Welcome to Chemistry 154!

Please make sure to sync your iClicker Cloud to Chem154 Section 113

Reminders

- **Worksheet: Unit 4**
- Due Oct. 9th at 11:59pm

- **Achieve Assignment #4**
- Due Oct. 9th at 11:59pm

- Watch Chapter 4 helpful videos on All Lectures site

Instructor Office Hours
Monday and Friday 7-8pm via Zoom (All Lectures Site)

PhET – VSEPR

https://phet.colorado.edu/en/simulation/molecule-shapes

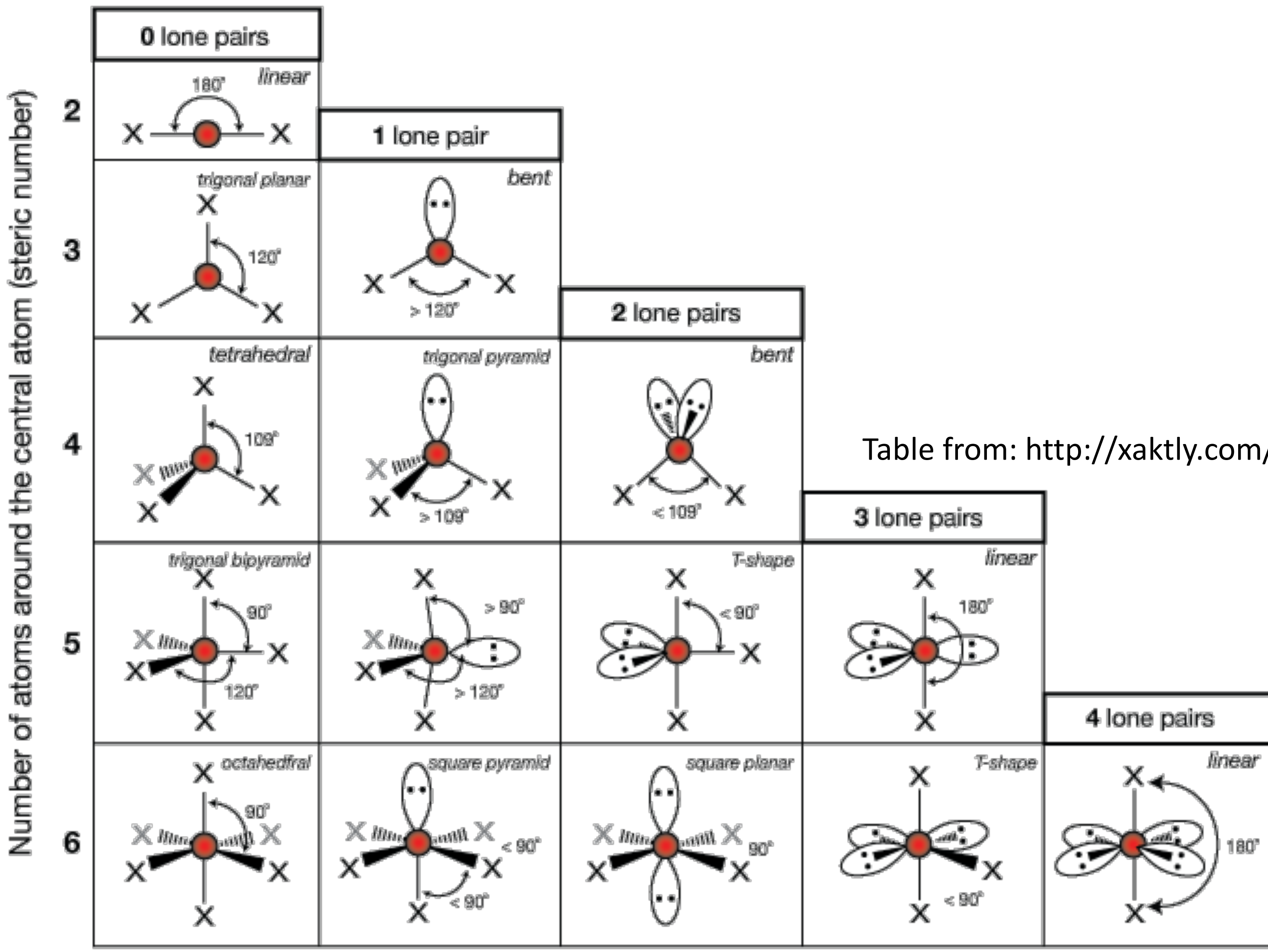


Table from: http://xaktly.com/VSEPR.html

Electron repulsion

Determining the number of 90° repulsions and their type can be used to rationalize the molecular shape adopted by a molecule.

LP – LP	Stronger repulsions
LP – BP	
BP – BP	Weaker repulsions

Worksheet Question #19

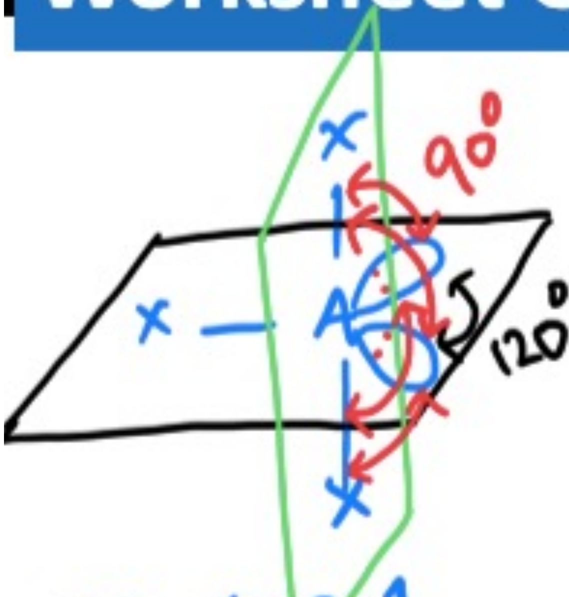
ClF_3 has a trigonal bipyramidal parent shape with two lone pairs on the central atom. As such, it can take have two possible molecular shapes: T-shape or trigonal planar (see below).

a) Determine the number of 90° LP-LP, LP-BP, and BP-BP interactions in each of these geometries. Write your answers in the table below.

b) Based on your answers to a., which molecular geometry is ClF_3 more likely to exhibit? Briefly explain your answer.

Click any answer on your clicker when you have finished this worksheet question!

