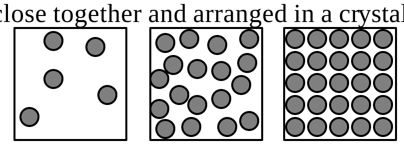
10 • States of Matter & IMFs
Comparing Gases, Liquids, and Solids
(1 of 16)

Properties of matter depend on the model that gas particles are spread out; liquids are close together, but random; and solids are close together and arranged in a crystal lattice.



Volume and **shape**, **compressibility**, and the ability of substances to **diffuse** depend on these models.
Gases have **no set shape or volume**.
Liquids have a **constant volume**, but **no set shape**.
Solids have **constant volume** and **shape**.

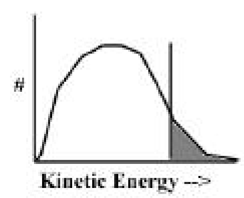
10 • States of Matter & IMFs
Surface Tension
(2 of 16)

Surface tension- a measure of the amount of energy needed to expand the surface area of a liquid.

An **interior** molecule is surrounded by molecules to which it is attracted… no net attraction. A **surface** molecule feels a **net attraction** toward the interior. To move a molecule to the surface (i.e. increase the surface area), energy must be used, work must be done. The **potential energy** of the liquid is **increased**.

Substances tend toward the **lowest potential energy** so liquids tend toward the **minimum surface area**. A **sphere** is the smallest surface area for given volume.

10 • States of Matter & IMFs
KE Distributions and Evaporation
(3 of 16)



In any sample of liquid, the distribution of KE varies. Particles to the right of the line (the "threshold energy" have enough KE to escape the IMF's holding them in the liquid.

Increasing the **temperature** (average KE) of the liquid **moves the curve to the right**. The **line** depends on the **IMF** of the liquid.

Only particles at the **surface** of the liquid may escape (evaporate.)

10 • States of Matter & IMFs
Molecular Crystals and IMFs
(4 of 16)

Substances that exist as **molecules** (as opposed to ionic, metallic, or covalent network crystals) are in three groups:

nonpolar molecules London Forces	**polar molecules** Dipole-dipole attractions	**polar with H-O-, H-N-, or H-F** H-bonding
Weak IMF. Due to polarizable e- clouds & temp. attraction	+ end of one molecule attracting - end of other molecule	Strong dipole because of high electroneg. /small size of O, N, & F

In **London Forces--larger atoms** and **larger molecules** have **stronger London forces** due to **more sites** or **more polarizable electron clouds**.

10 • States of Matter & IMFs
H_{vap} and IMFs
(5 of 16)

Heat of Vaporization, **ΔH_{vap}**, can be thought of as **the energy needed to vaporize a mole of a liquid**

It can be used as a **conversion factor** in a **calculation of heat** during a **phase change**. [*Calorimetry* is used for temperature changes *between* the phase changes.]

$$\text{Ex: } 111\,\text{g H}_2\text{O} \times \frac{1\,\text{mol H}_2\text{O}}{18.0\,\text{g H}_2\text{O}} \times \frac{40.6\,\text{kJ}}{1\,\text{mol H}_2\text{O}} = 250.\,\text{kJ}$$

It can also serve as a **indicator of the strength of the IMF** (intermolecular forces of attraction) in the liquid.

Ex: CH_4 (9.20 kJ/mol) vs. C_3H_8 (18.1 kJ/mol)

Larger molecule… greater IMF… greater H_{vap}

10 • States of Matter & IMFs
Vapor Pressures of Liquids
(6 of 16)

In a **closed container**, the number of particles changing from **liquid → vapor** will eventually equal the number of particles changing from **vapor → liquid**.

The **amount of vapor** when this balance is reached depends on the **IMF** and the **KE of the liquid** (& **not** on the volume of the container). The **pressure** exerted by this vapor is called the **equilibrium vapor pressure (VP)** of the liquid.

As **temperature increases**, the **VP increases**. (This is important for why/when a liquid **boils**.)

VP is another **indicator of the strength of the IMF**. The **stronger** the IMF, the **smaller** the VP.

10 • States of Matter & IMFs
Boiling Point and IMFs
(7 of 16)

Boiling occurs when the **vapor pressure (VP)** of a substance **=** the **air pressure** above the liquid.

You can boil a liquid by **increasing** the **VP** of the liquid (heating) or by **lowering** the **pressure *above*** the liquid.

The temperature at which a liquid reaches 760 mmHg is called the "normal boiling point" of the liquid.

---Again, BP is an indicator of IMF.---

↑ boiling points (**BP**) ~ **↑ IMF's** ~ **↓vapor pressures**.

Altitude (low air pressure) lowers the boiling temperature of water in an open container (increases cooking **time**).
Pressure cookers ↑ BP by ↑ the pressure above the liquid.

10 • States of Matter & IMFs
Freezing Point, Melting Point, ΔH_{fusion}
(8 of 16)

Freezing Point and Melting Point are the same temperature, just opposite directions. That is, a substance will freeze and melt at the **same temperature**.

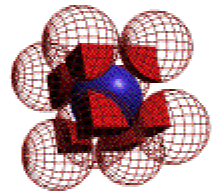
When you fuse two metals, you MELT them… thus the term **fusion** means **melting**. **ΔH_{fusion}** is the energy needed to melt a mole of solid into a mole of liquid.

