Oakland Schools Chemistry Resource Unit

Intermolecular Forces

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<u>Bonding: Intermolecular Forces</u>

Content Statements:

C2.2: Chemical Potential Energy

Potential energy is stored whenever work must be done to change the distance between two objects. The attraction between the two objects may be gravitational, electrostatic, magnetic, or strong force. Chemical potential energy is the result of electrostatic attractions between atoms.

C3.3: Heating Impacts

Heating increases the kinetic (translational, rotational, and vibrational) energy of the atoms composing elements and the molecules or ions composing compounds. As the kinetic (translational) energy of the atoms, molecules, or ions increases, the temperature of the matter increases. Heating a sample of a crystalline solid increases the kinetic (vibrational) energy of the atoms, molecules, or ions. When the kinetic (vibrational) energy becomes great enough, the crystalline structure breaks down, and the solid melts.

C4.3: Properties of Substances

Differences in the physical and chemical properties of substances are explained by the arrangement of the atoms, ions, or molecules of the substances and by the strength of the forces of attraction between the atoms, ions, or molecules.

C4.4: Molecular Polarity

The forces between molecules depend on the net polarity of the molecule as determined by shape of the molecule and the polarity of the bonds.

C5.4: Phase/Change Diagrams

Changes of state require a transfer of energy. Water has unusually high-energy changes associated with its changes of state.

Content Expectations:

C2.1c: Compare qualitatively the energy changes associated with melting various types of solids in terms of the types of forces between the particles in the solid.

C3.3B: Describe melting on a molecular level.

C4.3A: Recognize that substances that are solid at room temperature have stronger attractive forces than liquids at room temperature, which have stronger attractive forces than gases at room temperature.

C4.3c: Compare the relative strengths of forces between molecules based on the melting point and boiling point of the substances.

C4.3d: Compare the strength of the forces of attraction between molecules of different elements. (For example, at room temperature, chlorine is a gas and iodine is a solid.)

C4.3f: Identify the elements necessary for hydrogen bonding (N, O, and F).

C4.3g: Given the structural formula of a compound, indicate all the intermolecular forces present (dispersion, dipolar, hydrogen bonding).

C4.4a: Explain why at room temperature different compounds can exist in different phases.

C5.4c: Explain why both the melting point and boiling points for water are significantly higher than other small molecules of comparable mass (e.g., ammonia and methane)

Instructional Background Information:

Melting on a Molecular Level: Melting involves the disruption of the crystal lattice of a solid via the absorption of kinetic energy by the molecules in the lattice from their surroundings. As the forces holding the lattice together increase in strength so does the melting point of the solid.

Strong Forces: Ionic bonding, metallic bonding, and network-covalent bonding. Strong intermolecular forces result in room temperature solids with high melting and boiling points.

Metallic and Network Bonding is difficult to quantify.

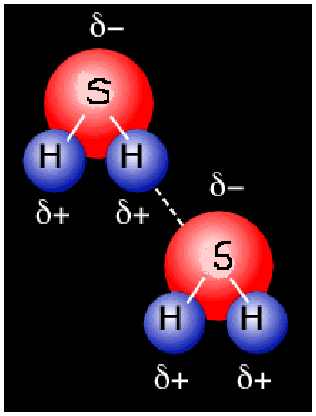
Ionic Bonding: Ionic bonds are the result of electrostatic attraction between positive and negative ions. Ionic bonding is directly proportional to ionic charge and inversely proportional to ionic size.

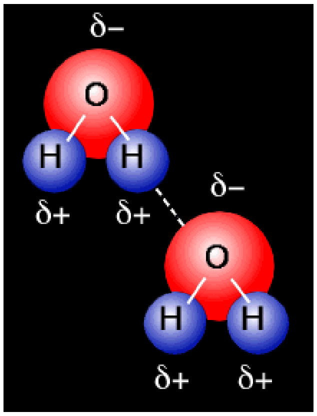
Weak Forces: Hydrogen bonding, dipole-dipole interactions, London dispersion forces.

Hydrogen Bonding: Hydrogen bonding is the unusually strong dipole-dipole interaction that occurs when a highly electronegative atom (N, O, or F) is bonded to a hydrogen atom. This bond nearly strips the hydrogen atom of its electrons leaving, essentially, a naked proton. This proton is highly attracted to the electron pairs on nearby molecules.

Hydrogen bonding is significantly stronger than the dipole-dipole interactions which are in turn stronger than London dispersion forces. Hydrogen bonding exists only in molecules with an N-H, O-H, or F-H bond.

Dipole-Dipole: Dipole-dipole interaction is the attraction between a partially negative portion of one molecule and a partially positive portion of a nearby molecule. Dipole-dipole interaction occurs in any polar molecule as determined by molecular geometry.





www.lbl.gov/images/MicroWorlds/H2OH-bond.gif

Dipole-Dipole Interaction

Hydrogen Bonding
(unusually strong Dipole-Dipole)

London Dispersion: London dispersion forces result from instantaneous non-permanent dipoles created by random electron motion. London dispersion forces are present in all molecules and are directly proportional to molecular size.

Effects of Intermolecular Forces: The strength of intermolecular forces present in a substance is related to the boiling point and melting point of the substance. Stronger intermolecular forces cause higher melting and boiling points.

EXAMPLES:

CH_4 - Methane: has only very weak London dispersion forces (lowest b.p. & m.p.)

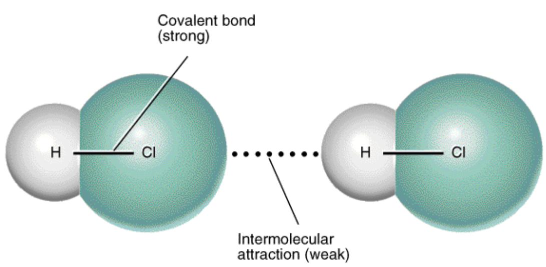
$CHCl_3$ - Chloroform: has dipole-dipole interaction (moderate b.p. & m.p.)

NH_3 - Ammonia: has hydrogen bonding and dipole-dipole interaction (high b.p. & m.p.)

The Forces between Molecules

All matter is held together by force. The force between atoms within a molecule is a chemical or intramolecular force. The force between molecules is a physical or intermolecular force. We learned about intramolecular forces and the energy it took to overcome these forces, earlier in our chemical studies. Now we will focus on intermolecular forces.

The Nature of Intermolecular Forces:



The Intermolecular Forces (forces between molecules) are weaker than Intramolecular Forces (The Chemical Bonds within an Individual Molecule). This distinction is the reason we define the molecule in the first place. The properties of matter result from the properties of the individual molecule (resulting from chemical bonding) and how the molecules act collectively (resulting from intermolecular forces).

Intermolecular Forces are longest-ranged (act strongly over a large distance) when they are **electrostatic**. Interaction of Charge Monopoles (simple charges) is the longest-

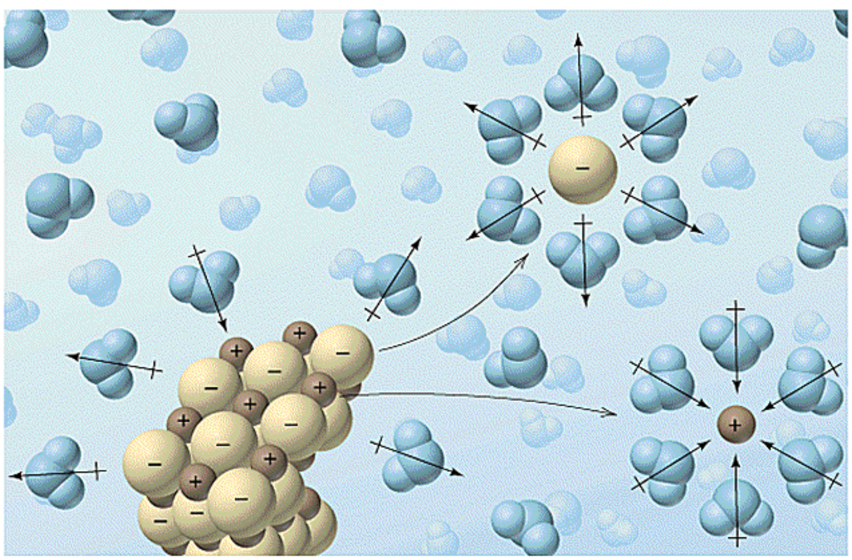
ranged electrostatic force.
Charge-Charge forces (found in ionic crystals)

$$F_{\text{charge-charge}} = \frac{q_1 q_2}{(4\pi\epsilon_0) r^2}$$

For like charges (+,+) or (-,-), this force is always repulsive. For unlike charges (+,-), this force is always attractive.

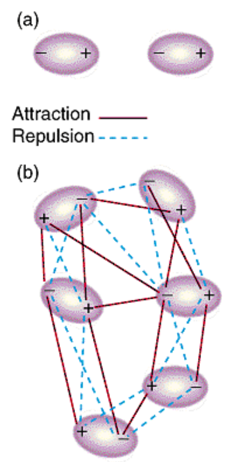
Charge-Dipole Forces:
An uncharged molecule can still have an electric dipole moment. **Electric Dipole**s arise from opposite but equal charges separated by a distance. Molecules that possess a dipole moment are called **Polar** molecules (remember the polar covalent bond?). Water is polar and has a dipole moment of 1.85 Debye. The Debye is a unit of dipole moment and has a value of 3.336 x 10^{-30} Coulomb meter.

