Did You Know?

- Carbon nanotubes, composed of interlocking carbon atoms, are 1000x thinner than an average human hair – but can be 200x stronger than steel.

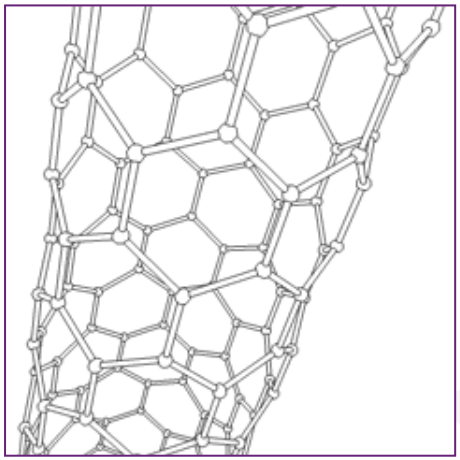
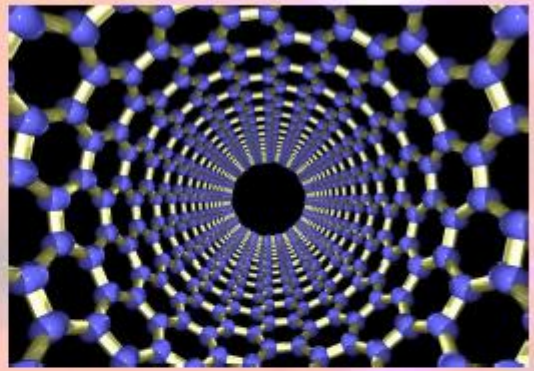
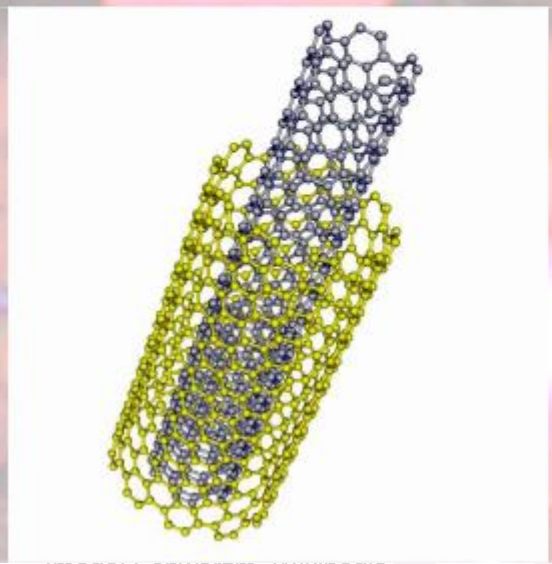


Image: Schwarzm, Wikipedia

CNT - Discovery

In 1991, Sumio Iijima discovers **multiwalled nanotubes** (MWNT) using the method of Krätschmer and Huffman.



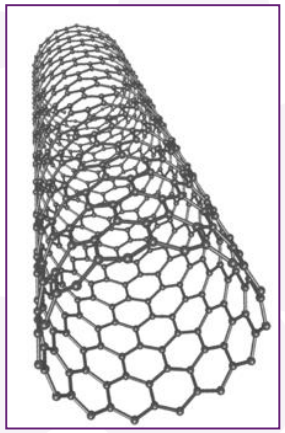


In 1993, Donald Bethune makes **single-walled** (SWNT) nanotubes by adding transition metals.

55

Image: Schwarzm, Wikipedia

Which Of These Object Are Made From Carbon?

