SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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National Science Education Standard—Physical Science
Chemical Formulas and Chemical Bonds

Atoms interact with one another by transferring or sharing electrons that are farthest from the nucleus. These outer electrons govern the chemical properties of the element

Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.

Teacher Materials

Learning Sequence Item:

1042

The Periodic Table, Electrons, and Chemical Bonds

January 1997
Adapted by: Gary Freebury, George Miller, and Linda Crow

Chemical Formulas and Chemical Bonds. Using an element's position on the periodic table and the idea of stable octets, students should determine the number of valence electrons the element would transfer or share in forming chemical bonds and the type of bonding that would occur when the element combines with another (*Chemistry, A Framework for High School Science Education, p. 56).*

Contents

This micro-unit was adapted by **Gary Freebury** (Flathead High School, Kalispell, Mont.), **George Miller** (University of California, Irvine), and **Linda W. Crow** (University of Houston-Downtown)

1042
Learning Sequence

Chemical Formulas and Chemical Bonds. Using an element's position on the periodic table and the idea of stable octets, students should determine the number of valence electrons the element would transfer or share in forming chemical bonds and the type of bonding that would occur when the element combines with another (*Chemistry, A Framework for High School Science Education, p. 56).*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
Table Tales **Activity 1** Confirming a Formula **Activity 2** Binary Formulas **Activity 3** Bonding Properties **Activity 4** Ionic Compounds **Assessment 1** Water by a Different Name **Assessment 2**			

Suggested Sequence of Events

Event #1

Lab Activity

1. Table Tales (20 minutes)

Event #2

Lab Activity

2. Confirming a Formula (30 minutes)

Event #3

Lab Activity

3. Binary Formulas (40 minutes)

Event #4

Lab Activity

4. Bonding Properties (30 minutes)

Event #5

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

Readings to be added.

Assessment items are at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple-choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

Table Tales

What can we find out using the periodic table?

Overview:

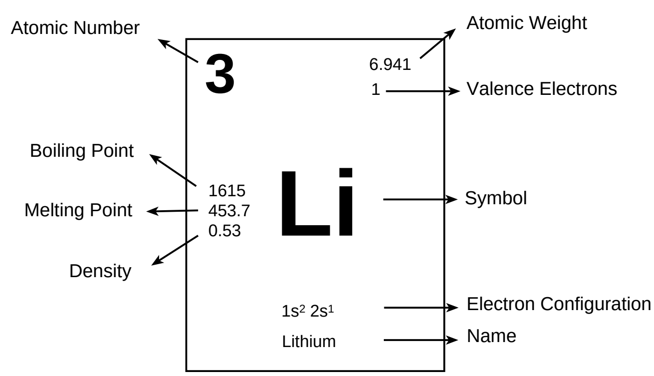
The periodic table allows us to easily determine the number of valence (or outer) electrons of a particular element by identifying the group to which the element belongs. This leads naturally to formulas for most compounds. In this activity students use the periodic table to determine the number of valence electrons for certain elements. It is assumed that students have already completed the micro-units concerning atomic structure (1038, 1039 and 1040). Students will have some difficulty in completing this micro-unit if they have not had the important experiences included in these earlier micro-units.

Materials:

Per student:
periodic table

Procedure:

Most periodic tables provide a wealth of information. Spend some time with students pointing out what can be determined with just this one table. For example:



Note that for this element, lithium, the atomic number, atomic weight, valence electrons, symbol, electron configuration, name, density, melting point, and boiling point are all given in a single box. Most tables have a key that identifies the information included in the table.

Using a periodic table, students should determine the number of valence electrons for the following elements: hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, neon, sodium, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, argon, potassium, and calcium. They should record their observations on a worksheet.

Then discuss with the class how these elements come together to form compounds. Indicate that elements must "bond" to form a compound, that this bonding involves the outer electrons (valence electrons), and that the goal in bonding is have a complete stable outer shell (usually eight electrons, the law of octets). Ask students the following question: Would it be easier to lose only one electron or to gain seven electrons? Students should understand that it would be easier to lose the one electron rather than to gain seven more electrons. Follow this question up with a series of questions concerning other combinations (lose two electrons or gain six electrons, lose three electrons or gain five electrons, etc.). By the end of this discussion students should conclude that if an element has one to three electrons or six to eight electrons, an easy decision can be made regarding gaining or losing electrons. However, if an element has four electrons in its outer shell the situation is not as clear.