As with ΔH_{vap}, ΔH_{fus} can be used as a **conversion factor** as well as an **indicator of IMF** strength.

Note: Freezing is more complicated than vaporization because the process of forming a crystal causes some subtle considerations which we will not deal with in this course.

10 • States of Matter & IMFs
Common Crystal Structures and Unit Cells
(9 of 16)

Three common crystal structures are Simple Cubic; Body-Centered Cubic (which means there is an atom, "a body," in the center of the cubic structure; and Face-Centered Cubic (with an atom in the center of each side or "face").



From Dr. John Gelder's Solid State Chemistry Page

A unit cell is the theoretical arrangement of atoms that, if repeated, will recreate the crystal.

This topic, although interesting, is no longer on the AP curriculum and will not be dealt with here. One resource is a page by OSU chemist, Dr. John Gelder. (See Card 16)

10 • States of Matter & IMFs
Four Types of Crystals -- Summary
(10 of 16)

Crystal	Molecular	Ionic	Covalent	Metallic
lattice points:	molecules or atoms	+ and - ions	atoms	positive ions
IMF's	London, dipole, H-bonding	attraction between + & - ions	covalent bonds	attr. between + ions & "sea of e-'s"
Props.	soft, low MP, non-conduct	hard, brittle, high MP, (l) (aq) conduct	v. hard, high MP, nonconduct (graphite)	high luster, conductor, variable MP, soft/hard
Ex	I_2 H_2O HI	NaBr	C SiC WC	Na° Fe° Cu°

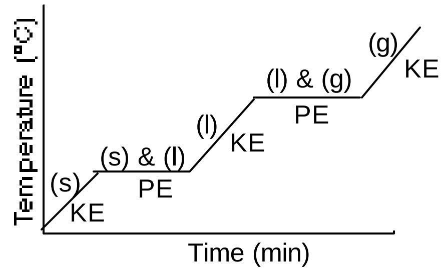
10 • States of Matter & IMFs
Crystal Types -- Further Notes
(11 of 16)

Students are often confused between **molecular crystals** in which covalent bonds hold the **molecules** together (but the IMF = London forces, dipole-dipole attractions or hydrogen bonding) and **covalent crystals** in which covalent bonds hold the **crystal** together (the IMF = covalent bonds).

Substances can conduct electricity for two reasons: **freely moving ions** or **delocalized electrons**.

Ionic compounds have freely ions in the liquid state and when dissolved in water.
Metals have delocalized electrons -- the "sea of electrons."
Graphite has a chicken-wire shaped π-bond above & below each sheet of sp^2-hybridized C atoms, allowing it to conduct.

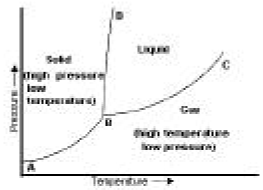
10 • States of Matter & IMFs
Heating and Cooling Curves
(12 of 16)



KE = kinetic energy changes which are times when the heat energy speeds up the molecules.

PE = potential energy changes which are times when the heat energy separates the molecules from solid to liquid or liquid to gas.

10 • States of Matter & IMFs
Phase Diagrams - I
(13 of 16)



The phase diagram shows the phases of a substance at all temperatures and pressures.

Moving across the diagram gives you the MP and then BP of a substance.

There is a point above which it is no longer possible to liquefy a substance (the **critical point**, C).
Moving vertically you can see the effect of pressure on the phase of the substance.
This is a diagram for a substance like CO_2, in which the liquid can be compressed into the solid. (Unlike H_2O.)

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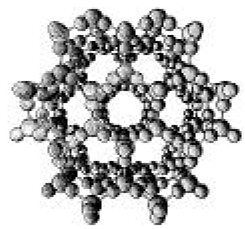
10 • States of Matter & IMFs
Phase Diagrams - II
(14 of 16)



Water's phase diagram is unique because the liquid phase is less dense than the solid phase. To maximize hydrogen bonding, the solid must expand.

The B-D boundary of the phase diagram has a negative slope.

The "triple point" is the temperature and pressure in which the solid, liquid, and vapor phases of a substance can co-exist. I visualize this as a boiling glass of ice water.

By increasing the pressure, dry ice can melt. By decreasing the pressure, solid water can sublime.

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10 • States of Matter & IMFs
Name of the Phase Changes
(15 of 16)

<u>**NRG is REQUIRED**</u>	<u>**NRG is RELEASED**</u>
solid ® liquid melting or fusion	**liquid ® solid** freezing
liquid ® gas vaporization evaporation or boiling	**gas ® liquid** condensation
solid ® gas sublimation	**gas ® solid** solidification

The **energy** involved in the phase change is <u>calculated</u> using
heat of fusion (solid ® liquid or liquid ® solid)
heat of vaporization (liquid ® gas or gas ® liquid)

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10 • States of Matter & IMFs
More Internet Resources
(16 of 16)

Searching the Internet, I found an interesting set of topic reviews. These are from Purdue University (Indiana)

I was looking at the topic, LIQUIDS, but there are many topics to choose from.
`chemed.chem.purdue.edu/genchem/topicreview/`

The unit cell is a frame from an online movie file on Dr. John Gelder's Solid State Chemistry page. (OK State Univ.)
`www.okstate.edu/jgelder/solstate.html`