

**THE USE OF MODELS AND CASE STUDIES
IN TEACHING BONDING**

By

Mark Joseph Erickson

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ABSTRACT

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The concepts of chemistry can often be more difficult to understand than the concepts of other sciences due to the fact that much of what is happening occurs at the atomic and molecular level and cannot be seen by the naked eye. When attempting to describe the properties of substances using the interaction of invisible atoms and ions to form chemical bonds, the challenges increase. An understanding of the differences and similarities between these structures and connecting differences in these invisible structures to the resulting physical properties can be difficult challenge for chemistry students. This study attempts to use case studies paired with labs and a variety of models of atoms, ions, and compounds to increase student understanding of the concepts and processes involved in chemical bonding. Based on the results of this unit the author plans to continue his use of case studies. The author also plans to continue to use models with more explicit discussion of modeling with the students.

DEDICATION

I would like to dedicate this thesis to my wife, Renee, and my two sons, Daniel and Caleb, who made many sacrifices in encouraging me through this process. I would also like to dedicate this thesis to my parents, Ron and Carla Erickson, who have continually encouraged and supported my education, along with the many other ways that they have blessed my life.

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Introduction

Chemical bonding, along with the rest of chemistry, attempts to explain observed events in the macroscopic world using the interaction of unseen atoms in the molecular world. The existence of atoms has been supported by evidence since John Dalton's *New System of Chemical Philosophy*, in 1808 (Dalton, 1808 and Coward, 1927). However, it was not until 100 years later that the size of a molecule and the size of the nucleus could be estimated. Jean Perrin in 1908 used the formulas of Albert Einstein to calculate the size of an atom using Brownian motion, an achievement that some claim finally proved the existence of atoms (Einstein, 1905; Perrin, 1908; and Newburgh, 2006). Ernest Rutherford calculated the size of the nucleus using the scattering of alpha particles by gold atoms in 1913 (Rutherford, 1913 and Bishop, 1990). When the efforts of two Nobel laureates and 100 years are required to prove the existence of these particles, it becomes obvious that atoms, ions, and molecules are not easily described.

A Review of Student Difficulties with Concepts in Chemical Bonding

“Confusions and difficulties over a number of chemical concepts require a different perspective, since these are abstract and formal explanations of invisible interactions between particles at a molecular level and are not likely to be arrived at from confrontation with the world of experience.” (Carr, 1984)

Abstract reasoning is essential for chemistry students because unimaginably minute particles are used to explain the changes and reactions that are studied (Harrison and Treagust, 1996). It has been shown that the fundamental concept of the particulate nature of matter can be difficult for students not just in chemistry, but in other sciences as well (de Vos and Verdonk, 1996).

Several studies have been done on the challenges and misconceptions students have with the particulate nature of matter. It has been shown that many times students fail to use “atoms and molecules” in their explanations of chemical changes, even when they have been emphasized in class (Hesse, 1992). Students studying gas laws have been shown to have misunderstandings of the particulate nature of matter (Novick and Nussbaum, 1981). These difficulties with the particulate nature of matter can also be seen in students all the way up to the undergraduate college level (Nakhleh, 1992). Students also have difficulty distinguishing between the properties of matter, which is made up of multiple atoms, and the properties of the individual atoms themselves (Ben-Zvi et. al., 1986).

Chemistry requires not only the concept that all matter is composed of particles, but also distinguishes between the different types: atoms, molecules, or ions. In chemical bonding students must have some understanding of how these different particles interact with each other in different ways to form ionic, covalent, and metallic bonds. Studies have shown that students have misconceptions and difficulty defining the characteristics of atoms and molecules (Griffiths and Preston, 1992 and Tsapalis, 1997). Students also have difficulty distinguishing between bonding of molecules and ions (Butts and Smith, 1987). Some of these same misconceptions between types of particles and in bonding have been seen even at the undergraduate college level (Nicoll, 2001).

Misconceptions in the differences between atoms, molecules, and ions often start in grade school and educators should be aware and help students begin to understand the differences between atoms, molecules, and ions early on (Nakhleh, 1992). Several studies have also looked into the use of visual aids and learning tools, because of the importance of visuospatial thinking in chemistry (Wu and Shah, 2004). Others have suggested that teaching highly abstract models at

the introductory level is counter-productive (Coll and Treagust, 2001). Given the abstract nature of chemical bonding and the difficulties that some students have been shown to have, this study is investigating methods of increasing student understanding of chemical bonding. The focus will be on the use of case studies and on the use of models in order to increase student understanding.

A Journal Review of the Use of Case Studies in Science Education

Case studies “use realistic or true narratives to provide opportunities for students to integrate multiple sources of information in an authentic context, often engaging students with ethical and societal problems” (Yadav et. al., 2007). According to surveys of teachers who utilize case studies, most teachers responded that they use case studies for promoting student engagement (Herreid, 2011). Case studies may be used to stimulate interest by helping students see real-world applications to course activities (Hodges, 2005).

The use of problem based learning (PBL) has been studied in medical schools and found to be generally enjoyed by most students and long-term student outcomes comparable to traditional methods (Albanese and Mitchell, 1993). Similarly case studies have also been incorporated into teaching science at the college level (Herreid, 1994). Studies have shown that case studies have increased student-learning outcomes in biology program (Pai et. al., 2010), in teaching cellular respiration concepts (Rybarczyk et. al., 2007), and an introductory chemistry course (Brink et. al., 1995).

Some case studies designed for high school science classes have been published (Derriso, 2011), but none were found to fit the chemical bonding labs for this study. Therefore two case studies were designed by the author to be incorporated with the two labs.

In order to explain and describe these atoms, ions, and molecules, chemists and chemistry teachers use a variety of theoretical models or analogies which chemistry students often find both challenging and confusing (Harrison and Treagust, 1996). Pedagogical analogical models are “concrete” models that teachers often use to depict abstract or non-observable entities like atoms and molecules. One or more features dominate the analog’s concrete structure; e.g., ball-and-stick and space-filling molecular models (Harrison and Treagust, 1998). These models can give concrete examples and allow for simplifications for clearness of understanding. These oversimplifications and weaknesses should be identified with students as well (Harrison and Treagust, 1998).

Molecular models are one of the more commonly used models in chemistry and it has been shown that chemistry students who manipulate models are more successful in high school chemistry than those who merely see the teacher manipulate models (Gabel and Sherwood, 1980). Standard molecular models represent covalent bonds, which is only one-third of chemical bonding cases however. Furthermore to make the concept even more challenging, most chemical bonds are somewhere between covalent and ionic or even metallic bonds. Therefore no one model is sufficient and more than one type of model is necessary.

In using multiple models of a single concept, it becomes vitally important to indicate when a new model is being used, how it is different, and why it works effectively (Carr, 1984). Realizing that no model can be correct can be an important process. It has also been shown that chemistry students who can process multiple models think about science as more about process than about description of objects (Harrison and Treagust, 1998) and are more likely to build scientific understanding of natural phenomena (Adadan et. al., 2010). Furthermore, students' conceptual

understanding might be enhanced by comparing models of covalent, ionic, and metallic bonds and seeing them as part of similar processes (Thiele and Treagust, 1994 and Ardac and Akaygun, 2004).

In order to help students overcome some of the challenges of the concepts of chemical bonding strategies need to be used to support the students. Case studies help make connections to the real world and engage students. This should be helpful with the abstract concepts of chemical bonding. Physical models of the covalent bonds are regularly used in bonding. Reinforcing these with other types of models should be a natural method of helping student learning. This study will investigate how case studies and models might increase student understanding of chemical bonding.

Implementation

Description of Sample Population

The students selected for this study were from Lumen Christi Catholic High School located in Jackson, Michigan. Lumen Christi is a private catholic high school under the Diocese of Lansing. The 2009-2010 enrollment was 500 students and 37 faculty members. The student population is primarily college prep with over 95% of students attending college after graduation.

The participating students were selected from 132 juniors and seniors enrolled in one of four Regular Chemistry, or one of two of Honors Chemistry courses, all of which are taught by the author. Approval was obtained from the Institutional Review Board of Michigan State University for a project involving human subjects and from the Lumen Christi principal. Students were made aware of this study, which occurred as part of the unit on chemical bonding taught during the spring semester, and were given consent forms (see Appendix C). The consent forms were signed by both by a parent or guardian and the student. The sample group consists of 28 students (23% participation), 14 students (15% participation) from four Regular Chemistry classes and 14 students (44% participation) from two Honors Chemistry classes.