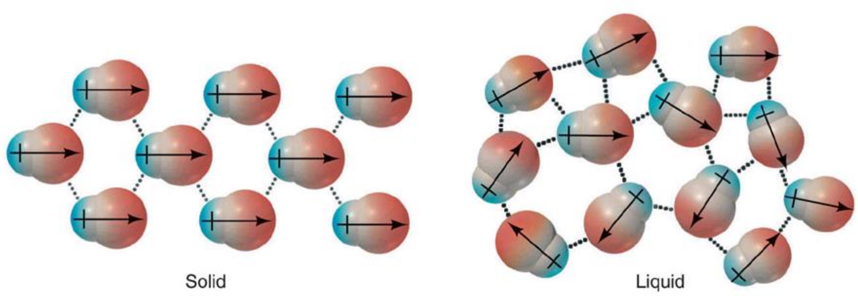
When salt is dissolved in water, the ions of the salt dissociate from each other and associate with the dipole of the water molecules. This results in a solution called an **Electrolyte**



The force may be understood by decomposing each of the dipole into two equal but opposite charges and adding up the resulting charge-charge forces. Notice that the Charge-Dipole Forces depend on relative molecular **orientation**. This means that the forces can be *attractive or repulsive* depending on whether like or unlike charges are closer together. On average, dipoles in a liquid orient themselves to form attractive interactions with their neighbors, but thermal motion makes some instantaneous configurations exist fleetingly that are, in fact, repulsive.

Dipole-Dipole forces exist between neutral polar molecules. Again, this force may be understood by decomposing each of the dipole into two equal but opposite charges and adding up the resulting charge-charge forces.





The following table demonstrates the effect of the dipole moment on the boiling point of several substances:

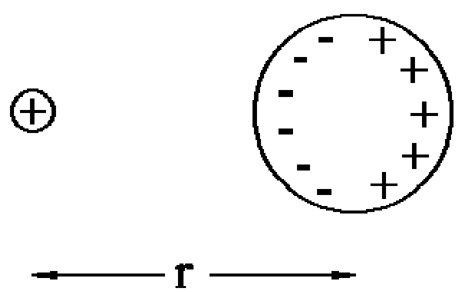
Substance	Molecular Mass [g/mol]	Dipole moment [Debye]	Normal Boiling Point [K]
Propane	44	0.1	231
Dimethyl ether	46	1.3	248
Chloromethane	50	2.0	249
Acetaldehyde	44	2.7	294
Acetonitrile	41	3.9	355

Electrostatic forces are defined (categorized) by the symmetry of the partners involved in the interaction. This symmetry is labeled by the first non-zero moment of the charge distribution, i.e. Monopole, Dipole, Quadrupole, etc. Electrostatic forces only exist between molecules with *permanent* moments of their charge distribution; Molecules do not have to distort or fluctuate in order to exhibit electrostatic intermolecular forces.

Electrostatics cannot explain the whole story, however. Molecules that are round and have no charge have no electrostatic forces between each other. How, then, do round molecules form liquids or solids?

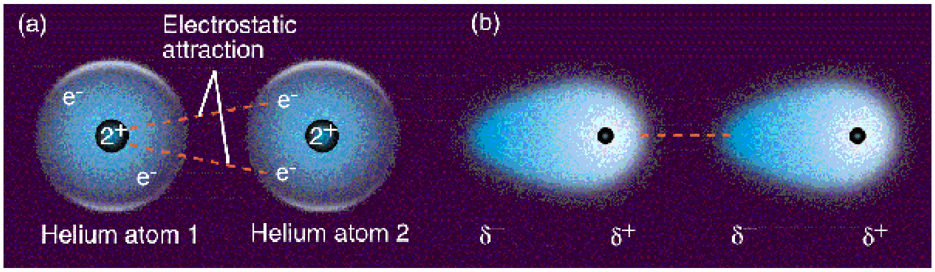
Inductive Forces and Dispersion

Inductive forces arise from the *distortion* of the charge cloud induced by the presence of another molecule nearby. The distortion arises from the electric field produced by the charge distribution of the nearby molecule. These forces are **always attractive** but are in general shorter ranged than electrostatic forces. If a charged molecule (ion) induces a dipole moment in a nearby neutral molecule, the two molecules will stick together, even though the neutral molecule was initially round and uncharged:



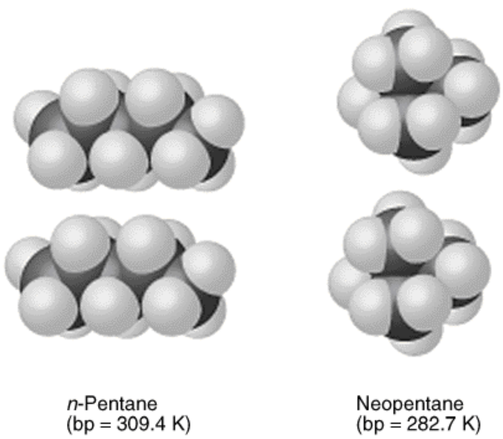
Other *inductive* forces exist (permanent dipole - induced dipole, etc.) but this one (charge-induced dipole) is the strongest.

Inductive forces that result not from permanent charge distributions but from **fluctuations** of charge, are not called inductive forces at all but are called **London Dispersion** forces. These forces are ubiquitous but are most important in systems that have no other types of molecular stickiness, like the rare gases. The rare gases may be liquefied, and it is dispersion forces that hold the atoms together (no electrostatic or inductive forces exits)

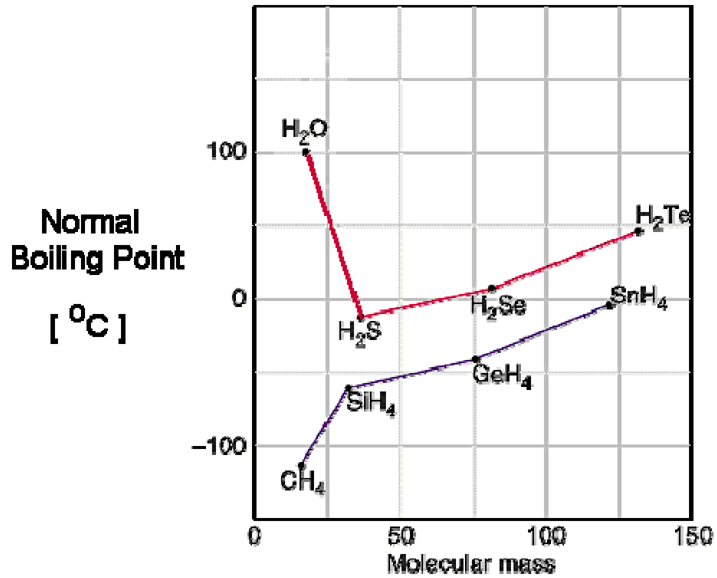


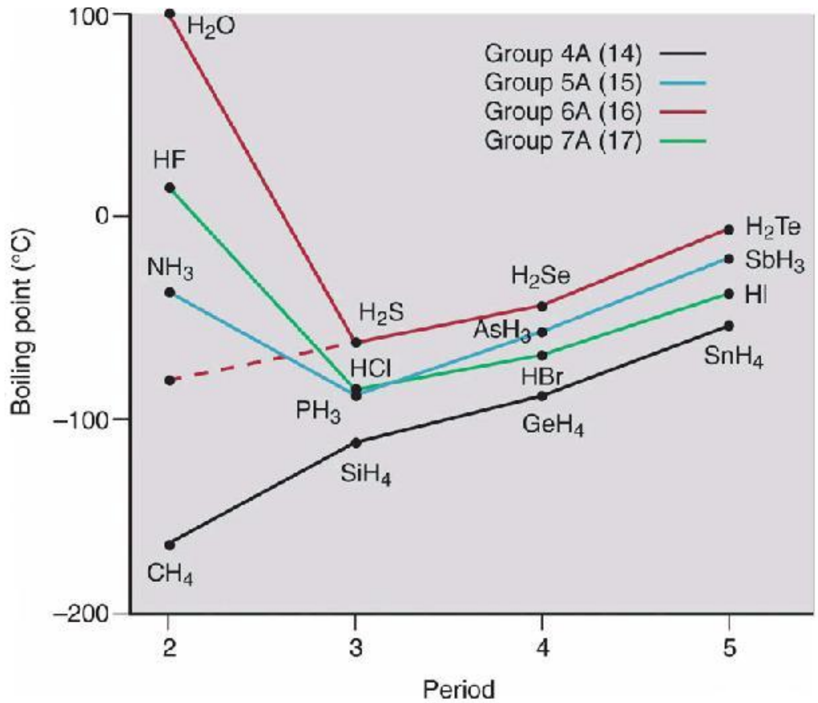
The movement of the electrons, even in the He atom, causes an instantaneous dipole to be formed. The time-averaged dipole moment of the atom is still zero. This dipole, however fleeting, can *induce* a dipole in a neighboring atom, causing a force. This force is always attractive but even shorter ranged (and weaker) than permanent dipole-induced dipole forces.

