

AP Test Review**BIG IDEA 2: PROPERTIES****Essential Knowledge****2. Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.**

Transformations of matter can be observed in multiple ways that are generally categorized as either chemical or physical change. These categories can generally be distinguished through consideration of the electrostatic (Coulombic) forces that are associated with a given change at the particulate level. The strength of such forces falls along a continuum, with the strongest forces generally being chemical bonds. Chemical changes involve the making and breaking of chemical bonds. For physical changes, the forces being overcome are weaker intermolecular interactions, which are also Coulombic in nature. The shapes of the particles involved, and the space between them, are key factors in determining the nature of these physical changes. Using only these general concepts of varying strengths of chemical bonds and weaker intermolecular interactions, many properties of a wide range of chemical systems can be understood.

2.A. Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.

There is a relationship between the macroscopic properties of solids, liquids, and gases, and the structure of the constituent particles of those materials on the molecular and atomic scale. The properties of solids, liquids, and gases also reflect the relative orderliness of the arrangement of particles in those states, their relative freedom of motion, and the nature and strength of the interactions between them. For gases, volumetric relationships can be used to describe ideal behavior, and a conceptual understanding of that behavior can be constructed based on the atomic model and a relatively simple kinetic molecular theory (KMT).

Solutions are an important class of mixtures; of particular importance is a conceptual understanding on the molecular level of the structure and composition of a liquid solution. In addition, the energetics of solution formation can be understood qualitatively through consideration of the interactions and structure of the components before and after the creation of the solution.

- 2.A.1. The different properties of solids and liquids can be explained by differences in their structures, both at the particulate level and in their supramolecular structures.
- Solids can be crystalline, where the particles are arranged in a regular 3-D structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo any overall translation with respect to each other. Inter-particle interactions and the ability to pack the particles together provide the main criteria for the structures of solids.
 - The constituent particles in liquids are very close to each other, and they are continually moving and colliding. The particles are able to undergo translation with respect to each other and their arrangement, and movement is influenced by the nature and strength of the intermolecular forces that are present.
 - The solid and liquid phases for a particular substance generally have relatively small differences in molar volume because in both cases the constituent particles are very close to each other at all times.
 - The differences in other properties, such as viscosity, surface tension, and volumes of mixing (for liquids), and hardness and macroscopic crystal structure (for solids), can be explained by differences in the strength of attraction between the particles and/or their overall organization.

- e. Heating and cooling curves for pure substances provide insight into the energetics of liquid/solid phase changes.
- 2.A.2. The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
- a. Ideal gases exhibit specific mathematical relationships among the number of particles present, the temperature, the pressure, and the volume.
 - b. In a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the total pressure is the sum of the partial pressures.
 - c. Graphical representations of the relationships between P, V, and T are useful to describe gas behavior.
 - d. Kinetic molecular theory combined with a qualitative use of the Maxwell-Boltzmann distribution provides a robust model for qualitative explanations of these mathematical relationships.
 - e. Some real gases exhibit ideal or near-ideal behavior under typical laboratory conditions. Laboratory data can be used to generate or investigate the relationships in 2.A.2.a and to estimate absolute zero on the Celsius scale.
 - f. All real gases are observed to deviate from ideal behavior, particularly under conditions that are close to those resulting in condensation. Except at extremely high pressures that are not typically seen in the laboratory, deviations from ideal behavior are the result of intermolecular attractions among gas molecules. These forces are strongly distance-dependent, so they are most significant during collisions.
 - g. Observed deviations from ideal gas behavior can be explained through an understanding of the structure of atoms and molecules and their intermolecular interactions.
- 2.A.3. Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.
- a. In a solution (homogeneous mixture), the macroscopic properties do not vary throughout the sample. This is in contrast to a heterogeneous mixture in which the macroscopic properties depend upon the location in the mixture. The distinction between heterogeneous and homogeneous depends on the length scale of interest. As an example, colloids may be heterogeneous on the scale of micrometers, but homogeneous on the scale of centimeters.
 - b. Solutions come in the form of solids, liquids, and gases.
 - c. For liquid solutions, the solute may be a gas, a liquid, or a solid.
 - d. Based on the reflections of their structure on the microscopic scale, liquid solutions exhibit several general properties:
 - 1. The components cannot be separated by using filter paper.
 - 2. There are no components large enough to scatter visible light.
 - 3. The components can be separated using processes that are a result of the intermolecular interactions between and among the components.
 - e. Chromatography (paper and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components.
 - f. Distillation is used to separate chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.
 - g. The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/inter-particle interactions before and after the dissolution process.
 - h. Generally, when ionic compounds are dissolved in water, the component ions are separated and dispersed. The presence of ions in a solution can be detected by use of conductivity measurements.
 - i. Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory. Molarity is defined as the number of moles of solute per liter of solution.

