Carbon Nanotube

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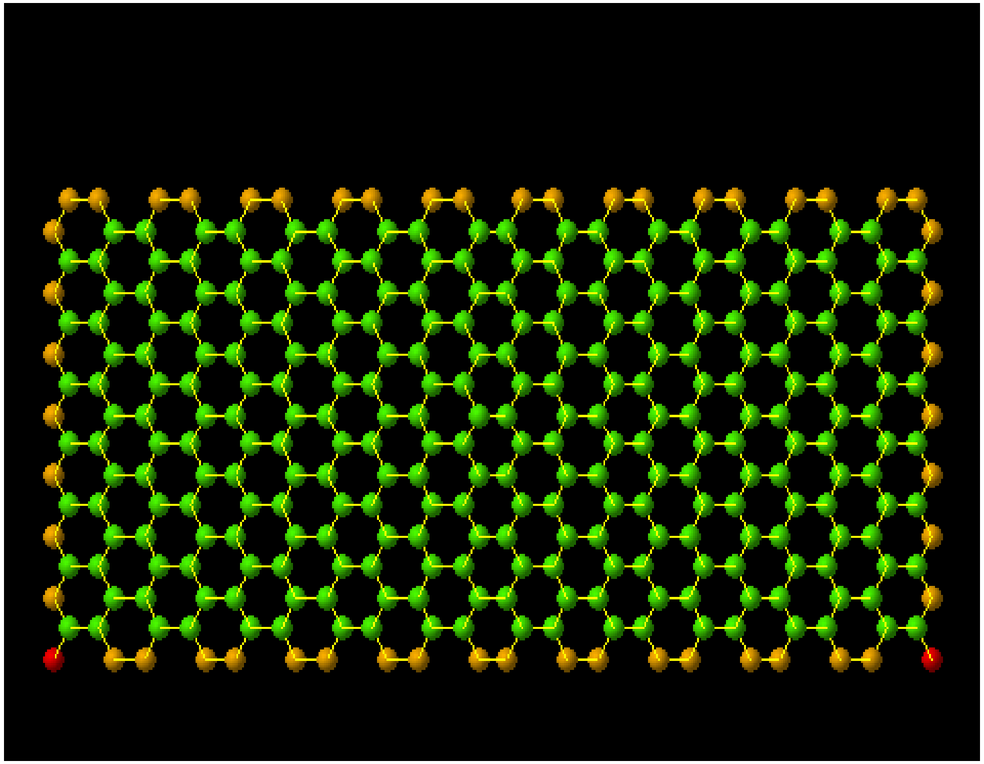
Carbon Nanotube

(CNT)

What Are Carbon Nanotubes (CNT)?

- CNT can be described as a sheet of graphite rolled into a cylinder
- Constructed from hexagonal rings of carbon
- Can have one layer or multiple layers
- Can have caps at the ends making them look like pills

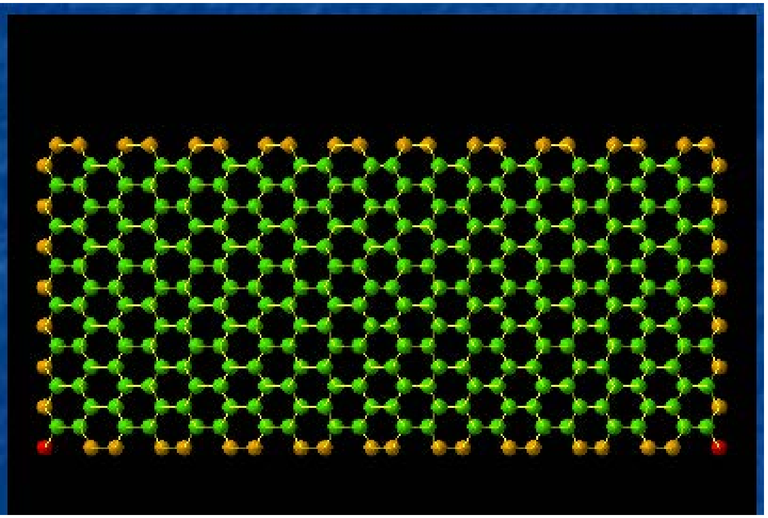


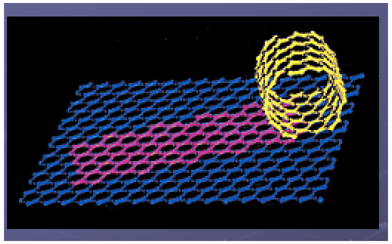
Carbon Nanotubes (CNT)

- Carbon nanotubes are cylindrical molecules ~1 nm in diameter and 1-100 microns in length.
  - Quasi 1D object
  - Molecule almost 1mm long
- They are constituted of carbon atoms only, and can essentially be thought of as a layer of graphite rolled-up into a cylinder.
- Most of these tubular fullerene molecules, discovered in 1991, consist of multiple shells, where many tubes are arranged in a coaxial fashion. (MWNT)
- In 1993 single-wall nanotubes (SWNT) were discovered. Because of their simple and well defined structure they serve as the model systems for theoretical calculations and key experiments.

