Carbon Nanotubes – Talking Points

Forms of Carbon: Carbon is found in all living things and is one of the most abundant elements on our planet.

- Carbon atoms can attach to one another, or bond, in several different ways to create different materials with varying properties.
- For example, diamond is one form of carbon; the graphite used in pencils is another.
- Carbon is also found in the nanostructured forms of spherical fullerenes ("buckyballs") and carbon nanotubes (CNTs).

Atomic Structure: The differing arrangements of atoms in the four forms of carbon create materials with very different properties.

- In diamond, the hardest known natural material, each atom is tightly bonded to four other carbon atoms. This makes a tripod-like shape called a tetrahedron, which is very strong.
- In contrast, each carbon atom in graphite is strongly bonded to three carbon atoms in the same plane and only weakly bonded to carbon atoms in other planes. The carbon atoms in the plane are arranged in the shape of hexagons, called *graphene sheets*, while the weak bonding out of plane allows the sheets to slide easily past each other. Graphite can easily "slide off" of a pencil onto the paper because of the layered structure formed by these sheets of carbon atoms.
- Imagine taking one graphite sheet and rolling it up into a ball, so it looks like a soccer ball, and you get a third form of carbon called a fullerene. Fullerenes are nanometer-sized soccer ball shaped molecules of carbon atoms. They consist of hexagons and pentagons that form a spherical shape.
  - Fullerenes were named after an architect, Buckminster Fuller, who was responsible for the design of the first geodomes. The "spaceship Earth" at Epcot Center in Disney World is a geodome you may recognize.
  - Some proposed applications of fullerenes include traveling to a diseased or damaged part of the human body to deliver medicines to specific areas, HIV inhibitors, or and signal amplifiers for fiber optic communications.
- The fourth form of carbon is a CNT, which looks like a single graphene sheet rolled up into a cylinder.
  - If you roll the sheet up in different ways then you get different patterns along the cross section of the tube.
  - Scientists have found that these three different types of carbon nanotubes have slightly different structures, which change their properties.
  - The three classifications of carbon nanotubes, determined by the orientation of the carbon hexagons, are called armchair, zig-zag, and chiral.
  - CNTs can also be described as single-walled (SWNT), resembling a single graphene sheet rolled up, or multi-walled (MWNT), like several SWNTs nested inside each other.

Properties of CNTs: The structures of the nanotubes —armchair, zigzag, and chiral— determine their unique physical properties, such as:

- *Electrical conductivity properties*: One of the main things that distinguish CNTs from other nanomaterials is their electrical properties. They can have

semiconducting properties (some zigzag, chiral) or metallic properties (armchair, some zigzag) depending on their structure.
    - CNTs are much better conductors of electricity than copper nanowires because there is less scatter of electrons. In a copper nanowire, tens of thousands of electrons travel through the center of the wire together. Imagine if many people rushed to get through a narrow door together – in a similar way, electrons rush altogether and bump into stationary atoms. As a result, the electrons move forwards, sideways and even backwards – this is called scattering. This scattering generates a lot of heat and wastes energy. On the other hand, in a carbon nanotube, there is not as much scattering, so the nanotubes do not lose as much heat and do not waste as much energy.
- *Mechanical properties (tensile strength)*: Based on small-scale experiments and theoretical calculations, a 1 in. (~2.5 cm) thick rope made of CNTs is predicted to be 100 times stronger than steel and 1/6 the weight of steel.
- *Thermal conductivity properties*: CNTs conduct heat very well. A nanotube's thermal conductivity is predicted to be 10 times higher than silver. Unlike metals, which conduct heat by moving electrons, CNTs conduct heat by wiggling the bonds between the carbon atoms themselves.

Applications of CNTs: Carbon nanotubes are currently being used for a number of significant applications.

- *Flat panel display screens:* An electrified nanotube will emit electrons from its end, like a small cannon. If those electrons are allowed to bombard a phosphor screen, an image can be created. Several companies are exploiting this unusual electronic behavior to make thinner, lighter display screens.
- *Nanocomposite materials:* Mixing nylon with carbon fibers (100–200 nm diameter) creates a nanocomposite material that can be injected into the world's smallest gear mold. The carbon fibers have excellent thermal conductivity properties that cause the nanocomposite material to cool more slowly and evenly, allowing for better molding characteristics of the nanocomposite. The tiny gears are currently being made for use in watches.
- *Chemical sensors:* Semiconducting CNTs display a large change in conductance (i.e., ability to conduct charge) in the presence of certain gases (e.g., NO_2 and NH_3). Researchers have been able to use nanotubes as sensors by exposing them to gas and measuring the change in conductance. In the future, nanotube sensors could be used for security and environmental applications as a smaller, faster, and more sensitive alternative to conventional sensors.
- *Nanoscale electronics:* Scientists have exploited the mechanical and electrical properties of CNTs to produce molecular electronic devices. One of the most significant applications is nanotube transistors. Transistors are devices that can act like an on/off switch or an amplifier for current and are used in nearly every piece of electronic equipment in use today. Scientists have been able to use semiconducting nanotubes as compact, more efficient alternatives to conventional transistors.