Worksheet Question #19



Structure 1

Structure 2

Structure 3

A = Cl   X = F in these perspective diagrams

show wedges and dashes based on 3D structure

Repulsion at 90°	Structure 1	~~Structure 2~~	Structure 3
LP–LP	0	~~1~~	0
LP–BP	4	~~3~~	6
BP–BP	2	~~2~~	0

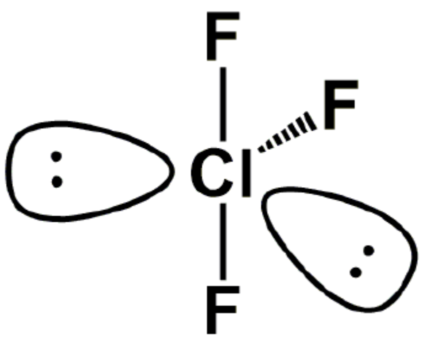
increasing strength

three options. which one minimizes repulsion?

- compare LP-LP first. Can't be structure 2.
- compare LP-BP next. structure 1 wins.

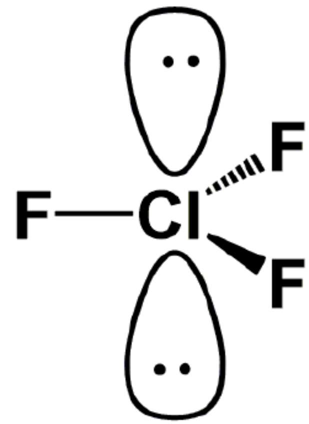
Worksheet Question #19 (b) CLICKER

…Based on your answers to a., which molecular geometry is ClF_3 more likely to exhibit? Briefly explain your answer.



T-shape

(A)

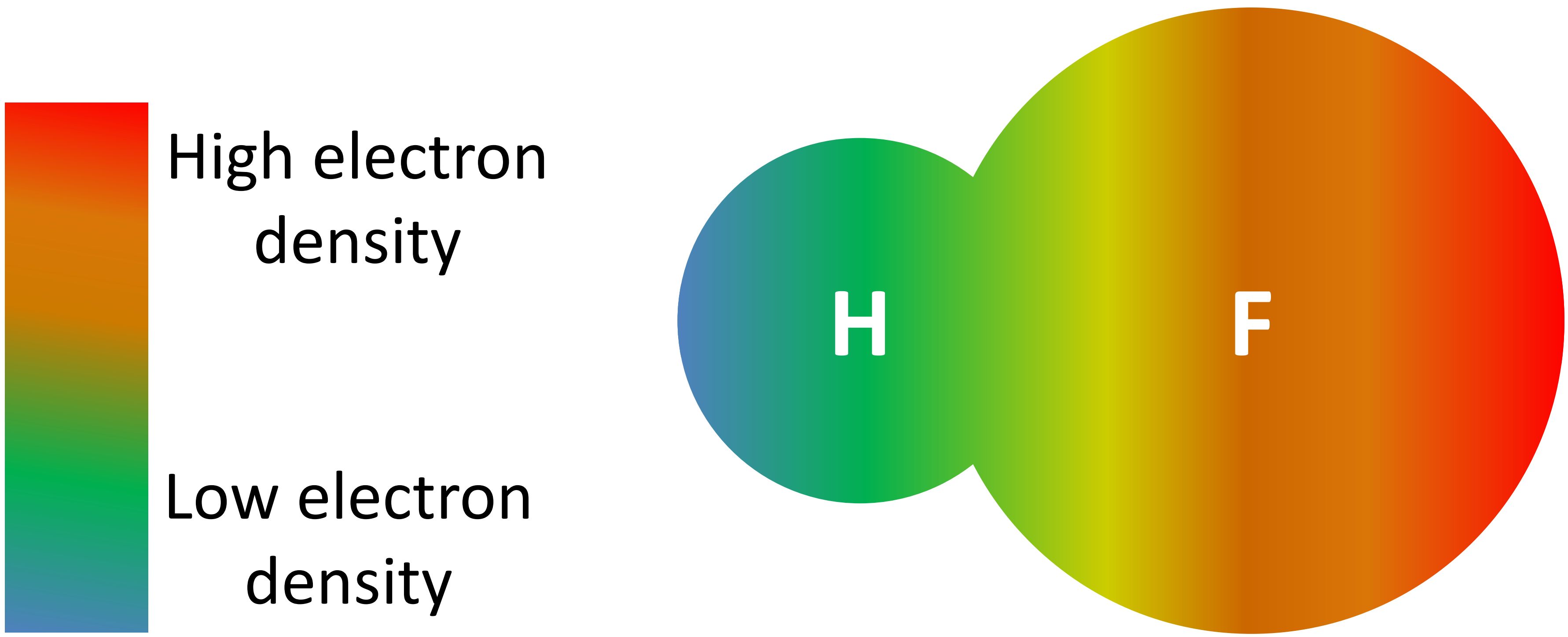


Trigonal planar

(B)

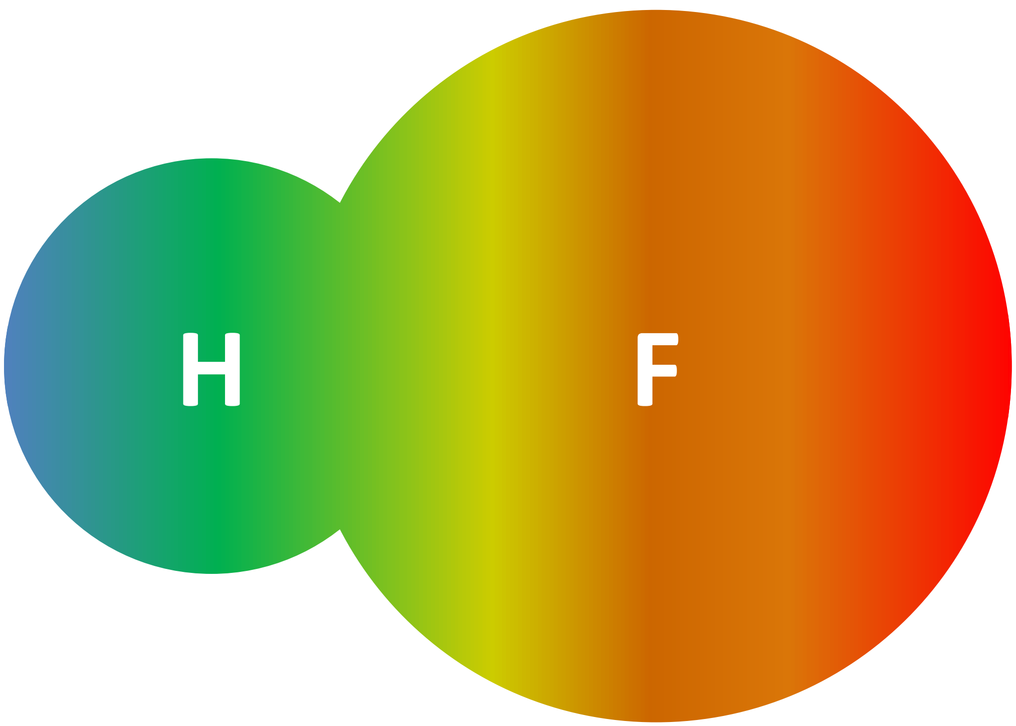
Bond Polarity

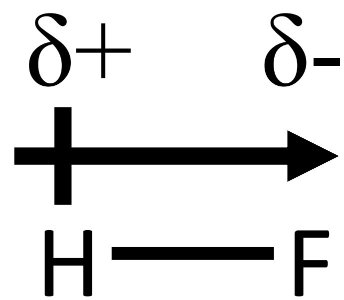
Because of differences in electronegativity, electrons are never equally distributed when two different atoms bond. This charge separation is known as a dipole. Bonds with a dipole are called **polar bonds**.



