Unit 6 POGIL #4

POGIL: You're So Darn Attractive!

Name: Group Members:

QOD: How do intermolecular forces determine liquids' boiling points?

Learning Objectives:

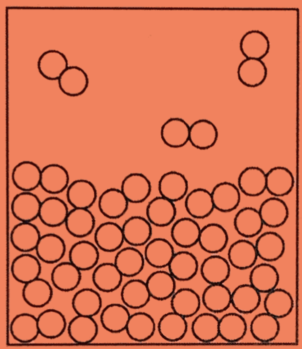
- ☐ Propose reasoning for the relationship between attractive forces and the boiling point and melting point of substances, among other properties.
- ☐ Develop the link between boiling points, attractive forces and (a) mass and (b) molecular polarity.

Text Reference: Chang and Goldsby (*Chemistry: The Essential Concepts*, McGraw-Hill, 2014) pp. 403–409.

Model II: Intermolecular versus Intramolecular Forces

Within a bulk sample (e.g., a solid or a liquid) of a molecular substance, there are discrete particles called **molecules**.

The diagram shows a sample of diatomic liquid bromine in equilibrium with its vapor. In this freeze frame image, the size of the molecules is greatly exaggerated.



Breaking *intermolecular* forces:

$Br_2(l) \rightarrow Br_2(g)$ 30.9 kJ/mol

Breaking *intramolecular* forces:

$Br_2(g) \rightarrow 2\ Br(g)$ 192.9 kJ/mol

Give complete answers to all questions. Provide explanations and show work, where necessary.

Key Questions

1. Look up the definitions for the following prefixes:
   (a) intra-

   (b) inter-

2. In the diagram of bromine (above):
   (a) shade a pair of circles representing atoms that are covalently bonded together.
   (b) draw a curve around a pair of molecules that are held together in the liquid phase.
3. What is an ***intramolecular*** force?

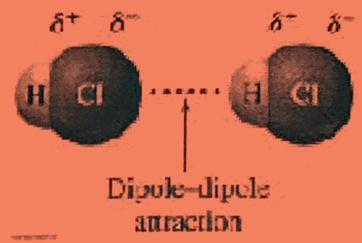
4. What is an ***intermolecular*** force?

5. Compare the strength of intermolecular forces with the strength of intramolecular forces.

6. (a) According to the model, when a substance vaporizes, what type of force is broken?

   (b) Are there other types of forces (not the answer to question 6a) broken during the vaporization process?

Model III: Dipole-Dipole Forces

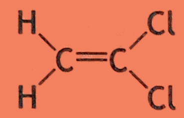


A polar compound is one in which there is a separation of charge within a molecule of the substance. Neighboring molecules in a bulk sample of a polar compound will arrange themselves in order to maximize attractive forces and to minimize repulsive forces between the molecules. (Of course, in a liquid there is still enough thermal energy so that the molecules are constantly moving past each other. So the situation being considered is a "time-averaged" picture.)

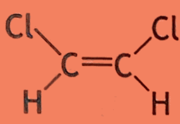
The net attractive forces between polar molecules are called **dipole-dipole forces**. Dipole-dipole forces are typically only about 1% as strong as a covalent bond.

7. If intermolecular forces are stronger between neighboring molecules in a bulk sample, will it require more heat energy or less heat energy to separate molecules from each other? Why?

8. NOTE: The size of a dipole is measured by its dipole moment, μ. The dipole moment is measured in a unit called Debye, D. Consider the molecules on the right, 1,1-dichloroethene and 1,2-dichlorethene (left and right). One compound has a boiling point of 37°C and the other has a boiling point of 60°C. Which one has which boiling point? Explain your decision.



μ = 1.34 D



μ = 1.90 D

Model IV: London Dispersion Forces

Regardless of whether or not a molecular substance is polar, all gases can be converted into a liquid (or solid) if enough heat is removed. This suggests that there is a second type of intermolecular force, one that holds both nonpolar and polar molecules together in a liquid or solid. These intermolecular forces are called **London dispersion forces** (also known as **London Forces** or **dispersion forces**), which are resultant "induced" dipole moments between neighboring molecules. Consider a sample of neon gas.

