UNIT 4

Organizing Atoms and Electrons

The Periodic Table and the Formulation of Compounds

Unit Overview

Unit 4 covers the most important and useful document in chemistry, the periodic table. Students will learn the history of the periodic table and how to decode the large amount of information provided by the table, including atomic mass, relative atomic size, and electron configuration. The unit also delves into the formation of ions and ionic compounds.

Learning Objectives and Applicable Standards

Participants will be able to:

1. Classify elements as metals, non-metals, or metalloids.
2. Synthesize the electron configuration and predict the reactivity of any element based on its position on the periodic table.
3. Identify trends in effective nuclear charge, atomic size, ionization energy, electron affinity, ionic size, and electronegativity.
4. Provide the name and formula of any ionic compound.

Key Concepts and People

1. **Dmitry Mendeleev and Henry Moseley:** Mendeleev is the father of the modern periodic table. He used relative masses and reactivity trends to make his version. Moseley ranked elements based on atomic number.
2. **A Tour of the Periodic Table:** The periodic table conveys important information about the elements, including atomic number, mass, and metallic character. The text provides a quick guide for interpreting this information.
3. **Periodic Trends:** Certain properties of elements, such as atomic radius, electronegativity, and ionization energy, change in predictable patterns from left to right and top to bottom on the periodic table. These trends allow us to rank elements with respect to these properties based on their relative position on the periodic table.

4. **Energy Levels, Orbitals, and Electron Configuration:** An atom's electrons are located outside its nucleus in energy levels and orbitals. There are rules that dictate in which energy level and orbital electrons of a given atom can be found.

5. **Forming Compounds:** Atoms will gain, lose, or share electrons to obtain a more stable electron configuration. To achieve this goal, atoms will form two major types of bonds: ionic and covalent. There are particular naming conventions that govern how ionic and covalent compounds are named.

Video

For centuries, chemists tried different methods to organize elements around patterns of chemical and physical trends, or regularities, eventually leading to the modern periodic table. Electron configuration is a powerful predictive tool, a simple extension from the periodic table. Physical characteristics, including atomic radius and reactivity, all depend on electron configuration and can be teased from a careful understanding of the periodic table. A living document, the periodic table is continually updated as new manmade heavy elements are discovered in research laboratories.

VIDEO CONTENT

Host Science Explanation
"Arranging the Elements"

Dr. Mala Radhakrishnan, Assistant Professor of Chemistry at Wellesley College, discusses the organization of the periodic table and the information that can be learned from it.

Laboratory Demonstration
"Periodic Trends in Reactivity"

Reactivity is the tendency of an element to undergo a chemical reaction. It increases as atomic number goes up in each group or family of elements. Harvard University Lecture Demonstrator Daniel Rosenberg drops lithium, sodium, and potassium into water to show that reactivity increases as you move down the alkali metal group. The demonstration ends with historic footage of 20,000 pounds of metallic sodium being dumped into a lake.

Host Science Explanation
"Electron Configuration"

Dr. Mala Radhakrishnan explains that the reactivity of an element depends on its atomic structure, and in particular, its electron configuration. Only the outermost, or "valence," electrons are involved in reactions. The formation of compounds is based on the fact that elements are more stable with a full outer shell of electrons. Elements in the same group in the periodic table have the same number of valence electrons, and thus will react in similar ways to obtain a full outer shell.

Laboratory Demonstration
"Alkaline Earth Metals"

Daniel Rosenberg demonstrates that the alkaline earth metals are less reactive than the alkali metals. He also shows that magnesium does not react readily with room temperature water, unlike lithium, sodium and potassium. Calcium, which is below magnesium on the periodic table, is more reactive in water than magnesium, but not as reactive as lithium, sodium, or potassium.

History of Chemistry
"Seaborg's Elements"

The periodic table is arranged in orbital blocks. The *s*, *p*, and *d* blocks demonstrate predictable patterns, but discovery of *f* block elements led to a rearrangement of the periodic table. Dr. Darleane C. Hoffman recounts the discovery of elements synthesized in the Lawrence Livermore National Laboratory in California during World War II. Dr. Glenn T. Seaborg, her collaborator, added the actinide series at the bottom of the periodic table because plutonium acted more like a lanthanide than a transition metal. Seaborg's team discovered many of the elements in the actinide series and beyond. Element 106 is named seaborgium in honor of Dr. Seaborg's many contributions to chemistry.

