Carbon Nanotubes in Our Everyday Lives

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Abstract:

The objective of this activity is to create an awareness of carbon nanotubes (CNT) and how their use in future applications within the field of nanotechnology can benefit our society. This newly developed activity incorporates aspects of educational frameworks such as "How People Learn" (Bransford, Brown, & Cocking, 1999)) and "Backwards Design" (Wiggins & McTighe, 2005). This workshop was developed with high school and potentially advanced middle school students as the intended audience. The workshop facilitators provide a guided discussion via PowerPoint presentation on the relevance of nanotechnology in our everyday lives, as well as CNT potential applications, which are derived from CNT structures. An understanding of a carbon atom structure will be obtained through the use of hands-on models that introduce concepts such as bonding and molecular geometry. The discussion will continue with an explanation of how different types of molecular structures and arrangements (shapes) can form molecules and compounds to develop various products such as carbon sheets. The manipulation of carbon sheets into different carbon nanotubes (e.g. single-walled, multi-walled, etc.) will be demonstrated through a hands-on activity using folded sheets of paper.

At the end of the activity, participants will be able to 1) describe characteristics of CNTs, 2) identify potential applications for CNTs in everyday life, 3) and describe key characteristics of nanotechnology. These are the outcomes of the activity, and are discussed in detail in the presentation.

Module Objective:

The primary goal of this presentation and exercise is to create an awareness of carbon nanotubes (CNTs), their molecular structure and geometries, how they are used in common applications within the field of nanotechnology, and their benefits to our society.

Student learning Objective:

Participants will be able to:

- Describe characteristics of CNTs.
- Identify potential applications for CNTs in everyday life.
- Describe key characteristics of nanotechnology.

Key Words: Nanotechnology; Carbon nanotubes; Graphene; Carbon; Carbon structure

Intended Grade Level: advanced middle & high school students

Time Required: 55 minutes

Pre-requisite Knowledge: Prior knowledge of chemical or molecular structures, especially that of carbon is helpful, but not required.

MatEd Core Competencies Covered:

1B	Demonstrate laboratory skills
7B	Explain the nature of carbon-based structures
10	Compare the properties of carbon-based structures

Table of Contents:

Materials and Equipment Needed:

Appropriate computer and projection capabilities are needed to utilize the accompanying PowerPoint presentation.

Graphene print sheet (copy to print included on slide **12; three per student**), toothpicks, 1 ½ inch to 2 inch Styrofoam balls (five to ten per student or group), color markers or highlighters, and clear scotch tape.

Note: Hardened marshmallows or Kix® cereal can be used. However, glue must be used to properly secure the toothpicks to the cereal.

Curriculum Overview and Instructor Notes:

Many middle and high school students are taught about units of measurements but may not be able to conceptualize the actual size of units smaller than the “milli-” (10^{-3}) scale. Similarly, many students are taught about the carbon atom but may not be exposed to various molecular structures and arrangements (allotropes) that are formed with only carbon atoms. The carbon nanotubes geometric structures and their characteristic properties are very important concepts studied in any introductory class to nanotechnology. It is expected that most students will not be exposed to the properties and applications of the carbon nanotubes. This presentation (to be modified by the facilitator) and the activities (explained below) can help the students conceptualize the size of materials at the nano-scale, identify examples of nano-materials in general, and identify applications of one of these materials, particularly—carbon nanotubes (CNTs). Instructors are encouraged to include visuals (described below) which provide real-life representations or applications of the technical concept included in this module.

Background for Teachers:

One element highly studied and used for many nanotechnology applications is carbon. Carbon can come in various forms known as allotropes, which have only carbon-carbon bonding, with no other element present. Diamond, graphite (pencil tips), graphene, fullerenes (e.g. buckminsterfullerenes, such as buckyball, and carbon nanotubes), lonsdaleite, and amorphous carbon are a few of the allotropes of carbon (Davies, 2007).Graphite, graphene, buckyballs and carbon nanotubes all have the same carbon molecular orbital structure (Brown & Foote, 2002). For each carbon atom in these allotropes, three of the four electrons in its outer valence shell form C-C sp^2 hybridized orbitals, so that each atom is connected evenly to three carbons in the xy plane (Davies, 2007).This even C-C sp^2 bonding forms a hexagonal (honeycomb) lattice (or molecular geometry structure). The fourth electron, which resides in the p_z orbital (π electron cloud), is not bound to a single carbon and is free to move to other carbon atoms (delocalized). In the case of graphite, the π electron cloud interacts in the form of dipole-dipole interaction to form weak van der Waals "bonds" giving rise to stacked sheets. A single sheet in graphite is called graphene (Davies, 2007). Similar to buckyballs and carbon nanotubes, the fourth electron in graphene moves freely throughout the connecting carbons' π electron cloud, and produces phenomenal electronic properties. Buckyballs and carbon nanotubes are spherical and cylindrical arrangements respectively of graphene, and these different arrangements produce different electronic, thermal, and mechanical properties. Due to their exceptional properties, nanometer size, and strength, graphene, buckyballs, and especially carbon nanotubes have great potential for nanotechnology applications such as replacement of silicon, copper and aluminum wires in electronic device, used to enhance computer chips, batteries, fabrics (body armor), building structures, and many more (Davies, 2007).

