

# **N28 – Intermolecular Forces**

Going in Depth

# Types of IMFs

- **Hydrogen Bond**
- **Dipole-Dipole**
- **London Dispersion Forces**



**These three talked about in Honors Chem**

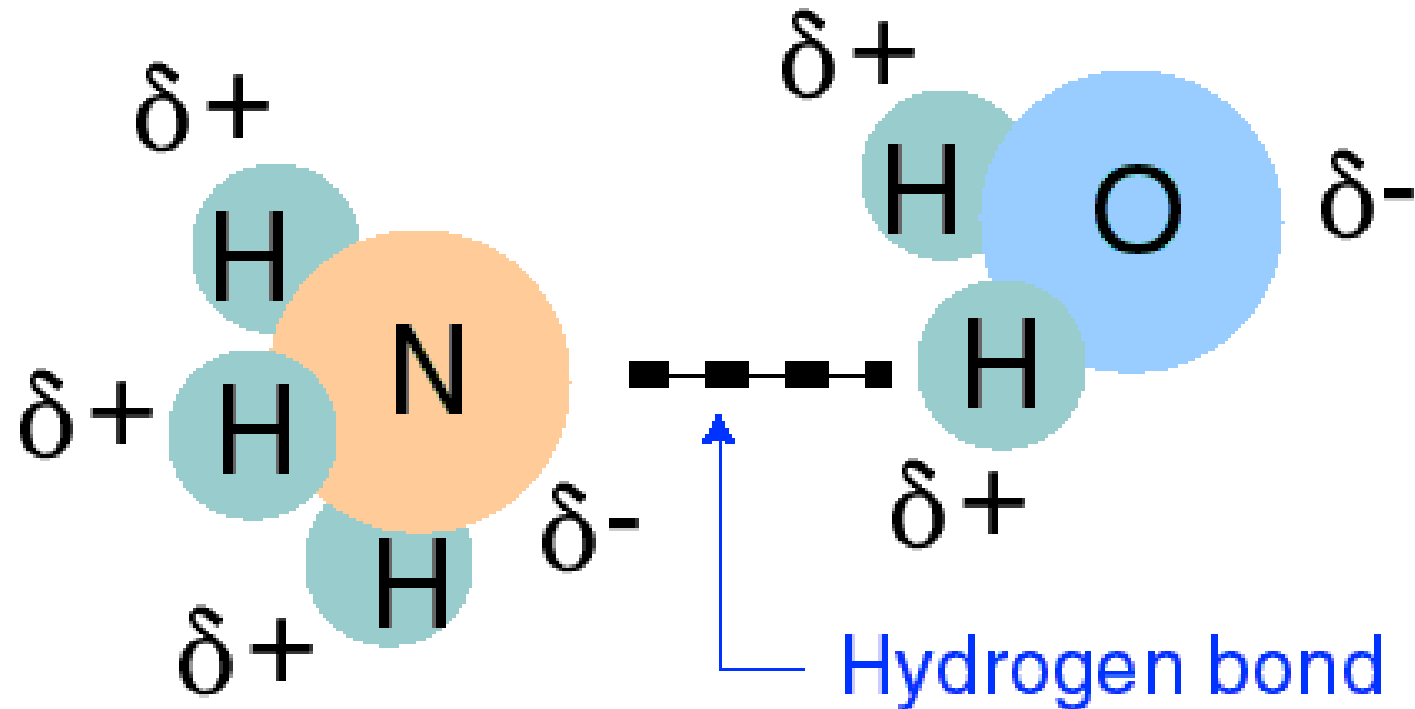
- **Ion-Dipole Forces**
- **Ion Induced Dipole**
- **Dipole Induced Dipole**



**These three talked are probably new**

# Hydrogen Bonding

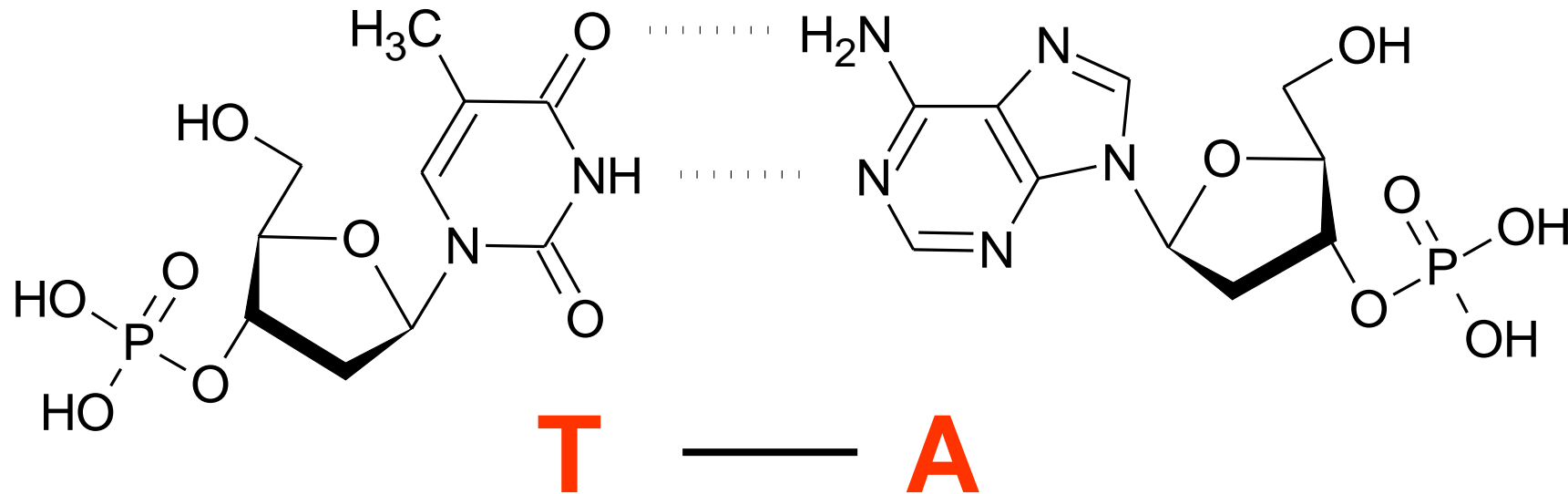
Bonding between hydrogen and more electronegative neighboring atoms such as oxygen and nitrogen