Current Chemistry Research
"Synthesizing New Elements"

Scientists at Lawrence Livermore National Laboratory are working on synthesizing superheavy elements, which are defined as elements above atomic number 107. They use particle accelerators to combine two smaller nuclei. Research teams analyze data about new, superheavy elements to determine physical and chemical properties.

Unit Text

Content Overview

The unit begins with a look at the scientists responsible for the development of the periodic table: Dmitri Mendeleev and Henry Moseley. The text then provides a tour of the periodic table, explaining the information contained in the individual boxes in the table as well as how to identify elements as metals, non-metals, and metalloids based on their location within the table. The text defines atomic mass, atomic number, and isotopes. The unit then discusses electron configuration and describes how a full valence shell is related to the stability of a given atom. The subsequent three sections focus on periodic trends, including effective nuclear charge, atomic radii, ionization energy, and electron affinity. The last two sections describe forming and naming ionic compounds.

Sidebar Content

1. **The Last Natural Element:** Rhenium represents the last element that was discovered in nature. The periodic table has continued to expand due to the discovery of

man-made elements in the laboratory.

2. **The Periodic Table as Art:** The periodic table can have many different arrangements, including artistic renderings. *Divining Nature: An Elemental Garden* is a 3-D art installation by Washington, D.C. artist Rebecca Kamen.

3. **Athletes, Artificial Steroids, and Carbon-14**: Different isotopes of carbon have different properties. By testing for the presence of carbon-14, carbon-12, and carbon-13 in the blood stream, sporting organizations can detect if an athlete has been using synthetic steroids.

4. **Mass Spectrometry:** Mass spectrometry identifies compounds based on their mass-to-charge ratio. Compounds are vaporized, ionized, and sent through magnetic plates toward a detector.

5. **Absorption of Strontium in the Aftermath of Chernobyl:** This sidebar explains the health risks of strontium-90 absorption in the area surrounding Chernobyl following the nuclear disaster in 1986. Strontium-90 can replace calcium in bones and cause many health problems.

Interactives

Historical Timeline of Chemistry

This interactive illustrates how different discoveries build upon, disprove, or reinforce previous theories. This not only reinforces basic chemistry concepts, but also emphasizes the nature of science. Scientists mentioned in this unit are listed on the timeline. It might be interesting to point out that Mendeleev developed his version of the periodic table well before the atomic theorists knew the internal structure of the atom.

During the Session

Before Facilitating this Unit

Some of the topics in this unit can be more methodical and less relatable to everyday life, such as electron configuration and nomenclature. It is important to give students lots of practice problems, but also to provide students with opportunities to move around the classroom and use their hands. These topics will often elicit questions such as, "When am I ever going to use this?" Use the video to show real-world applications.

Tips and Suggestions

1. **It is not necessary to memorize the periodic table**. It is more important to understand what information is contained within the periodic table and how to use the

periodic table to find it.

2. **When analyzing the data on trends, many students will notice that there are quite a few exceptions**. The point of this unit is to see the general trends and not become bogged down in the outliers. Assess students based on their knowledge of the trends, not on their ability to memorize exceptions.

3. Emphasize the fact that **Roman numerals convey the charge on a transition metal,** not the number of the atom in a molecule.

4. **Students will need lots of practice problems for nomenclature**. It can be very frustrating, so be creative when giving formative assessments or activities. See additional references for online tools to make quizzing students more interesting.

Starting the Session: Checking Prior Thinking

You might assign students a short writing assignment based on the following questions, and then spend more time discussing prior thinking. This will help elicit misconceptions.

1. What does it mean to be "periodic"? List two examples of phenomena that occur periodically.

2. What is an element?

3. What are some properties of metals and non-metals?

Before Watching the Video

Students should be given the following questions to consider while watching:

1. What is the trend in reactivity for the alkali metals?

2. List two factors that led to the development of the current periodic table.

3. How are new elements made and named?

Watch the Video

After Watching the Video

Use these additional questions as follow-up, either as a group discussion or as short writing assignments.

1. What are some of the advantages to the common form of the periodic table?

2. Explain what the following statement means: The periodic table is a living document.

3. What is the valence shell? Why is it important?

4. What is needed for magnesium to react with water? Why isn't that required for calcium?

5. What is a homolog? Why is it necessary to use a homolog in the study of super heavy elements?

Group Learning Activities

Make Your Own Periodic Table Project

Objective

Students will gain the experience of organizing related objects of their choosing. This activity emphasizes that the arrangement of similar objects can take many forms, but some are more useful than others. Many students are mystified by the periodic table, and this activity helps students to realize that it is just one way to organize elements.

