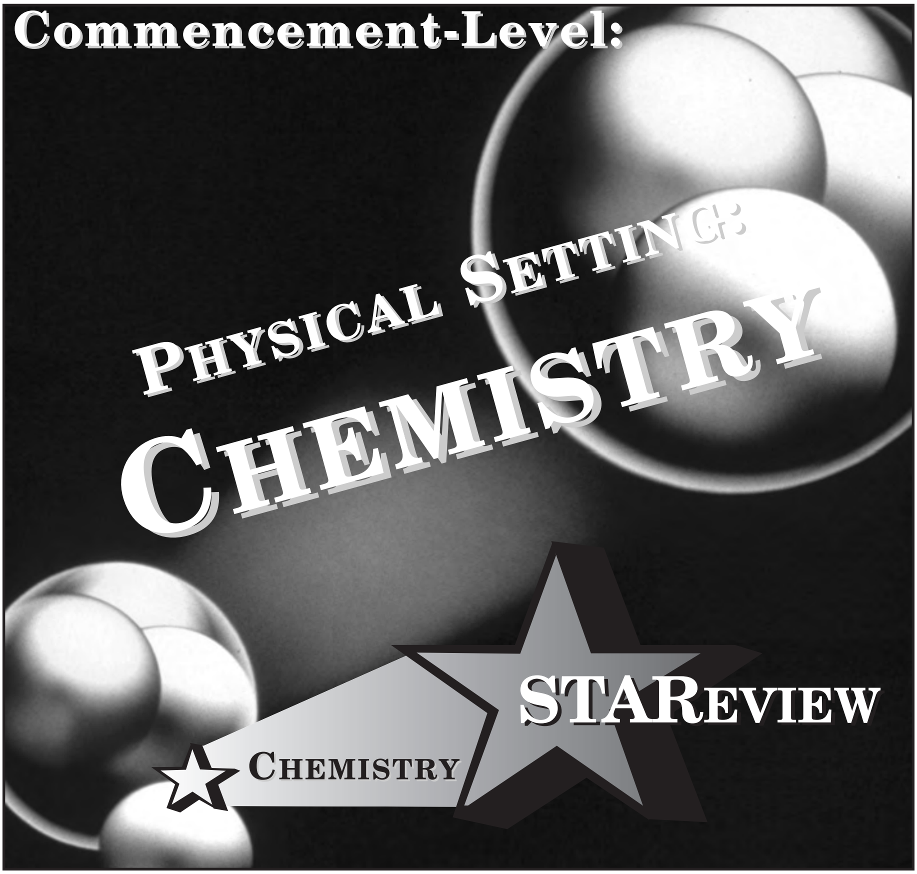

Authors
Nicholas R. Romano
Philip K. Cameron

Editors
Wayne Garnsey & Paul Stich
Fran Harrison, Associate Editor

Artwork & Graphics
Eugene B. Fairbanks & Wayne Garnsey

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DEDICATION & THANKS

Dedicated to our students, with the sincere hope that this book will further enhance their education and better prepare them with an appreciation and understanding of their role in the care and protection of Earth.

SPECIAL THANKS

Nicholas Romano:
Dedicated with much appreciation and thanks
to Shirley and Marietta Romano Mendler.

Philip Cameron:
Dedicated to my wife Elsa, sons Philip and Daniel, and my colleagues at John Jay High School for their constant support, help, and understanding during the development of this book.

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Sr. Kathleen McKinney, CSJ, Ed.D
Ms. Fran Harrison
Dr. Wayne Moreau
Ms. Paula Ranous
Mr. William Schoen
Ms. Judith Shuback
Mr. Brian Timm

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To the Student & Teacher

Physical Setting: Chemistry STAReview is written based on the new standards and assessments for chemistry. It is a comprehensive review of the Key Ideas, Major Understandings, Performance Indicators, Process Skills, and Real World Connections as set forth in the University of the State of New York Education Department: *Physical Setting: Chemistry Core Curriculum*.

"Open First"

The student should upon receiving this *STAReview* begin by reading this section: "To the Student."

- Start by reviewing the Table of Contents (previous 4 pages). This will give an overview of the major topics reviewed in this book.
- Now, become familiar with Unit 13 (page 335) Index & Glossary. This section is an extensive listing of the key chemical terms that one needs to know in order to understand the material. A brief definition or explanation of the term is given together with cross-referenced pages to direct the student to additional material directly related to the term.

Organization

The book is organized "conceptually," but the review is linked through the following organizational parts.

- **Standards** are the overall, general goals that apply to all scientific and indeed most general learning. For example, each Standard contains several goals, such as "Analysis, Scientific Inquiry, and Engineering Design in order to pose questions, seek answers, and develop solutions."
- Within each Standard, **Key Ideas** are used to further define the generalized objectives to be reached. For example, Standard 1 has several Key Ideas such as Key Idea 1 within the Scientific Inquiry part of Standard 1, that is, "to develop explanations of natural phenomena in a continuing, creative process."
- For each Key Idea there are several **Process Skills** which specifically identify what processes the student must learn in order to demonstrate the particular Key Ideas of a general Standard. These Skills are identified and found in all Units followed by explanations of the Skill and questions to test the student's abilities in preparation for the final, year-end test.

- Associated with both Standards and their Key Ideas are the **Performance Indicators**. These tell the student specifically what he/she is expected to know in order to answer correctly the questions on the final, year-end test. In other words, the specific objectives of the testing. These are identified at the beginning of each Unit and again at the end of each unit with the Part A, B, and C questions.

- Finally, there are the **Major Understandings**. Each Performance Indicator has specific concepts and chemical understandings to learn. This is the "meat and potatoes" of *Physical Setting: Chemistry STAReview*. These Major Understandings are first listed at the beginning of each Unit, are further developed in the text, examples, sample problems, and illustrations that follow, and are tested through out the Unit in the Skills and at the end of each Unit in Parts A, B, and C.

Meaning of Symbols

Symbols are critical in chemistry. So, the authors have developed a mini-help system. Stars are used to help navigate the student through the more complex Major Understandings in chemistry.

Stars indicate two important things: Some starred material may not be *specifically* referred to in the *Core Curriculum*, but this text is needed for better understanding of major chemical concepts. Also, stars may note special material that further explains Major Understandings, Skills, and Real World Connections.

In addition, the ☆ followed by a page number, directs the student to related material. These stars can help either by (1) providing a page reference to where that concept is further explained, or (2) give the student additional information making total understanding better.