Size (Volume and Shape) determines the magnitude of the dispersion force. *The bigger the size, the larger the dispersion force.*



Hydrogen Bonding



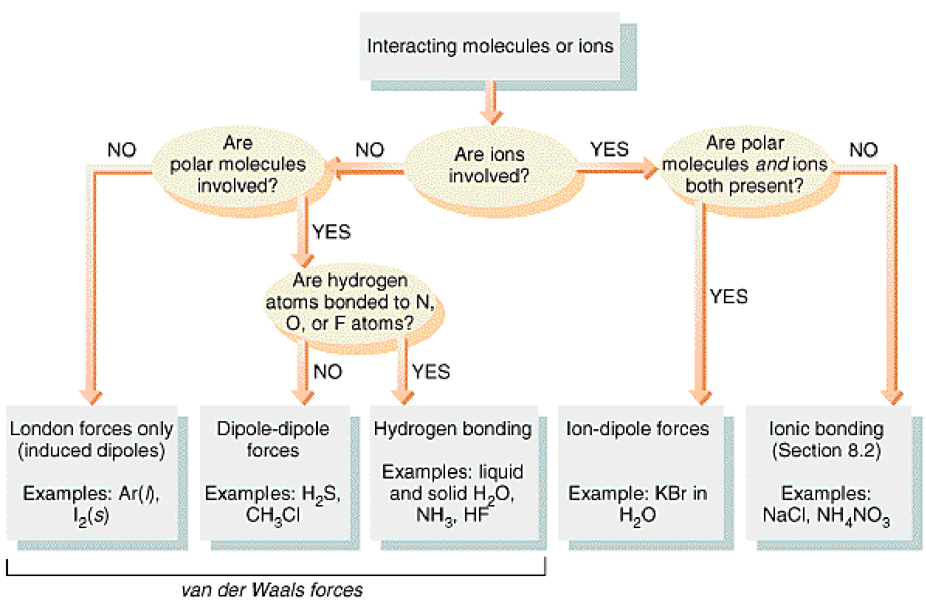


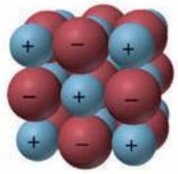
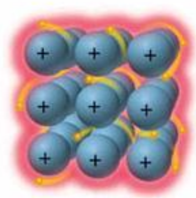
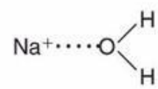
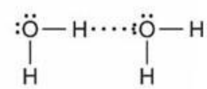
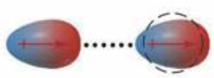
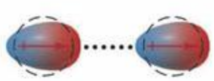
The figure above shows the normal boiling point temperatures for several related substances. This boiling point diagram tells us about the intermolecular forces between a homologous series of small hydrogen containing molecules. Look first at the Group **IV** hydrides, from CH_4 through SnH_4. The boiling points of these molecules increase with increasing mass, as one would expect. The group **VI** hydrides do the same thing, with the notable exception of WATER! A special type of intermolecular force exists between water molecules called hydrogen bonding, which raises its boiling point significantly with respect to its isovalent homologs.

Hydrogen is unique among the elements because it has a single electron which is also a valence electron. When this electron is hogged by another atom in a polar covalent bond, a significant fraction of the hydrogen nucleus becomes uncovered and the bare nucleus desperately seeks to be covered by electrons from other atoms (modesty?).

A Hydrogen Bond is the attractive interaction between two closed shell species that arises from the link of the form A-H···B, where **A** and **B** are highly electronegative elements and **B** possesses a lone pair of electrons. Normally, hydrogen bonds only exist when atoms **A** and **B** are Nitrogen, Oxygen, and Fluorine. If the element **B** is anionic (such as Cl^-) and thus a very good electron donor, it may also participate in hydrogen bonding. Hydrogen bonding is very important the function of proteins, as these interactions determine the way they fold (their shape), and this determines how they react in the cell. Fluorine hydrogen bonds not found too often in biochemistry, but can be important in certain synthetic materials properties.

Summary of Types of Intermolecular Forces



Force	Model	Basis of Attraction	Energy (kJ/mol)	Example
Bonding				
Ionic		Cation–anion	400–4000	NaCl
Covalent		Nuclei–shared e^- pair	150–1100	H—H
Metallic		Cations–delocalized electrons	75–1000	Fe
Nonbonding (Intermolecular)				
Ion-dipole		Ion charge–dipole charge	40–600	
H bond	$\overset{\delta^-}{\text{—A}}\text{—}\overset{\delta^+}{\text{H}}\cdots\cdots:\overset{\delta^-}{\text{B}}\text{—}$	Polar bond to H–dipole charge (high EN of N, O, F)	10–40	
Dipole-dipole		Dipole charges	5–25	I—Cl····I—Cl
Ion–induced dipole		Ion charge–polarizable e^- cloud	3–15	$Fe^{2+}\cdots\cdot O_2$
Dipole–induced dipole		Dipole charge–polarizable e^- cloud	2–10	H—Cl····Cl—Cl
Dispersion (London)		Polarizable e^- clouds	0.05–40	F—F····F—F

http://www.chem.ufl.edu/~itl/2045/lectures/lec_g.html

Three types of force can operate between covalent molecules:

- Dispersion Forces
  also known as London Forces (named after Fritz London who first described these forces theoretically 1930) or as Weak Intermolecular Forces or as van der Waal's Forces (named after the person who contributed to our understanding of non-ideal gas behavior).
- Dipole-dipole interactions
- Hydrogen bonds

Relative strength of Intermolecular Forces:

- Intermolecular forces (dispersion forces, dipole-dipole interactions and hydrogen bonds) are much weaker than intramolecular forces (covalent bonds, ionic bonds or metallic bonds)
- dispersion forces are the weakest intermolecular force (one hundredth-one thousandth the strength of a covalent bond); hydrogen bonds are the strongest intermolecular force (about one-tenth the strength of a covalent bond).
- dispersion forces < dipole-dipole interactions < hydrogen bonds

Dispersion Forces (London Forces, Weak Intermolecular Forces, van der Waal's Forces)

- are very weak forces of attraction between molecules resulting from:
  - momentary dipoles occurring due to uneven electron distributions in neighboring molecules as they approach one another
  - the weak residual attraction of the nuclei in one molecule for the electrons in a neighboring molecule.

The more electrons that are present in the molecule, the stronger the dispersion forces will be.

Dispersion forces are the only type of intermolecular force operating between non-polar molecules, for example, dispersion forces operate between hydrogen (H_2) molecules, chlorine (Cl_2) molecules, carbon dioxide (CO_2) molecules, dinitrogen tetroxide (N_2O_4) molecules and methane (CH_4) molecules.

Dipole-Dipole Interactions

- are stronger intermolecular forces than Dispersion forces
- occur between molecules that have permanent net dipoles (polar molecules), for example, dipole-dipole interactions occur between SCl_2 molecules, PCl_3 molecules and CH_3Cl molecules.
  If the permanent net dipole within the polar molecules results from a covalent bond between a hydrogen atom and either fluorine, oxygen or nitrogen, the resulting intermolecular force is referred to as a hydrogen bond (see below).

- The partial positive charge on one molecule is electrostatically attracted to the partial negative charge on a neighboring molecule.

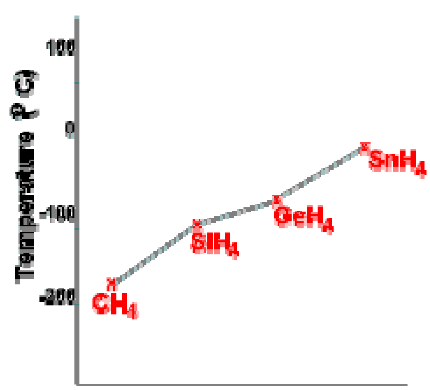
Hydrogen bonds

- occur between molecules that have a permanent net dipole resulting from hydrogen being covalently bonded to either fluorine, oxygen or nitrogen. For example, hydrogen bonds operate between water (H_2O) molecules, ammonia (NH_3) molecules, hydrogen fluoride (HF) molecules, hydrogen peroxide (H_2O_2) molecules, alkanols (alcohols) such as methanol (CH_3OH) molecules, and between alkanoic (caboxylic) acids such as ethanoic (acetic) acid (CH_3COOH) and between organic amines such as methanamine (methyl amine, CH_3NH_2).
- are a stronger intermolecular force than either Dispersion forces or dipole-dipole interactions since the hydrogen nucleus is extremely small and positively charged and fluorine, oxygen and nitrogen being very electronegative so that the electron on the hydrogen atom is strongly attracted to the fluorine, oxygen or nitrogen atom, leaving a highly localized positive charge on the hydrogen atom and highly negative localized charge on the fluorine, oxygen or nitrogen atom. This means the electrostatic attraction between these molecules will be greater than for the polar molecules that do not have hydrogen covalently bonded to either fluorine, oxygen or nitrogen.