The unit took place over a period of six-weeks (Table 1) with a Pre- and Post-Test (Appendix C) at the start and end. The unit was introduced with identifying the properties of metals and non-metals in the Metals vs. Non-Metals Activity (Appendix D). This served the function of looking at distinguishing substances by their properties and identifying metals and non-metals, since this distinction is used in identifying the types of bonding. This was followed by relating the

Table 1: Description and Sequence of Activities	
Activity	Description
Pre-Test	This is a 27 question assessment designed using the Michigan MEAPS to determine student's prior knowledge of the objectives. This item was designed specifically for this study.
Metal versus Non-Metal Survey	In this group activity students are given samples of metals and non-metal elements and asked to identify and investigate some of the physical properties that distinguish them. The students then use these properties to classify some unknown samples as metals or non-metals. This is a new activity designed during this study.
Phoenix Lander Case Study	This case study uses the context of the NASA Mars Lander program to investigate the make-up of the Martian surface among other things. The students are given information about some Martian rock samples and asked to classify them as ionic, covalent, or metallic. This is a new case study designed during this study.
Ionic, Covalent, and Metallic Lab	This lab has students observe some properties of ionic, covalent, and metallic substances and identify some of the trends of these properties. The students then use this information to classify some unknown samples as ionic, covalent, or metallic. This was a previously designed lab modified during this study.
Models	Models of ionic, covalent, and metallic bonds are presented to the students. Styrofoam models, graphic models, and animated models are presented for each type of bond. These models were made and found during this study.
Molecular Models Activity	This activity has students create molecular models of several covalent compounds. The students then draw a picture of this model and classify it as either polar or non-polar. This was a previously used activity.
Molecular Analysis Case Study	This case study presents students with descriptions of common substances without using the common name. Students are asked to classify the substances as ionic, covalent, or metallic. Then students answer questions about the bonding in another common substance from its Lewis structure. This is a new case study designed during this study.
Review of Models	Models of ionic, covalent, and metallic bonds are presented to the students as a review of the types of bonding. The use of these models was not restricted to two specific times as they were used as examples of bonding during the course of the unit as well.
Post Test	The 27 question assessment is given to the students again as part of the end of unit test to determine how student learning has changed.
Final Exam	The final exam included 5 questions from the Pre- / Post-Test assessment to check for long-term retention of the concepts.

physical properties of substances to their structure using the Phoenix Lander Case Study (Appendix E) with the Ionic, Covalent, and Metallic Lab (Appendix F). As a part of this unit models (Figures 3-7) of the different types of bonding were used with the instruction. This was followed by a closer look at covalent molecules using the Molecular Modeling Lab (Appendix G) and the Molecular Analysis Case Study (Appendix H).

Description of Case Studies and Lab Activities Incorporated into Instruction

The first case study, the Phoenix Lander Case Study (Appendix E), was used with the Ionic, Covalent, and Metallic Lab (Appendix F). This was an interrupted case study in which information was supplied to students in parts between which the students come to some conclusion before being supplied the next piece of information (Herreid, 2005). The context of the case was the two Phoenix Landers, which NASA sent to Mars in 2007. One of the five stated mission goals was to determine the composition of the Martian soil. Students were shown photos of Mars' surface taken by previous orbiters (www.nasa.gov/phoenix) showing different types of Martian geology. Students were then shown photos, graphics, and animations describing the Phoenix mission and the Lander equipment (Appendix E).

The students then did the Ionic, Covalent, and Metallic Lab (Appendix F) in which they were given eighteen substances with the correct chemical formulas. Using the chemical formulas students determined whether the substances were classified as ionic, covalent, or metallic. The students recorded physical properties of the substances such as relative melting point, hardness, solubility in water, conductivity of the solid, and conductivity in solution. The students then completed a chart (Table 15) indicating the physical properties of ionic, covalent, and metallic substances.

Eight electrical conductivity testers (Figure 1), enough for each lab group, were also built for this study in order to enhance the lab and increase student involvement. The testers used 9-V batteries and LEDs and were built using instructions found on the Internet (Reeves, 2010). These replaced the single conductivity tester using 120-V and a 60-Watt light bulb that the author had previously been using with this lab. The solid powders that were used in this lab were first put in solution and then allowed to re-crystallize before being given to students. This was an attempt to give the substances a more natural appearance (Figure 2) to fit the context of the case study and help the students make connections to real life.

In the second portion of the Phoenix Lander case study, the students were given sample practice questions giving some physical properties of different substances (Appendix I). They then classified the substances as ionic, covalent, or metallic using the chart of properties from the lab. The students were then given six unknown substances without the chemical formulas. By finding the physical properties of these substances in the lab, the students classified these as ionic, covalent, or metallic substances.

The next day, the students were given the correct classifications for the unknown substances to check their hypotheses. The results of the Phoenix Lander mission were also given to the students, including the fact that it is suspected that snowflakes were seen by the Lander (www.NASA.gov/Phoenix).

The second case study, the Molecular Analysis Case Study (in Appendix H), is used following the Molecular Models Lab (in Appendix G). Descriptions, photos, and a Lewis structure of several common substances were used as a context for the students to apply their knowledge of bonding.

Figure 1: Photo of Electrical Conductivity Tester

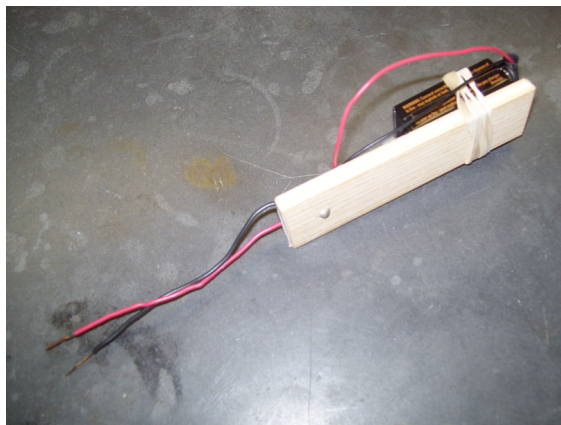


Photo of 9-V electrical conductivity tester used in Ionic, Covalent, and Metallic Lab. This tester can be used to test conductivity of a solid or of a solution. (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.)

Figure 2: Photo of Re-crystallized Substances



Photo of some substances used in Ionic, Covalent, and Metallic Lab. The substances were re-crystallized in an attempt to give them a more natural appearance.

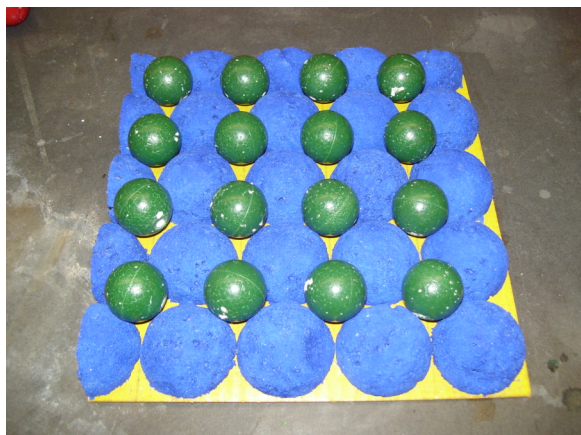
In the Molecular Models Lab (Appendix G) the students used “ball and stick models” to show the bonding in several covalent molecules. The molecules were chosen to include examples of single, double, and triple bonding, examples of tetrahedral, trigonal pyramidal, bent, trigonal planar, and linear geometries, and one formula which could be depicted in two forms. After constructing the molecules, students drew them on the worksheet, and then classified them as either polar or non-polar. They then answered some questions about covalent bonding.

In the Molecular Analysis Case Study (Appendix H), the students were given descriptions of several common substances without using the common name. These descriptions included information about the use of the material and some of the physical properties. Photos of a sample of each substance were provided, except for clear liquids or gases. The photos and descriptions of these substances were taken from the Internet (www.wikipedia.com). The students then matched the descriptions to the correct chemical formula based on whether it had ionic, covalent, or metallic properties. Finally, the students used a Lewis structure to answer questions about the covalent bonds of another common substance.

Description of Models and Metal Non-Metal Activity Incorporated Into Instruction

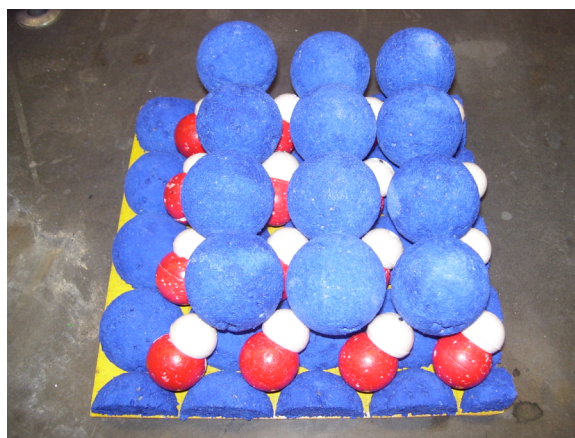
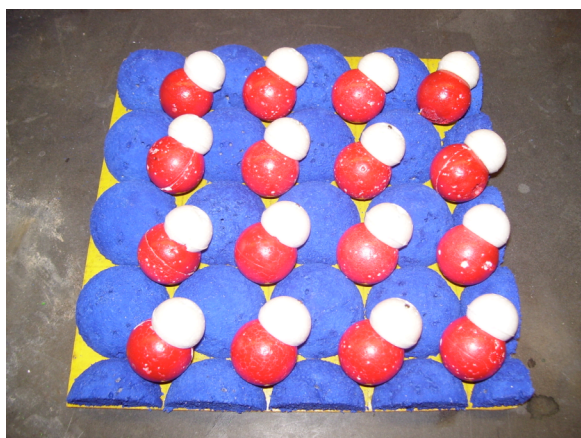
Attempts were made in this study to use as many types of models as possible to depict ionic, covalent, and metallic bonds. Concrete models made from painted Styrofoam balls were made for ionic, covalent, and metallic bonds. Examples of ionic bonds (Figure 3) were developed and used to illustrate the alternating pattern of anions and cations in the crystal lattice structure. Polyatomic ions were also modeled (Figure 4) so that they could be switched in for the non-metal anions to further illustrate the differences between types of bonds. Covalent models (Figure 5) were made of all the molecules used in class illustrations, the Molecular Modeling lab, and of the common VSEPR geometries. In addition, enough models of water molecules were