This module focuses only on carbon nanotubes, however further lessons could be developed by teachers in a similar fashion to this module, to introduce graphene and other materials of the fullerene family. To incorporate this lesson and lessons of similar nature into a curriculum, this module follows aspects of the standards of science and technology, according to the National Science Education Standards. This module derives information from prior knowledge and/or serves as an introduction to new information based upon many of the standards covered in the standards for physical science, earth and space science, and science in personal and social perspectives. This module is best suited for students in grades 9 thru 12, based upon these standards as described below (excerpt from*(National Science Education Standards, 1996)*) , but can be tailored for grades 6 thru 8 with appropriate grade level content. The highlighted standards in the tables below are the standards that this module builds its' content on and/ or introduces as new knowledge.

TABLE 6.9. CONTENT STANDARDS, GRADES 5-8

UNIFYING CONCEPTS AND PROCESSES	SCIENCE AS INQUIRY	PHYSICAL SCIENCE	LIFE SCIENCE
Systems, order, and organization	Abilities necessary to do scientific inquiry	Properties and changes of properties in matter	Structure and function in living systems
Evidence, models, and explanation	Understandings about scientific inquiry	Motions and forces	Reproduction and heredity
Change, constancy, and measurement		Transfer of energy	Regulation and behavior
Evolution and equilibrium			Populations and ecosystems
Form and function			Diversity and adaptations of organisms
EARTH AND SPACE SCIENCE	**SCIENCE AND TECHNOLOGY**	**SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES**	**HISTORY AND NATURE OF SCIENCE**
Structure of the earth system	Abilities of technological design	Personal health	Science as a human endeavor
Earth's history	Understandings about science and technology	Populations, resources, and environments	Nature of science
Earth in the solar system		Natural hazards	History of science
		Risks and benefits	
		Science and technology in society	

TABLE 6.10. CONTENT STANDARDS, GRADES 9-12

UNIFYING CONCEPTS AND PROCESSES	SCIENCE AS INQUIRY	PHYSICAL SCIENCE	LIFE SCIENCE
Systems, order, and organization	Abilities necessary to do scientific inquiry	Structure of atoms	The cell
Evidence, models, and explanation	Understandings about scientific inquiry	Structure and properties of matter	Molecular basis of heredity
Change, constancy, and measurement		Chemical reactions	Biological evolution
Evolution and equilibrium		Motions and forces	Interdependence of organisms
Form and function		Conservation of energy and increase in disorder	Matter, energy, and organization in living systems
		Interactions of energy and matter	Behavior of organisms
EARTH AND SPACE SCIENCE	**SCIENCE AND TECHNOLOGY**	**SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES**	**HISTORY AND NATURE OF SCIENCE**
Energy in the earth system	Abilities of technological design	Personal and community health	Science as a human endeavor
Geochemical cycles	Understandings about science and technology	Population growth	Nature of scientific knowledge
Origin and evolution of the earth system		Natural resources	Historical perspectives
Origin and evolution of the universe		Environmental quality	
		Natural and human-induced hazards	
		Science and technology in local, national, and global challenges	

Module Procedure and Slide Layout:

1. Begin module with one-minute assessment described below. (Optional)

2. Show slide presentation: (Slide numbering starts from after title slide.)

    i. Slide **2**: Definition of nanotechnology *(Note: This definition is the authors' simplified definition, summarizing the many definitions of nanotechnology.)*

ii. Slide **3**: Picture illustrating the relationship between materials, on the nanoscale and macroscale.

Note to Teachers:

- *Quick Assessment /Question for students:* Ask students to visualize what "nano" means in size, and ask them to give you some examples of what physical objects are in nanometer size.

- An image, like the one displayed on slide **3**, is a great example to help students visualize how small a nanometer is. The website provided, which is a publication from Medill Reports - Chicago, Northwestern University, has several images that illustrate scaling. Those images, along with the one illustrated, were provided by the National Nanotechnology Coordination Office and the National Center for Electron Microscopy, Lawrence Berkeley Lab and U.S. Department of Energy.

