Chapter 7. Gases, Liquids, and Solids

Introduction to Inorganic Chemistry
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Online Tests on Following days
March 24, 2017: Test 1 (Chapters 1-3)
April 10, 2017 : Test 2 (Chapters 4-5)
April 28, 2017: Test 3 (Chapters 6,7 &8)
May 12, 2017 : Test 4 (Chapters 9, 10 &11)
May 15, 2017: Make Up Exam: Chapters 1-11)

.

Chapter 7

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Section 7.1

The Kinetic Molecular Theory of Matter

Common Physical Properties of Matter

- Volume and Shape
- Density
- Compressibility
- Thermal Expansion

These properties are explained by(**KMT**)

Section 7.1

The Kinetic Molecular Theory of Matter

Compressibility

- A measure of the change in volume of a sample of matter resulting from a pressure change.

Section 7.1

The Kinetic Molecular Theory of Matter

Thermal Expansion

- A measure of the change in volume of a sample of matter resulting from a temperature change.

Section 7.1

The Kinetic Molecular Theory of Matter

Distinguishing Properties of Solids, Liquids, and Gases

Table 7.1 Distinguishing Properties of Solids, Liquids, and Gases

Property	Solid State	Liquid State	Gaseous State
volume and shape	definite volume and definite shape	definite volume and indefinite shape; takes the shape of its container to the extent that it is filled	indefinite volume and indefinite shape; takes the volume and shape of the container that it completely fills
density	high	high, but usually lower than corresponding solid	low
compressibility	small	small, but usually greater than corresponding solid	large
thermal expansion	very small: about 0.01% per °C	small: about 0.10% per °C	moderate: about 0.30% per °C

Section 7.1

The Kinetic Molecular Theory of Matter

Kinetic Molecular Theory of Matter

1. Matter is composed of tiny particles (atoms, molecules, or ions) that have definite and characteristic sizes that do not change.

Section 7.1

The Kinetic Molecular Theory of Matter

Kinetic Molecular Theory of Matter

2. The particles are in constant random motion and therefore possess kinetic energy.
   - Kinetic energy – energy that matter possesses because of particle motion.

Section 7.1

The Kinetic Molecular Theory of Matter

Kinetic Molecular Theory of Matter

3. The particles interact with one another through attractions and repulsions and therefore possess potential energy.
   - Potential energy – stored energy that matter possesses as a result of its position, condition, and/or composition.
   - Electrostatic interaction – an attraction or repulsion that occurs between charged particles (ultimately responsible for the origin of potential energy)

Section 7.1

The Kinetic Molecular Theory of Matter

Kinetic Molecular Theory of Matter

4. The kinetic energy (velocity) of the particles increases as the temperature is increased.
   – Kinetic energy of particles in a system depends on the temperature (increases with increase in temperature).

Section 7.1

The Kinetic Molecular Theory of Matter

Kinetic Molecular Theory of Matter

5. The particles in a system transfer energy to each other through elastic collisions.

Section 7.1

The Kinetic Molecular Theory of Matter

Differences Among Solids, Liquids, and Gases

- Explained by the relative magnitudes of kinetic energy and potential energy (electrostatic attractions).
- Kinetic energy is a disruptive force that tends to make the particles of a system increasingly independent of one another.
- Potential energy is a cohesive force that tends to cause order and stability among the particles of a system.

Section 7.2

Kinetic Molecular Theory and Physical States

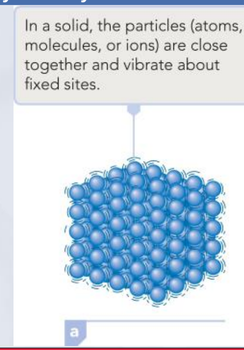
Solid

- The physical state characterized by a dominance of potential energy (cohesive forces) over kinetic energy (disruptive forces).
- Particles in a solid are drawn close together in a regular pattern by the strong cohesive forces present.
- Each particle occupies a fixed position, about which it vibrates because of disruptive kinetic energy.

Section 7.2

Kinetic Molecular Theory and Physical States

Solid



Section 7.2

Kinetic Molecular Theory and Physical States

Definite Volume and Definite Shape

- The strong, cohesive forces hold the particles in essentially fixed positions, resulting in definite volume and definite shape.