Finally, Study

Success comes through study. The authors and editors of *Physical Setting: Chemistry STAReview* are teachers. This book has been written to provide the student with the best "outside help" possible. But, it can only help the student, if the student uses it consistently, with purpose, and focused study.

We wish you good studying and success on your final, year-end test.

UNIT 4
CHEMICAL BONDING

KEY IDEA 5

ENERGY AND MATTER INTERACT THROUGH FORCES THAT RESULT IN CHANGES IN MOTION.

PERFORMANCE INDICATOR 3.1

PERFORMANCE INDICATOR 5.2
EXPLAIN CHEMICAL BONDING IN TERMS OF THE BEHAVIOR OF ELECTRONS.

UNIT 4 – MAJOR UNDERSTANDINGS

- ☆ 3.1dd Compounds can be differentiated by their physical and chemical properties.
- ☆ 5.2g Two major categories of compounds are ionic and molecular (covalent) compounds.
- ☆ 5.2a Chemical bonds are formed when valence electrons are:
  • transferred from one atom to another (ionic)
  • shared between atoms (covalent)
  • mobile within a metal (metallic)
- ☆ 5.2e In a multiple covalent bond, more than one pair of electrons are shared between two atoms. Unsaturated organic compounds contain at least one double or triple bond.
- ☆ 5.2l Molecular polarity can be determined by the shape of the molecule and distribution of charge. Symmetrical (nonpolar) molecules include CO_2 , CH_4 , and diatomic elements. Asymmetrical (polar) molecules include HCl, NH_3, and H_2O.
- ☆ 5.2c When an atom gains one or more electrons, it becomes a negative ion and its radius increases. When an atom loses one or more electrons, it becomes a positive ion and its radius decreases.
- ☆ 5.2i When a bond is broken, energy is absorbed. When a bond is formed, energy is released.

UNIT 4
CHEMICAL BONDING

This unit is related to Key Idea 5 for the text and Performance Indicators 3.1 and 5.2 for the assessments.

INTRODUCTION

A **chemical bond** results from simultaneous attraction of electrons (either single or paired) to two or more nuclei. Two major categories of compounds are ionic or molecular (covalent) compounds.

A – THE NATURE OF CHEMICAL BONDING

BONDS BETWEEN ATOMS

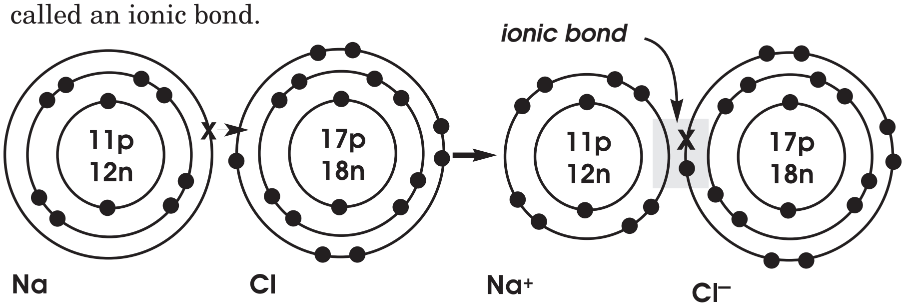
The electrons involved in bond formation may be transferred from one atom to another or may be shared equally or unequally between two atoms. When atoms of the elements enter into a chemical reaction, they do so in a manner that results in their becoming more like **inert** (noble gas) gas atoms. In this state, they contain their maximum complement of valance electrons, and they are in a condition of maximum stability.

UNIT 4 – MAJOR UNDERSTANDINGS (CONTINUED)

- ☆ 5.2b Atoms attain a stable valence electron configuration by bonding with other atoms. Noble gases have stable valence configurations and tend not to bond.
- ☆ 5.2n Physical properties of substances can be explained in terms of chemical bonds and intermolecular forces. These properties include conductivity, malleability, solubility, hardness, melting point, and boiling point.
- ☆ 5.2d Electron-dot diagrams (Lewis structures) can represent the valence electron arrangement in elements, compounds, and ions.
- ☆ 5.2j Electronegativity indicates how strongly an atom of an element attracts electrons in a chemical bond. Electronegativity values are assigned according to arbitrary scales.
- ☆ 5.2k The difference in electronegativity between two bonded atoms is used to assess the degree of polarity in the bond.
- ☆ 5.2h Metals tend to react with nonmetals to form ionic compounds. Nonmetals tend to react with other nonmetals to form molecular (covalent) compounds. Ionic compounds containing polyatomic ions have both ionic and covalent bonding.

Ionic Bonds

An **ionic bond** is formed by the transfer of one or more electrons from metals to nonmetals. This transfer of electrons results in the formation of ions. The attraction between a positive ion and a negative ion is called an ionic bond.

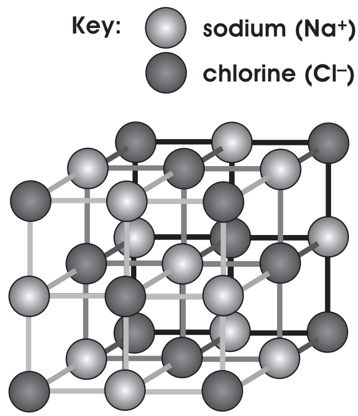


In ionic bonding, the number of electrons transferred is such that the atoms involved achieve an "inert" gas configuration, except for some transition elements. Since the ion has a different electron configuration than the atom, the properties of the ion differ from those of the atom. Also, ionic bonds may form between ions that were formed in a previous reaction as a result of a transfer of ions. For example:

$$\overset{+\;\;-}{\mathbf{AgNO_3}}(aq) + \overset{+\;\;-}{\mathbf{NaCl}}(aq) \rightarrow \overset{+\;\;-}{\mathbf{AgCl}}(s) + \overset{+\;\;-}{\mathbf{NaNO_3}}(aq)$$

Characteristics of Ionic Solids – Ionic solids have high melting points and do not conduct electricity. In the geometric structure of the solid ionic crystal, ions form the crystal lattice and are held in relatively fixed positions by electrostatic attraction. When melted or dissolved in water, the crystal lattice is destroyed and the ions move freely. This free movement of ions permits electrical conductivity. Examples of ionic solids are sodium chloride and magnesium oxide.

Crystal Lattice Energy – The structure at the right is an example of an ionic solid – sodium chloride (NaCl) (also, see crystals, pg. 108). Each ion is surrounded by an electric field of attraction to oppositely charged ions. The positions of the ions in a crystal of sodium chloride, determined by x-ray diffraction, are represented by lattice points which form a three-dimensional structure called a **lattice structure**. Its stability is measured experimentally and referred to as **crystal lattice energy**. The greater the energy released in the formation of the crystal, the more stable the crystal will be.