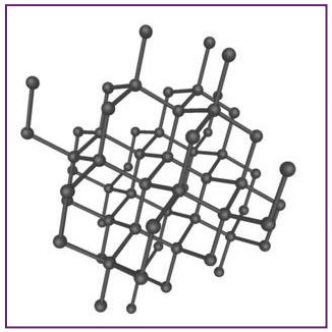


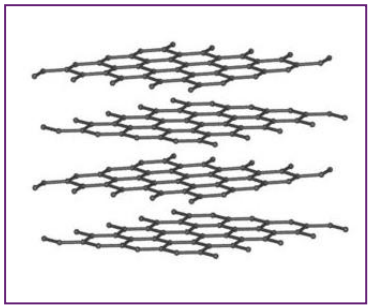
Diamond Graphite Nanotube Coal

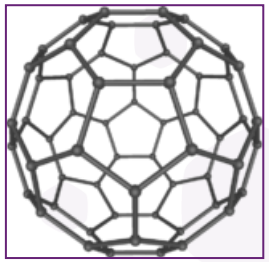
Images: L To R: snapr@flickr, swamibu@flickr, orangeacid@flickr, Mstroeck @ Wikipedia,

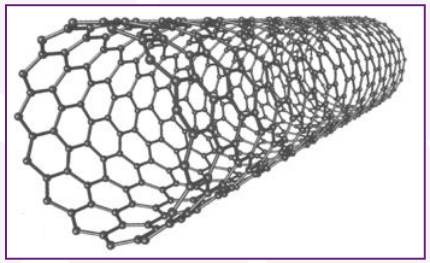
Did You Know?

Allotropes of carbon have different covalent bonding arrangements.







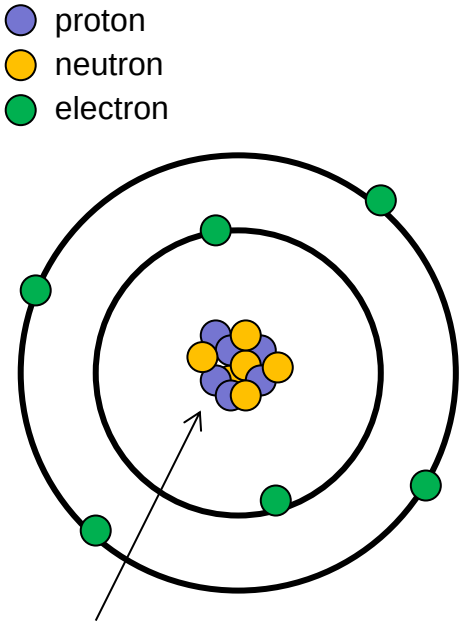


diamond **graphite** **buckyball** **nanotube**

- Carbon atoms form covalent bonds by sharing outer shell electrons with each other
- Diamond, graphite, buckyballs and carbon nanotubes all have different covalent arrangements of carbon atoms
- The differing covalent arrangements of carbon atoms lead to the different properties of carbon allotropes.

Image: Mstroeck @ Wikipedia

Covalent Bonding Sharing Electrons

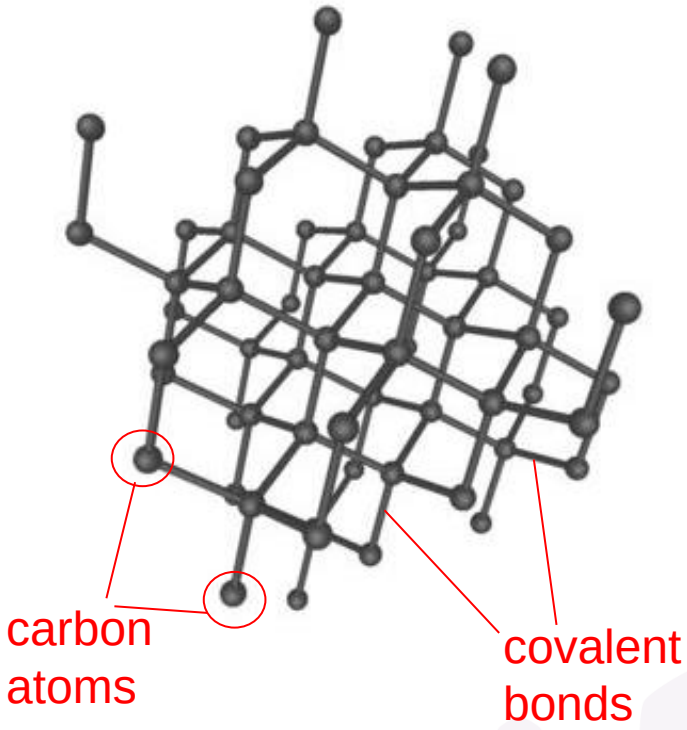


A **covalent bond** is a form of chemical bonding that is characterised by the sharing of pairs of electrons between atoms