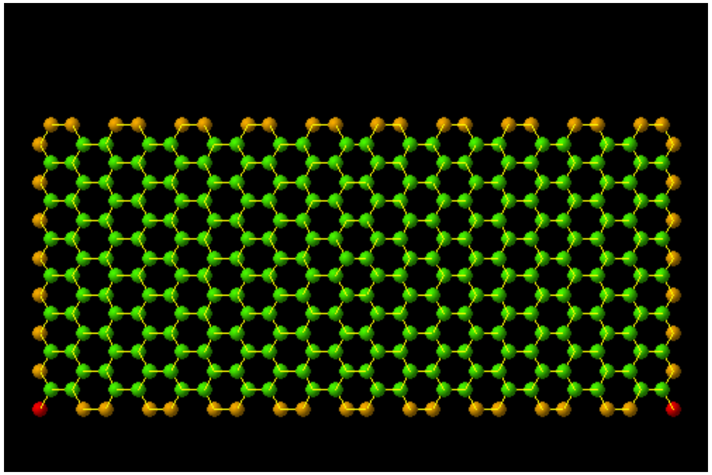
Formation of Carbon Nanotube

- **Carbon Nanotubes are built up using graphite sheet, which is the most stable form of crystalline carbon.**
- **A carbon Nanotube is obtained by rolling up a plain graphite sheet into a tubular shape.**





Roll up



Graphite Sheet

Carbon Nano Tube

Carbon Nanotube can be classified into Two type

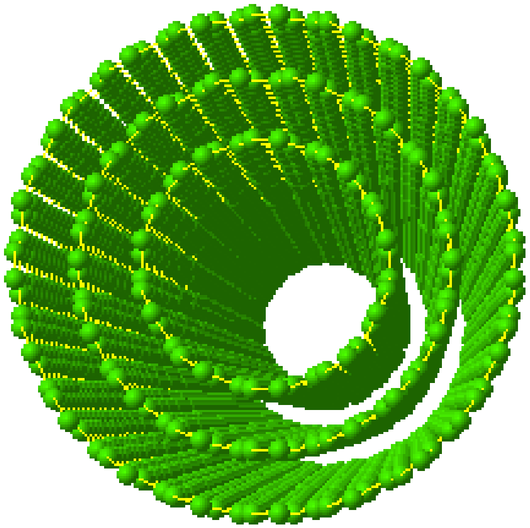
1. Single wall carbon Nanotube (SWNT)
2. Multiwall Carbon Nanotube (MWNT)

Single-wall carbon Nanotubes (SWCNTs) can be considered to be formed by the **rolling of a single layer of graphite** into a seamless cylinder.

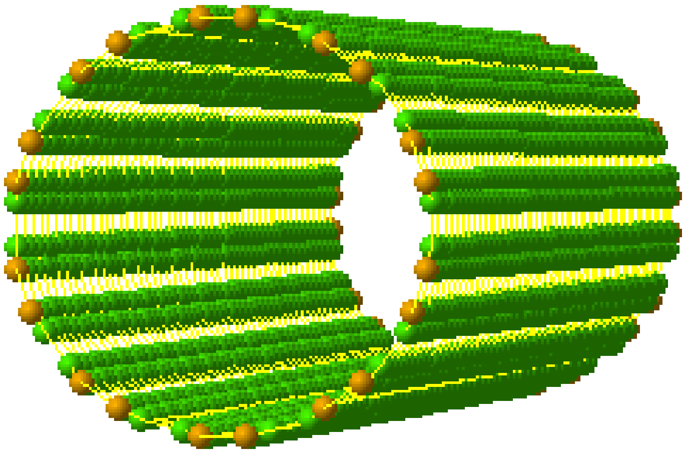
A Multiwall carbon Nanotube (MWCNT) can similarly be considered to be a **coaxial assembly of cylinders of SWCNTs**, one within another.

The separation between tubes is about equal to that between the layers in natural graphite. Hence, Nanotubes are one-dimensional objects.

