Chem 103, Section F0F
Unit VII - States of Matter and Intermolecular Interactions
Lecture 19

- Physical states and physical changes
- Description of phase changes
- Intermolecular interactions
- Properties of Liquids
- Unique Properties of water

Lecture 18 - Covalent Bonding

Reading in Silberberg

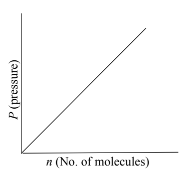
- Chapter 12, Section 1
  - *An Overview of Physical States and Phase Changes*
- Chapter 12, Section 2 (pp. 440-443)
  - *Quantitative Aspects of Phase Changes*
- Chapter 12, Section 3
  - *Types of Intermolecular Forces*

Introduction

In lab we have investigated the properties of gases

- We have used the Atomic Microscope to simulate gases as colliding spheres.
- We looked at
  - Pressure as a function of the number of atoms (or molecules) (Avogadro's Law)

$$P \propto n$$

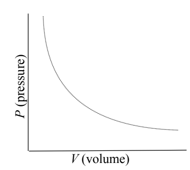


Introduction

In lab we have investigated the properties of gases

- We have used the Atomic Microscope to simulate gases as colliding spheres.
- We looked at
  - Pressure as a function of volume (Boyle's Law)

$$P \propto \frac{1}{V}$$

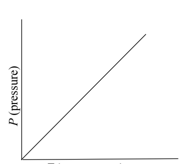


Introduction

In lab we have investigated the properties of gases

- We have used the Atomic Microscope to simulate gases as colliding spheres.
- We looked at
  - Pressure as a function of the temperature (Charles's Law)

$$P \propto T$$



Introduction

These laws can be be combined into the Ideal Gas Law

$$P \propto \frac{nT}{V}$$

$$P = \frac{nRT}{V} \quad (R = \text{Ideal Gas Law Constant})$$

$$PV = nRT$$

Introduction

The properties of gases is determined primarily by their kinetic energy, E_k.

- Molecules are attracted to one another by intermolecular forces, which also gives them potential energy, E_p.
- When the potential energy becomes greater than the kinetic energy, then **condensed phases**, such as liquids and solids, will form.

Physical States and Phase Changes

For a substance made up of molecules, there are two types of forces:

- **Intramolecular forces**
  - Which are *within* the molecule
    - ionic bonds
    - covalent bonds
    - metalic bonds
  - They hold the molecule together (bonding forces) and influence a substance's *chemical properties*.
- **Intermolecular forces**
  - Which are *between* the molecules
  - They influence a substance's *physical properties*.

Physical States and Phase Changes

When a substance changes phases (gas, liquid solid),

- It is the intermolecular forces that change
  - Not the *intramolecular* forces.
- The chemical behavior of the three states are identical.
  - These are determined by the *intramolecular* forces
    - ionic bond
    - covalent bonds
    - metallic bonds

Physical States and Phase Changes

A Kinetic view of states

- The attractive potential energy that is derived from the intermolecular forces arises primarily from electrostatic interactions.
- The strength the these forces is given by Coulomb's Law and is inversely proportional to the distance that separates the molecules.

$$E_p \propto \frac{q_1 \bullet q_2}{r^x}$$

where q_1 and q_2 are two charges

and r is the distance separating them

Physical States and Phase Changes

The intermolecular potential energy behaves like the intramolecular energy (bond energy).

- Instead of internuclear distances, we are interested instead in intermolecular distances.

Physical States and Phase Changes

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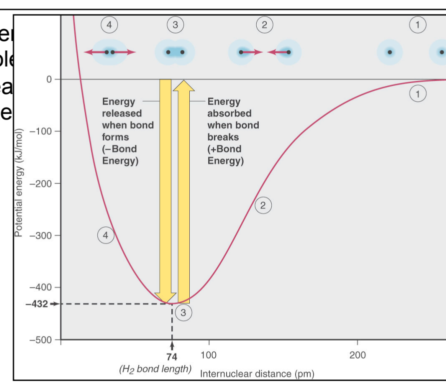

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Physical States and Phase Changes

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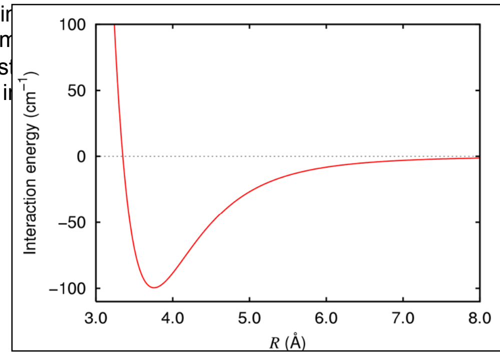


Physical States and Phase Changes

The intermolecular potential energy behaves like the intramolecular energy (bond energy).