Figure 3: Photos of Binary Ionic Model



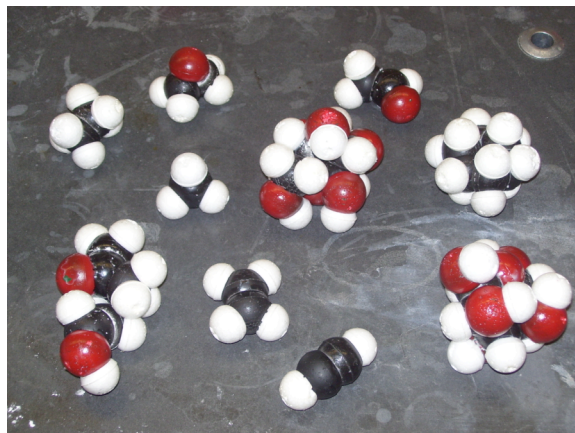
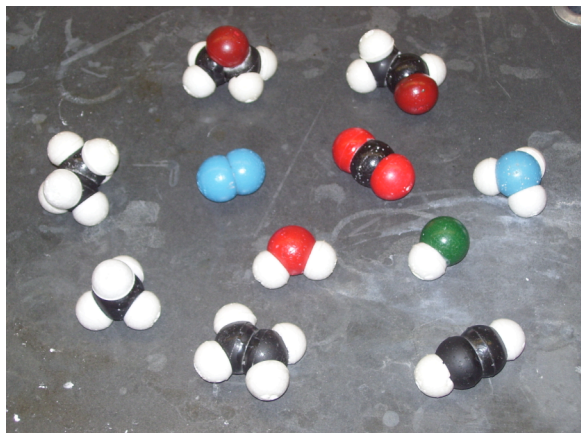
Photos of ionic bonding model a binary compound with non-metallic ions showing the alternating pattern of the crystal lattice structure. The larger spheres represent the anions and the smaller spheres represent the cations.

Figure 4: Photos of Polyatomic Ionic Model



Photos of polyatomic ionic model with polyatomic ions illustrating the interaction of two types of chemical bonds. The larger spheres represent the metallic cations and the paired spheres represent covalently bonded hydroxide anions.

Figure 5: Photos of Covalent Bonding Models



Photos of covalent bonding models including molecules of nitrogen, hydrogen chloride, water, carbon dioxide, ammonia, methane, ethane, ethane, ethyne, acetone, benzene, and two forms of sugar.

Figure 6: Photos of Solution of Ionic Bond Models in Covalent Water Molecules Models



Photo of a model of an un-dissolved ionic precipitate in a “beaker” of models of covalent water molecules followed by the same solution after shaking or “dissociation” of the model ionic compound resulting in its “disappearance” into solution.

Figure 7: Photos of Metallic Bonding Model



Photo of metallic bonding model showing the crystal pattern of metal atoms in delocalized metallic bonds.

Figure 8: Photos of Samples of Ionic, Covalent, and Metallic Substances



Photos of samples of ionic, covalent, and metallic substances for group and class use.

created to fill a large container representing a beaker of water (Figure 6). Models of ionic compounds were then added to the bottom with model water molecules over them to show the solution and dissociation of ionic compounds when the beaker is shaken. Metallic models (Figure 7) showing delocalized bonding were more difficult to create and only one “concrete” example was used.

Graphic models of each type of bond, borrowed from the Internet, were also selected to be presented. The examples were all chosen from a single site in order that comparisons between the three might be made more easily. The examples also showed the transition from the atomic state to the bonded state in order to stress differences between atoms, ions, and molecules.

It has been demonstrated that technology may be used to enhance visual models by turning them into animations (Williamson and Abraham, 1995). Therefore, animations of all three types of bonding were found on the Internet and presented with the other models at least twice during the study (Table 1).

In addition it was decided to use as many actual samples of the compounds formed by ionic, covalent, and metallic bonds (Appendix I) as possible. This was an attempt to connect the models to the real world experiences of sight, touch, and smell that they were representing. This was also an attempt to make the instruction and activities more hands on. Samples were collected of over thirty ionic, over fifteen covalent, and at least eight metals (Table 2 and Figure 8).¹ Samples were prepared in a method to avoid powdered forms to reflect a more natural state

¹ A special thanks to following members of the MSU faculty and staff who provided some of the materials for these collections. Tom Palazzolo, from the MSU physics machine shop, provided several of the metal samples in these collections, Dr. Merle Heidemann who provided several ionic rocks and some chemical samples from the DSME storeroom and to Dr. Ken Nadler who provided a set of scintillation vials for this collection.

Table 2: List of Ionic, Covalent, and Metallic Samples

Ionic	Solids	Compounds	carbonates: calcium carbonate, ammonium bicarbonate nitrates: aluminum nitrate, calcium nitrate, potassium nitrate, cupric nitrate hydrate, ferric nitrate hydrate, silver nitrate, ammonium nitrate phosphates: potassium phosphate hydrate monobasic hydroxides: sodium hydroxide, manganese dioxide sulfates: aluminum sulfate hydrate, calcium sulfate, potassium sulfate, sodium sulfate, manganese sulfate hydrate, cupric sulfate hydrate, ferric sulfate, ammonium sulfate chlorides: barium chloride, cupric chloride hydrate, ferric chloride hydrate, cobalt chloride hydrate, manganese chloride hydrate, ammonium chloride, potassium chlorate <i>others</i> : potassium ferricyanide, potassium permanganate, potassium chromate, potassium dichromate hydrate, ammonium dichromate, sodium acetate, lead acetate, silica gel, slate*, mica*, quartz*
Covalent	Solids	Element	carbon*, sulfur*, iodine
		Compound	dextrose, starch, methyl red sodium salt, methyl orange sodium salt, analine yellow, ascorbic acid, malachite green, acid violet, Trypan blue
	Liquid	Compound	water, methanol, acetone, isopropyl alcohol
	Gas	Element	nitrogen, oxygen
		Compound	carbon dioxide, methane
Metallic	Solid	Element	aluminum*, copper*, tin*, zinc*, lead*, molybdenum, tungsten
		Alloy	brass*, mild steel*, stainless steel

than the prepared powders direct from the supply company.

A Metal vs. Non-Metal Activity (see Appendix D) was developed to help familiarize the students with the properties of metals and non-metals. After first investigating several properties of metal and non-substances, the students were given several unknown samples and asked to use their properties to classify them as metals or non-metals.

Description of Assessment Tool

Students completed both a 17 question Pre- and a Post-test (Appendix C). This assessment was designed to evaluate the effectiveness of each of the case studies as well as the models and metal non-metal activity in context of the Michigan MEAPS for chemical bonding (Appendix B). The test was composed of seven multiple-choice questions with four short response questions to give some insight into student thought processes (Table 3). Two matching sections with thirteen items were also included for students to classify different substances and properties. Two questions had students draw Lewis structures of a given molecule and a short answer question had students explain the differences between a molecule and an ionic compound. Statistical analysis were performed using a paired two sample student t-test using Excel. An alpha value of 0.05 was selected as the level of significance for all t-tests.

In addition, five questions (5, 7a, 11d, 11g, and 11h) were used on the final exam. Student performance on these questions was used to give an indication of students' retention of the material.

Table 3: Focus of Assessment Questions									
Question #	MEAP Objective	Metal vs. Non-Metal	Ionic, Covalent, and Metallic Lab	Phoenix Lander Case Study	Molecular Analysis Case Study	Molecular Modeling Activity	Models	Question Type	Point Value
1	C4.3e		X		X		X	Multiple Choice	1
2	C2.1a				X	X	X	Multiple Choice	1
2b	C2.1a				X	X	X	Short Answer	2
3	C4.3e		X		X		X	Multiple Choice	1
4	C4.3e				X			Multiple Choice	1
4b	C4.3e				X			Short Answer	2
5	C4.3e				X			Multiple Choice	1
6	C4.3e		X		X		X	Multiple Choice	1
6b	C4.3e				X			Short Answer	2
7a	C4.9b	X						Matching	1
7b	C4.9b	X						Matching	1
7c	C4.9b	X						Matching	1
7d	C4.9b	X						Matching	1
7e	C4.9b	X						Matching	1
8	C5.5a		X		X			Multiple Choice	1
8b	C5.5a		X		X			Short Answer	2
9	C5.5c				X	X	X	Multiple Choice	1
10a	C5.5c				X	X	X	Lewis Diagram	2
10b	C5.5c				X	X	X	Lewis Diagram	2
11a	C5.5d		X	X			X	Matching	1
11b	C5.5d		X	X			X	Matching	1
11c	C5.5d		X	X			X	Matching	1
11d	C5.5d		X	X			X	Matching	1
11e	C5.5d		X	X			X	Matching	1
11f	C5.5d		X	X			X	Matching	1
11g	C5.5d		X	X			X	Matching	1
11h	C5.5d		X	X			X	Matching	1
12	C5.5e				X	X	X	Short Answer	2
27 questions		5	13	8	15	6	17		35 points

Results

The results of the Pre- and Post-Test (Table 4) show that the students displayed an adequate degree of understanding of the unit with overall scores of 60 for the Regular and 73 for the Honors. In addition more than 70 percent of the students answered correctly for more than half of the questions. There were a few questions for which the student scores did not improve. The questions about properties of metals and non-metals account most of the questions that did not show improvement, but the scores all showed mastery of the material. Question 11e (Appendix C), which asked about the type of substances that conduct electricity in solution, showed poor results. One possibility is that in the Ionic, Covalent, and Metallic Lab (Appendix F) students reused the beakers when they tested solubility and conductivity causing some solutions to appear conductive when they were not. The lab should be adjusted or the results discussed more thoroughly. Conductivity of substances needs to be stressed more in the future based on the results of question 11h (Appendix C) also.