Section 7.2

Kinetic Molecular Theory and Physical States

High Density

- The constituent particles of solids are located as close together as possible (touching each other). Therefore, a given volume contains large numbers of particles, resulting in a high density.

Section 7.2

Kinetic Molecular Theory and Physical States

Small Compressibility

- Because there is very little space between particles, increased pressure cannot push the particles any closer together; therefore, it has little effect on the solid's volume.

Section 7.2

Kinetic Molecular Theory and Physical States

Very Small Thermal Expansion

- An increased temperature increases the kinetic energy (disruptive forces), thereby causing more vibrational motion of the particles. Each particle occupies a slightly larger volume, and the result is a slight expansion of the solid. The strong, cohesive forces prevent this effect from becoming very large.

Section 7.2

Kinetic Molecular Theory and Physical States

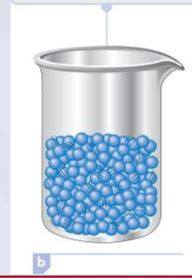
Liquid

- The physical state characterized by potential energy (cohesive forces) and kinetic energy (disruptive forces) of about the same magnitude.
- Particles that are randomly packed but relatively near one another.
- The molecules are in constant, random motion; they slide freely over one another but do not move with enough energy to separate.

Section 7.2

Kinetic Molecular Theory and Physical States

Liquid



The particles in a liquid, though still close together, freely slide over one another.

Section 7.2

Kinetic Molecular Theory and Physical States

Definite Volume and Indefinite Shape

- The attractive forces are strong enough to restrict particles to movement within a definite volume. They are not strong enough to prevent the particles from moving over each other in a random manner that is limited only by the container walls.

Section 7.2

Kinetic Molecular Theory and Physical States

High Density

- The particles in a liquid are not widely separated; they are still touching one another. Therefore, there will be a large number of particles in a given volume – a high density.

Section 7.2

Kinetic Molecular Theory and Physical States

Small Compressibility

- Because the particles in a liquid are still touching each other, there is very little empty space. Therefore, an increase in pressure cannot squeeze the particles much closer together.

Section 7.2

Kinetic Molecular Theory and Physical States

Small Thermal Expansion

- Most of the particle movement in a liquid is vibrational because a particle can move only a short distance before colliding with a neighbor.
- The increased particle velocity that accompanies a temperature increase results only in increased vibrational amplitudes.
- The net effect is an increase in the effective volume a particle occupies, which causes a slight volume increase in the liquid.

Section 7.2

Kinetic Molecular Theory and Physical States

Gas

- The physical state characterized by a complete dominance of kinetic energy (disruptive forces) over potential energy (cohesive forces).
- Attractive forces among particles are very weak and are considered to be zero.
- The particles move essentially independently of one another in a totally random manner.

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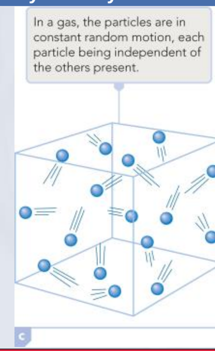
Section 7.2

Kinetic Molecular Theory and Physical States

Gas



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Section 7.2

Kinetic Molecular Theory and Physical States

Indefinite Volume and Indefinite Shape

- The attractive (cohesive) forces between particles have been overcome by high kinetic energy, and the particles are free to travel in all directions.
- Particles completely fill their container and the shape of the gas is that of the container.

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Section 7.2

Kinetic Molecular Theory and Physical States

Low Density

- The particles are widely separated.
- There are relatively few particles in a given volume, which means little mass per volume.

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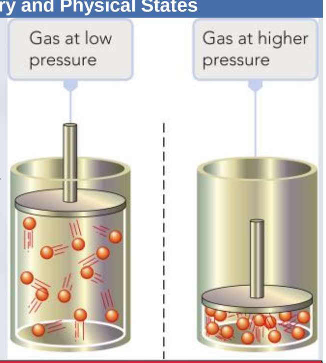
Section 7.2

Kinetic Molecular Theory and Physical States

Large Compressibility

- A gas is mostly empty space. When pressure is applied, the particles are easily pushed closer together, decreasing the amount of empty space and the volume of the gas.