*Hydrogen bonding between ammonia and water*

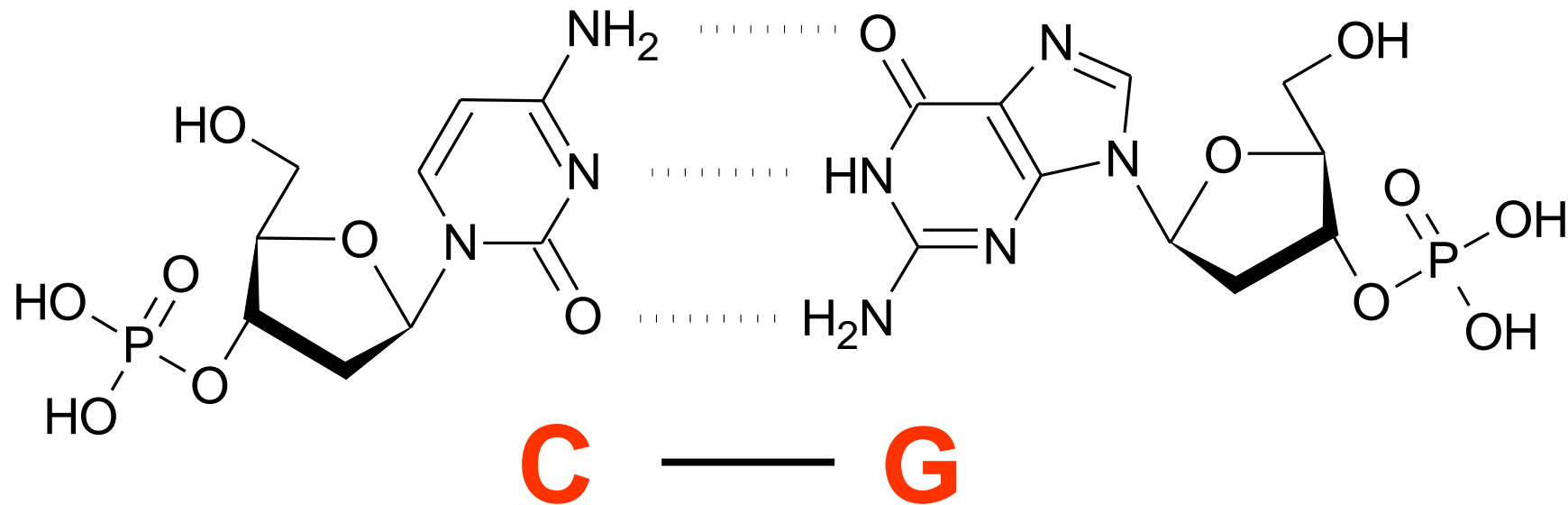
# Hydrogen Bonding in DNA

**T**hymine hydrogen bonds to **A**denine



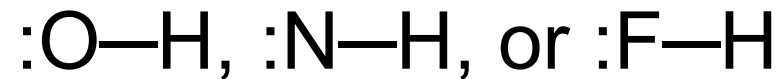
# Hydrogen Bonding in DNA

**C**ytosine hydrogen bonds to **G**uanine



# Hydrogen Bonding

- When a very electronegative atom is bonded to H, it strongly pulls the bonding electrons toward it.



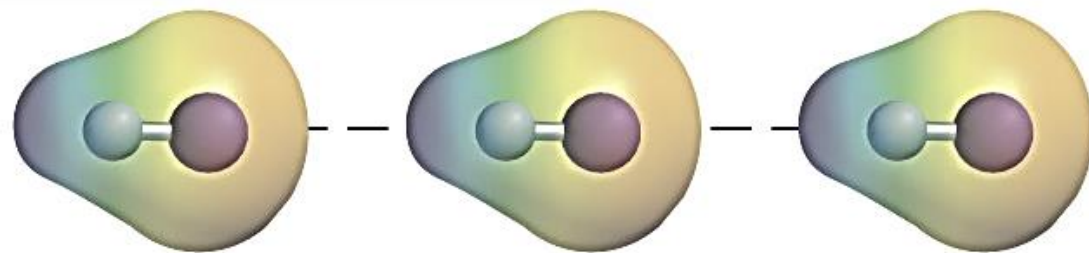
- Because H has no other electrons, when its e<sup>-</sup> is pulled away, the nucleus becomes de-shielded, exposing the H proton.
- The exposed proton acts as a very strong center of positive charge, attracting all the electron clouds from neighboring molecules.

# Hydrogen Bonding

When H bonds directly to F, O, or N, the bonding atoms acquire relatively large partial charges. This gives rise to strong dipole-dipole attractions between neighboring molecules.