- **MWNT**
  - Consist of 2 or more layers of carbon
  - Tend to form unordered clumps
- **SWNT**
  - Consist of just one layer of carbon
  - Greater tendency to align into ordered bundles
  - Used to test theory of nanotube properties



Multi wall CNT



Single wall CNT

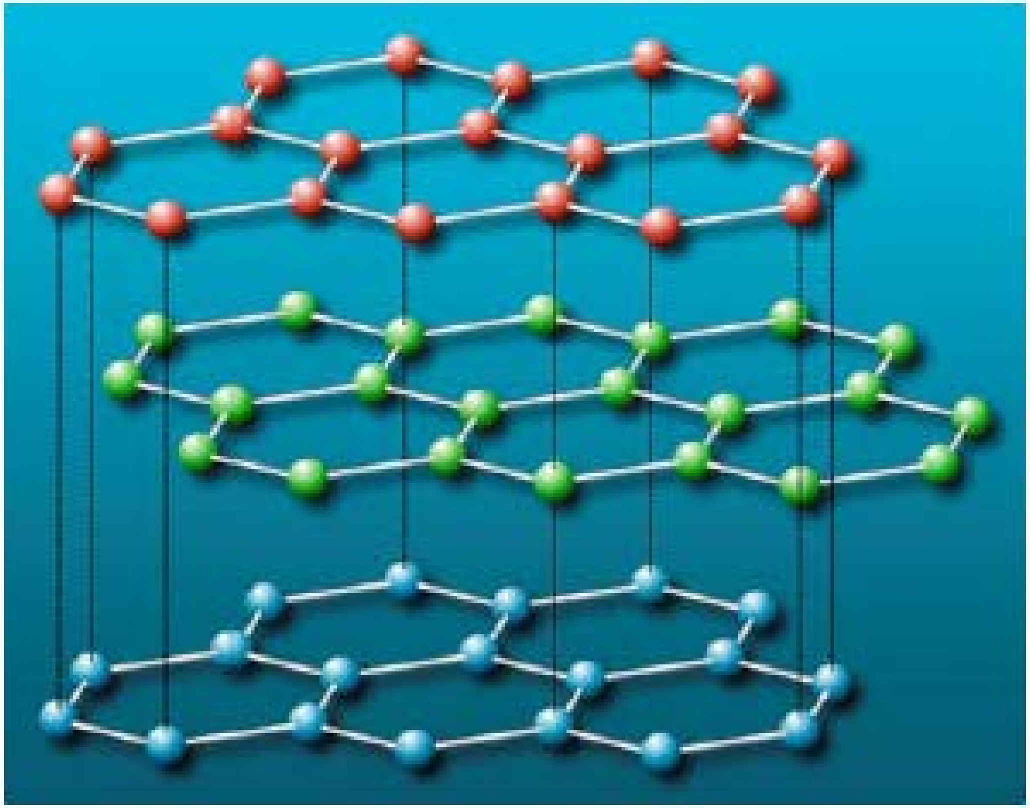
Nanotube's characteristic

- Seemless cylindrical molecules
- Diameter as small as 1 nm.
- Length: a few nm. to serveral micron
- As a monoelemental polymer: Carbon atoms only
- As hexagonal network of carbon atoms
- CNTs are single molecules comprised of rolled up graphene sheets capped at each end.

Structure of Carbon Nanotube

The Carbon Nanotube is made by a graphite sheet of **Hexagonal lattice** structure.

Therefore, simply, the lattice structure of Carbon Nano Tube is Hexagonal.



Hexagonal structure

Chiral Vector and Chiral angle

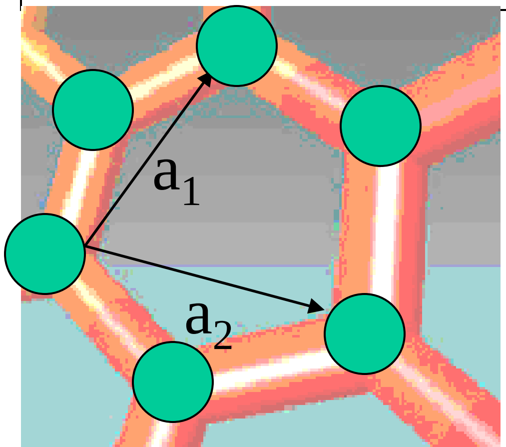
The **structure** of a Single-Wall Carbon Nanotube (SWCT) is expressed in terms of one-dimensional unit cell, **defined by the vector called Chiral Vector.**

A Chiral vector ($\boldsymbol{C}_h$) of an unrolled graphene sheet is defined as,

$$C_h = n\boldsymbol{a}_1 + m\boldsymbol{a}_2$$

where n and m are integers (or) Chiral numbers ($0 \leq |m| \leq n$), $\boldsymbol{a}_1$ and $\boldsymbol{a}_2$ are real space unit vectors of a hexagonal lattice.

