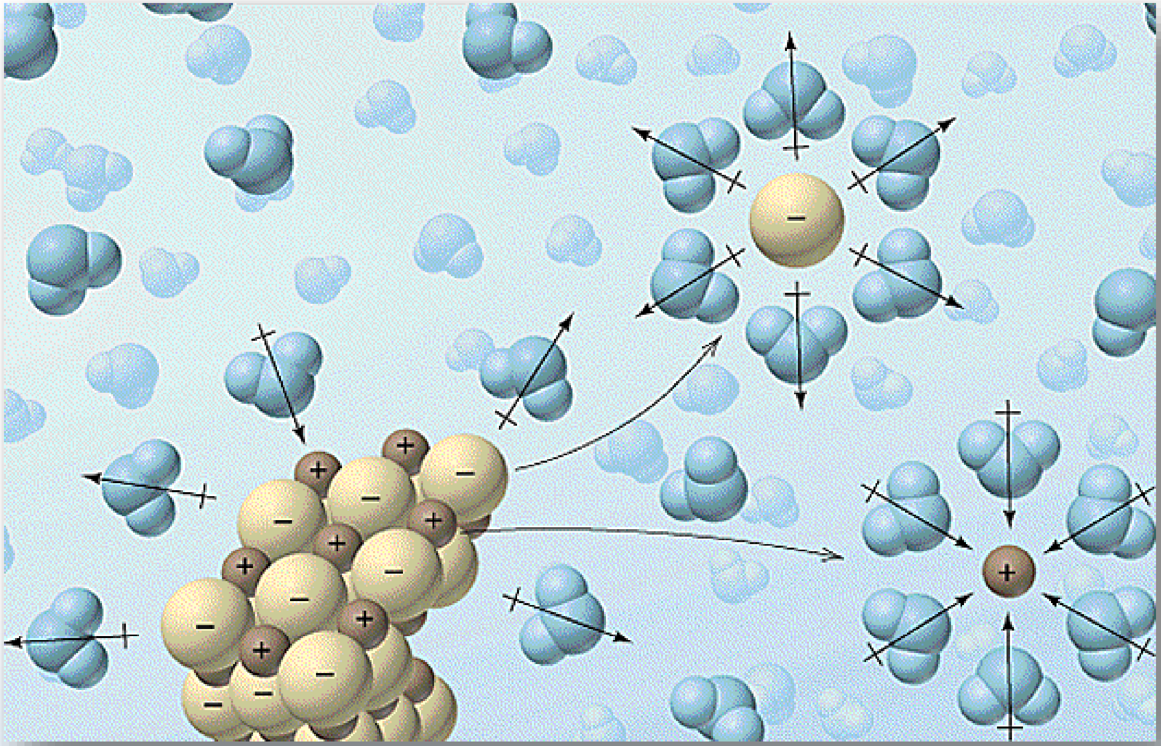


Phys 102 – Lecture 2

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

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

"Force on q_1 due to q_2"

"Coulomb constant"

$k = 9\times10^9 \ \mathrm{N\cdot m^2/C^2}$

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

"Permittivity of free space"

$\varepsilon_0 = 8.85\times10^{-12} \ \mathrm{C^2/N\cdot m^2}$

Direction

Opposite charges attract, like charges repel

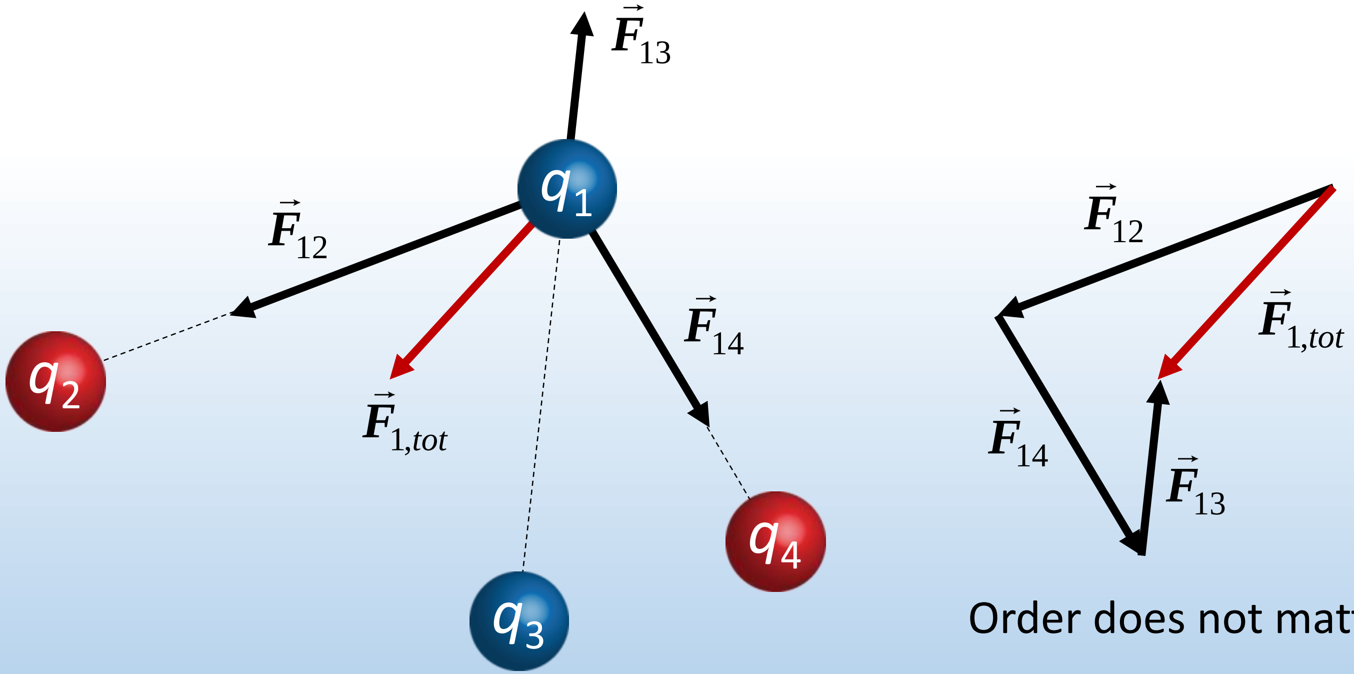
$$\vec{\boldsymbol{F}}_{12} = -\vec{\boldsymbol{F}}_{21}$$