Effect of Intermolecular forces on melting and boiling points of molecular covalent substances:

Since melting or boiling result from a progressive weakening of the attractive forces between the covalent molecules, the stronger the intermolecular force is, the more energy is required to melt the solid or boil the liquid.

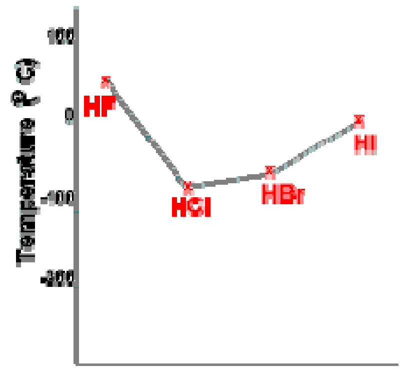
If only dispersion forces are present, then the more electrons the molecule has (and consequently the more mass it has) the stronger the dispersion forces will be, so the higher the melting and boiling points will be.
Consider the hydrides of Group IV, all of which are non-polar molecules, so only dispersion forces act between the molecules.
CH_4 (molecular mass ~ 16), SiH_4 (molecular mass ~ 32), GeH_4 (molecular mass ~ 77) and SnH_4 (molecular mass ~ 123) can all be considered non-polar covalent molecules.
As the mass of the molecules increases, so does the strength of the dispersion force acting between the molecules, so more energy is required to weaken



Boiling Points of Group IV Hydrides

the attraction between the molecules resulting in higher boiling point.

If a covalent molecule has a permanent net dipole then the force of attraction between these molecules will be stronger than if only dispersion forces were present between the molecules. As a consequence, this substance will have a higher melting or boiling point than similar molecules that are non-polar in nature.
Consider the boiling points of the hydrides of Group VII elements.
All of the molecules HF (molecular mass ~ 20), HCl (molecular mass ~ 37), HBr (molecular mass ~ 81) and HI (molecular mass ~ 128) are polar, the hydrogen atom having a partial positive charge ($H^{\delta+}$) and the halogen atom having a partial negative charge ($F^{\delta-}$, $Cl^{\delta-}$, $Br^{\delta-}$, $I^{\delta-}$).
As a consequence, the stronger dipole-interactions acting between the hydride molecules of Group VII elements results in higher boiling points than for the hydrides of Group IV elements as seen above.
With the exception of HF, as the molecular mass increases, the boiling points of the hydrides increase.
HF is an exception because of the stronger force of attraction between HF molecules resulting from hydrogen bonds acting between the HF molecules. Weaker dipole-dipole interactions act between the molecules of HCl, HBr and HI. So HF has a higher boiling point than the other molecules in this series.



Boiling Points of Group VII hydrides

Effect of Intermolecular Forces on Solubility

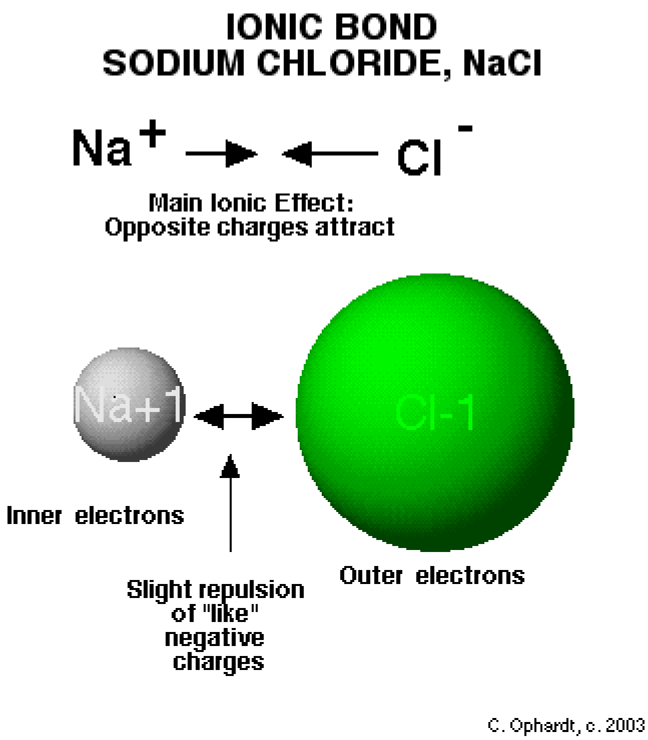
In general like dissolves like:

- non-polar solutes dissolve in non-polar solvents
  Paraffin wax ($C_{30}H_{62}$) is a non-polar solute that will dissolve in non-polar solvents like oil, hexane (C_6H_{14}) or carbon tetrachloride (CCl_4).

Paraffin wax will NOT dissolve in polar solvents such as water (H_2O) or ethanol (ethyl alcohol, C_2H_5OH).

- polar solutes such as glucose ($C_6H_{12}O_6$) will dissolve in polar solvents such as water (H_2O) or ethanol (ethyl alcohol, C_2H_5OH) as the partially positively charged atom of the solute molecule is attracted to the partially negatively charged atom of the solvent molecule, and the partially negatively charged atom of the solute molecule is attracted to the partially positively charged atom of the solvent molecule.
  Glucose will NOT dissolve in non-polar solvents such as oil, hexane (C_6H_{14}) or carbon tetrachloride (CCl_4).
- Ionic solutes such as sodium chloride (NaCl) will generally dissolve in polar solvents but not in non-polar solvents, since the positive ion is attracted the partially negatively charged atom in the polar solvent molecule, and the negative ion of the solute is attracted to the partially positively charged atom on the solvent molecule.

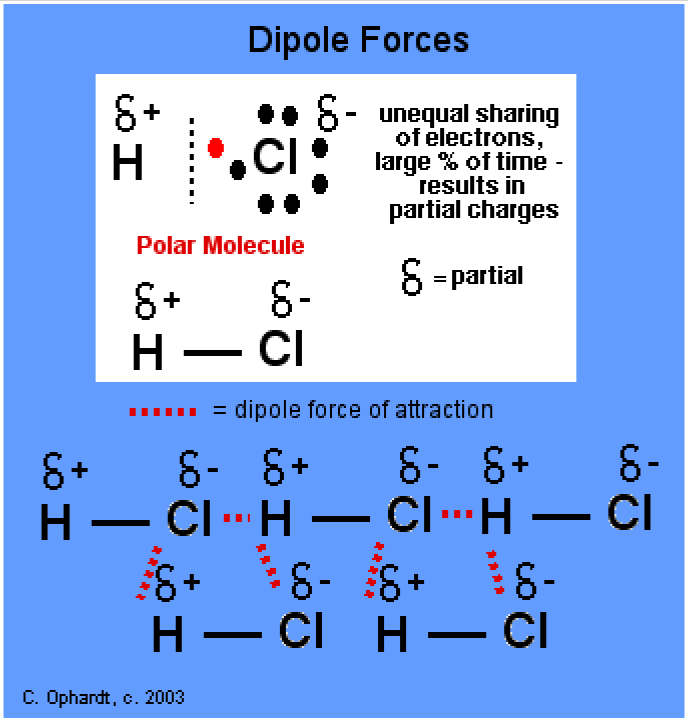
http://www.ausetute.com.au/intermof.html



INTERMOLECULAR FORCES

Introduction:
The physical properties of melting point, boiling point, vapor pressure, evaporation, viscosity, surface tension, and solubility are related to the strength of attractive forces between molecules. These attractive forces are called **Intermolecular Forces**. The amount of "stick togetherness" is important in the interpretation of the various properties listed above.
There are four types of intermolecular forces. Most of the intermolecular forces are identical to bonding between atoms in a single molecule. Intermolecular forces just extend the thinking to forces **between** molecules and follows the patterns already set by the bonding within molecules.

1. IONIC FORCES:
The forces holding ions together in ionic solids are electrostatic forces. Opposite charges attract each other. These are the strongest intermolecular forces. Ionic forces hold many ions in a crystal lattice structure. Review - Ionic Bonds

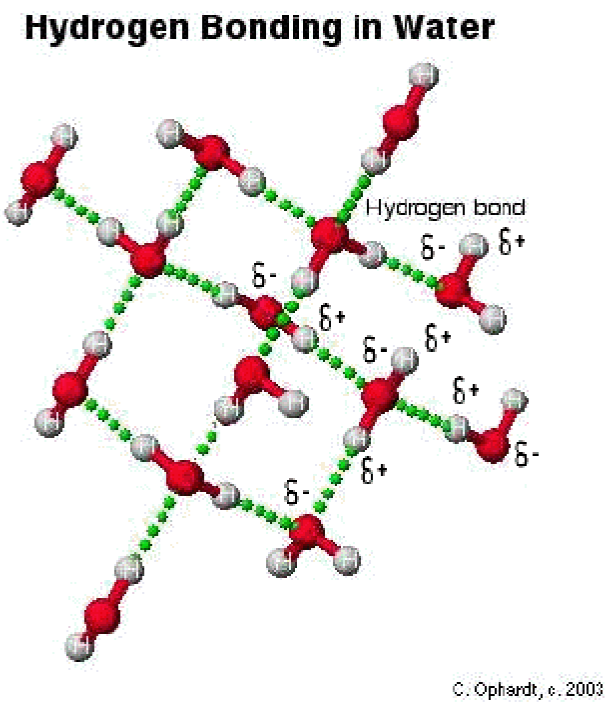


2. DIPOLE FORCES:

Polar covalent molecules are sometimes described as "dipoles", meaning that the molecule has two "poles". One end (pole) of the molecule has a partial positive charge while the other end has a partial negative charge. The molecules will orientate themselves so that the opposite charges attract principle operates effectively.

