Your questions/comments

IMPORTANT ANNOUNCEMENT: Homework 1 deadline extended to Thursday 8AM

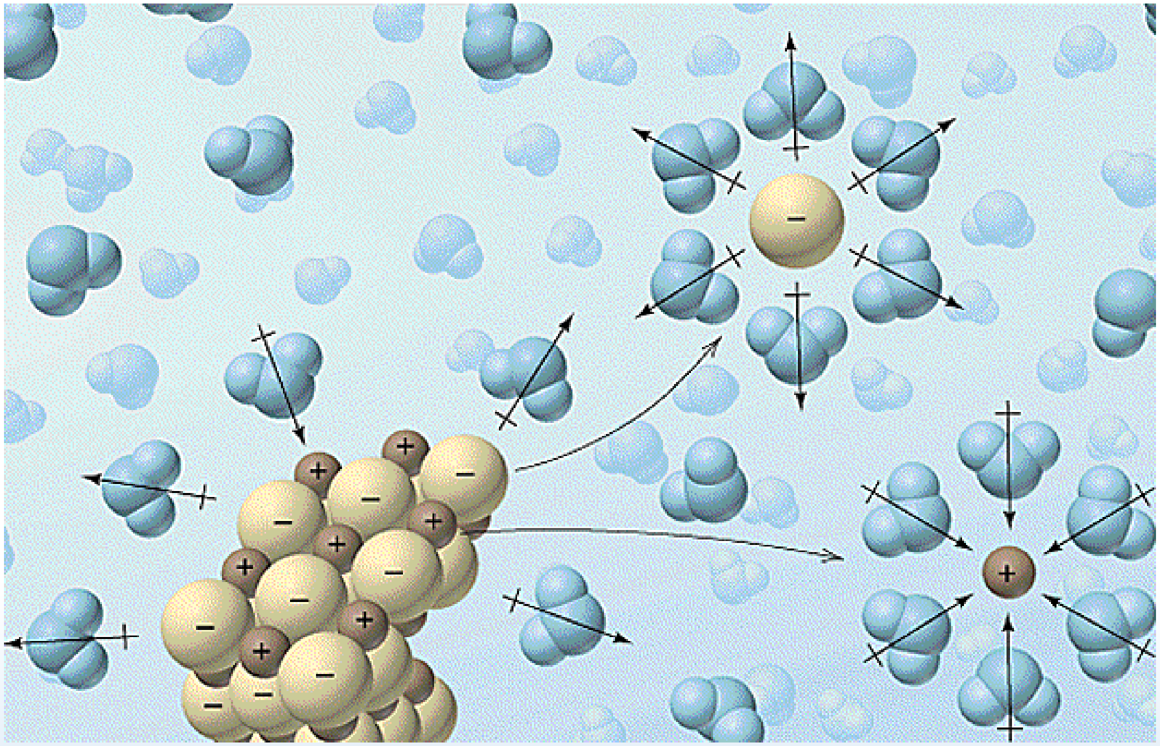
“I found superposition to be difficult in the pre-lecture.”

“I’m really confused of the Superposition principle. How do you know where to connect the different vectors to find their components?”

“The superposition problems are a bit difficult and it would be helpful to learn more intuitive ways to figure out these questions where there are no numbers given.”

“Could we do an example with an atom when talking about dipole forces as well as charge vectors? I am not finding the current concepts too difficult. Right now they're okay, but I'm anxious about how we might be using these concepts later in the semester and how difficult this class might become.”

“Checkpoint question 2 seemed to be the most difficult for me to figure out. If you have a dipole with + and - charges, how do you decide in which direction the dipole moment travels if there is no "negative"?



Phys 102 – Lecture 2

Coulomb's Law & Electric Dipoles

Today we will...

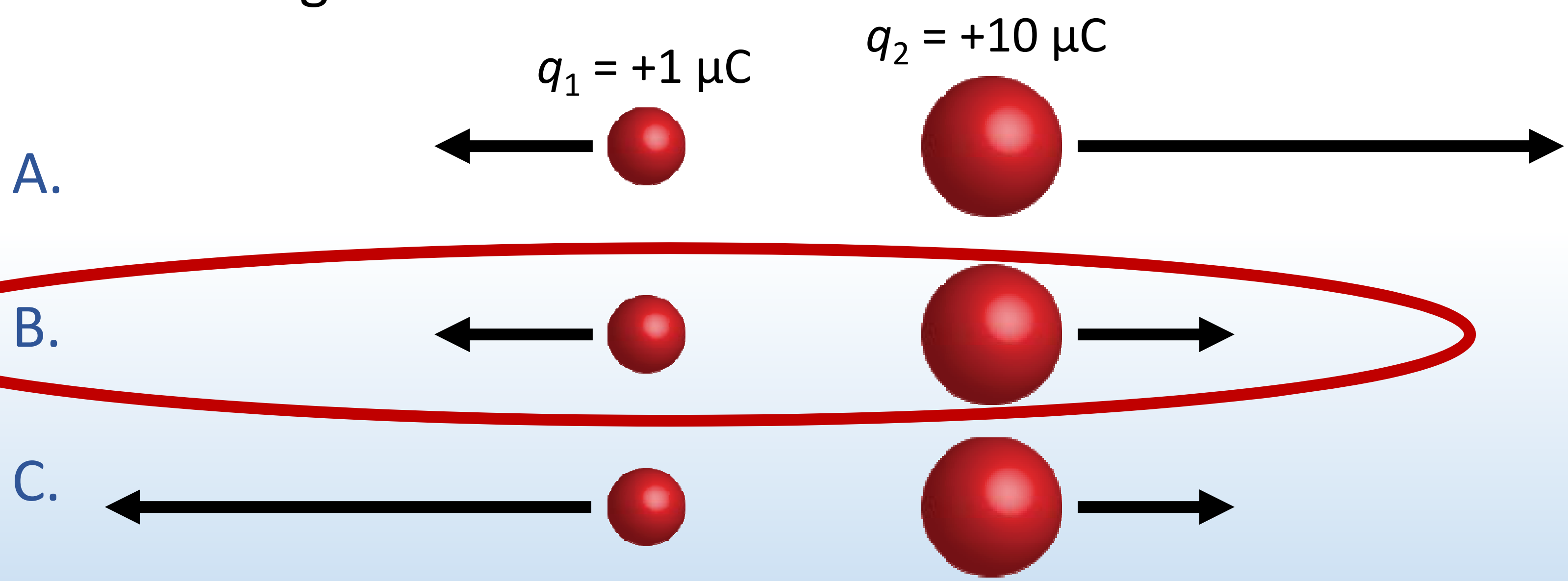
- Get practice using Coulomb's law & vector addition
- Learn about electric dipoles
- Apply these concepts!

