

MODULE 7

Intermolecular Forces

**Ref: Chapter 7 of Textbook, pages
185- 193**

STATES OF MATTER (DISCUSSED IN CHAPTER MATTER)

- A **SOLID** IS THE PHYSICAL STATE CHARACTERIZED BY A DOMINANCE OF POTENTIAL ENERGY (COHESIVE FORCES) OVER KINETIC ENERGY (DISRUPTIVE FORCES).
- A **LIQUID** IS THE PHYSICAL STATE CHARACTERIZED BY POTENTIAL ENERGY (COHESIVE FORCES) AND KINETIC ENERGY (DISRUPTIVE FORCES) OF ABOUT THE SAME MAGNITUDE.
- A **GAS** IS THE PHYSICAL STATE CHARACTERIZED BY A COMPLETE DOMINANCE OF KINETIC ENERGY (DISRUPTIVE FORCES) OVER POTENTIAL ENERGY (COHESIVE FORCES).

FACTORS DETERMINING PHYSICAL STATE

- THE PHYSICAL STATES ARE DETERMINED BY
 - CHEMICAL IDENTITY
 - TEMPERATURE
 - PRESSURE

AT ROOM TEMPERATURE AND PRESSURE LARGE MAJORITY OF THE NATURALLY OCCURRING ELEMENTS ARE SOLIDS (75 OUT OF 88)

11 ARE GASES (H, O, N, F, Cl, He, Ne, Ar, Kr, Xe, Rn)

2 ARE LIQUIDS (Br AND Hg)

PROPERTIES OF PHYSICAL STATES

- SOLID, LIQUIDS AND GASES HAVE FEW DISTINGUISHING FEATURES

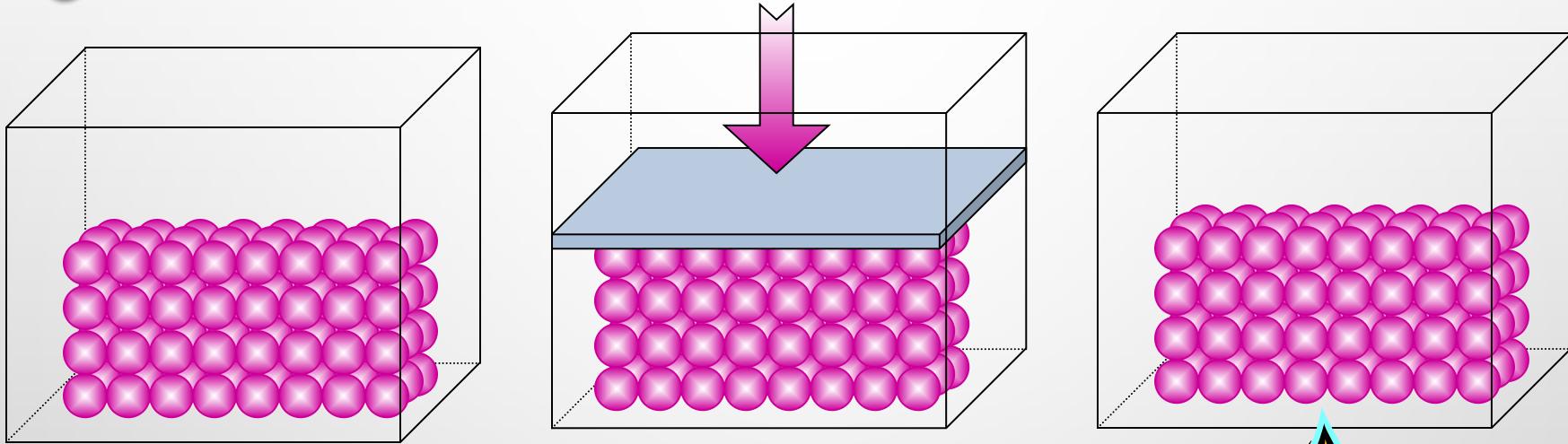
- VOLUME AND SHAPE
- DENSITY
- COMPRESSIBILITY
- THERMAL EXPANSION

ALREADY
DISCUSSED IN
CHAPTER #
Matter

COMPRESSIBILITY IS A MEASURE OF THE VOLUME CHANGE RESULTING FROM A PRESSURE CHANGE.

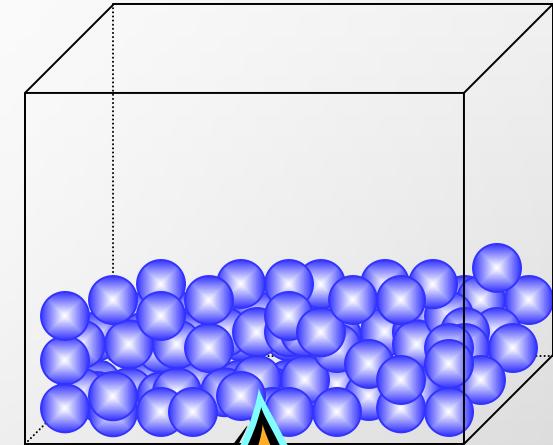
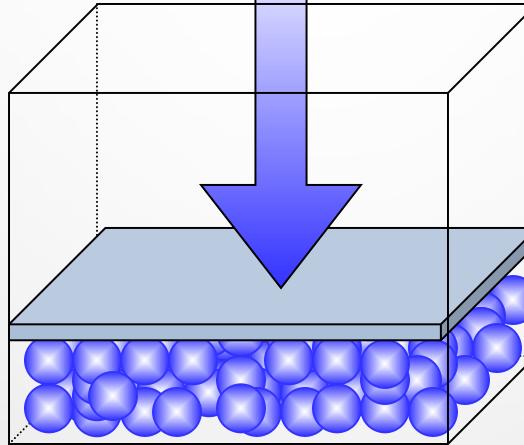
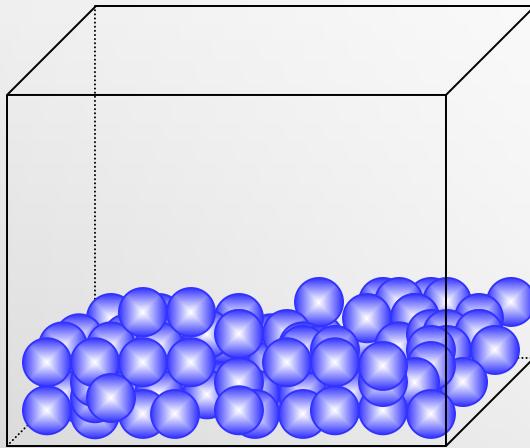
THERMAL EXPANSION IS A MEASURE OF THE VOLUME CHANGE RESULTING FROM A TEMPERATURE CHANGE.

Solid State - Cohesive potential energy dominates over disruptive kinetic energy.



