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ABSTRACT

This booklet is one of a set of eight designed to be used in a self-paced introductory chemistry course in conjunction with specified textbooks and computer-assisted instruction (CAI) modules. Each topic is introduced with a textbook reading assignment and additional readings are provided in the booklet. Also included are self-tests (and answers), CAI module assignments, and suggested breakpoints for student-teacher consultations. Each booklet contains specific cognitive objectives to be met by completion. This booklet covers four major bonding topics: chemical formulas, nomenclature, oxidation numbers, and types of bonding. (MH)

ILS CHEM PAC No. **4**

BONDING

by

William Torop

West Chester State College
West Chester, Pennsylvania

Student No. & Name ....

Date Started ....

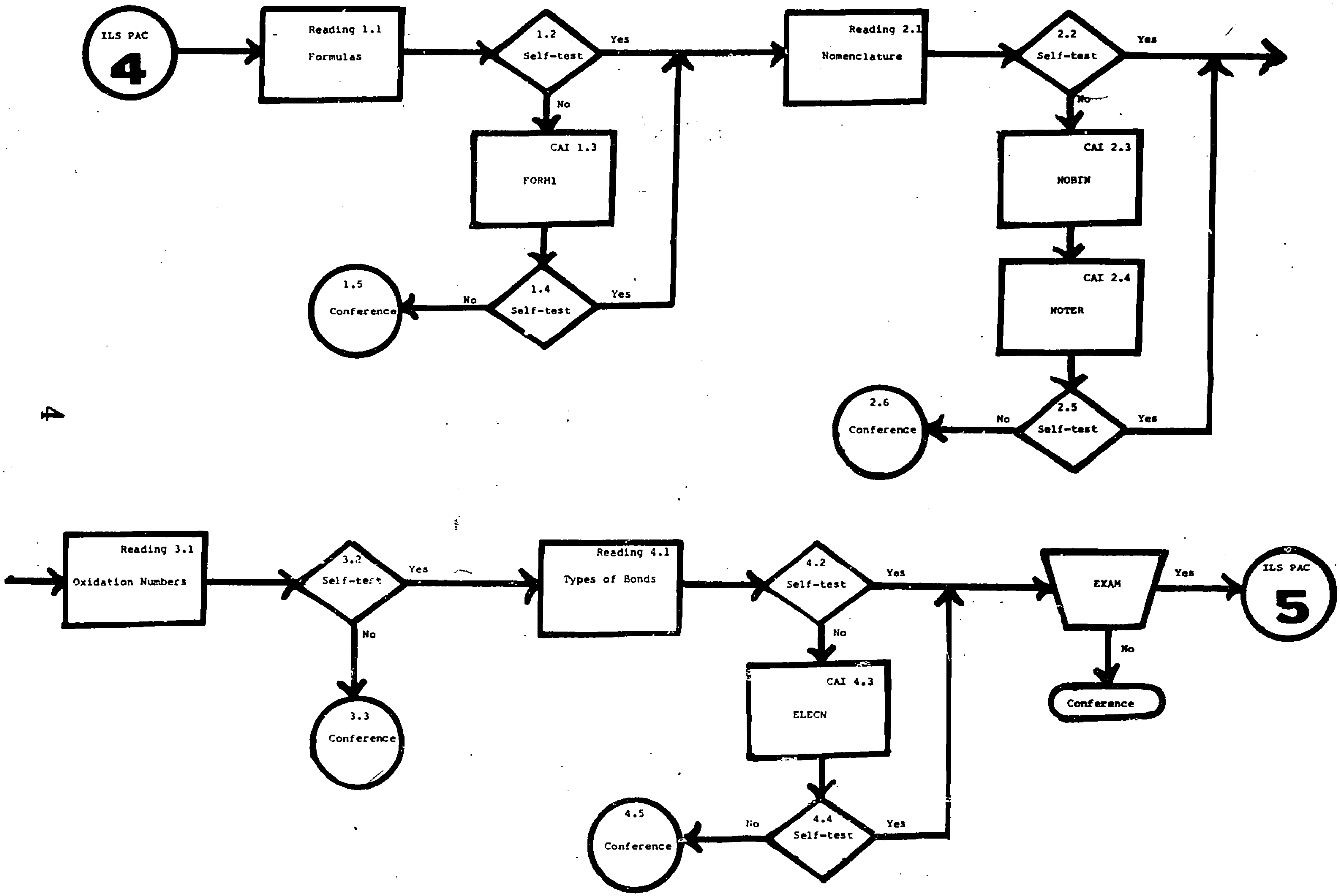
Date Completed ....