  Molecular interactions
  Polar vs. nonpolar molecules
  Hydrophilic vs. hydrophobic
  Permanent vs. induced dipole

  Chemistry!

ACT: Coulomb's Law

Two charges q_1 = +1 μC and q_2 = +10 μC are placed near each other. Which of the following diagrams correctly depicts the forces acting on the charges?



The two charges exert forces equal in magnitude and opposite in direction (Newton's Third Law! – Phys. 101).

$$F_{12} = F_{21} = \frac{k|q_1||q_2|}{r^2} \qquad \vec{\boldsymbol{F}}_{12} = -\vec{\boldsymbol{F}}_{21}$$

Recall: Coulomb's Law

Vector

Force between charges q_1 and q_2 separated a distance *r*:

Magnitude

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

"Force on q_1 due to q_2"

"Coulomb constant"

$k = 9\times10^{9}\ \mathrm{Nm}^2/\mathrm{C}^2$

$$= \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$

"Permittivity of free space"

$\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{C}^2/\mathrm{Nm}^2$

Direction

Opposite charges attract, like charges repel

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

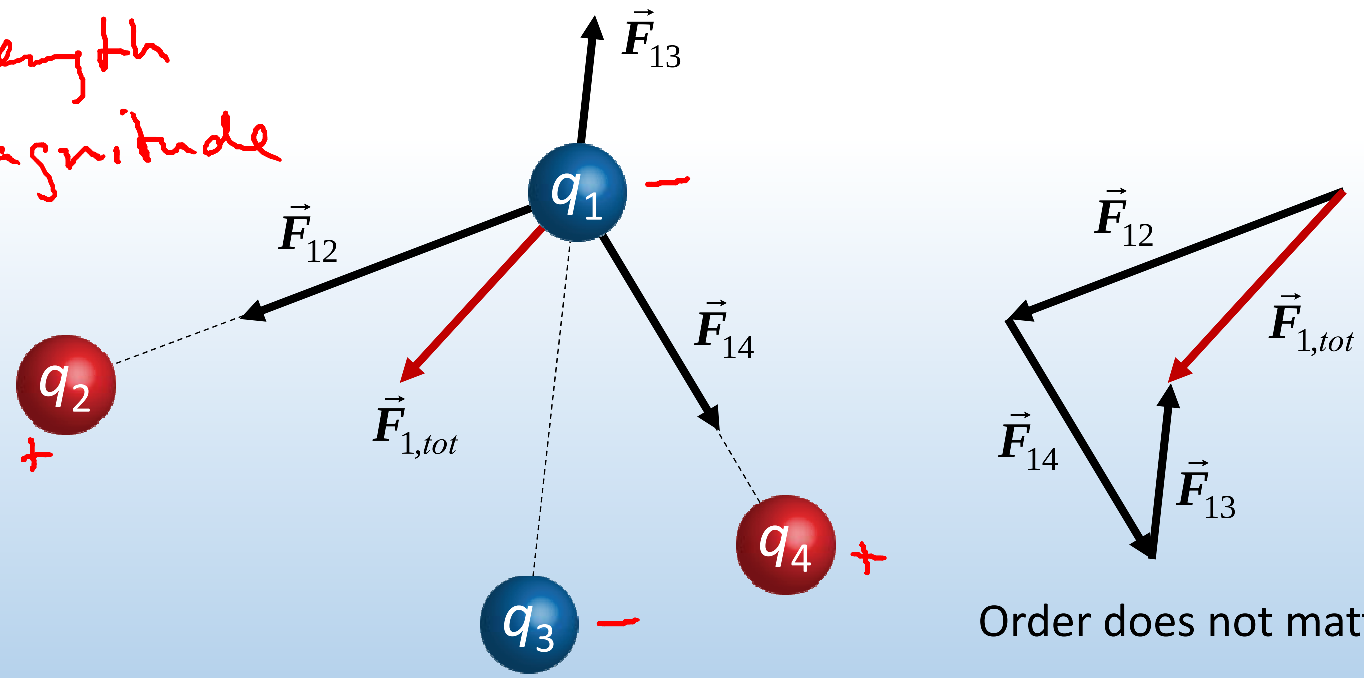
Superposition principle

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?

vector length
= magnitude

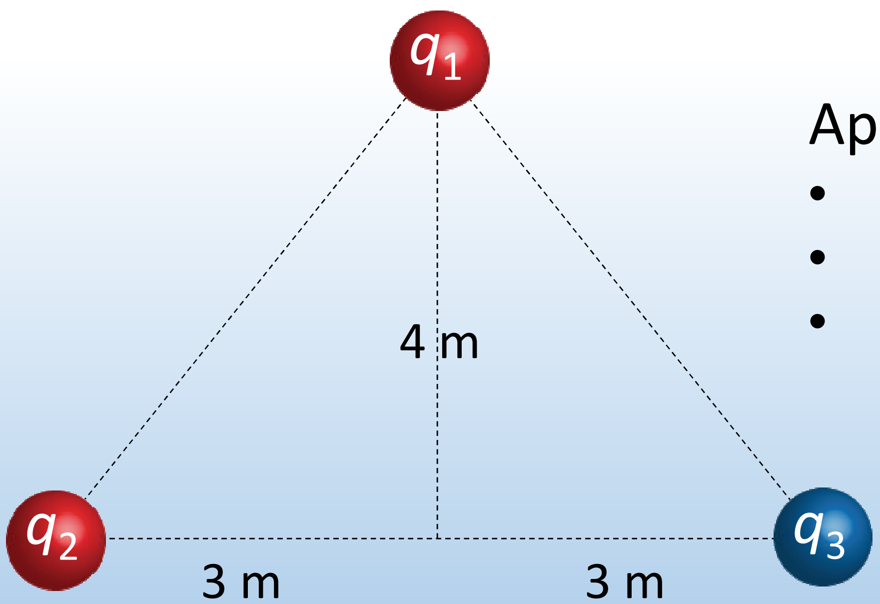


Order does not matter!