Representation of Bond Polarity

An arrow pointing towards the most electronegative atom is used to show bond polarity. The end of the arrow with the most electron density has the label δ- while the other end has the label δ+

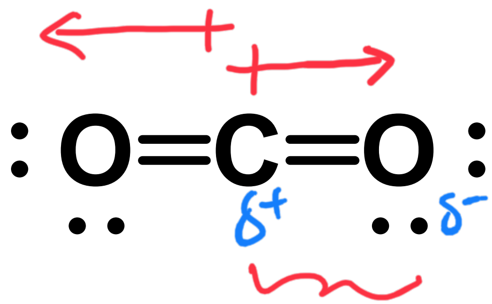




Molecular polarity

The polarity of a molecule depends on the three dimensional arrangement of atoms. For example, although the C=O bond is polar, the CO_2 molecule is non-polar.

perspective diagram



overall dipole moment = 0

non-polar.

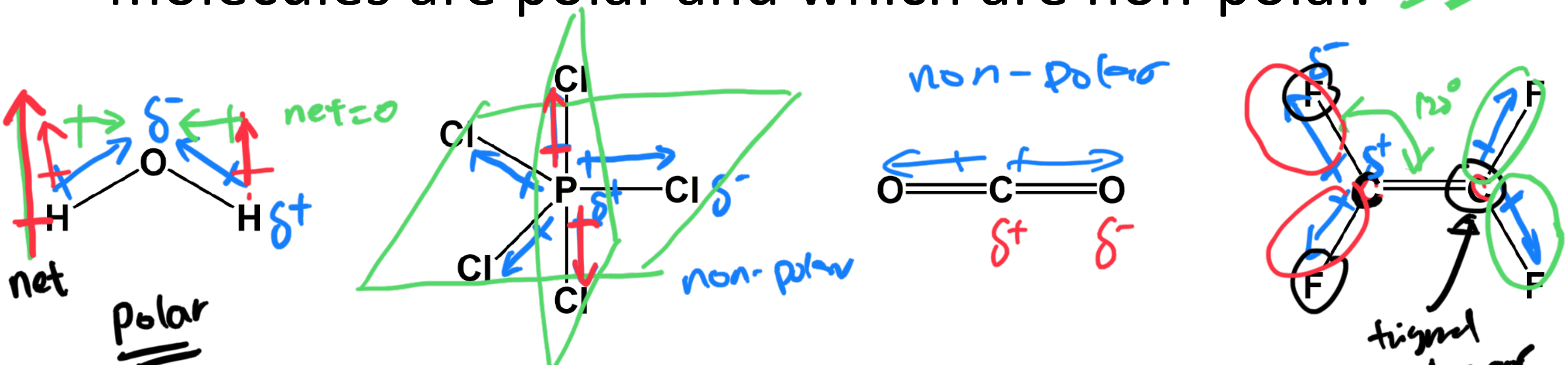
Determining molecular polarity

1. Draw the VSEPR molecular shape of the molecule
2. Draw arrows to show bond dipoles for each bond in a molecule
3. Do a vector addition for each dipole drawn
4. If the vector addition is zero, the molecule is non-polar. If the vector addition is non-zero, the molecule is polar

Worksheet Question #21

Add arrows to show bond dipoles for the following polar covalently bonded compounds. Add δ+ and δ- to the following structures. Lone pairs are NOT shown. Determine which molecules are polar and which are non-polar.

non-polar

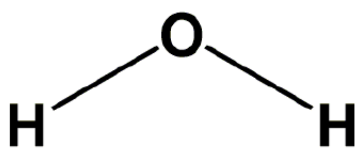


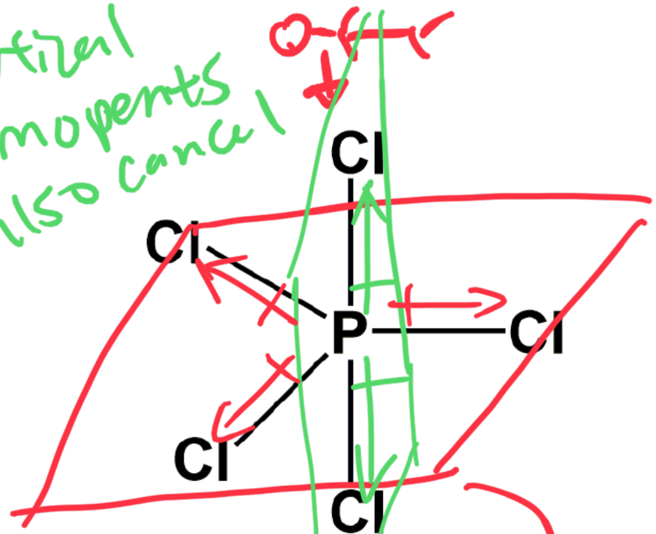
Click any answer on your clicker when you have finished this worksheet question!

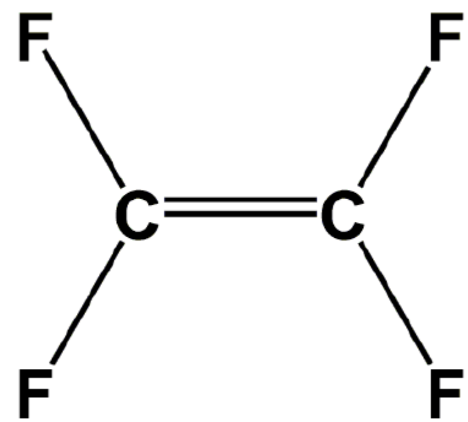
Worksheet Question #21 – Clicker Question

Which of the molecules in Question 21 are polar?

