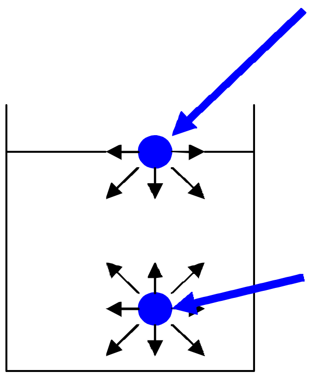
PROPERTIES OF LIQUIDS

- Properties of liquids are related to the INTERMOLECULAR FORCES OF ATTRACTION in various liquids.

I. SURFACE TENSION



Molecule attracted toward the interior of the liquid

Molecule:- attracted equally in all directions
- experiences no net force

RESULT:

1. Any liquid will tend to reduce its surface area (surface molecules will tend to move inward)

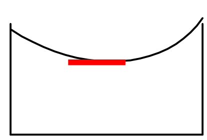
2. The stronger the intermolecular forces of attraction, the stronger the tendency of the liquid to reduce its surface area.

SURFACE TENS ION

- is the tendency of a liquid to reduce its surface area
- can be measured as the energy required to increase the surface area (counteracts the natural tendency of liquids)

EXAM PLES:

1. Falling raindrops are nearly spherical (smallest surface area)
2. A pool of water on a flat surface is circular
3. A needle floats on water: Water behaves as though "it had a skin"

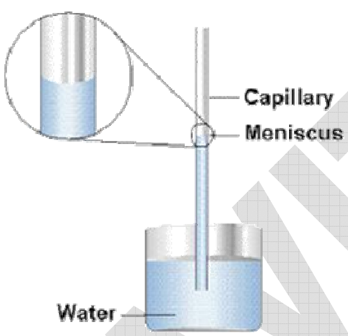
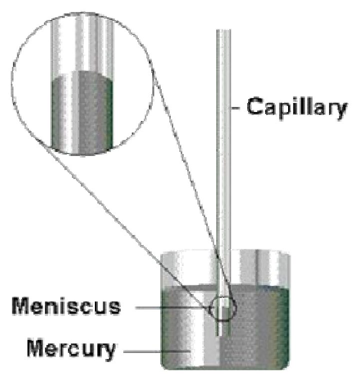


II. VISCOSITY:

- Viscosity is the resistance to flow exhibited by fluids.
- Viscosity depends on:
  - IntermolecularForcesofAttraction
    The stronger the molecules attract, the more viscous the fluid
  - Temperature
    The lower the temperature, the more viscous the fluid.
    This is important for oils used for car engines.
  - TheLengthofMolecules
    Long molecules tend to tangle together and cause the fluid to have high viscosity.

III. CAPILLARY ACTION

- Capillary action is the property of some liquids to rise in narrow glass tubes (capillary tubes)

WATER CONCAVE MENISCUS (edges curved upward)	MERCURY CONVEX MENISCUS (edges curved downward)
 Waterrises in the capillary tubes	 Mercurydrops in capillary tubes
Attractive forces between glass and water molecules > Attractive forces between water molecules	Attractive forces between glass and mercury atoms < Attractive forces between mercury atoms

- Important for survival of plants and trees.
- Water travels upward in plants due to capillary action (many capillary tubes formed between celullose fibers)

INTERMOLECULAR FORCES (I.M. FORCES)

- I.M. forces are forces of attraction between molecules of a molecular substance

Ne →¬ Ne	H–H →¬ H–H	H–Cl →¬ H–Cl	H_2O →¬ H_2O

I.M. FORCES determine:

1. Heatofvaporizationofaliquid (ΔH_v)
   - ➢ When a liquid vaporizes, the molecules must overcome the I.M. forces of attraction.
   - ➢ This requires energy (ΔH_v = Heat of vaporization)
   - ➢ The stronger the IM forces of attraction, the larger the Heat of Vaporization

2. VaporPressureofLiquids(p_v)
   - ➢ The easier the molecules leave the liquid from surface (move into the vapor phase), the higher the vapor pressure.
   - ➢ The stronger the IM forces of attraction, the lower the Vapor Pressure (p_v)

3. BoilingPoint(B.P.)
   - ➢ Recall:B.P. is the temperature at which Vapor Pressure(p_v) = atmospheric pressure (p_{atm})
   - ➢ Recall: The lower the p_v , the higher the B.P.
   - ➢ The stronger the IM forces of attraction, the higher the B.P.