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

Calculation: four charges

Calculate the total force on charge q_1 = +2 μC due to charges q_2 = +7 μC, q_3 = –3.5 μC



Fundamental concept: Superposition

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

Approach:

- Draw forces
- Calculate magnitudes of forces
- Add <u>vectors</u>

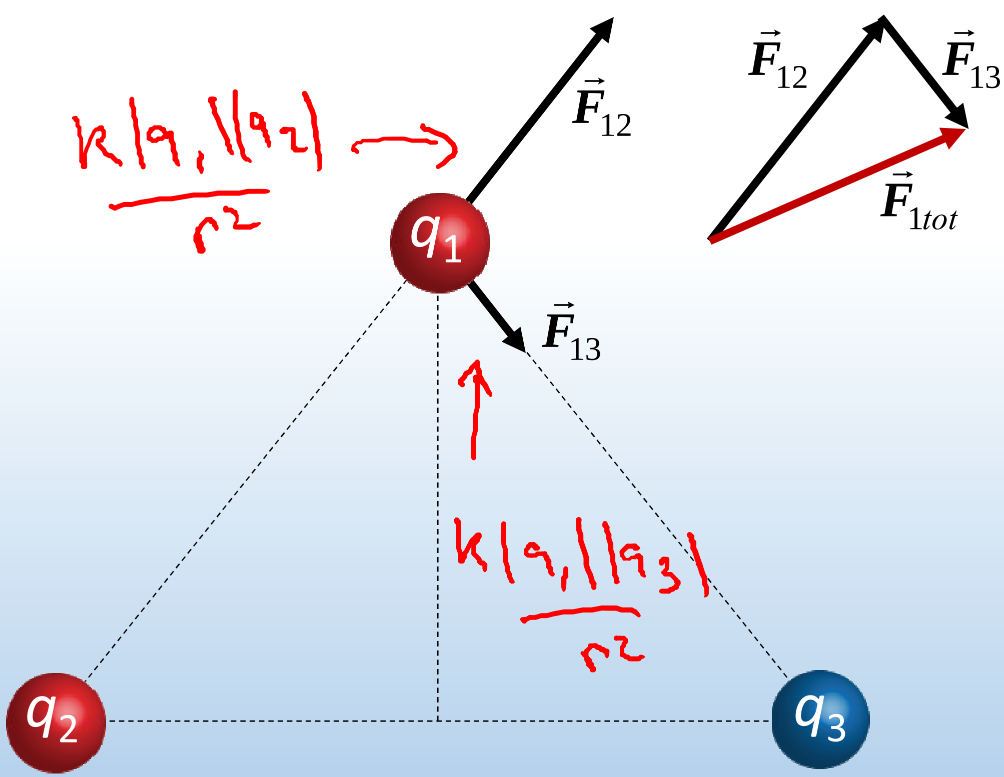
  Decompose into *x*-, *y*-components

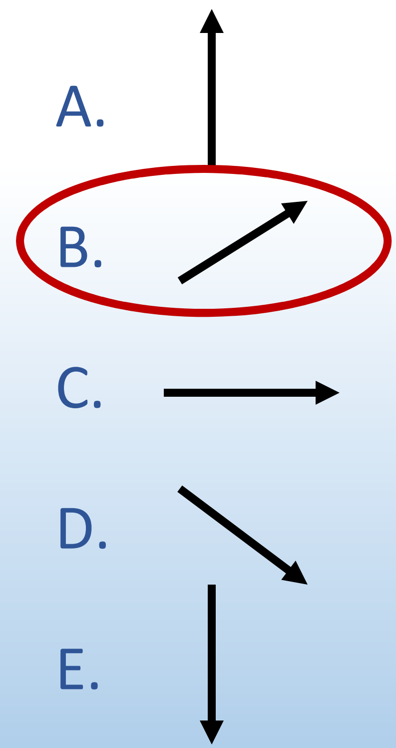
  Add like components

May need geometry, trigonometry

ACT: four charges

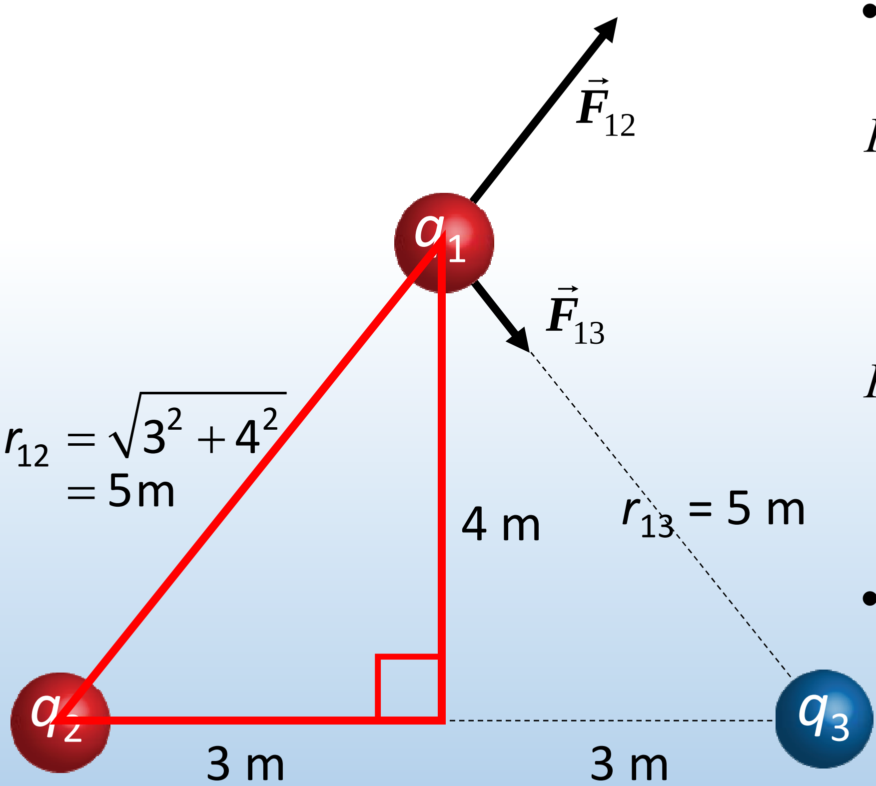
Which vector best represents the total force on charge $q_1 = +2\ \mu C$ due to charges $q_2 = +7\ \mu C$ and $q_3 = -3.5\ \mu C$?