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?

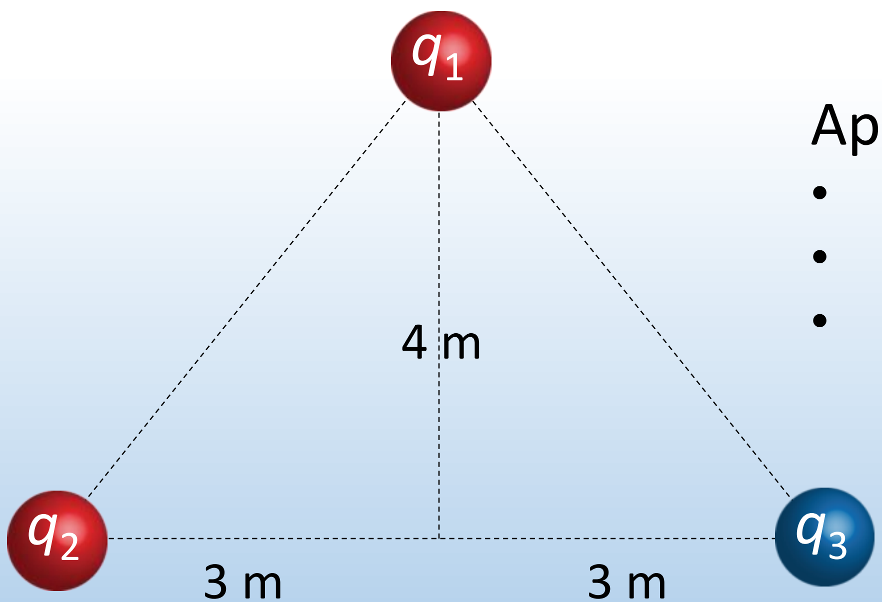


Order does not matter!

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

Calculation: four charges

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



Fundamental concept: Superposition

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

Approach:

- Draw forces
- Calculate magnitudes of forces
- Add vectors

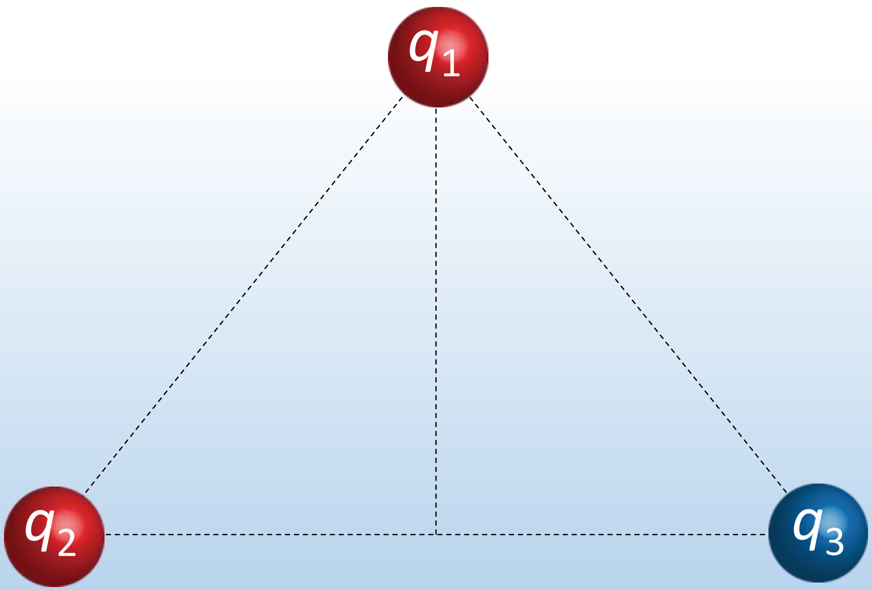
  Decompose into *x*-, *y*-components
  Add like components

$$\underbrace{\hphantom{\text{Decompose into x-, y-components}}}_{\text{May need geometry, trigonometry}}$$

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 $q_3 = -3.5\ \mu C$?



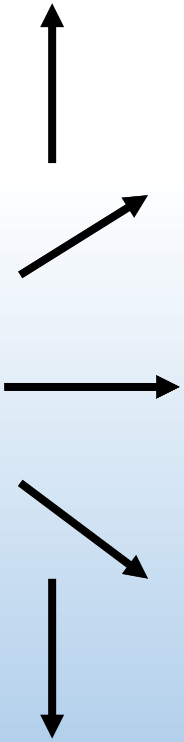
A.