- *Explanation of Image:* If you take a carbon nanotube (which is 1 nanometer in diameter) and multiply its size by 100,000, you get the diameter of one strand of hair (approximately 100 micrometers). Then, if you multiply the width of the strand of hair by another 100,000, you get the width of a typical house (10 meters). It's as if you have magnified the CNT a "billionth times".

iii. Slides **4**: Slide **4** gives a list of examples (as shown below) of how nanoscale materials are used in nanotechnology to improve the quality of our everyday lives. The next slide (**4a can be added to your liking**) gives a pictorial example of life improvements by comparing devices from the 1980s and 1990s to current devices (e.g., radio to iPod or shuffle, old cell phones to current cell phone).

- *Quick Assessment /Discussion for students:* During this time students could be asked to recollect what components (transistors, microchips) and if advanced enough, composition of materials (silicon based chips, etc.), were used to power the older devices compared to current ones.

3. Activity 1: 5 minutes

Student objective: To make different geometric structures of carbon.

a. Give each student (or group of students) 5 to 10 Styrofoam balls (to represent carbon atoms) and 25 to 30 toothpicks (to represent the bonds between carbon atoms).

b. Ask the students to make two different carbon geometric structures that have *one structure* with the all of the carbon atoms attached (with toothpicks) to four other carbons and a *second carbon structure* with all of the carbon atoms attached to three other carbon atoms. (*Note:* VSEPR is not a prerequisite for this activity, if the instructions are followed correctly. However, if the students have learned or are learning VSEPR, then this would be a good time to remind students of the rules of molecular geometry and bond angles for a more geometrically accurate structure.)

c. Have the students compare their structures. Slide **5** shows the possible three bonded (graphene) and four bonded (diamond) carbon structures.

4. Continue with slide presentation.

iv. Slide **6**: Allotropes of carbon. The students should be able to correlate their structures with some of the carbon structures and corresponding pictures in this slide.

v. Slide 7 (Transitional Slide): Slide **7** focuses on the planar carbon structure (graphene) and the two materials made from this structure (carbon nanotubes and graphite). Slide **(7a can be added to your liking)** can show pictorial examples for materials that use graphite; for example pencils, filament for floodlights, and the new Sharpie graphite pencil (chemically modified graphite). The rest of the presentation can now transition from graphite to carbon nanotubes.

Note to Teachers:

- It is important to explain that carbon nanotubes and graphene have the same molecular structure geometry; the graphene is in a sheet form while the CNT is arranged in the cylinder form. A demonstration should be shown (or made into another 5 minute activity) with the paper printed graphene sheets showing the difference between the carbon nanotubes (cylinder shape folded sheet), graphene (a single flat sheet), and graphite (several sheets of paper on top of each other).

- Another important point to focus on is that carbon has four outer shell electrons that can form four covalent bonds (like in diamond). However, graphene (and subsequently graphite and carbon nanotubes) only have three covalently bonded electrons per atom, leaving a free electron, and is the reason for the amazing electronic properties in these materials, as previously explained.

vi. Slide **7** to **10**: These slides display images of different arrangements of graphene sheets to make carbon nanotubes with different tube orientations; changing the view of the atom arrangement displays small to large radii or multi-walled carbon nanotubes (slide **10**).

5. Activity 2: 10-15 minutes

Student objective: To create different shape carbon nanotubes.

a) Give the students two to three Graphene printed sheets, several pieces of tape, and colored makers or highlighters.

b) Ask the students to color each connecting carbon (hexagonal space) a different color or alternating colors, as shown in the images on slides **7** and **9**.

c) Then they are to make different shapes with the sheets (i.e., folded lengthwise, widthwise, or diagonally) and use tape to hold the sheets in their form. The objective is to use the colored hexagonal space on the sheet to show the difference in atom arrangements in the different shapes (armchair, chiral, and zigzag).

Note to Teachers: (See Reference (Davies, 2007) page 13)

- The widthwise folding, *Armchair* (slide **7**), is a good conductor. The lengthwise folding, *Chiral* (slide **8**), is a poor conductor (insulator), and the diagonal folding, *Zigzag* (slide **9**), is a semiconductor.

- Each CNT in the folding example (slide 7 to **9**), has a shaded/colored path. This is the favorite *running* path of the electron. Following the shaded/ colored path for each CNT, we can see why the Armchair is a good conductor (the electron will run in a straight path,) and the Chiral is a poor conductor (the electron will run in a circular path). The Zigzag is a semiconductor (the electron will run in a helix path; not too fast and not too slow).

d) *The armchair CNT will be used for the rest of the presentation.* The students should be encouraged to make sheets with different radii using the lengthwise armchair shape. Place sheets with the different radii within each other to demonstrate multi-walled carbon nanotubes.

6. Continue with slide presentation.

vii. Slide **11**: Carbon nanotubes of the armchair shape of different diameters give rise to different electronic and structural properties. Refer back to multi-walled carbon nanotubes in slide **10** when discussing its structure-property correlation.

Note to Teacher: Correlation between CNTs structure and physical properties.

