NanoLeap

Nanoscale Materials and Their Properties
Teacher Guide Unit 3: *Neat and Discrete Nanoparticle*s
Lesson 3.1 Carbon Chemistry

Objectives for *Neat and Discrete Nanoparticles*
Lesson objectives: Carbon Chemistry **(Bold)**
Students will be able to:

9. **Identify elements that can form discrete nanoparticles.**
    a. **Recognize that discrete nanoparticles are a result of covalent bonding patterns.**
10. **Compare and contrast the properties of several allotropes of carbon (i.e., graphite, diamond, fullerenes).**
    a. **Analyze the covalent bonding patterns of carbon and the resulting three dimensional shapes of molecules and carbon allotropes.**
    b. **Relate the bonding and structure of carbon nanoparticles to their properties (i.e., corannulene, buckyballs, fullerenes, nanotubes).**
11. Explore the potential applications of carbon nanoparticles and nanotechnology.
    a. Define nanotechnology as the use of discrete nanoparticles to produce useful products and materials.
    b. Compare and contrast endohedral (cage) and exohedral fullerene compounds and their applications.
    c. Describe the properties and potential uses of carbon nanotubes.
12. Evaluate the usefulness and feasibility of nanotechnology research and products for the future (i.e., space elevator).

Suggested Time Frame: 45–60 Minutes

Chemistry Concepts

- Carbon chemistry and bonding patterns
- Covalent bonds
- VSEPR Theory
- Allotropes of carbon
- Intermolecular Forces
- Organic chemistry (especially organic structural formulas)
- Mass Spectrometry

❖ **New Concept**
• **Review**

At a Glance for the Teacher

- Introduce the proposed space elevator

- Review carbon chemistry and bonding patterns
- Review VSEPR three-dimensional shapes
- Compare and contrast allotropes of carbon – diamond and graphite
- ❖ Introduce discovery of buckyballs
- ❖ Complete "Activity Sheet 4–Buckyball Model"
- Answer "Making Connections" questions
- Review "Flow Chart"

Materials

- PowerPoint – *Neat and Discrete Nanoparticles: Carbon Chemistry*
- Computer with LCD Projector
- Plastic hexagonal chicken fencing (optional)
- Clay balls and toothpicks to model VSEPR theory
- Student Handbook
- Student Handbook-Teacher Version

Advanced Preparation

- See Student Handbook-Teacher Version for specific material preparation.

<u>Slide #</u> **Student Handbook Page #**	*<u>Teacher Background Information and Pedagogy</u>* **Teacher Script**
Slide 1 Title Slide	
Slide 2	**Recall from the introductory video *NanoSize Me* that carbon nanotube cables are being considered to support a space elevator!** **Some groups think that the project can be launched by 2020!**
Slide 3	**For scale, note that the proposed ribbon reaches almost one-fourth of the way to the moon!**
Slide 4	**Why haven't we already built a space elevator?** (students might suggest that we lack the technology or the money to undertake this endeavor) {Click} **No materials were available that were both *strong* enough and *lightweight* enough.** {Click} **Carbon holds the key…**

Slides 5	
Slides 5 Refer to the Glossary in the Student Handbook for terms related to carbon chemistry. Student Handbook-TV: Page 97 Student Handbook Page: 58	1) *Refer to the Glossary in the Student Handbook for terms listed below related to carbon chemistry. At the end of this teacher guide "Direct Vocabulary Instruction" is described. One field test teacher had students work in pairs using this strategy for one vocabulary term. When complete the student pairs presented their term to the class.* o *Allotrope* o *Buckminsterfullerene* o *Buckyballs* o *Discrete Nanoparticles* o *Endohedral* o *Exohedral* o *Fullerenes* o *Multi-walled Nanotubes (MWNT)* o *Nanotubes* o *Single-walled Nanotubes (SWNT)* o *Ball and stick* 2) *Illustrate a model of methane, CH_4, in which the bonds (sticks) point in four tetrahedral directions.* 3) *Discuss how ionic bonds are not directional in nature. A sodium cation, for example, can be regarded as a spherical glob of charge that indiscriminately attracts as many negatively charged anions as possible in a structure determined largely by the relative sizes of the ions involved.* 4) *Review the trends with respect to bond type by asking the following question:* **What elements on the periodic table are most likely to form discrete nanoparticles? (i.e., Which elements predominately form covalent bonds?)** {Click} **Those that form covalent bonds, elements to the right of the transition metals, are most likely to form discrete nanoparticles.** *(groups 13 through 16)* {Click} **Why?** {Click} **These elements form covalently bonded molecules with specific geometry.** {Click} **The central atom in these molecules form a relatively small number of bonds to neighboring atoms.**

