FULLERENE: A GIFT OF NANOSCIENCE

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ADDIS ABABA UNIVERSITY
DEPARTMENT OF
PHYSICS

FULLERENE: A GIFT OF NANOSCIENCE

By

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I sincerely and gratefully acknowledge the sponsorship from SNNP of educational Bureau and also the full co-operation and support from Physics Department of AAU to fulfill my dream and desire.

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CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

CHAPTER SEVEN

CHAPTER EIGHT

CHAPTER NINE

CHAPTER TEN

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I sincerely and gratefully acknowledge the sponsorship from SNNP of educational Bureau and also the full co-operation and support from Physics Department of AAU to fulfill my dream and desire. I am indebted to them.

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ABSTRACT

Over past two decades a revolution has taken place in the miniaturization of device technology for low cost and maximum efficiency. New materials are explored through intensive research and outcome is nanoscsle devices. It all the rapid growth of nanomatreials and technology follows thereafter. In this dissertation our interest is to throw some light on such an industrially potential nanomaterial called FULLERENE.

The discovery of Fullerenes gave a whole new insight into carbon materials, particularly graphitic ones. The C60 structure followed geometric principles and this made people realize that a great variety of hollow, closed carbon structures, including carbon nanotubes, could be made based on the same principles.

Carbon nanotubes have an interesting property that they are predicted to be either semi-conducting or conducting depending on the chirality's and diameter of the nanotube. They are expected to be conductive additives to plastics and for use in electrochemical applications. Another approach is to use the carbon nanotube as a template for a nanotube of an inorganic oxide. Thus, nanotubes offer exciting possibilities in the material, chemical and physical sciences.

Fullerene and fullerene based nanomaterials have highly promising future application and tremendous impact in modern civilization. **Therefore the main objectives of this project are to focus on some relevant issues like:**

- **What is fullerene and fullerene based martial-carbon nanotubes?**
- **How to deal with the important concepts in structure of fullerene and carbon nanotubes?**
- **How to synthesis fullerene and carbon nanotube?**
- **Why fullerene and carbon nanotube are extraordinary?**
- **How they find potential applications and utilities in every sphere of life and civilization?**
- **How one can image and probe nanostructures like fullerenr and carbon nanotube?**

PRELUDE

Nanotechnology is the science of manipulating and characterizing matter at the atomic and molecular level. It is one of the most promising and exciting fields of science today, involving a multitude of science and engineering disciplines, with widespread applications in electronics, advanced materials, medicine, and information technology. One of the first obvious benefits of nanotechnology is the improvement in manufacturing techniques on the atomic scale. For example, nanotechnology likely represents the future of information processing and storage; computer can be about 100 times smaller and use millions times less power. Materials can be about 100 times stronger than steel. This means that most human scale-products would consist almost entirely of empty space, reducing material requirements and cost.

Nanotechnology progressed in recent times, because of the discovery of fullerenes the Zero D of carbon and carbon nanotubes the 1D form of carbon have stimulated great research interests all over the world in carbon materials.

The major break through in carbon materials was the identification of fullerene C60 as a molecule having the shape of a regular truncated icosahedron’s by Professors Robert F. Curl, Jr., Richard E. Smalley, and Sir Harold W. Kroto, culminated in their Nobel Prize in Chemistry in 1996.The discovery of fullerene lead to the discovery of carbon nanotubes.

Iijima reported the first synthesis and characterization of carbon nanotubes from NEC Japan in 1991. Theses molecular carbon fibers consisting of tiny cylinders of graphite, closed at each end with caps, which contain precisely six pentagonal rings.

Carbon nanotubes have captured the imagination and interests of researchers worldwide for its extraordinary electronic properties, amazing stiffness, strength, resilience, and chemists in particular for their potential as nano test tubes. On a more speculative level, nanotechnologists have discussed possible nanotube based gears and bearings too. Nanotechnology is the worldwide hot and top issue of science and technology to describe matter and processes occurring in it at a nanoscale level (called nanoscience) and manipulating materials (atoms and molecules) at nanolevel to produce nanosize materials, that is why I am interesting to write my dissertation on nanosize materials called Fullerene (A gift of Nanoscience).

The different chapters of the dissertation are organized as follows. In chapter one I will discuss a short review of nanotechnology, nanoscience, its recent development and present global distributions. In chapter two we will see the discovery of fullerene, in chapter three its structure and bonding, in chapter four different techniques of synthesis of fullerene. I will discuss in chapter five extraordinary properties and technological applications of fullerene. As mentioned above the discovery of fullerene lead to the discovery of carbon nanotubes, hence in chapter six we will discuss the discovery of nanotube and types of nanotube, i.e. single-walled carbon nanotube and multi-walled carbon nanotube. In chapter seven we will see different techniques of synthesis of carbon nanotube and in chapter eight mechanical, dynamical, electrical and thermal properties of carbon nanotube will be explained. In chapter nine I will discuss recent research and applications and future direction.

Finally in chapter ten we will discuss different techniques of imaged and probe nanostructures that has been essential to the evolution of nanotechnology.

CHAPTER ONE

1. Background

1 .1 History of Nanosience and Nanotechnolgy

Up to 1959 most scientists and engineers were primarily concerned with the theory of breaking very small things. But in 1959 the thought of nanotechnology (but predating use of that name) forwarded in the talk that Richard Feynman on December 29th 1959 at the annual meeting of the American Physical Society at the California Institute of Technology entitled "There is Plenty of Room at the Bottom" [1-5]. In his talk Feynman described how the laws of nature do not limit our ability to maneuver things at the molecular level atom by atom. Instead, he said, it was our lack of equipment and techniques for doing so. Feynman in his lecture talked about "How do we write small?" "Why not we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?" "Information in small scale", the possibility to have "Better electron microscope" that could take the image of the atoms, doing things small scale through “The marvelous biological system", "Miniaturizing the computer", "Rearranging the atoms" to build various nanostructures and nanodevices and behavior of "Atoms in the small world" which include atomic scale fabrication as a bottom-up approach opposed to the top-down approach that we are accustomed to. Bottom-up approach is self-assembly machines from basic chemical building blocks, which is considered to be the ideal through which nanotechnology will ultimately be implemented. Top-down approach is assembly by manipulating components with much larger devices, which is more readily achievable using the current technology [1, 4]. Feynman suggested a means to develop the ability to manipulate atoms and molecules "directly" by developing a set of one-tenth-scale machine tools analogous to those found in any machine shop. These small tools would then help to develop and operate a next generation of one-hundredth scale machine tools, and so forth. As the size gets smaller, we would have to redesign some tools because the relative strength of various forces would change. Gravity would become less important, Quantum effect become more prominent, such as surface tension would become more important; van deer Waals attraction would become important etc. Due to the small size at which nanotechnology operates, physical phenomena not observed at the macroscopic scale dominate. These nanoscale phenomena include quantum size effects and short-range forces. Furthermore the vastly increased ratio of surface area-to-volume ratio promotes surface phenomena. Feynman's 1959 lecture initiated a number of research activities among the scientists at the time.

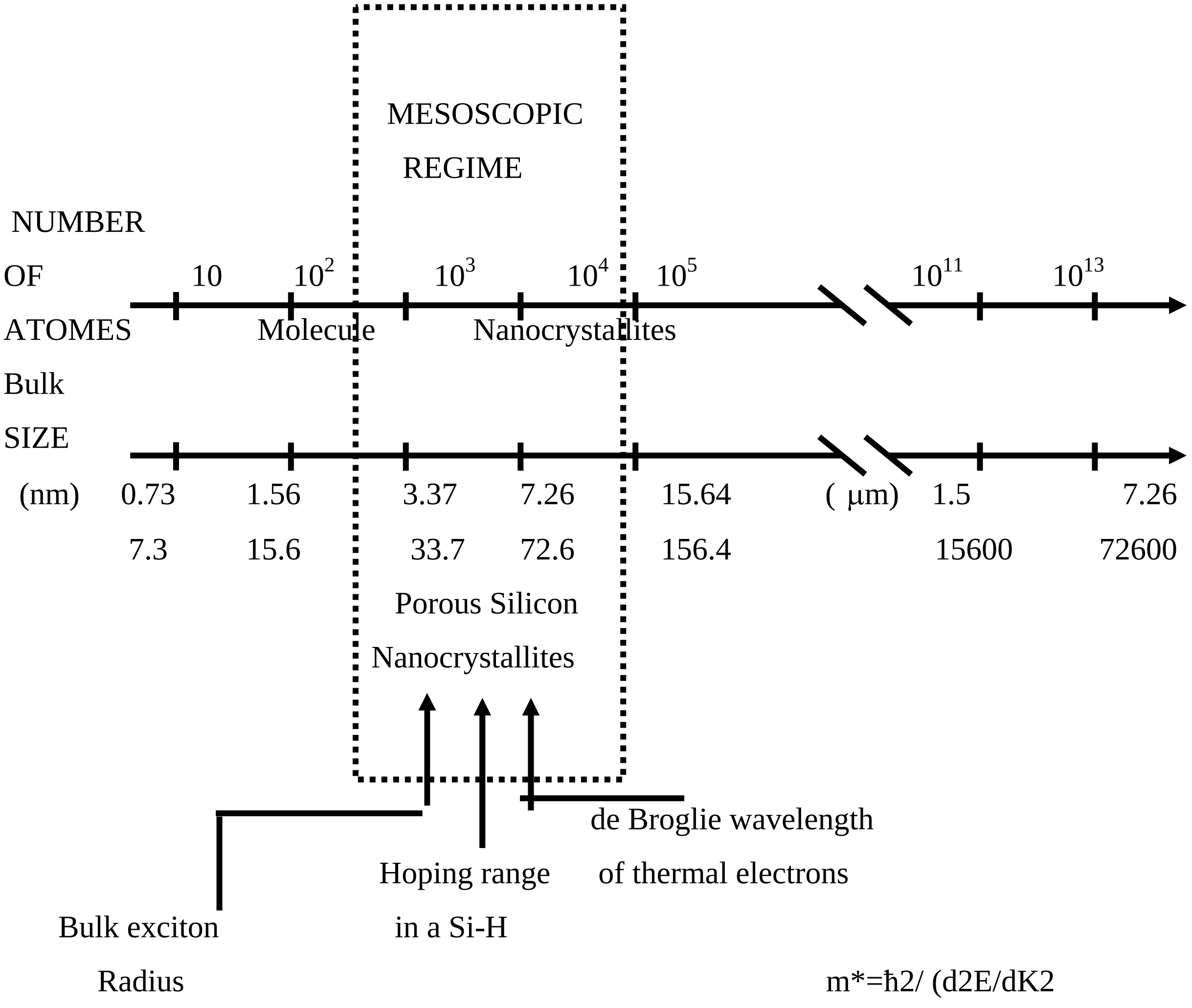
The term "nanotechnology" was defined by Tokyo Science University Professor Norio Taniguchi in a 1974 paper (N. Taniguchi, "On the Basic Concept of 'Nano-Technology'," Proc. Intl. Conf. Prod. Eng.Tokyo, Part II, Japan Society of Precision Engineering, 1974.) As follows: "'Nano-technology' mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or one molecule." In the 1980s the basic idea of this definition was explored in much more depth by Dr. Eric Drexler, who promoted the technological significance of nano-scale phenomena and devices through speeches and the books Engines of Creation: The Coming Era of Nanotechnology and Nanosystems: Molecular Machinery, Manufacturing, and Computation, and so the term acquired its current sense[6].

