Intermolecular Forces (Chapter 10)

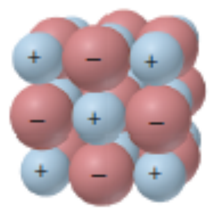
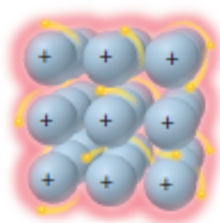
Learning Objectives

What will you be learning?

- Identify the different types of intermolecular forces
- Determine what are the different intermolecular forces present
- Determine the strength of intermolecular forces and determine their effect on physical properties
- Compare molecules physical properties based on intermolecular forces
- Understand why water is unique

Intermolecular Forces

Brief Description of Intramolecular Forces (bonding)

Force	Model	Basis of Attraction
Bonding		
Ionic		Cation–anion
Covalent		Nuclei–shared e^- pair
Metallic		Cations–delocalized electrons

IONIC:
e.g NaCl, $MgCl_2$

COVALENT:
e.g. Cl_2, H_2

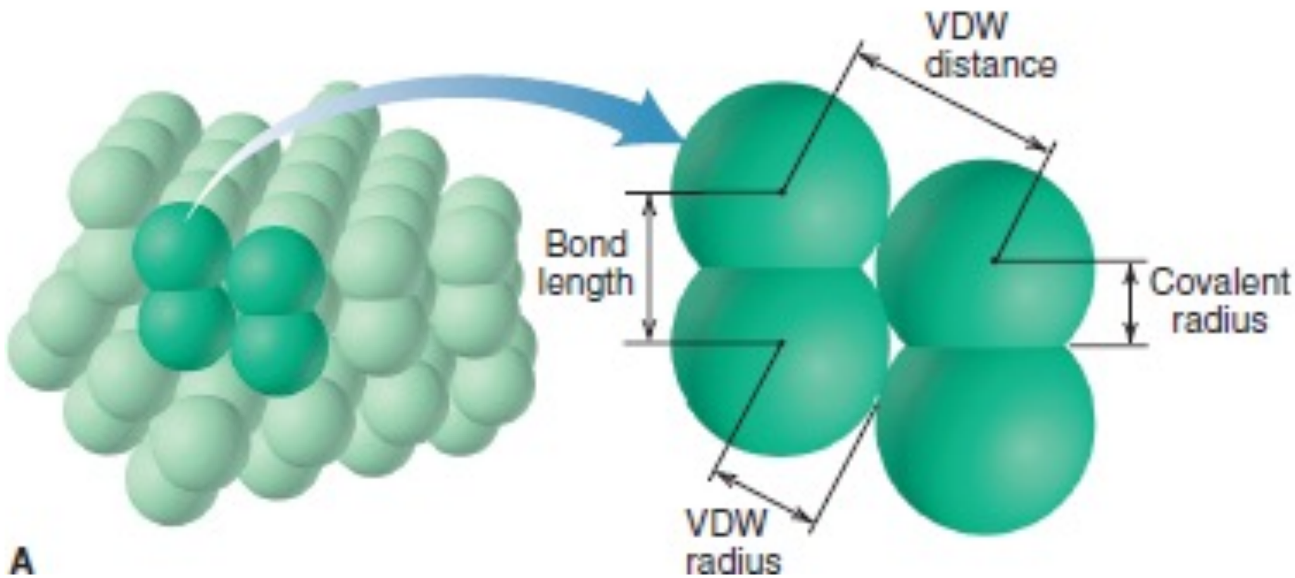
METALLIC:
e.g. Fe

In this Chapter (11) we will be discussing – **INTER**molecular forces – the forces between molecules with partial charges or between ions and molecules

Intermolecular forces are *weaker* than intramolecular forces

How do molecules approach each other?

For a Cl_2 molecule



Relation between intermolecular forces and physical properties

Increased intermolecular forces – Increased boiling point
More interaction between molecules, more heat needed to change from liquid to gaseous state

Intermolecular forces affect how soluble a compound will be in a solvent (water, ethanol, etc) – Why does salt dissolve in water?

Intermolecular forces affect viscosity and other physical properties of molecules

But what determines intermolecular forces?

Intermolecular forces <u>between</u> molecules depend upon the interaction <u>between</u> molecules.