Slide 6	**Discrete nanoparticles have sizes in the range 1 to 100 nm, which resemble large molecules, and cannot be extended in three dimensions to make a macro-sized material. They are “individual” particles that have unique characteristics determined by their composition and structure.** **Characteristics of discrete nanoparticles:** {Click} demonstrate **covalent bonding** {Click} are **three-dimensional** {Click} include **individual “gigantic” molecules (e.g., cellulose, fats, plastics)** {Click} are **non-extendable** **What is meant by non extendable?** (They cannot get any bigger—cannot bond to anything else)
Slide 7	**Let’s focus our attention mostly on discrete nanoparticles made from *carbon*…** 5) *Emphasize the location of carbon in the periodic table and remind students that it has an atomic number of 6. This is a good time to review the number of protons, neutrons, and electrons along with atomic mass. Point out that this element forms covalent bonds exclusively.*
Slide 8	6) *Review carbon chemistry:* **What is carbon’s electron orbital diagram?** {Click} *Use the periodic table to review the orbital diagram to show carbon’s electron orbital diagram.* {Click} **How many bonds does carbon always form?** {Click} **four** {Click} **These can be**: • **four single bonds** • **two single bonds and one double bond** • **two double bonds** • **one single bond and one triple bond** 7) *Having ball and stick models available of the three configurations for students to view or build might be useful.*

Slide 9	8) *Review that carbon always forms four bonds and that these bonds are found in single, double, and triple patterns. Ask students to recall or draw each VSEPR shape and angle for each. Alternatively, have students use clay balls and sticks to model these bonding patterns.* • **four single bonds** {Click} **Tetrahedral with bond angles of approximately 109º** • **two single bonds and one double bond** {Click} **Planar with 120º bond angles** • **two double bonds** {Click} **Linear with 180º bond angles** • **one single bond and one triple bond** {Click} **Linear with 180º bond angles**
Slide 10	**What are allotropes?** *Allotropes are one of two or more forms of an element in the same physical state. Different allotropes can have very different physical and chemical properties.* {Click} **What are the common allotropes of carbon?** {Click} **graphite and diamond**
Slide 11	**How are the carbon atoms arranged in diamond?** {Click} **Each interior carbon is covalently bonded to four others in a tetrahedron.**
Slide 12	**How are carbon atoms arranged in graphite?** {Click} **The carbon atoms are arranged in planar layers (sheets).** *Single sheets are referred to as graphene.* {Click} **Each carbon atom is covalently bonded to three others resulting in a hexagonal pattern.** {Click} **Very weak forces exist between the layers (gray lines in the figure above).** {Click} **The individual layers extend indefinitely in two dimensions.**
Slide 13	9) *Review what we know about carbon and graphite, then pose the question:* {Click} **What is the bonding pattern around a given carbon atom in graphite?** {Click} **Two single bonds and one double bond.** *Note to Teacher: This is a classic resonance structure and many of the important properties of fullerenes are due to the extraordinary amount of resonance.*

Slide 14	**In the mid 1980s, scientists experimented by vaporizing graphite using a laser. In this process, graphite was vaporized by a laser beam into a carrier gas stream and the vaporization products were allowed to condense. A new substance was formed.** {Click} **This is a diagram of the first experiment with graphite.** 10) *You might also take this opportunity to provide the names of the principal investigators who were awarded a Nobel prize for their discovery that arose from these experiments. The names are Richard Smalley, Robert Curl, and Harold Kroto.*
Slide 15	**Scientists knew the substance was carbon, but it wasn't graphite, diamond, or individual carbon atoms.** {Click} **So, what was it?** {Click} **They proposed the formula of the material was C_{16}. How would chemists represent the structure of C_{16}?**
Slide 16	**C_{16} fragment – a flat structure that does not contain hydrogen.** {Click} **What is wrong with this picture?** {Click} **Hint: Remember, carbon always forms four bonds.** *Red arrows will appear pointing to the "dangling" bonds that have unsatisfied valences (i.e., only have three bonds rather than four).* **Answer: The ten carbon atoms on the outermost edges are bonded to only THREE other atoms!! These ten atoms contain unsatisfied valences or "dangling" bonds.** **The structure can't be C_{16}.**
Slide 17	**The product obtained in the lab was identified by mass spectrometry. The mass spectrum of the product is shown below. The major condensation product was a stable and surprisingly inert substance composed of PURE carbon, and it had a mass of 720 amu (or Daltons).** *Mass spectrometry is a technique that permits one to determine the exact mass of a material in a sample, including those that are very small. The output of a mass spectrometer is a graph of mass versus the relative amount of a given material having that specific mass.* {Click} **How many carbon atoms did the sample contain?** *To derive this answer, take the major particle's mass of 720 amu (the big peak) and divide by carbon's mass of 12 amu. Thus, 720 / 12 = 60 atoms, or, C_{60}.*