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Section 7.2

Kinetic Molecular Theory and Physical States

Moderate Thermal Expansion

- An increase in temperature means an increase in particle velocity.
- The increased kinetic energy enables the particles to push back whatever barrier is confining them, and the volume increases - the space between the particles changes.

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Section 7.3

Gas Law Variables

Gas Law

- A generalization that describes in mathematical terms the relationships among the following properties of of a gas
- Amount (n, moles)
- Pressure (atm, mm Hg, psi)
- Temperature (K)
- Volume (L)

Section 7.3

Gas Law Variables

Pressure

- The force applied per unit area on an object

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

- 1 atm = 760 mm Hg = 760 torr
- 1 atm = 14.7 psi

Section 7.3

Gas Law Variables

Pressure of a Gas

- The force that creates pressure is that which is exerted by the gas molecules or atoms as they constantly collide with the walls of their container.

Section 7.3

Gas Law Variables

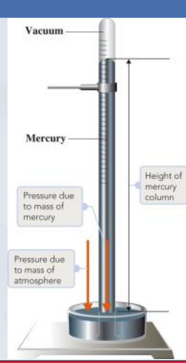
Barometer

- A device used to measure atmospheric pressure.

Section 7.3

Gas Law Variables

Barometer



Section 7.4

Boyle's Law: A Pressure-Volume Relationship

Boyle's Law

- Pressure and volume are inversely related (at constant *T*, temperature, and *n*, # of moles).

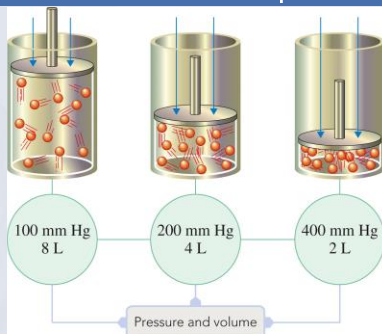
$$P = k\frac{1}{V}\ ;\ P_1 = k\frac{1}{V_1}\ ;\ P_2 = k\frac{1}{V_2}$$

$$P_1 \times V_1 = P_2 \times V_2$$

Section 7.4

Boyle's Law: A Pressure-Volume Relationship

Boyle's Law



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Section 7.4

Boyle's Law: A Pressure-Volume Relationship

Exercise

A sample of helium gas occupies 12.4 L at 23°C and 0.956 atm. What volume will it occupy at 1.20 atm assuming that the temperature stays constant?

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Section 7.4

Boyle's Law: A Pressure-Volume Relationship

Exercise

A sample of helium gas occupies 12.4 L at 23°C and 0.956 atm. What volume will it occupy at 1.20 atm assuming that the temperature stays constant?

$$P_1 \times V_1 = P_2 \times V_2$$
$$(0.956\ \text{atm})(12.4\ \text{L}) = (1.20\ \text{atm})(V_2)$$
$$V_2 = 9.88\ \text{L}$$

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Section 7.5

Charles's Law: A Temperature-Volume Relationship

Charles's Law

- Volume and temperature (in Kelvin) are directly related (at constant *P* and *n;* # of moles).
- K = °C + 273

$$V = kT \;;\; V_1 = kT_1 \;;\; V_2 = kT_2$$
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

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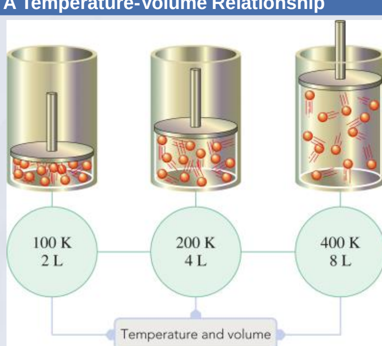
Section 7.5

Charles's Law: A Temperature-Volume Relationship

Charles's Law



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Section 7.5

Charles's Law: A Temperature-Volume Relationship

Exercise

Suppose a balloon containing 1.30 L of air at 24.7°C is placed into a beaker containing liquid nitrogen at –78.5°C. What will the volume of the sample of air become (at constant pressure)?