B.

C.

D.

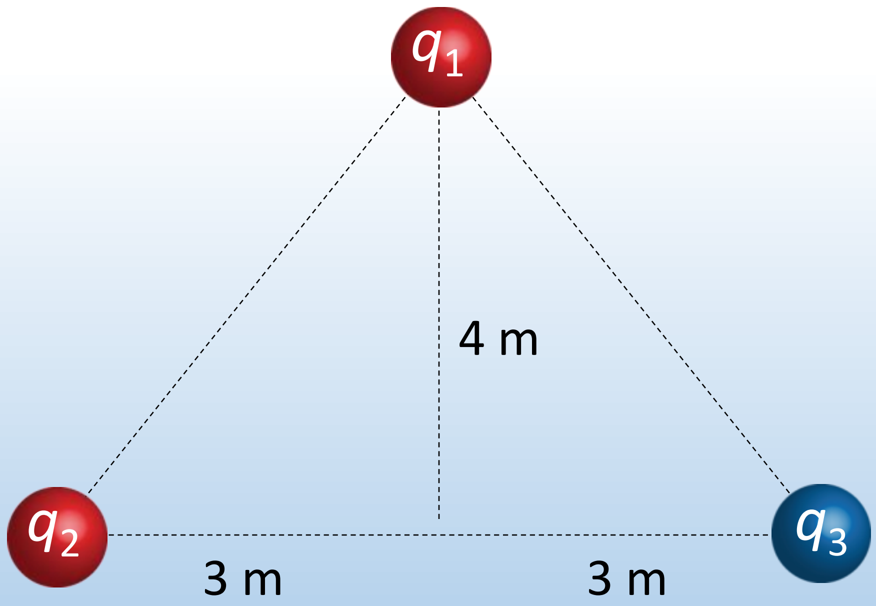
E.



