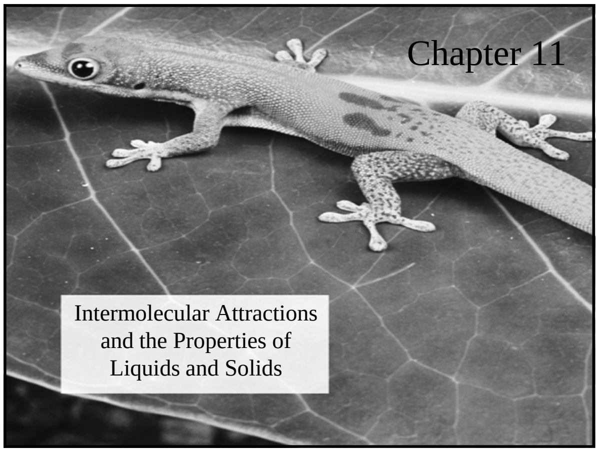

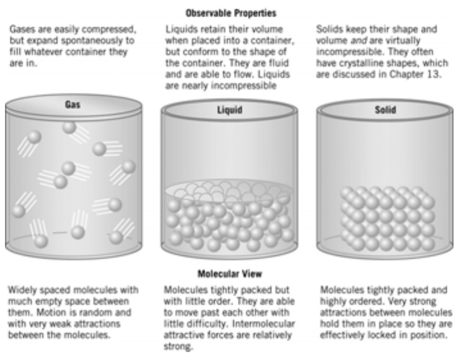

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Intermolecular forces

- Forces of attraction between molecules
- Directly dependent on the distance between the molecules
  - As the distance between molecules increases, the intermolecular forces between them will decrease
- Evident in liquids and solids, but NOT gases
  - Remember, we assume ideal gases

3

11.2 Intermolecular attractions

- **Int*er*molecular forces** control the physical properties of the substance.
- **Int*ra*molecular forces** are the chemical bonds within the molecule.

- Intramolecular forces are always stronger than intermolecular forces

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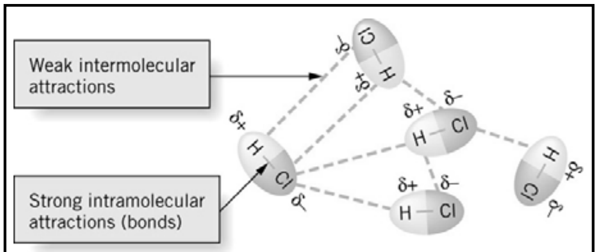

- Remember polar molecules?
- Intermolecular forces arise from the attractions between opposite charges.
- Also called **van der Waals forces**.

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Types of Attractive Forces

1. Dipole-Dipole Attractions (van der Waals)
2. Hydrogen bonds (forces)
3. London forces
4. Ion – dipole
5. Ion-induced dipole

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Dipole-Dipole (van der Waals)

- Dipole = two poles, a polar molecule
- The attraction between negatively charged end of one molecule with the positively charged end of another molecule
- Occur when one polar molecule encounters another polar molecule.
- The positive ends will be attracted to the negative ends.

Attractions (– –) are greater than repulsions (– –), so the molecules feel a net attraction to each other.

Hydrogen Bonding Forces

1. One molecule has a hydrogen atom covalently bonded to an atom of nitrogen, oxygen or fluorine.

2. The other molecule contains an atom of nitrogen, oxygen or fluorine.

Remember: they are not really bonds…just forces!

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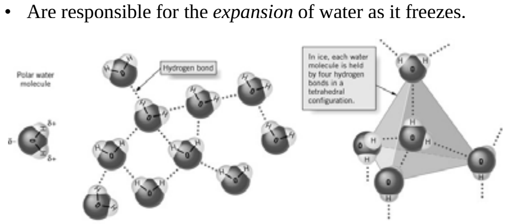
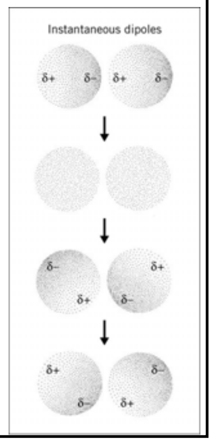
Hydrogen Bonding

- Hydrogen bonding can occur with any hydrogen that is bonded to either nitrogen, oxygen, or fluorine.
- Typically 5 – 10X stronger than Dipole-Dipole
- Are responsible for the *expansion* of water as it freezes.