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Section 7.5

Charles's Law: A Temperature-Volume Relationship

Exercise

Suppose a balloon containing 1.30 L of air at 24.7°C is placed into a beaker containing liquid nitrogen at –78.5°C. What will the volume of the sample of air become (at constant pressure)?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{1.30 \text{ L}}{(24.7 + 273)} = \frac{V_2}{(-78.5 + 273)}$$

$$V_2 = 0.849 \text{ L}$$

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Section 7.6

The Combined Gas Law

- The product of the pressure and volume of a fixed amount of gas is directly proportional to its Kelvin temperature.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

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Section 7.6

The Combined Gas Law

Exercise

At what temperature (in °C) does 121 mL of CO_2 at 27°C and 1.05 atm occupy a volume of 293 mL at a pressure of 1.40 atm?

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Section 7.6

The Combined Gas Law

Exercise

At what temperature (in °C) does 121 mL of CO_2 at 27°C and 1.05 atm occupy a volume of 293 mL at a pressure of 1.40 atm?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(1.05 \text{ atm})(121 \text{ mL})}{(27+273)} = \frac{(1.40 \text{ atm})(293 \text{ mL})}{(T_2 + 273)}$$

$$T_2 = 969 \text{ K} - 273$$

$$T_2 = 696°\text{C}$$

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Section 7.7

The Ideal Gas Law

- Describes the relationships among the four variables – temperature, pressure, volume and molar amount for a gaseous substance (one comprehensive law):

$$PV = nRT$$

(where R = 0.0821 L·atm/mol·K`

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Section 7.7

The Ideal Gas Law

Exercise

An automobile tire at 23°C with an internal volume of 25.0 L is filled with air to a total pressure of 2.18 atm (32 pounds per square inch). Determine the number of moles of air in the tire.

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Section 7.7

The Ideal Gas Law

Exercise

An automobile tire at 23°C with an internal volume of 25.0 L is filled with air to a total pressure of 2.18 atm (32 pounds per square inch). Determine the number of moles of air in the tire.

$$PV = nRT$$
$$(2.18\text{ atm})(25.0\text{ L}) = n(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})(23+273\text{ K})$$
$$n = 2.24\text{ mol}$$

Section 7.7

The Ideal Gas Law

Exercise

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25°C?

Section 7.7

The Ideal Gas Law

Exercise

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25°C?

$$PV = nRT$$
$$(P)(304.0\text{ L}) = \left(\frac{5.670\times 1000}{4.003}\right)(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})(25+273)$$
$$n = 114\text{ atm}$$

Section 7.8

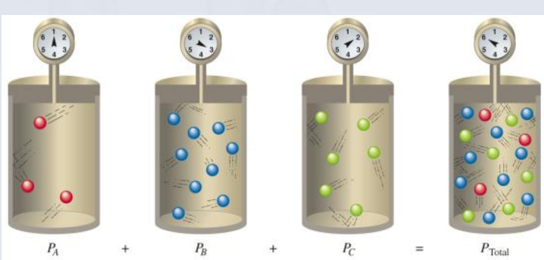
Dalton's Law of Partial Pressures

- For a mixture of gases in a container,

  $P_{Total} = P_1 + P_2 + P_3 + \ldots$
- The total pressure exerted by a mixture of gases is the sum of the partial pressures of the individual gases present.

Section 7.8

Dalton's Law of Partial Pressures



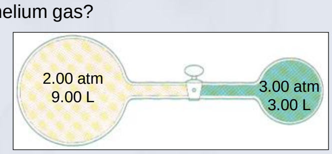
Section 7.8

Dalton's Law of Partial Pressures

Exercise

Consider the following container of helium at 45°C. Initially the valve is closed.

- After the valve is opened, what is the pressure of the helium gas?



Section 7.8

Dalton's Law of Partial Pressures

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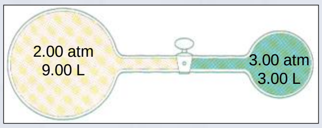


2.25 atm

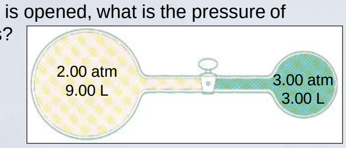
Section 7.8

Dalton's Law of Partial Pressures

Exercise

Consider the following container of helium at 45°C. Initially the valve is closed.

