Chapter 6 Lecture

General, Organic, and Biological Chemistry: An Integrated Approach

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Chapter 6

Intermolecular Forces: State Changes, Solubility, and Cell Membranes

Chapter Outline

6.1 Types of Intermolecular Forces

- ***Intermolecular forces*** are attractive forces between molecules that occur when there is a variation in the electron distribution in a molecule.
- Intermolecular forces are weaker than the weakest covalent bonds.
- Intermolecular forces arise when a partially negative charge on a molecule is attracted to a partially positive charge on another molecule.

6.1 Types of Intermolecular Forces, Continued

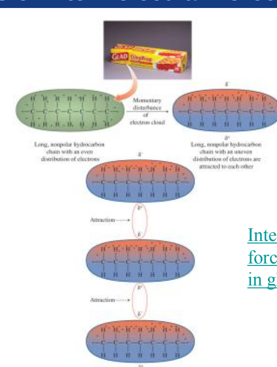
London Forces

- ***London forces*** occur momentarily in all molecules when electrons become unevenly distributed over a molecule's surface.
- A temporary unequal charge, or ***induced dipole***, is momentarily created in a molecule that attracts the electrons of a second molecule, creating an attraction between these two molecules.

6.1 Types of Intermolecular Forces, Continued

- London forces are significant only in nonpolar molecules because they are the only intermolecular force occurring in nonpolar molecules.
- Plastic wraps are made of long chain, nonpolar hydrocarbons. When plastic wrap folds back on itself, these long chains interact with each other creating a ***temporary dipole***. This temporary dipole causes the wrap to stick to itself.

6.1 Types of Intermolecular Forces, Continued



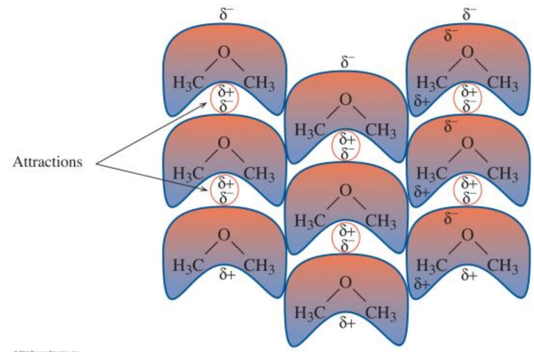
Intermolecular forces (LONDON) in ghecko feet

6.1 Types of Intermolecular Forces, Continued

Dipole–Dipole Attractions

- ***Dipole–dipole attractions*** occur between the dipoles of two polar molecules and are caused by the permanent, uneven distribution of electrons, which is caused by the electronegativity differences of atoms in the molecule.
- These attractions are stronger than London forces because the dipoles of polar molecules is permanent.

6.1 Types of Intermolecular Forces, Continued



6.1 Types of Intermolecular Forces, Continued

- Dipole–dipole attractions do not exist between nonpolar molecules.
- Polar molecules also have London forces, but the attraction of the dipoles is much stronger, making the London forces negligible.

6.1 Types of Intermolecular Forces, Continued

Hydrogen Bonding

- Some molecules have a strong attraction to each other due to a large dipole that arises from the partial charges on particular atoms.
- This force is known as ***hydrogen bonding***. It is a very strong dipole–dipole attraction between two molecules and involves hydrogen.

6.1 Types of Intermolecular Forces, Continued

- Hydrogen bonding requires the interaction between two molecules, a donor and an acceptor.
- Requirements for hydrogen bonding are shown in the following table.

REQUIREMENTS FOR HYDROGEN BONDING

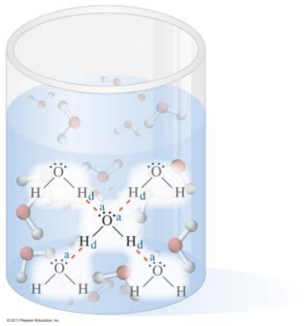
Name	Description
Hydrogen-bond donor (δ^+)	A molecule with a hydrogen atom covalently bonded to an oxygen, nitrogen, or fluorine (O, N, or F)
Hydrogen-bond acceptor (δ^-)	A molecule with a nonbonding pair of electrons on an oxygen, nitrogen, or fluorine (O, N, or F)

6.1 Types of Intermolecular Forces, Continued

- The high electronegativity of O, N, and F polarizes the hydrogen atom of the donor with a partial positive charge.
- This partial positive charge strongly attracts the high partial negative charge on the nonbonding electron pair of O, N, or F on the acceptor.
- This type of polarization and attraction, shown on the next slide, occurs between water molecules.