- j. Understanding how to prepare solutions of specified molarity through direct mixing of the components, through use of volumetric glassware, and by dilution of a solution of known molarity with additional solvent is important for performing laboratory work in chemistry.

2.B. Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.

Chemists categorize intermolecular interactions based on the structural features giving rise to the interaction. Although there are some trends in the relative strengths of these interactions, the specific structure and size of the particles involved can play a very important role in determining the overall strength of a particular intermolecular (or intramolecular) interaction. The properties of condensed phases and of many crucial biological structures are determined by the nature and strength of these interactions. Deviation from ideal gas behavior is generally a reflection of the presence of intermolecular interactions between gas particles. Thus, in all phases, the structure of particles on the molecular level is directly related to the properties of both the particles themselves and the behavior of macroscopic collections of those molecules.

- 2.B.1. London dispersion forces are attractive forces present between all atoms and molecules. London dispersion forces are often the strongest net intermolecular force between large molecules.
 - a. A temporary, instantaneous dipole may be created by an uneven distribution of electrons around the nucleus (nuclei) of an atom (molecule).
 - b. London dispersion forces arise due to the Coulombic interaction of the temporary dipole with the electron distribution in neighboring atoms and molecules.
 - c. Dispersion forces increase with contact area between molecules and with increasing polarizability of the molecules. The polarizability of a molecule increases with the number of electrons in the molecule, and is enhanced by the presence of pi bonding.
- 2.B.2. Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force.
 - a. Molecules with dipole moments experience Coulombic interactions that result in a net attractive interaction when they are near each other.
 - 1. Intermolecular dipole-dipole forces are weaker than ionic forces or covalent bonds.
 - 2. Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force that exists when very electronegative atoms (N, O, and F) are involved.
 - 3. Dipole-dipole attractions can be represented by diagrams of attraction between the positive and negative ends of polar molecules trying to maximize attractions and minimize repulsions in the liquid or solid state.
 - 4. Dipole-induced dipole interactions are present between a polar and nonpolar molecule. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.
 - b. Hydrogen bonding is a relatively strong type of intermolecular interaction that exists when hydrogen atoms that are covalently bonded to the highly electronegative atoms (N, O, and F) are also attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule or a different part of the same molecule. When hydrogen bonding is present, even small molecules may have strong intermolecular attractions.
 - c. Hydrogen bonding between molecules, or between different parts of a single molecule, may be represented by diagrams of molecules with hydrogen bonding and indications of location of hydrogen bonding.
 - d. Ionic interactions with dipoles are important in the solubility of ionic compounds in polar solvents.

- 2.B.3. Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
- Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present.
 - Boiling point
 - Surface tension
 - Capillary action
 - Vapor pressure
 - Substances with similar intermolecular interactions tend to be miscible or soluble in one another.
 - The presence of intermolecular forces among gaseous particles, including noble gases, leads to deviations from ideal behavior, and it can lead to condensation at sufficiently low temperatures and/or sufficiently high pressures.
 - Graphs of the pressure-volume relationship for real gases can demonstrate the deviation from ideal behavior; these deviations can be interpreted in terms of the presence and strengths of intermolecular forces.
 - The structure and function of many biological systems depend on the strength and nature of the various Coulombic forces.
 - Substrate interactions with the active sites in enzyme catalysis
 - Hydrophilic and hydrophobic regions in proteins that determine three-dimensional structure in water solutions