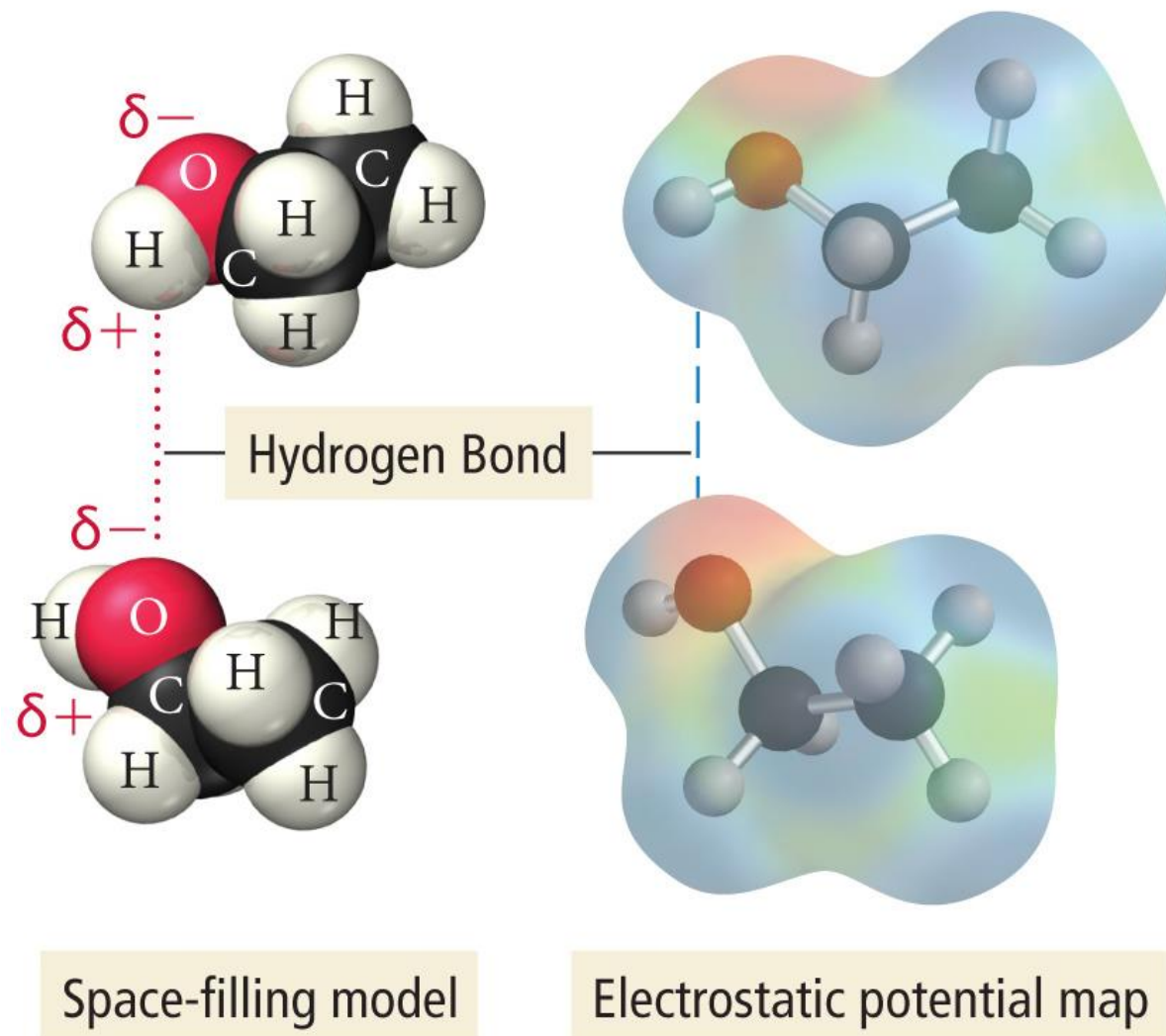
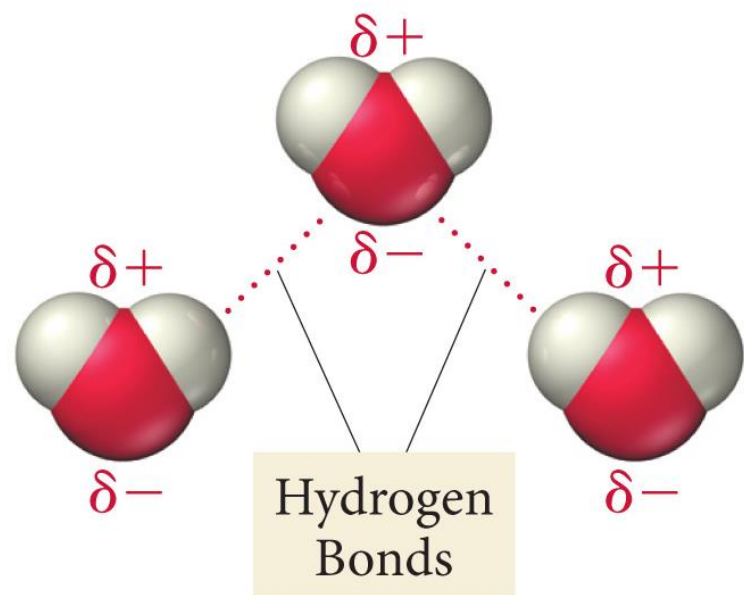
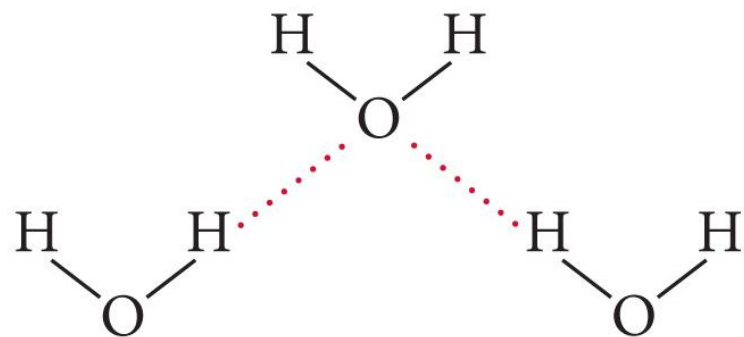


Space-filling model



Electrostatic potential map

# Hydrogen Bonding in Water and Ethanol





# **Hydrogen Bonding**

**H-bonds are very strong intermolecular attractive forces.**



- Stronger than dipole–dipole or dispersion forces

**Substances that can hydrogen bond will have higher boiling points and melting points than similar substances that cannot.**

**But H-bonds are not nearly as strong as chemical bonds.**

- 2–5% the strength of covalent bonds

# Effect of H-Bonding on BP

Name	Formula		Molar Mass (amu)	Structure	bp (°C)	mp (°C)
Ethanol	C <sub>2</sub> H <sub>6</sub> O		46.07	CH <sub>3</sub> CH <sub>2</sub> OH	78.3	−114.1
Dimethyl Ether	C <sub>2</sub> H <sub>6</sub> O		46.07	CH <sub>3</sub> OCH <sub>3</sub>	−22.0	−138.5

**Ethanol has H-Bonding and higher BP and MP**

# **Dipole – Dipole Attractions**

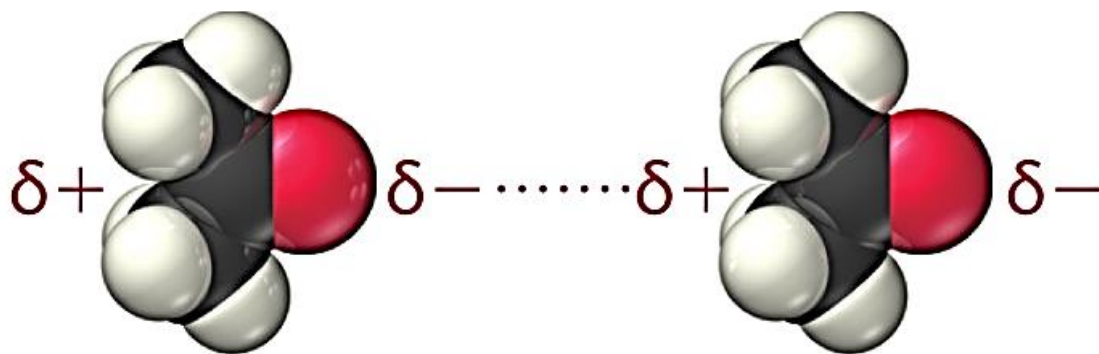
**Polar molecules have a permanent dipole.**

- Bond polarity and shape
- Dipole moment
- The always present induced dipole

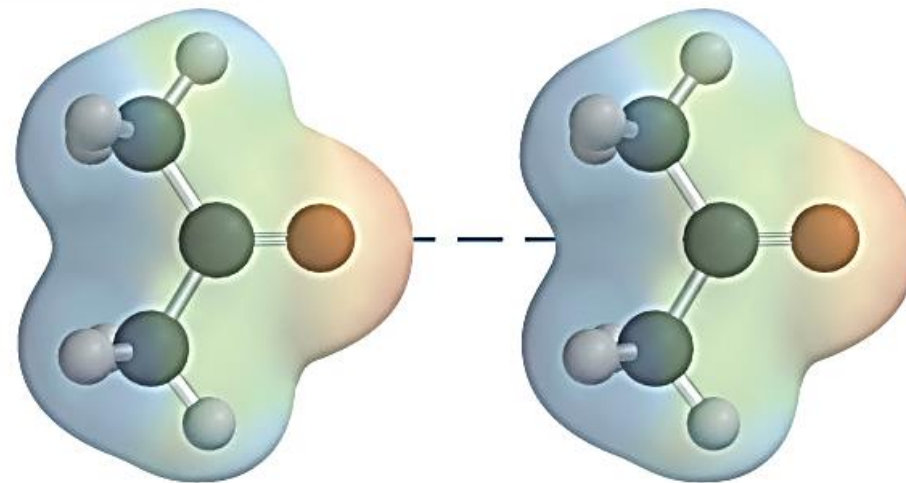
**The permanent dipole adds to the attractive forces between the molecules, raising the boiling and melting points relative to nonpolar molecules of similar size and shape.**

# Dipole – Dipole Attractions

The positive end of a polar molecule is attracted to the negative end of its neighbor.