COMMON VALENCES

	Monovalent (I)		Divalent (II)		Trivalent (III)	
Metals	ammonium	(NH_4)	barium	Ba	aluminum	Al
	hydrogen	H	calcium	Ca	antimony(III)	Sb
	copper(I) or cuprous	Cu	copper(II) or cupric	Cu	arsenic(III)	As
	lithium	Li	iron(II) or ferrous	Fe	chromium(III)	Cr
	potassium	K	lead(II) or plumbous	Pb	iron(III) or ferric	Fe
	silver	Ag	magnesium	Mg		
	sodium	Na	mercury(I) or mercurous	(Hg_2)*		
			mercury(II) or mercuric	Hg		
			tin(II) or stannous	Sn		
			zinc	Zn		
Nonmetals and Acid Radicals	acetate (from acetic acid)	(CH_3COO)	carbonate (from carbonic acid)	(CO_3)	arsenate (from arsenic acid)	(AsO_4)
	bromine (*in* bromides)	Br	chromate (from chromic acid)	(CrO_4)	nitrogen (*in* nitrides)	N
	chlorate (from chloric acid)	(ClO_3)	dichromate (from dichromic acid)	(Cr_2O_7)	phosphate (from phosphoric acid)	(PO_4)
	chlorine (*in* chlorides)	Cl	monohydrogen phosphate (from phosphoric acid)	(HPO_4)	phosphorus (*in* phosphides)	P
	cyanide (from hydrocyanic acid)	CN	oxalate (from oxalic acid)	(OOCCOO)†		
	dihydrogen phosphate (from phosphoric acid)	(H_2PO_4)	oxygen (*in* oxides)	O		
	fluorine (*in* fluorides)	F	oxygen (*in* peroxides)	(O_2)		
	hydrogen carbonate (from carbonic acid, also called bicarbonate)	(HCO_3)	sulfate (from sulfuric acid)	(SO_4)		
	hydrogen sulfate (from sulfuric acid, also called bisulfate)	(HSO_4)	sulfite (from sulfurous acid)	(SO_3)		
	hydroxyl [from water as H(OH)]	(OH)	sulfur (*in* sulfides)	(S)		
	iodine (*in* iodides)	I				
	nitrate (from nitric acid)	(NO_3)				
	nitrite (from nitrous acid)	(NO_2)				
	permanganate (from permanganic acid)	(MnO_4)				

*Mercury(I) compounds contain two mercury atoms acting *together* with a valence of II, e.g., mercury(I) chloride, Hg_2Cl_2, mercury(I) nitrate, $Hg_2(NO_3)_2$, and mercury(I) chromate, Hg_2CrO_4. The corresponding mercury(II) compounds are $HgCl_2$, $Hg(NO_3)_2$, and $HgCrO_4$.
†The oxalate radical is more usually written as (C_2O_4).

BONDING



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OBJECTIVES

Upon completion of the ILS Chem Pac on The Chemical Bond the student should be able to

1. Formulas

A. With the aid of a list of valences, given the names of 10 compounds named according to IUPAC rules, write the formulas for 9 of the compounds.

B. Given the formulas for 5 substances, identify the number of the various atoms present and the sum of all atoms present in a single molecule or formula unit of 4 of the substances.

C. Given the number of moles of 5 substances, and their formulas, calculate the number of particles--atoms, ions, molecules and/or formula units present in 4 of the substances.

2. Nomenclature

With the aid of a list of valences, given the formulas for 15 compounds, name 14 of the compounds according to IUPAC rules.

3. Oxidation Numbers

Given six formulas of molecules or ions, calculate the oxidation number of each element involved in five of the formulas.

4. Types of Bonds

Given the formula of a compound for which the octet rule is valid, draw an electron-dot (Lewis) formula to show the electron distribution and identify the type(s) of chemical bond(s) in 7 of the 8 compounds given.

ILS Chem Pac 4 - The Chemical Bond

[or "What Holds It Together?"]