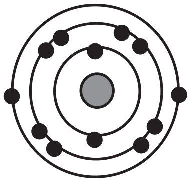


NaCl Crystal Lattice

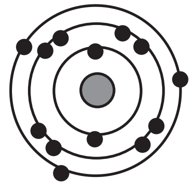
SKILLS 5.2I *DETERMINE THE NOBLE GAS CONFIGURATION AN ATOM WILL ACHIEVE WHEN BONDING.*

Directions: Name each of the following elements and draw each ionic configuration with its positive or negative charge

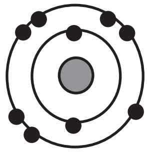
1 **Question**: ______________



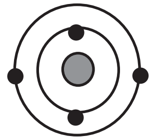
2 **Question**: ______________



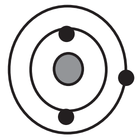
3 **Question**: ______________



4 **Question**: ______________



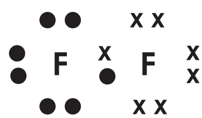
5 **Question**: ______________



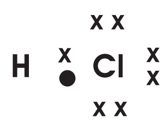
COVALENT BONDS

A **covalent bond** is a simultaneous attraction of two nuclei for the same electrons resulting in the sharing of those electrons. A covalent bond is formed when two atoms share electrons, instead of transferring them. In order to form this type of bond, the electronegativity difference between the two atoms forming the bond must be less than 1.7. Covalent bonds are classified as two types. Their structures can be demonstrated using Lewis dot structures.

Nonpolar Covalent Bond – When electrons are shared between atoms of the same element, they are shared equally, and the resulting bond is a **nonpolar bond**. An example of a nonpolar covalent bond is found in the fluorine molecule. Since the electronegativity of both fluorine atoms in the molecule is the same, the difference is zero, and the electron density of the molecule is symmetrical.

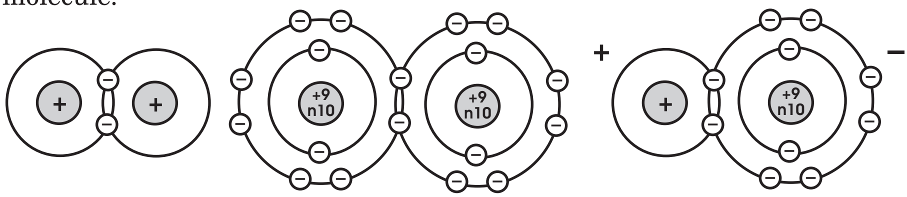


Polar Covalent Bonds – When electrons are shared between atoms of different elements, they are usually shared unequally. The resulting bond is polar. An example of a **polar covalent bond** is found in the hydrogen chloride molecule.



Chlorine, having an electronegativity value of 3.2 will attract the bonding electrons to a greater extent than hydrogen, which has an electronegativity value of 2.1. The difference of 1.0 denotes a covalent bond. Since the chlorine end of the molecule will show a greater electron density probability than the hydrogen end, the molecule will be asymmetrical and therefore polar.

In the illustration below, the hydrogen and fluoride molecules are both considered nonpolar, because both hydrogen atoms in the hydrogen molecule have the same electronegativity; therefore, the molecule is symmetrical. The same nonpolar symmetrical situation occurs in the fluorine molecule.



Hydrogen Gas
H_2

Fluorine Gas
F_2

Hydrogen Fluoride
HF

In the HF molecule, hydrogen has an electronegavity rating of 2.1 and fluorine 4.0; therefore, the fluorine atom attracts the shared electrons to a greater extent than hydrogen. The fluorine portion of the molecule becomes more negative, unlike the hydrogen which becomes more positive. This arrangement makes for an unsymmetrical molecule called a **dipole**. The product of the charge and the distance of partial separation is called the **dipole moment**.

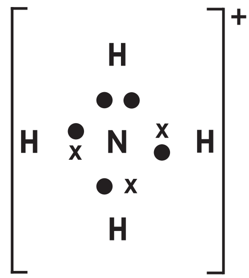
SKILLS 5.2V *DISTINGUISH BETWEEN NONPOLAR COVALENT BONDS (TWO OF THE SAME NONMETALS) AND POLAR COVALENT BONDS.*

Directions: Questions 6 through 13: : Identify the bond in each of the following molecules as either ***polar*** or ***nonpolar***.

6 __________ HBr
7 __________ Cl_2
8 __________ HF
9 __________ I_2
10 __________ N_2
11 __________ HCl
12 __________ O_2
13 __________ F_2

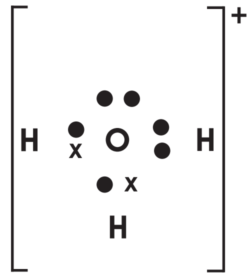
Coordinate Covalent Bonds – When the two shared electrons forming a covalent bond are both donated by one of the atoms, this bond is called a coordinate covalent bond. A coordinate covalent bond, once formed, is not different from an ordinary covalent bond. The difference lies in the source of the electrons involved in the bond. This type of bond is frequently involved in the bonding within polyatomic ions and is very important in modern acid-base theories.

A classic example of a coordinate covalent bond is the ammonium ion. In the ammonium ion, the nitrogen atom has five valence electrons. Three electrons are unpaired but are shared with the electrons from three hydrogen atoms. The other two form a full pair and are not shared.



ammonium ion

It is at this unshared pair of electrons that the electron density is so great that the molecule may attract a hydrogen ion (proton). When that occurs, the ion is formed and takes on a charge of positive one (+1). For example, water (H_2O) can attract a proton (hydrogen nucleus) to become a hydromium ion (H_3O^+)



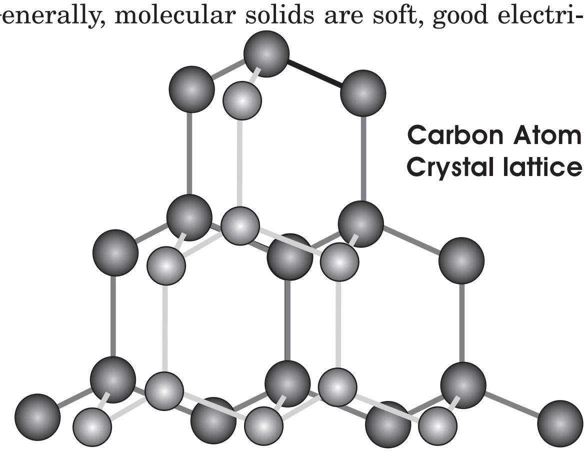
hydromium ion

Molecular Substances – A molecule may be defined as a discrete particle formed by covalently bonded atoms. A molecule has also been defined as the smallest particle of an element or compound capable of independent existence. When a stable molecule is formed, a covalent bond is established. The atoms that form the bond usually assume electronic structures of inert gases by sharing electrons. Examples of molecules include:

$\mathbf{H_2}$ $\mathbf{NH_3}$ $\mathbf{H_2O}$ $\mathbf{HCl}$ $\mathbf{CCl_4}$ $\mathbf{S_8}$ $\mathbf{C_6H_{12}O_6}$

Characteristics of Molecular solids – Molecular substances may exist as gases, liquids, or solids, depending on the attraction that exists between the molecules. Generally, molecular solids are soft, good electrical insulators, poor heat conductors, and have low melting points.