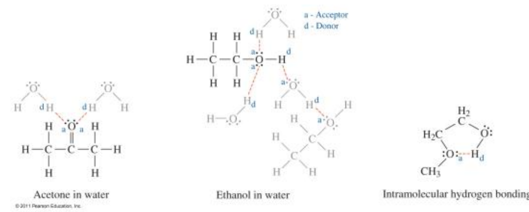
6.1 Types of Intermolecular Forces, Continued

Hydrogen Bonding in Water



6.1 Types of Intermolecular Forces, Continued

Hydrogen bonding occurs between the same molecules as seen in water, between two different polar molecules, or even between different parts of the same molecule.



6.1 Types of Intermolecular Forces, Continued

Ion–Dipole Attraction: A Similar Attractive Force

- An ***ion-dipole attraction*** is an attraction of an ion to the opposite partial charge on a polar molecule.
- This type of attraction occurs when table salt is dissolved in water. The sodium ion is attracted to the partial negative charge of water, and the chloride ion is attracted to the partial positive charge of water.

6.1 Types of Intermolecular Forces, Continued

An ion–dipole attraction plays an important role in the solubility of ionic compounds.

6.2 Intermolecular Forces and Solubility

The Golden Rule of Solubility

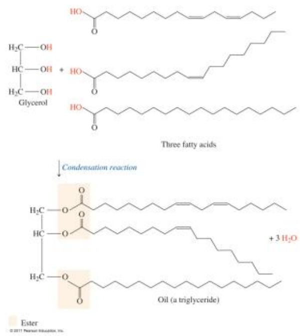
- The ***golden rule of solubility—***like dissolves like—means that molecules that are similar will dissolve each other.
- Molecules that have similar polarity and participate in the same types of intermolecular forces will dissolve each other.

6.2 Intermolecular Forces and Solubility, Continued

Applying the Golden Rule to Nonpolar Compounds

- Oil and water do not mix.
- Dietary oils, known as ***triglycerides***, are nonpolar organic compounds formed through the condensation reaction of glycerol with three fatty acids. This reaction is called ***esterification*** because an ester functional group is formed.

6.2 Intermolecular Forces and Solubility, Continued



6.2 Intermolecular Forces and Solubility, Continued

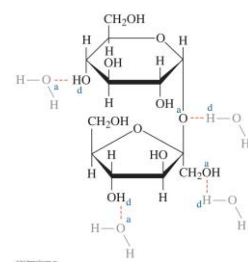
- Oils are nonpolar and attracted to neighboring molecules through London forces. Since water is polar, oil and water do not interact with each other, and therefore, they do not dissolve in each other.
- The attraction forces between water molecules are much greater than the attraction forces between a water molecule and an oil molecule.
- If a bottle of oil and vinegar salad dressing are mixed the contents will separate upon standing.

6.2 Intermolecular Forces and Solubility, Continued

Applying the Golden Rule to Polar Compounds

- When table sugar is added to water, it will dissolve. The hydroxyl groups on the sugar molecule make it a polar molecule.
- The hydroxyl groups of sugar interact with water through hydrogen bonding. Dipole–dipole interactions also occur.

6.2 Intermolecular Forces and Solubility, Continued



6.2 Intermolecular Forces and Solubility, Continued

Applying the Golden Rule to Ionic Compounds

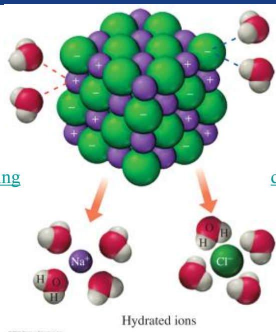
- Ion–dipole attractions can exist between water and ions.
- The intermolecular attractions between water and ionic compounds are stronger than the attractions between water and polar covalent compounds. This strong attraction often makes ionic compounds more soluble in water than covalent compounds.