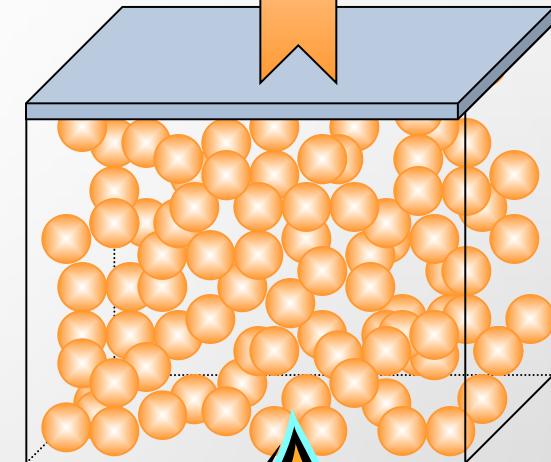
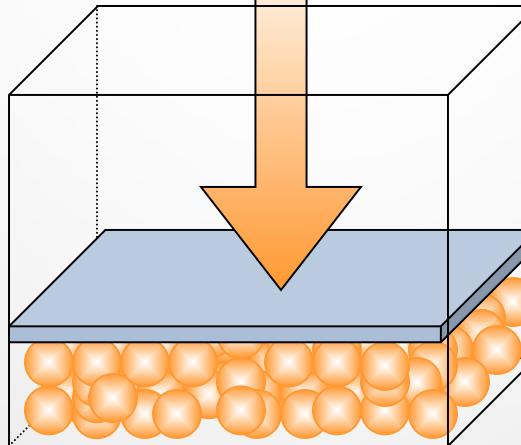
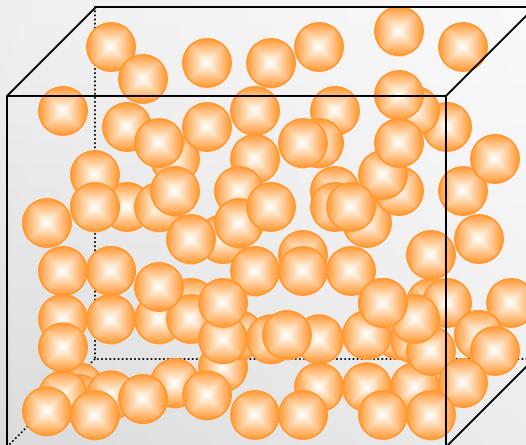
<u>Property:</u>	<u>Volume/Shape</u>	<u>Density</u>	<u>Compressibility</u>	<u>Thermal Expansion</u>
Solid	Definite volume Definite shape	Generally higher than other states	Small; doesn't respond to change in pressure	Very small compared to other states

Liquid State - Cohesive potential energy and disruptive kinetic energy are about equal.



Property:	Volume/Shape	Density	Compressibility	 Thermal Expansion
<i>Liquid</i>	Define volume Indefinite shape	Generally high, but still lower than solid state	Generally small, though slightly greater than solid	Small, but greater than solid

Gaseous State – Disruptive kinetic energy dominates over cohesive potential energy.



<u>Property:</u>	<u>Volume/Shape</u>	<u>Density</u>	<u>Compressibility</u>	 <u>Thermal Expansion</u>
Gas	Indefinite volume Indefinite shape	Generally low	Large; highly subject to change in pressure	Highly subject to changes of volume with temperature

Comparison of Properties of the States of Matter

Property ↓ State	Volume	Shape	Compressibility	Thermal Expansion
Solid	Definite	Definite	Very small	Very small (.01%/ $^{\circ}\text{C}$)
Liquid	Definite	Indefinite	Small (but > solid)	Small (0.10%/ $^{\circ}\text{C}$)
Gas	Indefinite	Indefinite	Large	Moderate (about .30%/ $^{\circ}\text{C}$)

**CHANGE OF STATE – A PROCESS IN WHICH
A SUBSTANCE IS TRANSFORMED FROM
ONE PHYSICAL STATE TO ANOTHER
PHYSICAL STATE. A PHYSICAL CHANGE.**

A PHYSICAL CHANGE CAN BE:

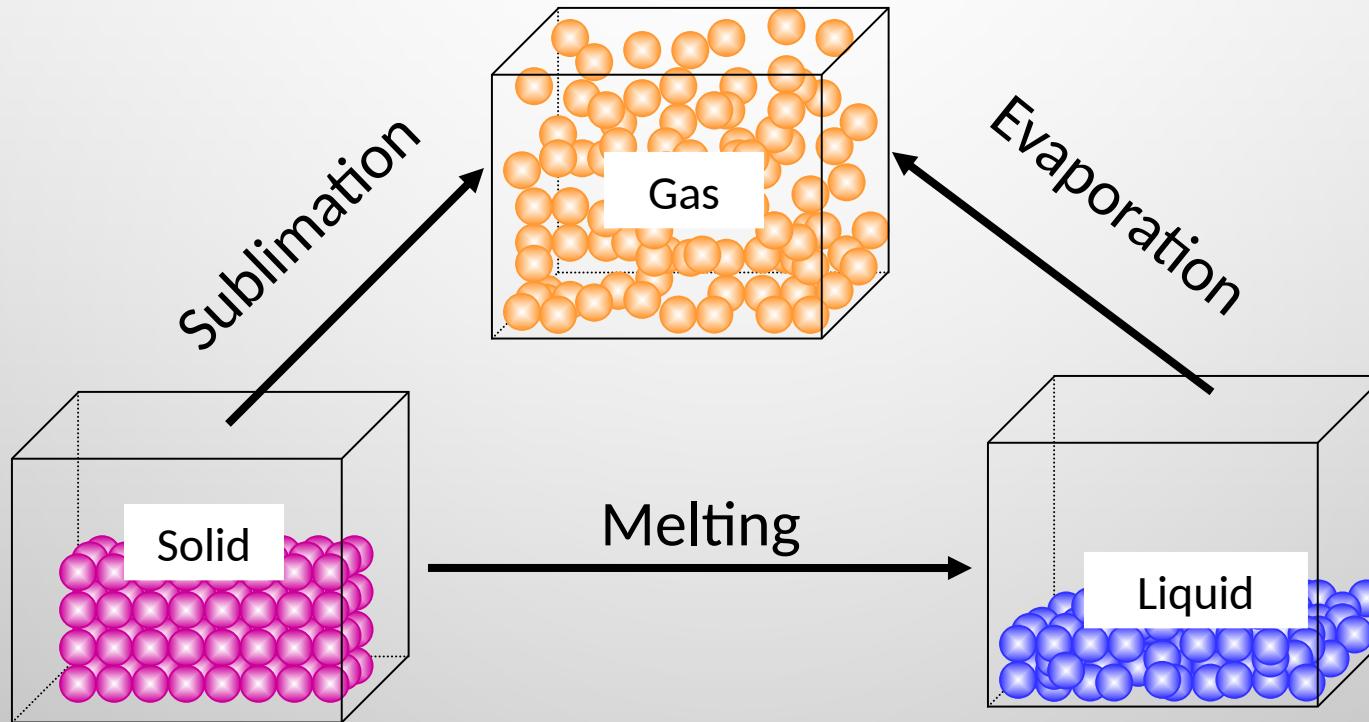
**ENDOTHERMIC CHANGE - REQUIRES THE INPUT
(ABSORPTION) OF ENERGY. AN ENDOTHERMIC
REACTION FEELS COLD TO THE TOUCH.**