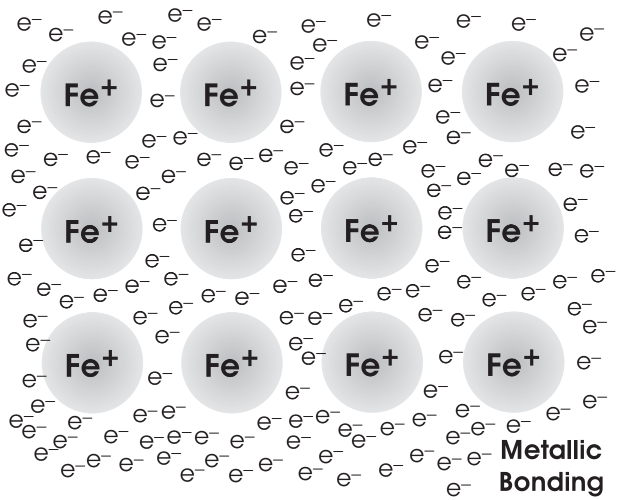
Network Solids – Certain solids consist of covalently bonded atoms linked in a network that extends throughout the sample with an absence of simple discrete particles. Such a substance is said to be a network solid.



Generally, network solids are hard, are poor conductors of heat and electricity, and have high melting points. Examples of network solids are diamond (C), silicon carbide (SiC), and silicon dioxide (SiO_2).

METALLIC BONDING

Metallic bonding occurs between atoms of metals that have a small number of valence electrons leaving them with many vacant valence orbitals and low ionization energies.



Metallic Bonding

A **metallic bond** consists of an arrangement of positive ions that are located at the crystal lattice sites and are immersed in a "sea" of mobile electrons. These mobile electrons can be considered as belonging to the whole crystal rather than to individual atoms.

Note: This mobility of electrons (previous page) distinguishes the metallic bond from an ionic or covalent bond and gives the metal the following characteristics:

- good conductors of electricity and heat
- great strength
- malleability and ductility
- luster

SKILLS 3.1XIX *DISTINGUISH AMONG IONIC, MOLECULAR, AND METALLIC SUBSTANCES, GIVEN THEIR PROPERTIES.*

Directions: Questions 14 through 23: Distinguish among ***ionic***, ***molecular***, and ***metallic*** substances according to their properties.

Ionic Properties	Molecular Properties	Metallic Properties
• poor conductor of electricity in solid state • high melting point • when melted or dissolved in water, become good conductors	• exists in gas, liquid, or solid state • soft • good insulators • poor heat conductor • low melting points	• good conductor of heat and electricity • great strength • good malleability and ductility • luster

14 __________ Al

15 __________ NaCl

16 __________ H_2O

17 __________ KF

(continued)

18 __________ HCl

19 __________ $C_{12}H_{22}O_{11}$

20 __________ Fe

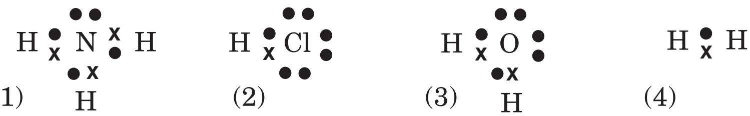
21 __________ NH_3

22 __________ CaS

23 __________ Cu

SKILLS 5.2I *DEMONSTRATE BONDING CONCEPTS USING LEWIS DOT STRUCTURES REPRESENTING VALANCE ELECTRONS; TRANSFERRED (IONIC BONDING; SHARED COVALENT BONDING), IN A STABLE OCTET.*

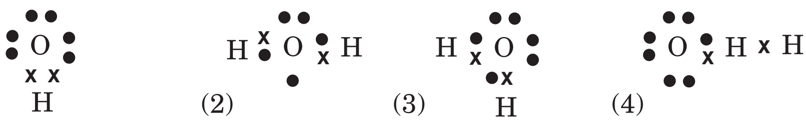
24 Which molecule contains a nonpolar covalent bond?



(1) (2) (3) (4)

25 Which substance exists as a metallic crystal at STP (standard, temperature, pressure)?
(1) Ar (2) Au (3) SiO_2 (4) CO_2

26 Which of the following Lewis dot structures best represents water?



(1) (2) (3) (4)

27 The bonds present in silicon carbide, SiC, are
(1) covalent
(2) ionic
(3) metallic
(4) van der Waals

28 Which compound has the greatest degree of ionic character?
(1) HF (2) HI (3) HCl (4) HBr

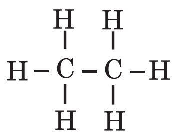
29 Which electron dot formula represents a molecule that contains a nonpolar covalent bond?

(1) (2) (3) (4)

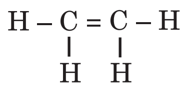
SATURATED & UNSATURATED COMPOUNDS

A bond formed between carbon atoms by the sharing of one pair of electrons is referred to as a **single bond**. Organic compounds, where carbon atoms are bonded by the sharing of a single pair of electrons, are said to be **saturated compounds**.