4. SurfaceTension
   - ➢ The stronger the IM forces of attraction, the higher the tendency for a reduced surface area, the larger the Surface Tension

5. Viscosity
   - ➢ The stronger the IM forces of attraction, the less freely the molecules move, the higher the viscosity

SUMM ARY:

Strong Intermolecular Forces of Attraction (such as in water) will result in:

- ➢ Large value for Heat of Vaporization (ΔH_v)
- ➢ Low Vapor Pressure (p_v) —> Nonvolatile Liquid
- ➢ High Boiling Point (B.P.)
- ➢ Large Surface Tension
- ➢ Viscous Liquid

TYPES OF INTERMOLECULAR FORCES

I. Van der Waals fo rc es

1. LondonForces(DispersionForces)
   - Attractive forces between nonpolar molecules

H–H → ¬ H–H

2. Dipole-DipoleForces
   - Attractive forces between polar molecules

H–Cl → ¬ H–Cl

II. Hyd rogen B ond in g

- Attractive forces between very polar molecules containing: H atoms, bonded to very electronegative atoms (F, O, N)

HF → ¬ HF	H_2O → ¬ H_2O	NH_3 → ¬ NH_3

I. Van der Waals fo rc es

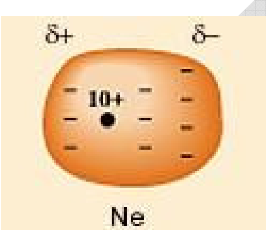
London Forces (Dispersion Forces)

- These are attractive forces between:

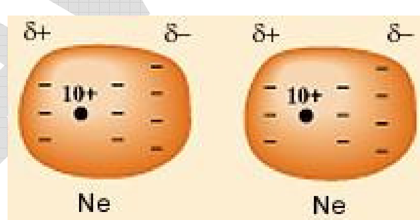
nonpolar molecules H–H → ¬ H–H and neutral atoms Ne → ¬ Ne

(monoatomic molecules, such as the noble gases)

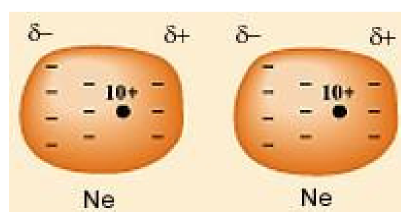
- These forces are caused by temporary dipoles that occur as a result of electrons shifting to one side of atom or of nonpolar molecule



At some instant, there are more electrons on one side of a Ne atom than on the other.



If this atom is near another Ne atom, the electrons on that atom are repelled. The result is two instantaneous dipoles, which give an attractive force.



Later the electrons on both atoms have moved, but they tend to move together, which gives an attractive force between the atoms.

London Forces:

- exist between ALL MOLECULES (POLAR AND NONPOLAR)
- are the only attractive forces between nonpolar molecules (Ne, N_2, F_2 , Cl_2 , Br_2 , I_2 , O_2)
- increase with **Molecular Weight**

Reason:

- They contain more electrons, therefore more shift
- They are larger atoms, which are easier distorted (electrons are further away from the nucleus)

CONSEQUENCE: THE LARGER THE MW, THE STRONGER THE LONDON FORCES, THE HIGHER THE BOILING POINT

Exa mp le:

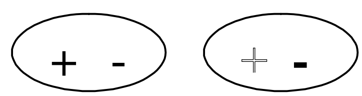
Substance:	F_2	Cl_2	Br_2	I_2
M.W. (g/mole)	38	71	160	254
B.P. (^oC)	– 188 ^oC	– 34 ^oC	+ 59 ^oC	+ 185 ^oC

