Atomic Structure: Elements

Strand Atomic Structure and Periodic Relationships

Topic Investigating atomic structure

Primary SOL CH.2 The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of
g) electron configurations, valence electrons, and oxidation numbers.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include
i) construction and defense of a scientific viewpoint.

Background Information (include information on periodic table)

In the periodic table, chemical elements are arranged by order of atomic number in such a way that the periodic properties (chemical periodicity) of the elements are made clear. The standard form of the table includes periods (usually horizontal in the periodic table) and groups (usually vertical). Elements in groups have some similar properties.

Students focus on the structure of the periodic table and the valance electrons in an element. Using this information with the octet rule, students use the power of the table to predict ion formation and the oxidation numbers associated with the ions formed.

Materials

- Periodic table of elements
- Clay in three different colors
- Toothpicks
- Six 12-inch balloons, two of each of three colors
- One 9-inch balloon of a different color
- String or ribbon
- Fluorescent bulb with some flaking of the white inner coating
- Light fixture for the bulb
- Bar magnet

Vocabulary

anion, cation, electromagnetic radiation, electron shell, electron-shell diagram, energy levels, ion, nucleus, orbita, orbital, oxidation, oxidation numbers, quanta, sublevel, valence

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introduction

1. Ask students to visualize the model of an atom as you draw an electron-shell diagram of a sodium atom. A sodium atom has 11 positively charged protons in its nucleus that will attract 11 electrons having negative electrical charges. The first two electrons attracted to

the nucleus will occupy the first electron-shell or energy level as though they were racing around the surface of a ping-pong ball with a marble inside it.

2. Now, ask students to imagine that the marble is the atom's nucleus and the surface of the ping-pong ball is the first electron-shell. The nucleus can attract nine more electrons. However, as those electrons fall toward the nucleus, the electrons that are already there repel them. In order for the forces of attraction (to the nucleus) and repulsion (away from the other electrons) to be balanced, the approaching electrons must reside in a higher electron shell farther away from the nucleus.
3. Next, ask students to imagine the ping-pong-ball-marble-atom placed inside a hollowed-out orange. According to the mathematical calculations made by the Danish physicist Niels Bohr and his colleagues, the second electron-shell can hold up to eight electrons before other approaching electrons are pushed to even higher energy levels. Therefore, the last electron attracted to the nucleus of the sodium atom will occupy the third energy level as though our hollowed-out-orange-ping-pong-ball-marble-atom were placed inside a basketball.
4. On the board, draw a model of electrons absorbing energy from one shell and leaping to the next shell, then falling back to the lower shell and giving off energy.
5. Have students copy this concept into their lab notebooks.
6. Inform students that Bohr's model of the atom was the first to explain why atoms of different elements give off specific colors of light when heated to very high temperatures: electrons leaping between energy levels emit specific frequencies of electromagnetic radiation.
7. On the board, write the formula for finding the amount of energy emitted by atoms: $E = hv$, where E = energy, v = the frequency of the radiation, and h = Planck's constant.
8. Explain that the German physicist Max Planck discovered that the amount of energy in all kinds of electromagnetic energy is always a multiple of Planck's constant. This means that all forms of electromagnetic energy are transmitted in tiny packets, which Planck called "quanta."
9. Assist students in constructing a clay model of atoms, using clay in three different colors and toothpicks. Assign each student a different element to work with. Advise them to space the electrons as far apart as they can within each electron-shell since they are repelling one another at all times.
10. Explain that the maximum number of electrons that can fit in the electrons-shells of atoms in the first three periods of the periodic table is 2, 8, and 8, respectively.
11. Show students how to draw Bohr electron-shell diagrams and write the electron dot structure for each element that they modeled in clay.

Procedure

Part 1: Introduction to Orbitals

1. Explain that each of the energy levels holds sublevels and that each sublevel in turn holds characteristic orbitals. There are four kinds of sublevels—s, p, d, and f. Each of these sublevels can hold a characteristic number of electrons, as follows:
   - s can hold up to 2 electrons.