1.2 What Makes Nanoscience Special?

In ancient time Greek Philosophers, understanding composition and structure of matter in terms of atoms. Since then to explain, matter in terms of atoms and atoms in terms of subatomic particles a number of philosophical, experimental and theoretical periods have been elapsed. Recently a new dimension of thought, interpreting matter by assembling atoms into their correct, precise, and right position at a nanoscale (bottom-up approach) has begun.

RELEVANT LENGTH SCALES

Energy level spacing > KT S/V ~Large e- eff. mass = me Gap ~ 4 eV	Energy level spacing ~ KT S/V ~1 e- eff. Mass = me* Gap ~ 2 eV	Energy level spacing << KT S/V → 0 e- eff. Mass < me Gap ~ 1.1 eV



$m^{*}=\hbar2/\ (d2E/dK2$

The area bounded by the dotted rectangle is the topically interested area called nanoscience [7]. Nanoscience is a new emerging area of science that involves studying and working with matter on ultra-small scale [8]. The Greek word "nano" (meaning dwarf) but "nano" now refers to dimensions that are one-billionth times smaller than a meter ($10^{-9} m$) .An average single human hair is about$10^{-4} m$. Thus if a segment of human hair is longitudinally divided in to 100,000 parts, then the diameter of one part will be one nanometer. For example, the Bohr's radius of hydrogen atom is 0.0529 nm [9] approximately 0.1 nm in diameter. Thus one nanometer equals a length covered by ten hydrogen atoms in the same row. In general, the average size of an atom is on the order of 0.1 to 0.2 nm in radius. Therefore, in one nanometer there may be 3-5 atoms depending on the atomic radii. "Nano" dimension is smaller than the usual meaning of small [10].

Nanoscience is about understanding how to assemble nanoscale materials and how to understand their properties [11]. Nanoscience cannot be called biology, chemistry, or physics; all sorts of scientists are studying very small things in order to better understand the world [12] rather it involve the integrated principles of the whole fields of science and mathematics. Thus, Nanoscience is an interdisciplinary subject [13]. Now let us define the term nanomaterials.

1.3 Nanomaterials

Conventional materials have grains varying in size anywhere from 100’s of microns (µm) to millimeters (mm). All nanomaterials are composed of grains, which in turn comprise many atoms. Nanomaterials are materials characterized by structures with dimensions on the order of 0.1-100 nm [11, 14] they possess properties, which are intermediate between those of the atoms, which constitute materials, and the bulk material. Therefore, the study of nanomaterials is leading to a deeper understanding of how the properties of material evolve as it grows by adding atoms.

Structures in nanoscale, called nanostructures, are considered at the borderline of the smallest of human made-devices and the largest molecules of living systems. Our ability to control and manipulate nanostructures will make it possible to exploit new physical, biological and chemical properties of systems that are intermediate in size, between single atoms, molecules and bulk materials [1].

Natural or man-made particles often have qualities and capabilities quite different from their microscopic counterparts. The reason why so many nanosolids look different from their larger counter parts is primarily due to their edges. A tiny piece of graphite would have many of its atoms at its edges, which are unstable. For example, gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales [1, 15]. Nanoscaled devices will bear much stronger resemblance to nature's nanodevices. Proteins, DNA, membranes etc. falls in that category [1].

Some of the specific reasons why nanoscale has become so important are the following

- The quantum mechanical properties electrons inside matter are influenced by variation on the nanoscale. By nanoscale design of materials it is possible to vary their macro and microscopic properties such as charge capacity, magnetization, and melting temperature, without changing their chemical composition.
- Nanoscale materials have very high surface area to volume ratio, making them ideal for use in composite materials, reacting systems, drug delivery, and chemical energy storage.
- Macroscopic systems made up of nanostructures can have much higher density than those made up of macrostructures. They can also be better conductors of electricity. This can result in new electric devices, smaller and faster circuits, more sophisticated functions, and greatly reduced power consumption [1]

1.4 Nanotechnology

As science becomes more sophisticated, it naturally enters the realm of nanotechnology. The essence of nanotechnology is that as things scaled down, they start to take on extremely novel properties. Nanotechnology as a collective term refers to technological developments on the nanometer scale, usually 1-100 nm [6]. It refers to science carried out at nanometer scale by manipulating individual atoms and molecules. It involves designing and constructing specific molecular structure, one atom at a time. This will require a thorough understanding of chemical bonding, because chemical bonding in which electrons take part holds every atom in a molecule to each other.

According to US National Science and Technology Council, "The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization". The aim is to exploit these properties by gaining control of structures and devices at atomic, molecular and supramolecular levels and to learn to efficiently manufacture and use these devices." In short nanotechnology is the ability to build micro and macro products with atomic precision [1].

Nanotechnology is often referred to a general-purpose technology. That is, because in its mature form it will have significant effect on almost all industries and all areas of the society. It offers better-built, longer lasting, cleaner and safe products for the home, for communication, for medicine, for transportation, for agriculture, and for industry in general [10].

The smallest element of a product would be built on assembly line, and then assembled into progressively larger assemblies until the final product is complete [2]. Generally the philosophy of nanotechnology is bottom-up approach of material production. Nanotechnology strives to use biological, chemical, physical, and computational techniques already in existence to build things with atomic precision. Nanotechnology is recognized everywhere as being the next major technology revolution [16]. Nanotechnology is often referred to a general-purpose technology. It is, a predominate technology that has coming, in the next subtropics we will focus on Molecular Nanotechnology, Self-Assembly and Bionanotechnology.

1.4.1 Molecular Nanotechnology

Manufactured products are made up from atoms. The properties of those products depend on how atoms are arranged. If we arrange the atoms in coal, we can make diamond. If we rearrange the atoms in sand (add a few trace other elements) we can make computer chips. If we rearrange the atoms in the dirt, water and air we can make potato. Today’s manufacturing methods are very crude at the molecular level. Casting, grinding and milling, etc, move atoms in a great tendering herd [3, 17].

Organic chemists have long been able to synthesize complex molecular structures, including drugs, by devising ingenious reagents and by contriving reaction conditions in such a way as to minimize undesired side reactions and maximize yield. The results obtained depend on the statistics of uncontrolled molecular collisions in solution involving all possible molecular degrees of freedom. Statistically improbable reactions may be slow. More important, solution-based reactions generally lead to unwanted and potentially toxic byproducts. This imprecision of present day chemical synthesis and manufacturing processes is one reason that drug standards are needed [2].

Molecular nanotechnology is the name given to a specific sort of manufacturing technology. As its name implies, molecular nanotechnology will be achieved when we are able to build things from the atom up, and we will be able to rearrange matter with atomic precision. In this application, precision means that there is a place for every atom and every atom is in its place. Other terms, such as molecular engineering or molecular manufacturing are also often applied when describing this emerging technology. Precise atomic-level fabrication is only been seen in the growth of crystals or in biological molecular machinery, like the ribosome, which assembles all the proteins in living creatures, or DNA, which carries the instructions for creating a living being [18].

The terms "nanotechnology", "molecular nanotechnology" or "molecular manufacturing" are all coined to mean manufacturing technologies that are able to grasp, manipulate and modify individual molecules, build products with almost every atom at the right place by molecular manipulation inexpensively and make arrangements of atoms consistent to let us make most products lighter, stronger, smarter, cheaper, cleaner, and more precise [2,17].

The key concepts of molecular nanotechnology are that molecules can be machines and that molecular engineers can work with molecules to build desired equipment just as effectively as today's engineers now work with bulk materials. Molecular nanotechnology has been defined as the three-dimensional positional control of molecular structure to create materials and devices to molecular precision [19]. The difference between nanotechnologists and biotechnologists is that the former do not restrict themselves to the biological limitations of the latter, and they are much more ambitious about the kinds of accomplishments that they want to achieve. In contrast, molecular nanotechnology would directly and rapidly produce and only the desired chemical, giving yields of 100%.

This would be achieved by precisely positioning and bringing together the individual molecules involved in the reaction in such away as to catalyze the reaction desired and only the reaction desired [2].

Nanotechnology develops minute technology; this is a model of "nanogears", only a few atoms wide.

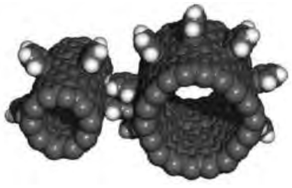


Figure1.Nanogears

1.4.2 Self-assembly

When we want to make a machine, we normally buy some nuts and bolts and parts and screw everything together. Nature works differently- biological "machines" assemble themselves. For instance, an intrinsic interaction within a biological motor, a cell membrane or a developing embryo work together collectively to produce a very complex functional structure. Researchers are just beginning to learn how to use the principles of self-assembly to design new structures at the nanoscale [20].

The fundamental characteristic of nanotechnology is that nanodevices self-assembled; they build themselves from bottom-up atom by atom. Self-assembly is the principle, which generates structural organization on all scales from molecules to galaxies. In the microscopic world, self-assembly occurs all the time, such as when proteins fold into complicated structures. The problem is that scientists still do not understand how such biological systems achieve self-assembly, so they have no blueprint to use in their quest of self-assembly. It is defined as processes in which pre-existing parts or disordered components of a pre-existing system form structures of patterns [20].

One of the problems facing nanotechnology is how to assemble atoms and molecules into smart materials and working devices. Supramolecular chemistry is here a very important tool. Supramolecular chemistry is the chemistry beyond the molecule, and molecules are being designed to self-assemble into larger structures. In this case, biology is a place to find inspiration: cells and their pieces are made from self-assembling biopolymers such as proteins and protein complexes [21.14].

An example of self-assembly in nature is the way that hydrophilic interaction (Interactions between water and other molecules such that the other molecules are attracted to water are called hydrophilic interactions) and hydrophobic interaction (Interactions between water and other molecules such that the other molecules are repelled by water are called hydrophobic interactions) cause cell membranes to self assemble

Hydrophobic and hydrophilic are important because many molecules in biology such as proteins and the molecules that make up the cell membrane have hydrophilic and hydrophobic regions on the same molecule. When put in water these molecules automatically organize themselves into more complex and biologically useful structures. This process is termed self-assembly.