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



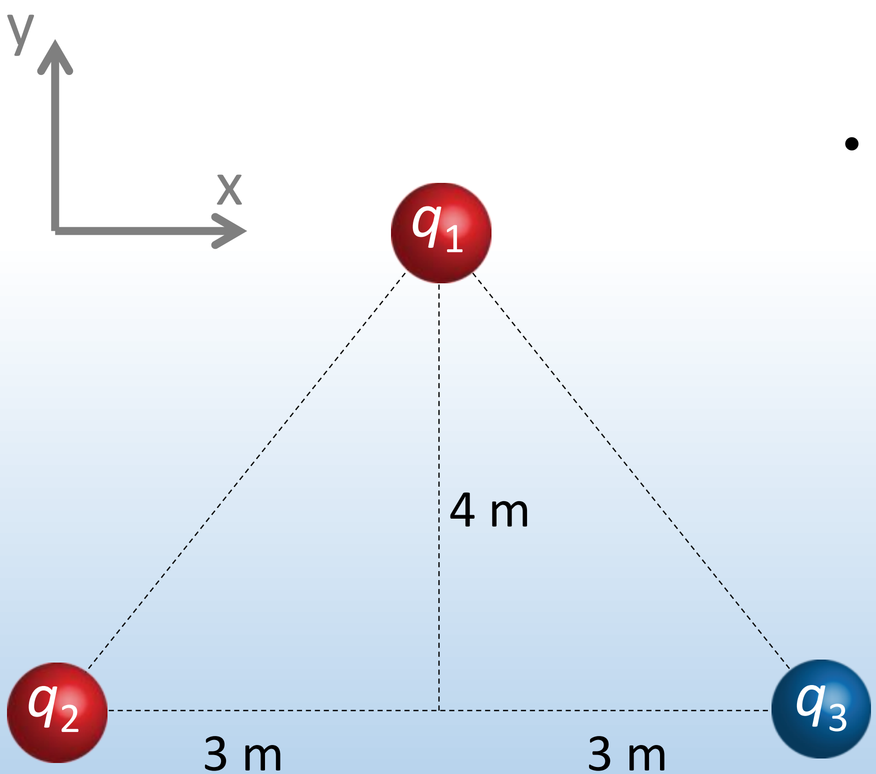
ACT: components

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

A. $3/4\ F_{12}$

B. $3/5\ F_{12}$

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

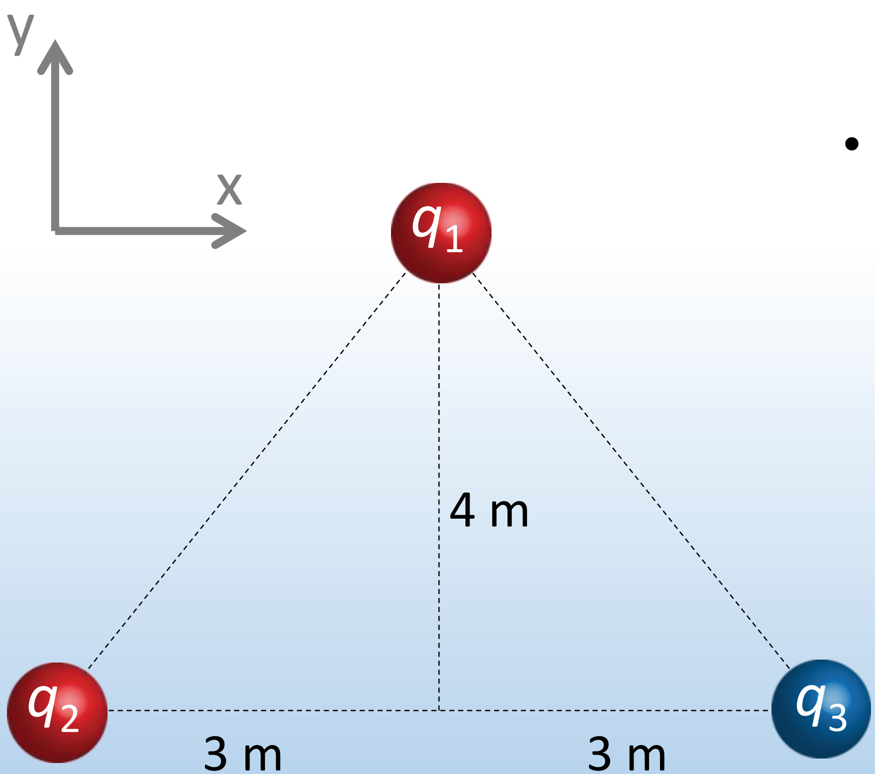


- Decompose vectors into components

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

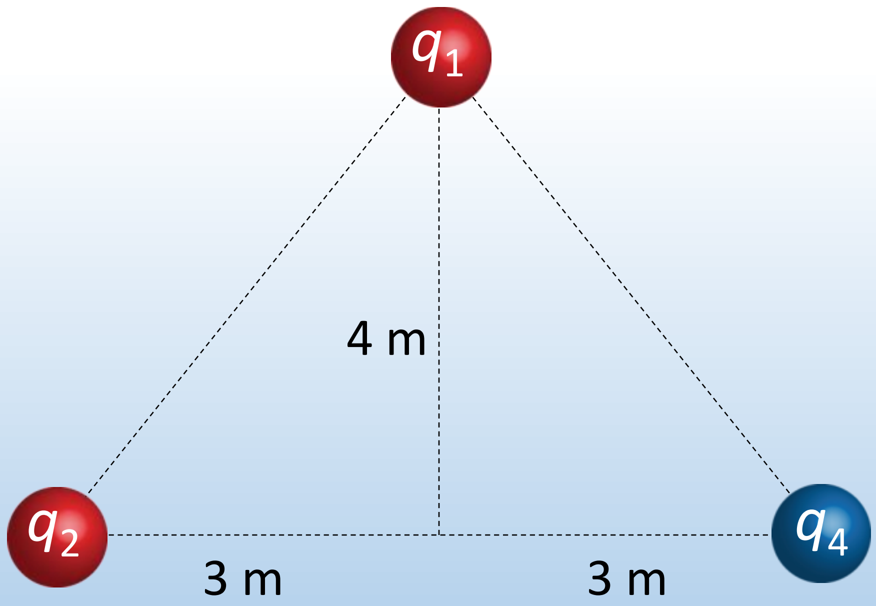


- Decompose vectors into components

Calculation: four charges

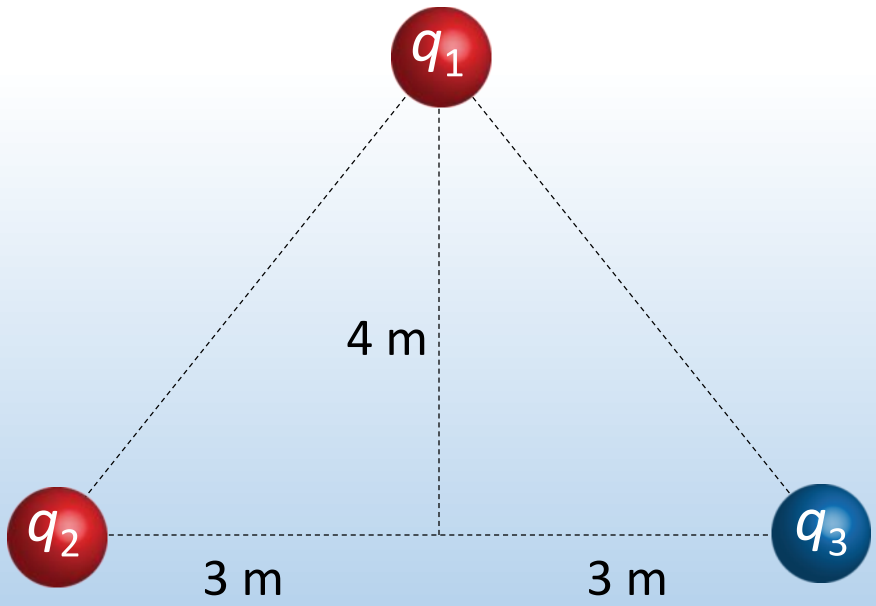
Calculate the total force on charge q_1 = +2 μC due to charges q_2 = +7 μC and q_3 = –3.5 μC