Calculation: four charges

Calculate the total force on charge q_1 = +2 μC due to charges q_2 = +7 μC and q_3 = –3.5 μC



- Calculate magnitudes of forces

$$F_{12} = k\frac{|q_1||q_2|}{r_{12}^2} = 9\times10^9\,\frac{|+2\times10^{-6}||+7\times10^{-6}|}{5^2} = 5.0\times10^{-3}\,\text{N}$$

$$F_{13} = k\frac{|q_1||q_3|}{r_{13}^2} = 9\times10^9\,\frac{|+2\times10^{-6}||-3.5\times10^{-6}|}{5^2} = 2.5\times10^{-3}\,\text{N}$$

- Note: magnitudes > 0

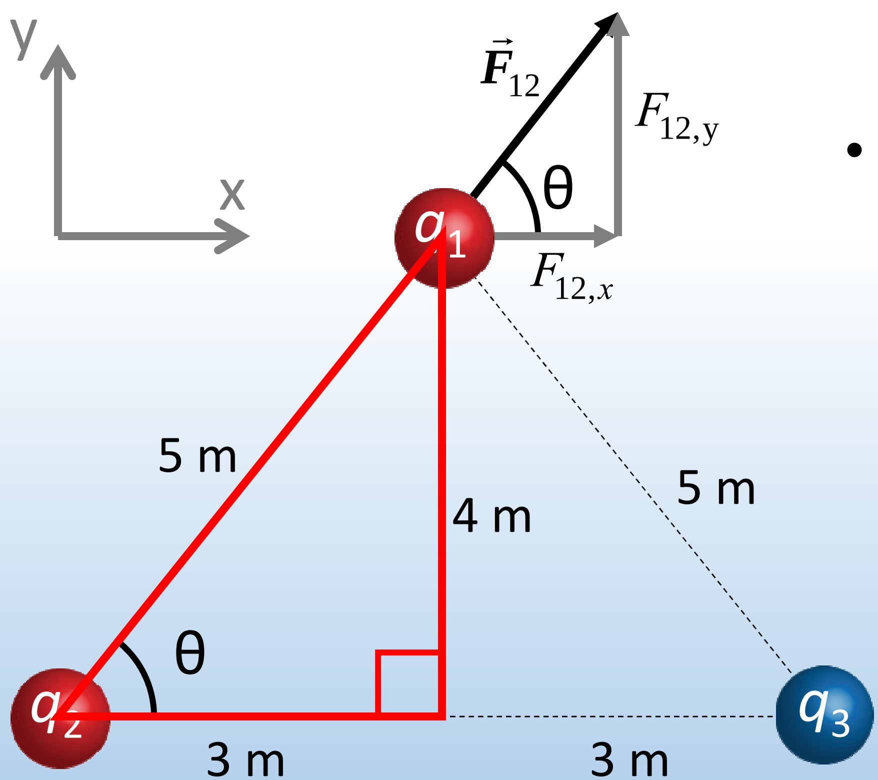
ACT: components

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

$$F_{12,x} = F_{12}\cos\theta = F_{12}\frac{3}{5} = 3.0\times10^{-3}\,N$$

$$F_{12,y} = F_{12}\sin\theta = F_{12}\frac{4}{5} = 4.0\times10^{-3}\,N$$

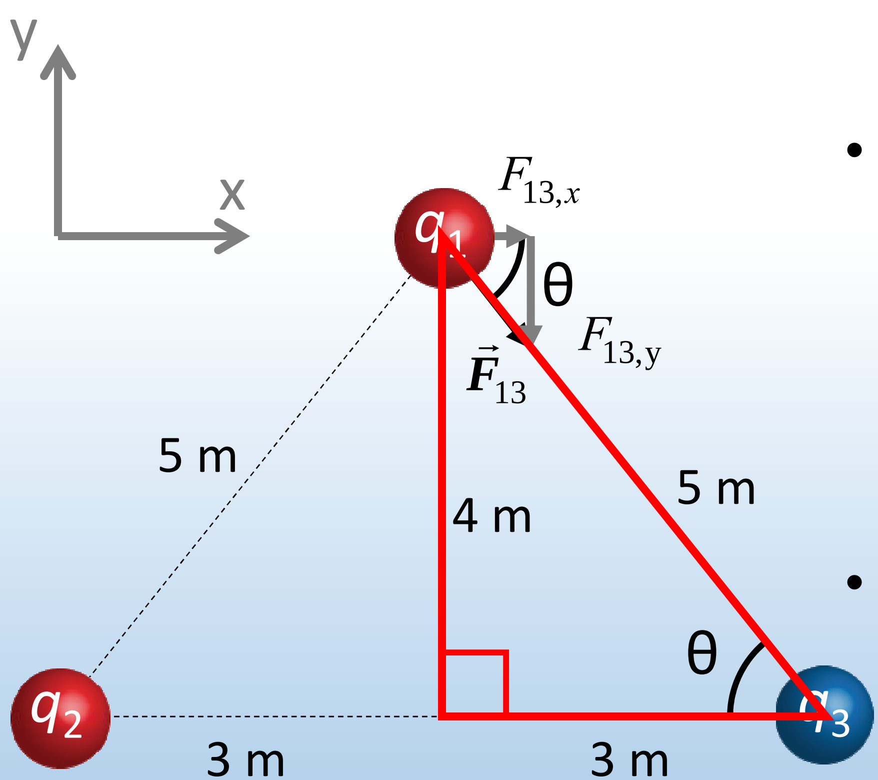
ACT: components

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

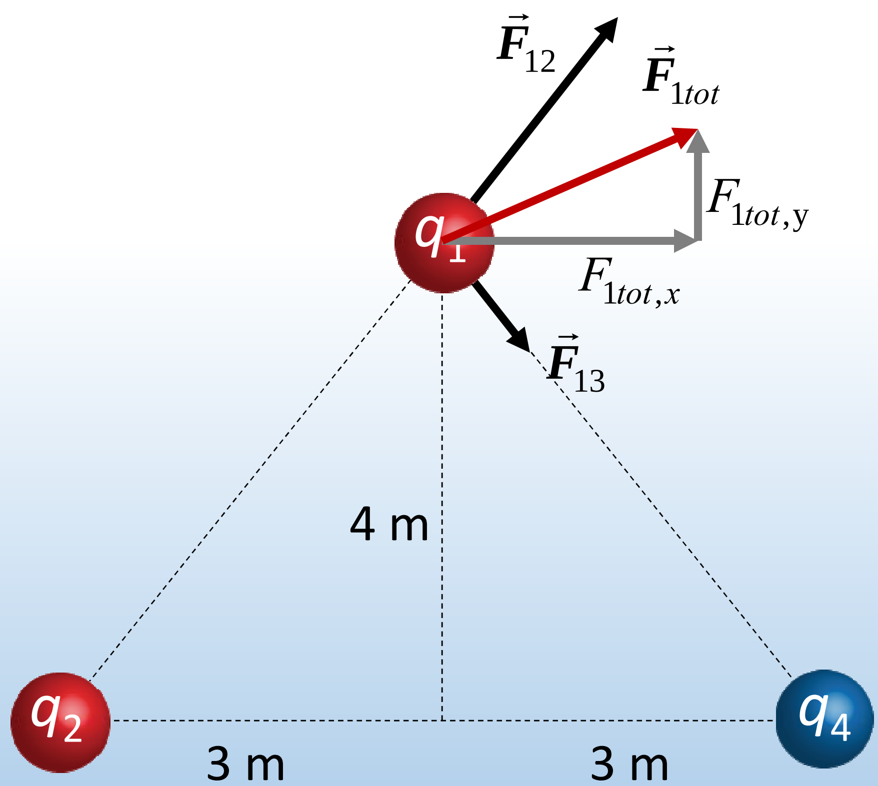
$$F_{13,x} = F_{13}\cos\theta = F_{13}\frac{3}{5} = 1.5\times10^{-3}\,\mathrm{N}$$

$$F_{13,y} = -F_{13}\sin\theta = -F_{13}\frac{4}{5} = -2.0\times10^{-3}\,\mathrm{N}$$

