Nanoscale Materials and Their Properties
Teacher Guide Unit 3: *Neat and Discrete Nanoparticle*s
Lesson 3.2 Fullerenes and Nanotubes

Objectives for *Neat and Discrete Nanoparticles*
Lesson objectives: Fullerenes and Nanotubes **(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: 60–90 Minutes

Chemistry Concepts

- Covalent bonds
- Chemical Formulas

❖ **New Concept**
• **Review**

At a Glance for the Teacher

❖ Introduce and define fullerenes
❖ Complete “Problem Sheet 7–Volume of a BuckyBall”
❖ Explore possible applications of fullerene compounds
❖ Describe properties and characteristics of carbon nanotubes
❖ Explore applications of carbon nanotubes
- Revisit the space elevator
- Answer “Making Connections” questions
- Review “Flow Chart”

Materials

- PowerPoint – *Neat and Discrete Nanoparticles: Fullerenes and Nanotubes*
- Computer with LCD Projector and speakers for the 12-minute optional NOVA video
- Student Handbook
- Student Handbook-Teacher Version
- Calculator for students
- K-W-L

Advanced Preparation

- See Student Handbook-Teacher Version for specific material preparation
- Check your computer for the required media player to show the Nova Science Now video (hyperlinked on slide 20) found at http://www.pbs.org/wgbh/nova/sciencenow/3401/02.html

Slide # **Student Handbook Page #**	*Teacher Background Information and Pedagogy* **Teacher Script**
Slide 1 Title Slide	
Slide 2	**What are some possible uses for a buckyball? Some ideas proposed included:** {Click} **molecular ball bearings** {Click} **drug delivery vehicles** {Click} **semiconductors/transistors** {Click} **Generally speaking, the commercial applications of buckyballs are novel, yet immature, in their applications.**
Slide 3	**However, the buckyball discovery has led to research on a new class of materials called *fullerenes*, or *buckminsterfullerenes*.** {Click} **Fullerenes are materials with:** {Click} **a three dimensional network of carbon atoms,** {Click} **in which each atom is connected to exactly three neighbors, and** {Click} **each atom is bonded by two single bonds and one double bond (e.g., C_{82}).**
Slide 4	**Why is diamond not a fullerene?** *In diamond, each carbon atom is bonded to four other carbon atoms (all single bonds).* {Click} **Why is graphite not a fullerene?** *Even though each atom is bonded to three others, the sheets of graphite are planar (two-dimensional structure).* {Click} **Are fullerenes a new allotropic form of carbon?** *Yes. Since this pure form of carbon is unlike diamond and graphite, it is recognized as a family of carbon allotropes.*
Slides 5 "Problem Sheet 7– Volume of a Buckyball" Student	**What other questions can we ask about fullerenes?** *This is an open-ended inquiry slide.* *1) Ask students to brainstorm ideas. You may want to write the questions provided by the class on the board. Using leading questions, try to elicit the question "Can we put anything inside of it?" if they do not come up with that question on their own.*

Handbook-TV: Page 95 Student Handbook : Page 57	*Other questions that students ask can be answered as part of their poster assignment. Due to time constraints we will only focus on the question concerning volume of a buckyball.* **How about: "Can anything be put inside of it?"** {Click} **A buckyball is *approximately* 1 nm in diameter, as determined by experiment.** *The usually quoted diameter of a buckyball is 7.6 angstroms, but here we round it off in order to simplify the calculation in the Problem Sheet 7–*Volume of a Buckyball. 2) *Refer to "Problem Sheet 7–Volume of a Buckyball" and complete before continuing to Slide 6.*
Slide 6 "Problem Sheet 7–Volume of a Buckyball" Student Handbook-TV: Page 95 Student Handbook : Page 57	3) *Review question 4 on Problem Sheet 7:* **Would the following fit inside of a buckyball?** {Click} **An *atom* of nitrogen** {Click} **d = ~120pm** {Click} **Definitely** *An atom of nitrogen has been shown experimentally to be able to fit inside a buckyball.* {Click} **A *molecule* of sulfuric acid** {Click} **d = ~700pm** {Click} **Not Likely** *This rather large molecule most likely would not fit.* {Click} **A *molecule* of hydrogen** {Click} **d = ~150pm** {Click} **Quite possibly** *This is a very small molecule and so it would likely fit within a buckyball cage.*
Slide 7	**Fullerenes with material inside are called cage compounds, or *endohedral compounds*.** {Click} **The formulas of endohedral compounds are shown as $M@C_{60}$—where *M* represents the item inside of the cage.** {Click} **Examples of known compounds include: $N@C_{60}$ and $La@C_{82}$** {Click} **What possible applications might there be for endohedral buckyballs?**

