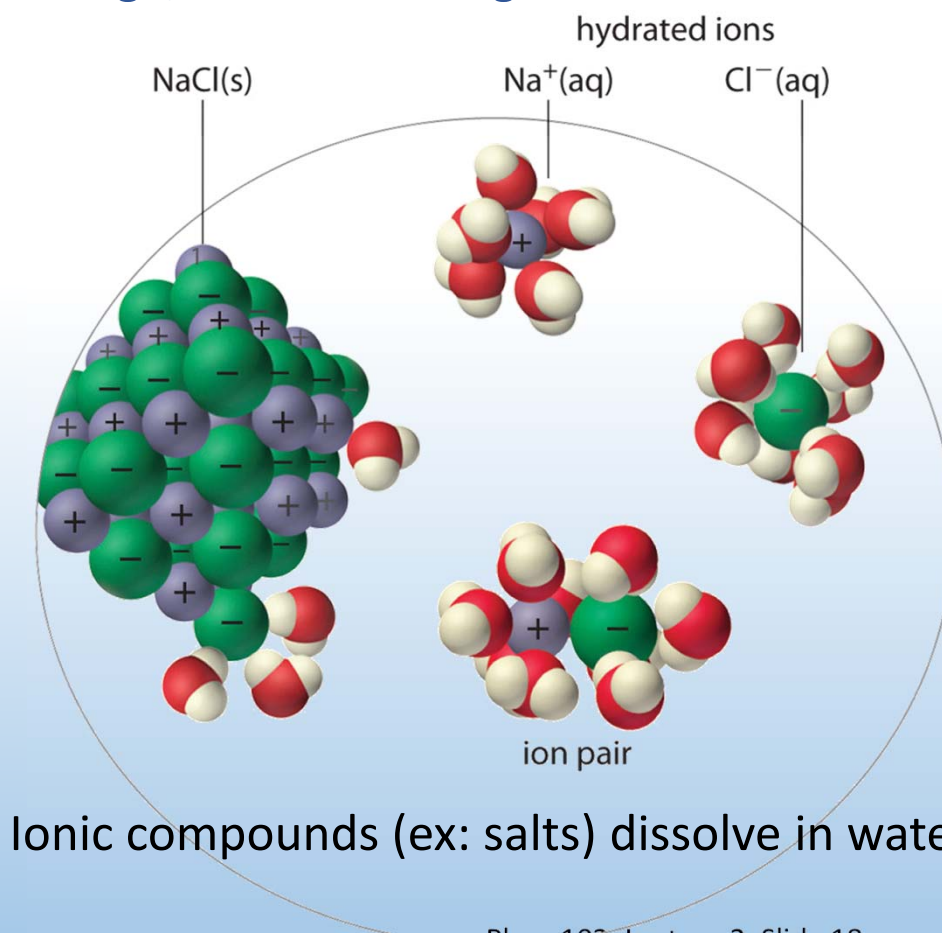
Polar molecules are attracted to ions

Dipole moment aligns away from + charge, toward – charge

Ex: ions in water & solubility



"Hydration shell"

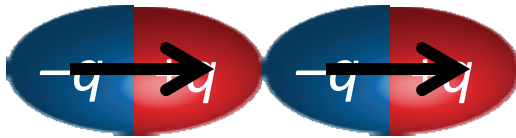


Ionic compounds (ex: salts) dissolve in water

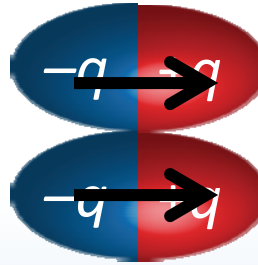


ACT: Two dipoles

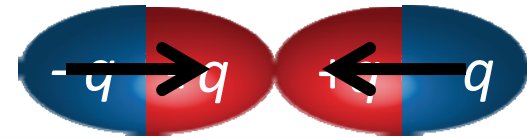
Which of the following arrangement of two dipoles leads to a net attractive force between the two?



A.



B.



