Intermolecular Forces

Solids, Liquids, Solutions, and Phase Changes

What I Absolutely Have to Know to Survive the AP* Exam

The following might indicate that the question deals with intermolecular forces:
Boiling points; vapor pressure; melting points; network solid; crystalline solids; metallic solids; sea of electrons; delocalized electrons; triple point; sublimation; deposition; condensation; boiling; melting; freezing; intermolecular forces; vapor pressure; Coulombic interactions, etc…

Coulombic Interactions – *It's All About the Attractions*

The strength and nature of the electrostatic forces or Coulombic interactions that exist *between* particles explain the properties or behaviors of substances.

- When a substance undergoes a physical change the forces being overcome (the intermolecular interactions) are Coulombic in nature.
- When answering questions about the physical changes and properties of ionic solids always consider Coulomb's law – it is all about the charge and the distance the charges are apart.

$$U_E \propto \frac{q^+q^-}{d}$$

Properties of Matter – *Let's Get Physical*

The different properties can be explained by differences in their structures at the particulate level. These properties reflect:

- Relative orderliness of the arrangement of their particles; i.e. the spacing between their (atoms, molecules, ions)
- Their relative freedom of motion
- *Nature and strength of the interactions between them*

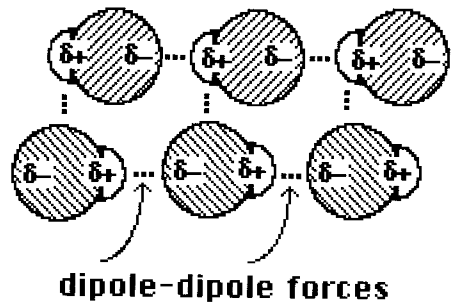
SOLIDS	Can be crystalline, where the particles are arranged in a regular 3-D structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. • Motion of the individual particles is limited • They do not undergo any overall translation with respect to each other. • Inter-particle interactions provide the main criteria for the structures of solids
LIQUIDS	Particles in liquids are very close to each other, and they are continually moving and colliding. • Their particles are able to undergo translation with respect to each other and their arrangement • Movement is influenced by the nature and strength of the inter-particle interactions that are present
NOTE	The solid and liquid phases for a particular substance generally have relatively small differences in molar volume. In both cases their particles are very close to each other at all times. This not true for the gas phase – where we assume the particles move independently having neither a definite shape or volume – as their particles are not "bound together" by inter-particle attractions

So…. What are these so called inter-particle attractions..?

Interparticle Attractions – *They're Sticky!* con't.

Dipole-dipole interactions

- Dipole forces result from the attraction among the positive ends and negative ends of polar molecules.
- The molecules align themselves such that the opposite poles align – they maximize the attraction and minimize the repulsion
- These dipoles result from the unequal distribution of electron density in the molecule
- Intermolecular dipole-dipole forces are weaker than ionic forces or covalent bonds.
- The larger the dipoles, the stronger the force of attraction between the two molecules, the stronger the ***Dipole-Dipole force***

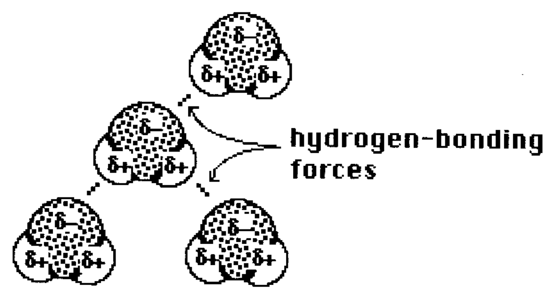


Dipole-induced dipole interactions

- Dipole-induced dipole interactions are present between a polar and nonpolar molecule.
- The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule

Hydrogen binding forces (*hydrogen bonding*)

- Type of dipole force
- Hydrogen bonding is a relatively strong type of intermolecular interaction
- Exists when hydrogen atoms that are covalently bonded to the highly electronegative atoms (N, O, and F) are also attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a ***different*** molecule, or a ***different part*** of the same molecule (think about the complex structures of a large biomolecule – like *DNA*)
- When hydrogen bonding is present, even small molecules may have strong intermolecular attractions. Think H_2O



NOTE:	Ionic interactions with dipoles are important in the solubility of ionic compounds in polar solvents. The positive and negative ions interact with the positive and negative ends of polar molecules, creating strong interactions – helping explain why NaCl is soluble in water.
WATCH OUT!	When comparing ***similar sized particles***, hydrogen binding forces > dipole forces > London dispersion forces. However, do not assume this is always the case. In substances with only London dispersion forces that have a considerably larger (thus very polarizable) electron cloud than the polar molecules, the London dispersion forces can be quite substantial and can be stronger than both Hydrogen binding forces or dipole-dipole forces…