- Instead of internuclear distances, we are interested instead in intermolecular distances.

Physical States and Phase Changes

A Kinetic view of states

- At the same time, these attractive interactions are disrupted by the the kinetic energy of the molecules, which is proportional to the absolute temperature.

$$E_k \propto T$$

Physical States and Phase Changes

A Kinetic view of states

- The three common states of matter are determined by the interplay between kinetic energy, E_k, and potential energy, E_p.

Gas: $E_k >> E_p$

Liquid: $E_k \approx E_p$

Solid: $E_k << E_p$

Physical States and Phase Changes

A Kinetic view of states

- The three common states of matter are determined by the interplay between kinetic energy, E_k, and potential energy, E_p.

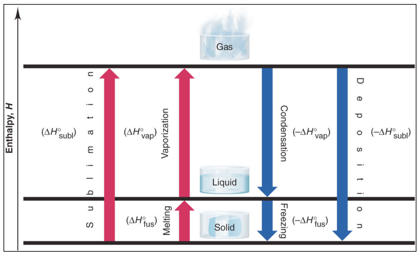
Table 12.1 A Macroscopic Comparison of Gases, Liquids, and Solids

State	Shape and Volume	Compressibility	Ability to Flow
Gas	Conforms to shape and volume of container	High	High
Liquid	Conforms to shape of container; volume limited by surface	Very low	Moderate
Solid	Maintains its own shape and volume	Almost none	Almost none

Physical States and Phase Changes

During phase changes

- The heat that is added is used to disrupt the intermolecular interactions and raise the potential energy between the molecules.



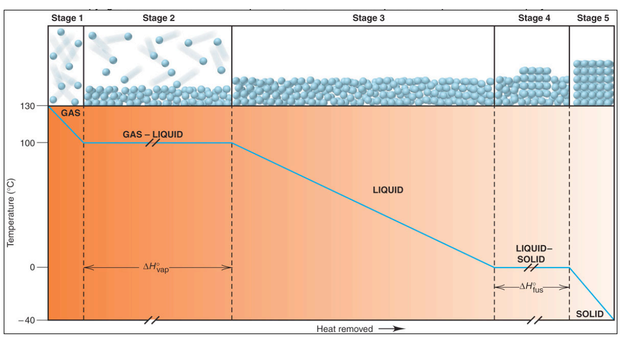
Physical States and Phase Changes

During phase changes

- The heat that is added is used to disrupt the intermolecular interactions and raise the potential energy between the molecules.
  - The heat energy required to convert a solid to a liquid is called the heat of fusion (ΔH^o_{fus}).
  - The heat energy required to convert a liquid to a gas is called the heat of vaporization (ΔH^o_{vap}).
  - The heat energy required to convert a solid to a gas is called the heat of sublimation (ΔH^o_{sub})
    - By Hess's Law $\Delta H^o_{sub} = \Delta H^o_{fus} + \Delta H^o_{vap}$.

The Quantitative Aspects of Phases Changes

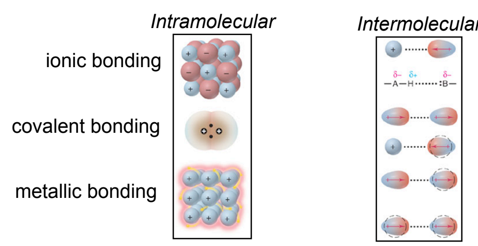
The heating-cooling curve:



Types of Intermolecular Forces

Both the intramolecular (bonding) and intermolecular forces are due electrostatic attractions.

- The relative magnitude of these forces are different
  - Bonding forces involve larger charges that are closer together
  - Intermolecular forces involve partial charges that are farther apart.



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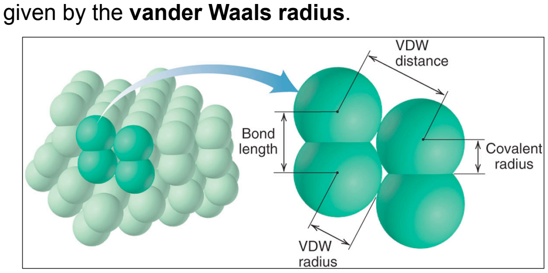
Types of Intermolecular Forces

Nonbonding atoms cannot approach as close together as bonding atoms.

- The distance of closest approach for non-bonding atoms is given by the **vander Waals radius**.