6.2 Intermolecular Forces and Solubility, Continued

- The ion–dipole attractions between ions of an ionic compound and water are so strong that the ionic bond between ions is disrupted.
- When multiple water molecules interact with an ion, the sum of these attractive forces is greater than the strength of the ionic bonds.
- When an ionic compound, such as sodium chloride, interacts with water, a process known as ***hydration*** occurs, during which ions are surrounded by water molecules.

6.2 Intermolecular Forces and Solubility, Continued

NaCl dissolving



dissolve NaCl

6.2 Intermolecular Forces and Solubility, Continued

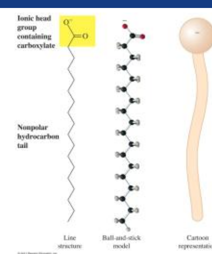
The Unique Chemistry of Soap

- Soap molecules undergo intermolecular attractive forces.
- Soaps are composed of fatty acid salts, which are ionic compounds. The carboxylic acid functional group in fatty acid salts are ionic because they contain the carboxylate form of the functional group.

6.2 Intermolecular Forces and Solubility, Continued

- The charge on the carboxylate group makes this end of the molecule ionic and polar. The remaining part of the molecule is nonpolar.
- Molecules like soap have a polar and nonpolar end and are known as ***amphipathic compounds***.

6.2 Intermolecular Forces and Solubility, Continued

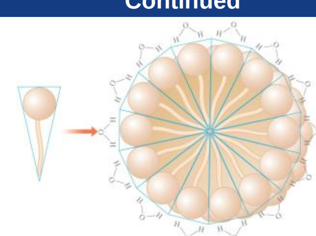


Amphipathic compounds do not dissolve in water. The nonpolar tails are ***hydrophobic*** (water fearing) and are excluded from water.

6.2 Intermolecular Forces and Solubility, Continued

- The ionic head of a soap molecule is ***hydrophilic*** (water loving) and interacts with water through ion–dipole interactions.
- Nonpolar hydrocarbon tails of soap interact with each other and form a core of a spherical molecule known as a ***micelle***. Water is excluded from the inner core.
- The polar heads interact with water and form the outer shell of this micelle.

6.2 Intermolecular Forces and Solubility, Continued



Soap works by trapping grease and dirt, which are nonpolar, in the inner core of the micelle, which then washes it away with water surrounding the outer shell.

6.3 Intermolecular Forces and Changes of State

Heat and Intermolecular Forces

- Intermolecular forces between two molecules are stronger when they are moving slowly than when they are moving more rapidly.
- When a substance is heated, its molecules move more rapidly, resulting in a decrease in the intermolecular forces between molecules.

6.3 Intermolecular Forces and Changes of State, Continued

- When a solid is heated, it melts to form a liquid, and when a liquid is heated, it evaporates to form a gas.
- These transitions are called ***changes of state*** or ***phase transitions***.
- The application of heat to a substance causes its molecules to move faster (kinetic energy), which disrupts the intermolecular forces holding the molecules together and causes a change from one state to another.

6.3 Intermolecular Forces and Changes of State, Continued

Boiling Points and Alkanes

- Why do compounds that are similar boil at different temperatures?
- First, we need to understand what happens at the molecular level during boiling.

6.3 Intermolecular Forces and Changes of State, Continued

- The temperature at which all molecules of a substance change from a liquid to a gas is called the ***boiling point***.
- Two things must happen during the boiling process:
  1. Molecules of the substance must push back the molecules of the atmosphere at the liquid surface.
  2. Molecules must overcome the attractive forces so they can move into the gas phase.

6.3 Intermolecular Forces and Changes of State, Continued

- Heat supplied during boiling provides the energy necessary to overcome these two tasks.

- The molecules of the atmosphere stay the same no matter what the liquid surface is, so the difference between boiling points must be due to the intermolecular forces.

6.3 Intermolecular Forces and Changes of State, Continued

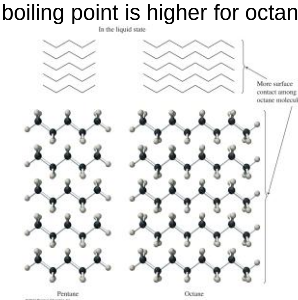
- Consider the two alkanes, pentane and octane. Pentane boils at 36 ºC and octane boils at 125 ºC.
- Pentane is a five-carbon, straight-chain alkane, whereas octane is an eight-carbon, straight-chain alkane.
- Both are nonpolar molecules that only exhibit London forces.