Case Studies and Labs

In this study, the scores of assessment questions that were also used on the final exam, 6 weeks later, seemed to remain fairly consistent or even increase (Table 5). The main exception was the question asking about conduction of electricity in solution. As some materials are conductive as solids, some in solution, and some non-conductive this is a fairly easily confused question. In fact, the scores for the honors class the scores actually increased. One of the strengths of the medical school PBLs is the long-term retention of learning as seen by test scores (Albanese and Mitchell, 1993). This was a case study and not PBL, but this may show that other factors, such as student interest, can be important factors in retention as well.

Table 4: Summary of Pre- and Post-Test Data							
	Percentage of Regular Students with Correct Responses				Percentage of Honors Students with Correct Responses		
	Pre-Test	Post-Test	p-value (2 tailed)		Pre-Test	Post-Test	p-value (2 tailed)
1	29	57	0.165		64	100	0.496
2	43	36	0.583		50	100	0.096
2b	16	48	0.008		34	43	0.901
3	57	71	0.336		57	93	0.269
4	21	71	0.003		50	86	0.543
4b	13	43	0.013		38	59	0.508
5	57	93	0.055		50	93	0.029
6	29	29	1.000		21	64	0.083
6b	9	21	0.221		14	38	0.073
7a	79	71	0.583		93	93	0.163
7b	93	100	0.336		100	93	0.083
7c	100	100	ns		100	100	0.083
7d	71	86	0.435		100	100	0.163
7ea	64	93	0.040		100	93	0.041
8	14	50	0.019		71	93	0.718
8b	5	23	0.003		43	48	0.887
9	21	86	0.002		79	100	1.000
10a	18	61	0.000		34	59	0.086
10b	29	71	0.000		79	73	0.214
11a	50	71	0.189		64	71	1.000
11b	43	50	0.612		21	57	0.041
11c	29	50	0.272		29	71	0.020
11d	50	86	0.019		93	100	0.579
11e	57	64	0.752		86	50	0.004
11f	29	86	0.001		57	86	0.269
11g	36	93	0.001		50	50	0.496
11h	50	71	0.272		64	93	0.269
12	4	21	0.086		16	71	0.001
Total	34	60	0.000		55	73	0.351

Table 5: Analysis of Retention of Student Learning on the Final Exam								
Question #	Phoenix Lander Case Study	Molecular Analysis Case Study	Percent of Regular Students with Correct Answers			Percent of Honors Students with Correct Answers		
			Pre-Test	Post-Test	Final Exam	Pre-Test	Post-Test	Final Exam
5		X	57	93	87	50	93	97
7a			79	71	89	93	93	100
11d	X	X	50	86	100			not tested
11g	X	X	36	93	62	50	50	77
11h	X	X	50	71	67	64	93	85

Table 6: Analysis of Correct Student Responses by Activity				
Activity	# of Questions	Percent Students Answering Correctly		
		Class	Pre-Test Average	Post-Test Average
Metal versus Non-Metal Activity	5	Regular	81	87
		Honors	99	96
Ionic, Covalent, and Metallic Lab	13	Regular	39	67
		Honors	58	77
Phoenix Lander Case Study	8	Regular	43	71
		Honors	58	72
Molecular Analysis Case Study	17	Regular	36	66
		Honors	55	77
Molecular Model Activity	6	Regular	22	54
		Honors	49	74
Models	15	Regular	24	52
		Honors	47	75

The assessment questions showed that several of the questions for the case studies indicated increases (see Table 6). The regular classes showed the greatest increases for these studies while the honors classes show lower increases. This could be due to the fact that the increased engagement helped the regular students greater than the honor students among other factors.

During the presentation of the Phoenix Lander Case Study (Appendix E), it was observed that the classes appeared more silent and less engaged than normal. In questioning of several students after class, the students responded that they did enjoy the presentation and doing something in a different way. The author is therefore unsure of the students' true reception of this particular case study. Other studies have found that students can have divided responses of they really liked it or they found it superfluous (Hodges, 2005) and this may be the case here.

Models, Molecular Model Activity, and Metal Non-Metal Activity

For the Modeling and the Molecular Modeling activity regular and honors classes showed significant gains during the unit. In comparison to the greater gains on the case studies by the regular classes, both groups seemed to benefit similarly for the Modeling and the Molecular Modeling activities. This may support the idea that multiple forms of models help with processing skills (Thiele and Treagust, 1994 and Ardac and Akaygun, 2004).

On the post assessment, it was noticed that several students attempted to use a Lewis diagram to show an ionic molecule. It was also noted that the scores for the MEAP on Lewis structures (Table 7) were higher than for the Modeling activities. This indicates that it is possible that not enough time was spent distinguishing between diagrams for covalent bonds and diagrams for ionic and metallic bonds.

Table 7: Analysis of Correct Student Responses on Lewis Structure Questions				
Activity		Percent of Students with Correct Responses		
		Class	Pre-Test Average	Post-Test Average
C5.5c	3	Regular	23	73
		Honors	64	77

Written diagrams are not as commonly seen for ionic bonds and almost never for metallic bonds. The differences between concrete models and physical properties of the different bonds were stressed several times, however drawings other than Lewis structures were not routinely used the differences in drawings was not stressed. This was a fault of this unit. Next year, more attention will be given to drawings of other types of bonding. This may give additional benefits as student generated drawings have been shown to help in understanding of modeling (Van Meter et. al., 2006).

The results for the activity comparing metals with non-metals showed both positive and negative results. This was also the topic for which the students showed the greatest prior knowledge. This activity may work better with the Periodic Table unit where this topic is first introduced. There is no clear evidence to support the need for having more activities of this type in this unit.

Overall Results

The overall test results for the regular class seem to support that this unit was mostly successful in improving student understanding. It also may indicate that the improvements were more significant in the regular class than in the honors class. This is reasonable in more than one way. The honors class showed more prior knowledge of the material meaning that the amount of new material and room for improvement is greater for the regular classes. As mentioned earlier, regular students are more likely to benefit from attempts to engage and use of multiple illustrations than honors students who are more motivated and capable of learning in other ways.

Discussion

Case Studies and Labs

Based on the author's experience with these case studies, I plan to continue using them and to expand them to include more of a PBL component. I have tried incorporating some PBL labs at the end of the semester and found the student response to be positive. I may attempt to use "Avogadro Goes to Court" (Bieron, 1999) or adapt labs from other trainings. During the research for this study, the author found other studies showing how PBL lab-based cases increase students' abilities to identify experimental variables that affect the outcome of an experiment (Grunwald and Hartman, 2010). It would also need to be seen if lab-based case studies are best used for introductory concepts early on or developed concepts at the end of units (Herreid, 2008).

Models, Molecular Model Activity and Metal Non-Metal Activity

The use of models appeared to be successful however improvement could be made. Using the bonding models throughout the year and being more explicit in the use of analogical models in other units should be beneficial. The benefit of manipulation of molecular models is seen in studies occurring over the length of at least a semester (Gabel and Sherwood, 1980). The benefit of the use of models to the honors classes also highlights the benefit of students recognizing the use of multiple models (Harrison and Treagust, 1996).

Although the use of animations was rather limited, the author intends to make greater use of animations in the future. They are more easily applied in other units and research has shown that they have some benefits. The use of animations either in lecture or by students has been shown to have the ability to increase student understanding of the particle nature of matter (Williamson

and Abraham, 1995) and the understanding of dissolution of sodium chloride (Kelly and Jones, 2007).

APPENDICES

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Appendix A: Student Consent Form (with Cover Letter)

PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, **The Use of Models and Case Studies in Teaching Chemical Bonding**, that I will conduct as part of chemistry this semester. My name is Mark Erickson. I am your science teacher this year and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

What is the purpose of this research? I have been working on effective ways to teach chemical bonding, and I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teachers' understandings about the best way to teach about science topics. Completion of this research project will also help me to earn my master's degree in Michigan State University's Division of Math and Science Education (DSME).

What will students do? You will participate in the instructional unit about chemical bonding. You will complete the usual assignments, laboratory experiments and activities, computer simulations, class demonstrations, and pretests/posttests just as you do for any other unit of instruction. There are no unique research activities – participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of students' work for my research purposes. This project will continue from October to August 2011. I am asking for permission from both students and parents/guardians (one parent/guardian is sufficient) to use copies of student work for my research purposes. This project will continue from October to August 2011.

What are the potential benefits? My reason for doing this research is to learn more about improving the quality of science instruction. I won't know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and their students can benefit from my research.

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, computer simulations, class demonstrations, and pretests/posttests. In fact, completing course work should be very beneficial to students. One risk that is very unlikely is that I might assign higher grades to students who agree to participate in the research than to students who say "no". I will minimize this risk by having another person store the consent forms (where you say "yes" or "no") in a locked file cabinet that will not be opened until after I have assigned the grades for this unit of instruction. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will

save all of your written work. Later I will analyze the written work only for students who have agreed to participate in the study and whose parents/guardians have consented.

How will privacy and confidentiality be protected? Information about you will be protected to the maximum extent allowable by law. Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that do not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of student's original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers (during the study) and in a locked file cabinet in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the completion of the study.

What are your rights to participate, say no, or withdraw? Participation in this research is completely voluntary. You have the right to say "no". You may change your mind at any time and withdraw. If either the student or parent/guardian requests to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

Who can you contact with questions and concerns? If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher.

Mark Erickson
3483 Spring Arbor Rd.
Jackson, MI 49203
merickson@jcslumenchristi.org
(517) 787-0630 x439

Dr. Merle Heidemann
118 North Kedzie Lab
Michigan State University
heidema2@msu.edu
(517) 432-2152 x107

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

How should I submit this consent form? If you agree to participate in this study, please complete the attached form. Both the student and parent/guardian must sign the form. Return the form to Mrs. Lefere, room 157, by January 31, 2010.