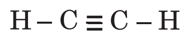
Organic compounds, containing two adjacent carbon atoms bonded by the sharing of more than one pair of electrons, are said to be **unsaturated compounds**. A bond between carbon atoms by the sharing of two pairs of electrons is referred to as a **double bond**. A bond formed between carbon atoms by the sharing of three pairs of electrons is referred to as a **triple bond**. Examples include



Single Bonds
(Saturated)



Double Bonds

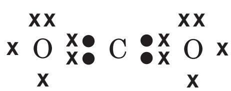


Triple Bonds

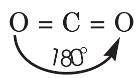
B – Directional Nature of Covalent Bonds

Non Polar Molecules

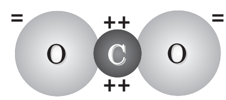
Because of the directional nature of the covalent bonds which form them, some molecules composed of more than two atoms may be nonpolar – even though the individual bonds are polar if the shape of the molecule is such that symmetric distribution of charge results (i.e., carbon dioxide – CO_2 is a nonpolar molecule). $\mathbf{CO_2}$ molecule can be shown in many ways. Examples follow:



electron dot
notation



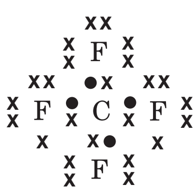
structural
formula



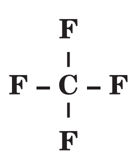
Electron Density Formula
of Carbon Dioxide – CO_2

Because of the greater electronegativity of oxygen, the electron density is greater around the oxygen atoms. The bond with an electronegativity difference of 0.9 is polar, but because the bond angle is 180° and the molecule is symmetrical, it is considered a nonpolar molecule.

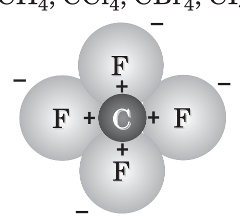
Carbon tetrafluoride molecule can be shown to be a nonpolar molecule with polar bonds (other examples include: CH_4, CCl_4, CBr_4, CI_4):



electron dot
notation



structural
formula



Electron Density Formula
of Carbon Tetrafluoride – CF_4

Fluorine has an electronegativity of 4.0, and Carbon has an electronegativity of 2.6. The difference, 1.4, indicates a polar covalent bond. However, because the tetrahedral molecule is symmetrical, the molecule is nonpolar.

When two hydrogen atoms bond to form a hydrogen molecule (H_2) they form a nonpolar bond with an electronegativity difference of 0. The molecule they form is a nonpolar, symmetrical molecule. This is true of other diatomic molecules such as oxygen, chlorine, and fluorine.

Because of its molecular structure, carbon tetrafluoride, called Freon-14 (CF_4) gas is used in refrigeration. Freon is symmetrical. It forms bonds between two Freon molecules with weak van der Waals forces which are easily affected by temperature and pressure. This causes the gas to condense and evaporate readily, making it a good refrigerant. Note: recent government restrictions have banned its use because of its negative effect on global warming.

Chemical Energy

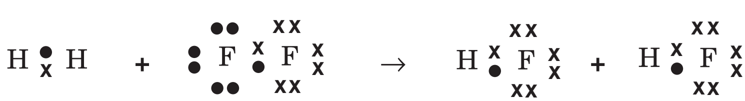
Potential energy is stored in molecules, and the transfer or release of some of this energy manifests itself in the form of chemical energy. Substances possess energy because of their composition and structure. Factors such as mass, types of bonding, and types of motion influence the absorption and storage of energy by molecules.

Energy Changes in Bonding

When two atoms are held together by a chemical bond, they are generally at a lower energy condition than when they are separated. Therefore, when a chemical bond is formed, energy is released, and when a chemical bond is broken, energy is absorbed.

Bonding & Stability

Because there is a release of energy when bonds are formed, systems at lower energy levels are more stable than systems at higher energy levels. So, it follows that bonding will more often occur among atoms if the changes lead to a lower energy condition and, therefore, a more stable structure. The more energy given off when a bond is formed, the stronger and more stable the bond will be. Also, the less energy given off in the formation of a bond, the weaker and less stable it will be. This is readily illustrated when hydrogen and fluorine combine to form hydrogen fluoride:



In order for the bonds of the reactants (ex.: hydrogen and fluoride molecules) to break and form the products, energy must be added:

436.8 kJ/mole + 155.4 kJ/mole → 567 kJ/mole + 567 kJ/mole

total energy in = 592.3 kJ   *total energy given off* = 1,134 kJ

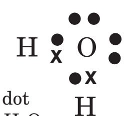
Note 1: As bonds are formed, energy is given off. It is easily seen that more energy is given off in the formation of the products, than is required to break the bonds in the reactants. Therefore, the products are more stable than the reactants.

Note 2: Review from Unit 1 the definition of valence electrons. Note that valence electrons may be represented by electron dot symbols in which the kernel of the atom is represented by the letter symbol for the element and the valence electrons are represented by dots.

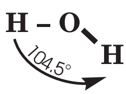
Note 3: Metals tend to react with nonmetals to form ionic compounds (i.e. NaCl, MgBr, KI). Nonmetals tend to react with nonmetals to form covalent (molecular) compounds; i.e. CO, NF_3, SCl_2. Compounds containing polyatomic ions have both ionic and covalent bonding. By definition these compounds are charged ionic substances; but, within the molecule they have covalent bonds; i.e. SO_4^{2-}, PO_4^{3-}, CN^-.

Polar Molecules

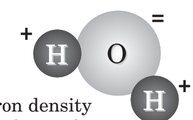
Generally, the geometric structure of covalent substances, which result from the directional nature of the covalent bond, helps to explain properties of the resulting molecule. The polarity of a water molecule is explained by the asymmetrical shape of the molecule. The water molecule (H_2O) is shown as follows:



electron dot notation– H_2O



structural formula– H_2O



electron density formula– H_2O

Oxygen's electronegativity is 3.4, and hydrogen's electronegativity is 2.1. The difference, 1.3, indicates a polar covalent bond. The bond angle is such that there exists an unsymmetrical distribution of electron density. Therefore, a polar molecule results. Other examples of polar molecules include the following (see *Reference Table S*):

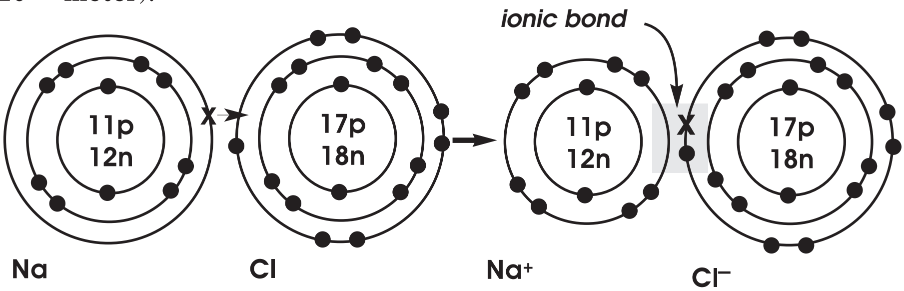
Hydrogen Chloride – electronegativity = hydrogen 2.1, chlorine = 3.2, difference = 1.1

Ammonia – electronegativity = hydrogen 2.1, nitrogen = 3.0, difference = 0.9

The electrons involved in bond formation may be transferred from one atom to another or may be shared equally or unequally between two atoms. When the atoms of these elements enter into a chemical reaction, they do so in a manner that results in their becoming more like "inert" gas atoms. In this state, they contain their maximum complement of valance electrons, and they are in a condition of maximum stability.