Valence electrons are the electrons in the outer shell or energy level of an atom that form covalent bonds

A carbon atom has 6 electrons, 4 of which are Valence electrons
Therefore, carbon atoms can form up to 4 Covalent Bonds

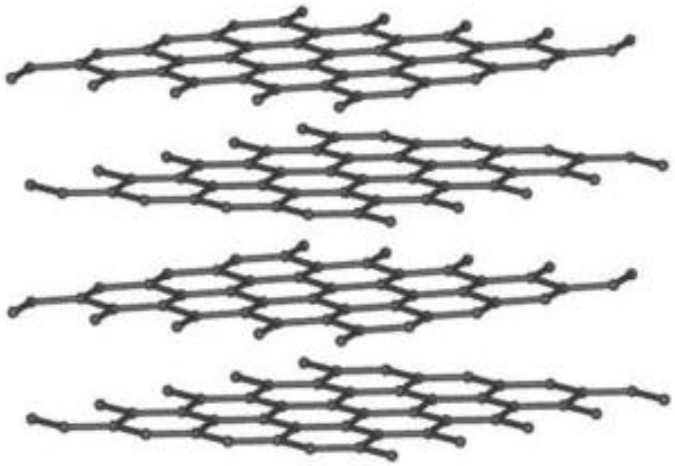
Covalent Bonds In Diamond



- Diamond is formed by a 3D box-like network of carbon atoms
- The continuous nature of the covalent arrangements forms a giant molecule
- Electrons are fixed.

Image: Wikipedia

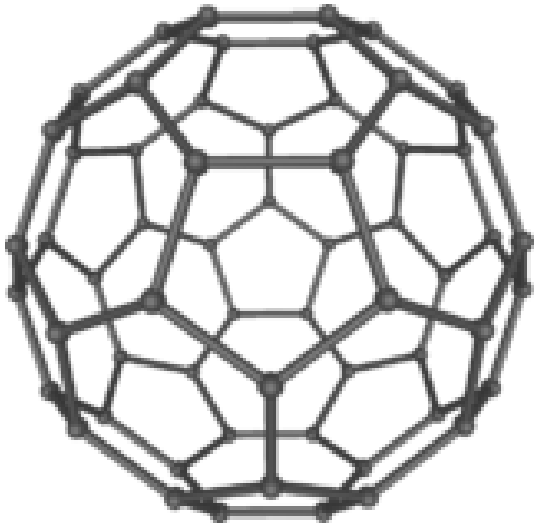
Covalent Bonds In Graphite



- Graphite is formed by hexagonally-arranged carbon molecules forming 2D layers of sheets
- Electrons are free to move between each carbon sheet.

Image: Wikipedia

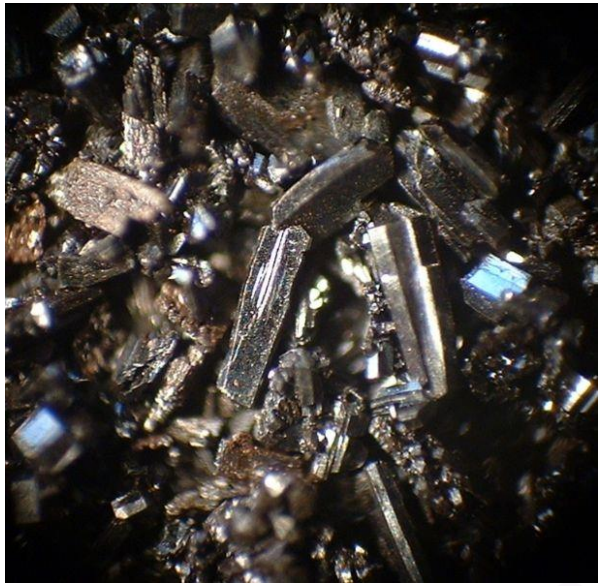
Covalent Bonds In Buckyballs



- Carbon atoms in buckyballs are arranged in a soccer ball shape
- C60 Buckyballs have 20 regular hexagon faces and 12 regular pentagon faces
  - these faces come together at 60 carbon atom vertices
- Electrons are localised internally due to the curvature of the structure.