- Add like components



Calculation: four charges

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



- Magnitude of total force
- Direction of total force

ACT: CheckPoint 1.1

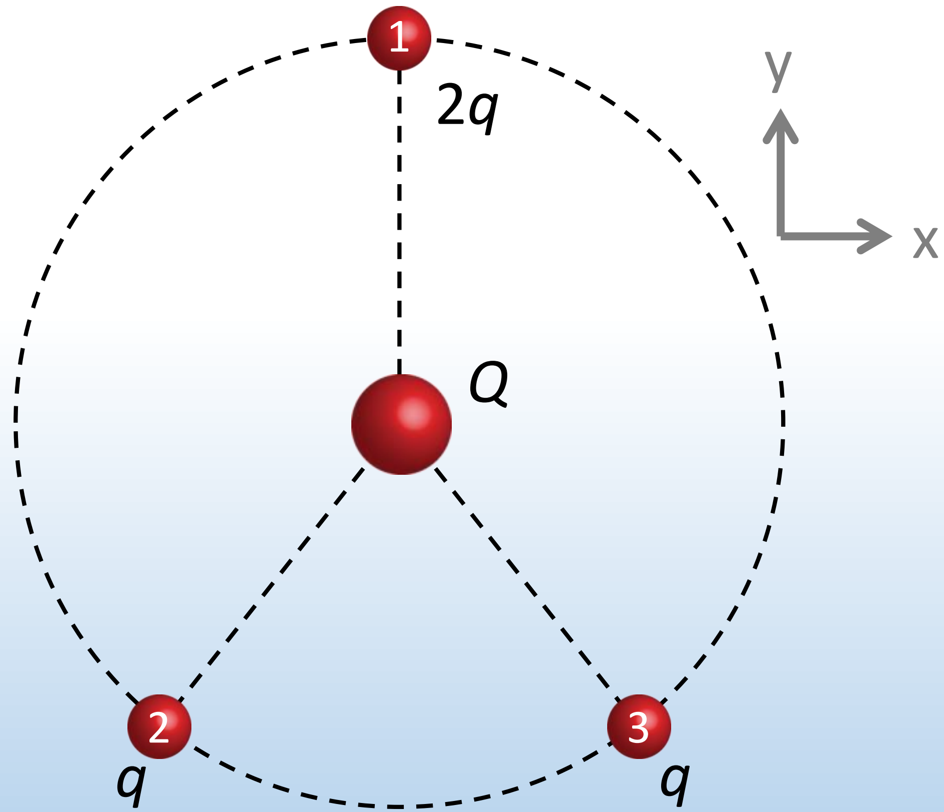
Consider three charges on a circular ring, $q_1 = +2q$, $q_2 = q_3 = +q$. A charge $+Q$ is placed at the center of the circle.

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

A. $F_x > 0$

B. $F_x = 0$

C. $F_x < 0$



ACT: CheckPoint 1.2

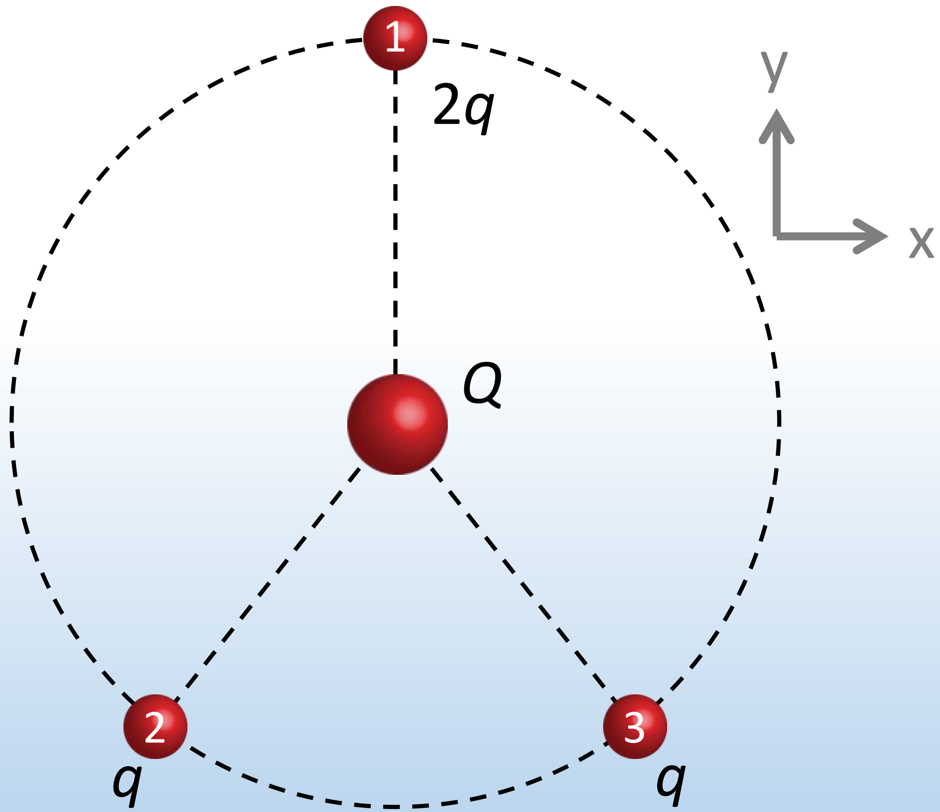
Consider three charges on a circular ring, $q_1 = +2q$, $q_2 = q_3 = +q$. A charge $+Q$ is placed at the center of the circle.