In the example on the left, hydrochloric acid is a polar molecule with the partial positive charge on the hydrogen and the partial negative charge on the chlorine. A network of partial + and - charges attract molecules to each other.

Review - Polar Bonds



3. HYDROGEN BONDING:

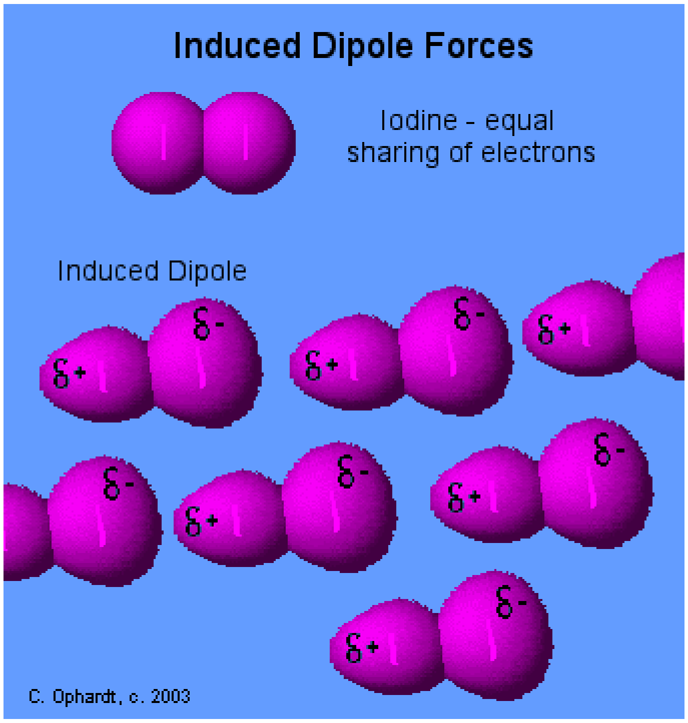
Link to more extensive discussion: **Hydrogen Bonding**

The hydrogen bond is really a special case of dipole forces. A hydrogen bond is the attractive force between the hydrogen attached to an electronegative atom of one molecule and an electronegative atom of a different molecule. Usually the electronegative atom is oxygen, nitrogen, or fluorine.

In other words - **The hydrogen on one molecule attached to O or N that is attracted to an O or N of a different molecule.**

In the graphic on the left, the hydrogen is partially positive and attracted to the partially negative charge on the oxygen or nitrogen. Because oxygen has two lone pairs, two different hydrogen bonds can be made to each oxygen.

This is a very specific bond as indicated. Some combinations which are not hydrogen bonds include: hydrogen to another hydrogen or hydrogen to a carbon.



4. INDUCED DIPOLE FORCES:
Forces between essentially non-polar molecules are the weakest of all intermolecular forces. "Temporary dipoles" are formed by the shifting of electron clouds within molecules. These temporary dipoles attract or repel the electron clouds of nearby non-polar molecules.
The temporary dipoles may exist for only a fraction of a second but a force of attraction also exists for that fraction of time. The strength of induced dipole forces depends on how easily electron clouds can be distorted. Large atoms or molecules with many electrons far removed from the nucleus are more easily distorted.
Review - Non-Polar Bonds

http://www.elmhurst.edu/~chm/vchembook/160Aintermolec.html

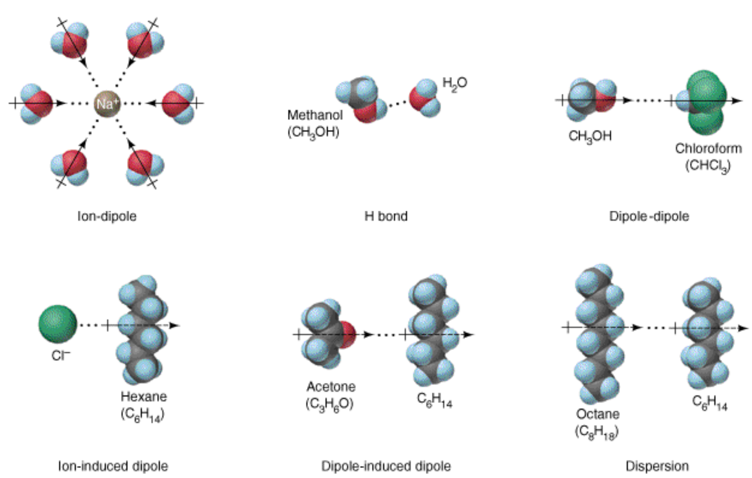
Classifying Intermolecular Forces

In general, intermolecular forces can be divided into several categories. The four prominent types are:

1. **Strong ionic attraction**
   Recall lattice energy and its relations to properties of solid. The more ionic, the higher the lattice energy. Examine the following list and see if you can explain the observed values by way of ionic attraction:
   LiF, 1036; LiI, 737; KF, 821; MgF_2, 2957 kJ/mol.
2. **Intermediate dipole-dipole forces**
   Substances whose molecules have dipole moment have higher melting point or boiling point than those of similar molecular mass, but their molecules have no dipole moment.
3. **Weak London dispersion forces or van der Waal's force** These forces always operate in any substance. The force arisen from induced dipole and the interaction is weaker than the dipole-dipole interaction. In general, the heavier the molecule, the stronger the van der Waal's force of interaction. For example, the boiling points of inert gases increase as their atomic masses increases due to stronger Landon dispersion interactions.

4. **Hydrogen bond**
   Certain substances such as H_2O, HF, NH_3 form hydrogen bonds, and the formation of which affects properties (mp, bp, solubility) of substance. Other compounds containing OH and NH_2 groups also form hydrogen bonds. Molecules of many organic compounds such as alcohols, acids, amines, and amino acids contain these groups, and thus hydrogen bonding plays an important role in biological science.
5. **Covalent bonding**
   Covalent is really intramolecular force rather than intermolecular force. It is mentioned here, because some solids are formed due to covalent bonding. For example, in diamond, silicon, quartz etc., the all atoms in the entire crystal are linked together by covalent bonding. These solids are hard, brittle, and have high melting points. Covalent bonding holds atoms tighter than ionic attraction.
6. **Metallic bonding**
   Forces between atoms in metallic solids belong to another category. Valence electrons in metals are rampant. They are not restricted to certain atoms or bonds. Rather they run freely in the entire solid, providing good conductivity for heat and electric energy. These behaviors of electrons give special properties such as ductility and mechanical strength to metals.

The division into types is for convenience in their discussion. Of course all types can be present simultaneously for many substances. Usually, intermolecular forces are discussed together with The States of Matter, which is linked to a well illustrated web-site. Intermolecular forces also play important roles in solutions, a discussion of which is given in Hydration, solvation in water. A summary of the interactions is illustrated in the following diagram:



http://www.science.uwaterloo.ca/~cchieh/cact/c123/intermol.html

Terms and Concepts

boiling point	ion-ion attraction	polarizable
Coulomb's law	lattice structure	solid
dipole-dipole force	liquid	sublimation
emulsion	London dispersion force	surface tension
freezing point	melting point	triple point
gas	meniscus	vapor pressure
hydrogen bonding	phase diagram	viscosity
intermolecular force	polar	

Instructional Resources

General overview of IMF:
http://www2.wwnorton.com/college/chemistry/gilbert/overview/ch9.htm
IMF Bonding terms/vocabulary game:
http://www.quia.com/mc/495607.html - Good online activity for the kids\
IMF Background Info:
http://www.chem.ufl.edu/~itl/2045/lectures/lec_g.html
IMF Student Tutorial:
http://www.ausetute.com.au/intermof.html

IMF background information and pictures:

http://www.elmhurst.edu/~chm/vchembook/160Aintermolec.html

IMF background and confidence building questions:

http://www.science.uwaterloo.ca/~cchieh/cact/c123/intermol.html

The following is a worksheet with answers of a typical student worksheet for practice and assessment.

Intermolecular Forces Worksheet

1) Using your knowledge of molecular structure, identify the main intermolecular force in the following compounds. You may find it useful to draw Lewis structures to find your answer.

   a) PF_3 ______________________________

   b) H_2CO ______________________________

   c) HF ______________________________

2) Explain how dipole-dipole forces cause molecules to be attracted to one another.

3) Rank the following compounds from lowest to highest boiling point: calcium carbonate, methane, methanol (CH_4O), dimethyl ether (CH_3OCH_3).