- This would be a good time to explain or review a basic principle of physics. Electricity, magnetism, and thermal conductivity are physical properties that cannot occur without the movement of electrons.

- Due to the free fourth delocalized electron in each carbon atom in the graphene or the CNT, they can freely move through and about the structure. Changing the radius size in the CNT can change how fast these free electrons flow through, therefore, varying their electronic properties.

- Faster moving electrons can send signals in wires for communication quicker than slower electrons, but may die out quicker than slower moving electrons (as shown in Slide **11**).

- Analogy: A runner (the electron) who starts running at a faster pace may run a shorter distance quickly and at high intensity (tube ***A*** with corresponding electron flow peak), but will tire (drop in electron flow peak) much quicker at a longer distance than a runner who starts slower (tubes ***B*** and ***C***).

- Multi-walled carbon nanotubes not only give good electron properties but also are stronger than single-walled carbon nanotubes (resist stress or fracture). These materials can be used in building materials to make more shock resistant buildings.

- *Quick Assessment /Question for students:* What places could use more shock resistant material? (*Possible Answer*: Places with very active fault lines include California, Japan, and the Pacific Islands)

viii. Slide **11a (can be added)**: Pictures can be shown to illustrate the many everyday applications carbon nanotubes can be applied to and improve due to their nanoscale size, unique shape and structure. These characteristics give very desirable electronic properties, as well as mechanical properties that can be obtained through chemically or physically altering the molecular structure. Some examples of applications are: solar panels, (http://www.gizmag.com/nano-solar-cell-effiviency-virus-mit/18504/) and (Dang et al., 2011), car batteries (Next Alternative Inc. Company http://www.next-alternative.com/), bicycles (Pro Machine SLC01 made by Swiss manufacturer BMC http://www.bmc-racing.com/us-en/about-bmc/portrait.html), and protective materials (made with buckypaper) (http://www.youtube.com/watch?v=hkijxr4z_mY and http://en.wikipedia.org/wiki/Buckypaper).

7. End module with one-minute assessment described below. (Optional)

Assessment for Students: 1 Minute

Before Presentation: On one side of an index card write the word "Before", then draw an image, or write anything that comes to mind when you hear the word nanotechnology.

After Presentation: On the other side of the same index card write the word "After", then draw an image, or write anything that comes to mind when you hear the word nanotechnology.

Optional Assessment for Students:

1. **What are the shape differences between graphite, graphene, and carbon nanotube?**

   Possible answer: *Graphene is a single layer carbon sheet, graphite is several layers of carbon sheets on top of each other, and a carbon nanotube is cylinder shaped graphene sheet or cylinder shaped single layer carbon sheet.*

2. **Describe two characteristics of carbon nanotubes.**

   Possible Answers: *Cylindrical shape; can be a good conductor, insulator, or semiconductor depending on the shape; can be placed in one another to make very strong multi-walled carbon nanotubes; nanometer in size; good thermal stability.*

3. **Which shaped carbon nanotubes gives the best electronic properties and what property?**

   Answer: *Armchair, conductor*

Teaching Resources:

- Wiggins, G., & McTighe, J. (2005). *Understanding by Design* (2nd ed.): Prentice Hall.
- Bransford, J.D., Brown, A.L., & Cocking, R.R. (Eds) (1999). *How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy Press.
- http://www.nnin.org/nnin_k12teachers.html. This website provides nanotechnology educational resources and activities for K-12 teachers.
- http://nanoyou.eu/en/nano-educators.html This website offers school programs on nanotechnology that consist of training materials, modules, and resources. The programs focus on nanotechnology in the areas of information and communication technology (ICT), energy and environment, and medicine.

- www.nanohub.org This website provides online simulations, pre-recorded lectures, seminars, and teaching resources for nanotechnology.
- www.nanowerk.com This website offers an "Introduction to Nanotechnology", covering definitions, applications, materials, and extensive background information on carbon nanotubes.

- http://nanozone.org/index.htm This website is an interactive website for K-6 students to aid in the better understanding of nanotechnology through games and online activities. This website also provides teaching resources for in class use.

Additional References:

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How People Learn: Brain, Mind, Experience, and School.* Washington, D.C.: National Academy Press.

Brown, W. H., & Foote, C. S. (2002). *Organic Chemistry* (3rd ed.). United States: Thomson Learning, Inc.

Dang, X., Yi, H., Ham, M. H., Qi, J., Yun, D. S., Ladewski, R., et al. (2011). Virus-templated self-assembled single-walled carbon nantubes for highly efficient electron collection in photovoltaic devices. *Nature Nanotechnology, 6*, 377-384.

Davies, A. G. (2007). *Advances in Nanoengineering: Electronics, Materials and Assembly (Chapter 1)*. London: Imperial College Press.

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