- Note: components can be positive *or* negative

Calculation: four charges

Calculate the total force on charge q_1 = +2 μC due to charges q_2 = +7 μC and q_3 = –3.5 μC



- Add like components

$$F_{12,x} = 3\times10^{-3}\,\text{N} \qquad F_{12,y} = 4\times10^{-3}\,\text{N}$$

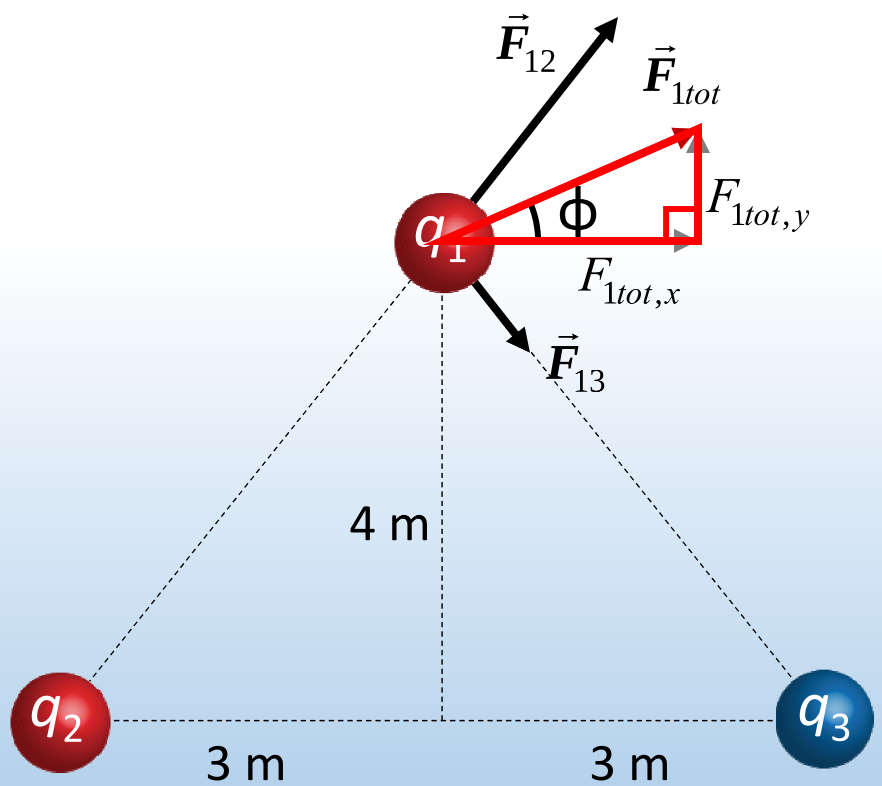
$$F_{13,x} = 1.5\times10^{-3}\,\text{N} \qquad F_{13,y} = -2\times10^{-3}\,\text{N}$$

$$F_{1tot,x} = 4.5\times10^{-3}\,\text{N} \qquad F_{1tot,y} = 2\times10^{-3}\,\text{N}$$

✓ Compare to drawing

Calculation: four charges

Calculate the total force on charge q_1 = +2 μC due to charges q_2 = +7 μC and q_3 = –3.5 μC



- Magnitude of total force

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

- Direction of total force

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

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.

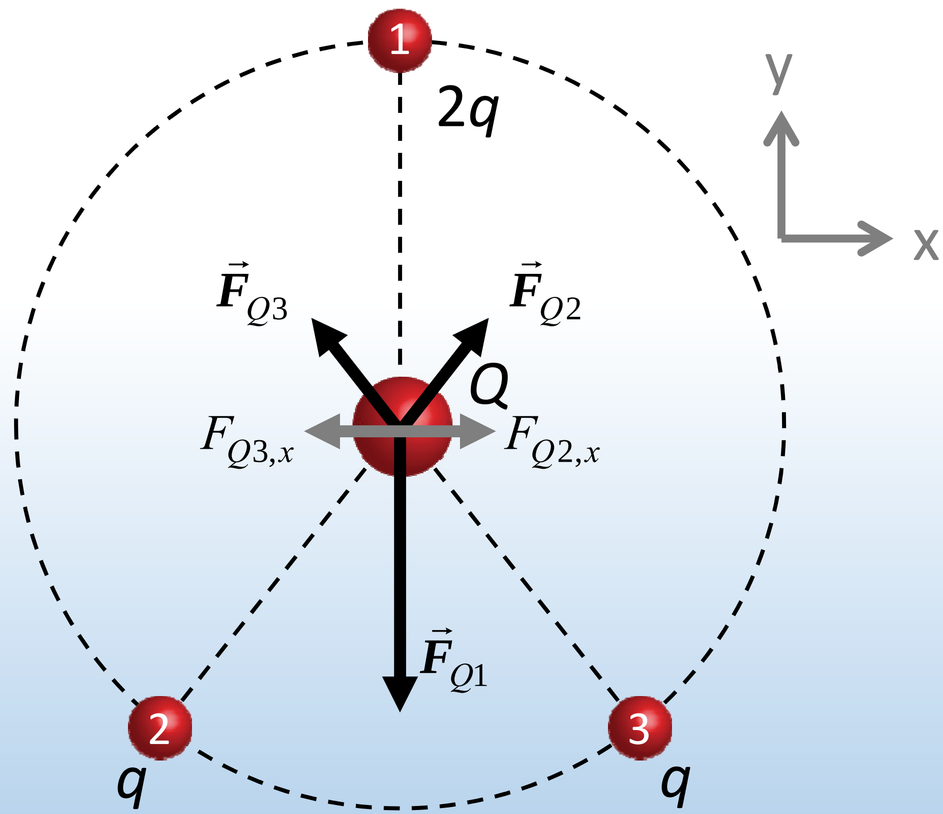
What is the x-component of the total force on Q?