Name of science course: Chemistry
Teacher: Mr. Mark Erickson
School: Lumen Christi High School

Parents/guardians should complete this following consent information:

I voluntarily agree to have _____ participate in this study.
(print student name)

Please check all that apply:

Data:

_____ I give Mr. Erickson permission to use data generated from my child's work in this class for her thesis project. All data from my child shall remain confidential.

_____ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in this research.

Photography, audiotaping, or videotaping:

_____ I give Mr. Erickson permission to use photos, audiotapes, or videotapes of my child in the class room doing work related to this thesis project. I understand that my child will not be identified.

_____ I do not wish to have my child's images used at any time during this thesis project.

Signatures:

(Parent/Guardian Signature)

(Date)

I voluntarily agree to participate in this thesis project.

(Student Signature)

(Date)

*****Important*****

Return this form to Mrs. Lefere.

Appendix B: Chemical Bonding MEAP Objectives

Chemical Bonding MEAP Objectives

C2 Forms of Energy Chemistry students relate temperature to the average kinetic energy of the molecules and use the kinetic molecular theory to describe and explain the behavior of gases and the rates of chemical reactions. They understand nuclear stability in terms of reaching a state of minimum potential energy.

C2.1x 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.

C2.1a Explain the changes in potential energy (due to electrostatic interactions) as a chemical bond forms and use this to explain why bond breaking always requires energy.

C4 Properties of Matter Compounds, elements, and mixtures are categories used to organize matter. Students organize materials into these categories based on their chemical and physical behavior. Students understand the structure of the atom to make predictions about the physical and chemical properties of various elements and the types of compounds those elements will form. An understanding of the organization the Periodic Table in terms of the outer electron configuration is one of the most important tools for the chemist and student to use in prediction and explanation of the structure and behavior of atoms.

C4.3x Solids Solids can be classified as metallic, ionic, covalent, or network covalent. These different types of solids have different properties that depend on the particles and forces found in the solid.

C4.3e Predict whether the forces of attraction in a solid are primarily metallic, covalent, network covalent, or ionic based upon the elements' location on the periodic table.

C4.9x The rows in the periodic table represent the main electron energy levels of the atom. Within each main energy level are sublevels that represent an orbital shape and orientation.

C4.9b Identify metals, non-metals, and metalloids using the periodic table.

C5 Changes in Matter Students will analyze a chemical change phenomenon from the point of view of what is the same and what is not the same.

C5.5 Chemical Bonds -- Trends An atom's electron configuration, particularly of the outermost electrons, determines how the atom can interact with other atoms. The interactions between atoms that hold them together in molecules or between oppositely charged ions are called chemical bonds.

C5.5A Predict if the bonding between two atoms of different elements will be primarily ionic or covalent.

C5.5x Chemical Bonds Chemical bonds can be classified as ionic, covalent, and metallic. The properties of a compound depend on the types of bonds holding the atoms together.

C5.5c Draw Lewis structures for simple compounds.

C5.5d Compare the relative melting point, electrical and thermal conductivity and hardness for ionic, metallic, and covalent compounds.

C5.5e Relate the melting point, hardness, and electrical and thermal conductivity of a substance to its structure.

Appendix C: Chemical Bonding Pre- and Post-Test with Rubric

Chemical Bonding Pre-test

____ 1) What type of attractive force holds, or bonds, oxygen and magnesium together?

- a) Ionic bond.
b) Covalent bond.
c) Metallic bond.
d) It does not react.

2) What happens to oxygen when it forms a bond with magnesium?

- a) It gains two electrons. b) It loses two electrons.
c) It shares 2 electrons. d) It does not react.

2b) Use one or two sentences to explain why this results in an attractive force between the atoms.

___ 3) What type of attractive force holds, or bonds, carbon and hydrogen together?

- a) Ionic bond.
b) Covalent bond.
c) Metallic bond.
d) It does not react.

4) What happens to carbon when it forms a bond with hydrogen?

- a) It gains four electrons. b) It loses four electrons.
c) It shares four electrons. d) It does not react.

4b) Use one or two sentences to explain why this results in an attractive force between the atoms.

5) What type of attractive force holds, or bonds, copper and zinc together?

- a) Ionic bond.
b) Covalent bond.
c) Metallic bond.
d) It does not react.

6) What happens to copper when it combines with zinc?

- a) It gains two electrons. b) It loses two electrons.
c) It shares 2 electrons. d) It does not react.

6b) Use one or two sentences to explain why this results in an attractive force between the atoms.

7) Use the periodic table to identify the following elements as either metals or non-metals.

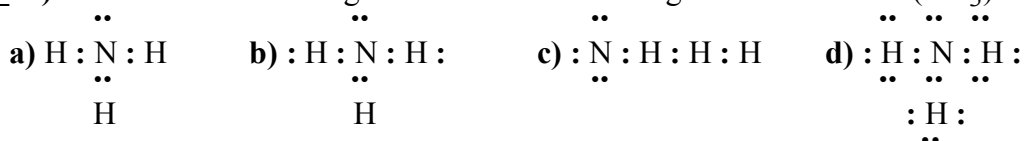
hydrogen iodine manganese phosphorus sodium

8) Which of the following elements will form an ionic bond with oxygen?

- a) calcium b) hydrogen c) sulfur d) nitrogen

8b) Use one or two sentences to explain why this element forms an ionic bond with oxygen.

___ 9) Which of the following is the correct Lewis diagram for ammonia (NH₃)?



10) Place the correct electron dots around the elements and then show the bonding for the compound.



In the following matching question each choice may be used more than once and some questions may have more than one answer.

11) Identify the following general characteristics as best describing either

a) ionic substances b) covalent substances c) metallic substances

- | | |
|-------------------------------------|--|
| ___ solid form conducts electricity | ___ does not conduct electricity in solution |
| ___ high melting and boiling point | ___ solid, liquid or gas at room temperature |
| ___ hard solid at room temperature | ___ conducts electricity in solution |
| ___ shiny and lustrous appearance | ___ low melting and boiling point |

12) Explain why an ionic compound, such as NaCl, is not considered a molecule and a covalent compound, such as H₂O, is a molecule. *You may use a drawing in your explanation if you choose.*

Chemical Bonding Pre-test Rubric

C4.3e Predict whether the forces of attraction in a solid are primarily metallic, covalent, network covalent, or ionic based upon the elements' location on the periodic table.

1) What type of attractive force holds or bonds oxygen and magnesium together?

- | | |
|----------------------------|-----------------------|
| a) Ionic bond. (+1) | b) Covalent bond. |
| c) Metallic bond. | d) It does not react. |

C2.1a Explain the changes in potential energy (due to electrostatic interactions) as a chemical bond forms and use this to explain why bond breaking always requires energy.

2) What happens to oxygen when it forms a bond with magnesium?

- | | |
|--|----------------------------|
| a) It gains two electrons. (+1) | b) It loses two electrons. |
| c) It shares 2 electrons. | d) It does not react. |

2b) Use one or two sentences to explain why this results in an attractive force between the atoms.

When the oxygen gains two electrons it becomes **negatively / anion (0.5) charged / ion (0.5)**. When the magnesium loses two electrons it becomes **positively / cation (0.5) charged / ion (0.5)**. The **oppositely charged** ions are now **attracted (1.0)** to each other. (+2)

0.5		0.5		0.5		0.5
negative		positive				attraction
anion		cation				electrostatic force
opposite		charges				force
loses/gains		electrons		more stable		X
				lower energy		X

C4.3e Predict whether the forces of attraction in a solid are primarily metallic, covalent, network covalent, or ionic based upon the elements' location on the periodic table.

3) What type of attractive force holds or bonds carbon and hydrogen together?

- | | |
|-------------------|-------------------------------|
| a) Ionic bond. | b) Covalent bond. (+1) |
| c) Metallic bond. | d) It does not react. |

4) What happens to carbon when it forms a bond with hydrogen?

- | | |
|---|-----------------------------|
| a) It gains four electrons. (+1) | b) It loses four electrons. |
| c) It shares four electrons. | d) It does not react. |

4b) Use one or two sentences to explain why this results in an attractive force between the atoms.

By sharing an electron with each of the four hydrogens, **carbon has eight valence electrons** and each **hydrogen has two valence electrons**. This results in a **more stable, or lower energy, state** that requires energy to break. (+2)

0.5		0.5		0.5		0.5
		eight e ⁻		sharing		electrons
two e ⁻		X				chemical bond
		octet rule				more stable
		full valence level				lower energy

5) What type of attractive force holds or bonds copper and zinc together?

- 6) What happens to copper when it combines with zinc?

- 6b) Use one or two sentences to explain why this results in an attractive force between the atoms. The copper shares two electrons with **other copper and zinc atoms**. The **delocalization** of these electron clouds results in a **more stable, or lower energy, state** that requires energy to break. (+2)

0.5		0.5		0.5		0.5
(loosely) shared e ⁻				delocalization		
				electron sea		
				more stable		X
				lower energy		X

7) Use the periodic table to identify the following elements as either metals or non-metals.

C5.5A Predict if the bonding between two atoms of different elements will be primarily ionic or covalent.

- 8b) Use one or two sentences to explain why this element forms an ionic bond with oxygen.

0.5		0.5		0.5
low electronegativity				Ca loses e^-
low attraction for e^-				becomes positively charged
metallic properties				
large difference in electronegativity				O takes e^-
				becomes negatively charged

9) Which of the following is the correct Lewis diagram for ammonia (NH_3)?