Image: Mstroeck @ Wikipedia

A Bit More About Buckyballs

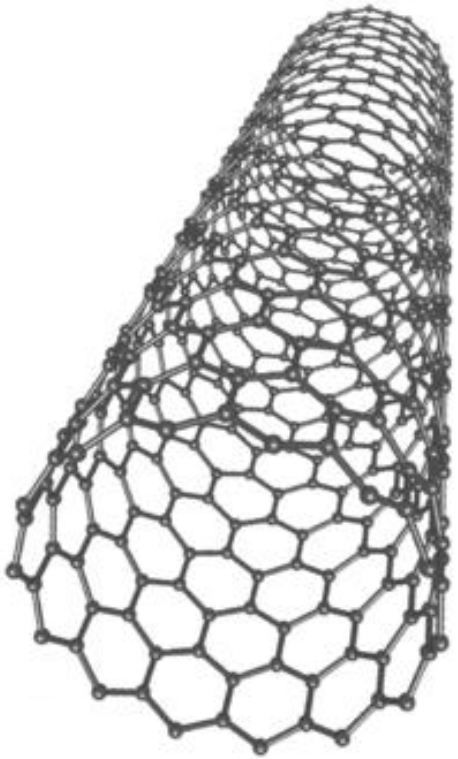


Buckyballs in crystalline form

- Buckyballs are also called fullerenes (after architect Richard Buckminster Fuller)
- Buckyballs were discovered in 1985 by Robert Curl, Harold Kroto and Richard Smalley
  - these scientists won the 1996 Nobel Prize in Chemistry for discovering this new allotrope of carbon.

Image: Wikipedia

Covalent Bonds In Carbon Nanotubes



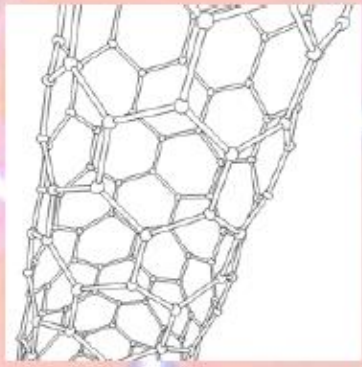
- Carbon nanotubes are formed by a layer of hexagonally-arranged carbon atoms rolled into a cylinder
  - usually have half buckyballs on one or both ends
- Electrons are localised internally, and some can move along the length of the tube
- Carbon nanotube diameter ~ 1nm
- Carbon nanotube length can be a million times greater than its width
- Nanotubes can be
  - single-walled (d = 1-2 nm), or
  - multi-walled (d = 5-80 nm).