	4) *Allow time for students to brainstorm ideas. Possible ideas may include:* o *hydrogen storage* o *delivery of radioactive metals entrapped inside of a fullerene to a particular site in a medical procedure.*
Slide 8	***Exohedral compounds*** **are those in which a wide variety of both inorganic and organic groups added to the** ***exterior*** **of the cage.** {Click} **These materials offer the most exciting potential for useful applications of fullerene materials.**
Slide 9	**Combination endo- and exohedral compounds have also been synthesized. An interesting example is:** {Click} **$Gd@C_{82}(OH)n$** {Click} **The gadolinium (Gd) is inside the cage and the outside is covered with hydroxyl groups.** {Click} **Gd@C82(OH)n is a possible enhancement material for magnetic resonance imaging, MRI.** 5) *You may need to explain that an MRI (Magnetic Resonance Imaging) is used to get detailed cross sectional images of the body. The contrast agent (Gd) helps in the detection of vascular tissues.*
Slide 10	**Commercial and biological possibilities exist:** {Click} **Sunscreens ~ due to the photophysical properties. They may reflect and absorb light of different wavelengths than macroparticles.** *For an extended investigation on sunscreens visit:* *http://www.nanosence.org/activities/clearsunscreen/index.html* {Click} **Antibacterials ~ due to redox and general chemical reactivity that may interfere with bacteria's ability to live or reproduce.** {Click} **Superconducting Materials ~ due to the physical properties allowing for greater conductivity of electricity at a much lower temperature.**
Slide 11	{Click} **Are there other carbon nanoparticles?** *Yes.* {Click} **If a sheet of graphite is rolled into a cylinder, what is wrong with this structure?** *Ask students for their ideas.* **Hint: Are all of the bonds satisfied?** *Some carbon atoms have "dangling bonds."* *You may use the sheet of plastic hexagonal chicken fencing again to demonstrate at this point.*

	{Click} **Hint: don’t forget about corannulene (buckybowls)!** *6) Initiate discussion and lead students to the idea of capping off the ends of the cylinder with a “buckybowl” (or half of a buckyball).*
Slide 12	**Now you have a carbon nanotube!**
Slide 13	{Click} **Discovered in 1991** {Click} **They have an internal cylinder diameter of 1 to 50nm.** {Click} **The length of nanotubes are about 100 nm up to several micrometers and longer.** {Click} **They can be single walled, called single walled nanotubes (SWNTs), or made up of multiple layers, called multi walled nanotubes (MWNTs).**
Slide 14	**Nanotubes have vastly different properties than fullerene cages.** {Click} **For example…**
Slide 15	**…it is incredibly strong!** {Click} **Why do you think nanotubes are so strong?** *Allow students to brainstorm and discuss.* {Click} **Hint: diamond’s strength is due to…** *Each carbon atom is covalently bonded to four other atoms (all single bonds).* {Click} **Because each carbon atom in a nanotube is covalently bonded to three others, it has great tensile strength.** *Note: Carbon nanotubes possess only covalent bonds (two single and one double on each atom). Like diamond, these covalent bonds impart strength. In graphite, there are weak intermolecular forces between the planar sheets of graphite, thus it is brittle and layers separate easily.*
Slide 16	**Nanotubes are also lightweight, have a high melting point, and can conduct electricity.** **What are some possible uses of nanotubes?** *Allow time for students to respond and facilitate any discussion linking back to the properties of nanotubes.* {Click} **nano-wires** {Click} **nano-test tubes** {Click} **nano-velcro** {Click} **nano-ropes** *For more information on applications of nanotubes, go to* [*http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=103060*](http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=103060)