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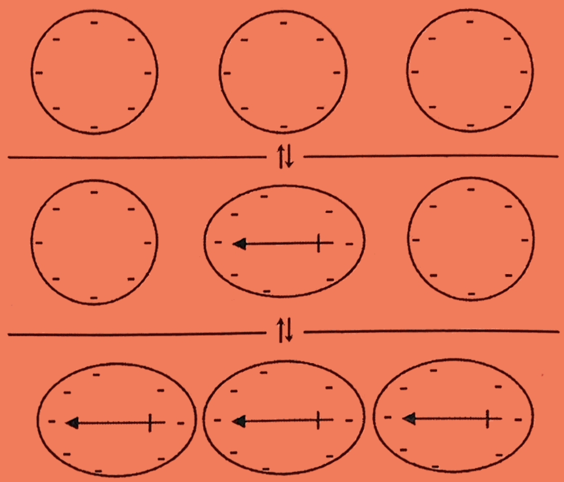
Consider a grouping of (nonpolar) atoms, each being represented as circular with its valence electrons equally distributed about the center. Remember electrons are not stationary particles, they are frequently delocalized and shift within a molecule. Imagine that at some particular moment in time the charge cloud of one of the atoms may become distorted, giving the particle a **temporary dipole**. This temporary dipole is very weak and short lived and the charge cloud of the atom may resume its previous spherically-symmetric shape. However, if other molecules are nearby, the temporary dipole may induce a dipole in the neighboring molecules. These **induced dipoles** are temporary, but neighboring molecules are constantly inducing moments between each other. Again, the diagram is representing a time-averaged picture.



9. Consider the boiling points for the noble gases, at the right.

gas	Ne	Ar	Kr	Xe
T_b (°C)	-245.9	-185.7	-152.3	-107.1

   (a) Rank the gases in order of increasing atomic radius (small to large).

   (b) Rank the gases in order of increasing strength of intermolecular forces (low to high). Justify your ranking.

   (c) As the valence electron cloud gets larger, would it be easier or harder for an extra electron to move to one side of the atom, thus giving the particle a temporary dipole moment? Justify your answer.

10. Alkanes are organic compounds that have a chemical formula of C_nH_{2n+1}, where *n* is the number of carbon atoms. Alkanes are either nonpolar or have *very* small molecular dipoles. Methane (CH_4) is a gas at room temperature. Butane (CH_3-CH_2-CH_2-CH_3) is a gas at 25°C, but the application of a little pressure allows it to be liquified. Hexane (CH_3-CH_2-CH_2-CH_2-CH_2-CH_3) is a liquid at 25°C. And icosane [$CH_3(CH_2)_{18}CH_3$] is a solid at 25°C.

   (a) What happens to the "surface area" of the valence electron clouds that neighboring molecules can have in contact with each other as the length of the alkane molecule increases?

   (b) What happens to the strength of the intermolecular forces as the length of an alkane molecule increases?

   (c) What is the relationship between the size of the molecule's valence electron cloud and the strength of intermolecular forces? Why is this the case?

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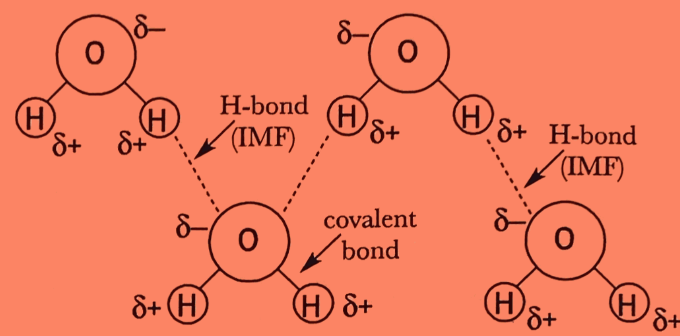
Model V: Hydrogen Bonding



