Chapter 11 part 1: Intermolecular forces

**Read:** BLB 11.1–2; 11.6

**HW:** BLB 11.9, 15, 21, 23, 25, 27; Supplemental 11.1–4

**Know:**
- intermolecular forces
  1. electrostatic interactions
  2. dispersion forces
  3. dipole-dipole interactions
  4. hydrogen bonds (H-bonds)

**What Bonus Deadlines are coming up??**

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**When is Exam 2?? ______________**

**Where do I go for Exam 2?? ______________**

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**Which homework/reading am I finished with?**

- [ ] Molecular Composition
- [ ] Organic
- [ ] Geometry, VSEPR, Polarity
- [ ] Hybrid orbitals, Bond Types, Resonance
- [ ] Intermolecular Forces

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**INTERMOLECULAR (IM) FORCES**

**Noncovalent interactions**

- **chemical bonds:** intramolecular forces
  150–1100 kJ/mol

- **intermolecular (IM) forces**
  1–50 kJ/mol

- **intermolecular interactions:** forces that hold covalent molecules together in groups

- **general classes of IM interactions:**
  1. electrostatic interactions
  2. dispersion forces
  3. dipole-dipole interactions
  4. hydrogen bonds (H-bonds)
Why doesn’t everything exist as a gas??

**Kinetic Molecular Description of Liquids and Solids**

**gas:**
Kinetic energy >> intermolecular forces

**liquid:**
Kinetic energy ~ intermolecular forces

**solid:**
Kinetic energy << intermolecular forces

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**IMF = Non-covalent Interactions**

<table>
<thead>
<tr>
<th>Type of Interaction</th>
<th>Strength (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical bonds</td>
<td>150-1100</td>
</tr>
<tr>
<td>Intermolecular (IM) forces</td>
<td>1-50</td>
</tr>
</tbody>
</table>

Relative strengths of intermolecular forces can be seen experimentally:

- What kind of attraction?
- What happens as intermolecular distances decrease?

**Strength of IM forces depends on:**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>charge on ion</td>
</tr>
<tr>
<td>μ</td>
<td>dipole moment</td>
</tr>
<tr>
<td>α</td>
<td>polarizability</td>
</tr>
</tbody>
</table>

**Define Polarizability:**

α increases as ____________________

α increases as ____________________
### TYPES OF INTERMOLECULAR FORCES

<table>
<thead>
<tr>
<th>Type</th>
<th>Depends on</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion-Ion</td>
<td>Q</td>
<td>Ionic bond</td>
</tr>
<tr>
<td>Ion-Dipole</td>
<td>Q, μ</td>
<td>Ions in aqueous solutions of electrolytes</td>
</tr>
<tr>
<td>Dipole-Dipole</td>
<td>μ</td>
<td>Polar molecules in nonpolar solvents</td>
</tr>
<tr>
<td>Ion-Induced Dipole</td>
<td>Q, α</td>
<td>Ions in nonpolar solvents</td>
</tr>
<tr>
<td>Dipole-Induced Dipole</td>
<td>μ, α</td>
<td>Polar molecules in nonpolar solvents</td>
</tr>
<tr>
<td>Dispersion</td>
<td>α</td>
<td>Induced-dipole induced dipole</td>
</tr>
<tr>
<td>Hydrogen Bonding</td>
<td></td>
<td>Directional dipole-dipole</td>
</tr>
</tbody>
</table>

**Hydrogen Bonding**
- must have H bonded
- DIRECTLY to N, O, or F

**ELECTROSTATIC FORCES**

- **Ion-Ion**
  \[ E \propto \frac{Q_1 Q_2}{d} \]

- **Ion-Dipole**
  \[ E \propto \frac{Q \mu}{d^2} \]

- **Dipole-Dipole**
  \[ E \propto \frac{\mu_1 \mu_2}{d^3} \]
LONDON DISPERSION FORCES (LDF)

\[ E \propto \frac{\alpha_1 \alpha_2}{d^6} \]

Induced Dipoles:

\[ \begin{align*}
\text{Na}^+ & \quad \text{Ar} \\
\text{+} & \quad \text{+} & \quad \delta^- & \quad \delta^+ \\
\text{Ar} & \quad \text{Na}^+ \\
\end{align*} \]

London Dispersion forces = Induced dipoles - induced dipoles forces

Ease of electronic distortion is:

What's happening to the electrons?
Is there a dipole moment?
What happens to neighboring molecules?