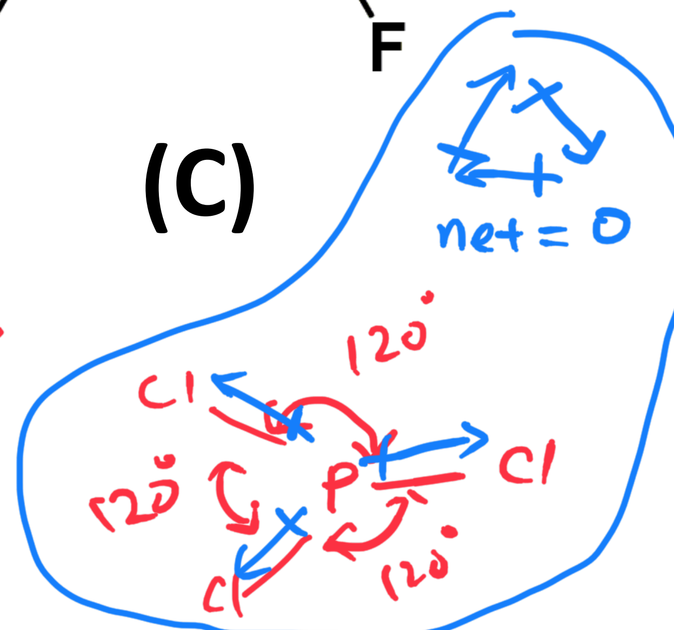
Vertical components also cancel







(A) (B) (C)

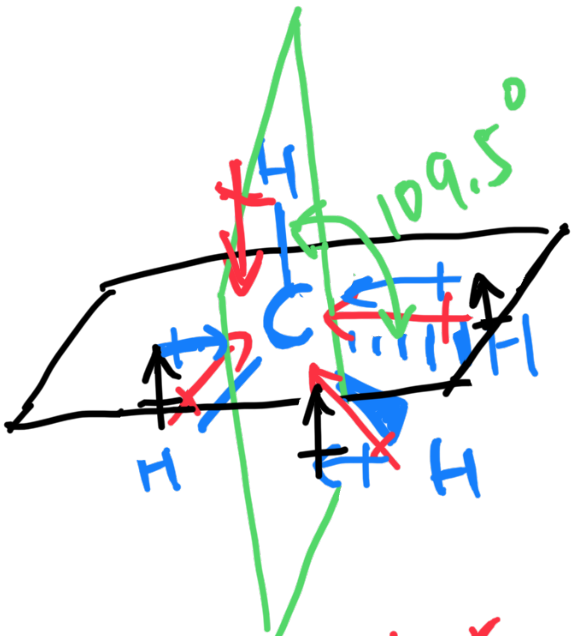


horizontal components

(D) Molecules A + B

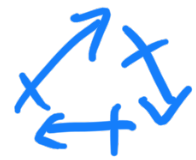
(E) Molecules A, B and C

[redacted]



non-polar

horizontal



net = 0

vertical

net = 0

overall dipole moment = 0

Unit 4
Intermolecular Interactions
&
Phases of Matter

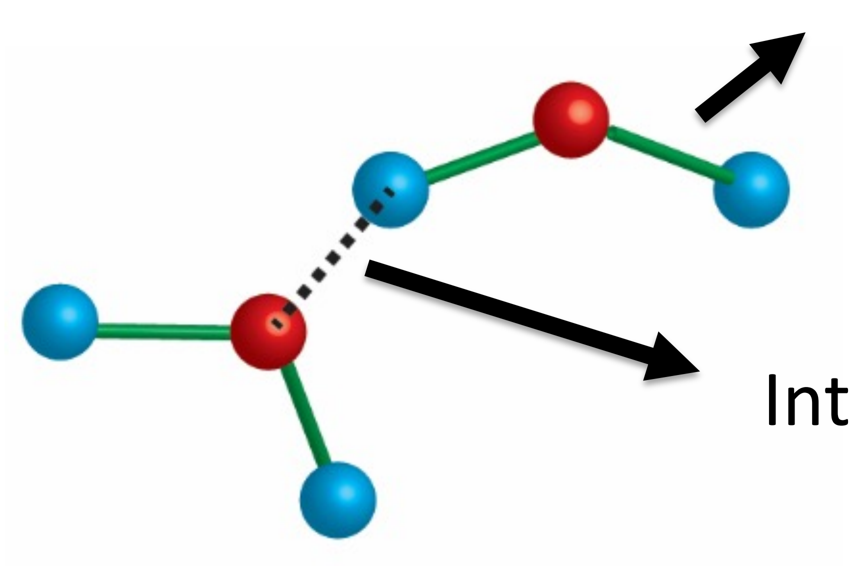
Learning Objectives

- Predict the types of intermolecular forces likely to be most important for a particular substance.
- Explain the relationships between intermolecular forces and properties such as melting point, boiling point, and vapor pressure.
- Analyze and interpret phase diagrams to obtain information about states of matter at different pressures and temperatures.
- Describe phase changes using appropriate terminology.
- Predict how changes in pressure and/or temperature will impact phase equilibria, or vice versa.