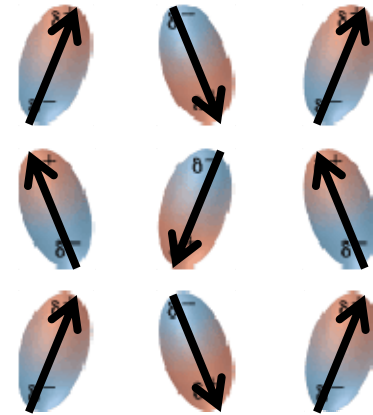
C.

D. Dipoles are neutral, they cannot attract or repel

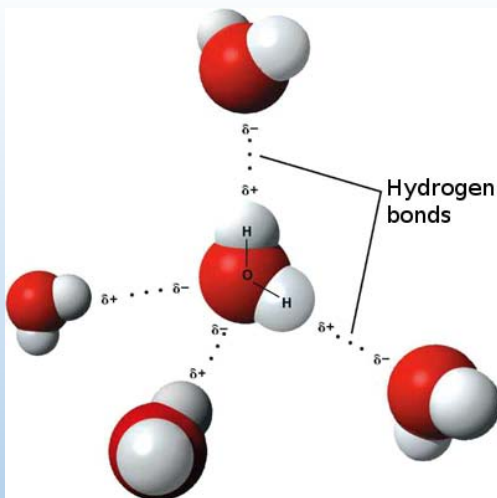
Dipole-dipole interactions

Polar molecules interact together

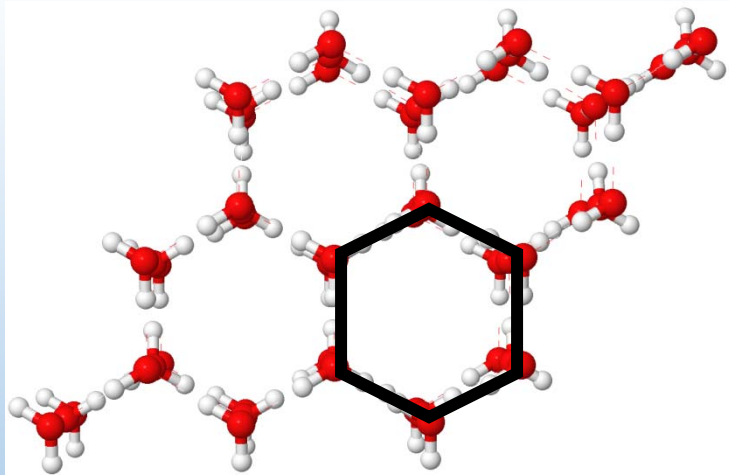
Dipole moments align end-to-end + to –
Like magnets!



Ex: hydrogen bond is a dipole-dipole interaction between water molecules



Hydrogen bond



Structure of ice



Snowflake

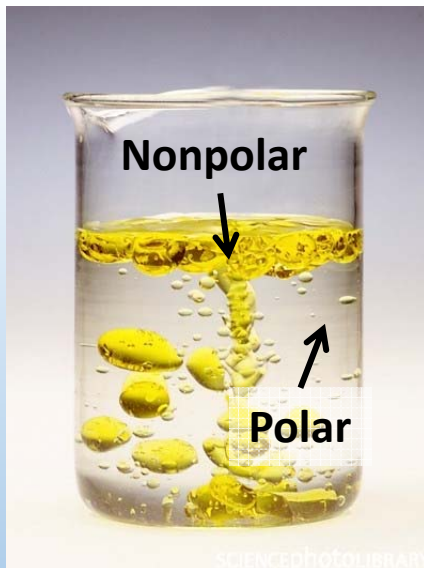
Hydrophilic vs. hydrophobic

Polar molecules interact with charged & polar molecules

Ex: charged & polar molecules attract water, nonpolar molecules do not

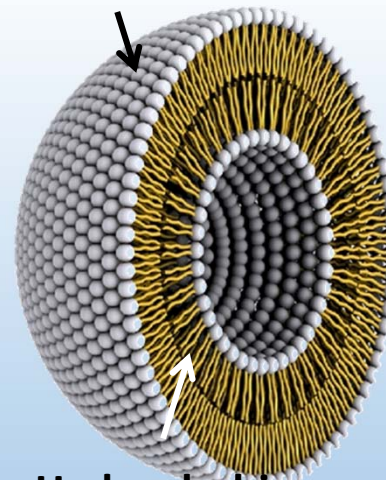
Hydrophilic

“attract water”