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

A. $F_y > 0$

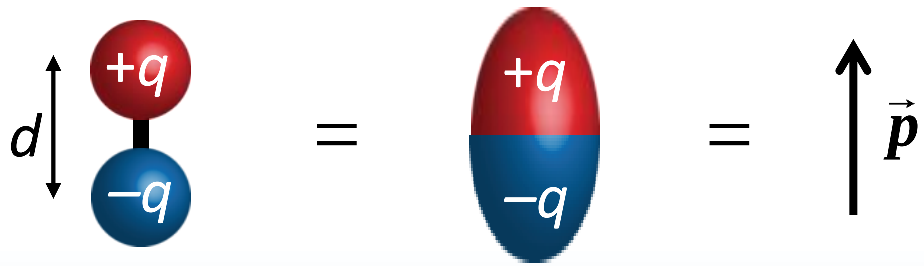
B. $F_y = 0$

C. $F_y < 0$



Electric dipole & dipole moment

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



<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

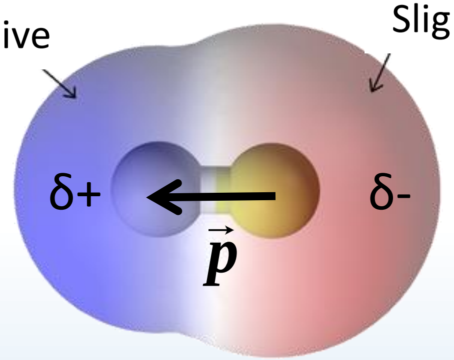
Electrons are not shared equally between chemically bonded atoms

Charge imbalance creates a ***bond dipole***

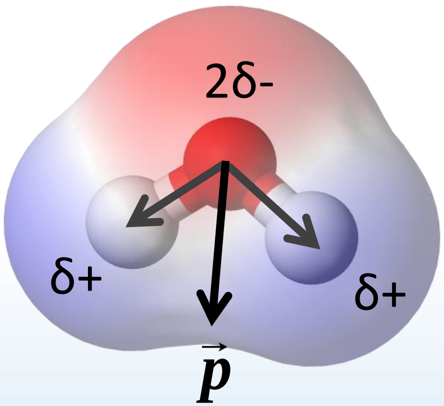
Ex: HF (hydrofluoric acid)

Slightly positive

Slightly negative



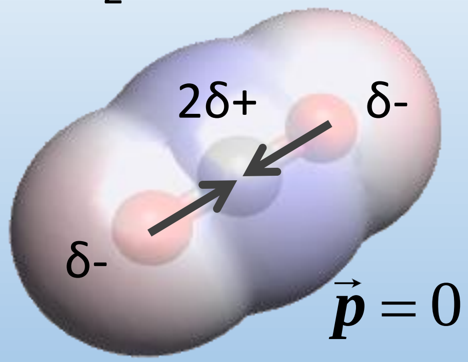
Ex: H_2O (water)



Polar

$p_{tot} > 0$

Ex: CO_2 (carbon dioxide)