It is illustrated in the diagram for a molecule with a polar head and a non-polar tail. We will see just such molecules involved in cell membranes [22].

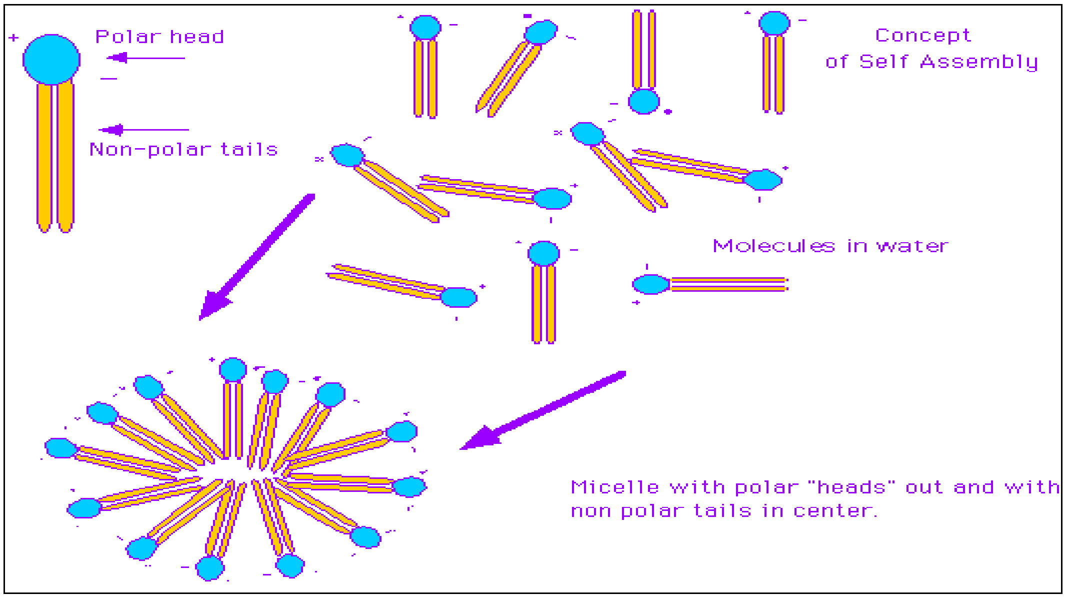


Figure 2 Micelle structure with polar heads out and non-polar tails in center.

Enzymes are natural molecular machines that adsorb individual reactant molecules from the surrounding solution and, as a result of precisely orienting them with respect to each other in a protected "nanoenvironment," catalyze reactions in a highly specific manner at very high speeds and under mild reaction conditions [11].

Molecular self-assembly is the assembly of molecules without guidance or management from an outside source. There are two types of self-assembly, intramolecular self-assembly and intermolecular self-assembly. Self-assembly can occur spontaneously in nature, for example in cells (such as the self-assembly of the lipid bilyer) and other biological systems, as well as in human engineered systems.

Importance of Self-assembly

Molecular self-assembly is a strategy for nanofabrication that involves designing molecules and supramolecular entities so that shape-complementarily causes them to aggregate into desired structures. Self-assembly have a number of advantages as a strategy: First, it carries out many of the most difficult steps in nanofabrication--those involving atomic-level modifications of structure--using the very highly developed techniques of synthetic chemistry. Second, it draws from the enormous wealth of examples in biology for inspiration: self-assembly is one of the most important strategies used in biology for the development of complex, functional structures. Third, it can incorporate biological structures directly as components in the final systems. Fourth, because it requires that the target structures be the thermodynamically most stable ones open to the system, it tends to produce structures that are relatively defect-free and self-healing [23].

A molecular assembler is a molecular machine capable of assembling other molecules given instructions, energy, and a supply of smaller "building block" molecules to work from. Distinction is sometimes made between synthetic and naturally occurring molecular assemblers. In cellular biology, the ribosome demonstrates the essential principles of a molecular assembler. Working within a cell's environment, it reads strands of RNA as its instructions and assembles specific large protein molecules out of more fundamental parts [2, 24].

1.4.3 Bionanot echnology

Nanotechnology works with objects that are on the order of 1 to 100 nanometers; a nanometer is one-billionth of a meter, about the size of several atoms. When combined with molecular biology, the possible applications of this nano-frontier are widespread and sound like the stuff of science fiction. Scientists currently are designing microscopic "nanobots", bioprobes and biosensors that, once implanted in the human body, could perform a number of medical duties, from delivering drugs to detecting malignant cells.

The nano-scale is where most biological processes occur. Thus, nanotechnology offers the prospect of mimicking the complex biological world with synthetic materials [11]. Bionanotechnology encompasses the study, creation, and illumination of the connections between structural molecular biotechnology and molecular nanotechnology since the development of nanomachinery might be guided by studying the structure and function of the natural nanomachines found in living cells. Bionanotechnology seeks to modify and find technological uses of natural nanocomponents. This involves mechanochemistry, sometimes also called "positional synthesis" or "positional assembly" is a technique for forming chemical bonds by direct computer control of the position of molecules [2].

Bionanotechnology is a new frontier of research that combines two seemingly incompatible materials - the building blocks of life and synthetic structures - at a tiny, molecular-sized scale.

1.5 Recent Development of Nanotechnolgy

- In October 2004, researchers at the University of Manchester succeeded in forming a small piece of material only 1 atom thick called graphene. Robert Freitas has suggested that graphene might be used as a deposition surface for a diamondoid mechanosynthesis tool
- As of August 23 2004, Stanfored University has been able to construct a transistor from single-walled carbon nanotubes and organic molecules. These single-walled carbon nanotubes are basically a rolled up sheet of carbon atoms. They have accomplished creating this transistor making it two nanometers wide and able to maintain current three nanometers in length. To create this transistor they cut metallic nanotubes in order to form electrodes, and afterwards placed one or two organic materials to form a semiconducting channel between the electrodes. It is projected that this new achievement will be available in different applications in two to five years.
- News.com reported on March 1st 2005 Intel is preparing to introduce processors with features measuring 65 nanometers. The company’s current engineers believe that 5

nanometer processes are actually proving themselves to be more and more feasible. The company showed pictures of these transistor prototypes measuring 65, 45, 32, and 22 nanometers. However, the company spoke about how their expectations for the future are for new processors featuring 15, 10, 7, and 5 nanometers. Currently the prototypes use CMOS (complementary metal-oxide semiconductors); however, according to Intel smaller scales will rely on quantum dots, polymer layers, and nanotube technology.

- Phys Org.com writes about the use of plasmons in the world. Plasmons are waves of electrons traveling along the surface of metals. They have the same frequency and electromagnetic field as light; however, the sub-wavelength size allows them to use less space. These plasmons act like light waves in glass on metal, allowing engineers to use any of the same tricks such as multiplexing, or sending multiple waves. With the use of plasmons information can be transferred through chips at an incredible speed; however, these plasmons do have drawbacks. For instance, the distance plasmons travel before dying out depends on the metal, and even currently they can travel several millimeters, while chips are typically about a centimeter across from each other. In addition, the best metal currently available for plasmons to travel farther is aluminum. However, most industries that manufacture chips use copper over aluminum since it is a better electrical conductor. Furthermore, the issue of heat will have to be looked upon. The use of plasmons will definitely generate heat but the amount is currently unknown.
- The further development in the field of nanotechnology focuses on the oscillation of a nanomachine for telecommunication. The article states that in Boston an antenna-like sliver of silicon one-tenth the width of a human hair oscillated in a lab in a Boston University basement. This team led by Professor Pritiraj Mohanty developed the sliver of silicon. Since the technology functions at the speeds of gigahertz this could help make communication devices smaller and exchange information at Gig hertz speeds. This nanomachine is comprised of 50 billion atoms and is able to oscillate at 1.49 billion times per second. The antenna moves over a distance of one-tenth of a picometer [27].

The recent development of Nanotechnology shows that in the coming era nanotechnology revolution will change the nature of almost every human objects and activities; the societal impact of this revolution will be greater than that of the first industrial revolution.

1.6 Global Distribution of Nanotechnology

Figure 3 shows the global distribution of nanotechnology companies. It can be seen that the nanotechnology industry is dominant by US companies (49%), followed by Europe (21%) and rest of the world (21%). UK NM industry only makes around 9% of the global nanotechnology sector. In view of the huge number of emerging new materials and applications, this situation is likely to change in the near future [8].

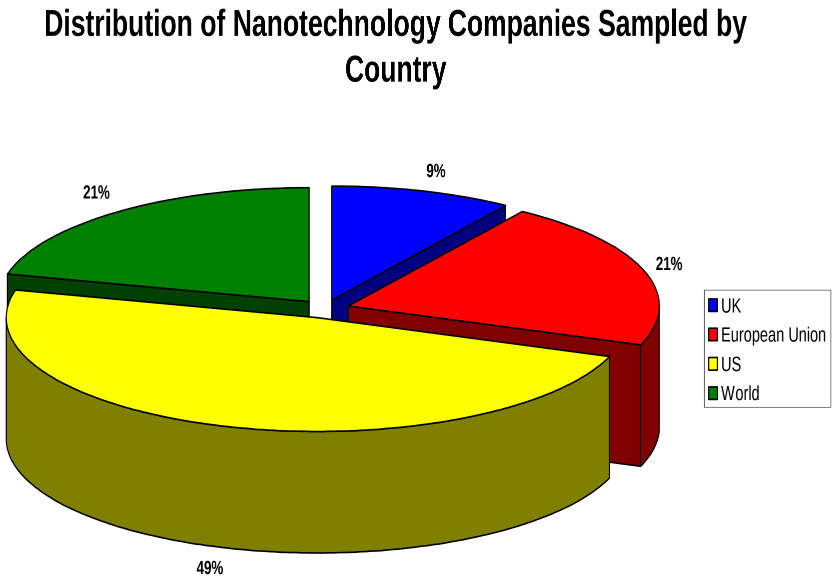


Figure 3 Distribution of nanotechnology companies [49][24]

Figure 4 shows the distribution of the NMs manufacturers according to the general type of NM products they produce. These products are free NMs, prior to blending or integration into secondary products. From this figure, it is clear that the global focus, at least in terms of the number of different manufacturers, is in fullerenes, nanotubes and fibers, and nanoscale metals. The large number and diverse nature of US manufacturing companies skew the average global distribution of companies. NM manufacturing in the UK, on the other hand, does not reflect the global emphasis on fullerenes, nanotubes and fibers. Rather, the emphasis is weighted heavily towards production of nanoscale metals and metal oxides (i.e., >50% of NMs manufacturers in the UK produce nanoscale metals)[8].