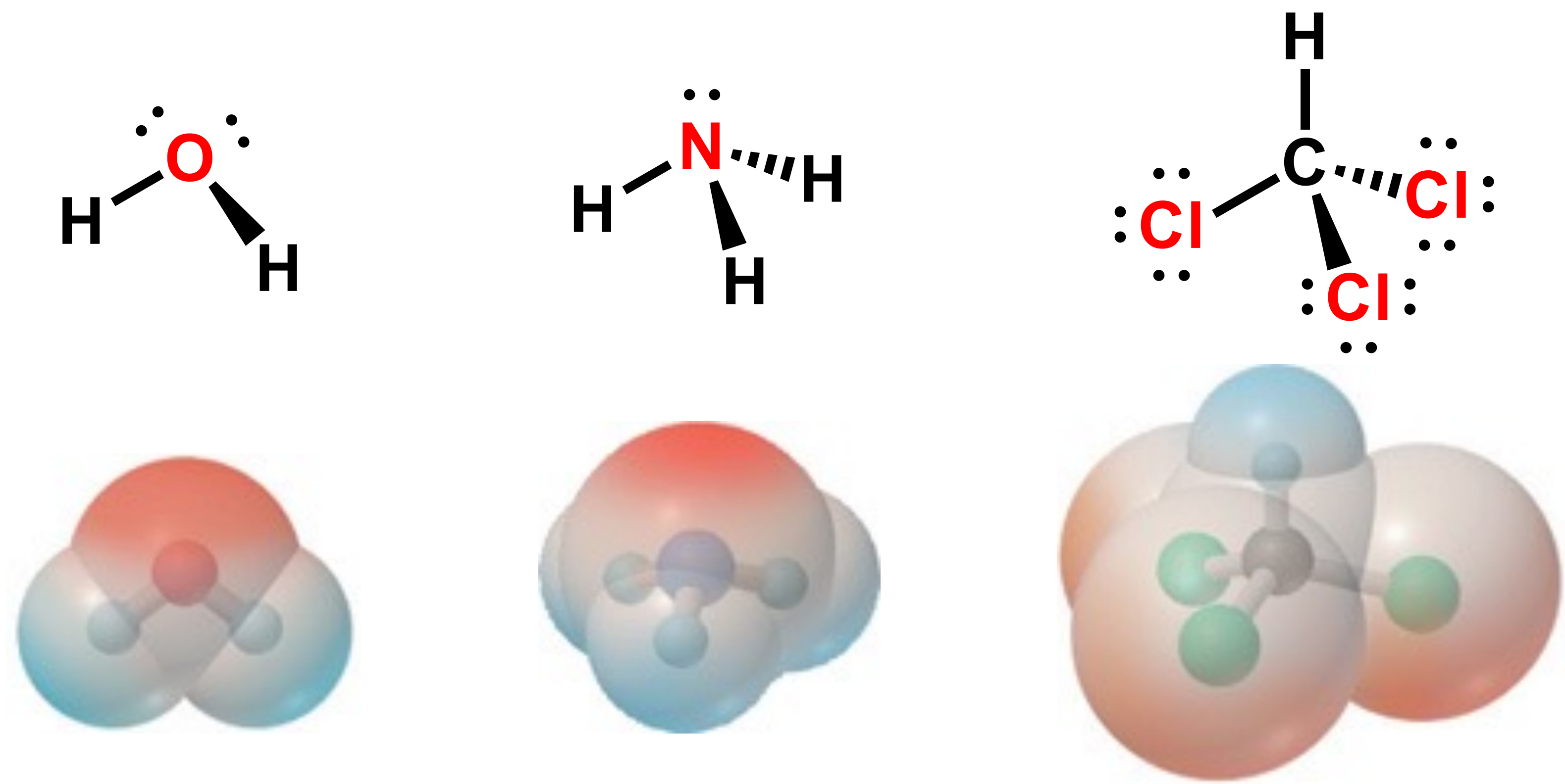
These interactions depend upon polarity of a molecule and polarizability

Polarity of Molecules

Based on the difference in χ (**Δχ**) between two atoms a **bond** can be described as polar (unequal sharing of electrons) or non-polar

POLAR MOLECULES: molecules with a net dipole moment (μ)

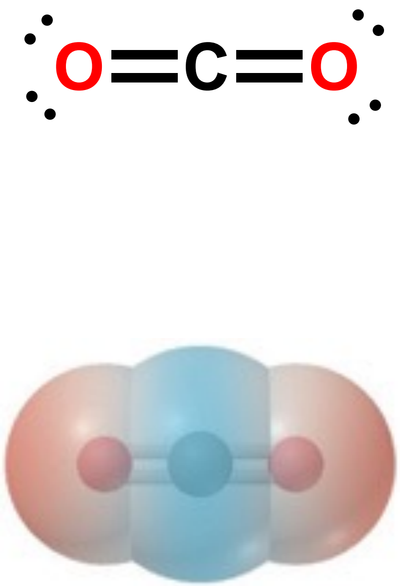
* "add up" the individual bond dipoles *

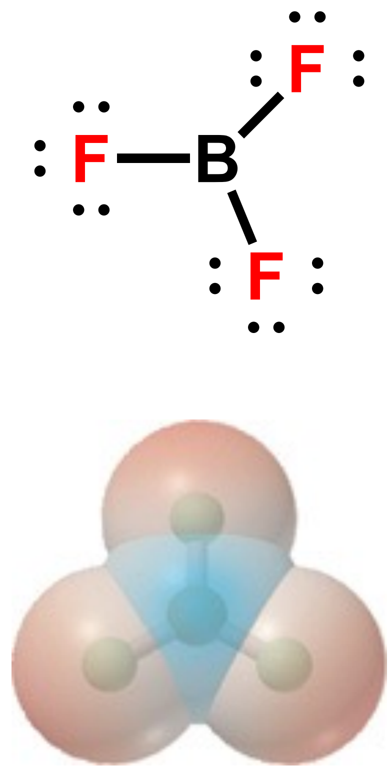


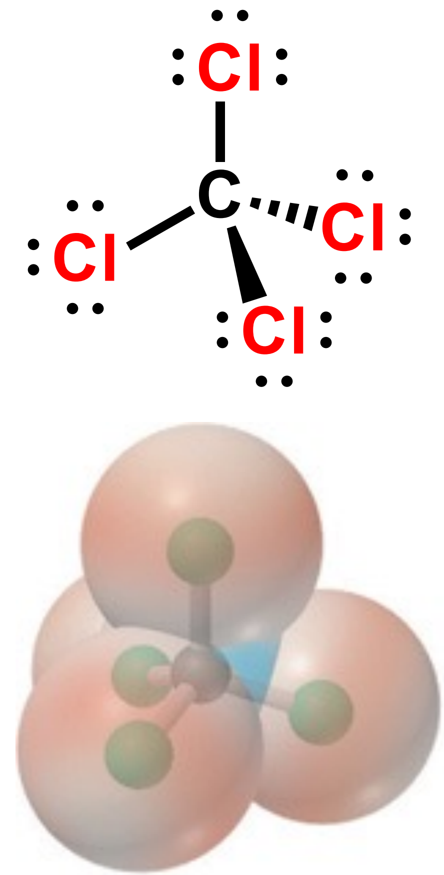
Polarity of Molecules

Based on the difference in χ (**Δχ**) between two atoms a **bond** can be described as polar (unequal sharing of electrons) or non-polar

NONPOLAR MOLECULES: molecules with **zero** net dipole moment (μ)
Either no individual bond dipoles or the individual bond dipoles cancel out







IMF 1: Ion-Dipole Force

1. Ion-Dipole Forces

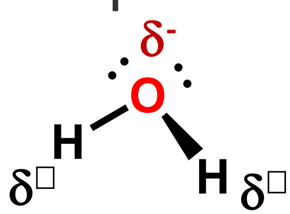
Attractive force between an ion and a polar molecule (dipole) (adding salt to water).