Chemical Bonds vs. Intermolecular Forces

Molecules built from strong forces

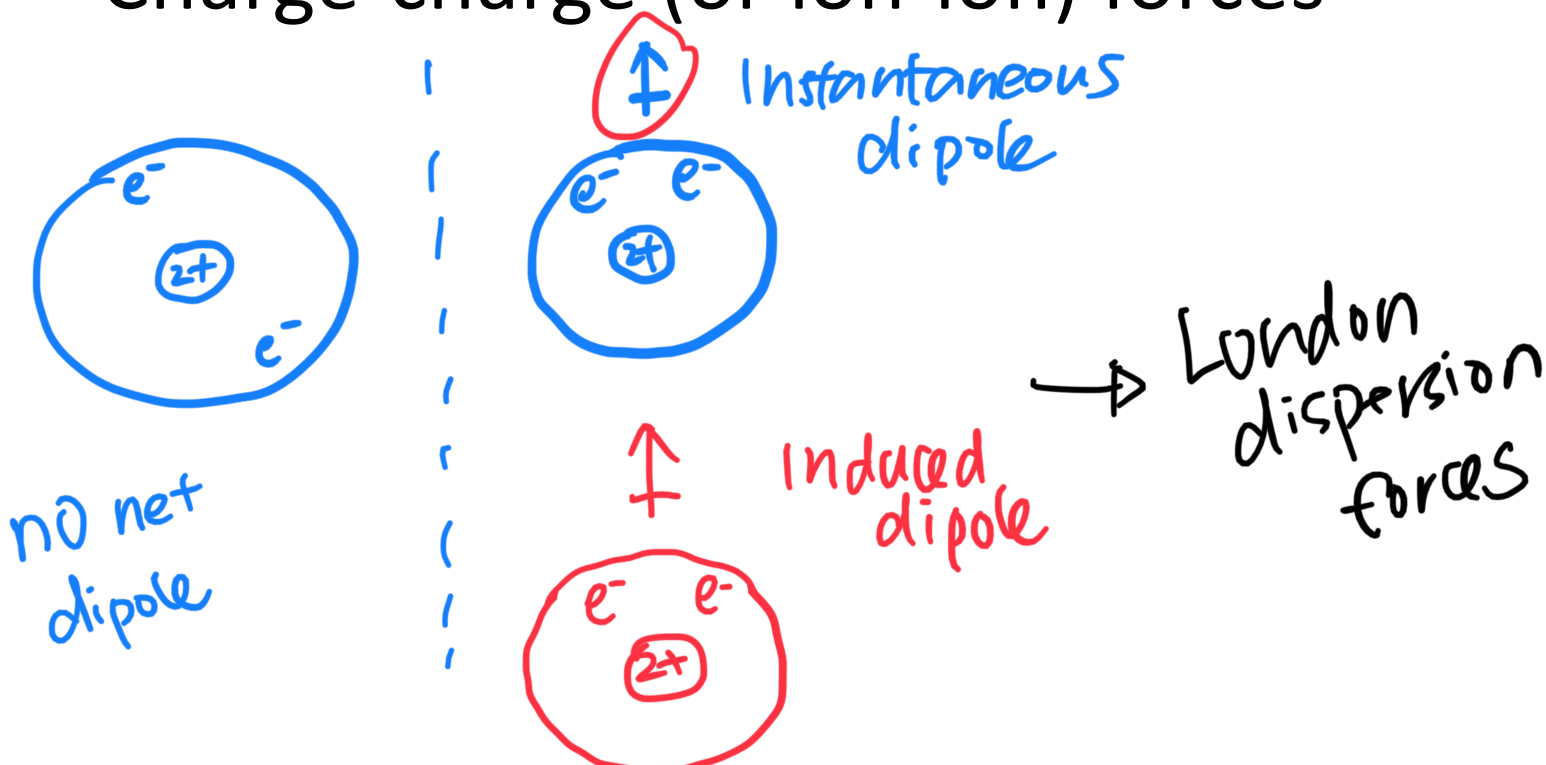
- Ionic bonds (300-700 kJ mol^{-1})
- Covalent bonds (100-500 kJ mol^{-1})



- Energy required to vaporize H_2O: 41 kJ mol^{-1}
- Bond energy of O-H bond in H_2O: 463 kJ mol^{-1}

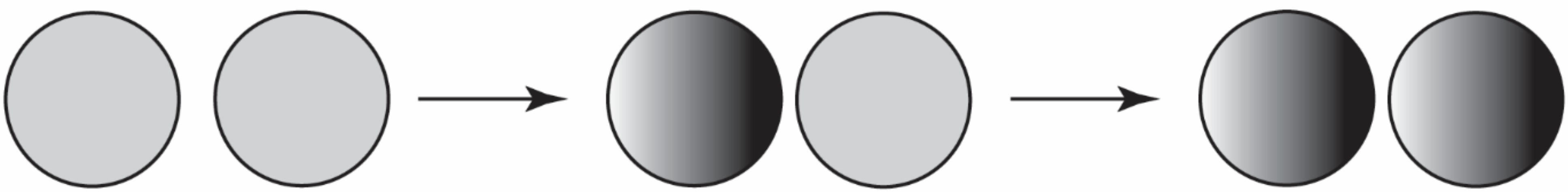
Intermolecular Forces

– London dispersion forces
– Dipole-dipole forces
– Hydrogen bonding
– Charge-dipole (or ion-dipole) forces
– Charge-charge (or ion-ion) forces



London Dispersion Forces

Also known as instantaneous dipole-induced dipole forces, they exist between all atoms and molecules, and are always attractive. Arise from a momentary asymmetry in electron density caused by charge fluctuations.



electrons are uniformly distributed

electrons in one atom (left) become asymetrically distributed generating an instantaneous dipole

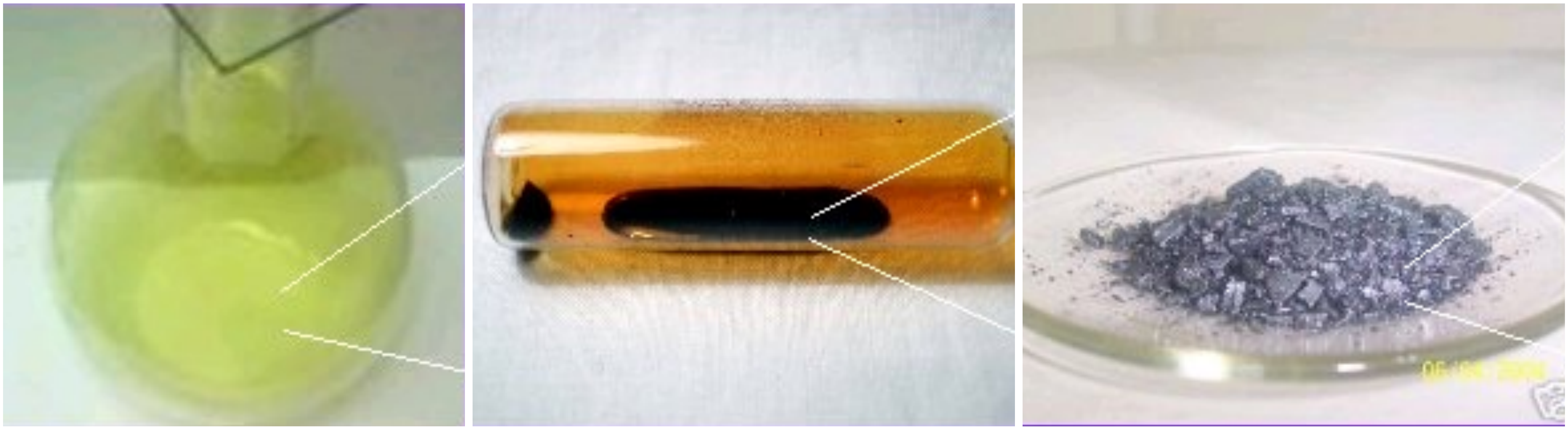
Instantaneous dipole induces another instantanous dipole in a neighbouring atom

Electric Polarizability

Measures how large a dipole can be induced by an external electric field. Polarizability is greater in species with more weakly bound or delocalized electrons, thus favouring dispersion.