At this point students should return to their worksheets of valences and predict whether the elements will tend to lose or gain electrons and how many electrons will be involved in this process. They should understand that the valences (oxidation numbers) are positive or negative. Since students have been exposed to atomic structure in previous micro-units, they should be able to explain that the total charge is indicated by the positive or negative charge. For example, sodium has a +1 valence, indicating that it would lose one electron and have an excess positive charge (proton). It is important that students come to these conclusions. Have them save their worksheets of valences and predictions. They will use this list later in Activity 3 and in micro-unit 1043.

Background:

The periodic table is a valuable tool that does more than just group elements neatly on a single sheet of paper. It can become a useful reference document. Most periodic tables have a key explaining what information is provided with each individual element. The number of electrons in the outer shell is important to determine since they control both the bonding and physical properties of that substance.

Variations:

None suggested.

Adapted from: none

Science as Inquiry

Confirming a Formula

How can we experimentally determine a formula?

Overview:

In this experiment students use a microchemistry approach to determine the formula of cobalt hydroxide. In the process they also determine the number of valence electrons for both the cobalt and hydroxide ions.

Note: Cobalt compounds are toxic and should not be placed as is in the sewer system. To dispose of cobalt compounds, first acidify the materials with 6-*M* hydrochloric acid and then add 3-*M* sodium sulfide. The cobalt will precipitate out as cobalt sulfide, and this compound can be thrown into the trash. Sodium hydroxide is caustic and corrosive. Be sure to wash hands after using these substances.

Materials:

Per class (demos):

test tubes (6 × 50 mm), 3
sodium hydroxide (.4 *M*), 60 mL
cobalt chloride (.4 *M*), 4 mL
ammonium thiocyanate (NH_4SCN) (5%), 1 mL
phenolphthalein (1%), 1 mL
micro-tip pipettes (1 mL), 2

Per lab group:

well plate (96 wells)
test tubes (6 × 50 mm), 11
micro-tip pipette (1 mL)
micro-tip pipettes (1 mL), as follows:
- pipette containing 1% phenolphthalein, 1
- pipette containing 5% NH_4SCN in acetone, 1
- pipettes containing .4-*M* sodium hydroxide, 3
- pipettes containing .4-*M* cobalt chloride, 3

ruler (with mm graduations)
graph paper

Procedure:

Begin this lab activity with three quick demonstrations of significant color changes that occur when color indicators are added to solutions containing sodium hydroxide and cobalt chloride. Be sure to use large enough amounts so that students can see the colors. To increase the amounts indicated just maintain the proportion of sodium hydroxide to cobalt chloride. An overhead could be used to display the colors, or the tubes could be passed around for firsthand observations.

Demo 1. Add 4 mL of sodium hydroxide to 20 mL of cobalt chloride. Add 2 drops of ammonium thiocyanate (NH_4SCN). Let the precipitate settle out. Students will observe the characteristic turquoise color of the liquid above the precipitate (decantate). The precipitate should also be blue-green. This indicates an excess of cobalt.

Demo 2. Add 20 mL of sodium hydroxide to 4 mL of cobalt chloride. Next add 2 drops of phenolphthalein. Let the precipitate settle out and show students the characteristic cream-colored precipitate. This indicates an excess of hydroxide.

Demo 3. Similarly, mix 20 mL of sodium hydroxide with 2 drops of phenolphthalein, revealing the pink color change. Phenolphthalein is an indicator of the presence of hydroxide.

Now have students place the 11 small test tubes in the first row of their 96-well plate. They should then add 24 drops of sodium hydroxide to test tube 1 and 24 drops of cobalt chloride to test tube 11. These test tubes (1 and 11) will serve as controls.