**EXOTHERMIC CHANGE - RELEASES ENERGY. AN
EXOTHERMIC REACTION FEELS WARM TO THE
TOUCH.**



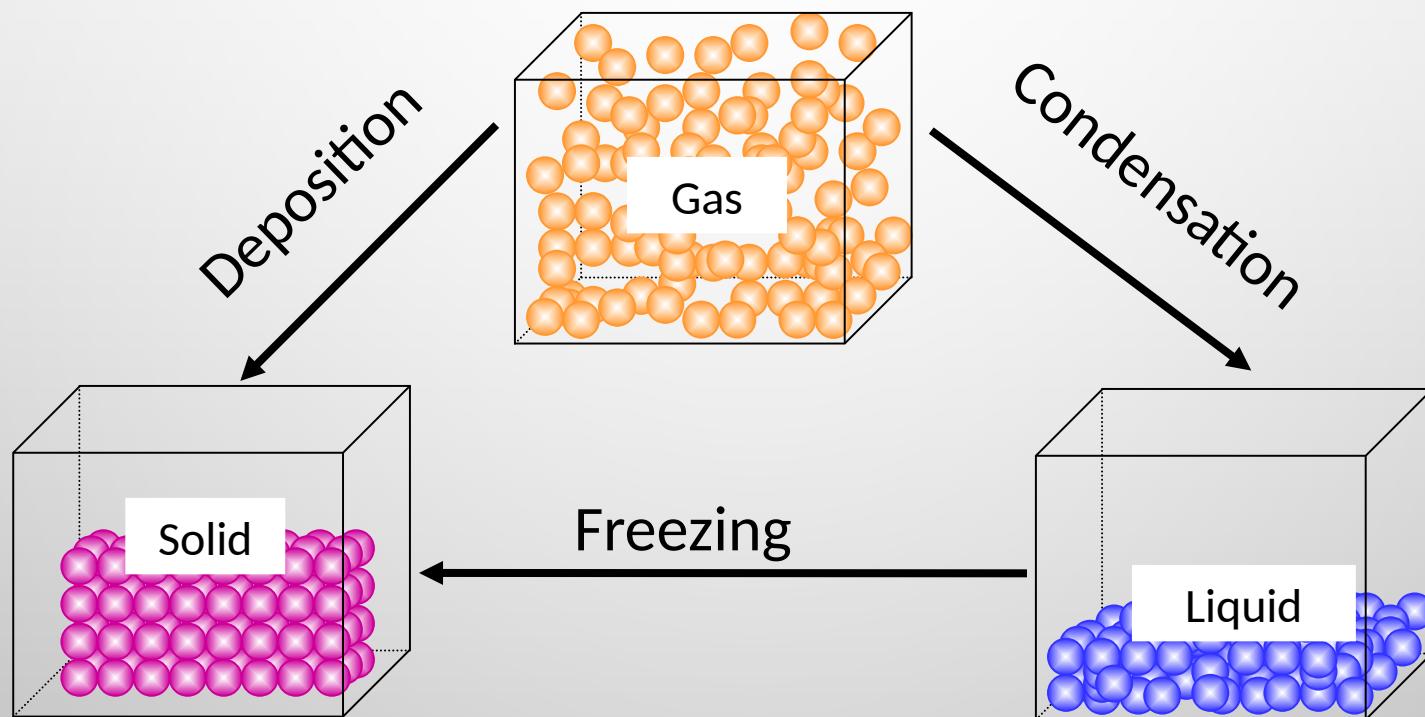
CHANGES OF STATE

Endothermic: absorbs heat/energy from the surrounding environment into the system.



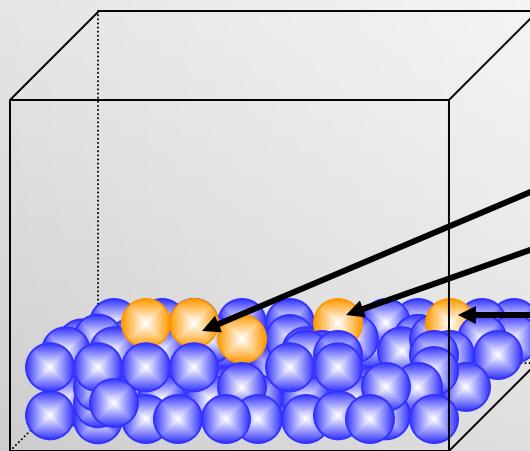
CHANGES OF STATE

Exothermic: releases heat/energy from the system into the surrounding environment.

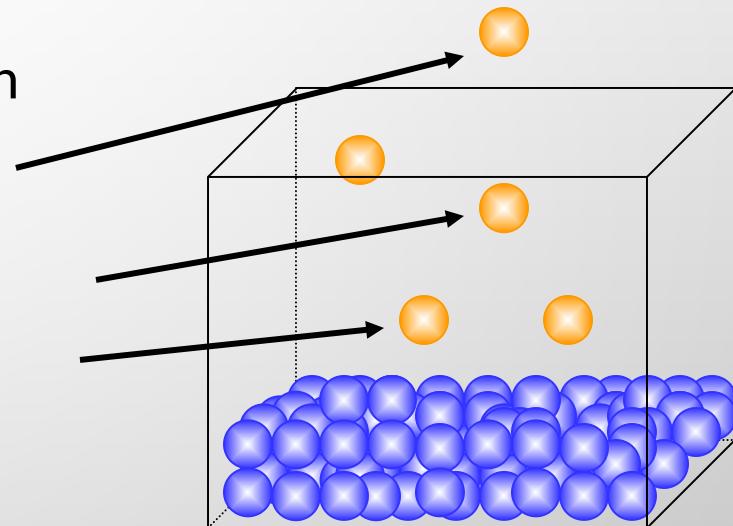


EVAPORATION OF LIQUIDS

EVAPORATION IS THE PROCESS BY WHICH MOLECULES ESCAPE FROM THE LIQUID PHASE TO THE GASEOUS PHASE.



Liquids evaporate when the molecules gain enough energy to escape the surface. This leaves a fresh surface for more molecules to escape from.



EVAPORATION OF LIQUIDS

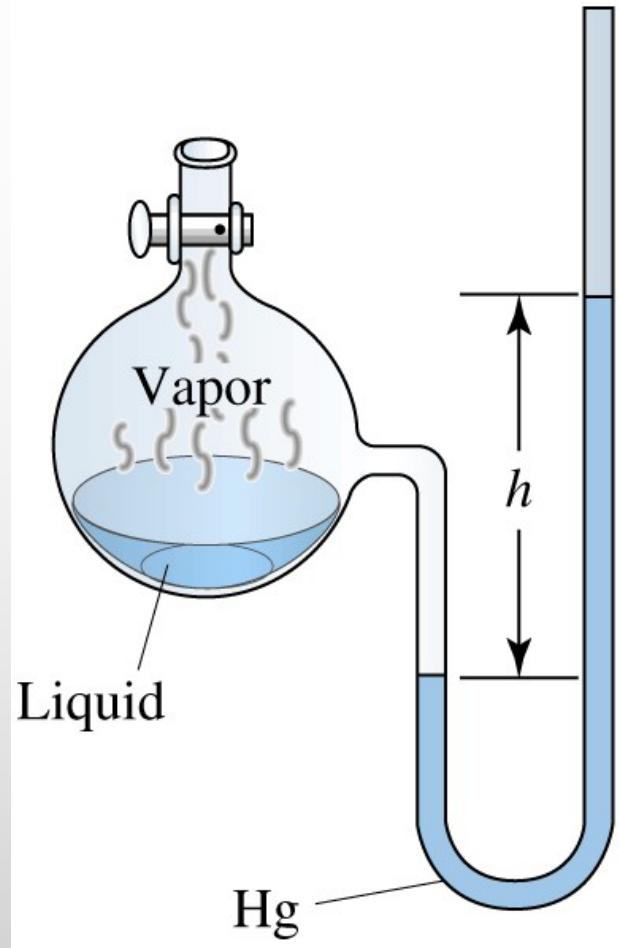
- EVAPORATION IS A SURFACE PHENOMENON.
- AT HIGHER TEMPERATURES, MORE MOLECULES IN A LIQUID POSSESS THE KINETIC ENERGY NEEDED TO ESCAPE THE LIQUID PHASE.
- THE TERM VAPOR APPLIES TO A SUBSTANCE THAT IS IN A GAS PHASE AT A TEMPERATURE WHERE IT IS NORMALLY A LIQUID.