	{Click}	**The evidence points to the formula C_{60} (mass 720 amu).**
Slide 18		**Could the structure of C_{60} be flat?**
	{Click}	**No – just like the C_{16} fragment, a planar C_{60} structure would also have "dangling bonds" on the outer edges.**
Slide 19		**How can you bend a sheet of C_{60} to connect the carbon atoms with dangling bonds?**
	{Click}	**Will it work to roll the sheet into a cylinder?** *No - If you simply roll the sheet into a cylinder and connect the atoms at the edge, there are still carbon atoms with dangling bonds on the ends of the cylinder.*
		11) You may also provide a large sheet of plastic hexagonal chicken fencing to each student group OR demonstrate with one sheet in front of the class. Roll the sheet of fencing into a cylinder or tube. As the sheet is rolled, students will notice that the ends of the cylinder still have dangling bonds.
	{Click}	**So what is the solution? Perhaps the answer can be found by looking at an organic compound.**
Slide 20		**Notice that this molecule, corannulene *($C_{20}H_{10}$)*, possesses a single 5-membered ring in addition to five 6-membered rings.**
	{Click}	**Clearly, by adding a 5-membered ring, the structure takes on a bowl-like shape with curvature. Aha!**
		How does this shape differ from the previous examples? *It is curved.*
Slide 21 "Activity Sheet 4– Buckyball Model" Student Handbook-TV: Page 88 Student Handbook: Page 53		**The mystery of C_{60} was finally solved. This material incorporates both 5-membered and 6-membered rings.**
	{Click}	**It soon became known as a "buckyball" because it resembles the famous architecture of Buckminster Fuller. The Nobel Prize in chemistry was awarded in 1996 for this work.**
		12) Refer to "Activity Sheet 4: Buckyball Model", in which students will construct a paper model of a buckyball.
		13) It might be interesting to discuss resonance structures. Typically, all bonds in C_{60} are drawn as single bonds to simplify things, but obviously this is not correct.
Slide 22		*14) The "Making Connections" questions at the conclusion of each lesson can be used at the end of the class period or the beginning of the next day as a warm up. Generally the first few questions are a review of the present lesson, while the last question is a preview of future lessons.*

	Answer for question one: elements that form covalent bonds, elements to the right of the transition metals, are most likely to form discrete nanoparticles. *Answer for question two:* • *as four single bonds: tetrahedral with bond angles of approximately 109º* • *two single bonds and one double bond: planar with 120º bond angles* • *two double bonds: linear with 180º bond angles* • *one single bond and one triple bond: linear with 180º bond angles* *Answer for question three:* • *Diamond: each interior carbon is covalently bonded to four others in a tetrahedron* • *Graphite: each interior carbon atom is covalently bonded to three others in a hexagonal pattern*
Slide 23	*15) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence.*

Direct Vocabulary Instruction Strategy

When introducing new vocabulary to students, teachers can help students learn the meaning by following the steps below.

1. Present learners with a brief explanation or description of a new term. For example: "Adhesive: A substance that can stick to another object."

2. Then, present learners with a nonlinguistic representation of the new term or phrase. This could be a drawing, an artifact, or even acting out the meaning of a word.

3. Ask learners to generate their own verbal description of "adhesive."

4. Ask learners to create their own nonlinguistic representation of "adhesive."

5. Periodically ask learners to review the accuracy of their explanations and representations.

Adopted from: Marzano, R. J., Pickering, D. J., & Pollock, J. E. (2001). *Classroom instruction that works: Research-based strategies for increasing student achievement.* Alexandria, VA: Association for Supervision and Curriculum Development.