- After the valve is opened, what is the pressure of the helium gas?



Boyel's and Dalton's partial pressure laws

$P_1 \times V_1 = P_2 \times V_2$

① $2 \times 9 = P_2 \times 12$; $P_2 = 1.50$

② $3 \times 3 = P_2 \times 12$; $P_2 = \underline{0.75}$

2.25

Section 7.9

Changes of State

- A process in which a substance is transformed from one physical state to another physical state.
- Usually accomplished by heating or cooling a substance, but pressure can also be a factor.
- Changes of state are examples of physical changes.

Section 7.9

Changes of State

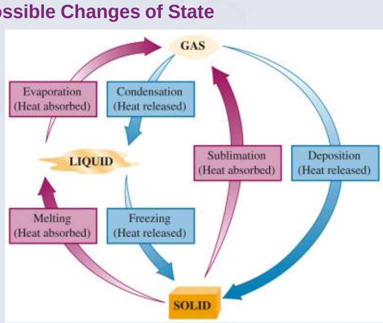
Six Possible Processes Leading to Changes of State

- Melting (Solid to liquid) Endothermic
- Freezing (Liquid to solid) Exothermic
- Evaporation (Liquid to gas) Endothermic
- Condensation (Gas to liquid) Exothermic
- Sublimation (Solid to gas) Endothermic
- Deposition (Gas to solid) Exothermic

Section 7.9

Changes of State

Six Possible Changes of State



Section 7.9

Changes of State

Two Categories

1. Endothermic change of state – change of state in which heat energy is absorbed.
   - Melting
   - Sublimation
   - Evaporation

Section 7.9

Changes of State

Two Categories

2. Exothermic change of state – change of state in which heat energy is given off.
   - Freezing
   - Condensation
   - Deposition

Section 7.10

Evaporation of Liquids

- Process by which molecules escape from the liquid phase to the gas phase.
- For a liquid to evaporate, its molecules must gain enough kinetic energy to overcome the attractive forces among them.

Section 7.10

Evaporation of Liquids

Rate of Evaporation

- Increased surface area results in an increased evaporation rate because a greater fraction of the total molecules are on the surface (so they are not completely surrounded by other molecules with attractive forces).

Section 7.10

Evaporation of Liquids

Rate of Evaporation

- Always increases as liquid temperature increases.
- A cooling effect is produced in the liquid when evaporation occurs.
- Vapor – A gas that exists at a temperature and pressure at which it ordinarily would be thought of as a liquid or solid.

Section 7.11

Vapor Pressure of Liquids

Evaporation of a Liquid in a Closed Container

a) The liquid level drops for a time.
b) Then becomes constant (ceases to drop).
c) Rate of evaporation equals the rate of condensation.

Section 7.11

Vapor Pressure of Liquids

Equilibrium

- A condition in which two opposite processes take place at the same rate.
- No net macroscopic changes can be detected, but the system is dynamic.
- Forward and reverse processes are occurring at equal rates.

Section 7.11

Vapor Pressure of Liquids

Vapor Pressure

- Pressure exerted by a vapor above a liquid when the liquid and vapor are in equilibrium with each other.
- Magnitude of vapor pressure depends on the nature and temperature of the liquid.

Section 7.11

Vapor Pressure of Liquids

Vapor Pressure

- Liquids that have strong attractive forces between molecules have lower vapor pressures than liquids that have weak attractive forces between particles.

Section 7.11

Vapor Pressure of Liquids

Vapor Pressure

- Substances that have high vapor pressures evaporate readily – they are volatile.
  - Volatile substance – a substance that readily evaporates at room temperature because of a high vapor pressure.

Section 7.12

Boiling and Boiling Point

Boiling

- A form of evaporation where conversion from the liquid state to the vapor state occurs within the body of the liquid through bubble formation.
- Occurs when the vapor pressure of the liquid reaches a value equal to that of the prevailing external pressure on the liquid (for an open container it's atmospheric pressure).