VAPOR PRESSURE OF LIQUIDS

VAPOR PRESSURE IS THE PRESSURE EXERTED BY VAPOR OVER A LIQUID IN A SEALED CONTAINER AT EQUILIBRIUM. VAPOR PRESSURE DEPENDS ON THE NATURE OF THE SUBSTANCE AND THE TEMPERATURE.

A VOLATILE SUBSTANCE EVAPORATES RAPIDLY AND HAS A VERY HIGH VAPOR PRESSURE.



HOW CAN YOU SAY THAT LIQUID IS BOILING ?

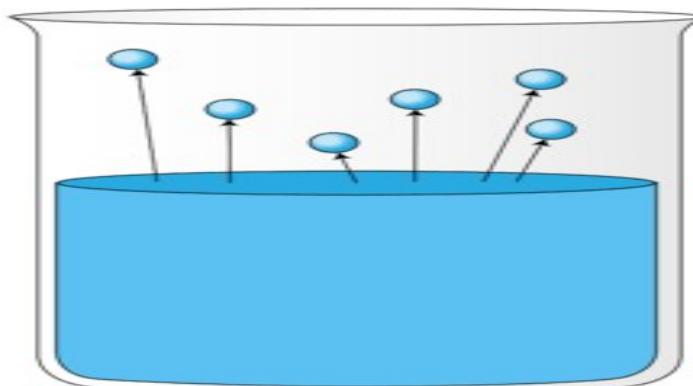
Boiling occurs when a liquid is turning to a gas rapidly, and within the body of the liquid, not just on the surface.

As gas bubbles form, they rise rapidly to the surface and escape.

WHAT IS BOILING POINT?

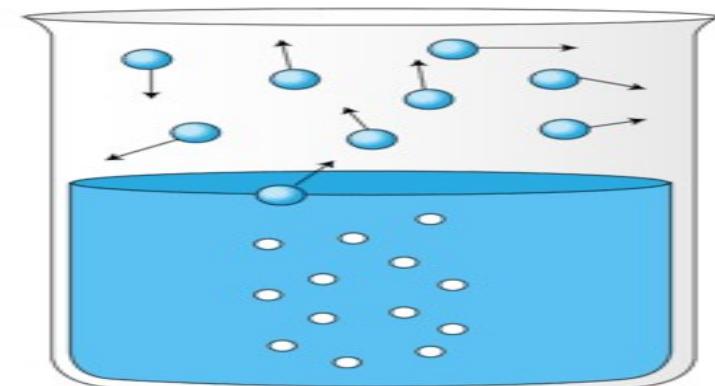
- BOILING POINT IS THE TEMPERATURE OF A LIQUID AT WHICH THE VAPOR PRESSURE OF THE LIQUID BECOMES EQUAL TO THE EXTERNAL (ATMOSPHERIC) PRESSURE EXERTED ON THE LIQUID.
- BOILING POINT (BP) FLUCTUATES WITH THE ATMOSPHERIC PRESSURE.
- BP CAN BE INCREASED WITH INCREASE IN THE EXTERNAL PRESSURE.
- BP CAN BE DECREASED WITH DECREASE IN THE EXTERNAL PRESSURE.

Evaporation



Vapor Pressure < Atmospheric Pressure
Bubbles cannot form

Boiling



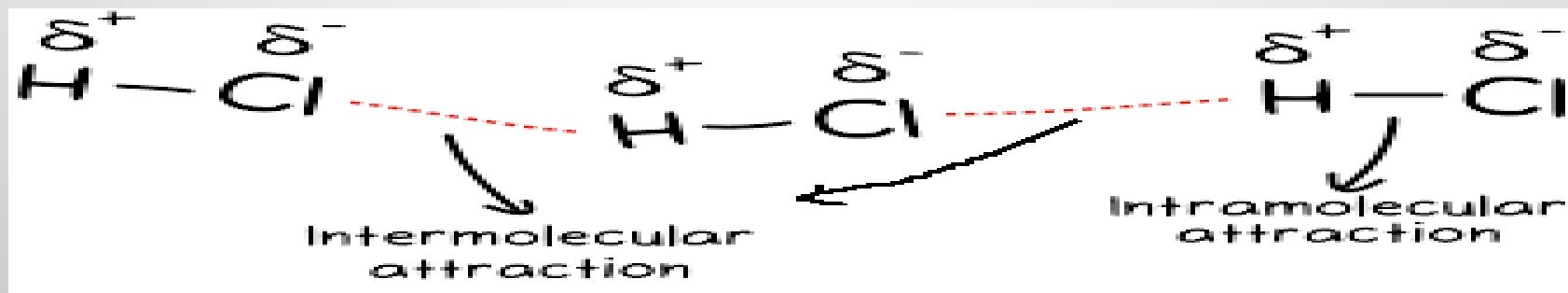
Vapor Pressure = Atmospheric Pressure
Bubbles can form and rise

INTERMOLECULAR FORCES IN LIQUIDS

HOW IT DIFFER FROM INTRAMOLECULAR FORCES

INTERMOLECULAR FORCES ARE ATTRACTIONS BETWEEN THE MOLECULES. (YOU WILL LEARN IN THIS CHAPTER)

INTRAMOLECULAR FORCES ARE THE FORCES THAT HOLD AN INDIVIDUAL MOLECULE TOGETHER (YOU ALREADY KNOW? IONIC AND COVALENT IN CHAPTER #7)