4) Explain why nonpolar molecules usually have much lower surface tension than polar ones.

Intermolecular Forces Worksheet Answers

1) Using your knowledge of molecular structure, identify the main intermolecular force in the following compounds. You may find it useful to draw Lewis structures to find your answer.

   a) PF_3 **dipole-dipole force**

   b) H_2CO **dipole-dipole force**

   c) HF **hydrogen bonding**

2) Explain how dipole-dipole forces cause molecules to be attracted to one another.
Polar molecules have partially positive and partially negative sides (which correspond to the side of the molecule which is more or less electronegative). Because opposite charges attract one another, these molecules stick electrostatically.

3) Rank the following compounds from lowest to highest boiling point: calcium carbonate, methane, methanol (CH_4O), dimethyl ether (CH_3OCH_3).
By using intermolecular forces, we can tell that these compounds will rank:
methane (Van der Waals forces), dimethyl ether (dipole-dipole forces), methanol (hydrogen bonding), calcium carbonate (ionic electrostatic forces that are much stronger than intermolecular forces).

4) Explain why nonpolar molecules usually have much lower surface tension than polar ones.
Because the molecules aren't attracted to each other as much as in polar molecules, these molecules are much less likely to have high surface tension.

Bonding: Intermolecular Forces

Activity #1 – Polymer Inquiry Activity

Questions to be investigated

What effect do intermolecular forces have on the properties of a substance?

Objectives

Students will observe the effects of changing intermolecular forces on the properties of a substance.

Teacher Notes

AKA: Oobleck, Glurch, Boogers (simple internet search will produce multiple variations).

This activity can be used as an opening or an ending inquiry. Just having student "play" with the silly putty can get them thinking about the why factor. Using this activity at the end of a polymer lesson can also bring together the ideas of cross-linking of chains of organic molecules.

Video Clip: Link will show an actual demonstration of the lab procedure.

Materials

Borax

Elmer's Glue

Water

Food Coloring (optional)

Plastic Cups

Tongue Depressors / Popsicle Sticks

Safety Concerns

Food coloring is not required and can be messy.

Real-World Connections

The manufacture of synthetic fabrics, plastics, and rubbers are all based on the same science as this activity.

Procedure / Description of Lesson

Cross-Linking a Polymer to Create Everyone's Favorite Childhood Toy, Silly Putty

Objective: The objective of this experiment is to cross-link a polymer and observe the changes in the physical properties as a result of this cross-linking. The changes in physical properties of a cross-linked polymer are also studied as the temperature is varied.

Review of Scientific Principles:

If a substance springs back to its original shape after being twisted, pulled, or compressed, it is most likely a type of polymer called an elastomer. The elastomer has elastic properties (i.e., it will recover its original size and shape after being deformed). An example of an elastomer is a rubber band or a car tire.

The liquid latex (Elmer's glue) which you use contains small globules of hydrocarbons suspended in water. The silly putty is formed by joining the globules using sodium borate (a cross-linker). The silly putty is held together by very weak intermolecular bonds that provide flexibility around the bond and rotation about the chain of the cross-linked polymer. If the cross-linked bonds in a polymer are permanent, it is a thermosetting plastic, even if above the glass-transition temperature (T_g). If the bonds are non-permanent, it can be considered either thermoplastic or an elastomer.

Time: A 20-25 minute period is required to perform the mixing/making of the silly putty.

Materials and Supplies:

- 55 % Elmer's glue solution in water
- 4 % borax solution (sodium borate)
- Styrofoam cups
- zip lock bags
- food colors

General Safety Guidelines:

- Since borax solid (a bleaching agent) and solution will burn the eyes, goggles and aprons should be worn.
- Hands should always be washed after kneading the silly putty and finishing the experiment.

Procedure:

1. Wear goggles and lab aprons.
2. Pour 20 ml of the Elmer's glue solution into a Styrofoam cup.
3. Add 10 ml of the cross-linker (borax solution) to each cup.
4. Immediately begin stirring the solutions together using the wooden stick.
5. After a couple of minutes of mixing, the silly putty should be taken out of the cup and kneaded in the hands. Don't worry about the material sticking to your gloves as these pieces will soon mix with the larger quantity with which you are working. Continue to knead until the desired consistency is reached.
6. Using a ruler to measure, drop the ball from a height of 30 centimeters. To what height does it rebound?
7. Stretch the silly putty slowly from each side.
8. Compress the silly putty back into a ball.
9. Pull the silly putty quickly from each side and compare the results.
10. Place the silly putty on some regular news print and press down firmly.
11. Remove the silly putty from the news print and make observations.
12. Repeat the same procedure on a comic section of the newspaper. The silly putty is non-toxic and safe to handle so you can put it in a zip-lock bag and take it home.
13. Follow good laboratory procedure and wash your hands with soap and water when you have finished the experiment.

Video Clip

Data and Analysis:

Height of the rebound _________ cm.

Observations of pulling the silly putty slowly:

Observations of pulling the silly putty quickly:

Observations of the silly putty on newsprint:

Observations of the silly putty on the comic's section of the newspaper:

Questions:

1. How do the physical properties of the glue, water mixture change as a result of adding the sodium borate?

2. What would be the effect (your thoughts) of adding more sodium borate solution?

3. What is the ratio of the height of the drop to that of the rebound distance?

4. Who in the class had the ball with the most elasticity?

5. How did you come to the conclusion of whose ball was most elastic?
   At Home:
   -Place your ball in the refrigerator for 10 minutes. Recheck the bouncing portion of this experiment.

6. What are your observations?

7. Why do you think this was observed?
   -Now place your ball about 6 inches from a light bulb for about 5 minutes and again recheck the bouncing portion of this experiment.

8. What are your observations?

9. Why do you think this happened?

Explain the Following:

10. Why does a car tire appear to be flat in the summer even though the gas inside is hotter than in the winter?

11. Why does a basketball bounce differently inside a gym than it does outside on a cold wintry day?

12. Why will a tire sometimes bump during the winter as a car is moving, only to smooth out its ride after the car has been traveling for a distance?

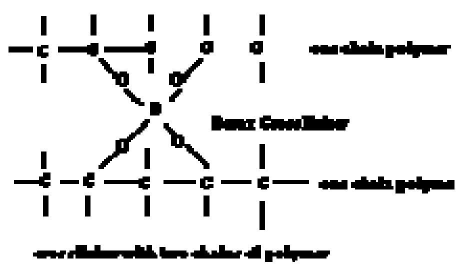
Teacher Notes:

Objective: The objective of this experiment is to investigate cross-linking using a similar technique as was used in the making of slime. The same parameters are worked again with a formal and a quantitative measurement used to describe elasticity. The added home investigation of the effect of temperature on the elasticity also includes concepts of molecular motion and intermolecular bond strength.

Review of Scientific Principles:

If a substance springs back to its original shape after being twisted, pulled, or compressed it is a type of polymer called an elastomer. The elastomer has elastic properties. It will recover its original size and shape after being deformed.

The liquid latex used contains small globules of hydrocarbons suspended in water. Joining these globules forms the mass with which the students will be working. The covalent bonds along the chain are strong, but the bonds between chains are normally weak. However, additives such as borax allow the formation of strong "cross-links" between chains, such as C-B-C. As the number of cross-links increases, the material becomes more rigid and strong.



If the rigidity of a polymer is noticed to decrease when a critical temperature is reached, the polymer is called a thermoplastic. If the bonds between polymer molecules are very strong, the material decomposes before any softening occurs. Such a material is called a thermoset plastic.

Natural sources of this liquid latex are milkweed, rubber trees, pine trees, aloe plants, and many desert plants. This latex is used to quickly mend and repair any damage to the outer covering of the plant.

Experimental:

There are many variations of this experiment.

1. The original silly putty was prepared using sodium silicate and mixing this with borax.
2. A variation also exists using laundry starch and mixing it with borax.
3. Similar variations also exist by sprinkling the borax evenly and gently over the solution of latex then working it with the hands. This does not require as much kneading to dehydrate the sample.

Time: - About 15 minutes are required to ready solutions, cups and tongue depressors.
10-15 minutes will be required in lab for testing and clean up.
The students will require 10-15 minutes of work at home in order to finish all of the experimental work on this laboratory and the write up.

Answers to Questions:

1. The liquid type of starting material should jell and become more viscous as cross-linking occurs.
2. The material will become more solid or rigid.
3. Student answer. This is only a method of measuring elasticity of the polymer. Stretching gives a similar means of comparison.
4. Student answer.
5. Greatest rebound to drop height ratio.
6. Here the student will be studying the effect of temperature variation on elasticity. Students are sometimes surprised if they place their sample into a freezer rather than a refrigerator. The results are that the ball will shatter rather than bounce.
7. The ball should be more elastic.
8. Contrary to what some students will predict, should the ball become too warm, the resulting ball will deform rather than continue to increase in elasticity.
9. The ball deformed rather than rebounding.

-All of the answers to the questions in the EXPLAIN THE FOLLOWING section involve the use of principles previously presented in this laboratory.

Assessment Ideas

Students can answer questions on the worksheet.