Students then add cobalt chloride to test tubes 2 through 10. Beginning with test tube 2, they add 4 mL of cobalt chloride, adding 2 mL more to each subsequent test tube (6 mL to test tube 3, 8 mL to test tube 4, etc.). An empty pipette can be used to transfer these volumes.

Next have students add sodium hydroxide to test tubes 2 through 10. They first add 20 drops to test tube 2. They then add 2 drops *less* to each subsequent test tube (18 mL of to test tube 3, 16 mL to test tube 4, etc.). An empty pipette can be used for this process.

When students have completed these additions, each test tube should contain the same volume—24 drops. Have them stir the solutions with a toothpick and then allow the test tubes to rest for approximately 30 minutes so that the precipitate settles to the bottom. While they are waiting have them construct a table as illustrated below showing the number of drops of cobalt chloride in each tube, the number of drops of sodium hydroxide in each tube, and the ratio of the number of drops of cobalt chloride to the number of drops of sodium hydroxide. After the precipitate has settled, students should measure the height of the precipitate in each test tube in millimeters and record each in their table.

Test Tube No.	Drops of Cobalt Chloride	Drops of Sodium Hydroxide	# of drops Cobalt Chloride / # of drops of Sodium Hydroxide
1	0	24	0/24
2	4	20	4/20
3	6	18	6/18
4	8	16	8/16
5	10	14	10/14
6	12	12	12/12
7	14	10	14/10
8	16	8	16/8
9	18	6	18/6
10	20	4	20/4
11	24	0	24/0

Next have students add the indicators:

Ammonium thiocyanate (NH_4SCN). Add 2 drops of NH_4SCN to each test tube, beginning with test tube 11, until there is no color change (2 drops to test tube 11, 2 drops to test tube 10, 2 drops to test tube 9, etc.)

Phenolphthalein. Add 2 drops of phenolphthalein to each test tube, beginning with test tube 1, until there is no color change (2 drops to test tube 1, 2 drops to test tube 2, 2 drops to test tube 3, etc.).

They should note any color changes and record these observations in their data table.

Background:

This experiment will reveal the number of valence electrons of cobalt and hydroxide and the resulting formula for cobalt hydroxide. Test tube 4, whose ratio is one to two, will produce the greatest amount of precipitate as measured with a ruler. This precipitate is cobalt hydroxide. This test tube will not change color with either indicator (ammonium thiocyanate or phenolphthalein). The ratio reveals the chemical formula and number of valence electrons for both cobalt and hydroxide. The chemical formula is $Co(OH)_2$, which means that cobalt has only two valence electrons and hydroxide has seven.

Test tubes 5 through 12 will have an excess of cobalt and should turn turquoise when ammonium thiocyanate is added. Test tubes 1 through 3 will have an excess of hydroxide and should turn pink when phenolphthalein is added.

To prepare the solutions:

1% phenolphthalein. Dissolve 1.0 g of phenolphthalein in 60 mL of 95% ethanol and dilute to 100 mL with distilled water. Solutions can also be purchased directly from scientific supply houses.

5% ammonium thiocyanate. Dissolve 5 g of NH_4SCN in 95 mL of acetone. Store in glass container and prepare fresh.

0.4-*M* cobalt chloride. Add 9.52 g of cobalt chloride to enough distilled water to make 100 mL of solution.

0.4-*M* sodium hydroxide. Add 1.6 g of sodium hydroxide to enough distilled water to make 100 mL of solution.

Variations:

None suggested.

Adapted from:
Ehrenkranz, David F. and John J. Mauch. *Chemistry in Microscale*. Iowa: Kendall-Hunt Publishing Company, 1991.

Teacher Sheet

Science as Inquiry

Naming a Binary Compound

What does the name of a compound tell us about the formula?

Overview:

In a previous micro-unit (1028), students learned the basic rules for balancing equations. Here students will build on that experience and examine the relationship between chemical formulas and their binary names.

Materials:

Per student:
periodic table
worksheet from Activity 1

Procedure:

Students are asked to name compounds formed by simple reactions. Make them aware of common names that are used instead of the binary names. For example CH_4 is referred to as methane instead of tetrahydrogen carbide.