Nonpolar

$p_{tot} = 0$

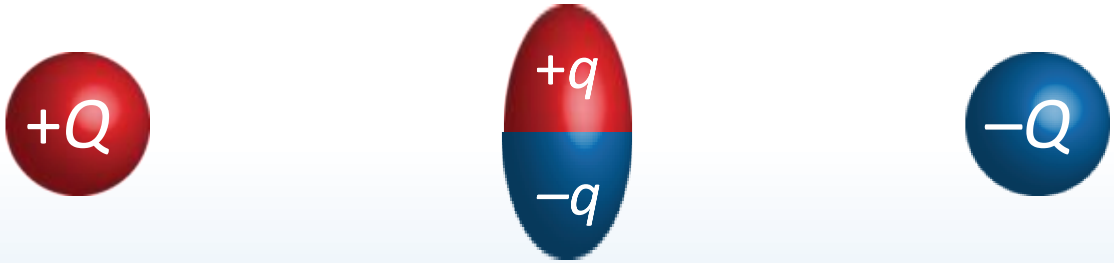
ACT: CheckPoint 2.1

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

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

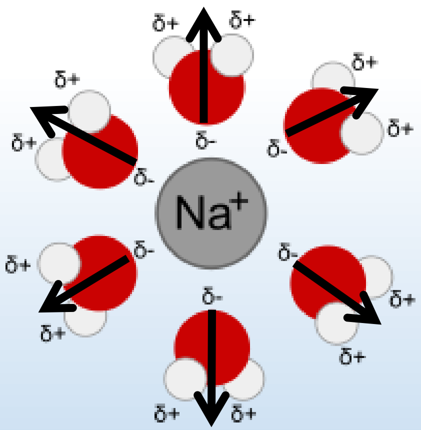
B. No

Ion-dipole interactions

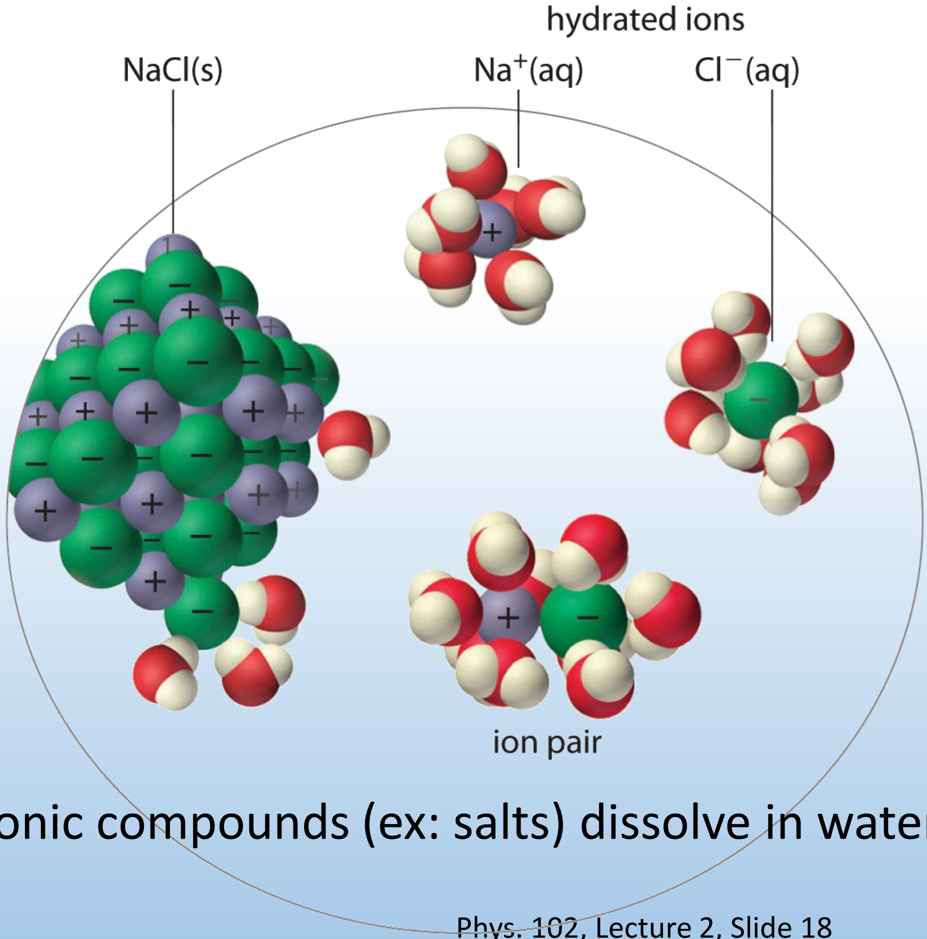
Polar molecules are attracted to ions

Dipole moment aligns away from + charge, toward – charge

Ex: ions in water & solubility



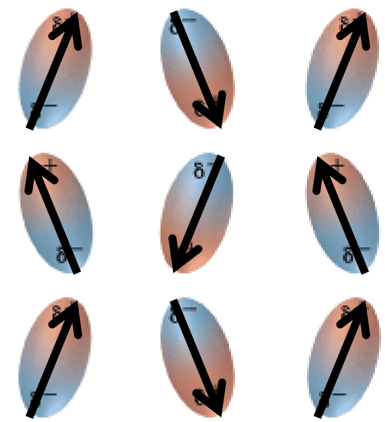
“Hydration shell”



Ionic compounds (ex: salts) dissolve in water

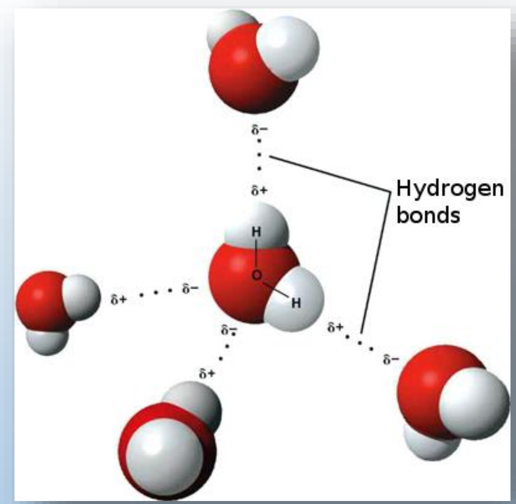
Dipole-dipole interactions

Polar molecules interact together

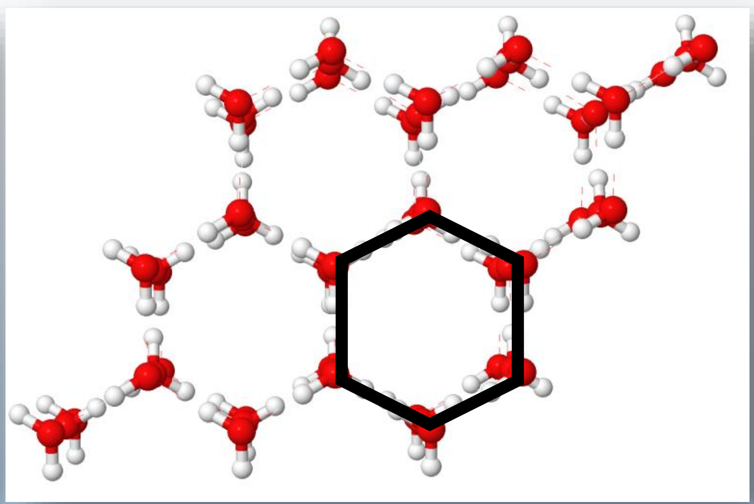


Dipole moments align end-to-end + to –
Like magnets!