Reading 1.1 - Read pages 42-43 in Medeiros, page 67 in Sackheim & Schultz, and pages 49 & 50 in Holum.
Notes:

Formulas are combinations of symbols which represent compounds or molecules. The nature and number of atoms in a molecule are also apparent from the formulas of a compound. However, the exact arrangement of the atoms is not apparent from the formula. For example, the formula of water is usually written H_2O, but each of the hydrogen atoms is in fact joined to the oxygen atom.

The number of atoms of an element in a molecule is indicated by a subscript. As above, H_2O implies that two hydrogen atoms and one oxygen atom are joined together in the water molecule. A coefficient is used to represent a number of atoms or molecules which are not joined, for example 2 H_2O and 3 H_2 represents two water molecules and three hydrogen molecules (each containing two atoms).

If a compound is ionic and does not exist in the molecular state, its formula represents the relative number of ions of each type in the crystal. Thus, NaCl means that in a crystal of sodium chloride, there are equal numbers of sodium and chloride ions present. Moreover, in one "mole" of sodium chloride there are one mole of sodium ions and one mole of chlorine ions.

To write the formula for a binary compound containing a metal, first write the symbols for both the metal and the non-metal in the compound. From the valence table find the valences of the two elements. Write in the proper figures to show that the sum of the valences is zero. Let's use these three steps to write the formula for aluminum sulfide. The symbol for aluminum is ...... (1) and the symbol for sulfur is ...... (2). The valence or oxidation number of Al is ...... (3) and the valence or oxidation number of S is ...... (4). One way to procede is to write the symbols side by side, and write each valence as a figure over the element it belongs with:

$$\overset{+3}{Al} \quad \overset{-2}{S}$$

Take the plus and minus signs off the figures, cross them over, and write them as subscripts. The formula then becomes Al_2S_3. This formula indicates two Al atoms with a valence of +3 each for a total of ...... (5) and three S atoms with a valence of -2 each for a total of ...... (6). Adding these totals, +6 plus -6, the valences add up to ...... (7).

To write the formula for a ternary compound procede as before, treating the radical as a single unit. An example of a ternary compound is sodium sulfate which contains the three elements ...... (8), ... (9), and ...... (10). The sulfur and oxygen part of the formula is called the sulfate radical. It is made up of two elements, but they are together as SO_4^{2-} where the radical acts like an element in itself. As before, we write the symbols and valences for each part.

$$\overset{+1}{Na} \quad \overset{-2}{SO_4}$$

Crossing the valences, we obtain the formula ...... (11).

In writing formulas for binary compounds containing two non-metals, the prefix mono, di, tri, or tetra indicate the number of atoms of the second element. The formula for carbon dioxide is ...... (12) which shows one carbon atom and two oxygen atoms in the molecule.

The answers for Reading 1.1 are:

1. Al	7. zero
2. S	8. sodium
3. +3	9. sulfur
4. -2	10. oxygen
5. 2(+3) = +6	11. Na_2SO_4
6. 3(-2) = -6	12. CO_2

Self-test 1.2a

Write formulas for the following:

1. sodium oxide
2. calcium nitride
3. iron (III) chloride
4. tin (II) oxide
5. copper (I) sulfate
6. aluminum phosphate
7. nitrogen dioxide
8. phosphorous trichloride
9. iron (II) nitrate
10. copper (II) sulfate

Self-test 1.2b

How many atoms of each element--and total number of atoms--are present in the following formulas?

11. $Al_2(SO_4)_3$
12. $Cu(NO_3)_2$
13. Na_2CO_3
14. $Ca_3(PO_4)_2$
15. $K_2Cr_2O_7$

Self-test 1.2c

How many atoms, ions, molecules and/or formula units are present in one mole of the following substances?

16. NaOH
17. $CuCl_2$
18. Na_2O
19. $Fe(NO_3)_2$
20. $FeSO_4$

If you missed more than one problem in Self-test 1.2a, 1.2b, or 1.2c, take the NO route (CAI 1.3).

CAI 1.3 - FORM1 - Formula Writing

This tutorial-practice module will assist you in writing the formulas of binary compounds and compounds which contain radicals. The elements and radicals are randomly selected from lists which provide for formula writing of 360 different chemical compounds.