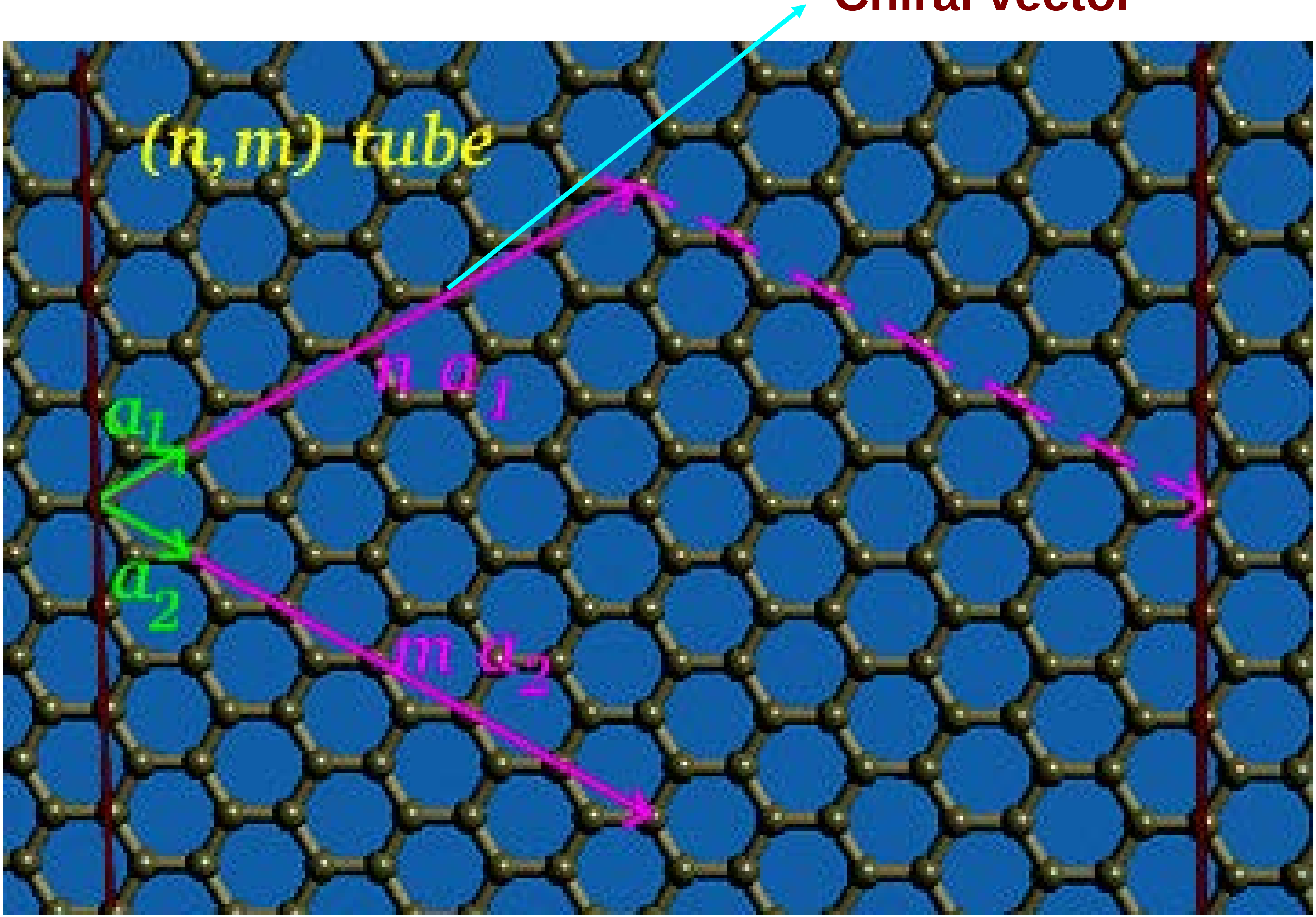
Chiral vector gives the orientation of Graphene (graphite) of plane graphite sheet and also gives the diameter of Carbon Nanotube



The **Chiral angle** is defined to be the angle between Chiral vector ($\boldsymbol{C}_h$) and the unit vector $\boldsymbol{a}_1$

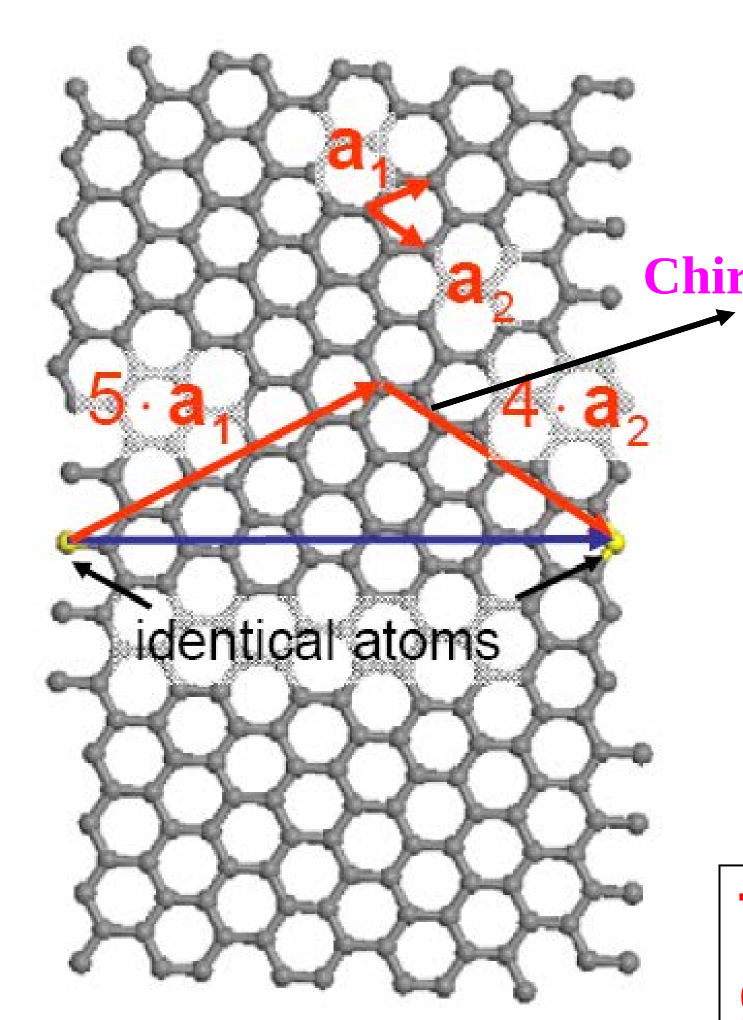
Representation of Chiral Vector in a Graphene sheet