Opening inquiry activity: use formative questions while the mixing is occurring and when problems may arise.

<u>Formative Questions:</u>

1. Why was it slimy before you added the borax? A: some H bonding
2. Why is it slimier after you add the borax? A: more IMF

Bonding: Intermolecular Forces

Activity #2 – The attraction of liquids to a balloon or comb

Questions to be investigated

Can a simple test determine whether or not a molecule is polar or non-polar?

Objectives

Students will be able to explain why certain streams of liquids are deflected by a charged object.

Teacher Notes

Works best on dry day. Any size buret will do as long as there is enough liquid to allow for a steady stream of liquid and completion of the lab.

This could be a great activity to introduce the concept of polar or non-polar molecules just by demonstrating and asking formative questions. It could also be used as a lab with formal question write-ups by the students during the lesson or at the end of the lesson for a summative assessment.

Materials

Buret	Water	Rubbing Alcohol (Ethyl or Isopropyl will work)
Hexane	Balloon or Comb	

Safety Concerns

Hexane and Alcohol are flammable. Care should be exercised.

Real-World Connections

The polarity of molecules greatly affects their behavior in the liquid state. Students can use this lab to show how certain molecules can be "moved around" inside of a cell.

Sources

David Consiglio – Southfield-Lathrup High School

Procedure / Description of Lesson

Procedure:

1. Fill a buret to the top with water.
2. Rub a balloon or comb through your hair.
3. Place a beaker under the buret.
4. Open the buret so that a constant stream of liquid flows into the beaker.
5. Bring the balloon or comb close to the fluid stream.
6. Repeat this procedure with alcohol and hexane.

Questions

1. Draw Lewis structures for water (H_2O), ethyl alcohol (CH_3CH_2OH), and hexane (C_6H_{14})?
2. Which of these structures has hydrogen bonding?
3. Which of these structures has dipole-dipole interaction?
4. What did you observe when you placed the balloon near the water stream?
5. What did you observe when you placed the balloon near the alcohol stream?
6. What did you observe when you placed the balloon near the hexane stream?
7. Why did the hexane and water behave differently? Explain your answer using at least 3 complete sentences.
8. Why are polar molecules attracted to the balloon but nonpolar molecules are not? Explain your answer using at least 3 complete sentences.

Assessment Ideas

Students can answer the questions included in the activity.

Use formative questioning during lab to assess each group's knowledge of why they are performing this procedure.

Bonding: Intermolecular Forces

Activity #3 – The Penny Drop Lab – Simple IMF lab

Questions to be investigated

What effects do intermolecular forces have on surface tension?

Objectives

Students will recognize that increased strength of intermolecular forces results in increased surface tension.

Teacher Notes

Students should bring in their own pennies.

Polypropylene pipettes are very helpful for this lab.

Materials

Pennies

Water

Rubbing Alcohol (ethyl or isopropyl will work fine here)

Safety Concerns

Rubbing alcohol is toxic and flammable. Care should be exercised when using.

Real-World Connections

Surface tension is important in the functioning of living organisms. For example, water striders (a type of insect) are able to “walk” on the surface of ponds.

Sources

David Consiglio – Southfield-Lathrup High School

Procedure / Description of Lesson

Procedure:

1. Place a penny face down on the table.
2. **CAREFULLY** add drops of water on top of the penny. Your goal is to put as many drops on top of the penny without any water falling onto the table.
3. Count the number of drops that the penny was able to hold. RECORD YOUR DATA.
4. Dry the penny.
5. Have each person in the group repeat the process. RECORD YOUR DATA.
6. Be sure to observe the penny from the side.
7. **CAREFULLY** add drops of alcohol on top of the penny. Your goal is to put as many drops on top of the penny without any alcohol falling onto the table.
8. Count the number of drops that the penny was able to hold. RECORD YOUR DATA.
9. Dry the penny.
10. Have each person in the group repeat the process. RECORD YOUR DATA.
11. Be sure to observe the penny from the side.

	Water Drops	Alcohol Drops
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Average		

Questions

1. Which liquid had the higher average number of drops?
2. Draw a Lewis Structure for water.
3. What shape is a water molecule?
4. What intermolecular forces are present in water?
5. What intermolecular forces are present in alcohol?
6. Which liquid, water or alcohol, has STRONGER intermolecular forces? Explain using at least 2 complete sentences.
7. Why do you think that liquid was able to have stay on top of the penny better? Justify your answer in terms of intermolecular forces. Use at least 2 complete sentences.
8. Suppose you were to try this experiment with acetone, a liquid that does not have any hydrogen bonding. How would you expect the result to be in comparison to the water and alcohol? Explain your answer using at least 2 complete sentences.

Assessment Ideas

Students can answer the questions on the worksheet.

Use formative questioning during lab to assess each group's knowledge of why they are performing this procedure.

Bonding: Intermolecular Forces
Activity #4 – Intermolecular Forces/Evaporation Lab

Questions to be investigated

How does the presence of intermolecular forces affect the rate of evaporation of various liquids?

Objectives

Students will be able to relate intermolecular forces to the properties of various substances.

Materials

Moist paper towels	Tap water
Alcohol-based wipes (Windex, Wet Ones, etc.)	Distilled water
Model kits	Olive Oil
Hot plate	Small beaker
Aluminum foil	Pipette
Isopropyl alcohol	

Safety Concerns

Hot plates can burn students and isopropyl alcohol is flammable. Care should be exercised and small quantities of alcohol should be used.

Real-World Connections

Certain liquids must be stored in air-tight containers because they can evaporate quickly. Gasoline is an excellent example of this concept.

Sources

Mrs. Earle's Chemistry Page: Mrs. Amy Earle Deep Run High School . Glen Allen, VA:

http://teachers.henrico.k12.va.us/deeprun/lavender_a/chemistry/Intermolecular%20Forces%20Lab.doc

Procedure / Description of Lesson

Objective: To explore the intermolecular forces between molecules.

Materials:

Moist paper towels
Alcohol-based wipes (Windex, Wet Ones, etc.)
Model kits
Hot plate
Aluminum foil
Isopropyl alcohol
Tap water
Distilled water
Olive Oil
Small beaker
Pipette

Procedure:

1. Clear bench top of all items. Mentally divide your section of benchtop in half. Wipe one half with a moist paper towel while your partner wipes the other half with a wet wipe. Time how long it takes for each half to dry.
2. Obtain a hot plate, enough aluminum foil to cover the heating surface, small beaker, a bottle of isopropyl alcohol and a bottle of distilled water. Cover the top of the hot plate with aluminum foil. Crimp the edges so that the foil is secured to the top of the hot plate. Turn the hot plate to 8 and wait about 5 minutes for the hot plate to warm up. With no overlap, place a small drop each of olive oil, tap water, distilled water and alcohol on the foil. Time how long it takes for each drop to evaporate. Stop at 5 minutes. Carefully observe any residue from the drops.

Benchtop towel/wipe test	**Time**	**Observations**
1. Moist paper towel		
2. Wet wipe		
Evaporation test	**Time**	**Observations**
1. Isopropyl alcohol		
2. Distilled water		
3. Tap water		
4. Olive oil		

Data Analysis:

1. What is the chemical formula and molar mass for water? Isopropyl alcohol's formula is C_3H_7OH ($CH_3CH(OH)CH_3$). Draw the Lewis structures for both and make molecular models for each. Based on the molar mass, which compound would you expect to evaporate first? Based on what you know about intermolecular forces, how do you explain the result you obtained?

2. What is the difference between tap water and distilled water? Was there an appreciable difference between the times for the two types of water? What was it (if any) and how do you explain it? Was there any difference in the residue? What was it (if any) and how do you explain it?

3. Draw Lewis structures for each of the substances you evaporated on the hot plate.

   Chemical formulas are:

   Isopropyl alcohol $CH_3CH(OH)CH_3$
   Water H_2O
   Olive oil (predominantly oleic acid) $C_{18}H_{34}O_2$ [set up structural formula as $CH_3(CH_2)_7CHCH(CH_2)_7COOH$ linking the carbon atoms in a chain and adding the hydrogens and oxygens in the order given].
   Describe each molecule in terms of polarity and presence/absence of hydrogen bonding and length of nonpolar portion of molecule. What would you predict about boiling points based on this analysis?

4. In Excel, make a graph of the time to evaporate each of the four substances you tested on the hot plate versus their molar masses. The independent variable is molar mass and the dependent variable is time. Characterize your graph. As a general rule, boiling points are proportional to molar masses. Does your data follow this trend? If not, which substances(s) don't follow the trend? How can you explain this anomaly?

5. Write a paragraph summarizing the concepts covered in this lab and what you learned that you didn't know before. There should be a minimum of five sentences and you should use scientific language to describe your ideas.

Assessment Ideas

Students can answer the questions in the lab worksheet.

Use formative questioning during lab to assess each group's knowledge of why they are performing this procedure.

Bonding: Intermolecular Forces

Activity #5 – Intermolecular Forces/Solubility Lab

Questions to be investigated

What is the effect of molecular structure on molecular properties?