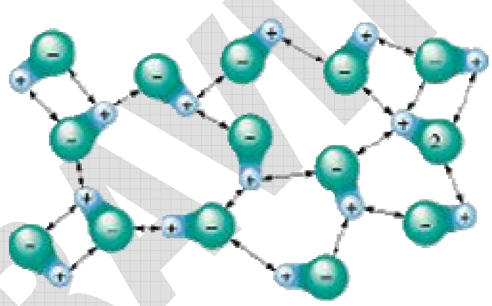
Gases at Room Temperature (F_2, Cl_2) — Liquid at Room Temperature (Br_2) — Solid at Room Temperature (I_2)

Dipole- Dipole Forces

- These are attractive forces between polar molecules

$\delta+\ \delta-$ $\delta+\ \delta-$
H–Cl → ¬ H–Cl





Alignment of polar molecules in liquid HCl

Note that the normal random motion of the molecules in a liquid only partially disrupts the alignment of the polar molecules of HCl

- If for two substances the M.W. is about the same (same strength of London Forces),

The Larger the Electronegativity Difference (ΔEN) → The More Polar the Molecule (the larger the Dipole Moment) → The stronger the IM Forces of Attraction → The Higher the Boiling Point (BP)

HYDROGEN BONDING

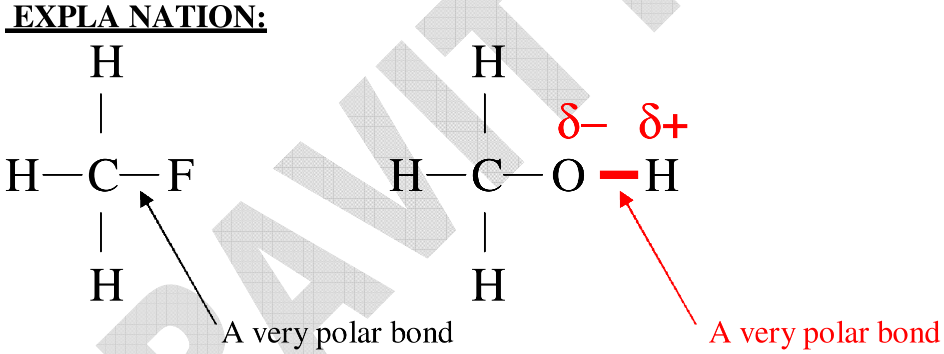
- These are attractive forces between very polar molecules containing H atoms, bonded to very electronegative atoms (F, O, N)

HF →¬ HF H_2O →¬ H_2O NH_3 →¬ NH_3

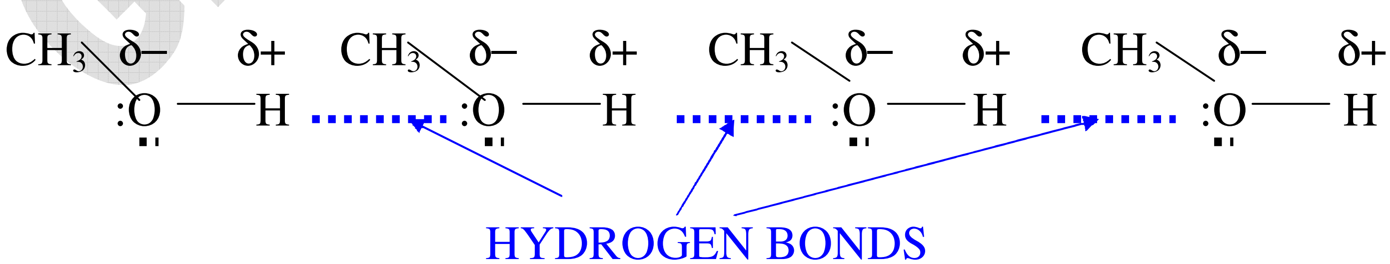
Consider:

Substance:	CH_3–F Fluoromethane	CH_3–OH Methanol	
M.W. (g/mole)	34	32	about the same
Dipole Moment (in Debye)	1.81	1.70	about the same polarity
B.P. (^oC)	–78 ^oC much lower	+ 65 ^oC much higher	??????????????????????
Implies:	IM Forces of Attraction	< IM Forces of Attraction	???????????????????????