List of Materials

- Student handouts outlining the project
- Computers
- Blank paper
- Markers
- Rulers

Setup

Make a handout detailing the instructions for the project as outlined in the procedure below.

Procedure

1. Divide the class into small groups and have each group select a topic to research. Make sure to obtain the teacher's permission before continuing. Example topics include shoes, fruit, vegetables, flowers, musical instruments, etc.

2. Create your own periodic table on the provided blank paper, using the rulers and markers.

3. Arrange examples of these objects into a periodic table that has 8 groups and 4 periods. The arrangement must demonstrate trends going from top to bottom within the groups and from left to right within the periods.

4. Projects will be graded on creativity, thoroughness, and a clear demonstration of trends.

Discussion

The following questions can help students think about what they have learned by doing the activity. Students may discuss the questions in-class or reflect on them in a journal.

1. What have you learned about organizing objects?

2. When your group was trying to determine its organizational scheme, was there only one correct answer? How did you decide which organizational scheme to use?

3. What patterns are evident in your periodic table? Try to think of another example of your chosen object and determine where it fits in your table.

Hazards
There is no increased risk of harm to do this activity.

Disposal
There are no special disposal considerations.

Color-Coding the Periodic Table

Objective
Students will analyze the trends in atomic radius, ionization energy, and electronegativity by color-coding the periodic table. Students will then be able to visualize where on the table the higher values tend to be, and where the lower values tend to be.

List of Materials
- Packet including values of atomic radius, ionization energy, and electronegativity for each element and three copies of the periodic table
- Colored pencils
- Calculators

Setup
Create packets including values of atomic radius, ionization energy, and electronegativity for each main group element and three copies of the periodic table. The periodic tables can be abbreviated to only include the eight main group elements, such as the one shown below. Each copy of the periodic table will be color coded for one of the trends.

H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar
K	Ca	Ga	Ge	As	Se	Br	Kr
Rb	Sr	In	Sn	Sb	Te	I	Xe
Cs	Ba	Tl	Pb	Bi	Po	At	Rn

Procedure
1. Develop a color scheme to represent large, medium, and small values for electronegativities. Electronegativities range from 0 to 4.0. Calculators may be needed to determine

reasonable ranges for each trend. An example of a potential range and color scheme could be:

0-1.2 = light green
1.2-2.6 = medium green
2.7 to 4.0 = dark green

2. Color each element on the periodic table according to the coloring scheme. On the first copy of the periodic table, fluorine would be shaded dark green because its electronegativity value is 4.0, and aluminum would be shaded a medium green because its value is 1.6.

3. Repeat by color-coding a new periodic table based on values of atomic radii, and then another for ionization energy. Make sure to include a key for the coloring scheme for each trend.

Discussion

Through this activity students will be able to see regions on the periodic table that tend to have larger or smaller values for each trend. The following questions can guide a discussion and help students reflect on this exercise.

1. What advantages does color-coding these trends provide?

2. What trends do you notice for electronegativity, atomic radius and ionization energy? Are there any similarities?

3. Which family of elements has the smallest atomic radii?

4. Based on the trend in atomic radius, rank the following elements from smallest to largest: Si, K, F, Al.

5. If an atom formed a positive ion by losing an electron, would you expect the atom to become larger or smaller? Why?

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

The Average Atomic Mass of Beanium (or Candium)

Objective

Students will practice calculating the average atomic mass of an element based on relative abundance. For this activity, a sample of different dried beans or small candy represents an element with multiple isotopes. Students will be given a random sample of a mixture of isotopes of the element and will calculate the average atomic mass of the element. At the end of this lesson, students should have a strong understanding of what an isotope is and how to calculate an average atomic mass.

List of Materials

- Samples of the element: either dried beans (kidney beans, navy beans, and chickpeas) or candy (Plain M&Ms, Peanut M&Ms, and Skittles)
- Balance
- Calculators
- Student handout

Setup

1. Divide the class into small groups.
2. Explain to students that the different beans or types of candy represent different isotopes of the element *beanium or candium*.
3. Provide each group of students with a sample of the element (about 50-100 pieces).

Procedure

1. Count the number of total particles and the number of each isotope.
2. Find an average mass of each isotope by weighing the total sample of the isotope and dividing by the number of particles.
3. Calculate an average atomic mass of the element based on the average mass and relative abundance of each isotope.