Space-filling model



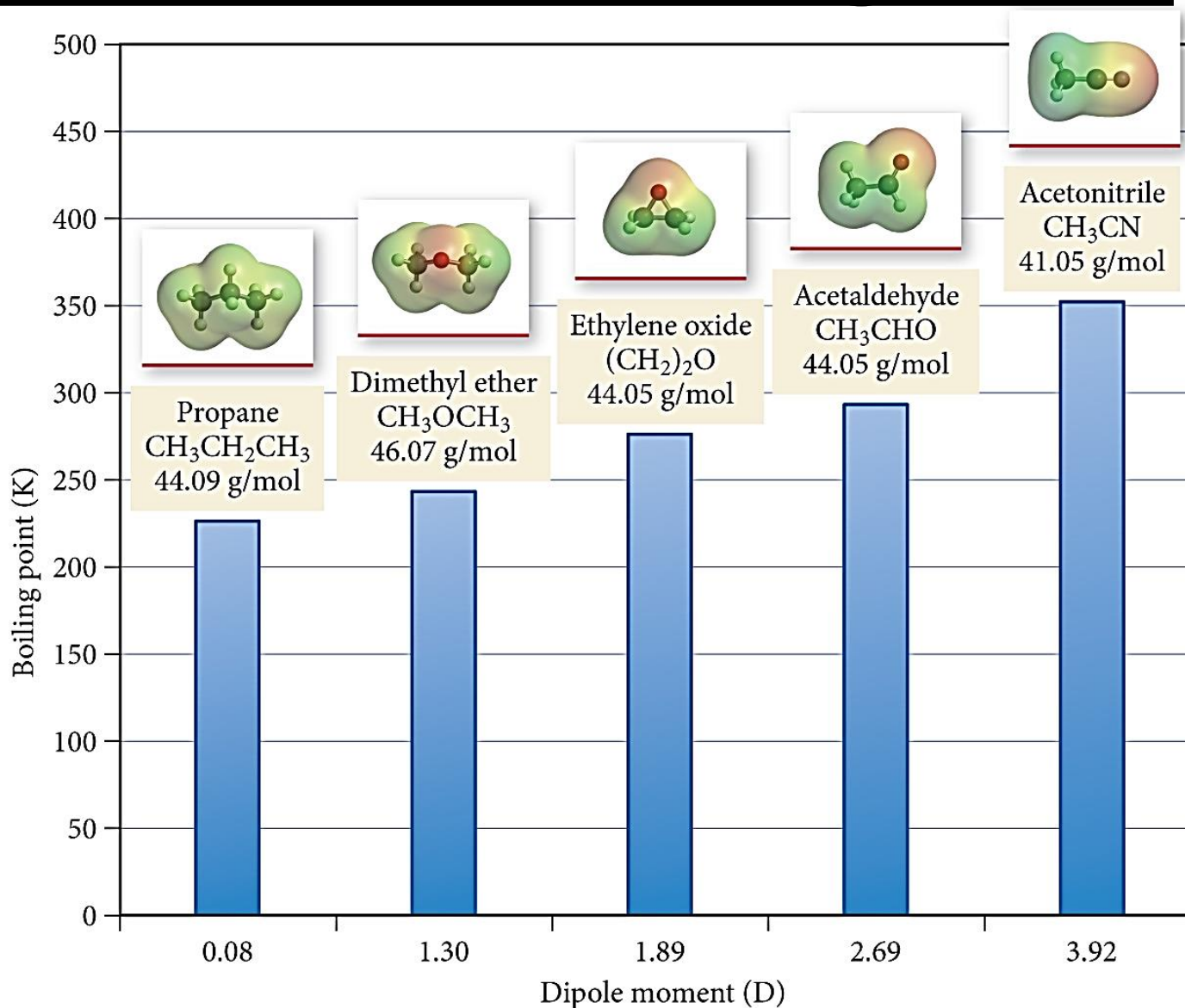
Electrostatic potential map

# Effect of DP-DP Attractions on BP and MP

Name	Formula	Molar Mass (amu)	Structure		bp (°C)	mp (°C)
Formaldehyde	CH <sub>2</sub> O	30.03	$\begin{array}{c} \text{O} \\    \\ \text{H}-\text{C}-\text{H} \end{array}$		-19.5	-92
Ethane	C <sub>2</sub> H <sub>6</sub>	30.07	$\begin{array}{cc} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & -\text{C}-\text{H} \\   &   \\ \text{H} & \text{H} \end{array}$		-88	-172

**Formaldehyde has DP-DP and higher BP and MP**

# Dipole Moment and Boiling Point



# London Dispersion Forces

## London force attractions

The temporary separations of charge that lead to the attraction of one nonpolar/noble gas molecule to its neighbors.

London forces increase with size of the electron cloud and with “increased polarizability” – You can **NOT** say “bigger” or “more electrons”



Fritz London  
1900-1954

# London Dispersion Forces

Electrons are not stationary – they move randomly. It is possible to have temporary unequal distribution of electrons.

Fluctuations in the electron distribution in atoms and molecules result in a **temporary dipole**.

- Region with excess electron density has partial (–) charge
- Region with depleted electron density has partial (+) charge

The attractive forces caused by these temporary dipoles are called dispersion forces.