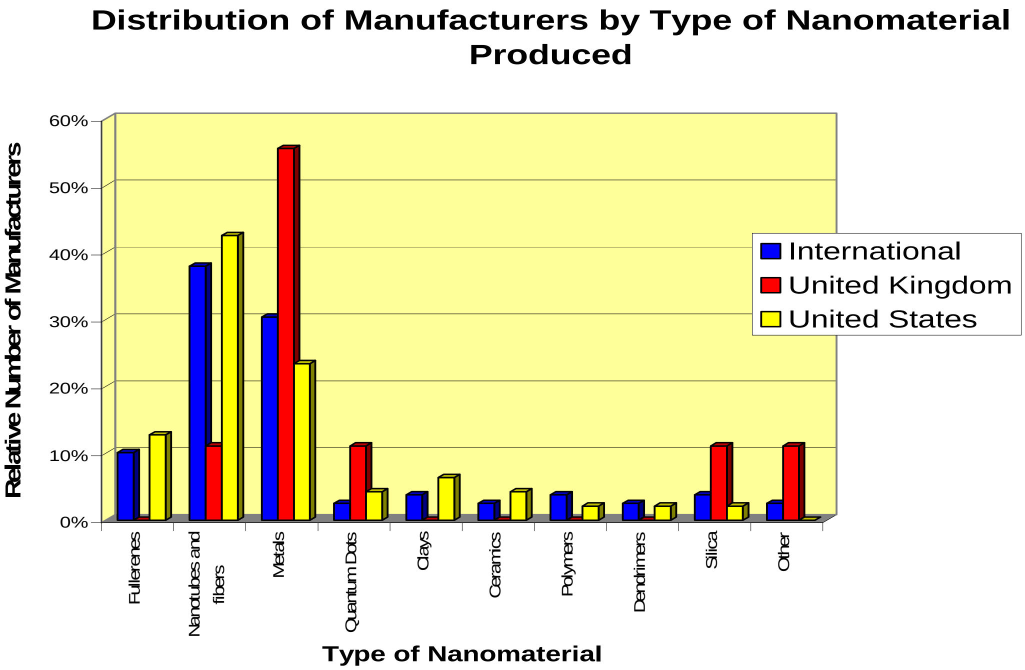


Figure 4 Distributions of manufacturers by type of nanomaterial produced [24]

1.7 Potential Benefits of Nanotechnology

Nanotechnology is the science of manipulating and characterizing matter at the atomic and molecular level. It is one of the most promising and exciting fields of science today, involving a multitude of science and engineering disciplines, with widespread applications in electronics, advanced materials, medicine, and information technology. One of the first obvious benefits of nanotechnology is the improvement in manufacturing techniques on the atomic scale. For example, nanotechnology likely represents the future of information processing and storage; computer can be about 100 times smaller and use millions times less power. Materials can be about 100 times stronger than steel. This means that most human scale-products would consist almost entirely of empty space, reducing material requirements and cost [13].

Manufacturing with nanotechnology may be able to solve many of the current problems.

- Water shortage is a serious problem. Most water is used for industry and agriculture; both of these requirements would be greatly reduced by molecular manufacturing.
- Infectious diseases continuing scourge in many parts of the world. Some of the most dramatic changes are expected in the realms of medicine. Scientists envision creating machines that will be able to travel through the circulatory system, cleaning the arteries as they go; sending out troops to track down and destroy cancer cells and tumors; or repairing injured tissue at the site of the wound [20].
- Electrical power is not available in many areas. The efficient, cheap building of light, electrical equipment, and power storage devices would allow the use of solar thermal powers as a primary and abundant energy source.
- Environmental degradation is a serious problem worldwide. High products can allow people to leave with much less environmental impact. Nanotechnology offers the promise of improved characterization of environmental problems through improved detection and monitoring capabilities, significantly reduced environmental effects from cleaner manufacturing and synthesis approaches that result in a reduction or elimination of wastes and reduced energy use, and unique solutions for remediation and the treatment of pollutants [15,23]. Once we have the ability to capture, position, and change the configuration of a molecule, we should be able to create filtration systems that will scrub the toxins from the air or remove hazardous organisms from the water we drink [20].
- Telecommunication and Information technology could benefit in terms of faster computers and advanced data storage.

1.8 Potential Risks Nanotechnology

For the near-term, critics of nanotechnology point to the potential toxicity of new classes of nanosubstances that could adversely affect the stability of cell membranes or disturb the immune system when inhaled, digested or absorbed through the skin. Objective risk assessment can profit from the bulk of experience with long-known microscopic materials like carbon soot or asbestos fibers. Nanoparticles in the environment could potentially accumulate in the food chain. An often-cited worst-case scenario is "grey goo", a hypothetical substance into which the surface objects of the earth might be transformed by self-replicating nanobots running amok. Societal risks from the use of nanotechnology have also been raised, such as hypothetical nanotech weapons (e.g. a nanomachine which and in the creation of undetectable surveillance capabilities consumed the rubber in tires would quickly disable many vehicles) [6].

Under this chapter we have seen briefly History of Nanoscience and nanotechnology; also we have answered the question that asked by most of the people" what makes Nanoscience special?" As mentioned above Nanoscience is a new emerging area of science that involves studying and working with matter on ultra-small scale, on the order of $10^{-9}m$. It is a small, small, small world. At this scale quantum effect is more prominent where as gravity is less important. We also discussed about nanotecnology and its potential benefits and risks. Based on this background in chapter two we will discuss industrially potential nanomatrial called fullerene

CHAPTER TWO

2. Fullerene

Carbon is one of the most remarkable of all chemical elements. It occurs in all living organisms. In fact, the field of organic chemistry, which began as the study of the chemistry of plants and animals, can also be called the chemistry of carbon compounds. In addition, carbon and its compounds are of critical importance to the world as sources of energy. Coal, oil, and natural gas-the so-called fossil fuels-all consist of pure carbon or carbon compounds. Finally’ carbon monoxide and carbon dioxide,

Figure 5 Gem-quality diamonds in Kimberlite (Reproduced by permission of National Aeronautics and Space Administration)

The two oxides of carbon are profoundly important not only in the survival of living organisms but also in a host of industrial operations. (An oxide is an inorganic compound whose only negative part is the element oxygen.)

Carbon was one of the first elements known to humans. A Greek historian of the fourth century B.C., for example, tells of a natural gas well in Turkey that provided a perpetual flame for religious ceremonies. Many reports also detail the practice of mixing lampblack, a form of carbon, with olive oil and balsam gum to make a primitive form of ink. And diamonds, another form of carbon, are described in the Bible and even older Hindu manuscripts.

Carbon occurs both as an element and in combined forms. As an element, it exists in tow different allotropic forms. (Allotropes are forms of an element that differ from each other in physical and, sometimes, chemical properties.) The two best-known allotropes of carbon are graphite and diamond. Graphite is a soft, shiny, dark gray or black, greasy-feeling mineral used to make the "lead" in lead pencils. Graphite is soft enough to be scratched with a fingernail.

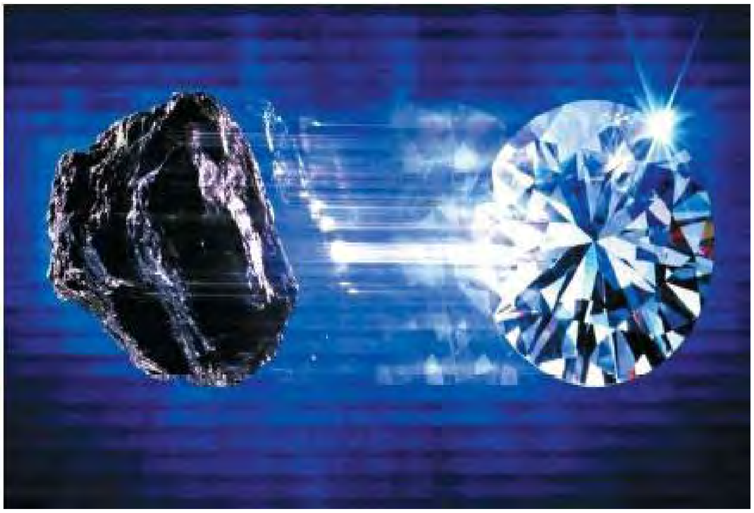


Figure 6.Carbon and a carbon-created diamond (Reproduced by permission of The Stock Market)

The second common allotrope of carbon is diamond. In striking contrast with graphite, diamond is the world's hardest natural material. Its ability to bend and spread light produces the spectacular rainbow "fire" that is often associated with diamond jewelry. Skillful gem cutters are able to cut and polish diamonds in a way that maximizes the effect of this natural property.

In 1985 the third allotrope of carbon was discovered. Next two sub tropics we will see its discovery and naming.

2.1 Discovery of Fulerene-Thrid Allotropes of Carbon

In 1985, research team lead by Richard Smalley and Robert Curl both of Rice University in Houston, Texas and Harold Kroto from of the University of Sussex in England, culminated in their Nobel Prize in Chemistry in 1996, and added a new form of carbon to the two well-known forms, diamond and graphite [10, 23]. These investigators used laser evaporation of graphite and they found Cn clusters such as C60 and C70. Thus they discovered that carbon is capable of forming 60-atom structure called Buckminsterfullerene [19, 25 26, 27].

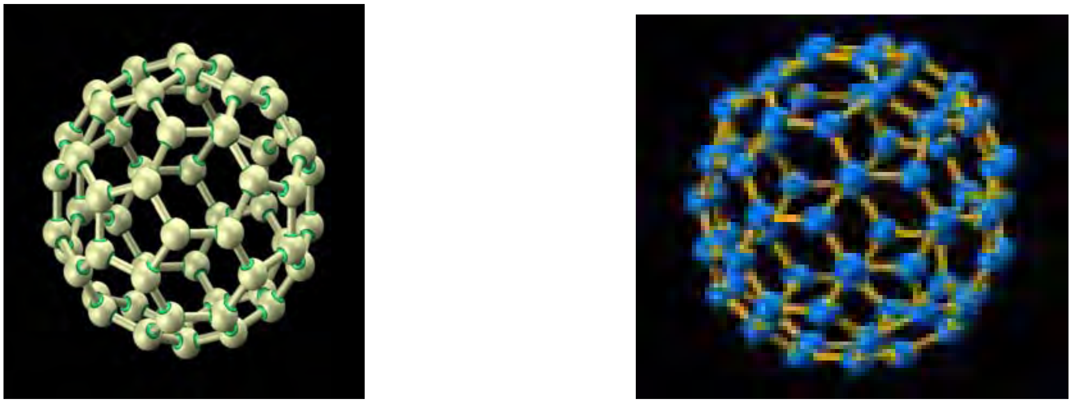


Figure 7 a) Buckminsterfullerene, C60 b) C70, C60's big brother.