These are between molecules from **two different compounds** (for example: between solute and solvent)

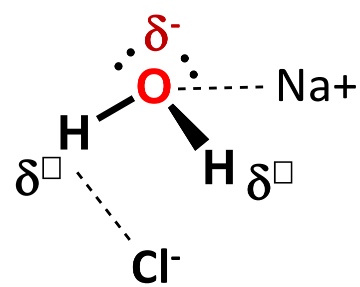
Ionic compound

NaCl, Na^+, Cl^-

Water: Polar compound



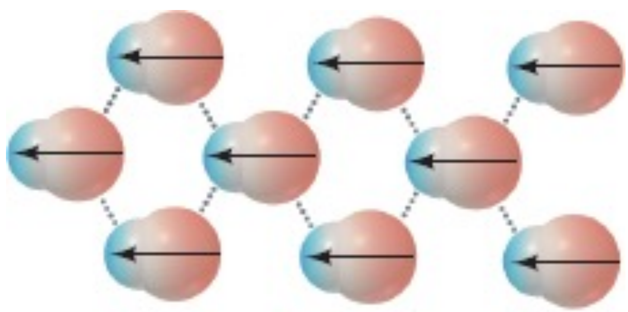
Ionic Salts dissolve in water due to the attraction between ions and the polar water molecules



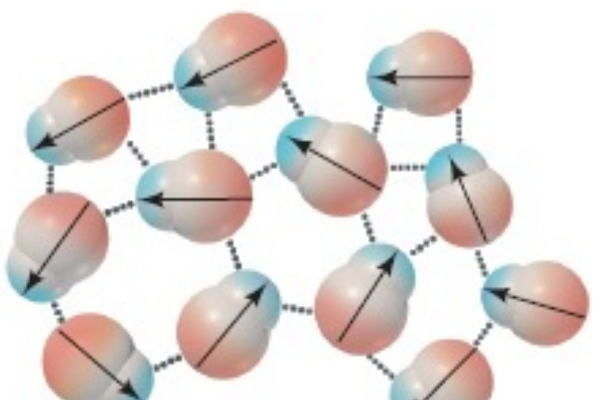
IMF 2: Dipole-Dipole Force

2. Dipole-Dipole Forces

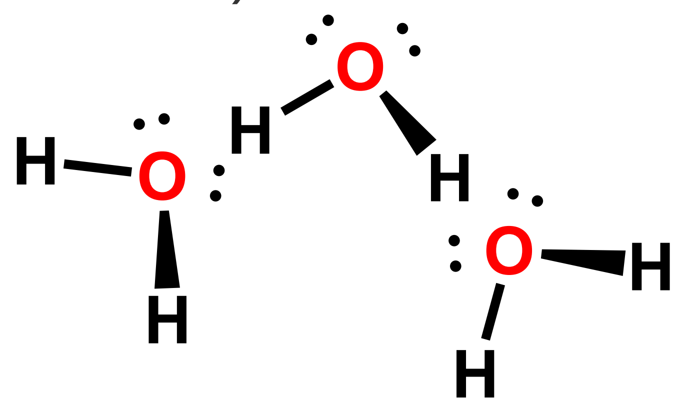
In the presence of an external field, positive pole of a polar molecule attracts the negative pole of another (only in polar molecules or between polar molecules)