- Aka London Forces

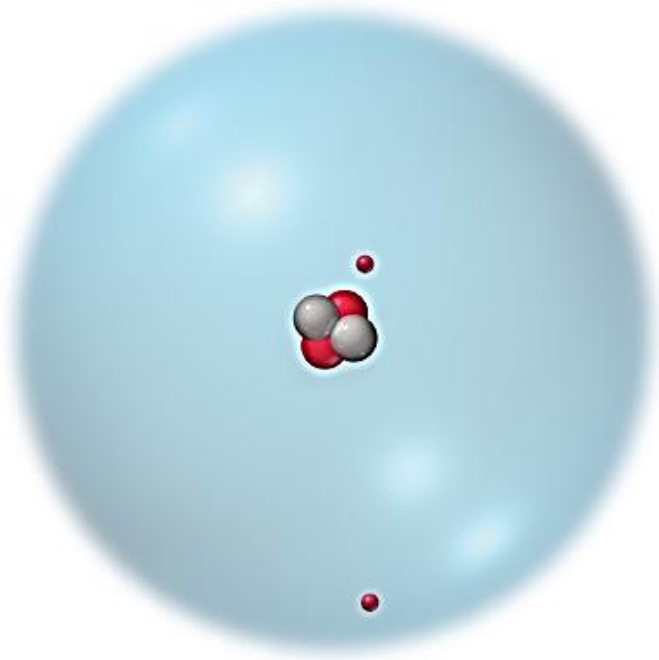


# **London Dispersion Forces**

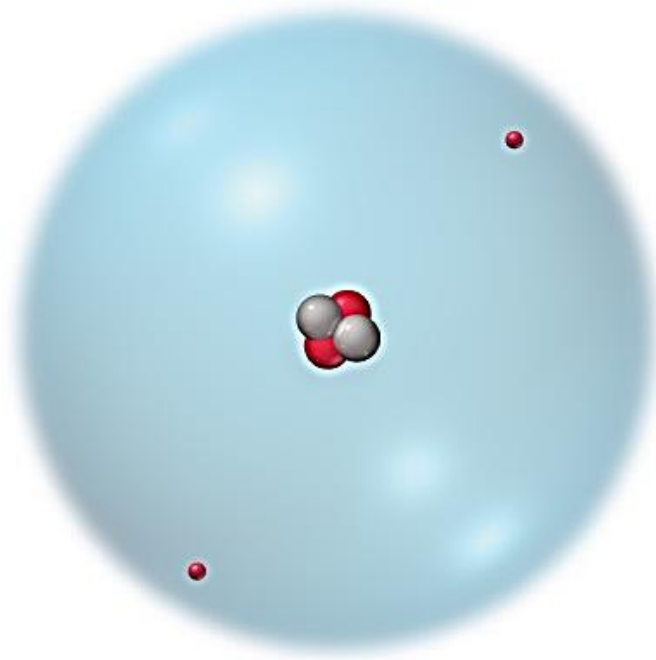
All molecules and atoms will have them.

As a temporary dipole is established in one molecule, it induces a dipole in all the surrounding molecules.

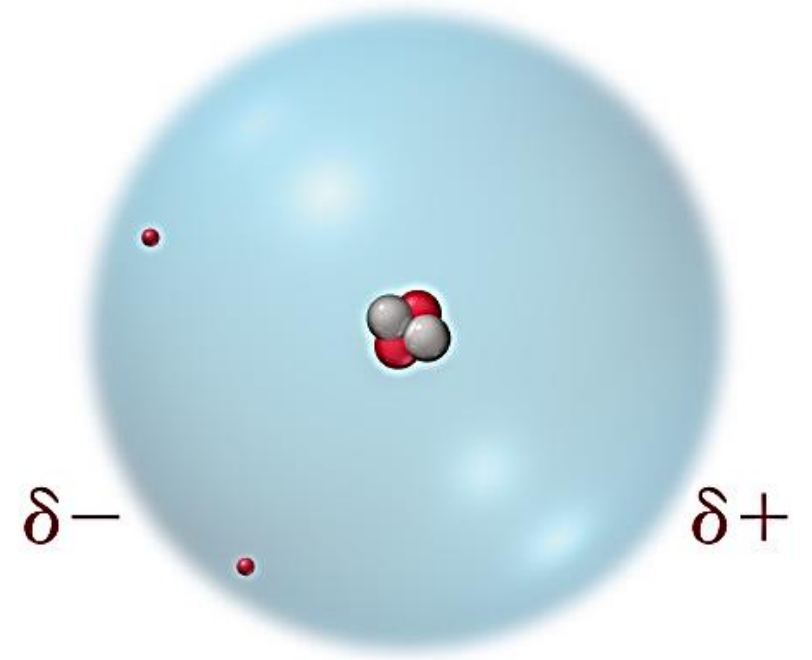
# London Dispersion Forces



Frame 1



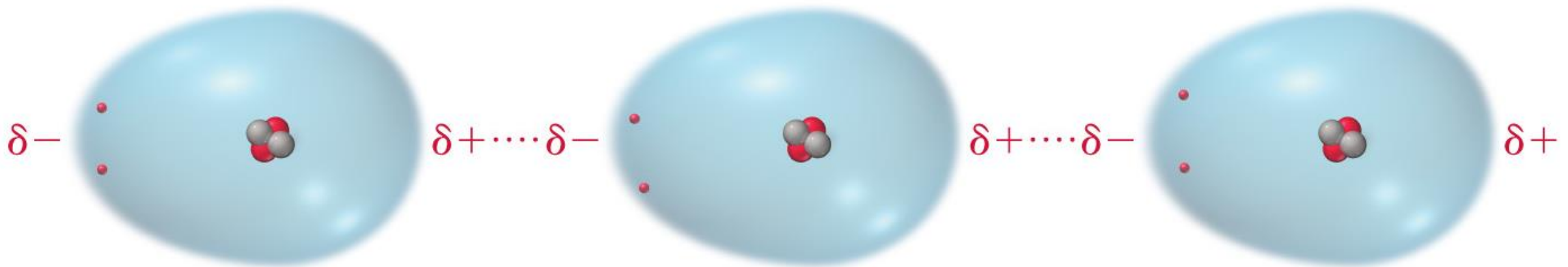
Frame 2



Frame 3

# London Dispersion Forces

An instantaneous dipole on any one helium atom can induce instantaneous dipoles on neighboring atoms, which then attract each other.



# Size of the Induced Dipole

The magnitude of the induced dipole depends on several factors.

## Polarizability of the electrons

**DO NOT SAY INCREASED  
MASS OR SIZE!**

- Volume of the electron cloud
- USUALLY: More electrons = larger electron cloud  
= increased polarizability = stronger attractions






## Shape of the molecule

- More surface area for interactions = larger induced dipole  
= stronger attraction

# Effect of e- Cloud Size on Size of LDF

- Noble gases are all nonpolar atomic elements.
- The stronger the attractive forces between the molecules, the higher the boiling point will be.