Types of Intermolecular Forces

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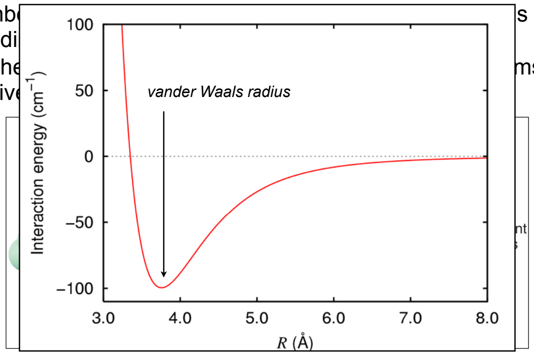

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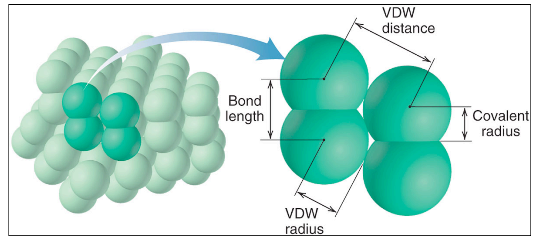

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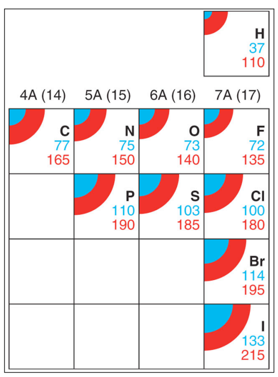
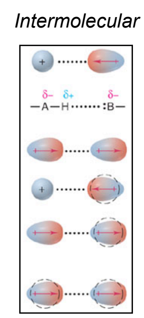


Types of Intermolecular Forces

The types of intermolecular forces include
- ion-dipole
- dipole-dipole
- hydrogen bonding
- dipole-induced dipole
- dispersion (induced dipole-induced dipole)

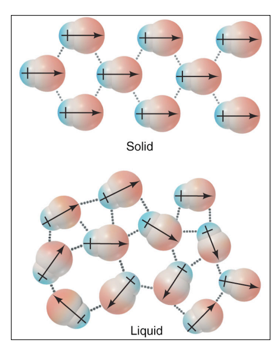


Types of Intermolecular Forces

The types of intermolecular forces
- Ion-dipole

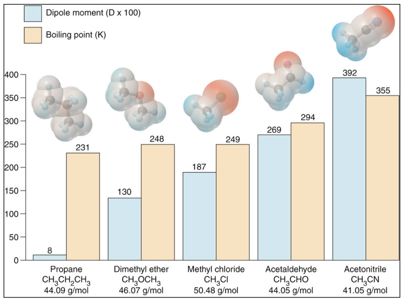
Types of Intermolecular Forces

The types of intermolecular forces
- Dipole-dipole



Types of Intermolecular Forces

The types of intermolecular forces
- Dipole-dipole



Types of Intermolecular Forces

The types of intermolecular forces
- Hydrogen bonds
  - Are a special type of dipole-dipole interaction
  - A hydrogen bond is formed when a hydrogen atom is shared between two strongly electronegative atoms
    - One of which the hydrogen atom is covalent bonded to (the donor)
    - The other of which has a lone pair of electrons (the acceptor)

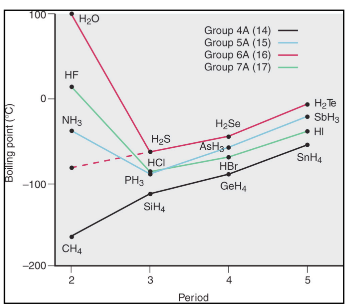
—B : ------H—A—

acceptor donor

- The donor and acceptor atoms need to be small and highly electronegative.
  - This limits the choices to N, O or F

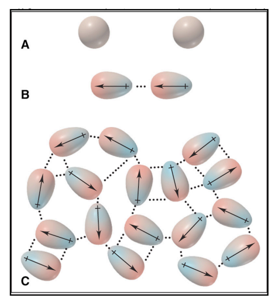
Types of Intermolecular Forces

The types of intermolecular forces
- Hydrogen bonds



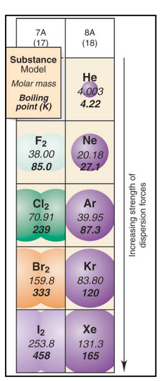
Types of Intermolecular Forces

The types of intermolecular forces
- Induced dipole/Induced dipole (London Dispersion Forces)



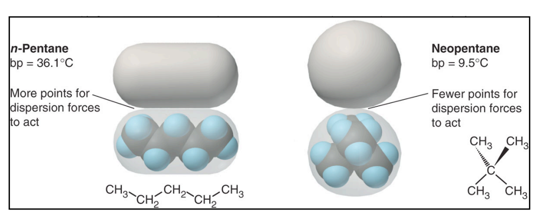
Types of Intermolecular Forces

The types of intermolecular forces
- Induced dipole/Induced dipole (London Dispersion Forces)
  - The magnitude of the force increases with the size of the molecules.