Again the computer teletype cannot write subscripts and lower case letters. It is also necessary for you to type all subscripts including **ones** (which are usually omitted). For example, water which is normally written H_2O, should be entered as H2O1. Be sure you type the letter O("OH) when you mean the letter and the 0 (zero) when you mean the number; likewise, be sure to type the number 1 and not an L for the number one.

Date Completed:

Self-test 1.4

CAI 1.3 will also count as Self-test 1.4. You should correctly write the formulas for 9 out of any 10 compounds presented in serial order.

Conference 1.5

If you are still having difficulty with formulas, please see your instructor.

Date:

Notes:

Reading 2.1 Read the same pages as in Reading 1.1.

To name a binary compound (contains only two types of elements) first name the positive element. If more than 1 common oxidation state exists, indicate the oxidation state by Roman numerals in parentheses. Then name the negative element, using the suffix "ide." For example, CaO is calcium oxide and $FeCl_2$ is iron (II) chloride.

If there is more than one compound formed by two non-metallic elements, the prefixes mono, di, tri, etc. are generally used to indicate how many atoms of the second element are present. For example, CO is carbon monoxide and CO_2 is carbon dioxide.

HCl is the formula for the gas named hydrogen chloride. It is also the formula for an acid derived from a binary compound. To name this type of acid, place the term hydro at the front of the stem of the negative ion, the letters ic at the end of the stem, and add the word acid. Thus, HCl is hydrochloric acid.

To name compounds which contain more than two types of elements, first name the positive element the same way as previously. Then name the negative radical based upon the following:

	SALT		ACID	
	PREFIX	SUFFIX	PREFIX	SUFFIX
GREATEST # OF OXYGEN ATOMS	Per-	-ate	Per-	-ic acid
1 LESS O ATOM	---	-ate	---	-ic acid
2 LESS O ATOMS	---	-ite	---	-ous acid
3 LESS O ATOMS	Hypo-	-ite	Hypo-	-ous acid
ZERO O ATOMS	---	-ide	Hydro-	-ic acid

Examples

$NaClO_4$ = sodium perchlorate — $HClO_4$ = perchloric acid

$NaClO_3$ = sodium chlorate — $HClO_3$ = chloric acid

$NaClO_2$ = sodium chlorite — $HClO_2$ = chlorous acid

NaClO = sodium hypochlorite — HClO = hypochlorous acid

NaCl = sodium chloride — HCl = hydrochloric acid

For acid salts (e.g. NaH_2PO_4), include hydrogen with an appropriate prefix in the name of the compound. Thus, NaH_2PO_4 is sodium dihydrogen phosphate. However, the latter compound is also properly called sodium hydrogen phosphate in another system.

Self-test 2.2

Name the following compounds according to IUPAC rules.

1. NaCl
2. CaC_2
3. $AlCl_3$
4. CuCl
5. $CuCl_2$
6. SO_2
7. SO_3
8. HBr
9. H_2S
10. H_3PO_4
11. H_3PO_3
12. H_3PO_2
13. $Ca_3(PO_4)_2$
14. $Ca_3(PO_3)_2$
15. $Fe_2(SO_4)_3$

If you missed more than one name in Self-test 2.2, take the NO route (CAI 2.3).

CAI 2.3 - NOBIN - Inorganic Nomenclature

This module provides drill in naming up to 152 binary compounds which are randomly generated. A brief review of IUPAC rules is also available.

This computer program first checks the name of the positive ion and then the name of the negative ion. Thus you must enter each name separately as shown in the following example.

Computer: NACL
Student: SODIUM (return)
Student: CHLORIDE (return)
Computer: GOOD...

You may terminate your work on this module at anytime by entering the word STOP.

Date Completed:

CAI 2.4 - NOTER - Inorganic Nomenclature

This module provides drill in naming the oxygen-containing acids and their salts. Formulas are randomly generated from a bank of 52 ternary compounds. A review of nomenclature rules is also available.

In this program it is NOT necessary that the name of each ion be entered separately. Thus a typical exchange would be:

Computer: NACLO4
Student: SODIUM PERCHLORATE (return)
Computer: GOOD...

Again you may terminate your work at anytime by entering the word STOP.

Date Completed:

Self-test 2.5

CAI 2.3 and 2.4 will also be used as Self-test 2.5. You should correctly name 14 compounds of any 15 presented in serial order in either or both modules.