Objectives

Students will be able to recognize the presence of hydrogen bonding, dipole-dipole interaction, and London dispersion forces.

Students will be able to correlate the presences of intermolecular forces and the melting point, boiling point, and salt solubility of a solvent.

Teacher Notes

Students must use the internet to find some of the quantities in the lab.

This activity can be used as an opening or an ending inquiry.

Materials

Water

Ethanol

Hexane

Sodium Chloride

Salicylic Acid (or other solid organic compound. Be careful for safety!)

Safety Concerns

Hexane and acetone are flammable and should not be used in an enclosed area. Proper ventilation and fire safety is required.

Salt and salicylic acid are eye irritants. Goggles should be worn at all times.

Real-World Connections

Solubility is very important in the paint and coatings industry as the pigment (solute) must be soluble in the vehicle (solvent). Thus watercolors contain different pigments than those found in oil-based paint.

Sources

David Consiglio – Southfield-Lathrup High School

Procedure / Description of Lesson

Materials:

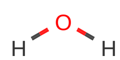
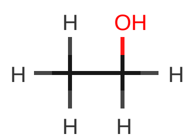
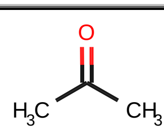
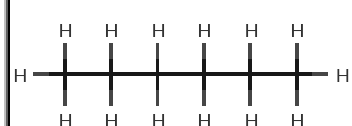
Water Ethanol Acetone Hexane Salt

Salicylic Acid

Procedure:

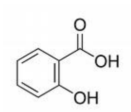
1. Add approximately 0.1g of NaCl to approximately 25mL of water, ethanol, acetone, and hexane.
2. Stir. Observe.
3. Add approximately 0.1 g of salicylic acid to approximately 25mL of water, ethanol, acetone, and hexane.
4. Stir. Observe.

Data Sheet:

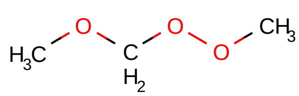
Label	Structure	Boiling Point (research)	Melting Point (research)	Salt Solubility (Y/N?)	Salicylic Acid Solubility (Y/N?)
Water					
Ethanol					
Acetone					
Hexane					

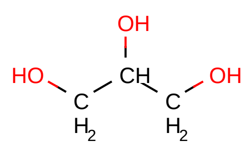
Questions:

Please answer on a separate sheet (or sheets) of paper and attach to your lab report.

1. Rank the four liquids in terms of size from smallest to largest.
2. Rank the four liquids in terms of strength of IMF from smallest to largest.
3. Rank the four liquids in terms of boiling point.
4. Which factor seems more important in determining boiling point, size, or IMFs. Explain.
5. What force(s) are most important for determining the properties of NaCl?
6. Which solvents showed significant NaCl solubility? Why do you believe this is?
7. What force(s) are most important for determining the properties of salicylic acid?
8. Which solvents showed significant salicylic acid solubility? Why do you believe this is? (hint: 

This is the structure of salicylic acid)
9. Consider the structures below:





Structure A Structure B

   a. Determine the formula of these two structures.
   b. Which of the two structures would you expect to have a higher boiling point? Explain.
   c. Which of the two structures would you expect to have a higher salt solubility? Explain.

Assessment Ideas

Students can answer the questions on the worksheet.

Use formative questioning during lab to assess each group's knowledge of why they are performing this procedure.

Bonding: Intermolecular Forces

Activity #6 – Intermolecular Forces / Lewis Structure Drawing

Questions to be investigated

Can the properties of substances be predicted by drawing structures and identifying intermolecular forces?

Objectives

Students will be able to predict properties of substances by looking at structures.

Teacher Notes

The first section of the Procedure/Description of the lesson is a chart and further background information. This can be used as a starting discussion of IMF or you can alter the chart to have students fill in sections as a summative assessment at the end of the lesson.

Materials

Use worksheet from procedure section.

Real-World Connections

Pharmaceutical companies might want to synthesize a molecule with certain properties. By analyzing the structure of the molecule such properties can be predicted.

Sources

General Chemistry Worksheets

[Susan Piepho's Websites] [Sweet Briar College Home Page] [Chemistry Department]
Chapter 11: Intermolecular Forces
http://spiepho.sbc.edu/worksheets/

Procedure / Description of Lesson:

Intermolecular Forces

Read the following chart and physical properties section:

Types of Solids*	*Intermolecular Force(s) Between Particles*
1. Metallic Crystals (Metals) Examples: Na, Cu, Fe, Mn	*Metallic bonding*: Valence electrons form mobile sea of electrons which comprise the metallic bond.
2. Ionic Crystals (Ionic Solids) Examples: NaCl, $MgCl_2$, MgO	*Ionic Bonding*: Attraction of charged ions for one another. Lattice energy is a measure of ionic bond strength.
3. Covalent Crystals (Network Solids) Examples (small class!): C(diamond), SiC(s), SiO_2 (quartz)	*Network covalent bonding.* Network solids are extremely hard compounds with very high melting and boiling points due to their endless 3-dimensional network of covalent bonds.
4. Molecular Crystals Examples: (a) Need H bonded to O, N or F: H_2O, HF, NH_3. (b) C_6H_6 (benzene), polyethylene, I_2, F_2, and all the compounds from (a) above. (c) CHF_3, CH_3COCH_3 (acetone) and H_2O, HF, NH_3.	One or more of the following: (a) *Hydrogen bonding*: Hydrogen bonds are weaker than covalent bonds, but stronger than (b) or (c) below. (b) *Dispersion forces* (induced dipole – induced dipole or London dispersion forces): universal force of attraction between instantaneous dipoles. These forces are weak for small, low-molecular weight molecules, but large for heavy, long, and/or highly *polarizable* molecules. They usually dominate over (c) below. (c) *Dipole-dipole forces*: these forces act between *polar* molecules. They are much weaker than hydrogen bonding.
5. Atomic Crystals Examples: He, Ne, Ar, Kr, Xe	*Dispersion forces*: See Section 4(b) above.

*Note: Many of the compounds given as examples are *not* solids at room temperature. But if you cool them down to a low enough temperature, eventually they will become solids.

Physical properties depend on these forces. The *stronger* the forces between the particles,

(a) The *higher* the *melting point*.
(b) The *higher* the *boiling point*.
(c) The *lower* the *vapor pressure* (partial pressure of vapor in equilibrium with liquid or solid in a closed container at a fixed temperature).
(d) The *higher* the *viscosity* (resistance to flow).
(e) The *greater* the *surface tension* (resistance to an increase in surface area).

Questions:

1. What *type of crystal* will each of the following substances form in its solid state? Choices to consider are *metallic*, *ionic*, *covalent*, or *molecular* crystals.

(a) C_2H_6 ____________ (b) Na_2O ______________ (c) SiO_2 ________________
(d) CO_2 ________________ (e) N_2O_5 _____________ (f) $NaNO_3$ ________________
(g) Al ___________________ (h) C(diamond) ________ (i) SO_2 ___________________

2. Circle ***all*** the compounds in the following list *which would be expected to form intermolecular hydrogen bonds* in the liquid state:

(a) CH_3OCH_3 (dimethyl ether) (b) CH_4 (c) HF (d) CH_3CO_2H (acetic acid) (e) Br_2 (f) CH_3OH (methanol)

3. Specify the *predominant intermolecular force* involved for each substance in the space immediately following the substance. *Then in the last column, indicate which member of the pair you would expect to have the higher boiling point.*

Substance #1	Predominant Intermolecular Force	Substance #2	Predominant Intermolecular Force	Substance with Higher Boiling Point
(a) HCl(g)		I_2		
(b) CH_3F		CH_3OH		
(c) H_2O		H_2S		
(d) SiO_2		SO_2		
(e) Fe		Kr		
(f) CH_3OH		CuO		
(g) NH_3		CH_4		
(h) HCl(g)		NaCl		
(i) SiC		Cu		

Answers:

1. (a) molecular; (b) ionic; (c) covalent (network solid); (d) molecular; (e) molecular; (f) ionic;
(g) metallic; (h) covalent (network solid); (i) molecular.

2. Hint: Molecule must contain H bonded to O, N, or F, since only H bonded to O, N, or F can form a hydrogen bond with an O, N, or F on another molecule. Thus (c), (d), and (f) should be circled.

3. Hint: Choices for the predominant intermolecular force are *metallic bonding*, *ionic bonding*, *network covalent bonding*, *hydrogen bonding*, and *dispersion forces (induced dipole – induced dipole forces)*. Dipole-dipole forces are generally dominated by dispersion forces and are rarely predominant.

(a) dispersion forces; dispersion forces; I_2.
(b) dispersion forces; hydrogen bonding; CH_3OH.
(c) hydrogen bonding; dispersion forces; H_2O.
(d) network covalent bonding; dispersion forces; SiO_2.
(e) metallic bonding; dispersion forces; Fe.
(f) hydrogen bonding; ionic bonding; CuO.
(g) hydrogen bonding dispersion forces; NH_3.
(h) dispersion forces; ionic bonding; NaCl.
(i) network covalent bonding; metallic bonding; SiC.

Assessment Ideas

Students can answer the questions included in the activity.