2.C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Covalent bonds, ionic bonds, and metallic bonds are distinct from (and significantly stronger than) typical intermolecular interactions. Electronegativity can be used to reason about the type of bonding present between two atoms. Covalent chemical bonds can be modeled as the sharing of one or more pairs of valence electrons between two atoms in a molecule. The extent to which this sharing is unequal can be predicted from the relative electronegativities of the atoms involved; the relative electronegativities can generally be understood through application of the shell model and Coulomb's Law. The Lewis structure model, combined with valence shell electron pair repulsion (VSEPR), can be used to predict many structural features of covalently bonded molecules and ions. Ionic bonding is the phrase used to describe the strong Coulombic interaction between ions in an ionic substance. The bonding in metals is characterized by delocalization of valence electrons.

- 2.C.1. In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.
- Electronegativity is the ability of an atom in a molecule to attract shared electrons to it.
 - Electronegativity values for the representative elements increase going from left to right across a period and decrease going down a group. These trends can be understood qualitatively through the electronic structure of the atoms, the shell model, and Coulomb's Law.
 - Two or more valence electrons shared between atoms of identical electronegativity constitute a nonpolar covalent bond.

- d. However, bonds between carbon and hydrogen are often considered to be nonpolar even though carbon is slightly more electronegative than hydrogen. The formation of a nonpolar covalent bond can be represented graphically as a plot of potential energy vs. distance for the interaction of two identical atoms. Hydrogen atoms are often used as an example.
 - 1. The relative strengths of attractive and repulsive forces as a function of distance determine the shape of the graph.
 - 2. The bond length is the distance between the bonded atoms' nuclei, and is the distance of minimum potential energy where the attractive and repulsive forces are balanced.
 - 3. The bond energy is the energy required for the dissociation of the bond. This is the net energy of stabilization of the bond compared to the two separated atoms. Typically, bond energy is given on a per mole basis.
- e. Two or more valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond.
 - 1. The difference in electronegativity for the two atoms involved in a polar covalent bond is not equal to zero.
 - 2. The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond. For diatomic molecules, the partial negative charge on the more electronegative atom is equal in magnitude to the partial positive charge on the less electronegative atom.
 - 3. Greater differences in electronegativity lead to greater partial charges, and consequently greater bond dipoles.
 - 4. The sum of partial charges in any molecule or ion must be equal to the overall charge on the species.
- f. All bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum. The difference in electronegativity is not the only factor in determining if a bond is designated ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and between two nonmetals the bonds are covalent. Examination of the properties of a compound is the best way to determine the type of bonding.

2.C.2. Ionic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.

- a. The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.
- b. Coulomb's Law describes the force of attraction between the cations and anions in an ionic crystal.
 - 1. Because the force is proportional to the charge on each ion, larger charges lead to stronger interactions.
 - 2. Because the force is inversely proportional to the square of the distance between the centers of the ions (nuclei), smaller ions lead to stronger interactions.

2.C.3. Metallic bonding describes an array of positively charged metal cores surrounded by a sea of mobile valence electrons.

- a. The valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.
- b. Metallic bonding can be represented as an array of positive metal ions with valence electrons drawn among them, as if the electrons were moving (i.e., a sea of electrons).
- c. The electron sea model can be used to explain several properties of metals, including electrical conductivity, malleability, ductility, and low volatility.
- d. The number of valence electrons involved in metallic bonding, via the shell model, can be used to understand patterns in these properties, and can be related to the shell model to reinforce the connections between metallic bonding and other forms of bonding.