The order in which the names of elements appear in compounds may create some unusual combinations. One easy way for students to remember order is that by convention the elements on the left side of the periodic table will be written first in this naming process (based on electronegativity). There is one exception—dichlorine oxide (Cl_2O). If two elements are in the same group or family (for example, fluorine and chlorine) the element that with the largest atomic number is written first (for example, ClF is chlorine fluoride).

A list of reactions and resulting compounds is included in the Student Materials. Have students provide the binary names. The names of the compounds are given in parentheses in the following teacher version.

Background:

Binary compounds consist of two elements that have been combined. Naming the compounds follows simple rules. The first word consists of the name of the first element (according to the convention above) and sometimes has a prefix indicating the number of atoms of the first element (to distinguish it from similar compounds with the same elements). The second word is composed of a prefix to indicate the number of atoms of the second element, followed by the name of the second element and the suffix "ide." For example, CO is carbon monoxide while CO_2 is carbon dioxide.

Variations:

None suggested.

Adapted from: none

$Mg(s) + H_2(g)$	$\longrightarrow$	$MgH_2(s)$ (magnesium dihydride)
$2Mg(s) + O_2(g)$	$\longrightarrow$	$2MgO(s)$ (magnesium oxide)
$Mg(s) + Cl_2(g)$	$\longrightarrow$	$MgCl_2$ (magnesium dichloride)
$2Al(s) + 3H_2(g)$	$\longrightarrow$	$2AlH_3$ (aluminum trihydride)
$4Al(s) + 3O_2(g)$	$\longrightarrow$	$2Al_2O_3(s)$ (dialuminum trioxide)
$2Al(s) + 3Cl_2$	$\longrightarrow$	$2AlCl_3$ (aluminum trichloride)
$C(s) + 2H_2(g)$	$\longrightarrow$	$H_4C(g)$ (tetrahydrogen carbide or methane)
$C(s) + O_2(g)$	$\longrightarrow$	$CO_2(g)$ (carbon dioxide)
$C(s) + 2Cl_2(g)$	$\longrightarrow$	CCl_4 (carbon tetrachloride)
$S(s) + H_2(g)$	$\longrightarrow$	$H_2S(g)$ (dihydrogen sulfide)
$S(s) + O_2(g)$	$\longrightarrow$	$SO_2(g)$ (sulfur dioxide)
$S(s) + Cl_2(g)$	$\longrightarrow$	SCl_2 (sulfur dichloride)
$H_2(g) + Cl_2 (g)$	$\longrightarrow$	$2HCl$ (hydrogen chloride)
$2Cl_2(g) + O_2(g)$	$\longrightarrow$	$2Cl_2O$ (dichlorine oxide)
$N_2(g) + 3H_2(g)$	$\longrightarrow$	$2H_3N(g)$ (trihydrogen nitride or ammonia)
$2N_2(g) + 3O_2(g)$	$\longrightarrow$	$2N_2O_3$ (dinitrogen trioxide)
$N_2(g) + 3Cl_2(g)$	$\longrightarrow$	$2NCl_3$ (nitrogen trichloride)
$F_2(g) + H_2(g)$	$\longrightarrow$	$2HF$ (hydrogen fluoride)

g = gas

s = solid

Teacher Sheet

Science as Inquiry

Bonding Properties

How do compounds reveal their bonding?

Overview:

In this activity students examine the physical properties of solids to see how these properties are associated with certain bonding types—ionic and covalent. For the most part, physical properties are determined by the type of bonding that holds the atoms together.

Materials:

Per lab group:

sodium chloride (solid), 4 g
silicon dioxide (silica gel or pure sand), 4 g
distilled water
evaporating dishes, 2
test tubes (with stoppers), 6
test tube rack
ring stand
crucible tongs
conductivity tester (battery operated)
spatula
stirring rod (glass)
Bunsen burner
metallic filings (optional)
lauric acid (optional)

Procedure:

Have students place 1-g samples of sodium chloride and silicon dioxide (sand) in separate evaporating dishes. They then test hardness by rubbing each solid with the end of a stirring rod and smell each substance (an odor usually indicates volatility).