EXPLA NATION:



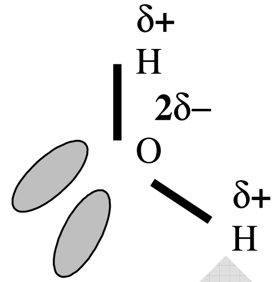
- CH_3-OHmoleculesareassociatedthroughHbonds:

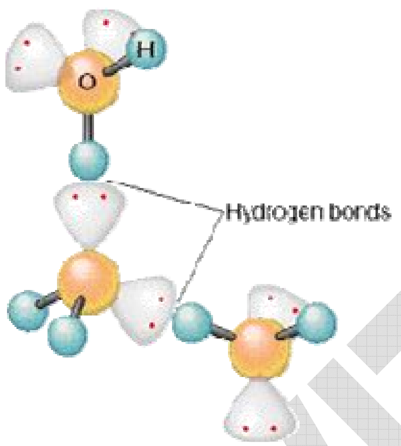


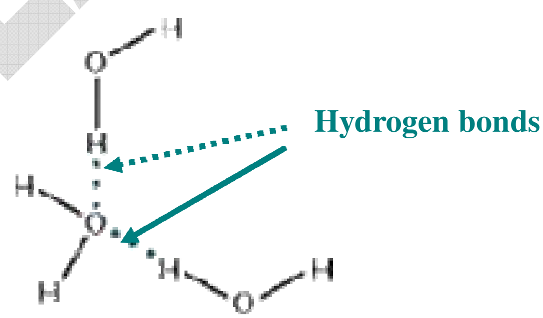
- HYDROGENBONDING is a Strong Intermolecular Force of Attraction that exists between:
    - ➢ H atoms bonded to very electronegative atoms (F, O, or N)

  and
    - ➢ a lone pair of electrons on a small electronegative atom (F, O, or N)

<u>HYDROGEN B ONDING IN WATER</u>







- The electrons in the O – H bond of H_2O molecules are attracted to the O atoms leaving the positively charged protons partially exposed.

- Result: A proton on one water molecule is attracted to a lone pair on an O atom in another H_2O molecule.

- Why is the HYDROGEN BONDING in water so strong ?
    1. The water molecule is very polar
    2. The H atom is special:
        - ➢ The bonding electrons in the O-H bond are strongly attracted toward the O atom
        - ➢ The (+) charge of the H nucleus (proton) is very well exposed (no other electrons in the atom)
        - ➢ The H atom is very strongly attracted to the lone pair of electrons of the neighboring O atom

ILLUSTRATINGTHEEFFECTOFHBONDINGONBOILINGPOINTS

BP(HF) = + 20 °C	BP(H_2O) = 100 °C	BP(NH_3) = - 30 °C	Effect of H bonding
BP(HCl) = - 85 °C	BP(H_2S) = - 60 °C	BP(PH_3) = - 90 °C	
BP(HBr) = - 65 °C	BP(H_2Se) = - 40 °C	BP(AsH_3) = - 65 °C	Effect of increase in M.W.
BP(HI) = -35 °C	BP(H_2Te) = O °C	BP(SbH_3) = - 18 °C	

NOTE:

1. Molecules associated through H bonding (HF, H_2O, NH_3 have much higher B.P.'s than molecules that are not associated through H bonding (HF, H_2O, NH_3)