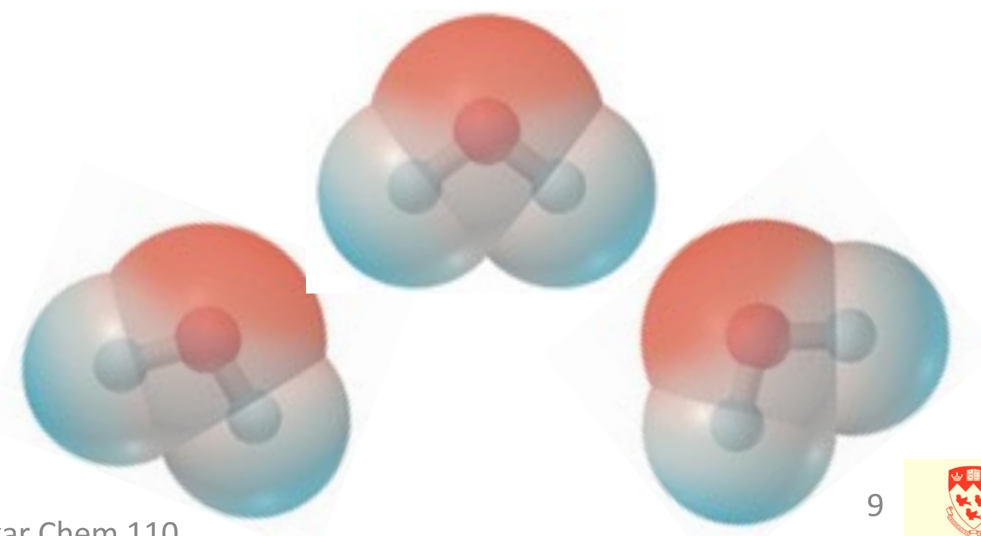


Solid



Liquid

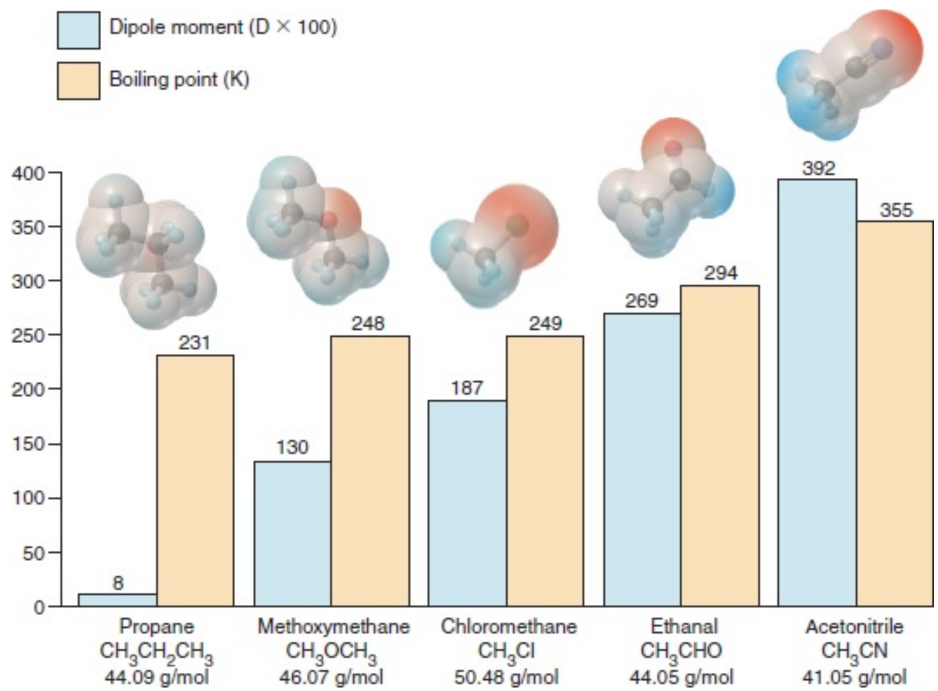




IMF 2: Dipole-Dipole Force

2. Dipole-Dipole Forces

For compounds of similar molar masses, the greater the molecular dipole moment, the greater the dipole-dipole forces, so the more energy it takes to separate the molecules **- higher boiling point**



IMF 2: Hydrogen Bonding (type of dipole-dipole force)

2.a Hydrogen Bonding (type of dipole-dipole force)

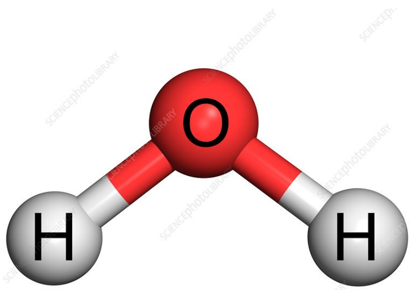
A special case of dipole force
Only when H-atom is bonded to a *small highly electronegative atom* with lone pairs.

H-atom directly bonded to N, O, and F

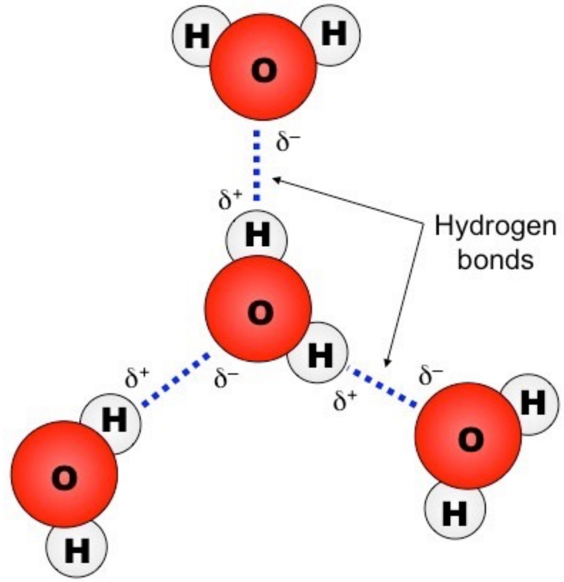
Why is H-bonding so special?

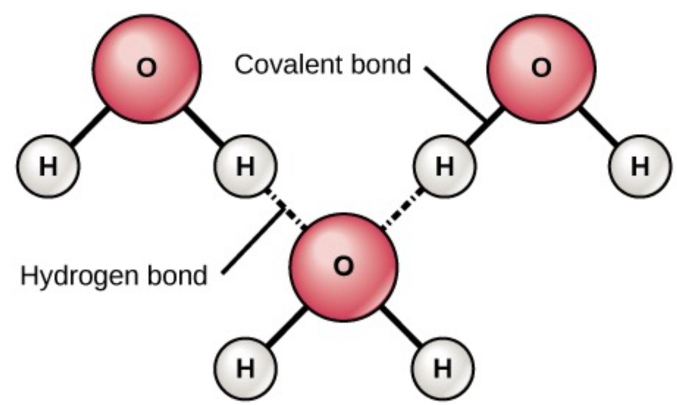
1. N,O, F most electronegative atoms - the covalently bonded H is highly (delta) positive
2. This force between delta positive (H) and delta negative(N, O, or F) is quite large (there is no shielding from other electrons as H only has one electron)