A. $F_x > 0$ 10%

B. $F_x = 0$ 87%

C. $F_x < 0$ 3%

All x-components cancel by symmetry



ACT: CheckPoint 1.2

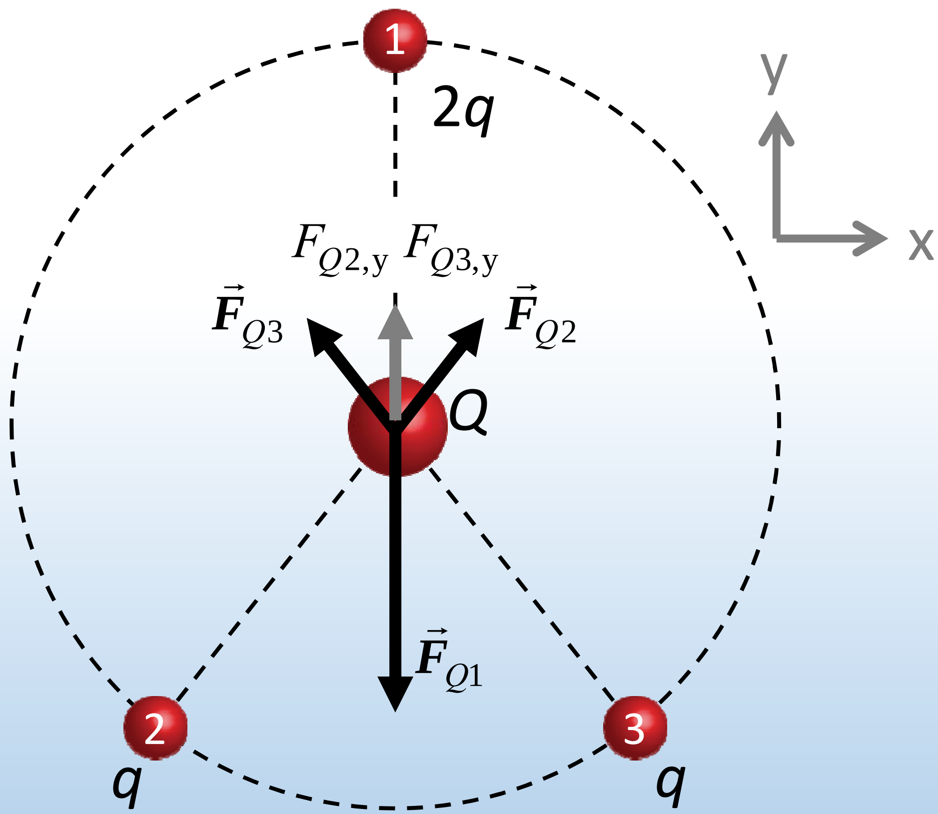
Consider three charges on a circular ring, $q_1 = +2q$, $q_2 = q_3 = +q$. A charge $+Q$ is placed at the center of the circle.

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

A. $F_y > 0$ 26%

B. $F_y = 0$ 36%

C. $F_y < 0$ 38%



Compare magnitudes:

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

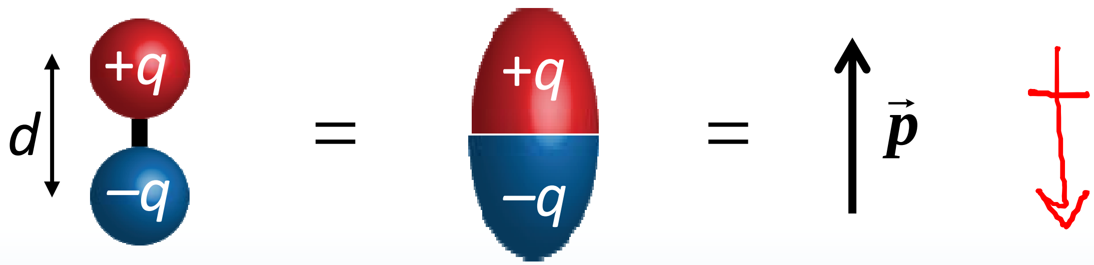
Compare y-components:

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

Electric dipole & dipole moment

A positive and negative charge of equal magnitude *q* separated by a (usually small) distance *d*

fixed



<u>*Dipole moment*</u> is measure of separated + and – charges

Magnitude

$$p \equiv qd$$

definition

Direction

From – to + charge (by convention)

Note: opposite from Lewis notation (Chemistry)

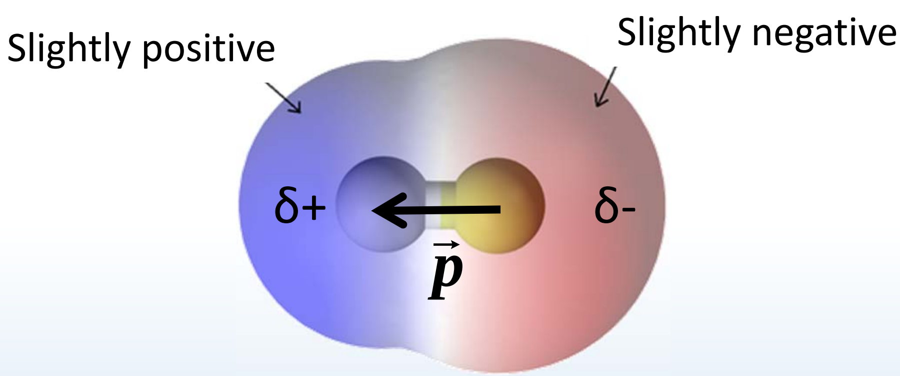
What are examples of electric dipoles?

Molecular dipole

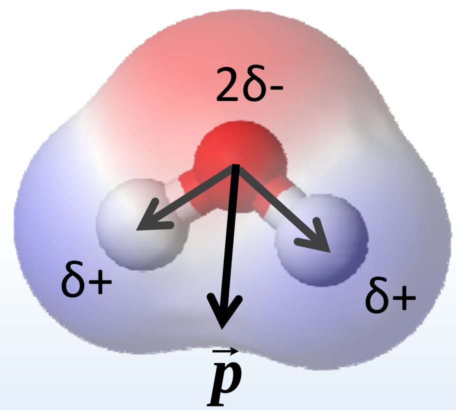
Electrons are not shared equally between chemically bonded atoms

Charge imbalance creates a *bond dipole*

Ex: HF (hydrofluoric acid)