**TABLE 11.3 Boiling Points of the Noble Gases**






Noble Gas		Molar Mass (g/mol)	Boiling Point (K)
He		4.00	4.2
Ne		20.18	27
Ar		39.95	87
Kr		83.80	120
Xe		131.30	165

# Effect of e- Cloud Size on Size of LDF

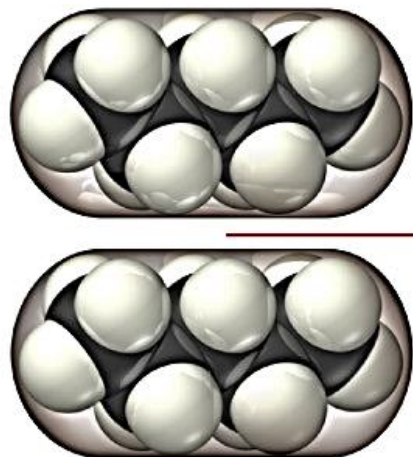
As the number of electrons increase, the size of the electron cloud increases and it is more “polarizable” – more likely to result in unequal electron distribution. Therefore, the strength of the dispersion forces increases.

The stronger the attractive forces between the molecules, the higher the boiling point will be.

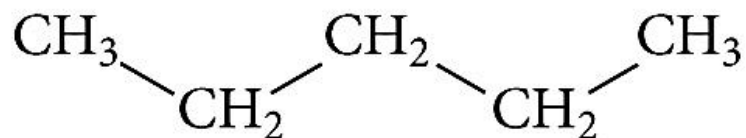
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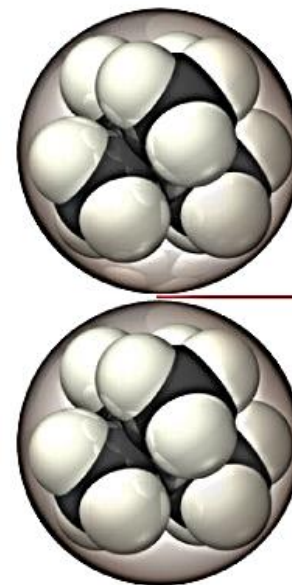
# Effect of Surface Area on Size of LDF