Oil and water

Hydrophilic



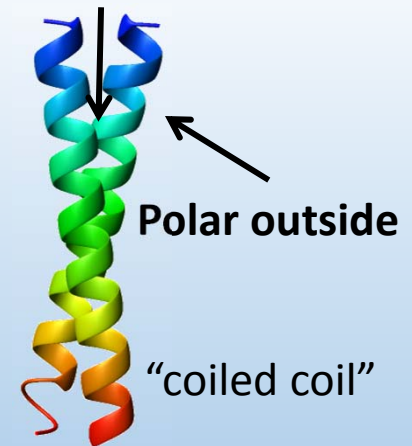
Hydrophobic

Cell membranes

Hydrophobic

“repel water”

Nonpolar inside



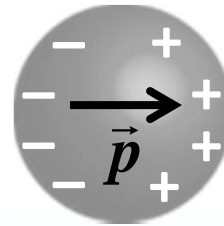
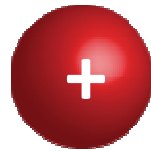
Protein structure

Phys. 102, Lecture 2, Slide 21



ACT: Charge & conductor

An uncharged conducting sphere is placed next to a fixed + charge. What happens when the uncharged sphere is released?



A. Nothing

B. Attracted to + sphere

C. Repelled from + sphere

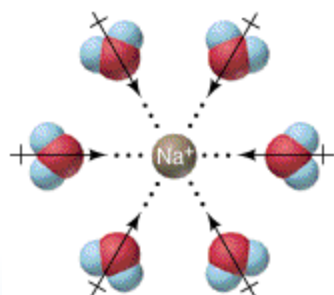
1. Positive charge attracts $-$, leaves $+$ on opposite side
2. Conductor is polarized \rightarrow induced dipole
3. As in previous ACT, net attractive force

DEMO

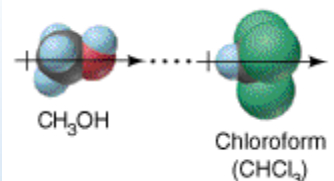
Molecular interactions

Interactions between molecules are understood in terms of charges and electric dipoles interacting by Coulomb's law

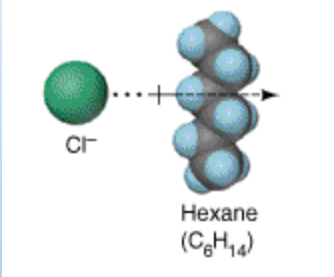
Ion-dipole



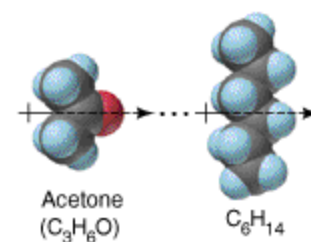
Dipole-dipole



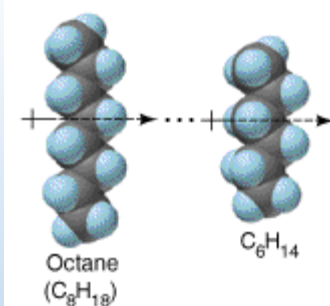
Ion-induced dipole



Dipole-induced dipole



Induced dipole-induced dipole?



Yes! Two nonpolar molecules can induce dipoles in each other and interact!
London dispersion or van der Waals force

Summary of today's lecture

- Coulomb's law
- Superposition principle $\vec{F}_{tot} = \sum \vec{F}$
- Electric dipole & dipole moment

Permanent vs. induced dipole