- 2.C.4. The localized electron bonding model describes and predicts molecular geometry using Lewis diagrams and the VSEPR model.
- Lewis diagrams can be constructed according to a well-established set of principles.
 - The VSEPR model uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom.
 - In cases where more than one equivalent Lewis structure can be constructed, resonance must be included as a refinement to the Lewis structure approach in order to provide qualitatively accurate predictions of molecular structure and properties (in some cases).
 - Formal charge can be used as a criterion for determining which of several possible valid Lewis diagrams provides the best model for predicting molecular structure and properties.
 - The combination of Lewis diagrams with the VSEPR model provides a powerful model for predicting structural properties of many covalently bonded molecules and polyatomic ions, including the following:
 - Molecular geometry
 - Bond angles
 - Relative bond energies based on bond order
 - Relative bond lengths (multiple bonds, effects of atomic radius)
 - Presence of a dipole moment
 - As with any model, there are limitations to the use of the Lewis structure model, particularly in cases with an odd number of valence electrons. Recognizing that Lewis diagrams have limitations is of significance.
 - Organic chemists commonly use the terms “hybridization” and “hybrid orbital” to describe the arrangement of electrons around a central atom. When there is a bond angle of 180° , the central atom is said to be sp hybridized; for 120° , the central atom is sp^2 hybridized; and for 109° , the central atom is sp^3 hybridized. Students should be aware of this terminology, and be able to use it. When an atom has more than four pairs of electrons surrounding the central atom, students are only responsible for the shape of the resulting molecule.
 - Bond formation is associated with overlap between atomic orbitals. In multiple bonds, such overlap leads to the formation of both sigma and pi bonds. The overlap is stronger in sigma than pi bonds, which is reflected in sigma bonds having larger bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond, and leads to structural isomers. In systems, such as benzene, where atomic p-orbitals overlap strongly with more than one other p-orbital, extended pi bonding exists, which is delocalized across more than two nuclei. Such descriptions provide an alternative description to resonance in Lewis structures. A useful example of delocalized pi bonding is molecular solids that conduct electricity. The discovery of such materials at the end of the 1970s overturned a long-standing assumption in chemistry that molecular solids will always be insulators.
 - Molecular orbital theory describes covalent bonding in a manner that can capture a wider array of systems and phenomena than the Lewis or VSEPR models. Molecular orbital diagrams, showing the correlation between atomic and molecular orbitals, are a useful qualitative tool related to molecular orbital theory.

2.D. The type of bonding in the solid state can be deduced from the properties of the solid state.

In solids, the properties of the material reflect the nature and strength of the interactions between the constituent particles. For this reason, the type of bonding that predominates in a solid material, and the nature of the interactions between the particles comprising the solid, can generally be inferred from the observed macroscopic properties of the material. Properties such as vapor pressure, conductivity as a solid and in aqueous solution, and relative brittleness or hardness can generally be explained in this way. Although recognizing the properties that can be associated with a particular type of bonding is valuable in categorizing materials, relating those properties to the structure of the materials on the molecular scale, and being able to make reasoned predictions of the properties of a solid based on its constituent particles, provides evidence of deeper conceptual understanding.

- 2.D.1. Ionic solids have high melting points, are brittle, and conduct electricity only when molten or in solution.
- a. Many properties of ionic solids are related to their structure.
 1. Ionic solids generally have low vapor pressure due to the strong Coulombic interactions of positive and negative ions arranged in a regular three-dimensional array.
 2. Ionic solids tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer.
 3. Ionic solids do not conduct electricity. However, when ionic solids are melted, they do conduct electricity because the ions are free to move.
 4. When ionic solids are dissolved in water, the separated ions are free to move; therefore, these solutions will conduct electricity. Dissolving a non-conducting solid in water, and observing the solution's ability to conduct electricity, is one way to identify an ionic solid.
 5. Ionic compounds tend not to dissolve in nonpolar solvents because the attractions among the ions are much stronger than the attractions among the separated ions and the nonpolar solvent molecules.
 - b. The attractive force between any two ions is governed by Coulomb's Law: The force is directly proportional to the charge of each ion and inversely proportional to the square of the distance between the centers of the ions.
 1. For ions of a given charge, the smaller the ions, and thus the smaller the distance between ion centers, the stronger the Coulombic force of attraction, and the higher the melting point.
 2. Ions with higher charges lead to higher Coulombic forces, and therefore higher melting points.
- 2.D.2. Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.
- a. A metallic solid can be represented as positive kernels (or cores) consisting of the nucleus and inner electrons of each atom surrounded by a sea of mobile valence electrons.
 1. Metals are good conductors because the electrons are delocalized and relatively free to move.
 2. Metals are malleable and ductile because deforming the solid does not change the environment immediately surrounding each metal core.
 - b. Metallic solids are often pure substances, but may also be mixtures called alloys.
 1. Some properties of alloys can be understood in terms of the size of the component atoms: —
Interstitial alloys form between atoms of different radius, where the smaller atoms fill the interstitial spaces between the larger atoms. (Steel is an example in which carbon occupies the interstices in iron.) The interstitial atoms do not appreciably expand the lattice, so the density is often substantially increased. The interstitial atoms make the lattice more rigid, decreasing malleability and ductility. —
Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (Brass is an example in which some copper atoms are substituted with a different element, usually zinc.) The density typically lies between those of the component metals, as with interstitial alloys, substitutional alloys are less malleable and ductile than pure metals.
 2. Alloys typically retain a sea of mobile electrons and so remain conducting.
 3. Often the surface of a metal or alloy is changed through a chemical reaction. An example is formation of a chemically inert oxide layer in stainless steel, through reaction with oxygen in the air.