Chiral vector



Understanding of Chiral vector

The integer n =5 and m=4 in the bellow diagram (n and m gives the number of hexagonal that Chiral vector passes)



primitive vectors of graphene

$\mathbf{a}_1, \mathbf{a}_2$

Chiral Vector (n,m) of nanotube

$$\mathbf{c}_h = 5 \cdot \mathbf{a}_1 + 4 \cdot \mathbf{a}_2 = (5,4)$$

$|\mathbf{c}_h|$: circumference of tube

The magnitude of Chiral vector gives the circumference value of Nanotube

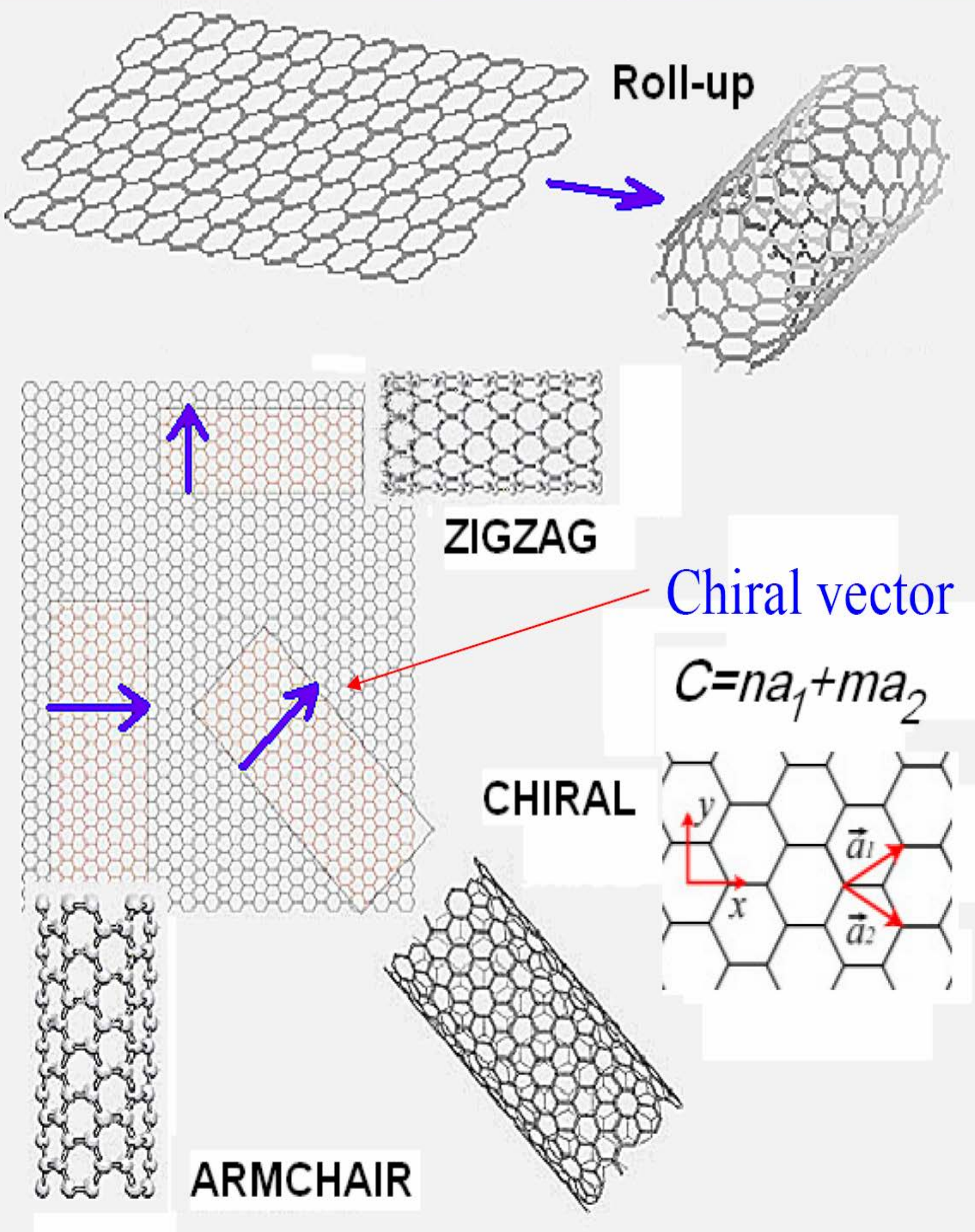
Types of Carbon Nanotube

Depending on the arrangement of carbon hexagonal unit cell and atom position, the CNT are divided into three type.

or

According to the direction of Chiral angles and Chiral vectors, SWNTs are classified in to three type (depending on how the two-dimensional graphene sheet is "rolled up“).

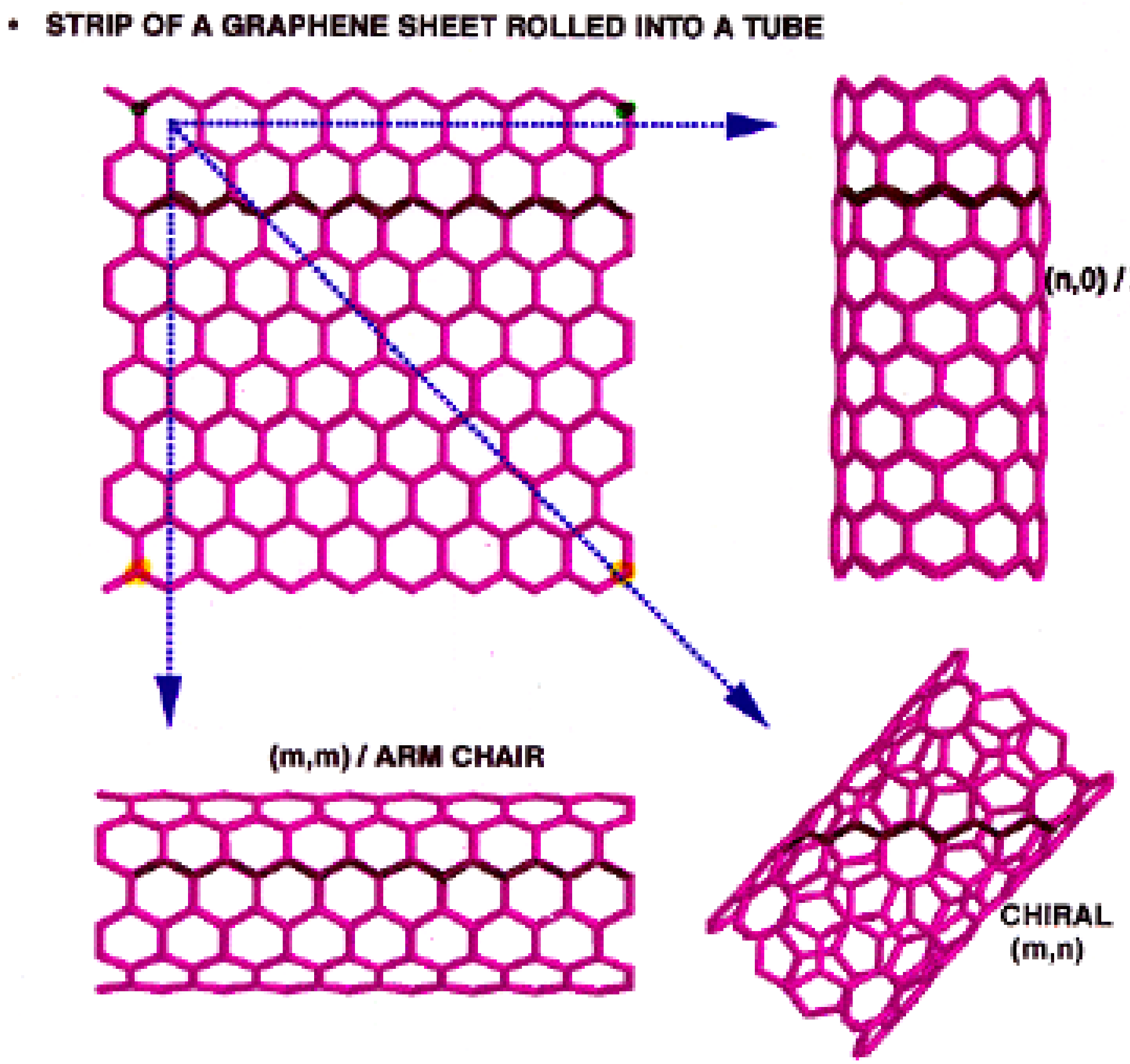
1. Aarmchair Nanotube
2. Zigzag Nanotube
3. Chiral nanotube