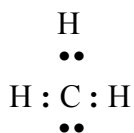
- $$\begin{array}{cccc} \begin{array}{c} \text{a) } \text{H} : \text{N} : \text{H} (+1) \\ \text{H} \end{array} & \begin{array}{c} \text{b) } : \text{H} : \text{N} : \text{H} : \\ \text{H} \end{array} & \begin{array}{c} \text{c) } : \text{N} : \text{H} : \text{H} : \text{H} \end{array} & \begin{array}{c} \text{b) } : \text{H} : \text{N} : \text{H} : \\ : \text{H} : \end{array} \end{array}$$

••

10) Place the correct electron dots around the elements and then show the bonding for the compound.



2 C-O bonds (+0.5)
 2 C-O pi bonds (+0.5)
 2 x 2 lone pairs (+0.5)



4 C-H bonds (+1.0)
 0 lone pairs (+0.5)

C5.5d Compare the relative melting point, electrical and thermal conductivity and hardness for ionic, metallic, and covalent compounds.

In the following matching question each choice may be used more than once and some questions may have more than one answer.

11) Identify the following general characteristics as best describing either

I) ionic substances C) covalent substances M) metallic substances

<u>M</u> solid form conducts electricity (+1)	<u>C</u> does not conduct electricity in solution (+1)
<u>I,M</u> high melting and boiling point (+2)	<u>C</u> solid, liquid or gas at room temperature (+1)
<u>I,M</u> hard solid at room temperature (+2)	<u>I</u> conducts electricity in solution (+1)
<u>M</u> shiny and lustrous appearance (+1)	<u>C</u> low melting and boiling point (+1)

every incorrect answer is negative 0.5 points

(except for high BP and hard solid every incorrect answer is negative 1.0)

C5.5e Relate the melting point, hardness, and electrical and thermal conductivity of a substance to its structure.

12) Explain why an ionic compound, such as NaCl, is not considered a molecule and a covalent compound, such as H₂O, is a molecule. You may use a drawing in your explanation if you choose.

The NaCl is formed by attraction of **any positive Na ion** towards **any negative Cl ion**. The H₂O is formed by the forming of bonds between **one specific O** and **two specific H**. NaCl isn't a molecule because the bonds are not restricted to particular atoms but rather the entire substance. (+3)

0.5		0.5		0.5		0.5
any Na		any Cl		one O		two H
		any Na or Cl				specific H and O
		repeating Na and Cl				units of H and O
Na ⁺ Cl ⁻		X				H-O-H

Appendix D: Metals vs. Non-Metals Activity

name _____
 date _____
 group _____

Metals vs. Non-Metals

Table 8: Metal Element Properties						
<i>metal</i>	color	phase	malleability	conductivity	magnetism	volatility
aluminum						
copper						
iron						
lead						
magnesium						
zinc						

Properties of metal elements:

1. color -
2. phase -
3. malleability -
4. conductivity -
5. magnetism -
6. volatility -

Table 9: Non-Metal Element Properties						
<i>non-metal</i>	color	phase	malleability	conductivity	magnetism	volatility
carbon						
nitrogen						
sulfur						

Properties of non - metal elements:

1. color -
2. phase -
3. malleability -
4. conductivity -
5. magnetism -
6. volatility –

Table 10: Unknown Elements						
unknown	Color	phase	malleability	conductivity	magnetism	volatility
A						
B						
C						
D						
E						
F						

Identify the unknowns as metals or non-metals with a brief explanation. Then find the identity of the unknowns from Mr. Erickson.

	metal / non-metal	identity
A		
B		
C		
D		
E		
F		

Appendix E: Phoenix Lander Case Study

Soil Data from Mars Phoenix Lander

Set Up

The Mars Landers have special equipment that allows them to analyze the soil on Mars in order to determine the composition of the surface, look for signs of water, and determine its suitability for human colonization. Given certain physical properties for a surface sample, what type of composition would you suspect?

Mission Overview

Mars is a cold desert planet with no liquid water on its surface. But in the Martian arctic, water ice lurks just below ground level. Discoveries made by the Mars Odyssey Orbiter in 2002 show large amounts of subsurface water ice in the northern arctic plain. The Phoenix Lander targets this circumpolar region using a robotic arm to dig through the protective top soil layer to the water ice below and ultimately, to bring both soil and water ice to the Lander platform for sophisticated scientific analysis.

The complement of the Phoenix spacecraft and its scientific instruments are ideally suited to uncover clues to the geologic history and biological potential of the Martian arctic. Phoenix will be the first mission to return data from either polar region providing an important contribution to the overall Mars science strategy "Follow the Water" and will be instrumental in achieving the four science goals of NASA's long-term Mars Exploration Program.

--Determine whether Life ever arose on Mars

--Characterize the Climate of Mars

--Characterize the Geology of Mars

--Prepare for Human Exploration

The Phoenix Mission has two bold objectives to support these goals, which are to (1) study the history of water in the Martian arctic and (2) search for evidence of a habitable zone and assess the biological potential of the ice-soil boundary.

Equipment

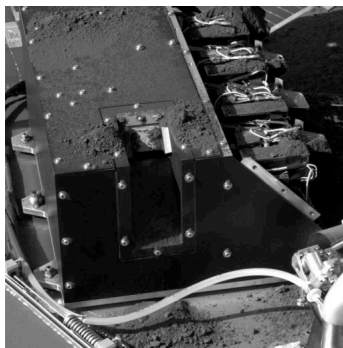


Figure 9: Wet Chemistry Lab (WCL)

http://www.nasa.gov/mission_pages/phoenix/images/press/WCL_delivery_2.html

Conductivity

The Thermal and Electrical Conductivity Probe (TECP) for NASA's Phoenix Mars Lander took measurements in Martian soil and in the air. The needles on the end of the instrument were inserted into the Martian soil, allowing TECP to measure the propagation of both thermal and electrical energy. TECP also measured the humidity in the surrounding air. The needles on the probe are 15 millimeters (0.6 inch) long.

Thermal Gas Evolver

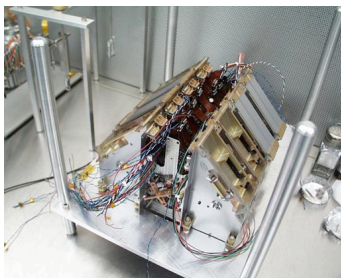


Figure 10: Thermal Evolved Gas Analyzer (TEGA)

www.nasa.gov/mission_pages/phoenix/

TEGA is a combination high-temperature furnace and mass spectrometer instrument that scientists will use to analyze Martian ice and soil samples. The robotic arm will deliver samples to a hopper designed to feed a small amount of soil and ice into eight tiny ovens about the size of an ink cartridge in a ballpoint pen. Each of these ovens will be used only once to analyze eight unique ice and soil samples. Once a sample is successfully received and sealed in an oven, the temperature is slowly increased at a constant rate, and the power required for heating is carefully and continuously monitored. This process, called scanning calorimetry, shows the transitions from solid to liquid to gas of the different materials in the sample: important information needed by scientists to understand the chemical character of the soil and ice. As the temperature of the furnace increases up to 1000°C (1800°F), the ice and other volatile materials in the sample are vaporized into a stream of gases. These are called evolved gases and are transported via an inert carrier to a mass spectrometer, a device used to measure the mass and concentrations of specific molecules and atoms in a sample. The mass spectrometer is sensitive to detection levels down to 10 parts per billion, a level that may detect minute quantities of organic molecules potentially existing in the ice and soil. With these precise measurement capabilities, scientists will be able to determine ratios of various isotopes of hydrogen, oxygen, carbon, and nitrogen, providing clues to origin of the volatile molecules, and possibly, biological processes that occurred in the past.

The TEGA is being built by a team at the University of Arizona, led by Dr. William Boynton and at the University of Texas, Dallas by Dr. John Hoffman. This team has developed several instruments for space flight, including a Differential Scanning Calorimeter (DSC) and Evolved Gas Analyzer (EGA) that flew on the ill-fated Mars Polar Lander, and the Gamma-Ray Spectrometer that is currently flying on the Mars Odyssey Orbiter. The latter instrument is returning data on the elemental composition of Mars and has provided evidence for high concentrations of subsurface ice in the Martian arctic.

Microscopy, Electrochemistry, and Conductivity Analyzer

The Microscopy, Electrochemistry, and Conductivity Analyzer (MECA) characterizes the soil of Mars much like a gardener would test the soil in his or her yard. By dissolving small amounts of soil in water, MECA determines the pH, the abundance of minerals such as magnesium and sodium cations or chloride, bromide and sulfate anions, as well as dissolved oxygen and carbon dioxide. Looking through a microscope, MECA examines the soil grains to help determine their origin and mineralogy. Needles stuck into the soil determine the water and ice content, and the ability of both heat and water vapor to penetrate the soil.

MECA's wet chemistry lab contains four single-use beakers, each of which can accept one sample of Martian soil. Phoenix's Robotic Arm will initiate each experiment by delivering a small soil sample to one beaker, which is ready and waiting with a pre-warmed and calibrated soaking solution. Alternating soaking, stirring, and measuring, the experiment continues for the entire day. It concludes with the addition of two chemical pellets. The first contains an acid to tease out carbonates and other constituents that are only soluble in acidic solutions. The second contains specific reagents to test for sulfates and soil oxidants.