2. An increase in Molecular Weight results in an increase of the B.P. (stronger London Forces

SUMM ARY

I. The Strength of Intermolecular Forces of Attraction increases in the following order:

LONDON FORCES → DIPOLE-DIPOLE FORCES → HYDROGEN BONDING

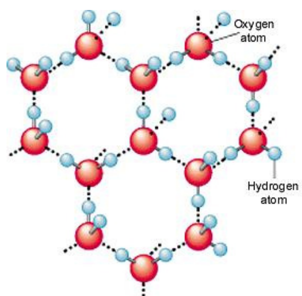
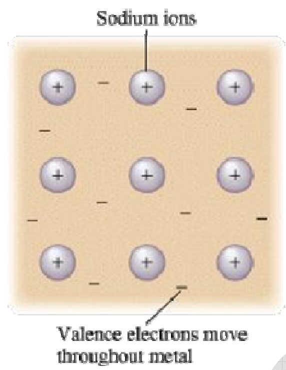
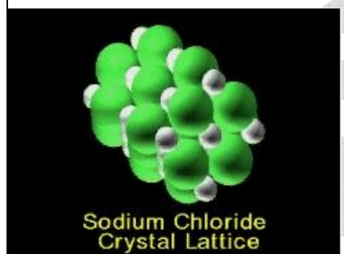
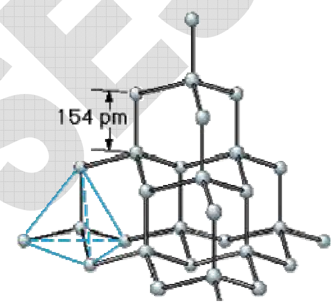
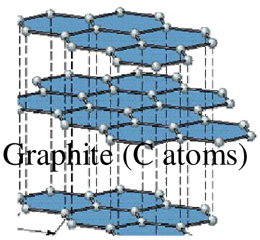
WEAKEST → STRONGEST

II. 1. Nonpolar Molecules are attracted by: - London Forces

2. Polar Molecules are attracted by: - London Forces
and
- Dipole-Dipole Forces

3. Polar Molecules containing H atoms bonded to very electronegative atoms (F, O, N) are attracted by:
- London Forces
and
- Dipole-Dipole Forces
and
- H bonding

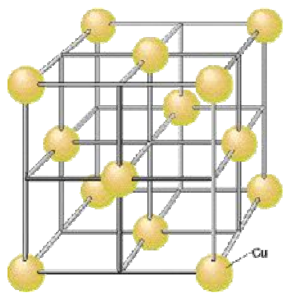
CLASSIFICATION OF SOLIDS

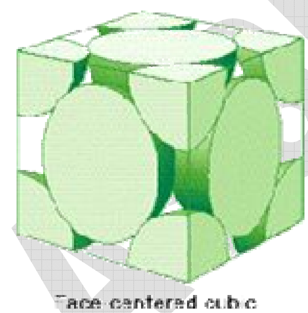
Molecular Solids	Metallic Solids	Ionic Solids	Covalent Network Solids
H_2O (s), CO_2 (s), I_2 (s) Ice dry ice	Na (s)	NaCl (s)	Diamond (s), Graphite (s) SiO_2 (s)
 **Ice** H_2O molecules connected through H bonds	 Positive ions surrounded by a "sea of electrons" (Metallic Bond)	 Positive and negative ions attracted by electrostatic forces of attraction (Ionic Bond)	 Diamond  Graphite (C atoms)
Intermolecular forces are relatively weak compared to Chemical Bonds	Metallic Bond (Chemical Bond)	Ionic Bond (Chemical Bond)	Covalent Bond (Chemical Bond)
Low melting points (below 300°C)	High melting points	High melting points	High melting points
Brittle	Malleable	Brittle	Brittle (very hard)
Non-conductor in any form	Good conductors	Non-conductor in solid Conductor in molten form	Non-conductor in any form (except Graphite)

CRYSTAL LATTICES

- A crystal is a three-dimensional ordered arrangement of basicunits (particles) that may be: atoms, molecules, or ions

Crystal Lattice of Copper **Unit Cell of Copper**

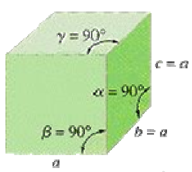




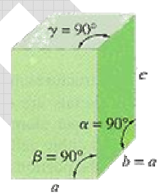
• Shows the arrangement of the basic units (lattice points) • The center of Cu atoms are chosen as lattice points.	• Smallest boxlike unit from which you can construct a crystal stacking unit.