Section 7.12

Boiling and Boiling Point

Boiling

Section 7.12

Boiling and Boiling Point

Boiling Point

- The temperature at which the vapor pressure of a liquid becomes equal to the external (atmospheric) pressure exerted on the liquid.
- Normal boiling point – the temperature at which a liquid boils under a pressure of 760 mm Hg.
- Boiling point changes with elevation.

Section 7.12
Boiling and Boiling Point

BP of Water at Various Locations That Differ in Elevation

Table 7.3 Boiling Point of Water at Various Locations That Differ in Elevation

Location	Feet Above Sea Level	Atmospheric Pressure (mm Hg)	Boiling Point (°C)
Top of Mt. Everest, Tibet	29,028	240	70
Top of Mt. McKinley, Alaska	20,320	340	79
Leadville, Colorado	10,150	430	89
Salt Lake City, Utah	4,390	650	96
Madison, Wisconsin	900	730	99
New York City, New York	10	760	100
Death Valley, California	−282	770	100.4

Section 7.12
Boiling and Boiling Point

Concept Check

What is the vapor pressure of water at 100°C? How do you know?

1 atm

Section 7.13
Intermolecular Forces in Liquids

Intramolecular Forces

- Forces "Within" molecules. Chemical bond keeping the molecule together are Intermolecular forces are strong. Eg. H_2O

Section 7.13
Intermolecular Forces in Liquids

Intermolecular Force

- An attractive force that acts between a molecule and another molecule. Eg. Between two H_2O molecules.
- Intermolecular forces are weak compared to intramolecular forces.

Section 7.13
Intermolecular Forces in Liquids

Three Main Types of Intermolecular Forces

- Dipole-dipole interactions (between polar molecules)
- Hydrogen bonds (between strongest polar molecules)
- London forces (between non-polar molecules)

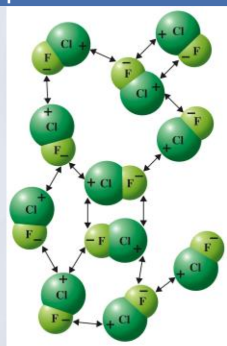
Section 7.13
Intermolecular Forces in Liquids

Dipole-Dipole Interactions

- An IMF that occurs between polar molecules.
- Molecules with dipole moments can attract each other electrostatically by lining up so that the positive and negative ends are close to each other. Eg. ClF
- The greater the polarity of the molecules, the greater the strength of the dipole-dipole interactions.

Section 7.13
Intermolecular Forces in Liquids

Dipole-Dipole Interactions Between ClF Molecules



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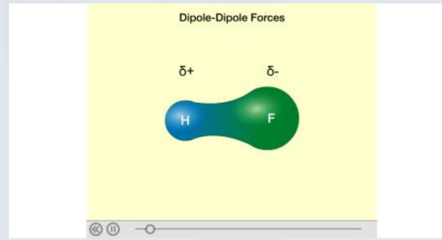
Intermolecular Forces in Liquids

Dipole-Dipole Interactions



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Section 7.13
Intermolecular Forces in Liquids

Hydrogen Bonds

- Unusually strong dipole-dipole interactions are observed among hydrogen-containing molecules in which hydrogen is covalently bonded to a highly electronegative element of small atomic size (fluorine, oxygen, and nitrogen).

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Section 7.13
Intermolecular Forces in Liquids

Two Factors in H_2O molecules

1. The highly electronegative element (O) to which hydrogen is covalently bonded attracts the bonding electrons to such a degree that the hydrogen atom is left with a significant d^+charge.
2. The small size of the “bare” hydrogen nucleus allows it to approach closely, and be strongly attracted to a lone pair of electrons on the electronegative atom of another molecule.