2.2 Buckminsterfullerene.

How would you like to have a molecule named after you? That is just what happened to one famous American in 1985, when scientists discovered an entirely new form of carbon. Until that time, chemists had thought that carbon existed in only two solid forms: graphite and diamond. Then, researchers at RiceUniversity in Texas and the University of Sussex in England found a strange-looking molecule consisting of 60 carbon atoms joined to each other in a large sphere. Under a microscope, the molecule looks like a soccer ball with 20 hexagons (six-sided figures) and 12 pentagons (five-sided figures) on its surface.

The Rice and Sussex chemists suggested naming the new molecule after American engineer and philosopher R. Buckminster Fuller (1895–1983). Fuller had created a number of exciting new architectural forms, one of which was the geodesic dome. A geodesic dome, like the new molecule, is a sphere made of many plane (flat) figures like the hexagon. Because of this similarity, the new molecule was given the name buckminsterfullerene or, more briefly, fullerene. Less formally, the molecules are also known as bucky-balls.

The discovery of fullerenes has created a whole new field of chemistry that involves the study of "hollow" molecules in the shape of spheres or cylindrical rods. In the early 1990s, astronomers announced the discovery of fullerene molecules in outer space [28, 29, 30, and 31].

2.3 Why Carbon is Special?

More than ten million compounds of carbon are now known. That number is far greater than the total of all non-carbon compounds that have been discovered. The special property that makes carbon so different from all other elements is the ability of its atoms to combine with each other in long chains. It is possible to find compounds in which two atoms of an element are joined to each other, but chains of more than two are rare. A chain of ten or more atoms (other than carbon) is virtually unheard of. Yet long chains of carbon atoms are the rule rather than the exception. For example, the protein molecules in your body consist of hundreds or thousands of carbon atoms connected to each other in a long chain. (Proteins are large molecules that are essential to the structure and functioning of all living cells.)

Furthermore, carbon atoms can form structures more complicated than chains. Some compounds have carbon chains with other chains branching off from them, carbon chains joined tail-to-end in rings or rings inside of rings, carbon chains in the shape of cages, boxes, and spheres, and carbon chains in other strange and fascinating shapes. The interesting point is that these strange molecular structures are not just laboratory curiosities. In many cases, they are found in some of the most important compounds in living organisms; that is why carbon is special

To sum up carbon is one of the most remarkable of all chemical elements that exists in three forms such as graphite, diamond and fullerene. Fullerene has different structure and bonding that of graphite and diamond. In chapter three we will deal with structure and bonding of fullerene.

CHAPTER THREE

3. Structures and Bonding of Fullerene

Although the fullerene wins the Nobel Prize 1996, this molecule has a long history. The structure of the regular truncated icosahedrons was known to Leonard de Vinci and to Albrecht Durer. In 1970 Osawa suggested that icosahedra C60 might be stable. As soon as Kroto Smalley and coworkers established the stability of the fullerene in gas phase, the study of fullerene had a rapid development. Thanks to experiments, we know that the crystalline materials formed from fullerenes are molecular solids. Moreover, the structure and properties of these solids are a result of the structure and properties of the constituent fullerene molecules. The fullerenes are built up of hexagons and pentagons.

Fullerenes consist of 20 hexagonal and 12 pentagonal rings as the basis of icosahedra symmetry closed cage structure. Each carbon atom is bonded to three others and is sp2 hybridized. The C60 molecule has two bond lengths - the 6:6 ring bonds can be considered "double bonds" and are shorter than the 6:5 bonds. C60 is not "super aromatic" as it tends to avoid double bonds in the pentagonal rings, resulting in poor electron delocalisation. As a result, C60 behaves like an electron deficient alkenes, and reacts readily with electron rich species. The geodesic and electronic bonding factors in the structure account for the stability of the molecule. In theory, an infinite number of fullerenes can exist, their structure based on pentagonal and hexagonal rings, constructed according to rules for making icosahedra.

3.1. The Truncated Icosahedron

The proposed structure for C60, a "truncated icosahedron"- (a polygon with 60 vertexes and 32 faces, 12 of which are pentagons and 20 of which are hexagons) is derived from an icosahedron by truncating or "snipping off" each of the twelve vertices (seeFigure8). Hence, a five-member ring - a pentagon, replaces each vertex. This snipping process also converts each of the twenty former triangular faces into six-member rings - hexagons [31].

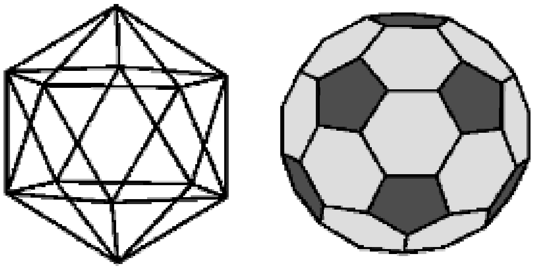


Figure 8.Icosahedron (left) and "truncated icosahedron" (right).

3.2. Analysis of the Bonding in C60

In the proposed structure for C60, a carbon atom occupies each vertex of the truncated icosahedron, and each carbon is three-connected to other carbon atoms by one double bond and two single bonds. Carbon atoms with this kind of connectivity are usually referred to as sp2 carbon because the orbital used to sigma-bond the three adjacent carbons are hybrids of the 2s orbital and the two 2p orbital (2px and 2py). The remaining 2p orbital (2pz) is responsible for the pi-bond.

Usually, an sp3 carbon and its three neighboring atoms are all coplanar. This is the case, for example, in graphite where there are infinite planar sheets of sp3 carbons arranged in edge-sharing hexagons. The p_Z orbital all lie parallel to each other and perpendicular to the graphite plane, generating a sea of Π- electron density above and below the plane.

In graphite, the C-C bonds are all equal in length and intermediate between normal single and double bonds. This "delocalization" can be explained by noting that graphite has many different but equivalent "resonance structures". (The resonance structures differ only in the placement of the double bonds.) Two of these are drawn for a portion of graphite in Fig.9

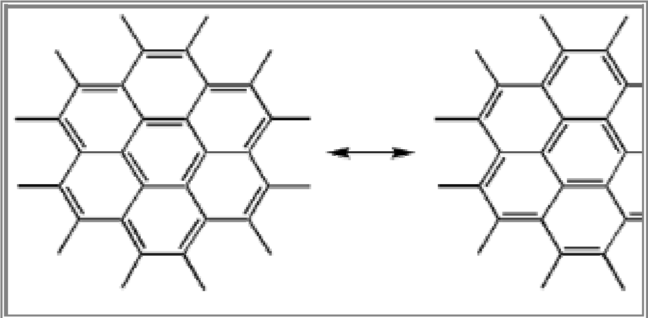


Figure.9 Two resonance structures of a portion of graphite.

Clearly, the proposed structure for C60 is not planar! The angle between pz and C-C bond vector, (see Figure 10), is 101.6° (as compared to 90° in planar graphite). The bowl-shape or concavity at each sp2 carbon center introduces some strain into the molecule. However, the high symmetry distributes that strain evenly across the entire structure [29,31].

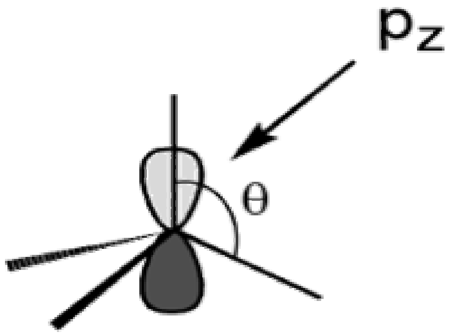


Figure 10. Theta (θ) is defined as the angle between the P_Z axis and a carbon-carbon bond vector.

3.3. Other Fullerenes

The truncated icosahedron is not the only possible fullerene-type structure. There are, in fact, many other hollow cage structures that can be constructed using only pentagons and hexagons. Interestingly, each of these structures contains exactly twelve pentagons, while the number of hexagons is arbitrary. The pentagons are necessary for closure. (Recall that graphite, which consists only of fused hexagons, is essentially a planar sheet. While this sheet may warp and bend, it can never close.) The number of vertices in closed fullerene-type structures is necessarily even.

The smallest possible fullerene would be C20, containing twelve pentagons and zero hexagons. However, such a structure would possess a great deal of strain, because the local topology at each carbon center would be highly non-planar. Other possible fullerenes include C28, C32, C60, and C70. Because the molecular strain tends to be concentrated in the five-member rings that are responsible for closure, structures that avoid contiguous (edge-sharing) pentagons are particularly stable. It turns out that C60 and C70 are the smallest carbon clusters for which this can be achieved [29, 31]

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3.4 Other Possible Structures for C60

While the truncated icosahedron structure for C60 is elegant and aesthetically pleasing, it is important to bear in mind that when it was proposed, there was only one piece of supporting experimental evidence - an unusually large peak at 720 in the mass spectrum. Other C60 cluster structures, including the following three, were possible.

a. Planar graphite fragments. The problem with this type of structure is that it contains many unsatisfied valences, and it is not clear why C60 should be any more stable than any other cluster size

b. Cyclic polyalkynes. In this structure, there are no unsatisfied valences but the stability of C60 vs. other cluster sizes is not easily rationalized

c. Other fullerenes, i.e., other hollow cage structures with different atom arrangements. These would necessarily be less highly symmetric than the truncated icosahedron and would less effectively distribute strain evenly around the molecule [29, 31]. We have seen the structure and bonding of Fullerene above, the reader asks a question, how to synthesize fullerene, to apply in our daily life. The next chapter will discuss some techniques of synthesizing of Fullerene that have dominant influences on the next industrial revolution.

CHAPTER FOUR

4. Fullerene Synthesis Techniques

Fullerenes occur only in small amounts naturally, but several techniques for producing them have been suggested. These are Vaporization of graphite rods, Resistive Heating of Graphite, Graphite arching, pyrolysis of hydrocarbons. In this chapter we will briefly see Graphite arching Vaporization of graphite rods, and Resistive Heating of Graphite as prototype.

4.1. Graphite Vaporization

While it was Kroto's idea to experiment with vaporized carbon, it was Smalley's apparatus that made the experiment possible. The apparatus was originally designed for the purpose of studying supersonic metal cluster beams, but proved effective on carbon clusters as well.