Halogen Species	Melting Point
F_2	-219.62°C
Cl_2	-101.5°C
Br_2	-7.3°C
I_2	113.7°C

Polarizability



Cl_2 Br_2 I_2

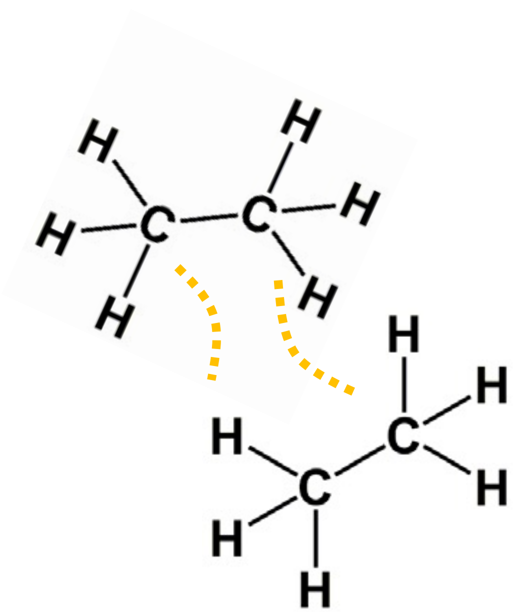
London dispersion forces increase

Boiling points

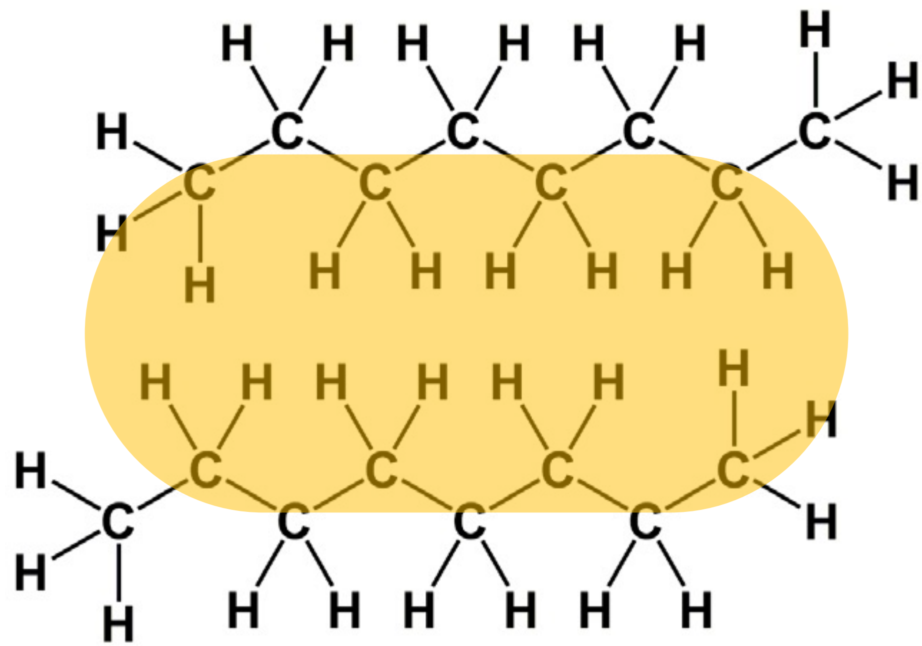
Noble Gas	Boiling Point (K)
Helium	4.2
Neon	27.1
Argon	87.3
Krypton	120.9
Xenon	166.1
Radon	211.5

Boiling Points of Hydrocarbons

Larger molecules have a greater number of polarizable atoms that contribute to making the total dispersion larger.



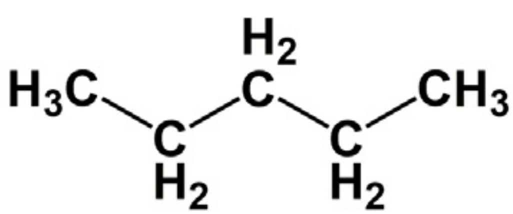
Ethane
Boiling point: -89 °C



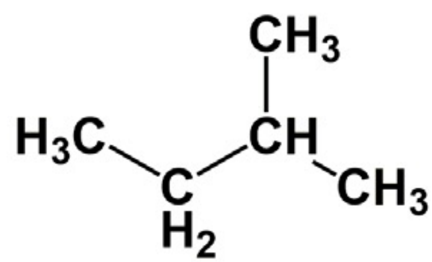
Octane
Boiling point: 125.6 °C

Boiling Points of Hydrocarbons

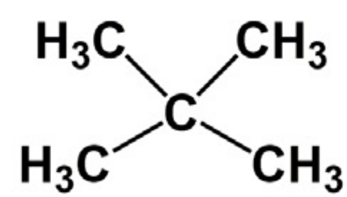
- Branching within a molecule reduces the possibilities for intermolecular interactions and lowers the melting/boiling points.
- Consider the boiling points below for three molecules with the same molecular formula (C_5H_{12}):