- p can hold up to 6 electrons.
- d can hold up to 10 electrons.
- f can hold up to 14 electrons.

  Orbitals within these sublevels also have characteristic shapes. The s-orbitals have the shape of a sphere, while p-orbitals have the shape of a dumbbell, and d-orbitals have a clover-like shape, with one type appearing as a dumbbell within a doughnut. The f-orbitals are not well defined.

2. All of these orbitals layer on top of each other to form the electron cloud that is the outer portion of the atom. Each orbital's location is determined by the electrons that are characteristically found there, and each electron's location is determined by the energy it has. It is due to this layering that we describe the structure of the electron cloud as a series of nested spheres. Even though the orbital's take on nonspherical shapes, when the orbitals of a sublevel are combined, they form sphere-like shapes, which nest inside the next larger sphere-like shape. The location of these sphere-like shapes within the nested spheres is determined by their energy levels, that is, the energy levels of the electrons that are in them.
3. In this activity, students will form models of s- and p-orbitals, using balloons. Students should notice that while it takes one balloon to form the spherical s-orbital (holding a maximum of two electrons), each dumbbell-shaped p-orbital requires two balloons to form it. This is due to the limitations of working with balloons, which are quite large, when modeling electrons, which are quite small. To make it easier to see each of the p-orbitals, make sure students pair up two balloons of the same color (x, y, z).
4. Have students blow up the pairs of balloons to form teardrop shapes. Tell them not to blow them to their largest volume, as they will need room for flexibility.
5. Instruct students to attach the pairs of balloons together with string to form dumbbell shapes. Have them slide the pairs of balloons together at their middles, aligning them to form the x, y, z orbitals of a p-sublevel.
6. Next, have each student blow up the smaller balloon to form a spherical s-orbital and then try to determine the best way to attach it to the p-orbital model in order to illustrate its true location.
7. Once students have figured out how to connect the orbitals, lead them in a discussion, using the following questions.
   - What did you observe about how easily the teardrop/dumbbell shapes fit together? Can you visualize the sphere in the space that the p-orbitals form?
   - Why was it so difficult to place the s-orbital in its proper place? Can it be done using balloons?
   - Where would you find the individual electrons if this were the p-orbital of the element nitrogen?
   - Can you tell which balloon the electron(s) would be in? Why, or why not?
   - What do you think the third quantum level orbitals would look like?

Part 2: Orbital Diagrams and Electron Configurations

1. By now students should be wondering how to put all of the information about orbitals on paper. Using the above activity as a springboard, draw some orbital diagrams on the board. Explain that all orbital diagrams do is use arrows to represent the spin of the electrons. Give them the rules for creating orbital diagrams:
2. The Pauli Exclusion Principle states that an orbital can hold a maximum of two electrons.
3. The Aufbau Principle states that electrons are added one at a time to the lowest energy orbitals available until all the electrons of the atom have been accounted for.
4. Hund's Rule states that electrons occupy equal energy orbitals so that a maximum number of unpaired electrons result.
5. Have students practice drawing some orbital diagrams.
6. Use the periodic table to help students see the electron configurations. Show them how the periodic table can be divided by the orbitals. Point out that when writing the electron configurations, the sum of the superscripts in an electron configuration represents the total number of electrons in the atom.
7. Have students practice writing as many electron configurations with their matching orbital diagrams as possible before the class period is over.

Part 3: Ionization, Valence Electrons, and Chemical Properties of Families of Elements

1. After reviewing the structure of atoms according to the Bohr model, explain that electrons in the last electron-shell are "vulnerable," i.e., if an atom has fewer than four electrons in its outer shell, it tends to "lose" them. Losing negatively charged electrons will leave an atom with an excess of positively charged protons in the nucleus, and these protons cannot leave under ordinary circumstances. (Changing the number of protons in the nucleus of an atom changes that atom into an atom of another element; this occurs only in nuclear reactions.) An atom with more protons than electrons becomes a positive (+) ion, called a "cation."
2. Explain that atoms with more than four electrons in their outer shell tend to "gain" electrons. This is because "gaps" remain in unfilled shells far from the nucleus, allowing extra electrons to be attracted to the "exposed" protons of the nucleus. Underscore that outer shells are most stable when they are filled. An atom with more electrons than protons becomes a negative (−) ion, called an "anion." These atoms can also share their electron-shells with other atoms.
3. Hand out periodic tables, and have students label the charges that each family/group of elements carries once the element has lost or gained an electron. Point out some of the physical and chemical properties that these families have because of the activity of their valence electrons.