Slide 17	**Application of a nano test tube** {Click} **Inner diameter ~1.2 nm** {Click} **Length ~ 2 micrometers** {Click} **Volume of 10^{-21} liter — a zeptoliter!!**
Slide 18	**Nanoropes** {Click} **Strongest fiber known – 100 times stronger than steel per gram** {Click} **What applications can you imagine for an unbelievably strong rope or cable made of such material?** *7) Have students brainstorm ideas about how nano ropes might be used. The space elevator may be recalled at this point.*
Slide 19	**Let's return to the space elevator that we considered at the beginning of this unit. Based on what we have learned about carbon nanotubes, do you think a space elevator may be possible?** *8) Ask students to justify their answers. Student answers should contain the following information: Carbon nanotubes can be single-walled or multi-walled and are composed mostly of hexagons, but on the ends there are pentagons. The tubes have a diameter of 1-50 nanometers and have a very high tensile strength, much stronger than steel based on weight.* *9) Click on the play button to watch a 12-minute episode from* Nova Science Now *about the space elevator.* *10) Select "Watch the Segment" by choosing the media (Quick Time, Real Video, or Windows Media) supported by your computer. You may want to change the zoom settings on your browser window or move the LCD projector farther back from the screen to provide a good size image of the video for the whole class. Note the other resources available on this site should you choose to explore this further with your students.*
Slide 20	**Some other things to think about:** **What are some issues or engineering considerations about the space elevator that may pose problems and must be dealt with before this becomes a reality?** *11) Ask students to respond to this question before continuing.* {Click} **Environmental advantages** {Click} **Lightning hazards** {Click} **Collisions with space junk** {Click} **Radiation damage to the ribbon** {Click} **Is there a limit to how large it can be?** {Click} **How it is initially deployed?**
Slide 21 K-W-L	**How do you think the field of nanotechnology may change your life — for better or for worse — over the next 50 years?**

sheet in the Student Handbook-TV: Page 3 Student Handbook Page 3	*12) This is the final screen and it provides the opportunity for a complete review of the field of nanotechnology. Some individuals may wish to discuss the possible health and environmental effects of nanoparticles.* ***13)*** *Review student's K-W-L sheets at the end of this unit. Allow time for them to finish the "L" column for what they have learned. You may choose to discuss any unanswered questions in class and ask students to do further research if necessary.*
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: graphite, diamond, fullerene* *Answer for question two:* • *Compare: Both are discrete carbon nanoparticle, each have hexagonal bond angles. Both have practical applications.* • *Contrast: Spherical: a three dimensional network of carbon atoms, in which each atom is connected to exactly three neighbors, and each atom is bonded by two single bonds and one double bond (e.g.,* C_{82}*)* • *Cylindrical: They have an internal cylinder diameter of 1 to 50 nm. The length of nanotubes are about 100 nm up to several micrometers and longer. They can be single walled, called single walled nanotubes (SWNTs), or made up of multiple layers, called multi walled nanotubes (MWNTs).* *Answers for question three: molecular ball bearings, drug delivery, antibacterial, semiconductors, sunscreen, nano-ropes, and nano-test tubes.* *Some answers for question four: environmental cleanup, self-cleaning polymer-based paints, transparent coatings and conducting films, self-tinting automotive glass, iron-polymer batteries for greater power generation, and spray forms of metallic oxide nanoparticles to contain and treat hazardous spills.*
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.*