Next, students add a small sample of each solid to separate test tubes. They place these tubes in a hot water bath and test for melting point. If the substances do not melt in the hot water bath, have students transfer the materials from the test tubes to an evaporating dish. Using a burner flame they can again try to determine the melting point.

To test for solubility, have students mix 0.5 g of each sample with 5 mL of water. They then stopper and shake the tube, looking for any signs of the solid dissolving. This solution should be saved for the next step.

Have students test conductivity by using a simple conductivity tester (battery, small bulb, and wire) to see if the substances will conduct an electrical current in the solid state and/or in a solution (saved from solubility test above).

Students can create data tables to organize their data and compare their results. Remind them that the differences can be explained by the bonding that holds these substances together and that this bonding can be explained by the valence electrons.

Background:

Students should easily be able to recognize the differences between these two solids. Sodium chloride has a high melting point, is brittle, is water soluble, and conducts electricity in a water solution. It possesses ionic bonds, reflected by the number of electrons that it has in its outer shell. Ionic solids such as sodium chloride have charged ions arranged in a crystal lattice in a way that creates a strong attraction. They are typically hard and have high melting points. They usually dissolve in water, and their solutions easily conduct electricity.

Silicon dioxide, which has covalent bonds, is hard, has a very high melting point, is not soluble in water, and will not conduct electricity in a water solution. Solids having covalent bonds have strong bonding that provides high melting points and an insolubility in water. They are generally nonconductors. It is important here that students note the physical differences between the two solids and relate them to the number of valence electrons.

Variations:

Metallic materials (iron filings) and molecular materials (lauric acid) provide examples of other types of bonding.

Adapted from:
Chemsource, *SourceBook*. New York: College of New Rochelle, 1994.

Science as Inquiry

Ionic Compounds

Item:

Calcium and phosphorus combine as an ionic compound. Write the correct formula and explain what you used as your criteria in arriving at this formula.

Answer:

Ca_3P_2. Calcium is located on the left side of the periodic table and tends to lose two electrons. Phosphorus needs three electrons. For both calcium and phosphorus to complete their outer layers (or shells) of electrons, three calcium atoms will need to lose six electrons to two phosphorus atoms, who need to gain six electrons.

Science as Inquiry

Water by a Different Name

Item:

What is the binary name for water? Why don't we use it?

Answer:

Dihydrogen oxide. The common name has been used for a long time and has been accepted as a correct name.

Consumables

Item	Quantity (per lab group)	Event
ammonium thiocyanate (NH_4SCN) (5%)	1 mL	2
cobalt chloride (.4 *M*)	4 mL	2
distilled water	—	4
graph paper	1 sheet	2
lauric acid (optional)	—	4
metallic filings (optional)	—	4
micro-tip pipettes (1 mL) as follows:		2
pipette containing 1% phenolphthalein	1	
pipette containing 5% NH_4SCN in acetone	1	
pipettes containing .4-*M* sodium hydroxide	3	
pipettes containing .4-*M* cobalt chloride	3	
periodic table, notebook size	1 per student	1, 3
phenolphthalein (1%)	1 mL	2
silicon dioxide (silica gel or sand)	4 g	4
sodium chloride, solid	4 g	4
sodium hydroxide (.4 *M*)	60 mL	2

Nonconsumables

Item	Quantity (per lab group)	Event
Bunsen burner	1	4
conductivity tester	1	4
evaporating dishes	2	4
micro-tip pipettes	3	2
stirring rod (glass)	1	4
ruler (mm)	1	2
spatula	1	4
ring stand	1	4
test tubes (6 × 50 mm)	14	2
test tubes with stoppers	6	4
test tube rack	1	4
crucible tongs	1	4
well plate (96 wells)	1	2

Key to activities:
1. Table Tales
2. Predicting a Formula
3. Binary Formulas
4. Bonding Properties

Activity Sources

Ehrenkranz, D.F. and J. J. Mauch. *Chemistry in Microscale.* Iowa: Kendall-Hunt Publishing Company, 1991.