Discussion

The following questions can guide a discussion to help students reflect on this exercise.

1. How can atoms of carbon-13 can exist if the mass doesn't match the one listed on the periodic table.
2. What is an isotope?
3. How is an average atomic mass determined?

Hazards

Be aware of any students with allergies before allowing students to eat any leftover candy. Do not eat candy if activity was performed on a lab bench.

Disposal

Beans can be saved for use in subsequent years.

Bond with a Classmate

Objective

Students require lots of practice problems to master ionic nomenclature. Bonding with a classmate allows students to move around the room while practicing these key skills.

List of Materials

- 25-35 ion cards. Make sure there is an even distribution of positive and negative charges. For smaller classes, it is helpful to have extra cards on hand, and to allow students to switch their cards. Make sure to include transition metal ions and polyatomic ions in addition to the usual monatomic ions. For example, include Li^{+}, Mg^{+2}, Al^{+3}, N^{-3}, O^{-2}, F^{-}, Zn^{+2}, Fe^{+2}, Fe^{+3}, Cu^{+}, Cu^{+2}, SO_4^{-2}, SO_3^{-2}, CH_3COO^{-}, NO_3^{-}, NO_2^{-}, *etc.*

- Student handout: a chart with the following columns: Cation, Anion, Compound Formula, and Compound Name.

Setup

1. Randomly distribute one ion card to each student.

2. Provide each student with a copy of the handout to record his or her compounds.

Procedure

1. Find a classmate with an ion of the opposite charge.

2. Record the identity of the individual ions and the name and formula of the compound they form.

Discussion

Ask students to share with class and write on the blackboard the name and formula of the compound that they formed. Check to ensure that students named compounds with transition metals appropriately and used parentheses when needed with polyatomic ions.

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

Polyatomic Ion Bingo!

Objective

Bingo is used to reinforce the names and identities of the polyatomic ions. Many students have trouble remembering the difference between similar ions, for example nitrate, nitrite, and nitride, and this activity can help students become more familiar with the ions before using them to make compounds.

List of Materials

- 25-35 Bingo cards with the names of ions on them. Alternately, the card can be filled with formulas of ionic compounds, and you can call out names of ions like nitrate and iron(II)
- Bingo chips (optional)

Teacher Setup

1. Randomly distribute one Bingo card to each student.
2. Make sure to establish rules such as how many rounds each student can win, whether you will continue a round until there are two, three, or four winners, and what the prize will be for winning.
3. Call the formula of the ion. For the first few rounds, it is useful to write the formula on the board and allow students to use a chart with a complete list of the ions. Later rounds should be much faster.

Procedure

1. Use the chips to cover your card as the teacher calls the formula of the ion.
2. Yell out "Bingo" when you have five in a row.

Discussion

Teachers can use the following for a discussion or students can reflect on these

1. What is the difference between nitrate, nitrite, and nitride?
2. What do you think the suffixes –ate and –ite mean?
3. The ion arsenide was not used in the Bingo game. What do you think its formula would be? What about arsenate and arsenite?

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

In-Class Chemical Demonstrations

Reactivity of Alkali Metals

Objective

This demonstration shows that as a group of metals descends on the periodic table, the reactivity increases.

WARNING: Sodium and potassium are highly reactive. Safety precautions need to be taken. Consult the MSDS or SDS for each chemical.

List of materials

- Large beaker (600 or 1000mL)
- Small knife or spatula
- Watch glass
- Small, pre-cut pieces of sodium and potassium are available for purchase as part of a periodic reactivity kit from some chemical suppliers, such as Flinn Scientific. These will allow you to do similar demonstrations as in the video, but on a smaller scale. The pre-cut pieces can be further divided into two or three pieces to obtain a visible but controlled reaction.
- Phenolphthalein to observe the formation of a base in water. (*optional*)

Procedure

1. Fill a large beaker (600 or 1000mL) two-thirds full of water. Add phenolphthalein if desired.

2. The sodium and potassium pieces are stored in oil. Remove one piece of sodium from the container and place on a watch glass. Cut it in half with a small knife or spatula.

3. Drop the small piece of sodium in the water and observe the reaction. The water will turn pink if phenolphthalein was used.

4. Place the second piece of sodium in the water and again observe the reaction.

5. Repeat the process with potassium.

6. Return the sodium and potassium to a secure storage area.

Discussion

The following questions can help guide students to think about what they learned by observing this demonstration.