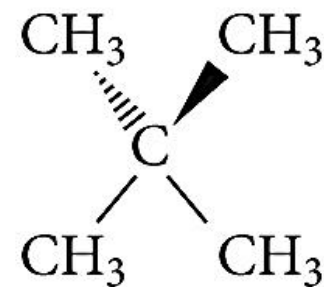
Large area for  
interaction



(a) *n*-Pentane

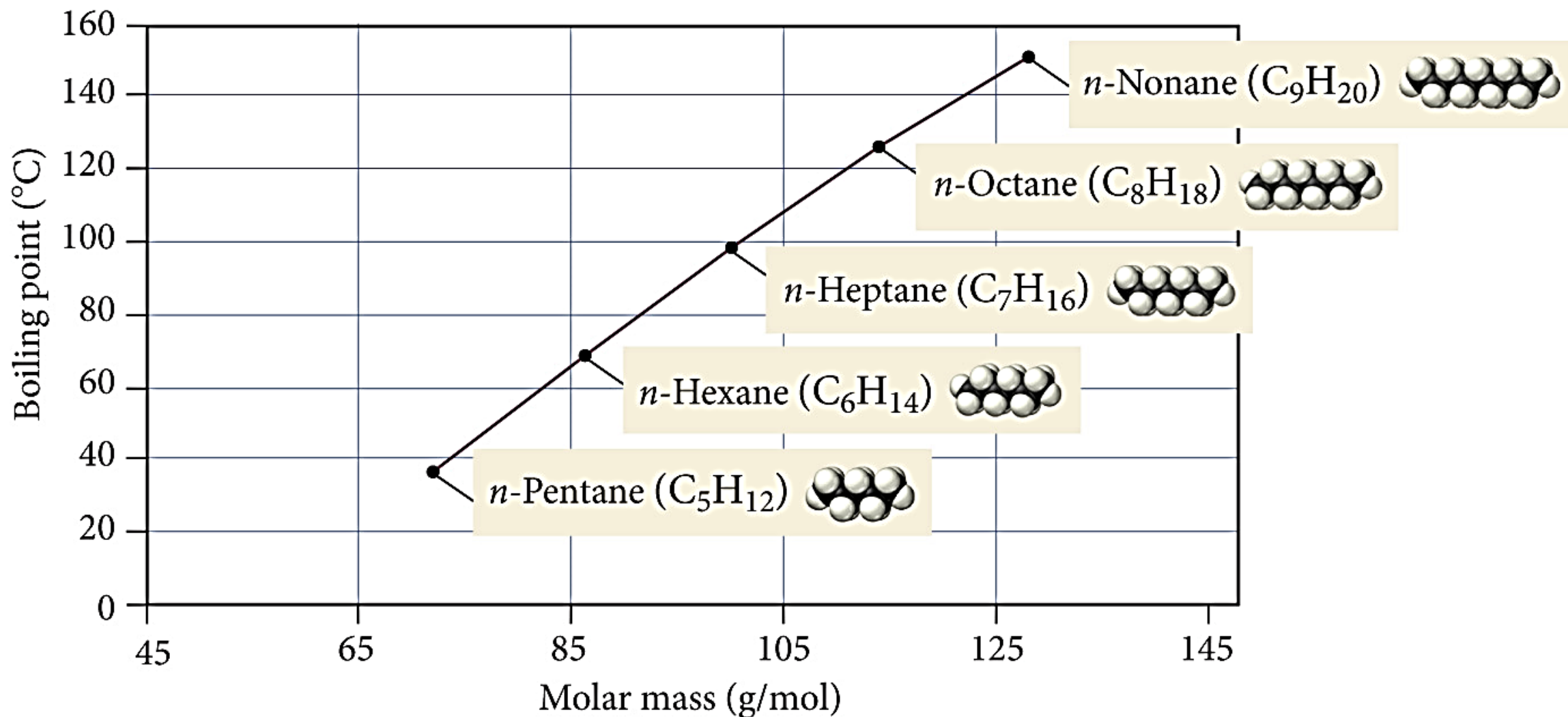


Small area for  
interaction



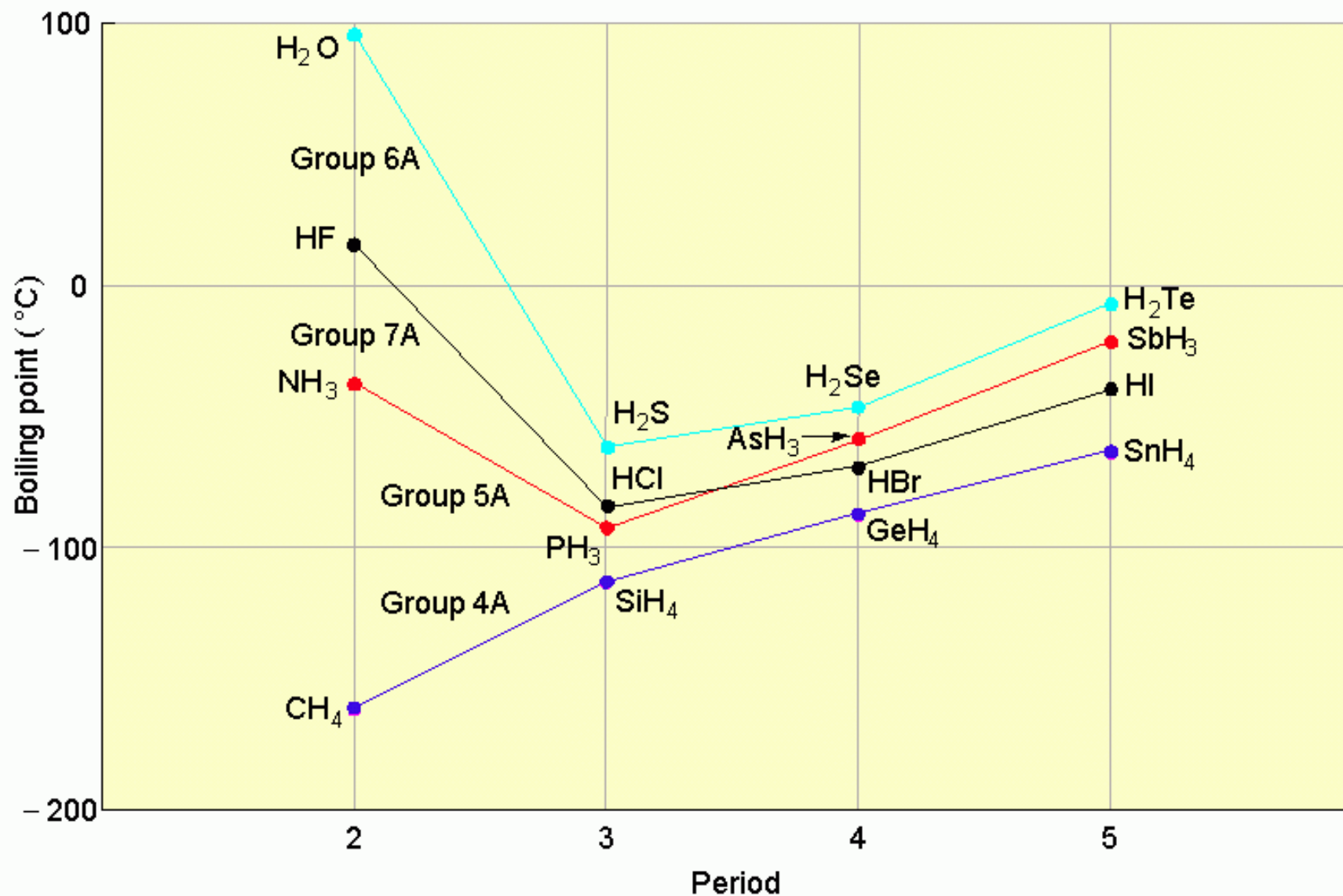
(b) Neopentane

# Boiling Points of n-Alkanes



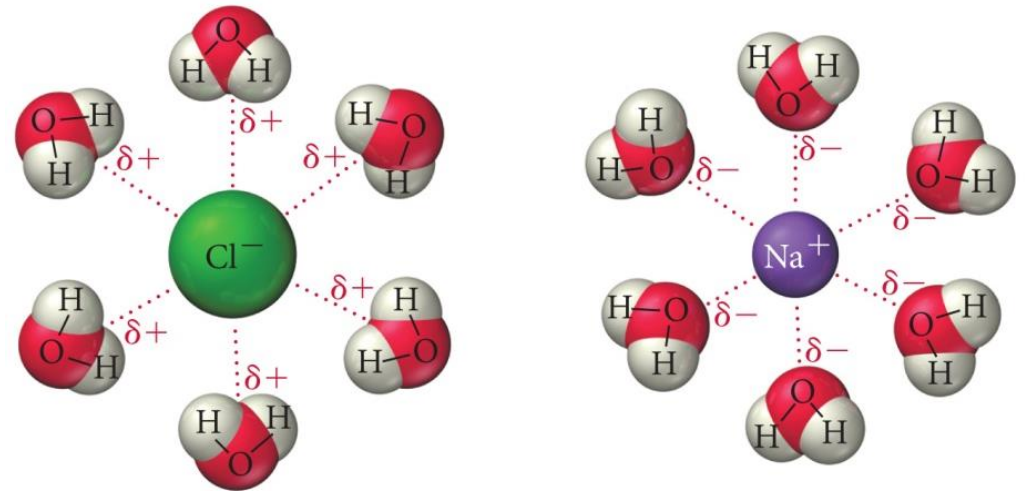


# BP as a Measure of IMFs



# Ion-Dipole Attraction

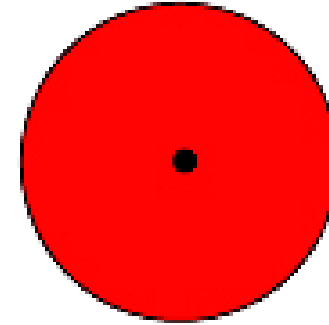
In a mixture, ions from an ionic compound are attracted to the dipole of polar molecules.



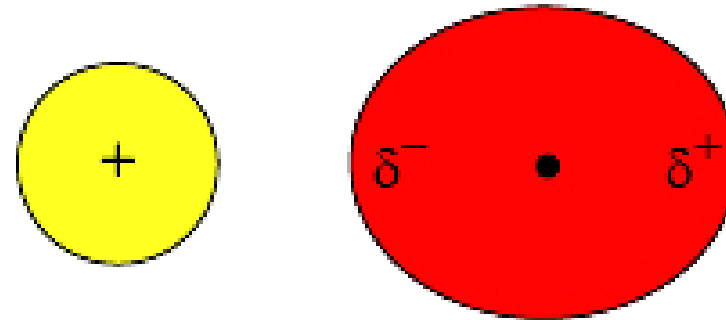
The strength of the ion–dipole attraction is one of the main factors that determines the solubility of ionic compounds in water.