Pentane
BP: 309.2 K



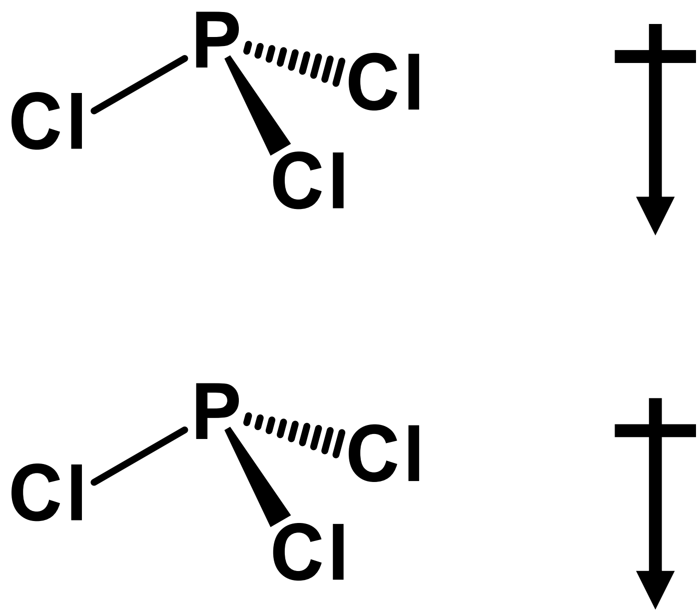
2-methylbutane
BP: 301.0 K



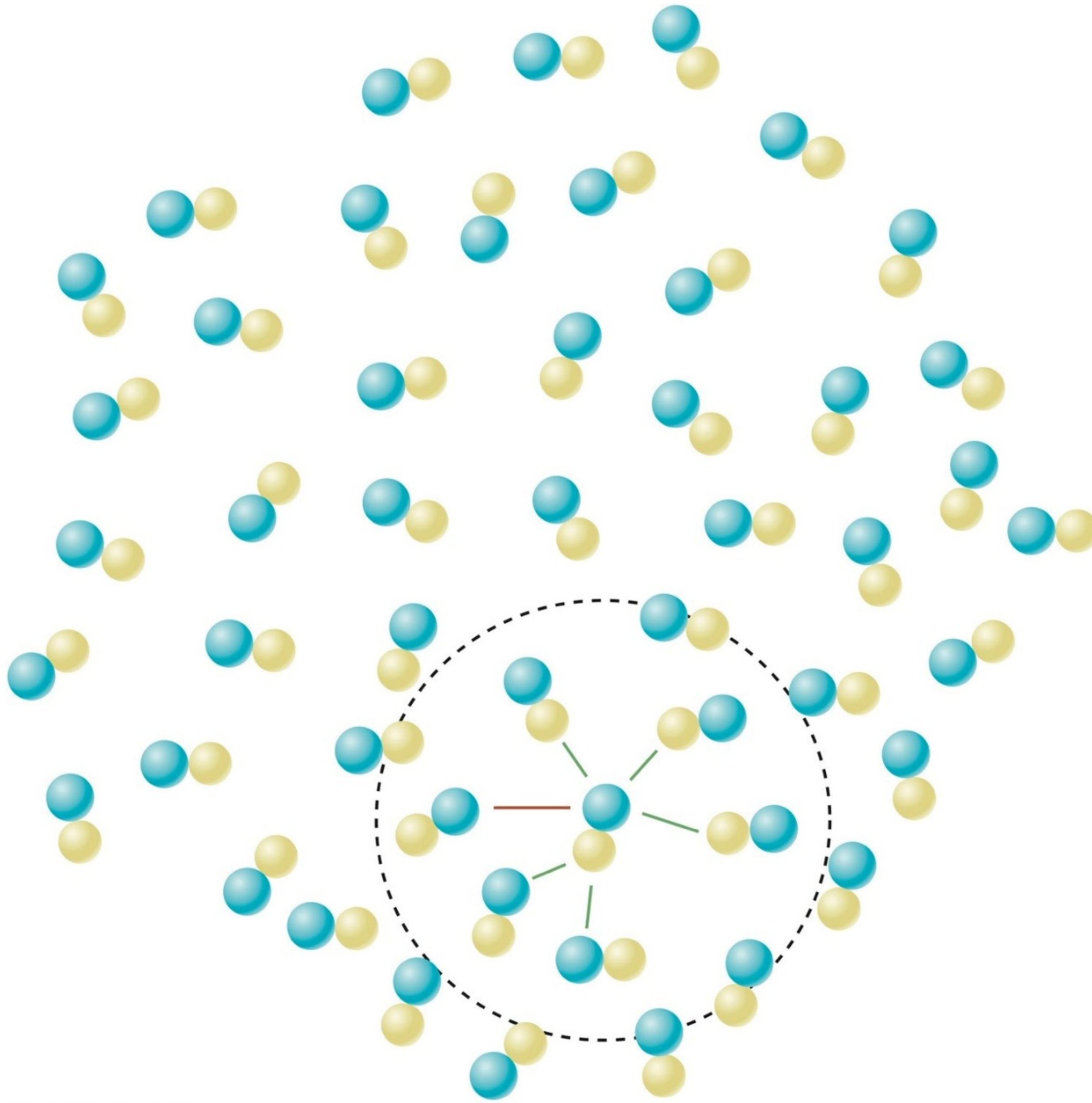
2,2-dimethylpropane
BP: 282.6 K

Dipole-dipole interactions

Dipole-dipole interactions arise from favourable alignment of dipoles in molecules.

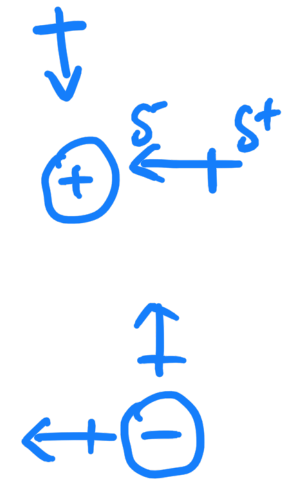


Dipole-dipole interactions



Charge-dipole interactions

Ions in a sea of polar molecules (e.g. H_2O)



- a.k.a. “solvation” of ions
- molecules orient to stabilize ionic charge
- effect is about 5-20 kJ/mol *per interaction*

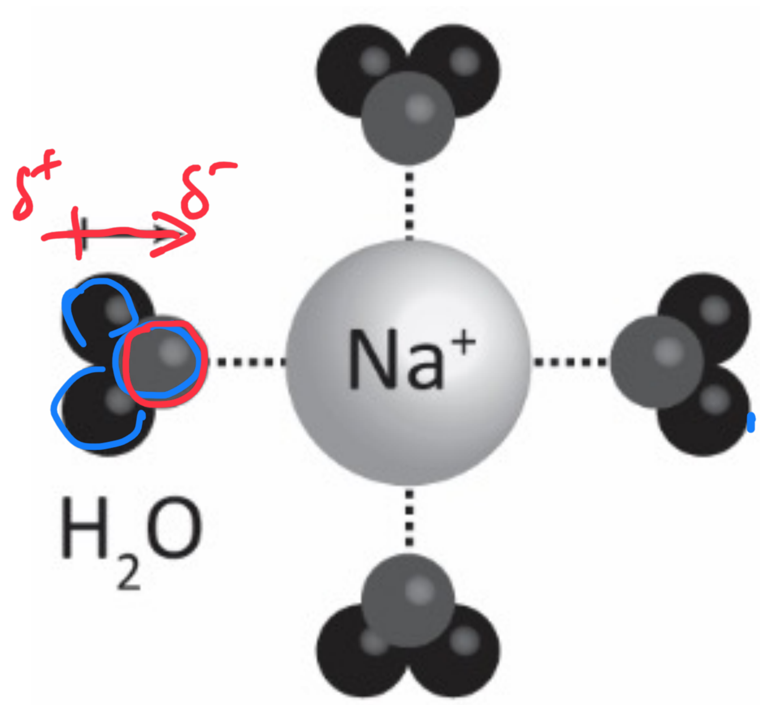
$$E \propto -\frac{|z|\mu}{r^2}$$

where:

z is the charge of the ion,

μ is the dipole moment, and

r is the distance between the ion and the molecule



Worksheet Question #1

What experiences greater ion-dipole forces in H_2O, Mg^{2+} or Na^{+}? Briefly explain your choice.