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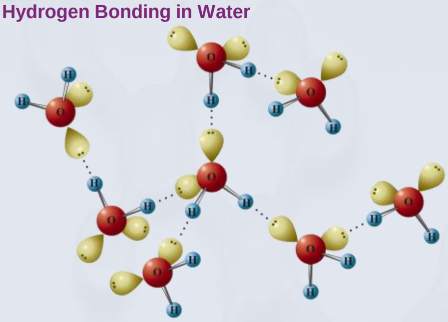
Section 7.13
Intermolecular Forces in Liquids

Hydrogen Bonding in Water



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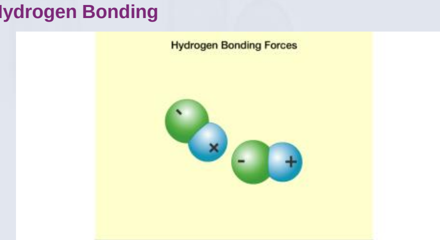
Section 7.13
Intermolecular Forces in Liquids

Hydrogen Bonding



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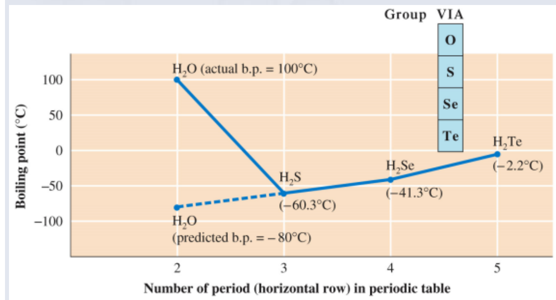
Section 7.13

Intermolecular Forces in Liquids

- The vapor pressures of liquids that have significant hydrogen bonding (N-H, O-H and F-H dipoles) are much lower than those of similar liquids wherein little or no hydrogen bonding occurs.

Section 7.13

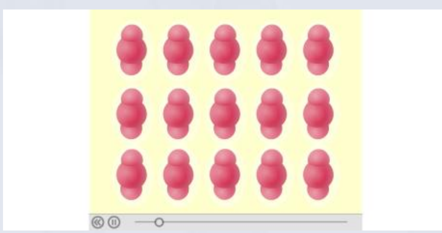
Intermolecular Forces in Liquids



Section 7.13

Intermolecular Forces in Liquids

London Forces: CO_2)



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Section 7.13

Intermolecular Forces in Liquids

London Forces

- A weak temporary intermolecular force that occurs between an atom or molecule (polar or nonpolar) and another atom or molecule (polar or nonpolar).
- Results from momentary uneven electron distributions in molecules.
- Significant in large atoms/molecules.
- Occurs in *all molecules*, including nonpolar ones.

Section 7.13

Intermolecular Forces in Liquids

Boiling Point Trends for Related Series of Nonpolar Molecules

Table 7.5 Boiling Point Trends for Related Series of Nonpolar Molecules: (a) Noble Gases, (b) Halogens

(a) Noble Gases (Group VIIIA Elements)			(b) Halogens (Group VIIA Elements)		
Substance	Molecular Mass (amu)	Boiling Point (°C)	Substance	Molecular Mass (amu)	Boiling Point (°C)
He	4.0	−269	F_2	38.0	−187
Ne	20.2	−246	Cl_2	70.9	−35
Ar	39.9	−186	Br_2	159.8	+59
Kr	83.8	−153			
Xe	131.3	−107			
Rn	222.0	−62			

Section 7.13

Intermolecular Forces in Liquids

Concept Check

Which are stronger, intramolecular bonds or intermolecular forces?

How do you know?

Section 7.13

Intermolecular Forces in Liquids

Concept Check

Which are stronger, intramolecular bonds or intermolecular forces?

How do you know?

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Section 7.13

Intermolecular Forces in Liquids

Concept Check

Which has the stronger intermolecular forces?

N_2 H_2O

Explain.

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Section 7.13

Intermolecular Forces in Liquids

Concept Check

Which has the stronger intermolecular forces?

N_2 H_2O

Explain.

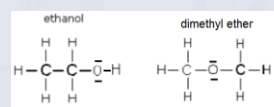
 93

Section 7.13

Intermolecular Forces in Liquids

Concept Check

Draw two Lewis structures for the formula isomers of C_2H_6O; C_2H_5OH and CH_3OCH_3 and compare the boiling points of the two molecules.



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Section 7.13

Intermolecular Forces in Liquids

Concept Check

Which gas would behave more ideally at the same conditions of P and T?

CO or N_2

Why?

 95

Section 7.13

Intermolecular Forces in Liquids

Concept Check

Which gas would behave more ideally at the same conditions of P and T?

CO or N_2

Why?

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