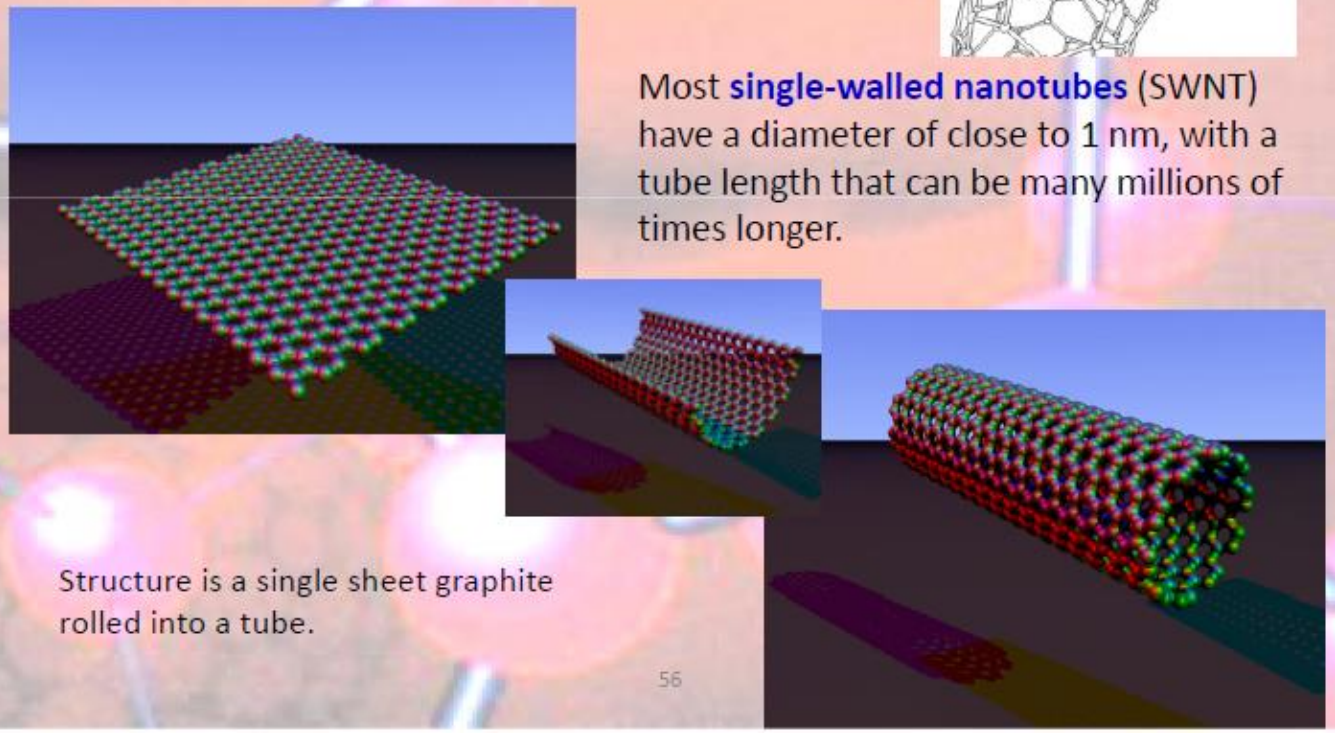
Image: Wikipedia

Properties of Carbon Allotropes

Carbon nanotubes

Carbon nanotubes (**CNTs**) are allotropes of **carbon** with a cylindrical nanostructure.