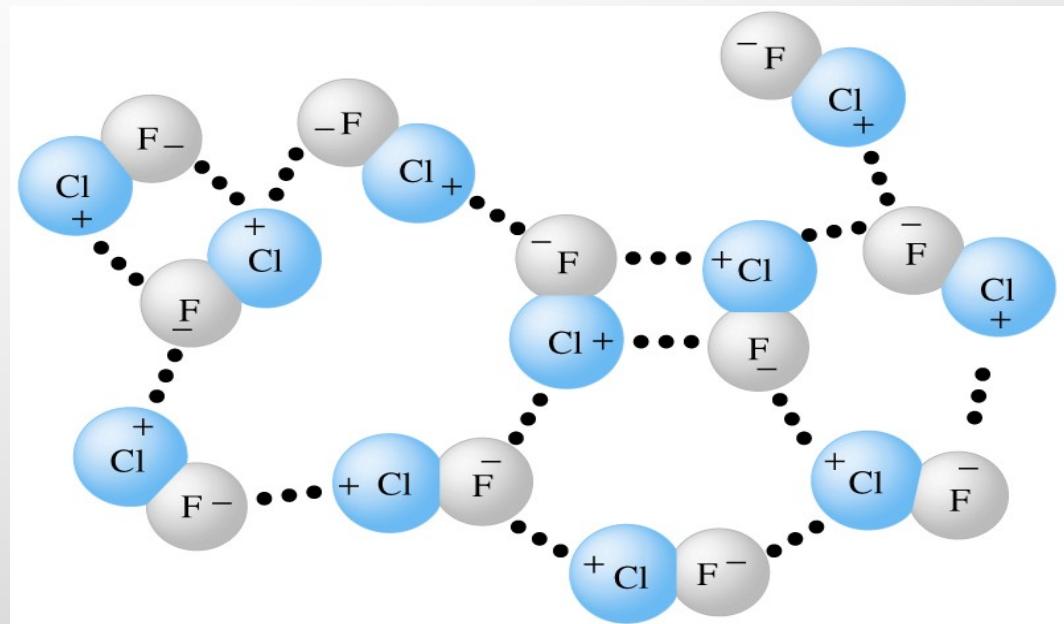
***Intermolecular** forces play a role in determining the physical properties of a substance – melting point, boiling point, shape.



KNOWING DIFFERENT INTERMOLECULAR FORCES

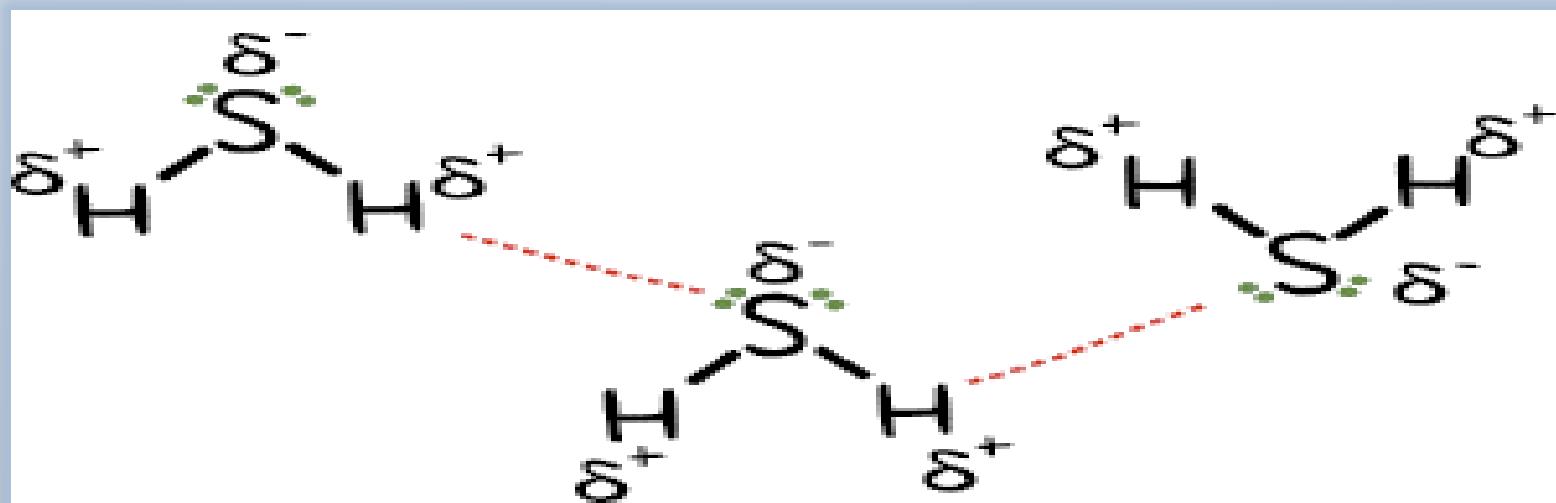
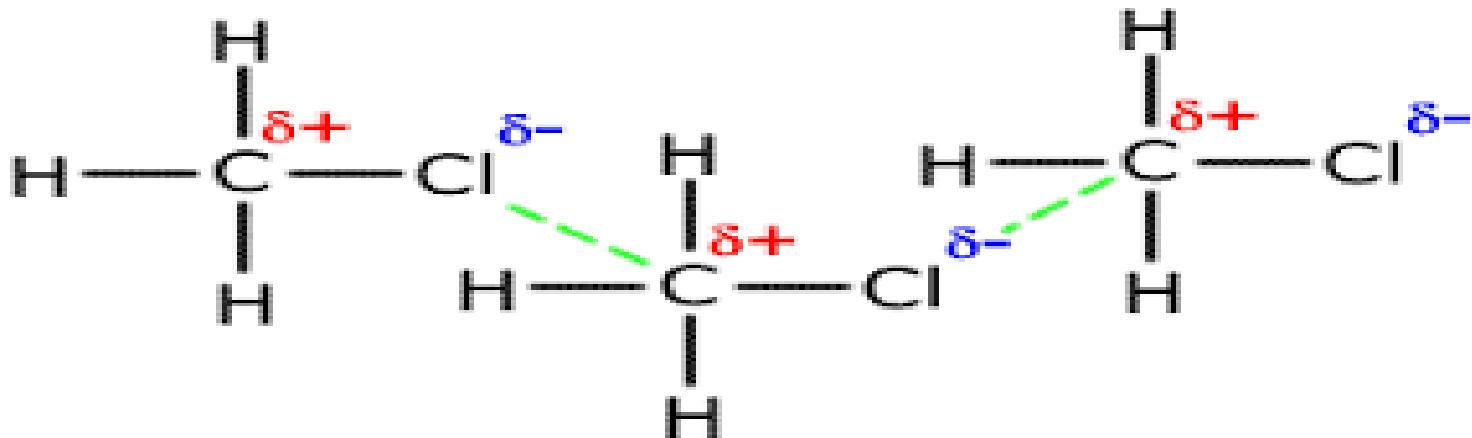
DIPOLE-DIPOLE INTERACTIONS: ATTRACTIONS BETWEEN POLAR MOLECULES.

Polar molecules are electrically uneven. This creates a dipole: a positive end and a negative end within a molecule.



The molecules tend to orient themselves such that the opposite poles are next to one another.