Ionic Radius

A loss or gain of electrons by an atom causes a corresponding change in size. Metal atoms lose one or more electrons when they form ions. Ionic radii of metals are smaller than the corresponding atomic radii. Nonmetal atoms gain one or more electrons when they form ions. Ionic radii of nonmetals are larger than the corresponding atomic radii. Atomic and ionic radii are usually measured in Angstrom (Å) units (1Å = 1 x 10^{-10} meter).



C – Intermolecular Forces

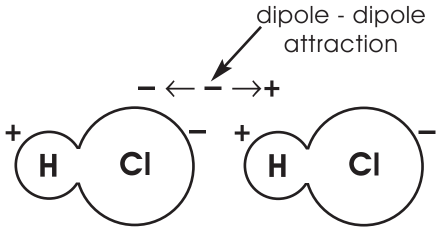
Physical properties of substances such as conductivity, malleability, solubility, hardness, melting point, and boiling point can be explained in terms of chemical bonds and intermolecular forces. The strength of attraction that an atom has for another atom is a measure of its electronegativity rating. It is an arbitrary scale proposed by American Linus Pawling (1901-1994). The electronegativity difference is used to assess the degree of polarity of a bond formed by two atoms. This polarity of intramolecular bonds results in polar molecules which are attracted to other polar molecules.

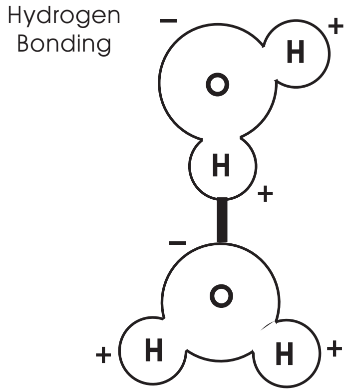
Dipoles

The asymmetric distribution of an electrical charge in a molecule causes a molecule that is polar in nature and is referred to as a **dipole**. That is, the uneven electron cloud density will cause one end of a molecule to be more negative than the other end. A molecule composed of only two atoms will be a dipole if the bond between the atoms is polar. For example, the hydrogen chloride molecule is a dipole because

- the chlorine atom is larger than the hydrogen atom, and
- the difference in electronegativity of hydrogen (2.1) and chlorine (3.2).

These factors allow chlorine to share electrons closer to itself than to hydrogen. When the bond is formed, the electron density around the chlorine atom is greater than around the hydrogen atom, leading to a polar molecule (a dipole). The bond between two hydrogen chloride molecules is a result of dipole—dipole attraction (at right)





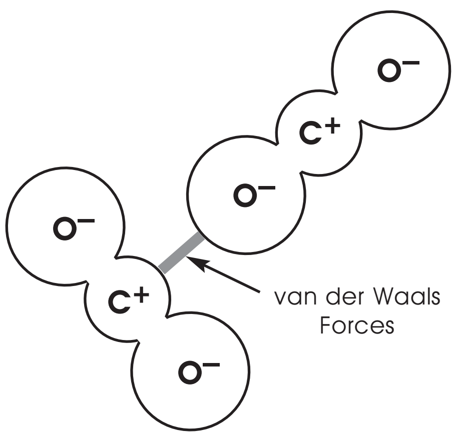
Hydrogen Bonding

Hydrogen bonds are formed between molecules when hydrogen is covalently bonded to an element of small atomic radius and high electronegativity. When a hydrogen atom is bonded to a highly electronegative atom, the hydrogen has such a small share of the electron pair that it acts like a bare proton.

As such it can be attracted to the more electronegative atom of an adjacent molecule. The sulfur atom is larger in radius and has an electronegativity of 2.6, compared to the smaller radius of the oxygen atom and its higher electronegativity of 3.4. The greater polarity of the water molecules results in stronger electrostatic bonds between them. This accounts for the lower vapor pressure and the higher boiling point of H_2O, as compared with the boiling point of H_2S.

Hydrogen bonding (shown in a quantity of water) is important in compounds of hydrogen with fluorine, oxygen, or nitrogen. These compounds represent special cases of dipole to dipole attraction.

These forces also account for the meniscus when water or any other liquid is poured into a measuring instrument.



Van der Waals Forces

In the absence of dipole attraction and hydrogen bonding, as in nonpolar molecules, weak attractive forces exist between molecules. These forces are called **van der Waals forces**.

Van der Waals forces make it possible for species of small nonpolar molecules, such as hydrogen, helium, oxygen, etc., to exist in the liquid and solid phases under conditions of low temperature and high pressure.

Van der Waals forces appear to be due to chance distribution of electrons resulting in momentary dipole attractions. Therefore, these forces are momentary electrostatic forces that increase as the distance between molecules decreases. Also, as the size of the molecules increases, the greater the Van der Waals forces.

The effect of molecular size on the magnitude of the van der Waals forces accounts for the increasing boiling points of a series of similar compounds (such as the alkane series of hydrocarbons).

Molecule Ion Attraction

Polar solvents, when interacting with ionic compounds, attract ions from these compounds and form a solution. Ionic compounds are generally soluble in polar solvents such as water, alcohol, and liquid ammonia. The negative ion of the substance being dissolved is attracted to the positive end of the adjacent polar molecules, while the positive ion is attracted to the negative end of the polar molecules. Water is the polar substance most commonly used to dissolve these ionic compounds. When an ionic compound is dissolved in water, its crystal lattice is destroyed, and water molecules surround each ion, forming hydrated ions. It is because water is a dipole that this attraction between the water molecules and the positive or negative ion exists. The orienting of water molecules around ions is called the hydration of the ions. This process is important in aqueous chemistry.

Polyatomic Ions

A single atom with a charge is called a **monatomic ion**. A compound of two or more covalently bonded atoms with a charge is called a polyatomic ion.

A polyatomic ion is very stable and behaves like a monatomic particle, because it contains strong covalent bonds. These bonds are stronger than the bonds that hold it to the rest of the atoms in the compound. Therefore, during reactions, the polyatomic ion usually remains intact as it passes from the reactants to the products.

Some polyatomic ions include: NH_4^+ (ammonium ion), PO_4^{-3} (phosphate ion), and NO_3^- (nitrate ion). Other examples can be found in the *Reference Table E*.