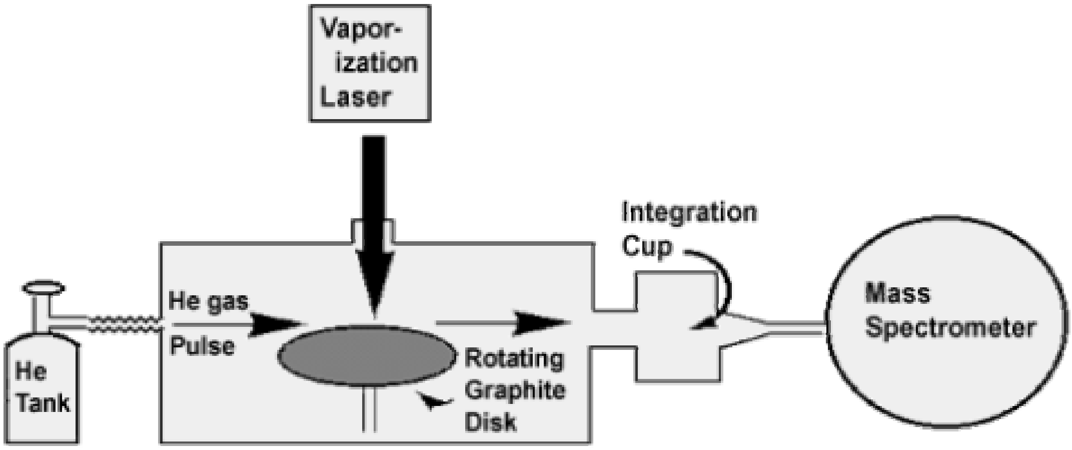


Figure 11.Graphite vaporization apparatus [32]

The laser was an Nd: YAG (neodymium-doped yttrium aluminum garnet)**,** which produced energies of approximately 30mJ at 535nm for 5ns. The graphite disk rotated as to keep a hole from being bored into the disk. The helium pulse cooled and condensed the resulting soot and also carried it into the ionization chamber where the condensed carbon clusters were ionized by direct one-photon excitation with an excimer laser pulse. The expansion of the cluster-laden gas produced a supersonic beam, which allowed for time-of-flight mass spectrometry. The mass spectrum of the soot reveled that C60 was present in microscopic quantities. The integrating cup increased the time between vaporization and expansion and was found to increase the yield of C60. However, the yield was still quite small. In fact, it was so small that no analysis of the C60 itself could be performed. Cox, experimented with variations of these conditions, in 1988. They found that 7.87 eV was the most effective energy for the ionizing photons. They also discovered that when a thick graphite sample was used, and the laser was allowed to bore a hole into the sample, greater yields of larger fullerenes (greater than 32 atoms) were observed. The cause of this phenomenon was thought to be the expansion of the plasma as it moves out of the hole into the lower pressure. This is similar to the phenomenon observed by Kroto, in which the C60 yield increased when the gas was kept under high pressure for a longer period of time [32].

4.2 Resistive Heating of Graphite (K-H method)

The first macroscopic quantities of C60 were produced in 1990 by what is now known as the Kratschmer-Huffman (K-H) method. Instead of vaporizing carbon with a laser, a graphite rod was slowly evaporated using resistive heating. This slower, more 'gentle' technique allowed for more control over the conditions that make C60 formation possible. This experiment was a monumental step because the production of macroscopic quantities of C60 made it possible to perform a more complete analysis of its properties. The analyses led to the first solid evidence that C60 was, in fact, a closed sphere.

Diederich repeated the resistive heating method in 1991. They not only provided further analytical evidence (electronic absorption, and IR spectroscopy, and CNMR) that the carbon clusters were fullerenes, but also isolated and characterized higher fullerenes such as C76, C84, C90, C94, and C70 [32,23].

4.3 Graphite Arching

The apparatus for this technique is comprised of graphite electrodes over which an ac or dc arc is produced, generating the necessary carbon soot. Haufler provided an outline for the "C60 Generator" less than a month after the K-H method was published. In this generator (fig. 12), the graphite rod and disk are connected to an external 60 Hz ac power source. The graphite is vaporized with a 100-200A current at an rms voltage of 10-20V.

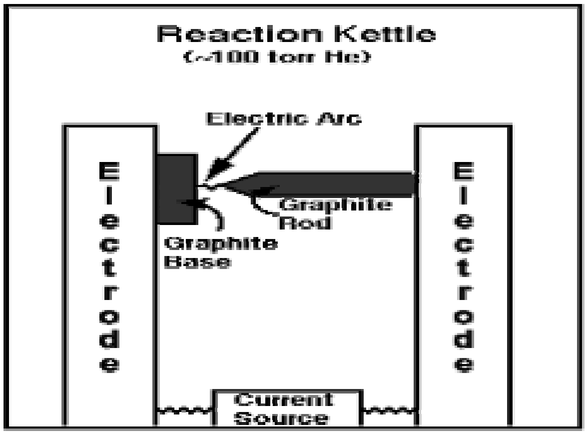


Fig. 12 Graphite arc apparatus [32]

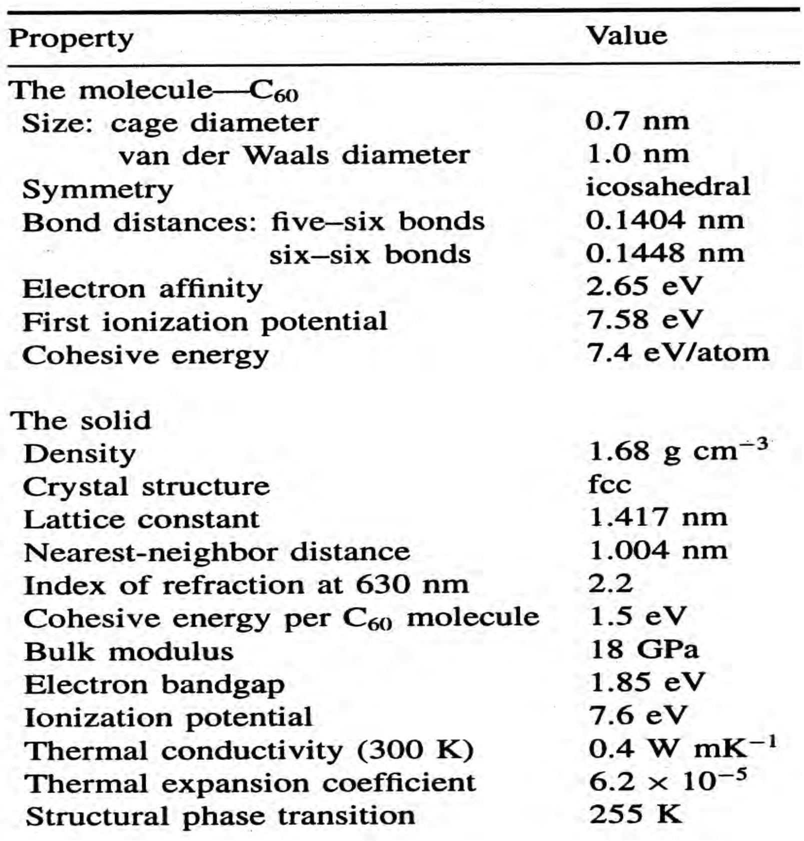
Not shown in this diagram is the helium source that condenses the carbon. This method, like the K-H method, allows for control over the carbon condensation conditions that allow for higher C60 yield. The graphite arcing technique is currently the most commonly used technique and is also used commercially [23, 32]. Let us ask questions here, why we need develop a technique for preparation of fullerene? What makes Fullerne different from Graphite and Diamond? Next chapter will discussed some special properties of Fullerene.

CHAPTER FIVE

5. What Makes Fullerene Extraordinary?

What is unusual about this molecule its high degree of symmetry, in fact, it can be shown theoretically that this shape is the most symmetric shape that can be obtained in three dimensions. It is indeed the most symmetrical molecule, or as one of its discoverer says, `the roundest of all molecules '. Because of its extraordinary symmetry, it is also highly stable. It is the unique arrangement of the carbon atoms in the Fullerene molecule, which is responsible for its remarkable properties. Just as different molecular structure causes a world of a difference between the properties of graphite (which is so soft that it is used for lubrication) and diamond (which is the hardest natural substance known to us) even though both are basically carbon; the Fullerene form of carbon is also distinctive. The properties of this form of Carbon are still being researched but already there is a tremendous excitement among the scientists.

Crystalline C60 is a molecular solid. That is, the crystals are formed from an ordered array of the C60 molecules, which retain their identity and many of their molecular properties. This is in contrast to the other crystalline forms of carbon—diamond and graphite, where there is no identifiable molecular sub-unit. Therefore, many of the properties of solid C60 come from those of the molecules. Table 1 lists separately some of the properties of the molecule and of the solid, which are discussed in here [32].



Property	Value
The molecule—C_{60}	
Size: cage diameter	0.7 nm
van der Waals diameter	1.0 nm
Symmetry	icosahedral
Bond distances: five–six bonds	0.1404 nm
six–six bonds	0.1448 nm
Electron affinity	2.65 eV
First ionization potential	7.58 eV
Cohesive energy	7.4 eV/atom
The solid	
Density	1.68 g cm^{-3}
Crystal structure	fcc
Lattice constant	1.417 nm
Nearest-neighbor distance	1.004 nm
Index of refraction at 630 nm	2.2
Cohesive energy per C_{60} molecule	1.5 eV
Bulk modulus	18 GPa
Electron bandgap	1.85 eV
Ionization potential	7.6 eV
Thermal conductivity (300 K)	0.4 W mK^{-1}
Thermal expansion coefficient	6.2×10^{-5}
Structural phase transition	255 K

Table-1 Molecular and solid properties of C60 [32]

5.1 Properties of the C60 Molecules

Because of the high symmetry of the C60 molecule (icosahedra) every carbon atom sits in an identical environment at the point of intersection of two hexagons and one pentagon. Thus the C60 molecule displays a CNMR spectrum consisting of a single line, which provided a striking confirmation of the buckyball model. The C60 molecule, because of its especially stable structure, is highly resistant to photo fragmentation. It is a very resilient survivor of collisions against surfaces, as shown by both experiments and theory.

The molecule has a large electron affinity. Initially, two- and three-electron reductions were shown in cyclic voltammeter; and more recently up to six electrons have been added reversibly. C60 has a closed-shell electronic structure with gap energy of about 1.9 eV between the highest occupied molecular orbital and the lowest unoccupied molecular orbital (the HOMO–LUMO gap). The cohesive energy is 7.4 eV per carbon atom.

During the years from 1985 to 1990, when there was much discussion of the buckyball but no experiments outside of molecular beams, it was widely believed that the C60 molecule would be very uncreative due to the complete absence of dangling bonds. This would also make it very abundant in the universe, since it would be stable against chemical destruction. When the molecule became available in abundance, it was found that many chemical species react easily with it. Reaction has been shown to occur with oxygen, hydrogen, fluorine, chlorine, and bromine. A common feature of such reactions is that a complex mixture of products is produced. For example, when the first halogenation's of was C60 s carried out a mixture of products was obtained, although C60 H36, which had so been found in the hydrogenation experiments of Haufler, dominated it. Similar effects have been found for C60Br36. Taylor and Walton have categorized the growing list of molecules C60 based on in a review [2].