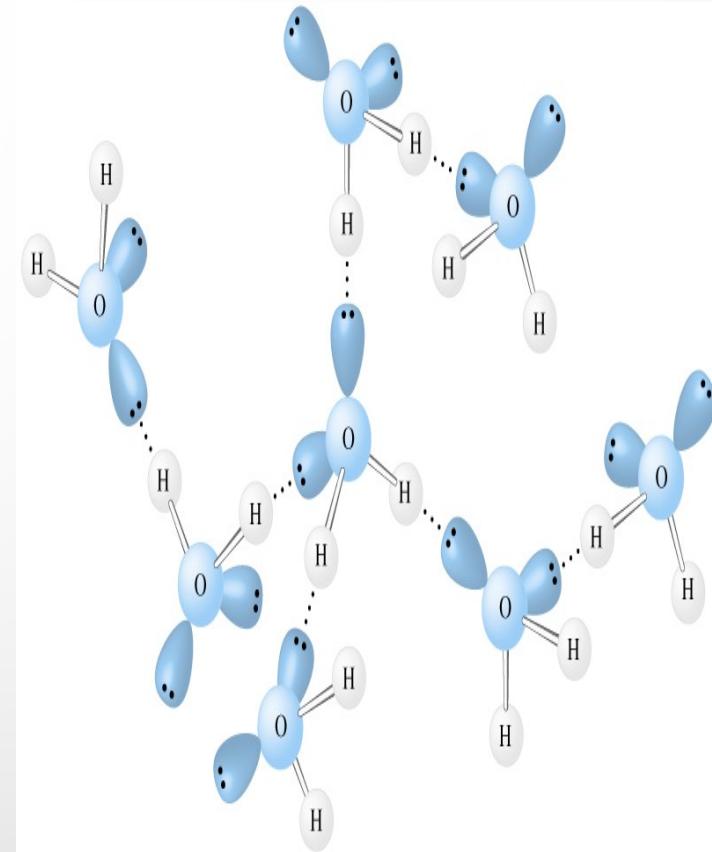
Dipole-Dipole Interactions –Examples:



HYDROGEN BONDING: AN ESPECIALLY STRONG FORM OF DIPOLE-DIPOLE INTERACTION.

FOR A HYDROGEN BOND TO OCCUR, YOU MUST HAVE HYDROGEN COVALENTLY BONDED TO F, O, OR N. THE H IN THIS COVALENT BOND CAN THEN BOND WITH ANOTHER F, O OR N TO FORM A HYDROGEN BOND.

*WATER IS THE EXAMPLE OF MOST COMMON COMPOUND THAT HAS HYDROGEN BONDS.



IN THIS FIGURE,
DOTTED LINE SHOWS
H-BONDING
BETWEEN TWO
WATER MOLECULES

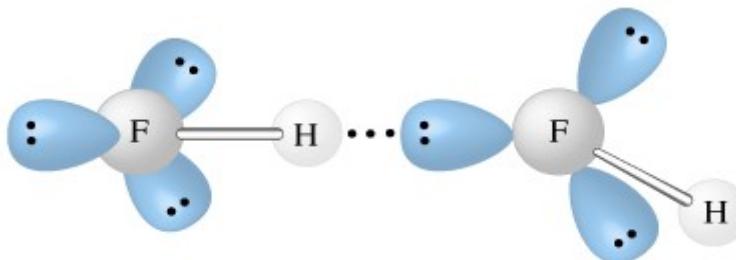


Two factors account for the strength of Hydrogen bonds between molecules:

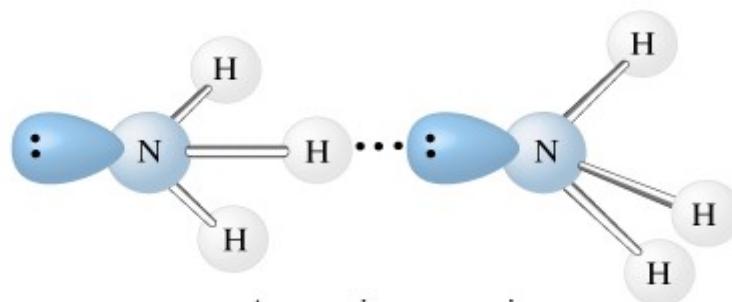
First: the highly electronegative partner dominates the electron sharing to such a degree that hydrogen is left void of electrons since hydrogen only has the one electron.

Second: Since hydrogen is so small it can bring its nucleus close to the unshared pair of electron on the electronegative atom

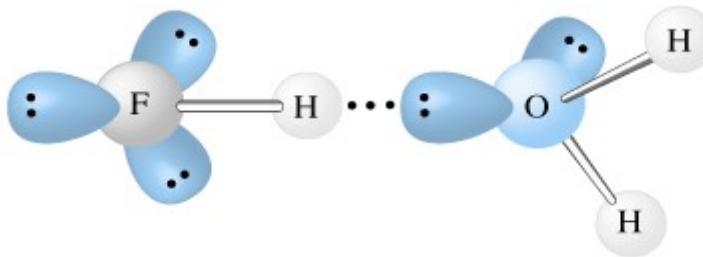
MORE EXAMPLES OF HYDROGEN BONDING



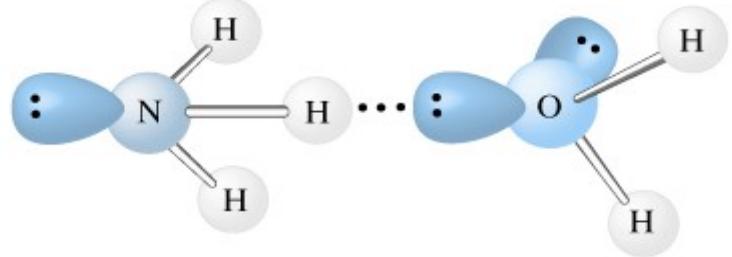
Hydrogen fluoride–hydrogen fluoride



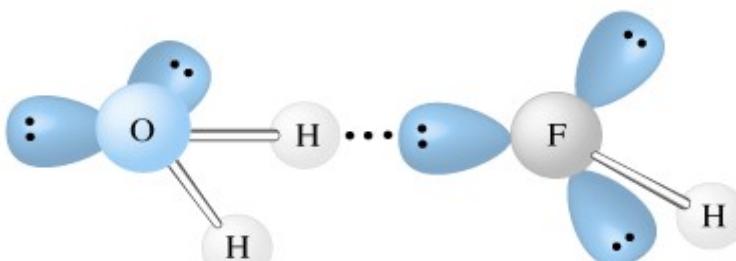
Ammonia–ammonia



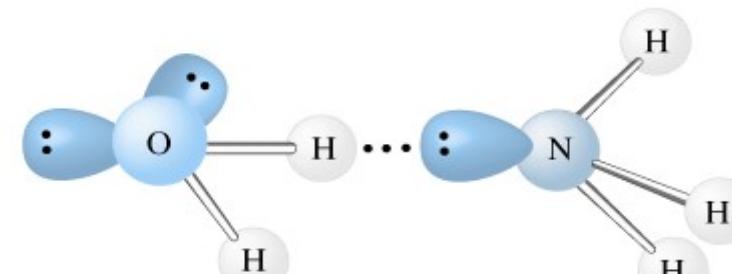
Hydrogen fluoride–water



Ammonia–water



Water–hydrogen fluoride



Water–ammonia



CONSEQUENCES OF HYDROGEN BONDS

- THE VAPOR PRESSURES OF LIQUIDS WITH SIGNIFICANT HYDROGEN BONDING ARE MUCH LOWER THAN THOSE OF SIMILAR LIQUIDS THAT HAVE LITTLE OR NO HYDROGEN BONDING.
- HYDROGEN BONDS MAKE IT MORE DIFFICULT FOR MOLECULES TO ESCAPE FROM THE LIQUID STATE.

*BOILING POINTS ARE MUCH HIGHER FOR LIQUIDS IN WHICH HYDROGEN BONDING OCCURS.



LONDON DISPERSION FORCES: WEAK TEMPORARY DIPOLE-DIPOLE INTERACTIONS THAT OCCUR BECAUSE OF MOMENTARY UNEVEN ELECTRON DISTRIBUTIONS IN **NONPOLAR MOLECULES.**

THESE ARE THE MOST COMMON INTERMOLECULAR FORCES.