- 2.D.3. Covalent network solids have properties that reflect their underlying 2-D or 3-D network of covalent bonds. Covalent network solids generally have extremely high melting points, and are hard.
- a. Covalent network solids consist of atoms that are covalently bonded together into a two-dimensional or three-dimensional network.
 1. Covalent network solids are only formed from nonmetals: elemental (diamond, graphite) or two nonmetals (silicon dioxide and silicon carbide).
 2. The properties of covalent network solids are a reflection of their structure.
 3. Covalent network solids have high melting points because all of the atoms are covalently bonded.
 4. Three-dimensional covalent networks tend to be rigid and hard because the covalent bond angles are fixed.
 5. Generally, covalent network solids form in the carbon group because of their ability to form four covalent bonds.
 - b. Graphite is an allotrope of carbon that forms sheets of two-dimensional networks.
 1. Graphite has a high melting point because the covalent bonds between the carbon atoms making up each layer are relatively strong.
 2. Graphite is soft because adjacent layers can slide past each other relatively easily; the major forces of attraction between the layers are London dispersion forces.
 - c. Silicon is a covalent network solid and a semiconductor.
 1. Silicon forms a three-dimensional network similar in geometry to a diamond.
 2. Silicon's conductivity increases as temperature increases.
 3. Periodicity can be used to understand why doping with an element with one extra valence electron converts silicon into an n-type semiconducting (negative charge carrying) material, while doping with an element with one less valence electron converts silicon into a p-type semiconducting (positive charge carrying) material. Junctions between n-doped and p-doped materials can be used to control electron flow, and thereby are the basis of modern electronics.
- 2.D.4. Molecular solids with low molecular weight usually have low melting points and are not expected to conduct electricity as solids, in solution, or when molten.
- a. Molecular solids consist of nonmetals, diatomic elements, or compounds formed from two or more nonmetals.
 - b. Molecular solids are composed of distinct, individual units of covalently bonded molecules attracted to each other through relatively weak intermolecular forces.
 1. Molecular solids are not expected to conduct electricity because their electrons are tightly held within the covalent bonds of each constituent molecule.
 2. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules.
 3. Molecular solids are sometimes composed of very large molecules, or polymers, with important commercial and biological applications.

Learning Objectives

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| 2.1 Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. | Big Idea 2 |
| 2.2 The student is able to explain the relative strengths of acids and bases based on molecular structure, inter-particle forces, and solution equilibrium. | Big Idea 2 |
| 2.3 The student is able to use aspects of particulate models (i.e., particle spacing, motion, and forces of attraction) to reason about observed differences between solid and liquid phases and among solid and liquid materials. | EK 2.A.1 |
| 2.4 The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and non-ideal behaviors. | EK 2.A.2 |
| 2.5 The student is able to refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample. | EK 2.A.2 |
| 2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. | EK 2.A.2 |
| 2.7 The student is able to explain how solutes can be separated by chromatography based on intermolecular interactions. | EK 2.A.3 |
| 2.8 The student can draw and/or interpret representations of solutions that show the interactions between the solute and solvent. | EK 2.A.3 |
| 2.9 The student is able to create or interpret representations that link the concept of molarity with particle views of solutions. | EK 2.A.3 |
| 2.10 The student can design and/or interpret the results of a separation experiment (filtration, paper chromatography, column chromatography, or distillation) in terms of the relative strength of interactions among and between the components. | EK 2.A.3 |
| 2.11 The student is able to explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces. | EK 2.B.1 |
| 2.12 The student can qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions. | EK 2.B.2 |
| 2.13 The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles. | EK 2.B.2 |
| 2.14 The student is able to apply Coulomb's Law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds. | EK 2.B.2 |
| 2.15 The student is able to explain observations regarding the solubility of ionic solids and molecules in water and other solvents on the basis of particle views that include intermolecular interactions and entropic effects. | EK 2.B.3 |
| 2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces. | EK 2.B.3 |