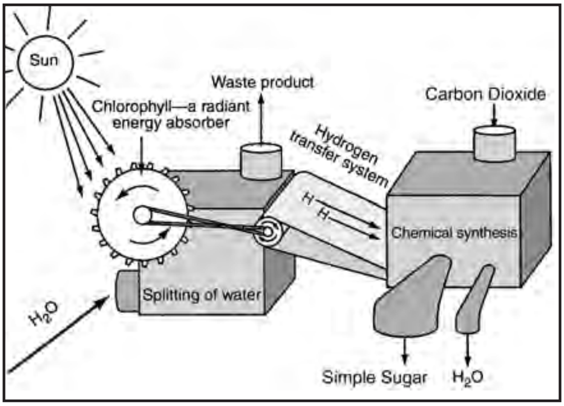
Although the bonds which keep the atoms in a polyatomic ion are covalent bonds, the polyatomic ions possess a charge. When they attach themselves to a metal ion or another polyatomic ion, they do so by forming an ionic bond. The final compound contains both ionic and covalent bonds. Some examples include: $Na^+NO_3^-$ and $NH_4^+OH^-$. In general,

- metals tend to react with nonmetals to form ionic compounds;
- nonmetals tend to react with other nonmetals to form covalent (molecular compounds; and,
- ionic compounds containing polyatomic ions have both ionic and covalent bonding.

Real World Connections

Free radicals are molecules which have one open bond and, as a result, have become charged. When these highly reactive molecules are present in great numbers in living organisms, they often react with other molecules, exchanging electrons and disrupting their normal molecular structure. This is particularly damaging in the case of large functioning macromolecules, such as carbohydrates, proteins, and nucleic acids.

Photosynthesis is the process during which light energy is converted into the chemical energy of organic molecules. Most of the chemical energy available to organisms results from photosynthetic activity. In addition to food production, photosynthesis releases most of the oxygen that is in the air.

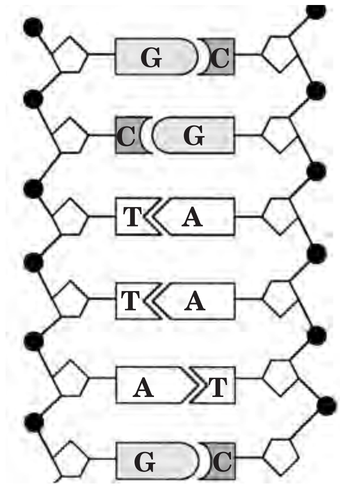


Most cells which carry on photosynthesis contain chloroplasts. These chloroplasts contain pigments which include chlorophylls ("green leaf"). Chlorophyll absorbs light energy. In the chloroplasts, carbon dioxide (CO_2) and water (H_2O) are used in the formation of simple sugar ($C_6H_{12}O_6$) molecules and oxygen (O_2). During photosynthesis, light energy is trapped by chlorophyll and converted into the chemical energy of simple sugar molecules. Simplified summary statements for photosynthesis are:

$$\text{Carbon Dioxide + Water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{Glucose + Water + Oxygen}$$

$$6\,CO_2 + 12\,H_2O \xrightarrow{\text{Enzymes}} C_6H_{12}O_6 + 6\,H_2O + 6\,O_2$$

DNA bonding. In 1953, James Watson (1928-), an American biologist, and Francis Crick (1916-), a British biophysicist, developed a model of the DNA molecule. This most important scientific breakthrough won them the Nobel Prize in 1962 and opened the door to modern genetics. In this model, the DNA molecule consists of two complementary chains of nucleotides.



The DNA molecule has a "ladder" type organization. This "ladder" is thought to be twisted around a protein "framework" in the form of a double helix. The uprights of the "ladder" are composed of alternating phosphate and deoxyribose molecules. Each rung of the "ladder" is composed of bases held together by relatively weak hydrogen bonds: adenine (A) - thymine (T) and guanine (G) - cytosine (C); thus the combinations: A—T and C—G.

Performance Indicator 3.1
Assessments

Part A – Multiple Choice

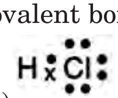
1 Which type of attraction results from the formation of weak momentary dipoles?
(1) ionic (3) molecule-ion
(2) metallic (4) van der Waals forces

2 Which substance contains nonpolar covalent bonds?
(1) H_2 (2) H_2O (3) $Ca(OH)_2$ (4) CaO

3 Which substance contains a bond with the greatest ionic character?
(1) KCl (2) HCl (3) Cl_2 (4) F_2

4 Compared to an atom of potassium, an atom of calcium has a
(1) larger radius and lower reactivity
(2) larger radius and higher reactivity
(3) smaller radius and lower reactivity
(4) smaller radius and higher reactivity

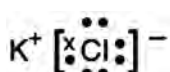
5 Which electron dot diagram represents a molecule that has a polar covalent bond?



(1)

(2)

(3)



(4)

6 Which type of bond is formed when an atom of potassium transfers an electron to a bromine atom?
(1) metallic (3) nonpolar covalent
(2) ionic (4) polar covalent

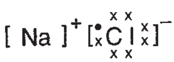
7 Which molecule is polar and contains polar bonds?
(1) CCl_4 (2) CO_2 (3) N_2 (4) NH_3

8 The *strongest* van der Waals forces of attraction exists between molecules of
(1) I_2 (2) Br_2 (3) Cl_2 (4) F_2

9 Which molecule has an asymmetrical shape?
(1) N_2 (2) NH_3 (3) Cl_2 (4) CCl_4

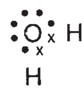
10 The elements Li and F combine to form an ionic compound. The electron configurations in this compound are the same as the electron configurations of atoms in Group
(1) 1 (2) 14 (3) 17 (4) 18

11 Which electron dot formula represents a substance that contains a nonpolar covalent bond?


(1)


(2)


(3)


(4)

12 The bond between hydrogen and oxygen in a water molecule is classified as
(1) ionic and nonpolar (3) covalent and nonpolar
(2) ionic and polar (4) covalent and polar

13 In which system do molecule-ion attractions exist?
(1) NaCl(*aq*) (3) $C_6H_{12}O_6$(*aq*)
(2) NaCl(*s*) (4) $C_6H_{12}O_6$(*s*)

14 Which sequence of Group 18 elements demonstrates a gradual *decrease* in the strength of the van der Waals forces?
(1) Ar(*l*), Kr(*l*), Ne(*l*), Xe(*l*) (3) Ne(*l*), Ar(*l*), Kr(*l*), Xe(*l*)
(2) Kr(*l*), Xe(*l*), Ar(*l*), Ne(*l*) (4) Xe(*l*), Kr(*l*), Ar(*l*), Ne(*l*)