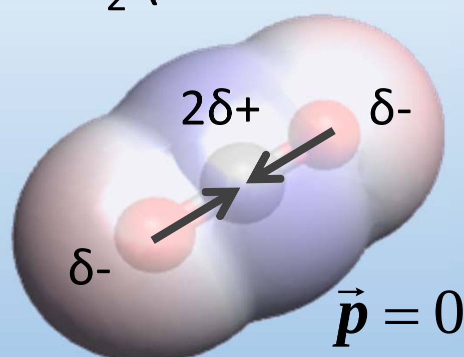
Ex: H_20 (water)



Polar

$p_{tot} > 0$

Ex: CO_2 (carbon dioxide)



Nonpolar

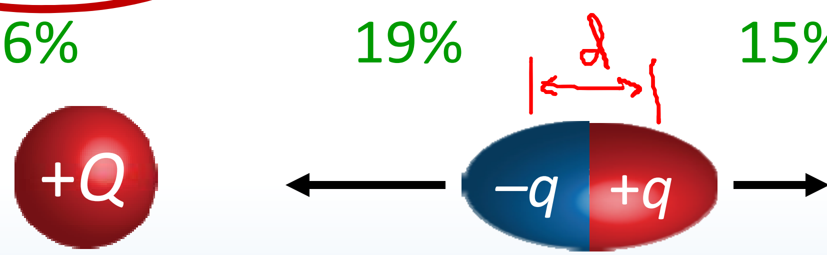
$p_{tot} = 0$

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 B. Zero C. Right

66% 19% 15%



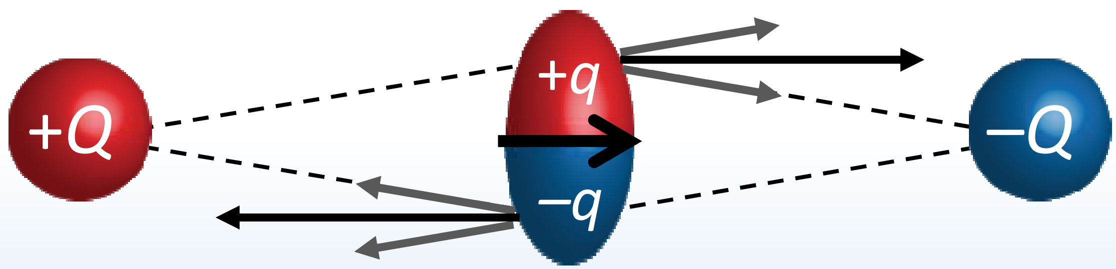
1. +*q* is repelled (force to right)
2. −*q* is attracted (force to left)
3. −*q* is closer to +*Q* so force to left is larger

"...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…

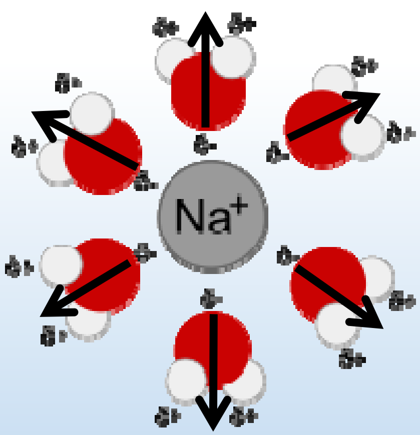
Total torque > 0!
Dipole spins!

Ion-dipole interactions

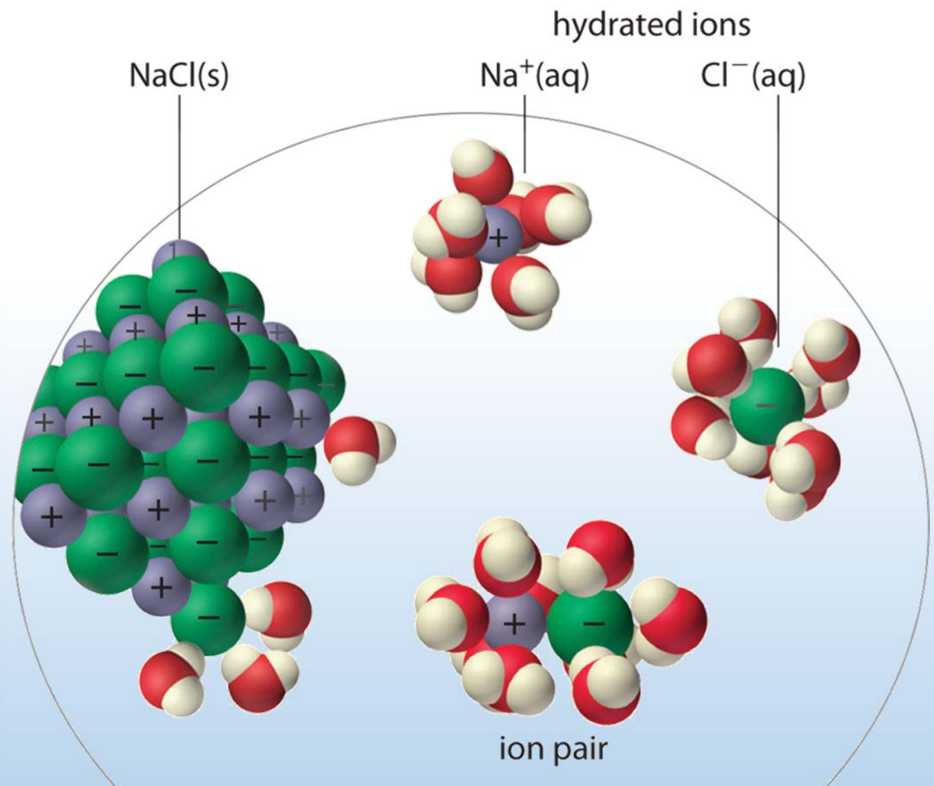
Polar molecules are attracted to ions

Dipole moment aligns away from + charge, toward – charge

Ex: ions in water & solubility



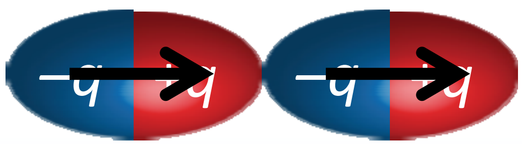
"Hydration shell"



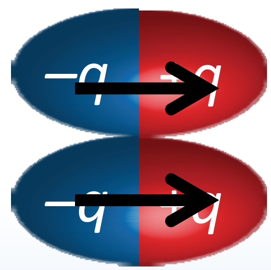
Ionic compounds (ex: salts) dissolve in water

ACT: Two dipoles

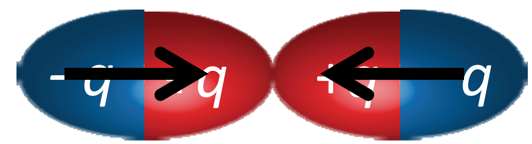
Which of the following arrangement of two dipoles leads to a net attractive force between the two?