- Various units cells with differing edge lengths and angles are shown below:

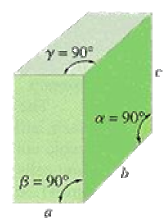
Cubic



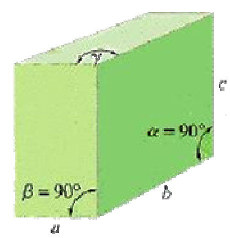
Tetragonal



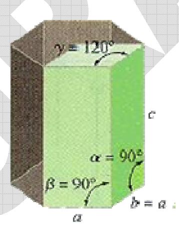
Orthorombic



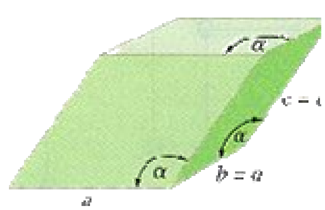
Monoclinic



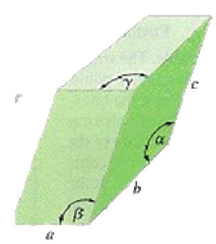
Hexangonal



Rombohedral



Triclinic

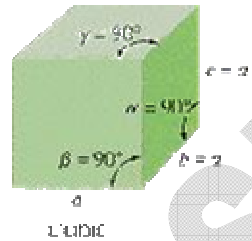


CUBIC UNIT CELLS

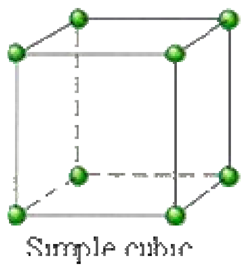
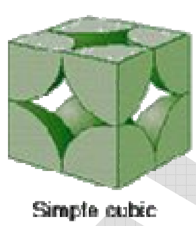
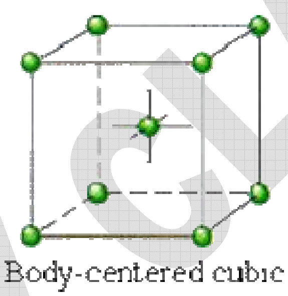
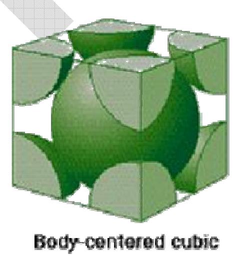
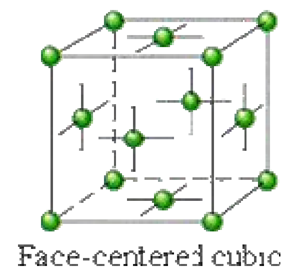
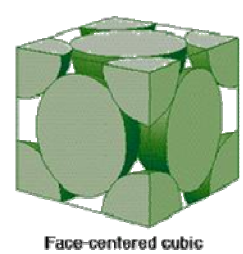
- Cubic unit cells are the simplest unit cells and therefore easiest to study in detail.

$a = b = c$

$\alpha = \beta = \gamma = 90^{\circ}$



- There are three types of Cubic cells

Simple Cubic Unit Cell (Simple)	**Body-Centered Cubic Unit Cell (BCC)**	**Face-Centered Cubic Unit Cell (FCC)**
  • Lattice points are situated only at the corners • Unit cell contains 1 atom • 52% of unit cell occupied by atoms • Least compact	  • Lattice points are situated at the corners and at the center of the unit cell • Unit cell contains 2 atoms • 68% of unit cell occupied by atoms	  • Lattice points are situated at the corners and at the center of each face • Unit cell contains 4 atoms • 74% of unit cell occupied by atoms • Most compact