Hydrogen Bonding Practice



No hydrogen bond





Importance of Hydrogen Bonding

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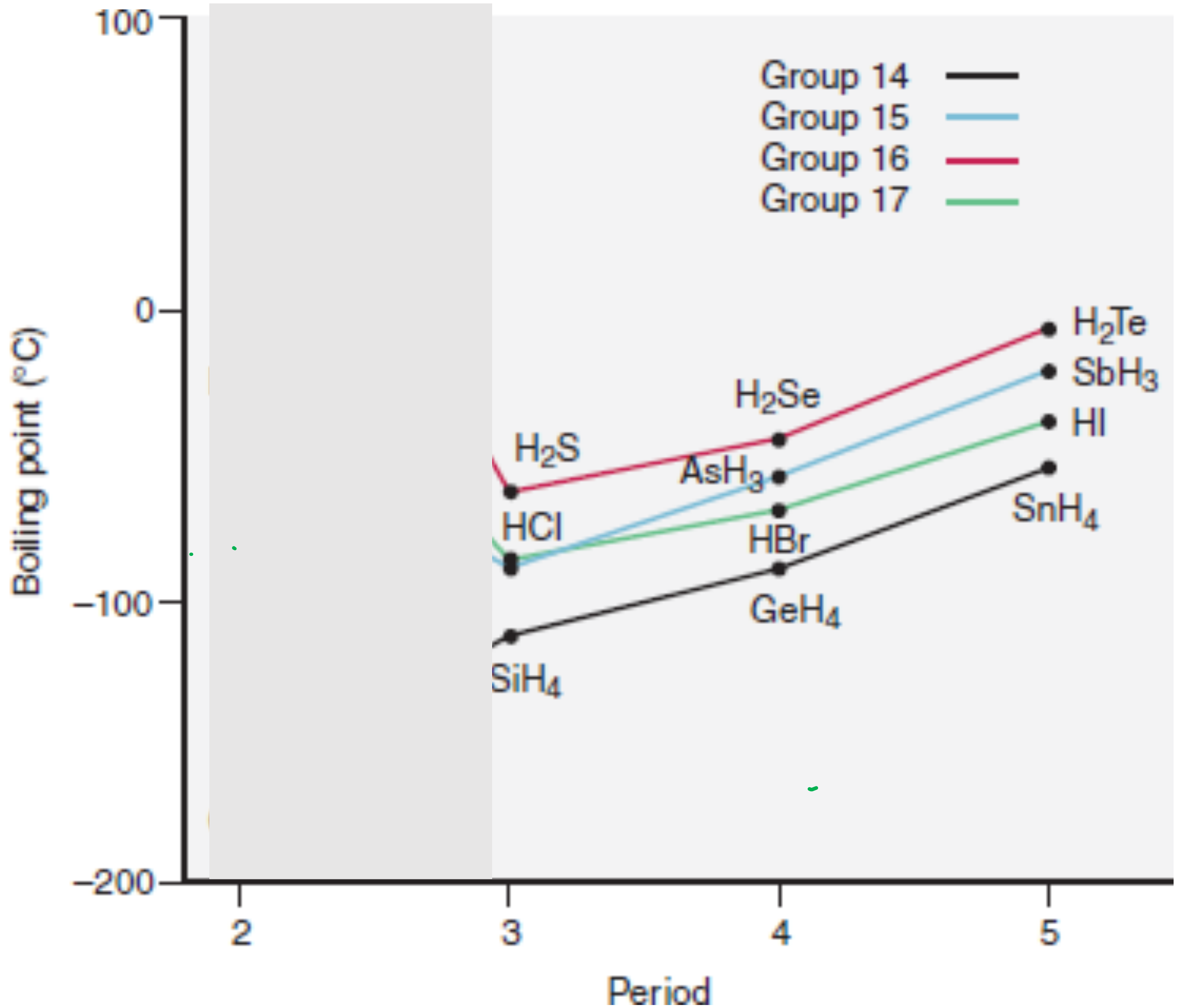
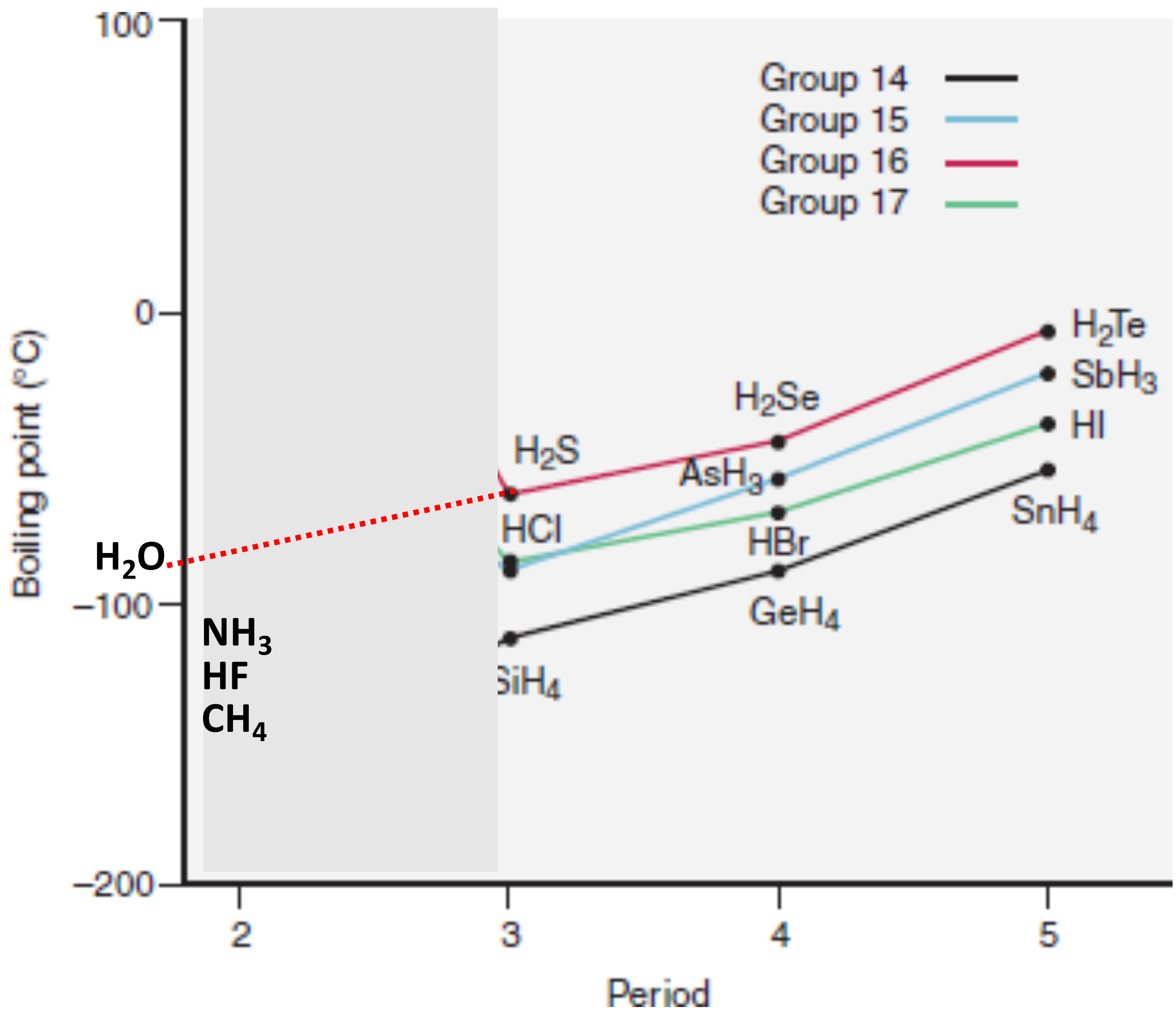