- If the Chiral vector passes through mid point of atomic bonding, it called "zig-zag line" Nanotube
- If the Chiral vector passes through the atoms of six fold axis, it armchair line" Nanotube
- If the Chiral vector line not along a mirror line then it is called chiral Nanotube

- The Chiral angle and Chiral vector(C_h) of zigzag Nanotubes is 0º and (n,0)
- The Chiral angle is 30º and Chiral vector (C_h) is (n,n) for armchair Nanotubes
- The Chiral angle is $0 \leq \theta \leq 30°$ The Chiral vector $n \neq m$ for Chiral Nanotube

The arrow indicates the rolling direction of graphene and the respective type of Carbon Nanotube is obtained



Properties of CNT

CNT exhibits extraordinary mechanical properties:

- The Young's modulus is over 1 Tera Pascal. It is stiff as diamond.

- The estimated tensile strength is 200 GPa. These properties are ideal for reinforced composites, Nano electromechanical systems (NEMS)

- The dimensions of CNT are variable (down to 0.4 nm in diameter)
- Apart from remarkable tensile strength, CNT nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic)

- CNT Nanotubes can be either electrically conductive or semi conductive, depending on their helicity(shape), leading to nanoscale wires and electrical components.

These one-dimensional CNT fibers exhibit

- Electrical conductivity as high as copper,
- Thermal conductivity as high as diamond,
- Strength 100 times greater than steel at one sixth the weight, and high strain to failure

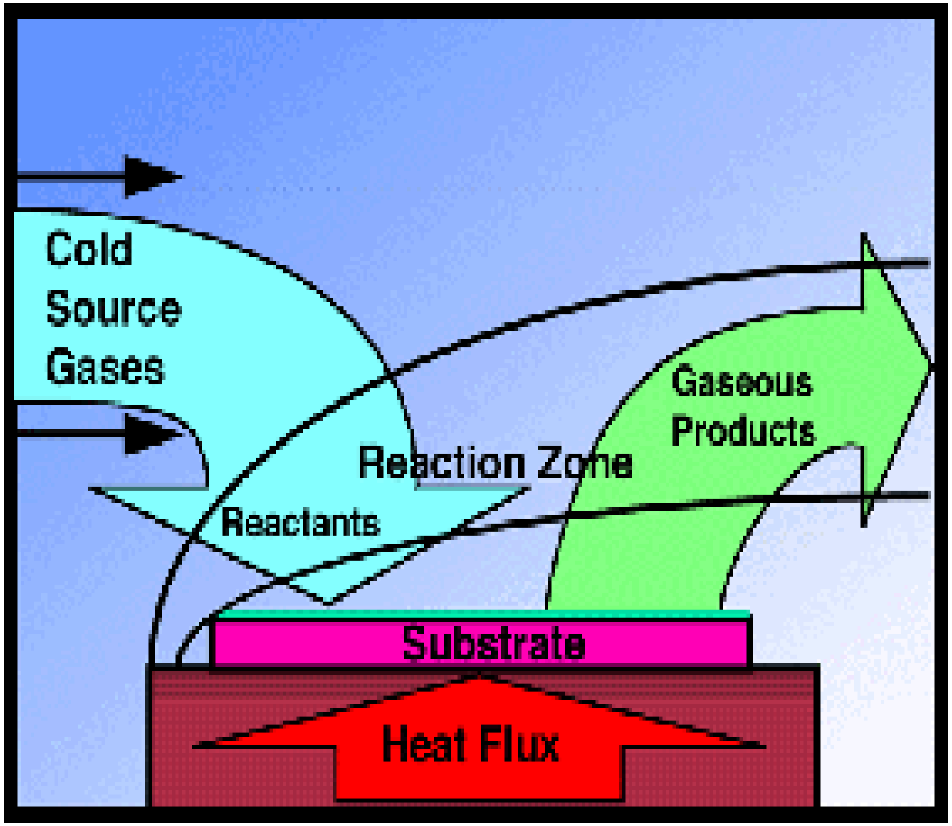
Preparation Technique

Carbon Nanotube (CNT) can be prepared by

1. **Sol-gel method**
2. **Chemical Vapour Deposition**
3. **Physical Vapour Deposition**
4. **Microwave synthesis**