5.2 Properties of the Solid

Since the solid is made up of tightly bound buckyballs, which are weakly bound together by van der Waals forces, the mechanical properties of the solid can be characterized as light, weak, and soft with respect to the other carbon forms. The density is 1.7 g cm-3 compared to that of graphite (2.3 g cm-3) and diamond (3.5g cm-3). Mechanical properties vary widely in the three forms of carbon because of the different bonding. Diamond is a very strong isotropic solid whereas graphite is a highly anisotropic solid, which yields easily to shear forces separating the planes, while maintaining high strength within the planes. Under the action of hydrostatic pressure, solid C60 compresses easily with a bulk modulus of 18 GPa, which is similar to the interplanar compressibility of graphite. As the hydrostatic pressure on solid is in C60 increased to 20 GPa, the solid becomes less compressible. Initially the electron clouds separating molecules yield easily under pressure. However, after the rigid cages begin to interact, the solid becomes much stiffer.

The electronic properties of the C60 molecule are largely preserved as the solid is formed. The minimum band gap in the solid of about 1.5 eV is similar to the HOMO–LUMO gap in the molecule with a slight broadening of the electronic energy bands in the solid. Thus solid C60 is a large-band gap semiconductor. Fig 13 shows HOMO_LUMO gap.

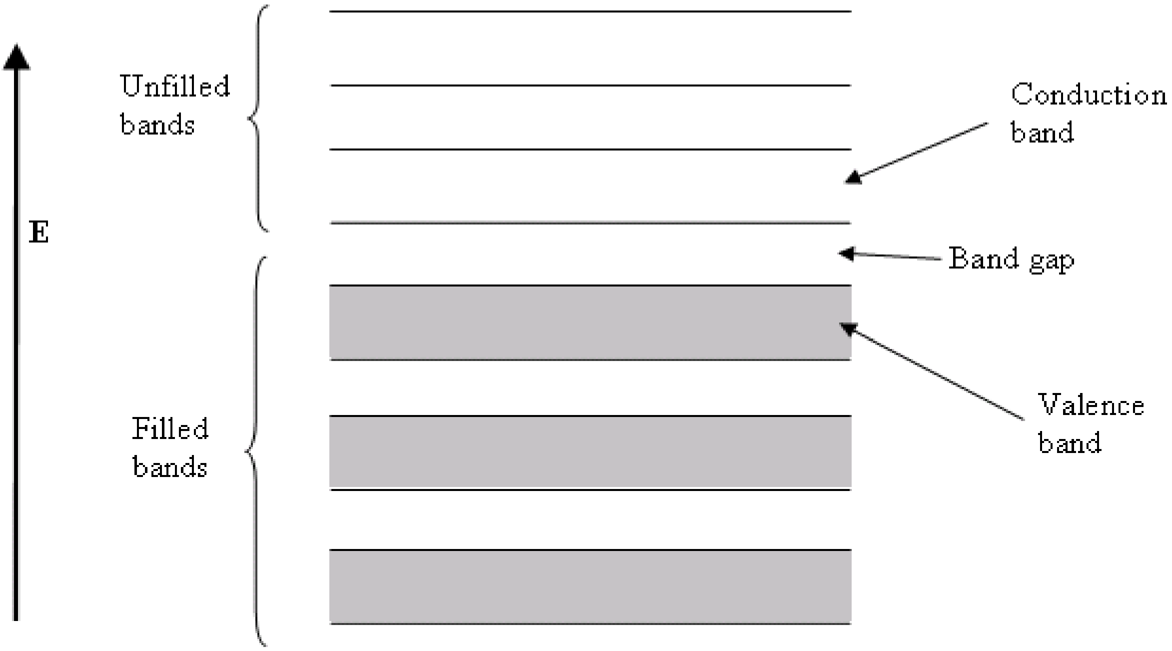


Figure 13.The HOMO–LUMO gap

Its electrical conductivity is very low. It is transparent in the near infrared and into the visible region where transitions near the band gap energy give it an orange color in thin films. The powder is usually gray to black in color depending on the size of the crystallites. The index of refraction in the visible is about 2.2 with some absorption, compared with diamond, which has an index of refraction of about 3.2 [23,32].

Data compiled by the CSC and the Sussex Fullerene Group, University of Sussex* Falmer, Brighton, East Sussex, BN1 9QJ [33].

Table 2 SOME PROPERTIES OF CARBON AND C60

	Diamond	Graphite	C60
Crystal Structure	Cubic	Hex.	FCC
Density (g cm-3)	3.30	2.27	1.65
Lattice constant (A)	3.513	a=2.456	14.15
	-	b=6.696	-
C-C length (A)	1.54	1.42	1.455
C=C length	-	-	1.391
Standard heats of formation (k cal mol-1)	0.4	0.0	9.08
Bulk modulus (G Pa)	1200	207	18(174)
Melting point (K)	3700	3800	Sublm. 800
Index of refraction	2.42	-	2.2 (600nm)
Conductivity	Insulator	Conductor	Semi conductor
resistivity (ohm m)	1 x 10+11	1.37 x 10-5	1 x 10+14 (room

			temp)
Naturally occurring deposit	Kimberlite	Pegmatite	Shungite
Location	S. Africa	Sri-Lanka	Russia
Crystal formation	Octahedral	Tubular	Hexagonal, cubic
Name meaning	'Invincible’	'To write'	Named after architect
Isothermal volume compressibilities (cm2 dyn-1)	0.18 x 10-12	2.7 x 10-12	6.9 x 10-12

Table 3 FURTHER PROPERTIES OF BUCKMINSTERFULLERENE

C - C length (gas phase)	1.458 Å
C = C	1.410 Å
Cage Diameter	7.11 Å
C60 - C60 nearest approach	3.1 Å
Ionization Potentials	
C60 to C60+	7.6 ± 0.2 eV
C60+ to C60 2+	12.25 ± 0.5 eV

C602+ to C60 3+	17.0 ± 0.7 eV
C603+ to C60 4+	21.7 eV by extrapolation
Electron affinity	2.6 eV
Band Gap	1.8 eV
Relative permittivity	4.4 ± 0.2
Absorption coefficients	6.07 x 105 cm-1 @ 220 nm
(Thin film)	1.21 x 105 cm-1 @ 442 nm
2nd order polarizability	Zero (Centrosymmetric)
3rd order polarizability	7.5 (± 2) x 10-34 esu.
13C NMR Chemical shift	142.68 ppm
Vapour pressure at 800K	8.1 x 10-4 Torr
Entropy of sublimation at 700 K	181.4 ± 2.3 kJ mol-1

5.3 Application/ Future Directions

The high chemical reactivity of the C60 molecules allows the synthesis of an enormous number of fullerene-derived polymers suitable for materials and biological applications. Fullerene molecules are rich in electronic properties. Potential applications of fullerene-containing polymers include conductive materials, optical devices, chemical sensors, electro luminescent cells, polymer grit triodes, and photolithography.

5.3.1 Superconductor:

WhenK$_3$C60 is cooled; its resistivity begins to drop sharply at about 18°K, indicating the onset of superconductivity (Hebard, 1991) [34]. Interestingly, as larger alkali-metal cations are incorporated into the lattice and the FCC lattice parameter (a) increases, the superconducting transition temperature, T_c, also increases (see Figure 14). Hence, the T_c for Rb$_3$ C60 rises to 28°K. This rise in T_c may be related to an increase in the density of states at the Fermi level with increasing lattice constant (Fleming, 1991) [34].

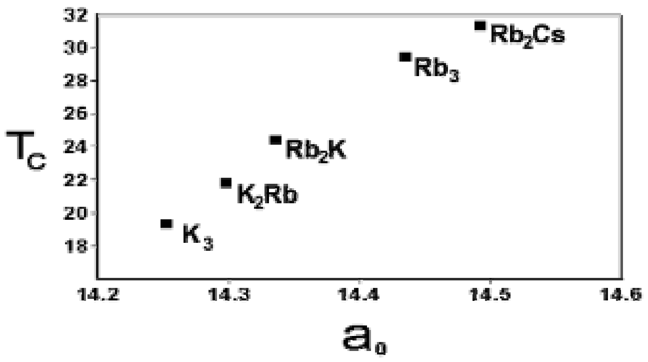


Figure14. Plot of super conducting transition temperature T_c (°K) vs. lattice parameter a_0 (angstroms) for various compositions of A_3C_{60}

The correlation between T_c and lattice constant (a) suggests that even higher T_c's could be obtained by incorporating larger and larger cations, A. There are two potential problems with this strategy. 1) As the C60 ions move apart, electron flow may be shut down. 2) If the cations, A, become too large to be accommodated in the octahedral and tetrahedral holes of the FCC lattice, a major reorganization of the packing would be required, which might lead to a loss of superconductivity.

Although the detailed mechanism of superconductivity A_3C60 remains to be established, the simplicity of the materials and the progress already made suggest a definitive resolution of this question may be achieved more quickly than in the case of high-T_c copper-oxide superconductors.

5.2.2 HIV Protease Inhibitor

C60 and its derivatives, because of their large size, stability, and hydrophobic character, may prove to have value as diagnostic or therapeutic agents in medicine. For example, derivatives of C60 are currently being investigated as potential inhibitors of the protease enzyme specific to the human immunodeficiency virus 1 (HIVP) (Friedman, 1993). The active site of this enzyme can be roughly described as an open-ended cylinder, which is lined almost exclusively by hydrophobic amino acids. Notable exceptions to this hydrophobic trend are two catalytic asp artic acids that catalyze the attack of water on a peptide bond of the substrate.

Because a C60 molecule has approximately the same radius as the cylinder that describes the active site of HIVP and since C60 and its derivatives are primarily hydrophobic, an opportunity exists for a strong hydrophobic van der Waals interaction between the Non-polar active site surface and the C60 surface. In addition, however, there is an opportunity for increasing binding energy by the introduction of specific electrostatic interactions. One obvious possibility involves salt bridges between the catalytic aspartic acids on the floor of the HIVP active site and basic groups such as amines introduced on the C60 surface. The key to exploiting this promising system will be the development of organic synthetic methodology to derivative the C60 surface in highly selective ways [34].

The synthesis of buckminsterfullerene, C60, and other Fullerenes, in 1985, stimulated researchers worldwide to search for other new forms of carbon. The search was given new impetus when it was shown in 1990 that C60 could be produced in a simple arc-evaporation apparatus readily available in all laboratories. It was using such an evaporator that the Japanese scientist Sumio Iijmai discovered fullerene-related carbon nanotubes in 1991.Next chapter focus on Fullerene based material- carbon nanotubes.