A.



B.

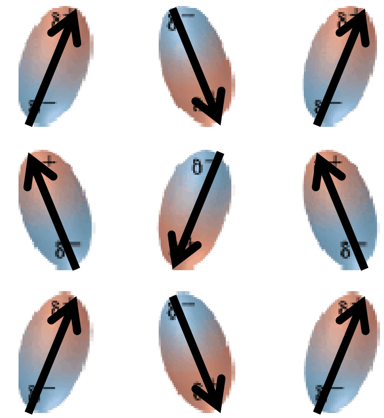


C.

D. Dipoles are neutral, they cannot attract or repel

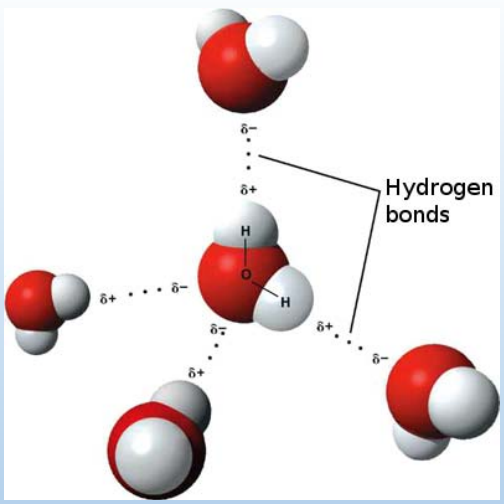
Dipole-dipole interactions

Polar molecules interact together

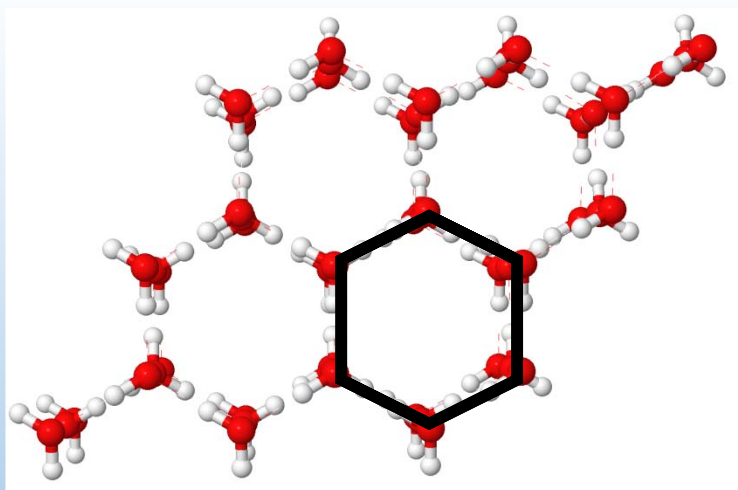


Dipole moments align end-to-end + to –
Like magnets!

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



Hydrogen bond



Structure of ice

Snowflake

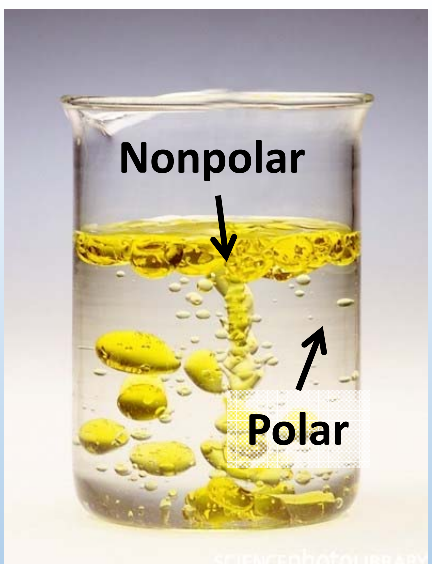
Hydrophilic vs. hydrophobic

Polar molecules interact with charged & polar molecules

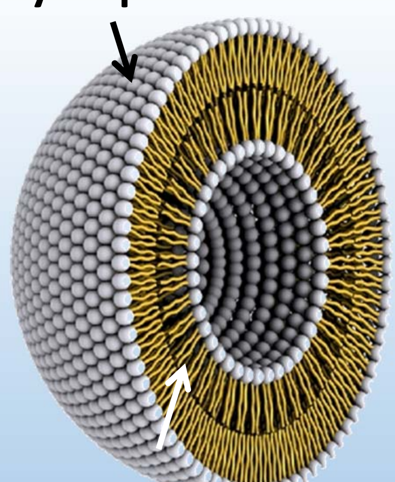
Ex: charged & polar molecules attract water, nonpolar molecules do not

Hydrophilic — Hydrophobic

"attract water" — "repel water"



Oil and water



Cell membranes

Protein structure

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* -> *induced dipole* vs permanent
3. As in previous ACT, net attractive force

DEMO

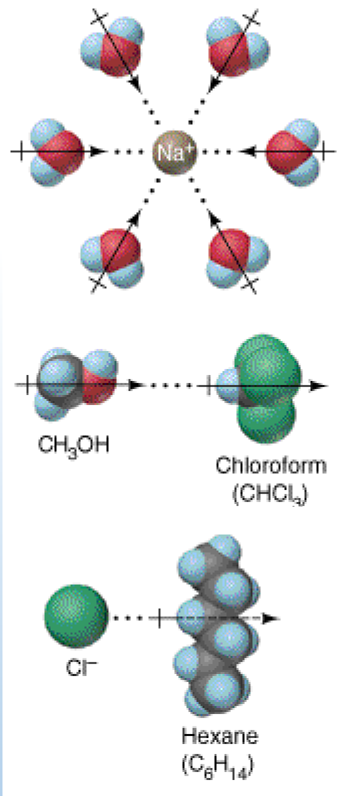
Molecular interactions

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

Ion-dipole

Dipole-dipole

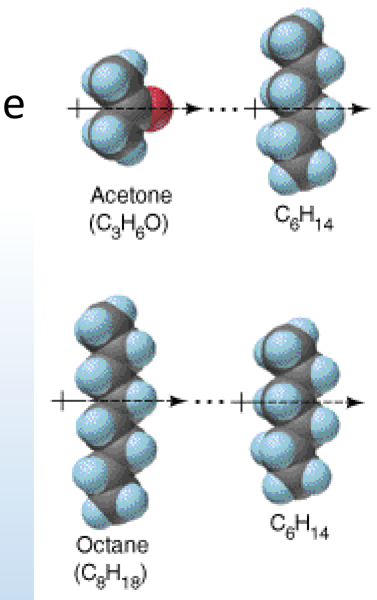
Ion-induced dipole



"Induced dipoles are hard to imagine within a biological system..."

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