The optical and atomic-force microscopes complement MECA's wet chemistry experiments. With images from these microscopes, scientists will examine the fine detail structure of soil and water ice samples. Detection of hydrous and clay minerals by these microscopes may indicate past liquid water in the Martian arctic. The optical microscope will have a resolution of 4 microns per pixel, allowing detection of particles ranging from about 10 micrometers up to the size of the field of view (about 1 millimeter by 2 millimeters). Red, green, blue, and ultraviolet LEDs will illuminate samples in differing color combinations to enhance the soil and water-ice structure and texture at these scales. The atomic force microscope will provide sample images down to 10 nanometers - the smallest scale ever examined on Mars. Using its sensors, the AFM creates a very small-scale "topographic" map showing the detailed structure of soil and ice grains.

Prior to observation by each of the microscopes, samples are delivered by the Robotic Arm to a wheel containing sixty-nine different substrates. The substrates are designed to distinguish between different adhesion mechanisms and include magnets, sticky polymers, and "buckets" for bulk sampling. The wheel is rotated allowing different substrate-sample interactions to be examined by the microscopes.

MECA's final instrument, the thermal and electrical conductivity probe, will be attached at the "knuckle" of the RA. The probe will probably consist of three small spikes that will be inserted into the ends of an excavated trench. In addition to measuring temperature, the probe will measure thermal properties of the soil that affect how heat is transferred, providing scientists with better understanding of surface and atmospheric interactions. Using the same spikes, the electrical conductivity will be measured to indicate any transient wetness that might result from the excavation. Most likely, the thermal measurement will reflect ice content and the electrical, unfrozen water content.

How could we determine the type of bonding of the Martian geology?

What physical and chemical properties would you expect for ionic, covalent, and metallic compounds?

Practice Data

Sample 1: conductive rock; high melting point,; does not dissolve into water

Type of rock: _____

Sample 2: non-conductive rock; high melting point; partially dissolves into water; electrolyte

Type of rock: _____

Sample 3: non-conductive rock; low melting point; dissolves into water; non-electrolyte

Type of rock: _____

Sample 4: non-conductive rock; high melting point; does not dissolve into water

Type of rock: _____

Unknown Samples

Give a brief explanation of your reasoning.

Sample A:

Type of rock: _____

Sample B:

Type of rock: _____

Sample C:

Type of rock: _____

Sample D:

Type of rock: _____

Sample E:

Type of rock: _____

Sample F:

Type of rock: _____

Conclusion

Temperatures measured on Sol 151, the last day weather data were received, showed overnight lows of minus 128 °Fahrenheit (minus 89 °Celsius) and day time highs in the minus 50 °F (minus 46 °C) range. The last communication from the spacecraft came on Nov. 2, 2008. Michael Hecht, the lead scientist for MECA.

Phoenix's preliminary science accomplishments advance the goal of studying whether the Martian arctic environment has ever been favorable for microbes. Additional findings include documenting a mildly alkaline soil environment unlike any found by earlier Mars missions; finding small concentrations of salts that could be nutrients for life; discovering perchlorate salt, which has implications for ice and soil properties; and finding calcium carbonate, a marker of effects of liquid water. Chemicals such as sodium, magnesium, chloride and potassium were also found.

"Not only did we find water ice, as expected, but the soil chemistry and minerals we observed lead us to believe this site had a wetter and warmer climate in the recent past -- the last few million years -- and could again in the future," said Phoenix Principal Investigator Peter Smith of the University of Arizona, Tucson.

Another surprise from Phoenix was finding ice clouds and precipitation more Earth-like than anticipated. The Lander's Canadian laser instrument for studying the atmosphere detected snow falling from clouds. In one of this week's reports, Jim Whiteway of York University, Toronto, and 22 coauthors say that, further into winter than Phoenix operated, this precipitation would result in a seasonal buildup of water ice on and in the ground.

Appendix F: Ionic, Covalent, and Metallic Lab

Name:
Group Members:

Date:

Ionic, Covalent, and Metallic Lab

Purpose / Objective:

STATEMENT OF THE PROBLEM

The purpose of this lab is to recognize the physical characteristics of ionic, covalent, and metallic substances. Then we will use the physical characteristics to classify several substances as ionic, covalent, or metallic.

Background Information / Definitions / Formulas:

RESEARCH THE PROBLEM

- 1) How can ionic compounds be identified from the formula?
- 2) How can covalent compounds be identified from the formula?
- 3) How can metallic substances be identified from the formula?

Safety Precautions: Keep flammable substances (alcohol, etc.) away from open flames. Wear safety glasses and follow standard safety procedures.

Objectives / Goals:

FORM AN HYPOTHESIS

Indicate whether you think the sample substances are ionic, covalent, or metallic.

Materials:

sample substances
penny
nail
glass plate

aluminum foil
Bunsen burner
ring stand
ring

TEST THE HYPOTHESIS

wire gauze
scintillation vial
conductivity tester

Procedure:

Pre-Lab Procedures

Read through all lab procedures.

Procedures

Hardness

Test the hardness of the solid samples. All liquid and gas substances have a hardness of '0'. If your fingernail can scratch or break the substance then the hardness is 1. If the substance will scratch a penny then the hardness will be 2 or greater. If a nail can scratch the substance then the hardness will be 3 or less. If the substance will scratch glass then the hardness would be 4 or greater. Some substances may not be able to be crushed. Record the hardness.

Table 11: Hardness Scale	
0	liquid or gas
1	fingernail
2	penny or copper
3	nail or iron
4	glass
5	can't be scratched

Volatility / Odor

All gases are volatile. For the liquid and solid substances, use proper wafting technique to test for a detectable odor from your substance. Record how strong the odor was.

Table 12: Volatility / Odor Scale	
0	no detectable odor
1	slight odor
3	strong odor
5	gaseous substance

Melting Point and Boiling Point

Place a small amount (~1g) of your substance in an aluminum tray. Place the tray on wire gauze over a Bunsen burner for a few minutes to observe if the substance will melt or not. As soon as the substance begins to melt or burn, remove the heat. Some substances may not melt even when placed directly in the flame. Record the relative melting point. Record also if the substance burns or oxidizes in the air instead of melting.

Table 13: Melting Point Scale	
0	gas
1	liquid
2	melts on tray
3	melts after min on tray
4	melts directly in flame
5	doesn't melt

Solubility in Water

Mass out 0.1 g of powdered substance and place it in a graduated scintillation vial with 5 mL of distilled water. Cap the vial and shake it to see if the substance will completely dissolve. If it is not completely dissolved, then add water to the 20 mL mark and observe the solubility. It may be completely dissolved, slightly dissolved, or not noticeably dissolved. Record the relative solubility of the substance and save the solution for the next section.

Table 14: Solubility Scale	
0	does not noticeably dissolve
1	slightly soluble in 20 mL
3	soluble in 20 mL
5	soluble in 5 mL

Electrical Conductivity

Use the conductivity tester to determine the conductivity of the substance directly or of the substance in solution. If the substance is not soluble in water indicate if it is conductive or not conductive. If the substance is at least partially soluble in water indicate if the solution is conductive or not conductive. Record the conductivity.

Post-Lab Clean-up

All solid substances should be returned to the materials area. All undissolved powders may be placed in the trashcan. Any solutions may be washed down the sink with excess water.

Ionic, Covalent and Metallic Lab

Table 15: Ionic, Covalent, and Metallic Properties

	Hardness / Volatility	Melting Point	Solubility in Water	Conductivity	Ionic, Covalent, or Metallic
air: nitrogen (N₂), oxygen (O₂), & carbon dioxide (CO₂)	V gaseous 5	very low 0	very soluble 5		
aluminum (Al)	H V				
ascorbic acid (C₆H₈O₆)	H V				
ammonium carbonate ((NH₄)₂CO₃)	H V	X			
brass (Cu and Zn)	H V				
dextrose (C₆H₁₂O₆)	H V				
ethyl alcohol (C₂H₆O)	V	X			
ferric chloride (FeCl₃)	H V				
ferric nitrate (Fe(NO₃)₃)	H V				
gypsum (CaSO₄)	H V				
potassium chloride (KCl)	H V				
shale (SiO₂ and Al₂O₃)	H V				
starch (C₆H₁₀O₅)	H V				
water (H₂O)	V	low 1			
zinc (Zn)	H V				

Graphs and Charts:**ANALYZE THE DATA**

- 1) Which substances were the hardest?
- 2) Which substances melted?
- 3) Which substances were electrolytes?
- 4) Which substances were conductive as solids?

Conclusion:**FORM A CONCLUSION**

- 1) Which of the substances are ionic substances?
- 2) Which of the substances are covalent substances?
- 3) Which of the substances are metallic substances?

Evaluation of Goals / Objective**ACCEPT / REJECT HYPOTHESIS**

- 1) Where your predictions about the type of substances correct?
- 2) What characteristics identify ionic bonds?
- 3) What characteristics identify covalent bonds?
- 4) What characteristics identify metallic bonds?

Appendix

Some ideas for the Ionic, Covalent, and Metallic Lab were taken from the following material found on-line at (Senese, 1999)

- **Electrical conductivity of the compound in aqueous solution.** Ionic compounds conduct electricity when dissolved in water, because the dissociated ions can carry charge through the solution. Molecular compounds don't dissociate into ions and so don't conduct electricity in solution.
- **Electrical conductivity of the compound in liquid form.** Ionic compounds conduct electricity well when melted; metallic solids do as well. Covalent molecular compounds do not, because they usually don't transfer electrons unless they react.
- **Hardness.** Molecular solids are usually much softer than ionic materials. Ionic crystals are harder but often quite brittle. Squeezing an ionic crystal can force ions of like charge in the lattice to slide into alignment; the resulting electrostatic repulsion splits the crystal.
- **Melting points and boiling points.** In an ionic compound, the forces of attraction between positive and negative ions are strong and high temperatures are required to overcome them. The melting and boiling points of ionic compounds are usually very high. A smaller amount of energy is required to overcome the weak attractions between covalent molecules, so these compounds melt and boil at much lower temperatures than metallic and ionic compounds do. In fact, many compounds in this class are liquids or gases at room temperature.
- **Enthalpies of fusion and vaporization** The enthalpy of fusion is the amount of heat required to melt one mole of the compound in solid form, under constant pressure. The enthalpy of vaporization is the amount of heat required to vaporize one mole of the compound in liquid form, under constant pressure. These properties are typically 10 to 100 times smaller for molecular compounds than they are for ionic compounds.