Solids – *It's All About their Types con't*	

Ionic Solids	Properties are related to the strong Coulombic interactions of positive and negative ions arranged in a regular three- dimensional array.
	• Generally have low vapor pressure
	• Tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer.
	• Their solids do not conduct electricity. However, when ionic solids are melted, they do conduct electricity because the ions are free to move.
	• When ionic solids are dissolved in water, the separated ions are free to move; therefore, these solutions will conduct electricity.
	• The attractive force between any two ions is governed by Coulomb's law: $U_E \propto \frac{q^+q^-}{d}$
	    • For ions of a given charge, the smaller the ions, and thus the smaller the distance between ion centers, the stronger the Coulombic force of attraction, and the higher the melting point.
	    • Ions with higher charges lead to higher Coulombic forces, and therefore higher melting points.

Liquids - *All About their Properties*	
Surface Tension	Molecules in the interior of a liquid are attracted by surrounding molecules in all 3–dimensions. A molecule at the surface of a liquid is attracted only by the molecules below it and on each side of it. This leads to surface tension. High surface tension indicates strong IMFs.
Capillary Action	Described by spontaneous rising of a liquid in a narrow tube. Adhesive forces between the molecules and the glass overcome the forces (IMFs) between molecules themselves. Water has a higher attraction for glass than for itself so its meniscus is inverted or concave, while Hg has a higher attraction for other Hg atoms, thus its meniscus is convex.
Boiling Point	Boiling point is the temperature at which the vapor pressure of a liquid equals the atmospheric pressure; at this point the molecules have enough energy to overcome their IMFs and enter the vapor phase. At this temperature the substance exists in equilibrium as liquid and gas particles.
Vapor Pressure	Vapor pressure is the pressure resulting from particles of a substance, which exist in the gas phase above the liquid (or solid). The weaker the IMFs, the higher the vapor pressure. *Why?* • The substance can more easily overcome those IMFs and break away into the gas phase, increasing the number of molecules in the gas phase (at that temperature), thus increasing the pressure above the liquid. • Increasing the temperature on the substance will increase the vapor pressure; again due to more molecules being able to overcome their IMFs and move into the gas phase.

Solution Formation – *All About those IMFs*

Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.

Substances with similar intermolecular interactions tend to be miscible or soluble in one another.

Solutions come in the form of solids, liquids, and gases

- For liquid solutions, the solute may be a gas, a liquid, or a solid.

Liquid solutions exhibit several general properties:

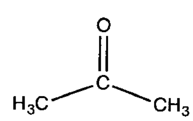
- The components cannot be separated using filter paper.
- There are no components large enough to scatter visible light.
- The components can be separated using processes that are a result of the intermolecular interactions between and among the components.
    - Chromatography (paper and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components.
    - Distillation is used to separate chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.
- The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/inter-particle interactions before and after the dissolution process.

CAUTION	Never use "like dissolves like" on the AP exam. EXPLAIN in terms of IMFs and energy….

Solution Formation:
Particles exhibit a number of inter-particle interactions (London dispersion, hydrogen binding, dipole-dipole, ion-dipole, etc…) and it is these interactions that either PROMOTE or PREVENT solution formation.
In order to dissolve a substance must…

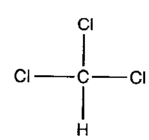
Overcome (requires energy) *both* solute-solute and solvent-solvent interactions
Form solute-solvent interactions upon mixing (releases energy)

A solution WILL form when the energy released due to the solute-solvent interactions is the same as (or more than) the energy needed overcome the solute-solute and the solvent-solvent interactions.
Example: dissolving acetone in chloroform



acetone

and

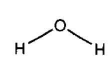


chloroform

Solute-Solute: acetone forms dipole-dipole interactions between their particles
Solvent-Solvent: chloroform forms dipole-dipole interactions between their particles
Solute-Solvent: when mixed together dipole-dipole interactions form between the acetone and chloroform particles

Example: dissolving sodium chloride in water

Na^+ and Cl^- and



water

Solute-Solute: positive sodium and negative chloride ions form ionic interactions between their particles
Solvent-Solvent: water forms hydrogen binding interactions between their particles
Solute-Solvent: when mixed together ion-dipole interactions form between the positive and negative ions of the salt and the polar water particles