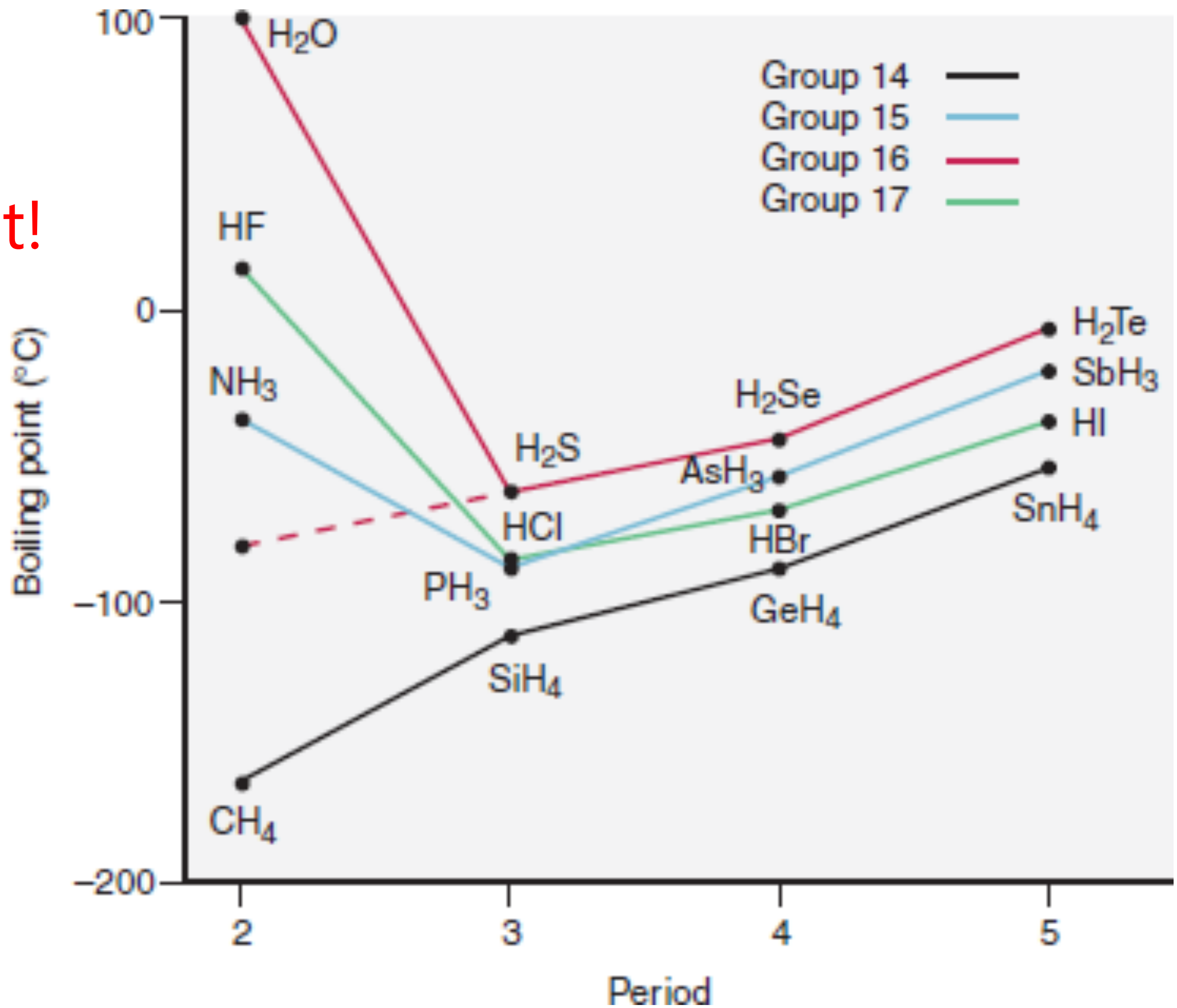
Importance of Hydrogen Bonding

If water did not have H-bonding its boiling point would have been about -100 °C



Importance of Hydrogen Bonding

Water has a really high boiling point!