Author: [Fred Senese senese@antoine.frostburg.edu](mailto:senese@antoine.frostburg.edu)

Appendix G: Molecular Models Lab

Name:
Group Members:

Date:

Molecular Model Lab

Purpose / Objective:

STATEMENT OF THE PROBLEM

The purpose of this lab is to use ball and stick models to represent several examples of covalent compounds and correctly predict the structure and polarity of the molecule.

Background Information / Definitions / Formulas:

RESEARCH THE PROBLEM

Group IV elements are **black spheres** with **4 holes** for bonding.

Group V elements are **blue spheres** with **3 holes** for bonding. (Some of the spheres may have 4 or 5 holes instead. These are extra for a different activity and only 3 holes should be used.)

Group VI elements are **red spheres** with **2 holes** for bonding.

Group VII elements are **purple, orange, green spheres** with **1 hole** for bonding.

Hydrogen atoms are the **yellow spheres** with **1 hole** for bonding.

Wooden sticks are for **bonds**. You may use them interchangeably or the shorter ones for bonds with hydrogen. **Metal springs** are for **double bonds** and should be used in pairs

Safety Precautions: No special safety precautions are required.

Objectives / Goals:

FORM AN HYPOTHESIS

I predict that the sample molecule is _____.

Materials:

TEST THE HYPOTHESIS

1 box of molecular models.

Procedure:

Pre-Lab Procedures

Remember the arrangement of the stored balls and sticks.

Procedures

For each of the given formulas build a model of the molecule. After having completed the model molecule, make a sketch of the molecule in the given box on the data sheet. The sketch should show the arrangement of the bonds and shape of the molecule. Be sure to designate single or double bonds and label the name of the element for each atom. You may be asked to have a certain number of completed models checked off during class.

Post-Lab Clean-up

Replace the balls and sticks to their correct places in the boxes. Return the complete molecule kits where they belong.

Data Table for Regular Classes

Data Tables:

COLLECT THE DATA

Table 16: Table of Covalent Molecules				
HF	polar / non-polar		H ₂ O	polar / non-polar
NH ₃	polar / non-polar		CH ₄	polar / non-polar
BrF	polar / non-polar		O ₂	polar / non-polar
N ₂	polar / non-polar		C ₄ H ₈	polar / non-polar
C ₂ H ₄ Cl ₂	polar / non-polar			polar / non-polar

Data Table for Regular Classes

Graphs and Charts:

ANALYZE THE DATA

- 1) Which molecules have double bonds?
- 2) Which molecules are polar?

Conclusion:

FORM A CONCLUSION

- 1) What is an example of a molecule with polar bonds that is non-polar?
- 2) What is a possible formula for the example molecule?

Evaluation of Goals / Objective

ACCEPT / REJECT HYPOTHESIS

- 1) What is the formula of the example molecule and was your hypothesis correct?

Data Table for Honors Classes

Data Tables:

COLLECT THE DATA

Table 17: Table of Covalent Molecules (Honors)				
N ₂	polar / non-polar		O ₂	polar / non-polar
S ₈	polar / non-polar		ICl	polar / non-polar
CO ₂	polar / non-polar		SF ₂	polar / non-polar
PH ₃	polar / non-polar		C ₂ H ₂	polar / non-polar
N ₂ F ₂	polar / non-polar		C ₂ H ₄	polar / non-polar

Data Table for Honors Classes

Table 17: Table of Covalent Molecules (cont.)				
CH ₂ CCH ₂	polar / non-polar		HNO ₂	polar / non-polar
CH ₂ O	polar / non-polar		CHCl ₃	polar / non-polar
C ₆ H ₁₂ O ₆	polar / non-polar			polar / non-polar

Graphs and Charts:

ANALYZE THE DATA

1) Which molecules have double bonds?

2) Which molecules are polar?

Conclusion:

FORM A CONCLUSION

1) What is an example of a molecule with polar bonds that is non-polar?

2) What is a possible formula for the example molecule?

Evaluation of Goals / Objective

ACCEPT / REJECT HYPOTHESIS

1) What is the formula of the example molecule and was your hypothesis correct?

Appendix H: Molecular Analysis Case Study

Analysis of Commonly Known Compounds

Pictures of Unknown Substances

Figure 11: Corundum



Figure 12: Lye



Figure 13: Pewter



Figure 14: Triinitrotoluene



Analysis of Commonly Known Compounds

Below is a list of the formulas of some commonly known compounds. Each compound also has a matching description of the properties of that compound. For some of these substances an uncommon name has been used to make the identification a little more challenging.

A. CH_3COCH_3

B. Al_2O_3

C. 93% Ag, 6% Sb, and 1% Cu

D. C_3H_8

E. NaOH

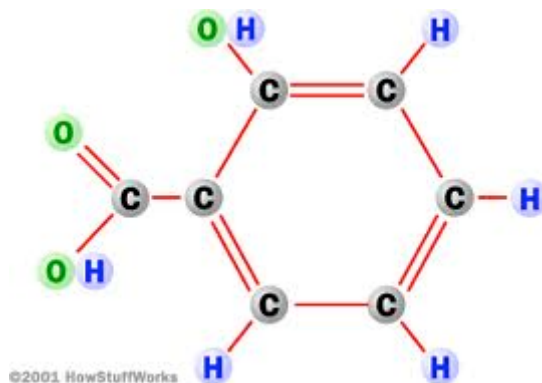
F. $\text{C}_7\text{H}_5\text{N}_3\text{O}_6$

Give the matching formula for each of the following descriptions. With the formula identify the substance as ionic, covalent, or metallic. For the covalent substances, identify if the substance is polar or non-polar as well. Give at least one reason for your identification (i.e. high melting point, conductive, etc.)

1. Corundum is an electrical insulator but has a relatively high thermal conductivity for a ceramic material. Its hardness makes it suitable for use as an abrasive and as a component in cutting tools.
2. Ethane is a colorless and odorless gas. It is isolated from natural gas and is a byproduct of petroleum refining. It has a melting point of -182°C and a boiling point of -89°C .
3. Lye is available as a coarse powder or as flakes. It is also available as a solution dissolved in water and is used in soaps and detergents. Lye also contains a polyatomic ion.
4. Pewter is a malleable alloy with a melting point around 200°C . It is a relatively easy material to cast and has been used in the production of various objects.
5. Propanone is a colorless flammable liquid that mixes with water. It is an important solvent and often used for cleaning in some industrial settings.
6. Triinitrotoluene, or TNT, is a yellow-colored solid best known as a useful explosive material with convenient handling properties. It melts at 80°C allowing it to be poured as well as safely combined with other explosives. It neither absorbs nor dissolves in water.

Aspirin is an analgesic used to relieve minor aches and pains and an antipyretic used to reduce fever, and as an anti-inflammatory. It is a white, crystalline substance with a melting point of 135°C. It is somewhat soluble in water. Answer the following questions using the structural formula of aspirin given below.

Figure 15: Lewis Structure of Aspirin



7. Give the formula for this substance and use the ball and stick models to create this compound.
8. Is this a polar or non-polar compound?
9. How many pi bonds does this compound contain?
10. What is the hybridization of the carbon atoms in this compound?
11. What is the hybridization of the oxygen atoms in this compound?

Appendix I: List of Sample Ionic, Covalent, and Metallic Substances

List of Sample Ionic, Covalent, and Metallic Substances

IONIC COMPOUNDS

Samples

carbonates: calcium carbonate, ammonium bicarbonate

nitrates: aluminum nitrate, calcium nitrate, potassium nitrate, cupric nitrate hydrate, ferric nitrate hydrate, silver nitrate, ammonium nitrate

phosphates: potassium phosphate hydrate monobasic

hydroxides: sodium hydroxide, manganese dioxide

sulfates: aluminum sulfate hydrate, calcium sulfate, potassium sulfate, sodium sulfate, manganese sulfate hydrate, cupric sulfate hydrate, ferric sulfate, ammonium sulfate

chlorides: barium chloride, cupric chloride hydrate, ferric chloride hydrate, cobalt chloride hydrate, manganese chloride hydrate, ammonium chloride, potassium chlorate

others: potassium ferricyanide, potassium permanganate, potassium chromate, potassium dichromate hydrate, ammonium dichromate, sodium acetate, lead acetate, silica gel, slate, mica, quartz

COVALENT COMPOUNDS

Sample Solids

Elements: **carbon**, **sulfur**, iodine

Compounds: dextrose, starch, methyl red sodium salt, methyl orange sodium salt, analine yellow, ascorbic acid, malachite green, acid violet, Trypan blue

Sample Liquids

Compounds: water, methanol, acetone, isopropyl alcohol

Sample Gases

Elements: nitrogen, oxygen

Compounds: carbon dioxide, methane

METALLIC COMPOUNDS

Samples

Elements: **aluminum**, **copper**, **tin**, **zinc**, **lead**, molybdenum, tungsten

Alloys: **brass**, mild steel, **stainless steel**

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