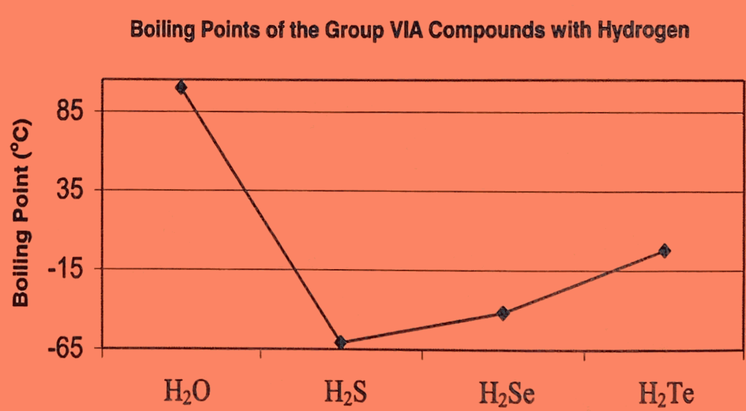
A special type of dipole-dipole force occurs in a bulk sample of H_2O. Consider the figure to the right.

This type of intermolecular force exists in samples of compounds that have N—H, O—H, and F—H bonds. Since all of them involve an atom that is bound to a hydrogen atom, these dipole-dipole forces are called "hydrogen bonds," even though they are NOT actual bonds. Hydrogen bonds, typically on the order of 30 kJ/mol, are many times stronger than the ordinary dipole-dipole force (and, thus, the reason they are classified as a distinct type of intermolecular force).

11. What are two special characteristics of the atoms N, O, and F that sets them apart from other elements?

12. Use Coulomb's Law to explain why hydrogen bonding only occurs in compounds with N—H, O—H, and F—H covalent bonds.

13. Consider the boiling points of the hydrides of the Group 16 elements, to the right:



Describe the intermolecular forces that exist in a bulk sample of each compound. Which intermolecular forces predominate (*i.e.,* are the strongest)? Explain why H_2O has the highest boiling point. Explain the trend in boiling point going from H_2S to H_2Se to H_2Te.

What is the key point you need to remember to classify an IMF as a H-bond?

Unit 6 POGIL #5

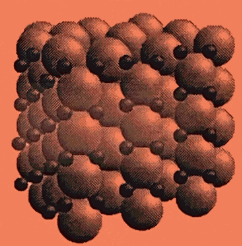
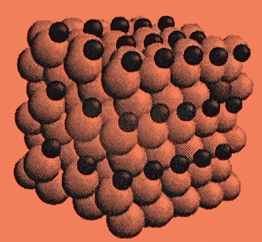
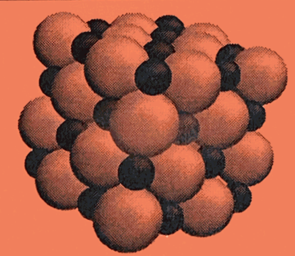
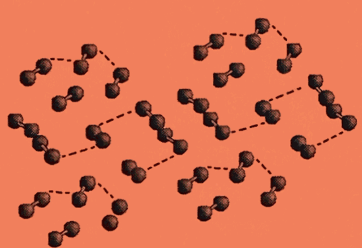
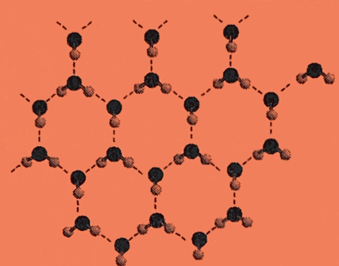
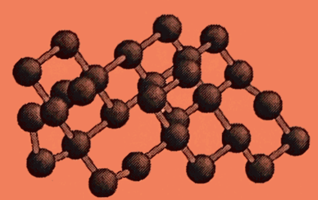
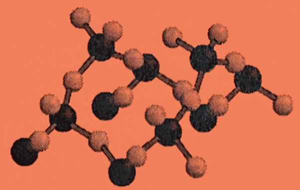
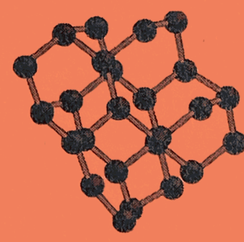
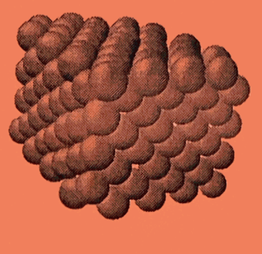
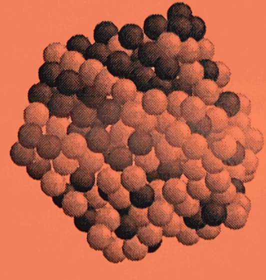
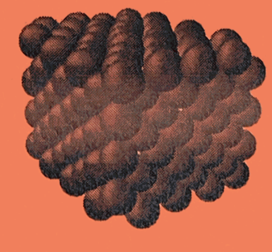
Types of Solids