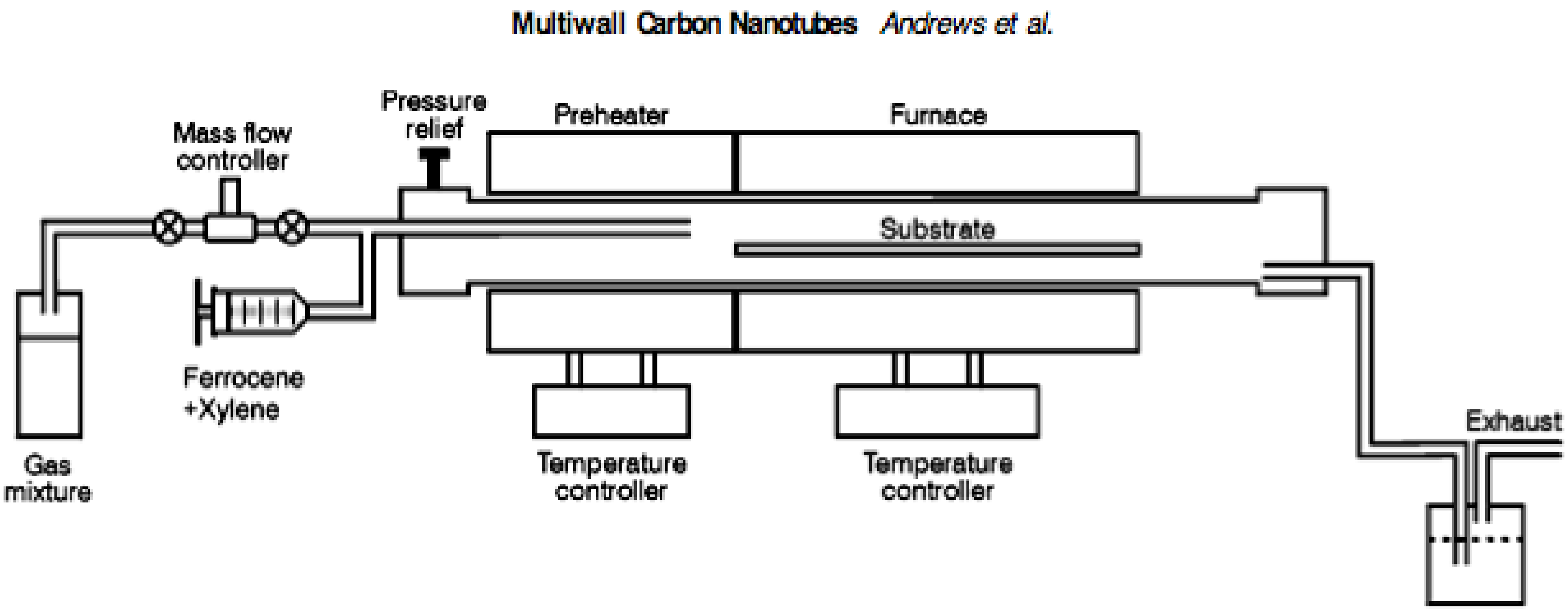
Chemical Vapor Deposition

1. Gas enters chamber at room temperature (cooler than the reaction temperature)
2. Gas is heated as it approaches the substrate
3. Gases then react with the substrate or undergo chemical reaction in the "Reaction Zone" before reacting with the substrate forming the deposited material
4. Gaseous products are then removed from the reaction chamber



Information and photo retrieved from:
http://www.sandia.gov/1100/CVDwww/cvdinfo.htm

Nanotube Synthesis By CVD Process



Schematic from: Andrews, Jacques, Qian, and Rantell, "Mulitwall Carbon Nanotubes: Synthesis and Application"

Nanotube Synthesis By CVD Process

- Source of carbon atoms usually comes from an organic compound
- Mixed with a metal catalyst and inert gas
- Atomized and sprayed into reactor with temperatures ranging from 600ºC to 1200ºC
- Pyrolysis of organic compound deposits carbon (as soot) and carbon nanotubes on reactor wall (usually a tube constructed from quartz)

Sources of Carbon

- Typical Organic/Catalyst Mixtures
  - Xylene/ferrocene (Andrews et al.)
  - Toluene, benzene, xylene, mesitylene, and *n*-hexane/ferrocene (Vivekchand et al.)
  - Ethylene and ethanol/Fe, Co, and Mo alloys (K. Mizuno et al.)

- Typical Carrier Gases
  - Argon
  - Hydrogen

Applications

- Electronic Devices
  - Nanotube TV’s
  - Nano-wiring
- High Strength Composites
  - 100 times as strong as steel and 1/6 the weight
- Conductive Composites
- Medical Applications
  - Encase drug into nanotube capsule for more predictable time release

Applications

- Electronic: FETs, interconnect, LED, detectors
- Power lines
- Hydrogen storage
- Functionalized to act as chemical detector
- For tough materials
- STM/AFM tips

Many potential applications have been proposed for carbon nanotubes, including conductive and high-strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; hydrogen storage media; and nanometer-sized semiconductor devices, probes, and interconnects. Some of these applications are now realized in products. Others are demonstrated in early to advanced devices, and one, hydrogen storage, is clouded by controversy. Nanotube cost, polydispersity in nanotube type, and limitations in processing and assembly methods are important barriers for some applications of single-walled nanotubes

THANKYOU