2.17	The student can predict the type of bonding present between two atoms in a binary compound based on position in the periodic table and the electronegativity of the elements.	EU 2.C
2.18	The student is able to rank and justify the ranking of bond polarity on the basis of the locations of the bonded atoms in the periodic table.	EK 2.C.1
2.19	The student can create visual representations of ionic substances that connect the microscopic structure to macroscopic properties, and/or use representations to connect the microscopic structure to macroscopic properties (e.g., boiling point, solubility, hardness, brittleness, low volatility, lack of malleability, ductility, or conductivity).	EK 2.C.2
2.20	The student is able to explain how a bonding model involving delocalized electrons is consistent with macroscopic properties of metals (e.g., conductivity, malleability, ductility, and low volatility) and the shell model of the atom.	EK 2.C.3
2.21	The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity.	EK 2.C.4
2.22	The student is able to design or evaluate a plan to collect and/or interpret data needed to deduce the type of bonding in a sample of a solid.	EU 2.D
2.23	The student can create a representation of an ionic solid that shows essential characteristics of the structure and interactions present in the substance.	EK 2.D.1
2.24	The student is able to explain a representation that connects properties of an ionic solid to its structural attributes and to the interactions present at the atomic level.	EK 2.D.1
2.25	The student is able to compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning.	EK 2.D.2
2.26	Students can use the electron sea model of metallic bonding to predict or make claims about the macroscopic properties of metals or alloys.	EK 2.D.2
2.27	The student can create a representation of a metallic solid that shows essential characteristics of the structure and interactions present in the substance.	EK 2.D.2
2.28	The student is able to explain a representation that connects properties of a metallic solid to its structural attributes and to the interactions present at the atomic level.	EK 2.D.2
2.29	The student can create a representation of a covalent solid that shows essential characteristics of the structure and interactions present in the substance.	EK 2.D.3
2.30	The student is able to explain a representation that connects properties of a covalent solid to its structural attributes and to the interactions present at the atomic level.	EK 2.D.3
2.31	The student can create a representation of a molecular solid that shows essential characteristics of the structure and interactions present in the substance.	EK 2.D.4
2.32	The student is able to explain a representation that connects properties of a molecular solid to its structural attributes and to the interactions present at the atomic level.	EK 2.D.4

AP Test Review

FREE RESPONSE PRACTICE

Abide by the time guidelines. Use only (1) a black or blue pen or No. 2 pencil, (2) a scientific or graphing calculator, and (3) the provided Periodic Table and list of Equations and Constants.

Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved at arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored.

2014 AP Chemistry #5 (9 minutes)

Nonmetal	C	N	O	Ne	Si	P	S	Ar
Formula of Compound	CF ₄	NF ₃	OF ₂	No compound	SiF ₄	PF ₃	SF ₂	No compound

Some binary compounds that form between fluorine and various nonmetals are listed in the table above. A student examines the data in the table and poses the following hypothesis: the number of F atoms that will bond to a nonmetal is always equal to 8 minus the number of valence electrons in the nonmetal atom.

- (a) Based on the student's hypothesis, what should be the formula of the compound that forms between chlorine and fluorine?
- (b) In an attempt to verify the hypothesis, the student researches the fluoride compounds of the other halogens and finds the formula ClF₃. In the box below, draw a complete Lewis electron-dot diagram for a molecule of ClF₃.