Types of Intermolecular Forces

The types of intermolecular forces
- Induced dipole/Induced dipole (London Dispersion Forces)
  - The magnitude of the force increases with the size of the molecules.
  - More specifically, the size of the surface that comes into contact.



Types of Intermolecular Forces

The types of intermolecular forces

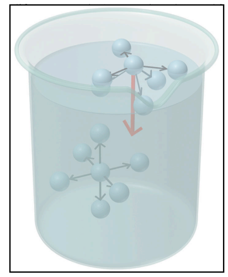
Table 12.2 Comparison of Bonding and Nonbonding (Intermolecular) Forces

Force	Model	Basis of Attraction	Energy (kJ/mol)	Example
Nonbonding (Intermolecular)				
Ion-dipole		Ion charge–dipole charge	40–600	$Na^+ \cdots OH_2$
H bond	$\delta-$ $\delta+$ $\delta-$ —A—H······:B—	Polar bond to H–dipole charge (high EN of N, O, F)	10–40	:Ö—H···:Ö—H (each O bonded to H)
Dipole-dipole		Dipole charges	5–25	I—Cl···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···Cl—Cl
Dispersion (London)		Polarizable e^- clouds	0.05–40	F—F···F—F

Properties of Liquid State

Surface tension

- Molecules at the surface experience a *net* downward attractions



Properties of Liquid State

Surface tension

- Molecules at the surface experience a *net* downward attractions

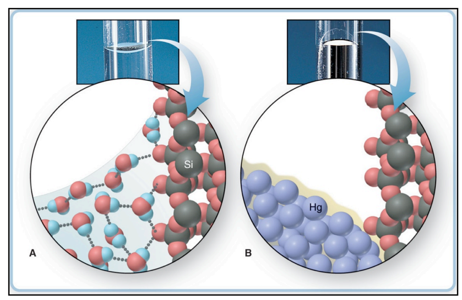
Table 12.3 Surface Tension and Forces Between Particles

Substance	Formula	Surface Tension (J/m^2) at 20°C	Major Force(s)
Diethyl ether	$CH_3CH_2OCH_2CH_3$	1.7×10^{-2}	Dipole-dipole; dispersion
Ethanol	CH_3CH_2OH	2.3×10^{-2}	H bonding
Butanol	$CH_3CH_2CH_2CH_2OH$	2.5×10^{-2}	H bonding; dispersion
Water	H_2O	7.3×10^{-2}	H bonding
Mercury	Hg	48×10^{-2}	Metallic bonding

Properties of Liquid State

Capillary Actions

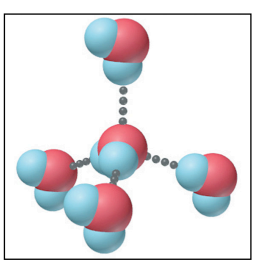
- Molecules in a liquid are attracted to other surfaces.



Uniqueness of Water

Compared to other molecule with similar composition, water displays a rather unique set of properties.

- A very good solvent for dissolving polar and ionic substances.
- Has a very high heat capacity
  - Can store a lot of heat energy



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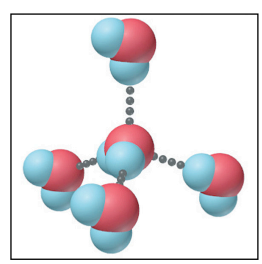
Compared to other molecule with similar composition, water displays a rather unique set of properties.

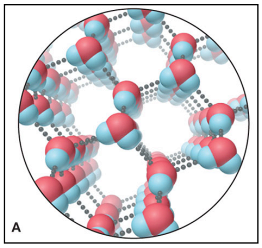
- A very good solvent for dissolving polar and ionic substances.
- Has a very high heat capacity
  - Can store a lot of heat energy
- Has high surface tension
- Has high capillary action



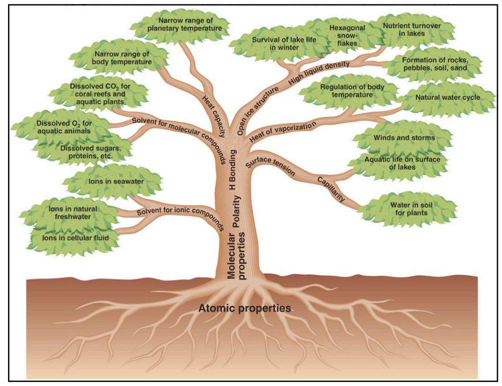
Uniqueness of Water

Compared to other molecule with similar composition, water displays a rather unique set of properties.

- Solid state is less dense than the liquid state.
  - Ice floats !!!



Uniqueness of Water



Unit VII - Up Next

The Lab Practical Exam (This Week)

The Final (Wed., 17. December, 1:00pm - 2:50pm)

The End