Polarizability

How easily can an electron cloud be distorted

Down a group: Polarizability increases

Across a period: Polarizability decreases

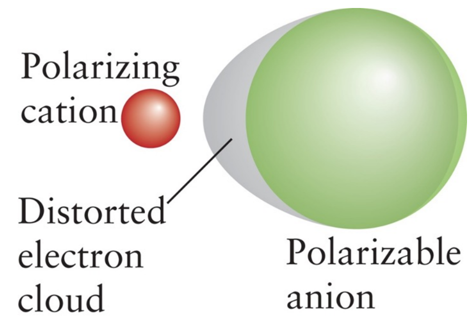


Figure 2D.4
Atkins, *Chemical Principles: The Quest for Insight*, 7e
W. H. Freeman & Company, © 2016 by P. W. Atkins, L. L. Jones, and L. E. Laverman

Cations: Less polarizable than their atoms

Anions: More polarizable than their atoms

Induced Dipoles in Molecules

Induced Dipole (cause for Dispersion Forces)

A nearby electric field can *induce* a distortion in the electron cloud

For a polar molecule — The distortion *enhances* the dipole moment

For a non polar molecule — The distortion *induces* a dipole moment

Ion – induced dipole
Intermolecular force of interaction between an Ion and neutral molecule

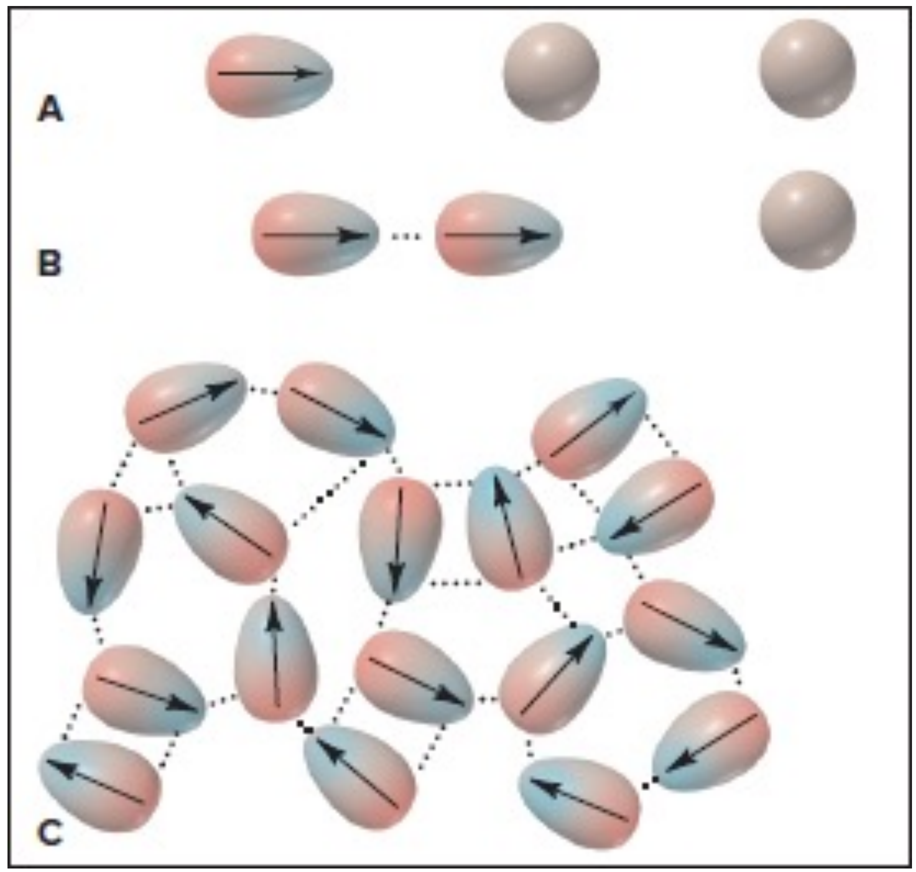
Dipole – induced dipole
Intermolecular force of interaction between a polar molecule and neutral molecule

IMF 3: Dispersion Force (all molecules have these forces)

3. Dispersion Forces or London Dispersion Forces

Forces responsible for the condensed states of nonpolar molecules : What is holding nonpolar molecules together?

Fritz London

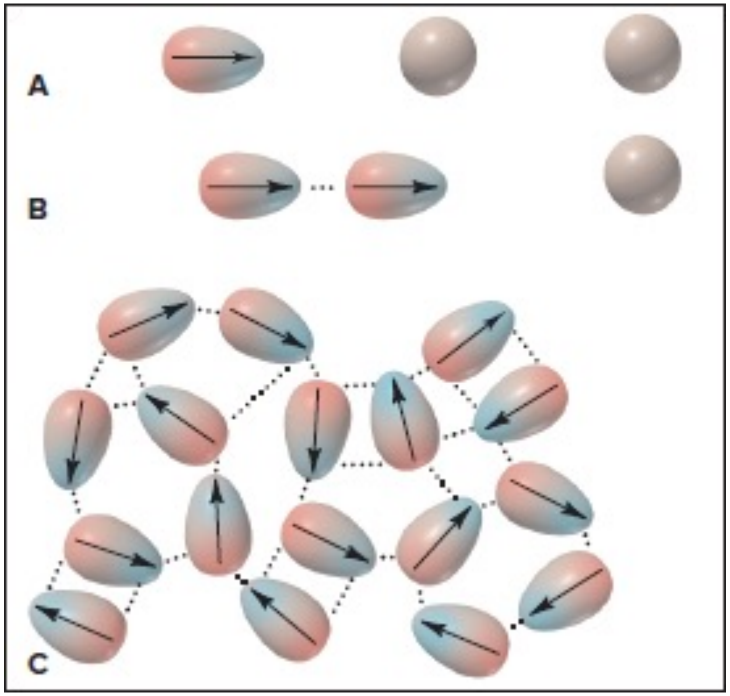


IMF 3: Dispersion Force (all molecules have these forces)