What are some common categories of solids, and their properties?

Why?

Not all solids are the same. Solid substances have a tremendously wide range of melting points. Helium melts at –272 °C while tantalum hafnium carbide melts at 4215 °C. Some are conductive, others are not. Some readily dissolve in water, others do not. In this activity, you'll look at four types of solids, the types of substances that are typically in each category, and some of the properties typical for each.

Model 1 – Arrangements of Atoms in Solids

Ionic Solids	 Iron(II) Sulfide (FeS)	 Calcium Bromide ($CaBr_2$)	 Sodium Chloride (NaCl)
Molecular Solids	 Nitrogen (N_2)	 Ice (H_2O)	 Dry Ice (CO_2)
Network Covalent Solids	 Diamond (Carbon)	 Silica (SiO_2)	 Silicon (Si)
Metallic Solids	 Platinum (Pt)	 Brass (Cu and Zn)	 Nickel (Ni)

1. List the four types of solids illustrated in Model 1.

2. Complete columns A–C in the table below by referring to the examples in Model 1. Place a check in the box that appropriately describes the types of atoms that are usually seen in each type of solid.

	A	B	C	D	E	F
	All atoms are nonmetals	**All atoms are metals**	**Atoms are metals and nonmetals**	**Molecular structure**	**Formula units**	**Attractive forces**
Ionic Solids						
Molecular Solids						
Network Covalent Solids						
Metallic Solids						

3. Complete columns D and E in the table above by referring to the examples in Model 1. Place an X in the box that appropriately describes the arrangement of atoms or molecules in the solid (either **molecular**—distinct molecules, or **formula units**—repeating units in three dimensions with no distinct molecules).

4. There are four possible forces of attraction that hold atoms or molecules together in a solid: covalent bonds, ionic bonds, metallic bonds and intermolecular forces. These depend on the type of atoms in the solid and whether the connections are between ions, atoms or molecules. Within your group, discuss the type of attractive forces that are most likely holding the atoms or molecules together in each type of solid. List your answers in column F in the table above.

STOP

Read This!

When a solid substance is heated, the weakest attractive forces in the solid structure are overcome, and the solid melts. In some cases, this results in individual atoms or ions, and in other cases, this results in individual molecules. Regardless, melting is a physical change and does not alter the chemical formula of the substance.

5. For each type of solid in Model 1, indicate the type of attractive forces that are broken upon melting, and describe the individual particles that make up the resulting liquid.

	Bonds/forces broken upon melting	Individual particles in the liquid
Ionic		
Molecular		
Network covalent		
Metallic		

6. Match the following descriptions with one of the four types of solids.

_______________ Metallic atoms with very loose electrons for a lattice of nuclei held together by a sea of electrons, or metallic bonds.

_______________ Nonmetal atoms form molecules with covalent bonds. The molecules are held together in a solid by intermolecular forces of attraction.

_______________ Metal and nonmetal atoms form a lattice of alternating positive and negative ions held together by ionic bonds.

_______________ Nonmetal atoms form a lattice structure held together with covalent bonds.

7. If a particular solid had very strong attractive forces, would you expect the melting point of that solid to be relatively high or relatively low? Explain your reasoning.