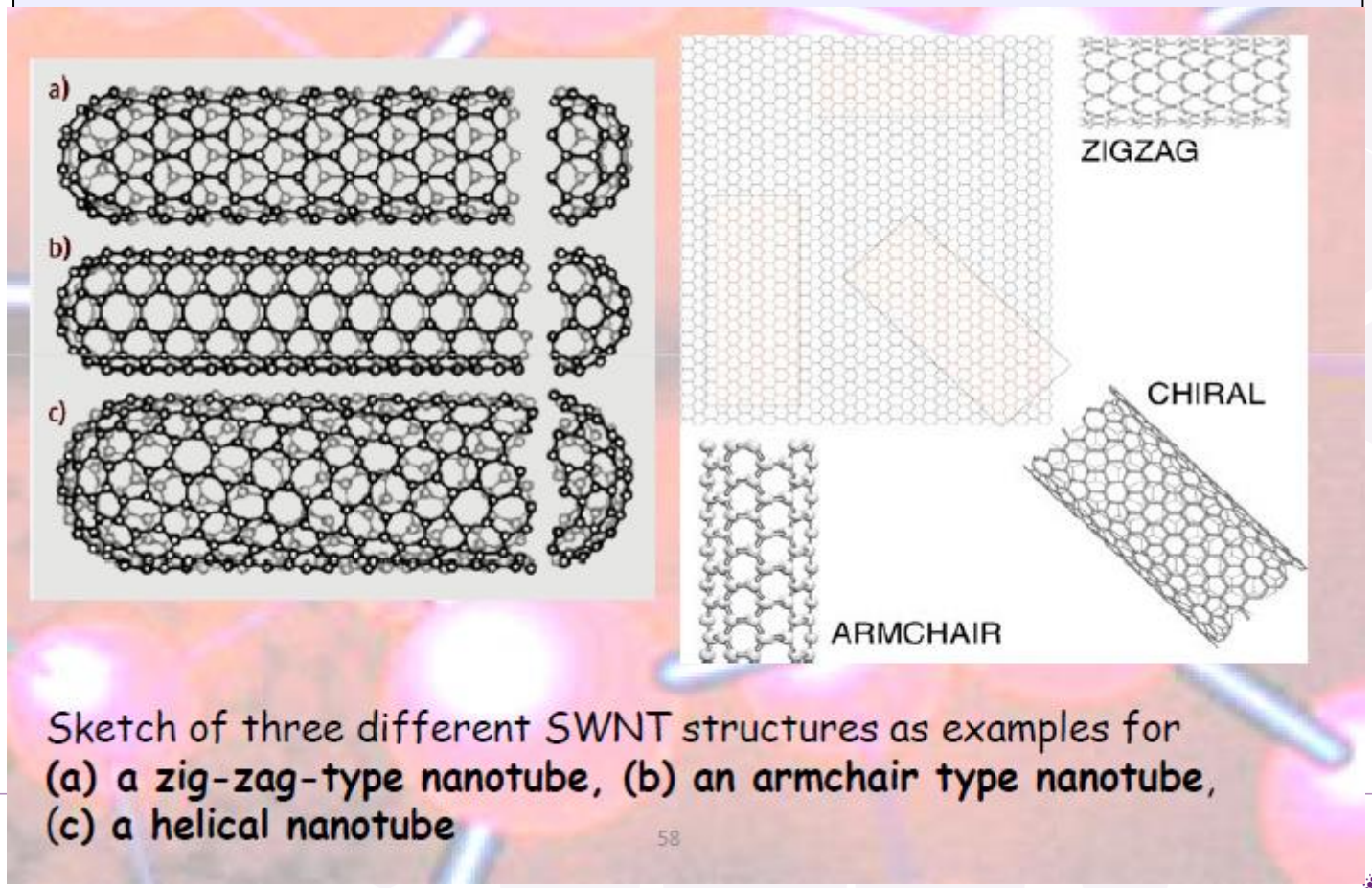




Most **single-walled nanotubes** (SWNT) have a diameter of close to 1 nm, with a tube length that can be many millions of times longer.

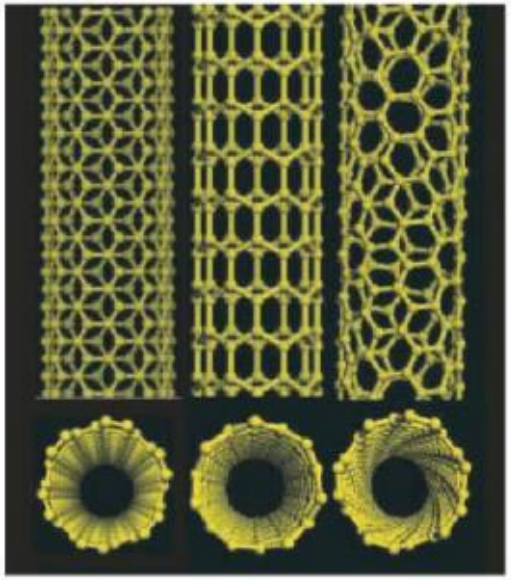
Structure is a single sheet graphite rolled into a tube.