# Ion Induced Dipole

**An ion can induce a dipole in a nonpolar molecule.  
By attracting the electrons in the nonpolar molecule the ion causes the nonpolar molecule to become slightly polar.**



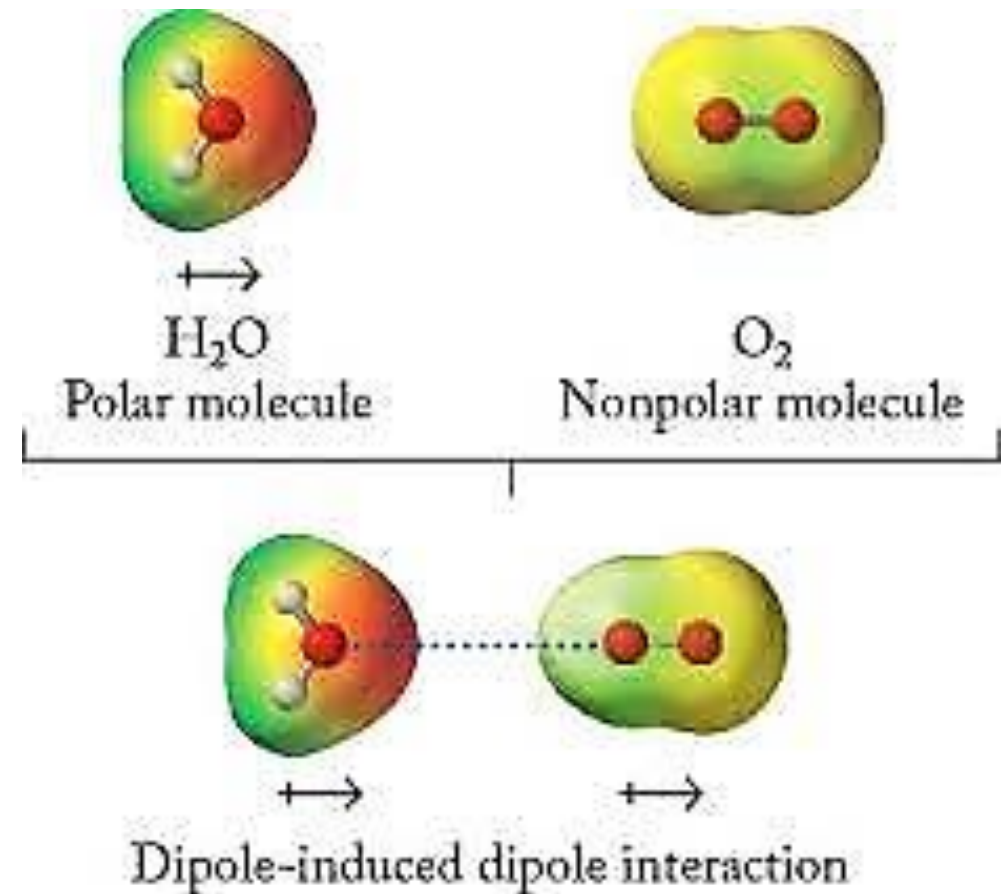
Spherical atom with no dipole.  
The dot indicates the location of the nucleus.



Upon approach of a charged ion, electrons in the atom respond and the atom develops a dipole.

# Dipole Induced Dipole

An dipole can induce a dipole in a nonpolar molecule. By attracting the electrons in the nonpolar molecule the dipole causes the nonpolar molecule to become slightly polar.



# **Be Careful When Ranking Things**

- It can be hard to rank the strength of IMFs in various molecules without lab data like BP or MP.
- If you have a TON of London Dispersion Forces you may end up with higher IMFs than anticipated.
- A ton of a weak force can result in a larger sum of attractive force than expected.
- In AP, things will either be obvious or you might be asked to explain unexpected results on BP and MP data where you want to consider things like the sum of weak forces ending up stronger.

# Be Careful When Listing Things

- It is common to just list the most dominant force, the strongest one that a molecule possesses.
- HOWEVER – in AP Chem it is common for them to want you to list ALL the forces.
  - So if something has H-bond you should say that it has H-Bond AND LDF (remember H-Bond is a type of really strong DP-DP so you don't need to list that one).
- How do you know when to just report one versus all of them? Who knows! Look for key words, err on the side of listing all unless a key word implies they just want dominant.

# Be Careful with Phrasing Answers

- IMF type questions often ask you to compare two (or more) molecules to each other, to explain for example why one has a higher BP than the other.
- You **HAVE TO MENTION BOTH THE MOLECULES** in the question! They specifically won't give points if you only mention one.
  - **Example:** Why does  $H_2O$  have a higher BP than  $CO_2$
  - **Good answer:** While  $CO_2$  has LDF forces,  $H_2O$  has LDF AND H-Bonding. The H-Bonding results in more intermolecular attractions so it has a higher BP than  $CO_2$  does.
  - **Bad answer:**  $H_2O$  has a higher BP because it has H-bonding.

# Summary

- London Dispersion Forces are the weakest of the intermolecular attractions.
- London Dispersion Forces are present in all molecules and atoms.
- The magnitude of the LDFs increases with increasing polarizability and surface area.



# Summary

- Polar molecules also have dipole–dipole forces.
- H-Bonds are the strongest of the intermolecular attractive forces a pure substance can have.
- H-bonds will be present when a molecule has H directly bonded to either O, N, or F atoms.

# Summary

- Ion–Dipole attractions are present in mixtures of ionic compounds with polar molecules.
- Ion–Dipole attractions are the strongest intermolecular attraction.
- Ion–Dipole attractions are especially important in aqueous solutions of ionic compounds.

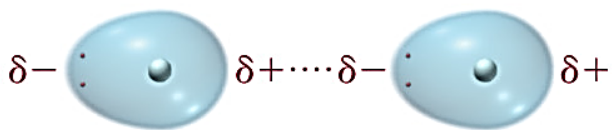
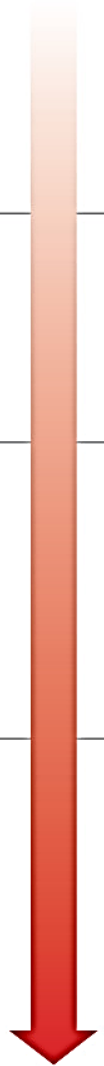
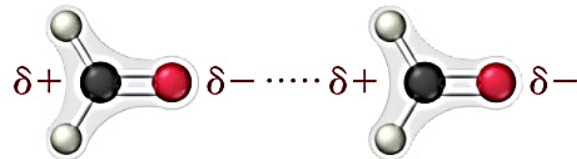
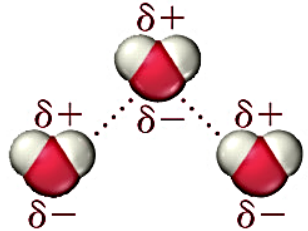
# Summary

- Ion induced Dipole attractions are when an ion can induce a dipole in a normally nonpolar molecule.
- Dipole induced Dipole attractions are when a dipole can induce a dipole in a normally nonpolar molecule.
- Be very careful with the difference between “Ion-Dipole” and “Ion Induced Dipole” - they are not the same! And be careful about the difference between “Dipole-Dipole” and “Dipole Induced Dipole” – they are not the same

# Summary

## Generic Ranking of Common IMFs

TABLE 11.4 Types of Intermolecular Forces

Type	Present in	Molecular perspective	Strength
<b>Dispersion</b>	All molecules and atoms		
<b>Dipole-Dipole</b>	Polar molecules		
<b>Hydrogen Bonding</b>	Molecules containing H bonded to F, O, or N		
<b>Ion-Dipole</b>	Mixtures of ionic compounds and polar compounds	