1. What is the trend in reactivity for the alkali metals?

2. Why is potassium more reactive than sodium?

3. Describe what happens at the atomic level in the reaction for both sodium and potassium. What are the products?

Hazards

It is good lab practice to review a chemical's Material Safety Data Sheet (MSDS or SDS) before working with any chemical. Follow instructions on the MSDS and encourage students to review them. Sodium and potassium are both very dangerous. The reaction should be done behind a blast shield and under a hood. Everyone in the room should be wearing safety goggles.

Disposal

Keep the remaining sodium and potassium in a secure location. The reacted water will be slightly basic. Check the pH and neutralize if necessary before disposing of it down the drain. Check local regulations for disposal criteria.

Going Deeper (In-Class Discussion or Reflection)

Teachers can use the following for a discussion or students can reflect on these questions in their journals.

1. What characteristics make the periodic table so useful for scientists and chemistry students alike?
2. Why are electron configurations of atoms important?
3. Why do atoms form ions and why do ions form compounds?
4. If you were to make a new element, what would you name it?
5. List 5 ways that chemistry students or scientists use the periodic table.
6. Would you rather win the Nobel Prize in chemistry or have an element named after you?

Before the Next Unit

Learners should read the Unit 4 text if they haven't already done so. They may wish to read one or more of the reading assignments from the list below, or, if you choose to have them use the course materials outside of class, they can watch the Unit 5 video and/or read the Unit 5 text as an assignment before the next session.

References and Additional Resources

Chemistry Interactive Review Activities. "Periodic Behavior and Ionic Bonding." ScienceGeek.net. Accessed July 23, 2013. http://www.sciencegeek.net/Chemistry/taters/directory.shtml

"Chemical Compounds Practice Quiz." Mr. Carman's Blog. Accessed July 23, 2013. http://www.kentschools.net/ccarman/cp-chemistry/practice-quizzes/compound-naming/

"Create Your Own Sporcle Games!" Sporcle.com Accessed July 23, 2013. http://www.sporcle.com/create/

Kean, Sam. *The Disappearing Spoon.* New York: Little Brown, 2010.

Kulis, Mark. *The Alien Periodic Table Challenge*. Accessed March 7, 2013. http://www.nclark.net/alienperiodictable___kulis.pdf

Logerwell, Mollianne G. and Donna R. Sterling. "Fun with Ionic Compounds." *The Science Teacher*, December 2007: 27-33.

Radioactive Wolves. Dir. Klaus Feichtenberger. By Klaus Feichtenberger. Perf. Harry Smith. PBS, 2011. DVD.

For Professional Development

In addition to watching the videos, reading the text, and going through the activities listed in the course guide, participants taking this course for professional development should read the following papers and answer the corresponding reflection questions. Participants should then complete the accompanying professional development assignments.

Further Reading & Reflection Questions

Salame, Issa., Samema Sarowar, Sazea Begum, and David Krauss. "Students' Alternative Conceptions about Atomic Properties and the Periodic Table." *The Chemical Educator* 16 (2011): 190-194. Accessed July 22, 2013. http://faculty.bmcc.cuny.edu/faculty/upload/Article-atomic-properties.pdf

1. Do you find the results of this study surprising? Why or why not?
2. What measures could you take to help students gain a conceptual understanding of periodic trends?
3. Do the results of this study change the way you think about assessing knowledge and understanding of periodic trends?

Talanquer, Vicente. "Recreating a Periodic Table: A Tool for Developing Pedagogical Content Knowledge." *The Chemical Educator*. 10(2005): 95-99. Accessed July 23, 2013. http://www.cbc.arizona.edu/tpp/TCEPeriodic.pdf

NOTE: Before reading the "Discussion and Reflection" section of this paper, think about, brainstorm, and write down ways that you would approach this activity. What strategies do you think you'd use to determine how to organize these elements?

1. In your brainstorming did you encounter any of the challenges encountered by the teachers in the study?
2. What does this activity offer that a simple matching of "alien" elements to the current periodic table does not?
3. What does this study reveal about the difficulty that high school students may have in understanding the periodic table?
4. How would you adapt this activity for high school classroom use?

Professional Development Assignments

1. After reading the papers above and reflecting on the questions presented develop a lesson plan designed to teach material presented in this unit.
2. Using a group activity or classroom demonstration presented in this course guide, show how you would implement it in your classroom. Where would it fit into your curriculum or standards? Would you change the demonstration or activity in any way? How would you assess student learning?