- (c) Two possible geometric shapes for the ClF₃ molecule are trigonal planar and T-shaped. The student does some research and learns that the molecule has a dipole moment. Which of the two shapes is consistent with the fact that the ClF₃ molecule has a dipole moment? Justify your answer in terms of bond polarity and molecular structure.

In an attempt to resolve the existence of the ClF₃ molecule with the hypothesis stated above, the student researches the compounds that form between halogens and fluorine, and assembles the following list.

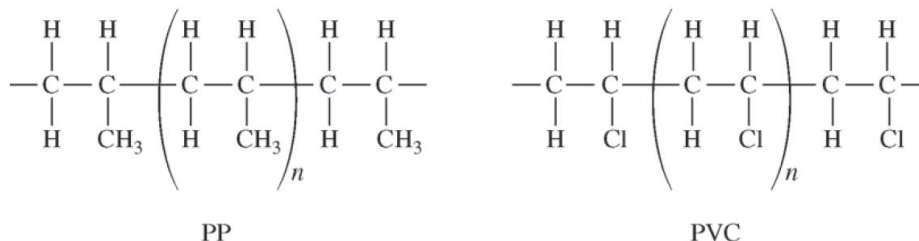
Halogen	Formula(s)
F	F ₂
Cl	
Br	BrF, BrF ₃ , BrF ₅
I	IF, IF ₃ , IF ₅ , IF ₇

- (d) Based on concepts of atomic structure and periodicity, propose a modification to the student's previous hypothesis to account for the compounds that form between halogens and fluorine.

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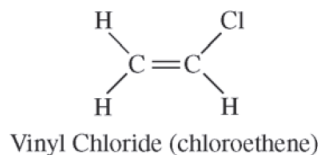
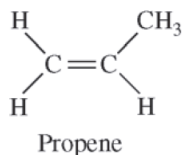
2014 AP Chemistry #6 (9 minutes)

A student places a mixture of plastic beads consisting of polypropylene (PP) and polyvinyl chloride (PVC) in a 1.0 L beaker containing distilled water. After stirring the contents of the beaker vigorously, the student observes that the beads of one type of plastic sink to the bottom of the beaker and the beads of the other type of plastic float on the water. The chemical structures of PP and PVC are represented by the diagrams below, which show segments of each polymer.



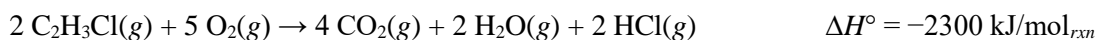
- (a) Given that the spacing between polymer chains in PP and PVC is similar, the beads that sink are made of which polymer? Explain.

PP is synthesized from propene, C_3H_6 , and PVC is synthesized from vinyl chloride, $\text{C}_2\text{H}_3\text{Cl}$. The structures of the molecules are shown below.



- (b) The boiling point of liquid propene (226 K) is lower than the boiling point of liquid vinyl chloride (260 K). Account for this difference in terms of the types and strengths of intermolecular forces present in each liquid.

In a separate experiment, the student measures the enthalpies of combustion of propene and vinyl chloride. The student determines that the combustion of 2.00 mol of vinyl chloride releases 2300 J of energy, according to the equation below.



- (c) Using the table of standard enthalpies of formation below, determine whether the combustion of 2.00 mol of propene releases more, less, or the same amount of energy that 2.00 mol of vinyl chloride releases. Justify your answer with a calculation. The balanced equation for the combustion of 2.00 mol of propene is $2 \text{C}_3\text{H}_6(g) + 9 \text{O}_2(g) \rightarrow 6 \text{CO}_2(g) + 6 \text{H}_2\text{O}(g)$.

Substance	$\text{C}_2\text{H}_3\text{Cl}(g)$	$\text{C}_3\text{H}_6(g)$	$\text{CO}_2(g)$	$\text{H}_2\text{O}(g)$	$\text{HCl}(g)$	$\text{O}_2(g)$
Standard Enthalpy of Formation (kJ/mol)	37	21	-394	-242	-92	0