These are the only attractive forces in *nonpolar* molecules and it is estimated that they account for 85% of the intermolecular force in the *polar* HCl molecule.

London Forces only play a minor role if hydrogen bonding is present.

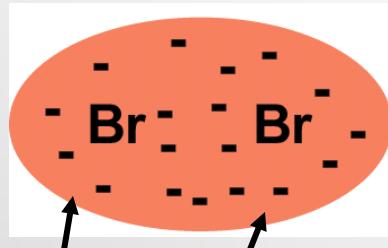
STRENGTH OF INTERMOLECULAR FORCES :

H- BONDING > DIPOLE-DIPOLE > LONDON DISPERSION
(POLAR MOLECULES) (POLAR MOLECULES) (NON POLAR
MOLECULES)

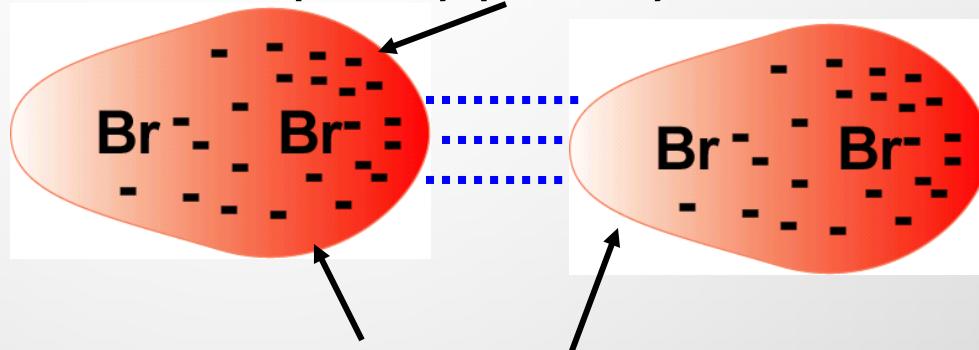


LONDON FORCES / INDUCED DIPOLE

At some point, most of the electrons will be on one side of the molecule, resulting in temporary polarity.



Electrons move quickly around nuclei.

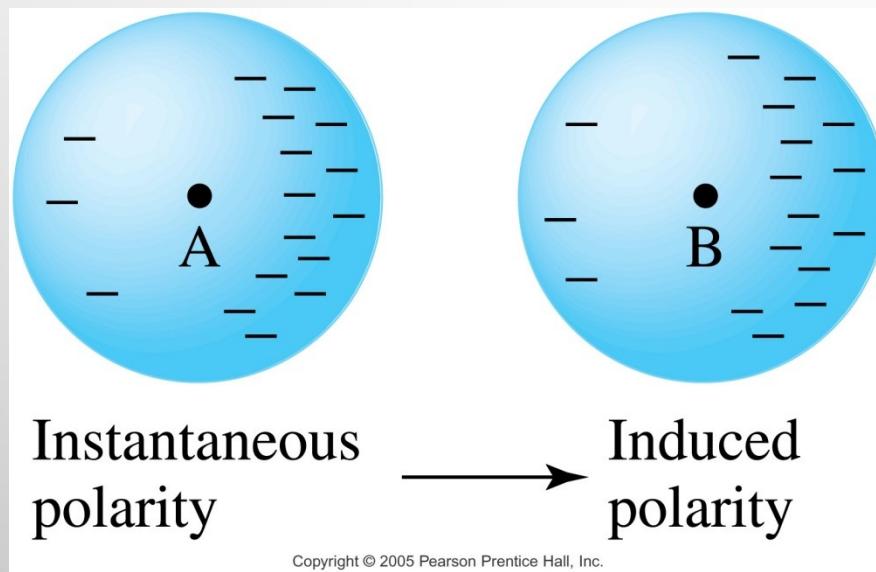


The temporary polarity will induce a similar temporary polarity in a nearby molecule.

Although London forces are fleeting interactions, they do explain the extreme increase in elemental boiling points as you move down the periodic table.



The strength of **London Forces** depends on how easy is to distort the polarity of the molecule.



The larger the diameter of the molecule, the easier it is to distort the polarity.

Larger diameter,
higher boiling points.

High polarizability, high boiling points:

SF_6 (symmetrical; bp= -64°C) vs $\text{C}_{10}\text{H}_{22}$ (linear; bp=174°C)

POLARIZABILITY – THE ABILITY TO DISTORT THE ELECTRON CLOUD

- POLARIZABILITY INCREASES DOWN A GROUP OF ATOMS OR IONS DUE TO SIZE INCREASES AND LARGER ELECTRON CLOUDS ARE MORE EASILY DISTORTED.
- POLARIZABILITY DECREASES FROM LEFT TO RIGHT ACROSS A PERIOD BECAUSE THE INCREASING EFFECTIVE NUCLEAR CHARGE HOLDS THE ELECTRONS MORE TIGHTLY
- CATIONS ARE LESS POLARIZABLE THAN THEIR PARENT ATOM BECAUSE THEY ARE SMALLER WHEREAS ANIONS ARE MORE POLARIZABLE BECAUSE THEY ARE LARGER IN SIZE – EXTRA ELECTRONS

REVIEW

Intermolecular Forces

- Dipole-dipole – between oppositely charged poles on polar molecules.
- Hydrogen bonding – special type of dipole-dipole force between H bonded to N, O, or F and the lone pair of electrons. The strength of hydrogen bonding comes from the large number of hydrogen bonds made in a solution more so than just the strength of one bond.
- London Forces are instantaneous dipole-induced dipole forces that occur among all particles and increase with number of electrons (molar mass).

REVIEW

- All **intermolecular** forces are weaker than bonding forces.
- Molecular shape determines the extent of contact between molecules and is a factor in the strength of dispersion forces.
- **Intermolecular** forces increase in magnitude with the size and polarity of the molecule.
- **Intermolecular** forces are a factor in solids and liquids but are negligible in the gas phase.

HOW TO PREDICT CHARACTERISTICS? WHAT DO WE NEED TO KNOW?

- NEED TO KNOW THE SHAPE OF THE MOLECULE.
- NEED TO KNOW THE TYPE OF MOLECULAR BONDING,
IONIC, POLAR AND NON-POLAR COVALENT.
ELECTRONEGATIVITIES!
- NEED TO KNOW IF THE MOLECULE IS POLAR OR IF IT CAN
BE POLARIZED.

Why is this (means: INTERMOLECULAR FORCES) important?

Use to predict

- Boiling points
- Vapor pressure
- Properties of liquids (like, Surface Tension)

BOILING POINTS

BOILING IS THE TEMPERATURE AT WHICH THE VAPOR PRESSURE OF THE LIQUID EQUALS THE PRESSURE OVER THE LIQUID.

- BOILING POINTS TEND TO INCREASE WITH MOLECULAR WEIGHT.
- POLAR MOLECULES BOIL AT SLIGHTLY HIGHER TEMPERATURES THAN NONPOLAR SUBSTANCES OF COMPARABLE MOLECULAR WEIGHT.
- HYDROGEN BONDING CAUSES A SIGNIFICANT INCREASE IN BOILING POINT.