6.3 Intermolecular Forces and Changes of State, Continued

- Because octane is a larger molecule than pentane, there is more surface area for molecular interaction.
- The larger surface area means that stronger London forces are exhibited by octane molecules than the forces seen in a smaller molecule like pentane.
- The stronger attraction forces between molecules must be overcome in order for the compound to boil.

6.3 Intermolecular Forces and Changes of State, Continued

More heat is necessary to disrupt these attractions, which means the boiling point is higher for octane than for pentane.



6.3 Intermolecular Forces and Changes of State, Continued

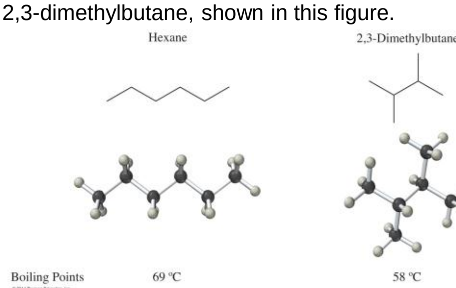
This table shows the boiling point of some common straight-chain alkanes. As the number of carbon atoms increases, the boiling point increases.

TABLE 6.1 BOILING POINTS OF COMMON STRAIGHT-CHAIN ALKANES

Name	Structure	Boiling Point °C
Methane	CH_4	−161
Ethane	CH_3CH_3	−89
Propane		−42
Butane		−0.5
Pentane		36
Hexane		69
Heptane		98
Octane		125
Nonane		151
Decane		174

6.3 Intermolecular Forces and Changes of State, Continued

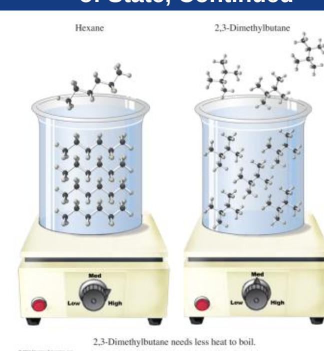
Consider the alkanes, hexane and 2,3-dimethylbutane, shown in this figure.



6.3 Intermolecular Forces and Changes of State, Continued

- These two compounds are structural isomers and have the same number of carbon atoms.
- Hexane is a straight-chain alkane and 2,3-dimethylbutane is a branched-chain alkane.
- Hexane has a boiling point of 69 °C and 2,3-dimethylbutane has a boiling point of 58 °C.
- This difference is due to the differences in surface area of the two molecules.

6.3 Intermolecular Forces and Changes of State, Continued



2,3-Dimethylbutane needs less heat to boil.

6.3 Intermolecular Forces and Changes of State, Continued

- Hexane has a larger surface area, which results in stronger London forces than those occurring in 2,3-dimethylbutane. Hexane molecules can also get closer together than the bulky 2,3-dimethylbutane molecules.
- More energy (heat) is required to overcome these stronger attractions in hexane, resulting in a higher boiling point, when compared to the boiling point of 2,3-dimethylbutane.

6.3 Intermolecular Forces and Changes of State, Continued

- For alkanes with the same number of carbon atoms, boiling point increases from branched chain to straight-chain to cycloalkanes
  - 2,2-dimethylbutane b.p.= 50 °C
  - 2,3-dimethybutane b.p.= 58 °C
  - Hexane b.p.= 69 °C
  - Cyclohexane b.p.= 81 °C

6.3 Intermolecular Forces and Changes of State, Continued

The Unusual Behavior of Water

- Water is a small molecule with only three atoms. Compare it to propane, which has 11 atoms.
- In terms of surface area, one might think that water would have a lower boiling point than propane. However, water boils at 100 °C, and propane boils at -42 °C. Something other than surface area accounts for this difference.

6.3 Intermolecular Forces and Changes of State, Continued

- Water molecules are held together through hydrogen bonding, which is a much stronger force than the London forces observed in propane.
- More heat is required to disrupt the hydrogen bond interaction in water.
- More heat required means higher boiling point.