Part 4: Glow in the Dark

1. In this activity, students will explore some of the properties of a fluorescent light bulb, which usually contains argon and mercury vapor. In a lighted room, have students examine the fluorescent bulb and note where the inner white coating has flaked off.

(More information regarding the structure and function of a fluorescent light bulb may be found at http://home.howstuffworks.com/fluorescent-lamp2.htm.)

2. Have students examine the bulb briefly in a dark room.
3. Return to the lighted room, and connect the bulb to the light fixture. *CAUTION! Unplug the fixture while inserting the bulb.*
4. Turn on the bulb, and have students carefully observe how it lights up, noting any colors they see. Have them compare the colors they observe at the spots where the white coating has flaked off with those that they see on the rest of the coated bulb. *CAUTION! Avoid staring at the light for long time periods.*
5. Place the bar magnet against the glass bulb, and have students observe and note any changes in the light pattern.
6. Unplug the fixture, and carry it into the dark room.
7. Have students cover one eye while they turn on the bulb for two minutes. Then, have them turn off the bulb, uncover their eye, and observe the bulb closely in the dark.
8. End the lab with a discussion based on the following questions:

Assessment

- **Questions**
  - How does the appearance of the light coming from uncoated spots on the bulb compare to its appearance on the rest of the bulb? (Light is more white and intense where there is coating on the glass and less white and intense where the coating is missing.)
  - What evidence do you have that the gas inside the bulb contains charged particles? (Since the gas appeared to be attracted or repelled by the magnet, one may speculate that there are charged or ionized particles in the bulb. Current flows through the bulb mainly by ionizing the inert gas in the bulb.)
- **Journal/Writing Prompts**
  - Discuss the properties of the elements in the bulb. Explain why they are used in a fluorescent bulb.
  - Describe the appearance of the fluorescent bulb after you turned it off in the dark room. Explain the significance of the bulb's coating. (The coating on the bulb continued to emit some light when the electricity was turned off.)
- **Other**
  - Write a two-to-three-paragraph conclusion, summarizing what was illustrated in the labs and what information or insight was gained from it. Do not simply summarize the procedure, except as necessary to explain the conclusion.

Extensions and Connections (for all students)

- Have students write one paragraph explaining the connection between the balloons and the locations of electrons and telling how this illustrates the structure of the electron cloud.
- Have students create a timeline of historical models of atoms.

Strategies for Differentiation

- Have students use graphic organizer software to create a personal reference chart for the rules pertaining to orbital diagrams including: Pauli Exclusion Principle, Aufbau Principle, and Hund's Rule. They also need to include maximum number of electrons allowed on each sublevel.
- Have students access the Web site "David's Whizzy Periodic Table" to see the emission spectra for individual elements. It also shows the orbital filling diagrams, which help relate the two together by showing them in the same visual presentation.
- Have students participate in an activity to build cations and anions. Make index cards, each having an element symbol and its corresponding ion. Give each student a card and a small box of poker chips with each color assigned a different charge—positive, negative, and neutral. Have students use these for the protons, electrons, and neutrons for their assigned element. Have them manipulate the negative electron chips to make the corresponding ions. Students should be given at least one cation and one anion to practice. Then, after checking, have them draw and label the models in their notebooks.
- Have students use spectroscopes or prisms to view the colors in white light, sunlight, and a fluorescent light bulb. Also, have them view a tube filled with hydrogen or neon gas.
- Teach students that each element gives off an individual light and that this is how the colors of neon lights are created. Have students research various types of light (e.g., Halogen) to discover the elements used to create its color. Have them identify locations of neon lights in their community.