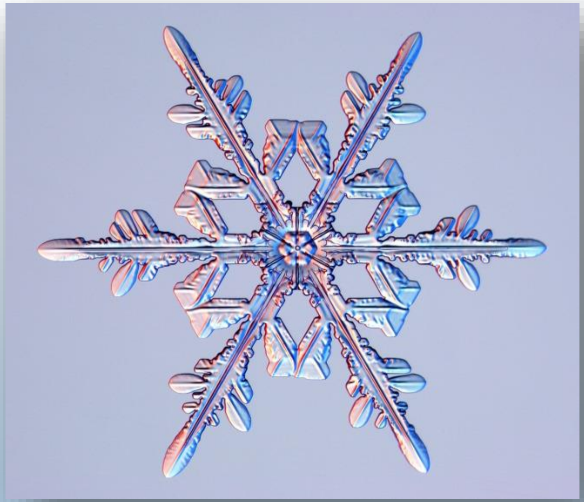
Ex: hydrogen bond is a dipole-dipole interaction between water molecules



Hydrogen bond



Structure of ice



Snowflake

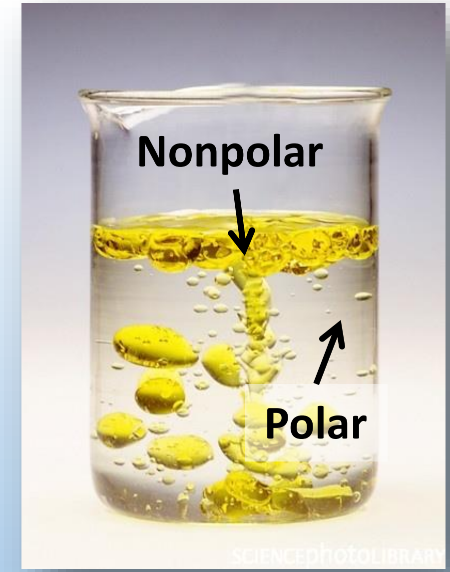
Hydrophilic vs. hydrophobic

Polar molecules interact with charged & polar molecules

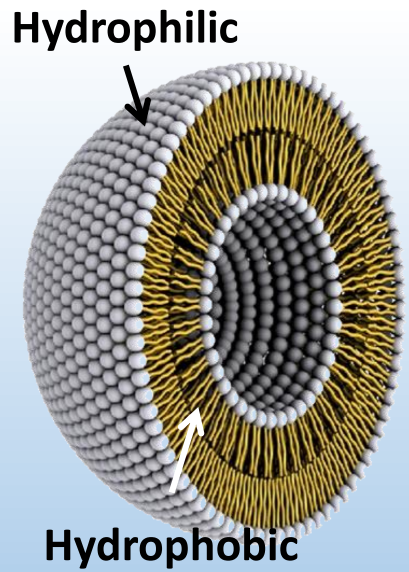
Ex: charged & polar molecules attract water, nonpolar molecules do not

Hydrophilic | Hydrophobic

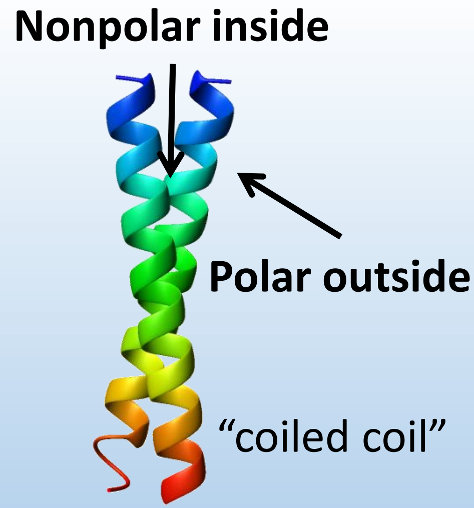
"attract water" | "repel water"



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?

DEMO

A. Nothing

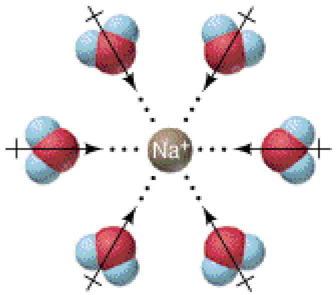
B. Attracted to + sphere

C. Repelled from + sphere

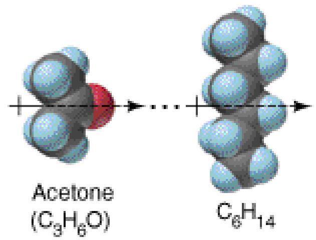
Molecular interactions

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

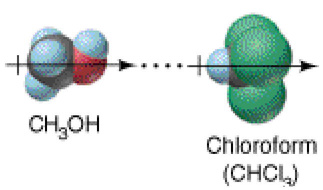
Ion-dipole



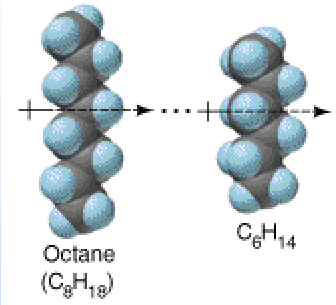
Dipole-induced dipole



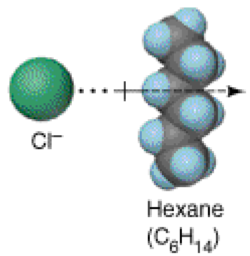
Dipole-dipole



Induced dipole-induced dipole?



Ion-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