15 Which substance is an example of a network solid?
(1) nitrogen dioxide (3) carbon dioxide
(2) sulfur dioxide (4) silicon dioxide

16 Which combination of atoms can form a polar covalent bond?
(1) H and H (2) H and Br (3) N and N (4) Na and Br

17 Which pair of atoms is held together by a covalent bond?
(1) HCl (2) LiCl (3) NaCl (4) KCl

PART B – CONSTRUCTED-RESPONSE

Directions: Use the following chemical equation for questions 1 through 3:

$$\mathbf{N_2 + 3H_2 \rightarrow 2NH_3 + 92.4\ kJ}$$

1 **Question**: Explain how the combined bond strengths of the reactants compares to the bond strengths found in the products of the accompanying reaction. [1]

2 **Question**: Describe the type of bond that exists between the atoms making up the NH_3 molecule. [1]

3 **Question**: The NH_3 molecule produced is capable of combining chemically with a H^+ ion to form a coordinate covalent bond as it produces the ammonium ion, NH^{4+}. Explain how this coordinate covalent bond is formed. [1]

Directions: Using the representative chemical species illustrated below, answer questions 4 through 7:

H_2, N_2, O_2, H_2O, NH_3, NH_4^+, CO_2, CCl_4, NaCl, $CuSO_4$, Fe, Al

4 **Question**: Identify and write the formula(s) of the molecule(s) that could form a coordinate covalent bond with an H^+ ion. [1]

5 **Question**: Identify and write the formula(s) for the compound(s) that contain both ionic and covalent bonds. [1]

6 **Question**: Identify and write the formula(s) for the compound(s) that contain a coordinate covalent bond. [1]

7 **Question**: Identify and write the formula(s) for the metals that are illustrated. [2]

Directions: Using the representative chemical species illustrated below, answer questions 8 through 14:

H_2, N_2, O_2, H_2O, NH_3, NH_4^+, CO_2, CCl_4, NaCl, $CuSO_4$, Fe, Al

8 Question: Identify and write the formula(s) of the nonpolar molecule(s) illustrated. [5]

9 Question: Identify and write the formula(s) of the polar molecule(s) illustrated. [1]

10 Question: Identify and write the formula(s) for the ionic compound(s) illustrated. [2]

11 Question: Identify and write the formula(s) for the molecule(s) that are nonpolar and held together by nonpolar covalent bonds. [4]

12 Question: Identify and write the formula(s) for the moleclules that are nonpolar and held together by polar covalent bonds. [2]

13 Question: Identify and write the formula(s) of those elements that are good conductors of heat and electricity, and are malleable and ductile. [2]

14 Question: Identify and write the formula(s) of the substance(s) that contain both ionic and covalent bonds. [2]

Part C – Extended Constructed-Response

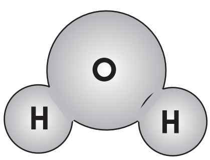
Article A: The many different organic molecules produced by carbon are made possible by the fact that carbon atoms are tetravalent. Carbon needs to form four bonds in order to complete its outer principle energy level. The electron configuration in the ground state only produces two half-filled orbitals in the *p* sublevel. However, due to sp^3 hybridization, carbon mixes the orbitals in its outer principal energy level and produces four half-filled orbitals, each with only one electron in it. These four half-filled orbitals are what make it possible for carbon to always form four bonds.

1 **Question**: Using the information supplied by the *Periodic Table*, state which outer principal energy level contains the valence electrons of carbon. [1]

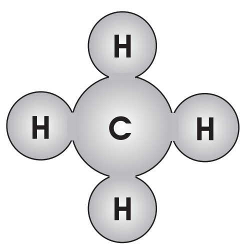
2 **Question**: Based on the article and based upon the electron configuration of carbon in the ground state, state how many bonds it would form if it did not undergo hybridization. [1]

Statement B: The polarity of molecules is based upon the distribution of the electrons within the molecule. If the electrons are evenly distributed within the molecule, the molecule will be nonpolar. However, if the electrons are unevenly distributed within the molecule, then the molecule will be polar.

3 **Question**: Using the electron distribution within the molecule and bond type between the atoms explain why water is a polar molecule. [1]



4 **Question**: Explain in terms of bond type and electron distribution why CH_4 is a nonpolar molecule. [1]



Statement C: Physical properties of substances can be explained in terms of chemical bonds and intermolecular forces. These properties include conductivity, malleability, solubility, hardness, melting point, and boiling point. Metals tend to react with nonmetals to form ionic compounds, and nonmetals tend to react with other nonmetals to form molecular compounds.

5 **Question**: In terms of the forces of attraction holding them together, explain why a NaCl crystal has a melting point of 800°C while an ice cube of pure water has a melting pint of 0°C. [3]

Statement D: Electronegativity indicates how strongly an atom of an element attracts electrons in a chemical bond. The difference in electronegativity between the bonding atoms determines the type of bond that exists between them.

6 **Question**: Arrange the following compounds in order of increasing electronegativity difference between the bonding atoms, and identify the type of bond that forms between the bonding atoms in each formula: NaCl, $AlCl_3$, PCl_5 [3]

PART D – LABORATORY SKILLS

IDENTIFY DIFFERENCES BETWEEN INORGANIC AND ORGANIC SUBSTANCES

Differences in solubility, melting point, stability, and electrical conductivity may be qualitatively demonstrated using sodium chloride and sucrose.

These differences are due, in the most part, to types of bonds in organic and inorganic compounds in solvents. Organic compounds dissolve in nonpolar solvents and are generally insoluble in polar compounds except organic acids and alcohol. Because of the weak van der Waals forces between the molecules, the molecules dissociate easily, giving them low melting points. Also as a result, they do not conduct electricity. Whereas, inorganic compounds usually have ionic bonds that will dissolve in polar solvents but not in nonpolar solvents. They have high melting points, making them very stable, and will conduct electricity in solution.

There are exceptions to these general observations. For instance, although plastics are organic substances, some conduct electricity and have high melting points.

Directions: For questions 1 through 4, indicate whether the characteristics listed below refer to inorganic or organic compounds.

1 **Question**: High melting point ________________

2 **Question**: Dissolves in nonpolar solvents. ________________

3 **Question**: When melted, conducts electricity. ________________

4 **Question**: Readily conducts electricity in solution. ________________

5 **Question**: Why does a solution of NaCl conduct electricity and a solution of sucrose does not?

6 **Question**: Why does NaCl and sucrose dissolve in water?

7 **Question**: Which compound is more soluble in water? Explain.