Model 2 – Melting Points and Enthalpies of Fusion

Type of Solid	Substance	Chemical Formula	Melting Point (°C)	Enthalpy of Fusion (kJ/mole)
Ionic	Iron(II) sulfide	FeS	1195	51.0
	Calcium bromide	$CaBr_2$	730	17.5
	Sodium chloride	NaCl	804	30.3
Molecular	Nitrogen	N_2	–210	0.72
	Water	H_2O	0.0	6.02
	Carbon dioxide	CO_2	–78	8.10
Network covalent	Diamond	C	3550	117.0
	Silica	SiO_2	1650	12.5
	Silicon	Si	1687	50.0
Metallic	Platinum	Pt	1770	24.0
	Brass	Cu and Zn	~930	Varies
	Nickel	Ni	1453	71.0

8. Notice that the substances listed in Model 2 are the same as those in Model 1.

   a. Which type of solid has the lowest melting points?

   b. Is your answer in part *a* consistent with your answer to Question 7?

9. The **enthalpy of fusion** given in Model 2 for each substance is a measure of the energy (in kJ) needed to melt a mole of that substance.

   a. Which type of solid has the lowest enthalpies of fusion?

   b. Is your answer in part *a* consistent with what you know to be the relative strength of the four types of attractive forces? Explain why or why not.

10. Using both melting point data and enthalpy of fusion data, rank the remaining three types of solids from weakest attractive forces to strongest attractive forces. Make sure there is consensus in your group before moving on.

STOP

Read This!

As you may have found in answering the previous question, there is a lot of overlap in properties among the four types of solids. For example, platinum (a metallic solid) has a higher melting point than several of the network covalent solids, but the majority of metallic solids have a much lower melting point than network covalent solids. The categories for solids are not as clear cut as we would like them to be; nevertheless, they are useful for predicting relative properties.

11. Use the concepts you have learned in this activity to predict the type of solid for each of the following substances. Anyone in your group should be able to justify your group's answers.

Substance	Chemical Formula	Melting Point (°C)	Enthalpy of Fusion (kJ/mole)	Type of Solid
Chlorine	Cl_2	−102	6.41	
Hydrogen bromide	HBr	−87	2.41	
Titanium	Ti	1668	20.9	
Sodium bromide	NaBr	747	26.1	
Boron	B	2076	50.2	
Mercury	Hg	−38.3	2.29	

Read This!

Properties other than melting point and enthalpy of fusion can be helpful when categorizing a substance as one of the four types of solids. For example, conductivity and solubility can give great insight into the structure of a solid. For a substance to be soluble in water it must be charged or polar. (Remember the rule "like dissolves like.") For a substance to be conductive, in any state, there must be charged particles in a mobile state so that they can complete a circuit.

Model 3 – Solubility and Conductivity of Solids

Substance	Chemical Formula	Solubility in Water	Conductive as a Solid	Conductive as a Liquid	Conductive in Aqueous Solution
Iron(II) sulfide	FeS	Insoluble	No	Yes	N/A
Calcium bromide	$CaBr_2$	Very soluble	No	Yes	Yes
Sodium chloride	NaCl	Very soluble	No	Yes	Yes
Nitrogen	N_2	Slightly soluble	No	No	No
Water	H_2O	N/A	No	Slightly	N/A
Carbon dioxide	CO_2	Slightly soluble	No	No	No
Diamond	C	Insoluble	No	No	N/A
Silica	SiO_2	Insoluble	No	No	N/A
Platinum	Pt	Insoluble	Yes	Yes	N/A
Brass	Cu and Zn	Insoluble	Yes	Yes	N/A
Nickel	Ni	Insoluble	Yes	Yes	N/A

N/A = not applicable

12. Refer to Model 3.

    a. Which type(s) of solid is generally very soluble in water?

    b. Which type(s) of solid is least soluble in water?

13. Refer to Model 3.

    a. Which type of solid is most conductive in the solid state?

    b. Use the concepts you have learned about the type of solid in part *a* to explain why it is conductive in the solid state.

14. Explain why ionic substances would be conductive after they are melted, even though they are not conductive as solids.

Extension Questions

15. The last column in Model 3 (Conductive in Aqueous Solutions) has several N/A entries. Give two reasons why conductivity data for those substances would not exist.

16. Engineers use materials to perform different functions based on the properties of the materials. For centuries we have used metals for tools and more recently for electrical circuits. What properties of metallic solids make them well suited for this purpose?