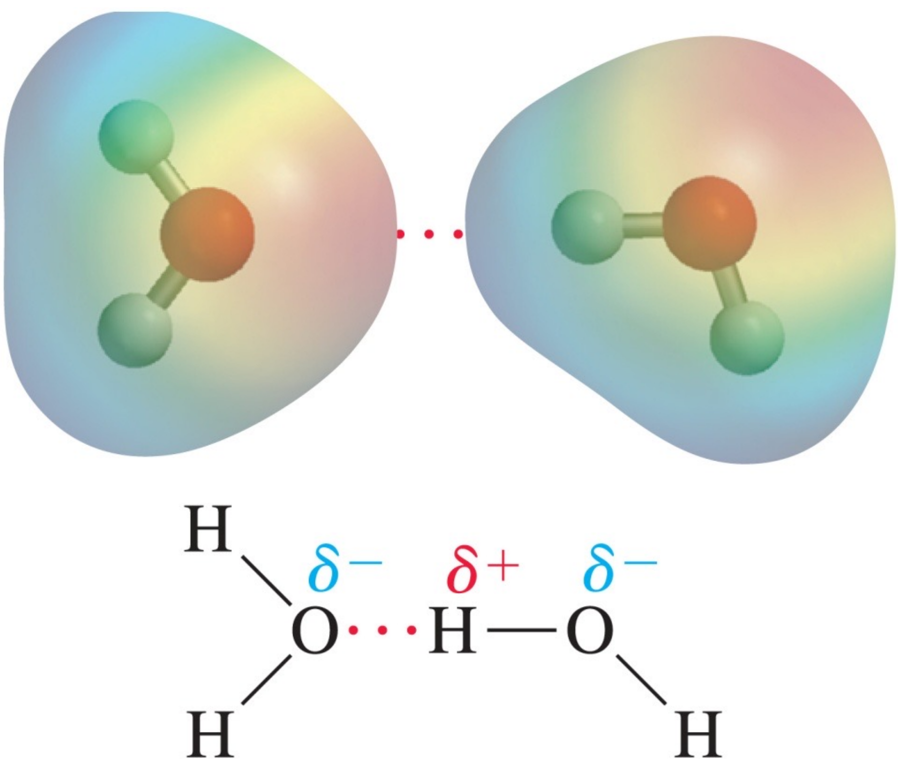
Click any answer on your clicker when you have finished this worksheet question!

Hydrogen Bonding

A strong dipole-dipole force in molecules with a hydrogen atom bonded to an electronegative atom (N, O, or F).

Energy ~ 10-40 kJ/mol

H_2O



Neat application: molecular self-assembly

https://www.youtube.com/watch?v=G25mMDCFMwo

https://www.youtube.com/watch?v=HU_pgHlWsdc

Hydrogen Bonding

Hydrogen attached to a N, O, F
interacting with
ANOTHER N, O, F

- special case
  - atom with large electronegativity (δ^-)
  - hydrogen atom (δ^+) attached to EN atom
  - **N**, **O**, and **F** ONLY
- stronger than dipole interactions
  - around 10-40 kJ/mol

Clicker Question

What type(s) of intermolecular forces are present in PH_3?

A. Dipole-Dipole
B. London Dispersion
C. Charge-Dipole
D. Hydrogen bonding
E. A and B

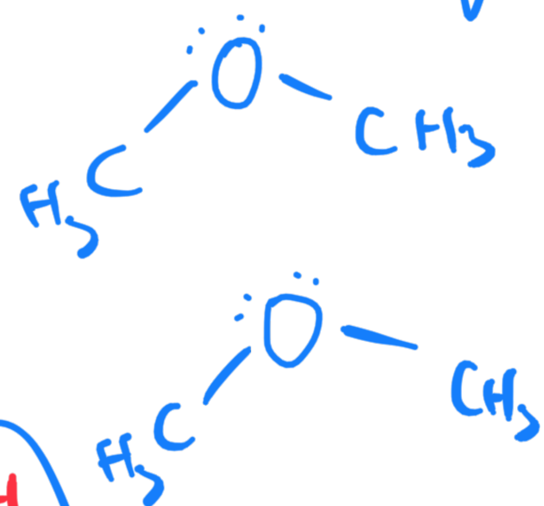
Clicker Question

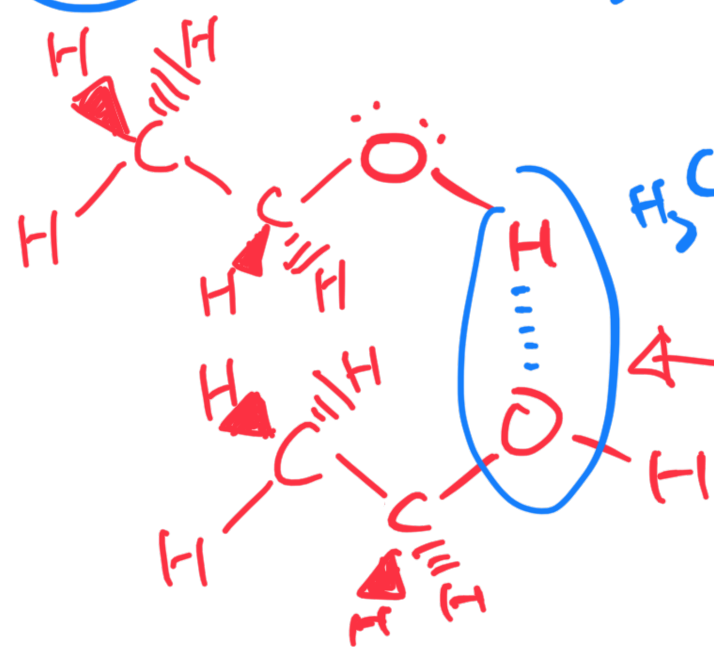
Which of these pure substances will **not** form hydrogen bonds?

no H-bonding

I) CH_3CH_2OH II) CH_3OCH_3

III) $H_3C{-}NH{-}CH_3$ IV) CH_3F





H-bonding

a) I and II
b) I and III
c) II and III
d) II and IV
e) I and IV

Summary

Force type	Strength	Exhibited by	Examples
London Dispersion forces	Weak	Present in all atoms and molecules. Strength increases as the number of electrons in the molecule increases (more polarizable)	I_2, Kr, PCl_5
Dipole-dipole interactions	Strong	Molecules with a permanent dipole.	PCl_3, ICl, CH_3Cl
Hydrogen bonds	Strong	Molecules with H bonded to F, O, or N. The large electronegativity difference and resulting permanent dipole are responsible for the strength of these forces.	HF, H_2O
Charge-charge or Ion-ion interactions	Very Strong	Ionic solids or ionic liquids.	NaCl, K_3PO_4