Conference 2.6

If you are still having difficulty with nomenclature, please see your instructor.

Date:

Notes:

Reading 3.1 - Read pages 60-61 in Medeiros, page 63 in Sackheim & Schultz, and pages 46 & 47 in Holum.
Notes:

The term oxidation number is an "artificial" electron bookkeeping device useful to chemists and arrived at by using the following rules:

1. Oxygen always has an oxidation number of -2 in any compound (except peroxides where it is -1).
2. Hydrogen always has an oxidation number of +1 in any compound (except hydrides where it is -1).
3. The algebraic sum of all the oxidation numbers in any compound must equal zero and in any radical must equal the charge on the radical.

To illustrate these rules look at $KMnO_4$. Each oxygen has an oxidation number of -2 so that 4 of them will total -8. Potassium, in Group Ia, has an oxidation number of +1. Since the sum must equal zero and we already have -8 for the oxygens and +1 for the potassium, the Mn (manganese) must have an oxidation number of +7 (+1 and +7 and -8 = 0).

Self-test 3.2

In H_2SO_4 the oxidation number of oxygen and hydrogen, as always, is -2 and +1 respectively. The oxidation number of sulfur is ...... (1). In $K_2Cr_2O_7$ the oxidation numbers of the elements are: potassium ...... (2), chromium ...... (3), and oxygen ...... (4). In Na_2SO_3 the respective oxidation numbers are: sodium ...... (5), sulfur ...... (6), and oxygen ...... (7).

Looking at the radical by itself, $[SO_3]^{2-}$, we see an oxidation state of minus two. Therefore, the sum of the oxidation numbers of the elements in the radical must equal -2. Three oxygens equal -6 and sulfur, therefore, to give a total of -2 must itself have an oxidation number of +4. In the nitrite radical, $[NO_2]^{1-}$, N has an oxidation number of ...... (9). P, in the phosphate radical, has an oxidation number of ...... (10).

Conference (3.3)

If you are still having difficulty with oxidation numbers, please see your instructor.

Date:

Notes:

Reading 4.1 - Read pages 40-41 and 44-51 in Medeiros, and pages 62-66 in Sackheim & Schultz, and pages 50-56 in Holum.
Notes:

The chemical activity of the elements is said to be due to the electrons in the outer energy level of the element. These electrons are called valence electrons. All elements react by gaining, losing, or sharing these valence electrons. An atom which has lost or gained electrons is called an ion. The element sodium (Group Ia) reacts by losing one electron to form the positive ion: Na^+. Chlorine (Group VIIa) reacts by gaining one electron to form the negative ion: Cl^-. These two oppositely charged ions are held together by the electrostatic attraction of their charges. This type of attraction, resulting from the transfer of electrons, is called an electrovalent or ionic bond.

Electrons can also be shared by two elements. In the case of hydrogen (H_2) the two hydrogen atoms share the two electrons. This type of sharing is called a covalent bond. Both elements have an equal attraction for the pair of electrons. However, in the compound HCl, while the two atoms share two electrons, the chlorine atom has a greater attraction for the electron pair than does the hydrogen atom. This "unequal" sharing is called a polar covalent bond.

A measure of the tendency to gain electrons is called electronegativity. Thus, an element with a high electronegativity will be one which has a great attraction for electrons and vice versa. Following is a table of the electronegativities of some common elements starting with F which has been assigned en electronegativity of 4.0. The greater the difference between the electronegativities of two elements chemically reacted with each other, the more ionic is the bond. As a "rule of thumb" we will establish an electronegativity difference of 2.3 or greater to consider a bond to be ionic.

Table 1 ELECTRONEGATIVITY VALUES OF SOME ELEMENTS
(on the arbitrary Pauling scale)

H 2.1																
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0	Sc 1.3	Ti 1.6	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5
Cs 0.7	Ba 0.9	La 1.1	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2
Fr 0.7	Ra 0.9	Ac 1.1														

Using the above table, decide whether a given bond is more likely to be ionic or more likely to be covalent. For example, in HCl, H has an electronegativity of 2.1 and Cl has an electronegativity of 3.0. The difference in these two electronegativities is 0.9 which is less than 2.3 so the bond is more likely to be covalent.