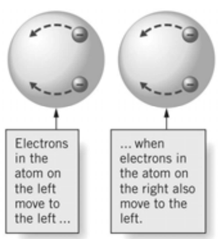


London Forces

- The (very) weak attractions between nonpolar molecules.
  - Electrons are constantly moving.
  - So, the electron density is constantly changing.
  - When electron density on a nonpolar molecule is unsymmetrical, the molecule will have a *momentary dipole*, or **instantaneous dipole**
- If the instantaneous dipole interacts with another molecule, it can produce an **induced dipole**.



London forces



- Also called London dispersion forces
- Relatively weak
- The magnitude of dispersion forces depends on how easy it is to **polarize** the electron cloud of a molecule.
- As the volume of the electron cloud increases, so does its **polarizability**.
- Therefore, the larger atoms (molecules) will have stronger forces.

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London Forces and Boiling Point

- We can use atomic size and molecular size to predict trends in boiling points.
- The larger the atoms or molecules, the stronger the dispersion forces, the higher the boiling point.
- Why? Because, larger molecules have higher polarizability and therefore they have stronger dispersion forces.
- The stronger forces require more energy to break → resulting in a higher boiling point.

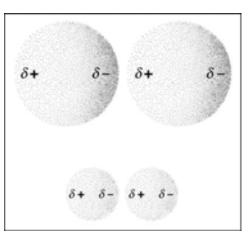

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TABLE 11.1 Boiling Points of the Halogens and Noble Gases

Group VIIA	Boiling Point (°C)	Group VIIIA	Boiling Point (°C)
F_2	−188.1	He	−268.6
Cl_2	−34.6	Ne	−245.9
Br_2	58.8	Ar	−185.7
I_2	184.4	Kr	−152.3
		Xe	−107.1
		Rn	−61.8

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- London forces depend on the number of atoms in the molecule.
- The boiling point of hydrocarbons demonstrates this trend.

TABLE 11.2 Boiling Points of Some Hydrocarbons*

Molecular Formula	Boiling Point at 1 atm (°C)
CH_4	−161.5
C_2H_6	−88.6
C_3H_8	−42.1
C_4H_{10}	−0.5
C_5H_{12}	36.1
C_6H_{14}	68.7
⋮	⋮
$C_{10}H_{22}$	174.1
⋮	⋮
$C_{22}H_{46}$	327

*The molecules of each hydrocarbon in this table have carbon chains of the type C—C—C—C—etc.; that is, one carbon follows another.

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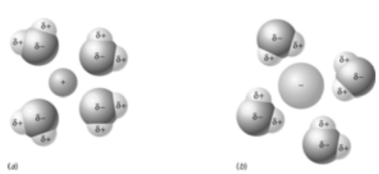
Ion-dipole and Ion-induced dipole

- These are the attractions between an ion and the dipole or induced dipole of neighboring molecules



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Ion-dipole forces and hydrates

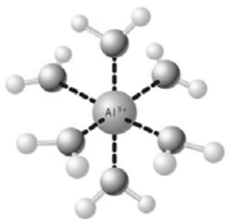

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TABLE 11.3 Summary of Intermolecular Attractions

Intermolecular Attraction	Types of Substances That Exhibit Attraction	Strength Relative to a Covalent Bond
Dipole–dipole attractions	Occurs between molecules that have permanent dipoles (i.e., polar molecules)	1–5%
Hydrogen bonding	Occurs when molecules contain N—H and O—H bonds	5–10%
London dispersion forces	All atoms, molecules, and ions experience these kinds of attractions. They are present in all substances.	Depends on sizes and shapes of molecules. For large molecules, the cumulative effect of many weak attractions can lead to a large net attraction.
Ion–dipole attractions	Occurs when ions interact with polar molecules	~10%; depends on ion charge and polarity of molecule
Ion–induced dipole attractions	Occurs when an ion creates a dipole in a neighboring particle, which may be a molecule or another ion	Variable, depends on the charge on the ion and the polarizability of its neighbor

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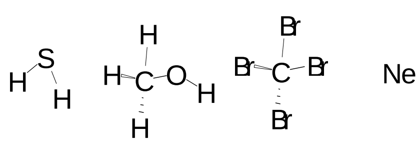
Identify the kinds of intermolecular forces present in the following compounds and then rank them in order of increasing boiling point: H_2S, CH_3OH, CBr_4, and Ne



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11.3 Forces and Physical Properties of Liquids and Solids

- Intermolecular attractions affect many physical properties of solids and liquids
  - Compressibility
  - Retention of volume and shape
  - Surface tension
  - Wetting
  - Viscosity

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Compressibility

- How tightly liquids and solids pack.
- **Compressibility –** a measure of the ability of a substance to be forced into a smaller volume
  - Solids and liquids are nearly incompressible because they contain very little space between particles
  - Why do they contain very little space?