Boiling Points of Nonpolar vs. Polar Substances

Nonpolar Substance

Polar Substance

Formula	Molecular Weight	Boiling Point °C	Formula	Molecular Weight	Boiling Point °C
N ₂	28	-196	CO	28	-192
SiH ₄	32	-112	PH ₃	34	-85
GeH ₄	77	-90	AsH ₃	78	-55
Br ₂	160	59	ICl	162	97

Problem:

How would you expect a boiling point of NO, to compare to the boiling point of N₂O? How about N₂ and O₂?

Since NO has a molecular weight considerably lower than N₂O (30 vs. 44) it should be lower in boiling.

Boiling point for NO = -153°C

Boiling point for N₂O = -88°C

Problem:

How would you expect a boiling point of nitric oxide, NO, to compare to the boiling point N₂ and O₂?

If molecular weight were the only factor the Bp for NO should be halfway between N₂ (-196°C) and O₂ (-183°C). However NO is a polar molecule and its Bp is higher than predicted (-153°C)

VAPOR PRESSURE

VAPOR PRESSURE IS THE PRESSURE EXERTED BY A VAPOR WHEN IT IS IN EQUILIBRIUM WITH THE LIQUID FROM WHICH IT IS DERIVED.

NOTE - STRONG INTERMOLECULAR FORCES IN A MOLECULE WILL RESULT IN LOW VAPOR PRESSURE
- IT TAKES MORE ENERGY FOR THE MOLECULE TO ESCAPE THE SURFACE THUS INCREASING THE BOILING POINT.

Diethyl ether $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$ with a low boiling point of 36.5°C This is a nonpolar molecule with London forces between molecules.

Ethanol $\text{CH}_3\text{CH}_2\text{OH}$ with a high boiling point of 78.3°C. This is a polar molecule with dipole-dipole forces and some hydrogen bonding between molecules.

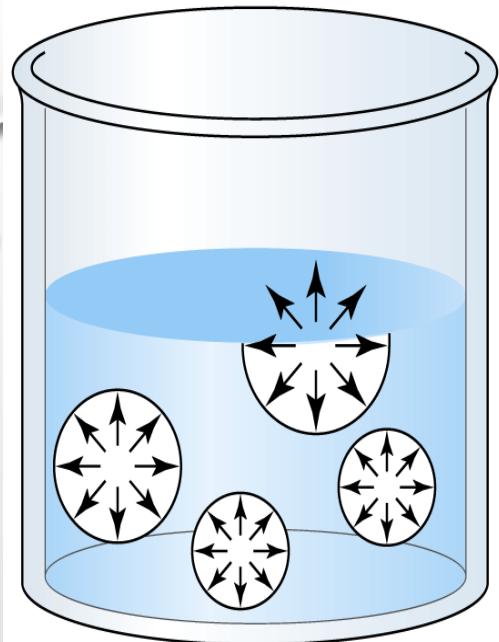
Water H_2O with a high boiling point of 100°C. This is a polar molecule with dipole-dipole forces and a great deal of hydrogen bonding between molecules.

High boiling points and strong intermolecular forces go hand in hand.

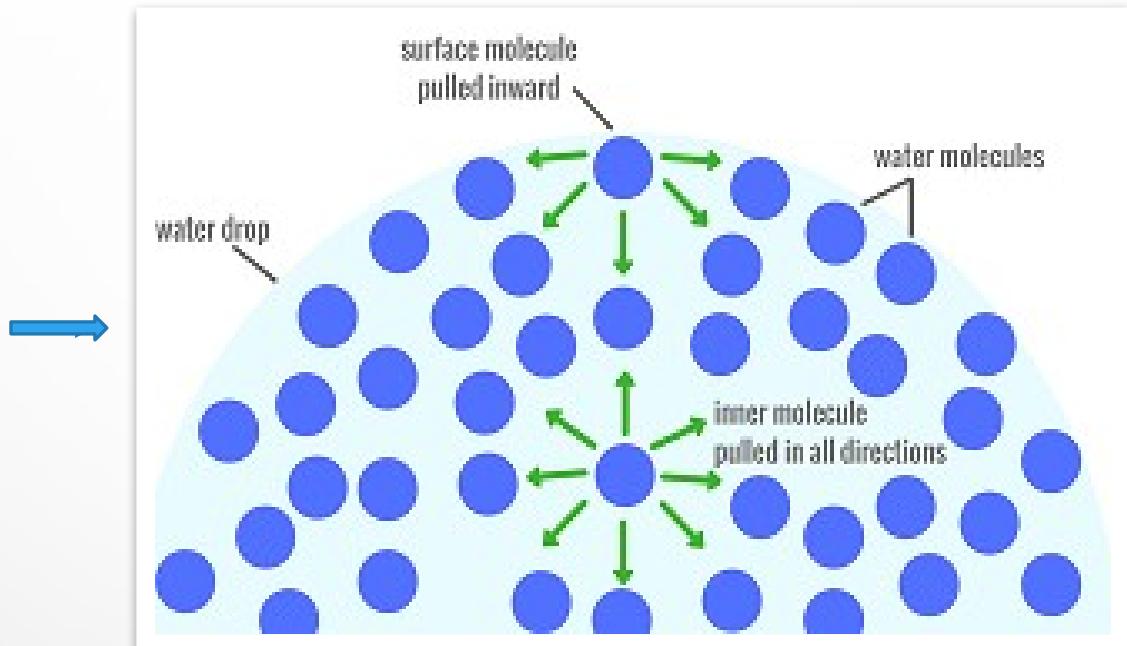
PROPERTIES OF LIQUIDS: SURFACE TENSION AND IMFS

SURFACE TENSION IS A MEASURE OF THE INWARD FORCE ON THE SURFACE OF A LIQUID CAUSED BY UNBALANCED INTERMOLECULAR FORCES.

- MOLECULES WITHIN LIQUID ARE SURROUNDED BY OTHER MOLECULES, EXPERIENCE INTERMOLECULAR ATTRACTIONS FORM ALL THE DIRECTIONS.
- THE MOLECULES AT THE SURFACE ONLY HAVE NEIGHBORS BELOW AND ON THE SIDES. THE **INTERMOLECULAR** FORCES EXERTED ARE ESSENTIALLY DOWNWARD. A LIQUID SURFACE TENDS TO HAVE THE SMALLEST POSSIBLE AREA – LIKE THAT OF A SPHERE. THE SURFACE TENDS TO BEHAVE LIKE A TAUT SKIN COVERING THE INTERIOR. (SEE ENLARGE PICTURE ON NEXT SLIDE)



A GLASS OF
WATER



ENLARGE VIEW OF
SURFACE TENSION ON
SURFACE AND INNER
SIDE

The stronger the **intermolecular** forces between particles in a liquid, the greater the surface tension.

Surface tension can be broken by dissolved substances.

WHERE TO FIND EXAMPLES ?

**INTERMOLECULAR FORCES EXPERIMENT IN YOUR LAB WILL
HELP YOU TO FIND ANSWERS TO HYPOTHESIS OF HOW
STRENGTH OF INTERMOLECULAR FORCES ARE RESPONSIBLE
FOR INCREASE AND DECREASE OF THE SURFACE TENSION
FOR DIFFERENT LIQUIDS.**