Self-test 4.2

In Na_2O the electronegativity of sodium is ...... (1) and oxygen is ...... (2) which gives an electronegativity difference of 2.6. This means the bond in Na_2O is more likely to be ...... (3).

Identify the type of bond in the following compounds.

4. PCl_3
5. K_2O
6. CaO
7. NO_2
8. AlN
9. $MgBr_2$
10. BF_3

If you missed more than one type of bond in Self-test 4.2, take the NO route (CAI 4.3).

CAI 4.3 - ELECN - Bonding and Electronegativity

With the aid of a Periodic Chart and a Table of Electronegativities, this module provides drill in identifying the more electronegative element and deciding if the bond of a chemical compound is more ionic or more covalent. The compounds are randomly generated.

Date Completed:

Self-test 4.4

CAI 4.3 will also count as Self-test 4.4. You should correctly identify the bonds in seven out of eight compounds presented in serial order.

Conference 4.5

If you are still having difficulty with types of bonds, please see your instructor.

Date:

Notes:

EXAM

ILS Pac 4 Exam will consist of 10 questions.

Objective 1 - Formulas - 3 questions

Objective 2 - Nomenclature - 3 questions

Objective 3 - Oxidation Numbers - 3 questions

Objective 4 - Types of Bonds - 1 question

See ILS Pac 0 (Student Directions) for Grading System Equivalents. Please remember that although the Exam is necessary for a grade it may not be sufficient. You may also be asked to have a final conference with your instructor.

CONFERENCE

Date:

Notes:

SUPPLEMENTARY MATERIAL

Objective 2 - Nomenclature

Program-Tape #8: Nomenclature

Objective 3 - Oxidation Numbers

Program-Tape #7: Oxidation Number, Formal Charge

Objective 4 - Types of Bonds

Audio-Tape A1: Lewis Structure and The Shapes of Molecules

ANSWERS

Self-test 1.2a

1. Na_2O
2. Ca_3N_2
3. $FeCl_3$
4. SnO (NOT Sn_2O_2)
5. Cu_2SO_4
6. $AlPO_4$ (NOT $Al_3(PO_4)_3$)
7. NO_2
8. PCl_3
9. $Fe(NO_3)_2$
10. $CuSO_4$

Self-test 1.2b

11. 2 Al, 3 S, 12 O and 17 total
12. 1 Cu, 2 N, 6 O and 9 total
13. 2 Na, 1 C, 3 O and 6 total
14. 3 Ca, 2 P, 8 O and 13 total
15. 2 K, 2 Cr, 7 O and 11 total

Self-test 1.2c

16. 6×10^{23} atoms & ions each of Na, O, H, Na^+ and OH^-
17. 6×10^{23} Cu atoms & Cu^+ ions
    $2 \times 6 \times 10^{23}$ (1.2×10^{24}) Cl atoms & Cl^- ions
18. $2 \times 6 \times 10^{23}$ (1.2×10^{24}) Na atoms & Na^+ ions
    6×10^{23} O atoms & O^{2-} ions
19. 6×10^{23} Fe atoms & Fe^{2+} ions
    $2 \times 6 \times 10^{23}$ (1.2×10^{24}) N atoms & NO_3^{2-} ions
    $6 \times 6 \times 10^{23}$ (3.6×10^{24}) O atoms
20. 6×10^{23} Fe atoms & Fe^{2+} ions
    6×10^{23} S atoms & SO_4^{2-} ions
    $4 \times 6 \times 10^{23}$ (2.4×10^{24}) O atoms

There are 6×10^{23} molecules or formula units in each formula.

Self-test 2.2

1. sodium chloride
2. calcium carbide
3. aluminum chloride
4. copper (I) chloride
5. copper (II) chloride
6. sulfur dioxide
7. sulfur trioxide
8. hydrobromic acid
9. hydrosulfuric acid
10. phosphoric acid
11. phosphorous acid
12. hypophosphorous acid
13. calcium phosphate
14. calcium phosphite
15. iron (III) sulfate

Self-test 3.2

1. +6
2. +1
3. +6
4. −2
5. +1
6. +4
7. −2
8. +5
9. +3
10. +5

Self-test 4.2

1. 0.9
2. 3.5
3. ionic
4. covalent
5. ionic
6. ionic
7. covalent
8. covalent
9. covalent
10. covalent