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Retention of Volume/Shape

- Gases conform to the shape of the container.
  - Why?
- Solids and liquids however keep the same volume regardless of container.
- Solids also retain shape.
  - Why?

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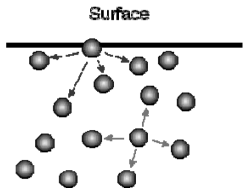
Surface Tension

- **Surface tension**: the tendency of a liquid to seek a shape with minimum surface area.
- Molecules in the interior experience an attractive force from neighboring molecules which surround on all sides
- Surface molecules of a liquid have a net inward force of attraction, forming a “skin”.



Wetting

- **Wetting –** the spreading of a liquid across a surface to form a thin film
- For wetting to occur, the intermolecular attractive force between the surface and the liquid must be about as strong as within the liquid itself
- Surfactants are added to detergents to lower the surface tension of water
- The “wetter” water can then get, the better access to the surface to be cleaned

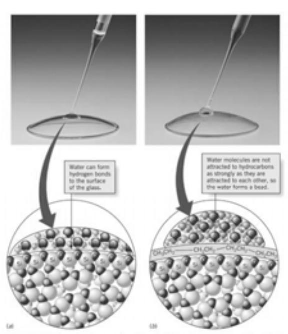
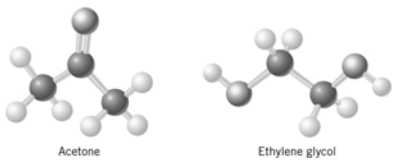


FIG. 11.15 **Intermolecular attractions affect the ability of water to wet a surface.** (*a*) Water wets a clean glass surface because the surface contains many oxygen atoms to which water molecules can form hydrogen bonds. (*b*) If the surface has a layer of grease, to which water molecules are only weakly attracted, the water doesn't wet it. The water resists spreading and forms a bead instead. *((a), (b) Michael Watson.)*

Viscosity

- **Viscosity –** the resistance to changing the form of a sample
- Viscosity is also called internal friction because it depends on intermolecular attractions and molecular shape.
- For example, acetone vs. ethylene glycol
- But what about water vs. rubber cement?



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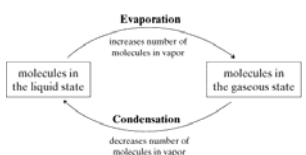
11.4 Changes of State

- As soon as a liquid is placed in an empty container, it begins to evaporate.
- If it is a closed container, molecules will begin to condense.
- When the rate of evaporation = rate of condensation, the system is in **dynamic equilibrium**



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Some definitions

- Evaporation: liquid to a gas
- Condensation: gas to a liquid
- Sublimation: solid to a gas (skips liquid phase)
- Deposition: gas to a solid (skips liquid phase)
- Melting: solid to a liquid
- Freezing: liquid to a solid

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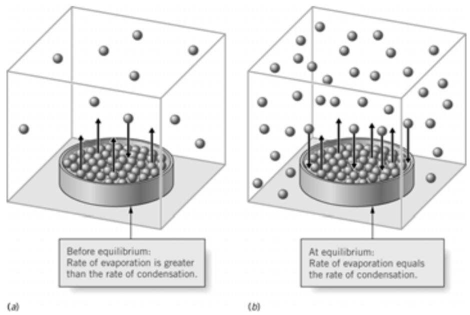
Liquid/Gas Dynamic Equilibrium



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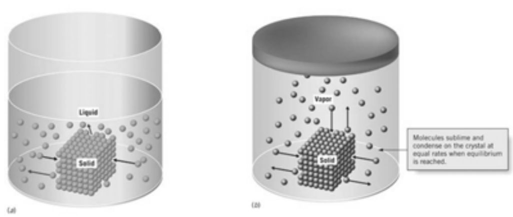
Solid/Liquid Solid/Gas