ALL molecules have LDF Interactions

\[
\text{Ar} \ \ || \ \ H-\text{Cl} \quad \text{Cl}-\text{H} \quad \text{in addition to dipole-dipole} 
\]

Dispersion forces are related to:

1. 
2. 

Size is related to:

![Graph showing boiling points of different molecules](image)

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Chapter 11
SHAPE Affects the amount that two molecules can interact (the more interaction, the more LDF):

5-Carbon Alkanes

n-pentane BP = 36.2°C

C—C—C—C—C (straight chain)

neopentane BP = 9.5°C

C—C

(neopentane (bp = 99.4°C)

2-methyl butane is in between:

BP = 28°C

C—C—C—C

(neopentane (bp = 309.4 K)

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Are Alkanes polar?

What kind of IMF?
Effect of Hydrogen “Bonding” on BP of water

The effect of hydrogen bonding is also seen in the abnormally high boiling points of \( \text{NH}_3 \) and \( \text{HF} \).

Hydrogen Bonding

- H bonded directly to a very electronegative atom (N, O, F) interacts with lone electron pairs on N, O, F of another molecule.
  - H bond energies are ~ 4-25kJ/mole
  - Strong IMF’s
  - Weak compared to covalent bonds, but are “directional” like covalent bonds.

Hydrogen Bonding Explains:
- why ice floats on water
- double helix in DNA
- \( \alpha \)-helix in proteins

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**Importance of H bonding in DNA & RNA**

**Polymers:** high molecular wt. materials formed from many small molecules called _________ (repeating unit).

**nucleotides:**
- 4 organic bases: bind specifically in pairs

DNA double helix is held together by hydrogen bonding interactions.

α-Helix structure for a protein is held together by hydrogen bonding interactions.
How do you know which has the strongest IM forces?

- **compare B.P. and M.P.**
  Higher B.P. (M.P.) means stronger IM forces

- **If substances are similar, follow trends.**
  Example: inert gases
  Is shape different?
  What happens to BP as MW increases?

- **If trends compete, need BP or MP**

<table>
<thead>
<tr>
<th>Eg.</th>
<th>CH₃Cl</th>
<th>CH₃Br</th>
<th>CH₃I</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>–24.2°C</td>
<td>3.6°C</td>
<td>42.4°C</td>
</tr>
<tr>
<td>μ increases</td>
<td>size (polarizability) increases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  **London Dispersion forces dominate here**

### Energies of Interaction Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Example ε (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covalent</td>
<td>C—C</td>
</tr>
<tr>
<td>Electrostatic</td>
<td></td>
</tr>
<tr>
<td>ion-ion</td>
<td>Na⁺ ——Cl⁻</td>
</tr>
<tr>
<td>ion-dipole</td>
<td>Na⁺ ——CF₃H</td>
</tr>
<tr>
<td>dipole-dipole</td>
<td>CF₃H —— CF₃H</td>
</tr>
<tr>
<td>London dispersion</td>
<td>CF₄ ——CF₄</td>
</tr>
<tr>
<td>Hydrogen Bonding</td>
<td>H₂O ——H₂O</td>
</tr>
</tbody>
</table>
### IMF Effect on BP

<table>
<thead>
<tr>
<th>Type</th>
<th>Example</th>
<th>BP(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covalent</td>
<td>C(graphite)</td>
<td>4827</td>
</tr>
<tr>
<td>Ion-ion</td>
<td>NaCl</td>
<td>1413</td>
</tr>
<tr>
<td>H-bonding</td>
<td>H₂O</td>
<td>100</td>
</tr>
<tr>
<td>Dipole-Dipole</td>
<td>CHF₃</td>
<td>−82</td>
</tr>
<tr>
<td>London Dispersion</td>
<td>CF₄</td>
<td>−129</td>
</tr>
</tbody>
</table>

- **What happens to all intermolecular interactions at the boiling point?**
- **What happens to the BP if the interaction is strongest?**

![Flowchart for determining intermolecular forces](image.png)
Which intermolecular forces are important in the **hydrocarbon**?

1. LDF only  
2. LDF and dipole-dipole  
3. LDF, dipole-dipole, H-bonding  
4. only dipole-dipole  
5. only H-bonding

Which intermolecular forces are important in the **carboxylic acid**?

1. LDF only  
2. LDF and dipole-dipole  
3. LDF, dipole-dipole, H-bonding  
4. only dipole-dipole  
5. only H-bonding

Which intermolecular forces are important in the **aldehyde**?

1. LDF only  
2. LDF and dipole-dipole  
3. LDF, dipole-dipole, H-bonding  
4. only dipole-dipole  
5. only H-bonding