Types of Carbon Allotropes

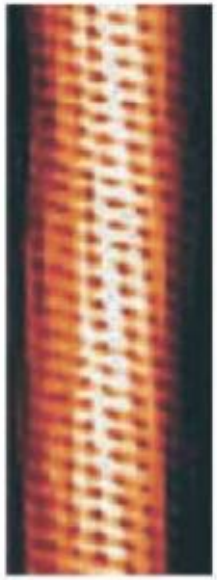


Sketch of three different SWNT structures as examples for (a) a zig-zag-type nanotube, (b) an armchair type nanotube, (c) a helical nanotube

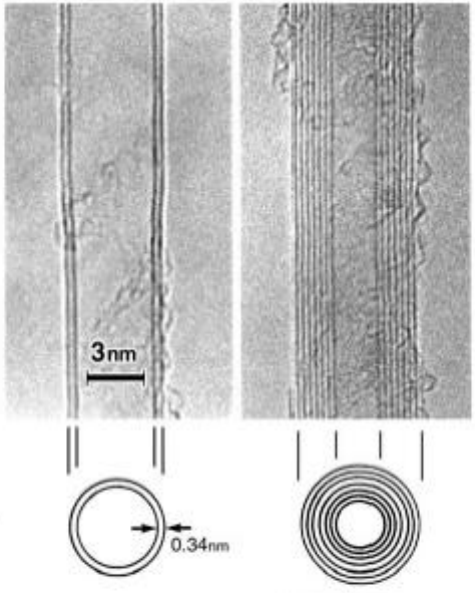
Types of Carbon Allotropes



armchair Zig-Zag Chiral

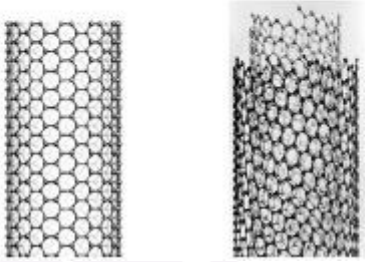


TEM Chiral



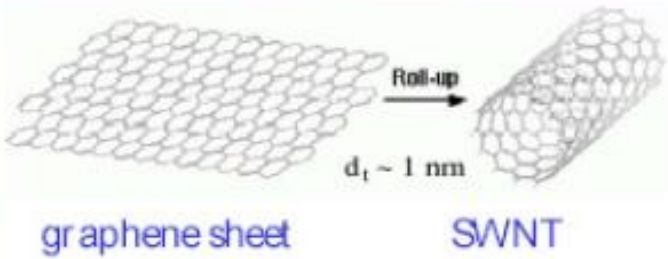
Up to cm long

SWNT
(single
Wall nanotube)
Diameter ~ 1.4 nm

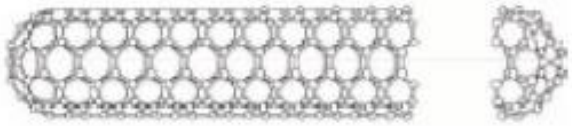


MWNT
(multiwall)
Diameter 10-20 nm

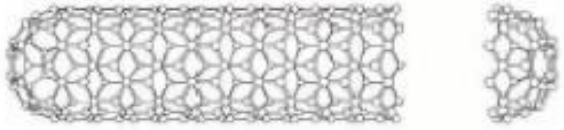
Properties of Carbon Allotropes



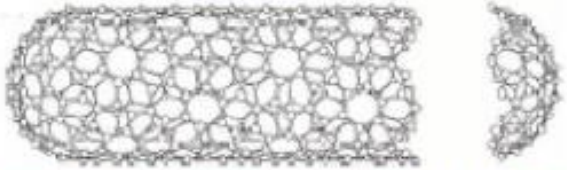
armchair



zigzag



chiral



- Size: Nanostructures with dimensions of ~1 nm diameter (~10 atoms around the cylinder)
- Electronic Properties: Can be either metallic or semiconducting depending on diameter and orientation of the hexagons
- Mechanical: Very high strength, modulus, and resiliency. Good properties on both compression and extension.
- Physics: 1D density of electronic states
- Single molecule Raman spectroscopy and luminescence.
- Single molecule transport properties.
- Heat pipe, electromagnetic waveguide.

Properties of Carbon Allotropes

Allotrope	Hardness	Tensile strength	Conducts heat	Conducts electricity
Coal	+	+	+	no
Graphite	++	++	+++++	+++++
Diamond	+++++	Not known	+++	no
Buckyballs	+++++	++++	+	+
Carbon Nanotubes	++++++	+++++	+++++	++++++