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11.5 Vapor Pressure

- **Vapor Pressure (*vp*)** - the pressure of the gas above the liquid phase
- At dynamic equilibrium, the pressure is termed **equilibrium vapor pressure.**
  - Sometimes just called **vapor pressure.**

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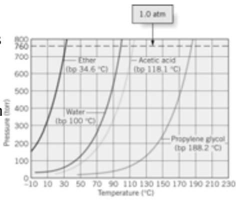
Factors Affecting Vapor Pressure

- Two main factors affect *vp*
  - Chemical Composition
    - An increase of intermolecular forces → a decrease in vapor pressure.
  - Temperature
    - An increase in temperature results in an increase in evaporation → an increase in vapor pressure.
- Vapor pressure is NOT dependent on surface area or volume.



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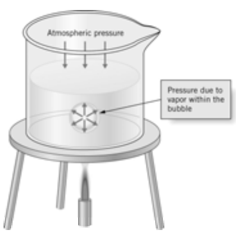

11.6 Boiling Point

- **Boiling point** (*bp*) – the temperature at which the vapor pressure of the liquid is equal to the prevailing atmospheric pressure
- The **normal boiling point** (*nbp) is* the temperature at which the vapor pressure is 1 atm
- Molecules with stronger intermolecular forces have higher boiling points.

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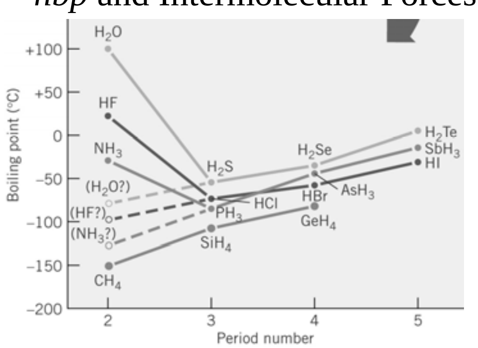
nbp and Intermolecular Forces



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11.7 Changes of State and Phase Diagrams

- There are three states of matter
  - Solid
  - Liquid
  - Gas
- A transformation from one state to another is called a phase change
- Each phase change is associated with a change in energy of the system.

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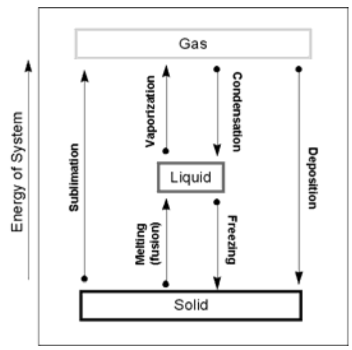

These changes above can be represented by a heating curve or cooling curve.

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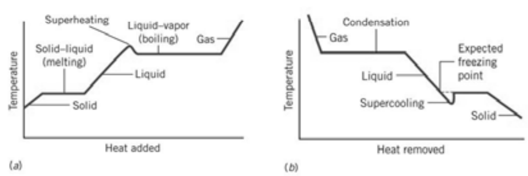
Heating and Cooling Curves

The "flat" regions of the curves identify the melting and boiling points.



•Heating Curve •Cooling Curve

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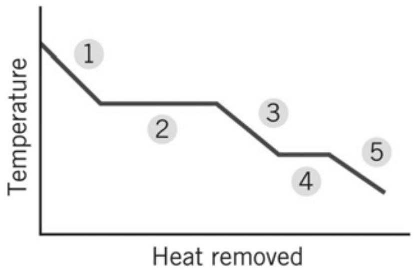

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We are skipping 11.9, 11.10, and 11.11.

11.8 Le Châtelier's Principle

- What happens if the dynamic equilibrium is disturbed?
- **Le Châtelier's Principle** – when a dynamic equilibrium in a system is upset by a disturbance, the system responds in a direction that tend to counteract the disturbance, and if possible, restore equilibrium.

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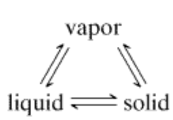
11.12 Phase Diagrams

- Illustrate the relationship between phases of matter and the pressure and temperature
- The lines identify the conditions under which two phases exist in equilibrium
- Triple point – point at which all three phases coexist



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Critical Temperature and Critical Pressure

- One would expect that as temperature increases, the vapor pressure of the liquid will continue to increase
- It does, to a point → the critical point
- Point at which the interface between a solid and liquid disappears, and a supercritical fluid is formed
- The critical temperature and critical pressure are notated as T_c and P_c

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