A. If nonpolar molecules far apart – no effect on each other.

B. When they're close together – they can induce an instantaneous dipole

C. At low temperatures molecules are closer together

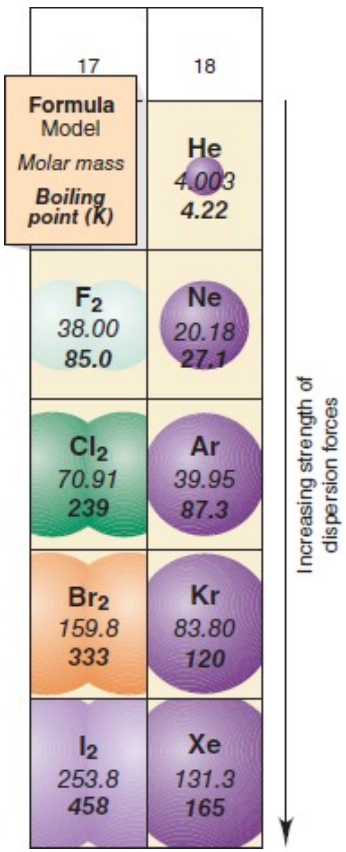


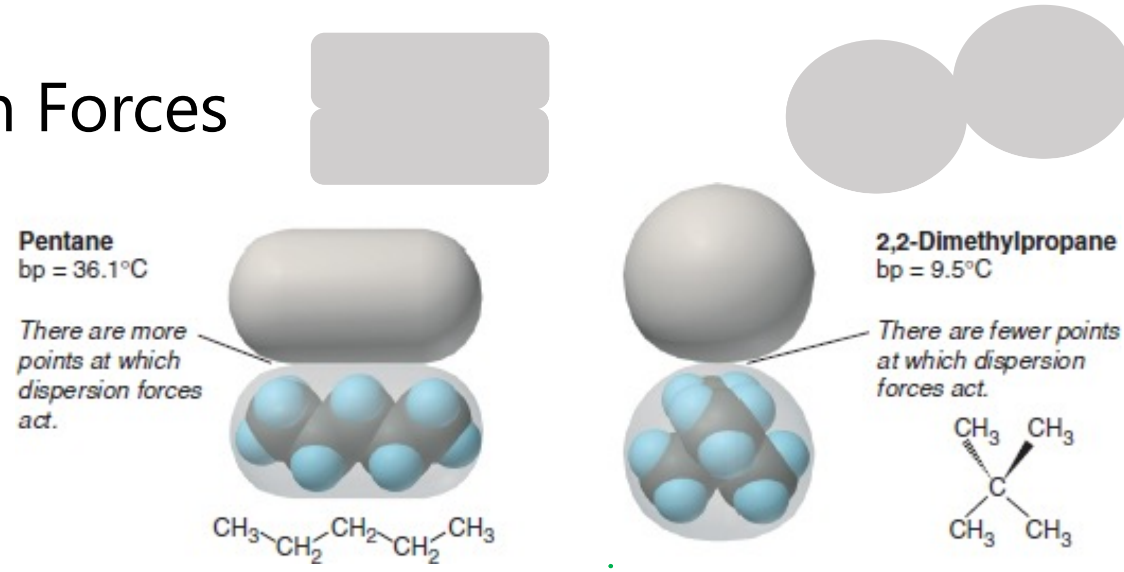
What causes dispersion forces? Instantaneous induced dipole-dipole forces

All molecules have dispersion forces.
Nonpolar molecules **<u>only have</u>** London Dispersion Forces.
Weakest intermolecular forces

Dispersion Forces: Comparing nonpolar molecules

Factors affecting Dispersion Forces





Molecular Formula: C_5H_{12}

Effect of molecular shape:
When molecules make more contact with each other: Dispersion forces increase

Relative Strength: Depends on the **polarizability** of the particles. So weak for small particles (like He) but stronger for larger particles

Summary of Intermolecular Forces

Force	Model	Basis of Attraction	Energy (kJ/mol)	Example
Nonbonding (Intermolecular)				
Ion-dipole		Ion charge–dipole charge	40–600	$Na^{+}\cdots O(H)_2$
H bond	$\overset{\delta^-}{—A}—\overset{\delta^+}{H}\cdots\cdots\overset{\delta^-}{:B}—$	Polar bond to H–dipole charge (high EN of N, O, F)	10–40	$:\ddot{O}(H)—H\cdots:\ddot{O}(H)—H$
Dipole-dipole		Dipole charges	5–25	$I—Cl\cdots I—Cl$
Ion–induced dipole		Ion charge–polarizable e^- cloud	3–15	$Fe^{2+}\cdots O_2$
Dipole–induced dipole		Dipole charge–polarizable e^- cloud	2–10	$H—Cl\cdots Cl—Cl$
Dispersion (London)		Polarizable e^- clouds	0.05–40	$F—F\cdots F—F$

Comparing intermolecular forces between molecules

1. Determine which intermolecular forces are present

2. H-bonding > dipole-dipole > dispersion forces
(**<u>All molecules</u>** have dispersion forces)

3. If comparing two non-polar molecules, compare polarizability (size) and shape (surface area).

4. Compare properties
High intermolecular forces – High boiling point/high surface tension/high viscosity