CHAPTER SIX

6. Carbon Nanotubes-Fullerene Based Material s.

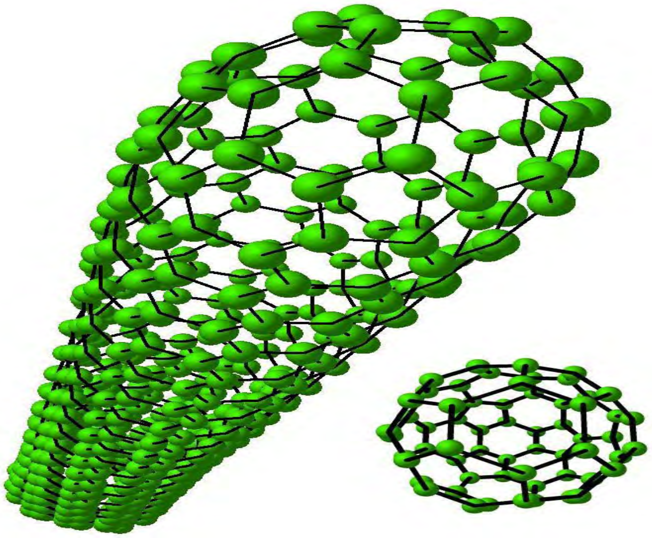


Figure15. Carbon nanotube-fullerene based martial [31]

Carbon nanotubes (CNT) are a particular form of fullerenes, first reported by Iijima. They are similar in structure to C60 but are elongated to form tubular structures, 1-2 nm in diameter. They can be produced with very large aspect ratios and can be more than 1 mm in length. In their simplest form, nanotubes comprise a single layer of carbon atoms arranged in a cylinder. These are known as single-wall carbon nanotubes (SWCNTs). They can also be formed as multiple concentric tubes (multi-wall carbon nanotubes, MWNTs) with diameters up to 20 nm, and length greater than 1 mm. CNTs have great tensile strength and are considered to be 100 times stronger than steel, whilst being only one sixth of its weight, making them potentially the strongest, smallest fiber known. They also exhibit high conductivity, high surface area, unique electronic properties, and potentially high molecular absorption capacity. Applications which are currently being investigated include; polymer composites (conductive and structural filler), electromagnetic shielding, electron field emitters (flat panel displays), super capacitors, batteries, hydrogen storage and structural composites.

One major focus of current research on nanotubes is on scaling-up of production rates to kilogram (or greater) quantities, because many of the applications require bulk quantities of the material. For production of large quantities of CNTs, chemical vapors deposition (CVD) method is the current method of choice. Nanotubes have also been produced from other materials including silicon and germanium but the development of various forms and applications for CNTs remains the main focus of activity in this chapter [35, 36].

6.1 Discovery of Carbon Nanotube

In 1991, the Japanese electron microscopist, Sumio Iijima (a researcher at the NEC laboratory in Tsukuba, Japan) discovered that carbon could be made to a form of tubular structures while he was studying the material deposited on the cathode during the arc-evaporation synthesis of fullerenes. By using transmission electron microscope (TEM) to magnify carbon ash, he found that the cathode deposit contained a variety of closed graphitic structure. In that ash he found tiny cylinders made of carbon atoms with the diameters in the order of nanometers and he called the cylinders nanotubes. The graphite layer appears somewhat like "a rolled-up chicken wire" with a continuous unbroken hexagonal mesh and carbon at the apexes of the hexagons. Therefore, it was found that when an electric arc struck between two carbon electrodes in inert gas atmosphere carbon nanotubes are synthesized. Therefore, it can be thought that the newly discovered carbon variety as an elongated fullerene type and spherical fullerenes are sometimes called buckyballs, while cylindrical fullerenes are called buckytubes or nanotubes [23, 21, 37].

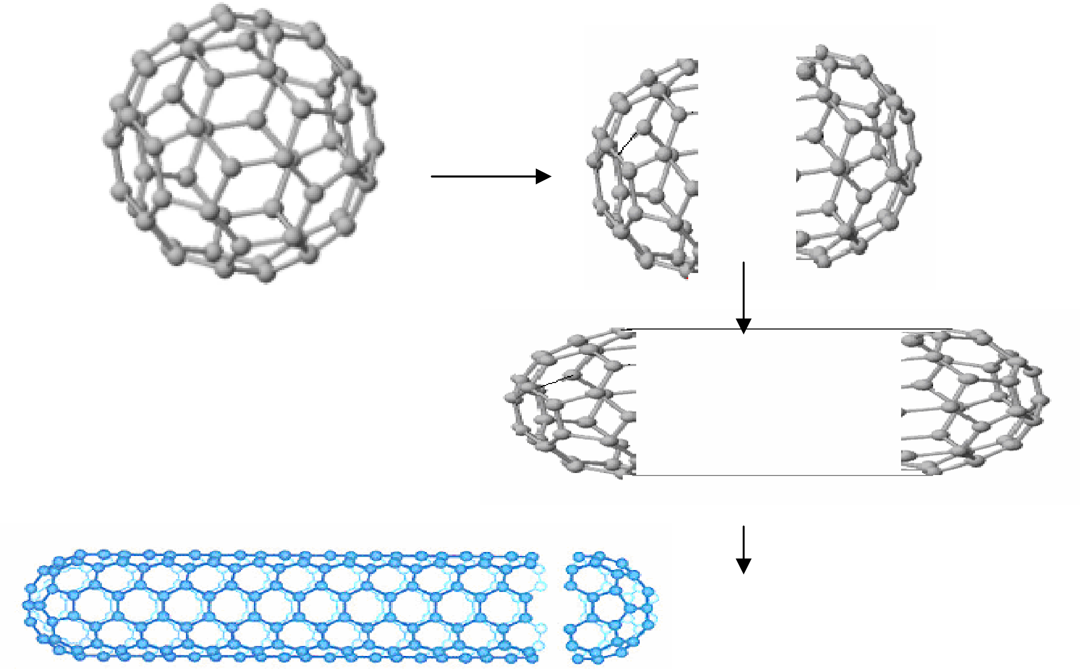


Figure 16. From fullerene to carbon nanotube

A "carbon nanotube" is a tube-shaped material made up of carbon that has a diameter of measuring on the nanometer scale. Their name derives from their size; nanotubes are on the order of only a few nanometers wide (on the order of one ten-thousandth the width of a human hair), and their length can be millions of times greater than their width. They can also be thought as of narrow sheets of a million or more carbon atoms linked together in a hexagonal rings connected as in graphite, but rolled in to a very long cylinder that is 1-2 nm in diameter internally. By comparison, a hair is about 100,000 nanometers across. To illustrate how narrow the nanotubes are, a carbon nanotube long enough to reach from earth to the moon could be rolled into a ball of the size of poppy seed [2].

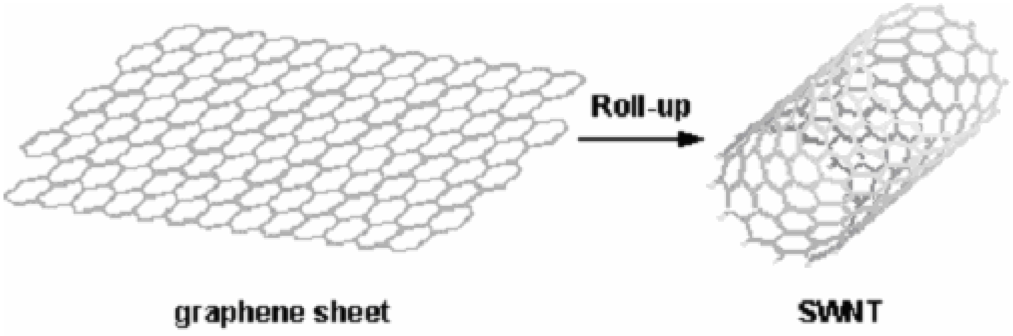
6.2 Types of Carbon Nanotube

A nanotube is a member of the fullerene structural family, which also includes buckyball. Whereas buckyballs are sphericalin shape, a nanotube is cylindrical, with at least one end typically capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers (approximately 100,000 times smaller than the width of a human hair), while they can be up to several micrometers in length. There are two main types of nanotubes:

6.1.1 Single-walled

The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite (graphene) into a seamless cylinder. The molecular structure of a carbon nanotube is often depicted as rolled chicken wire. Carbon nanotube exists as a macromolecule of carbon analogous to a sheet of graphite rolled in to a cylinder.

A cylinder of SWNT is generated when a graphene sheet of a certain size that is wrapped in a certain direction. We can only roll a grapheme in a discrete set of directions in order to form a closed cylinder. Two atoms in the graphene sheet are chosen, one of which servers the role as origin. The sheet is rolled until the two atoms coincide.



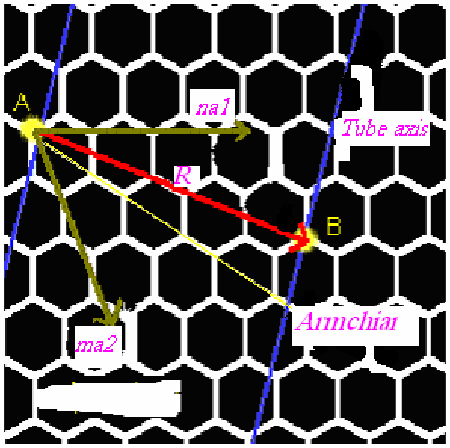


Figure 17 Planar sheet of graphite to be rolled up to form carbon nanotube

The vector pointing from the first atom towards the other (from 'A' to 'B', in Fig. 17) is called the chiral vector R and its length is equal to the circumference of the nanotube. The direction of the nanotube axis is perpendicular to the chiral vector. SWNTs with different chiral vectors have dissimilar properties such as optical activity, mechanical strength and electrical conductivity.

The way the graphene sheet is wraps represented by a pair of indices of chiral vector (n, m). The integer's n and m denote the number of unit along two directions in the honeycomb lattice of graphene. This is often thought of as representing the number of carbon atoms around.

Draw two parallel lines along the tube axis where the separation takes place. In other words, if you cut along the two lines and then match their ends together in a cylinder, you get a nanotube. Now, find any point on one of the tube axes that intersects one of the carbon atoms (say point A). Next, draw the Armchair line which travels across each hexagon, separating them into two equal halves. Now that you have the armchair line drawn, find a point along the other tube axis that intersects a carbon atom nearest to the Armchair line (say point B). Now connect A and B with your chiral vector, R. The wrapping angle is formed between R and the armchair line [23].

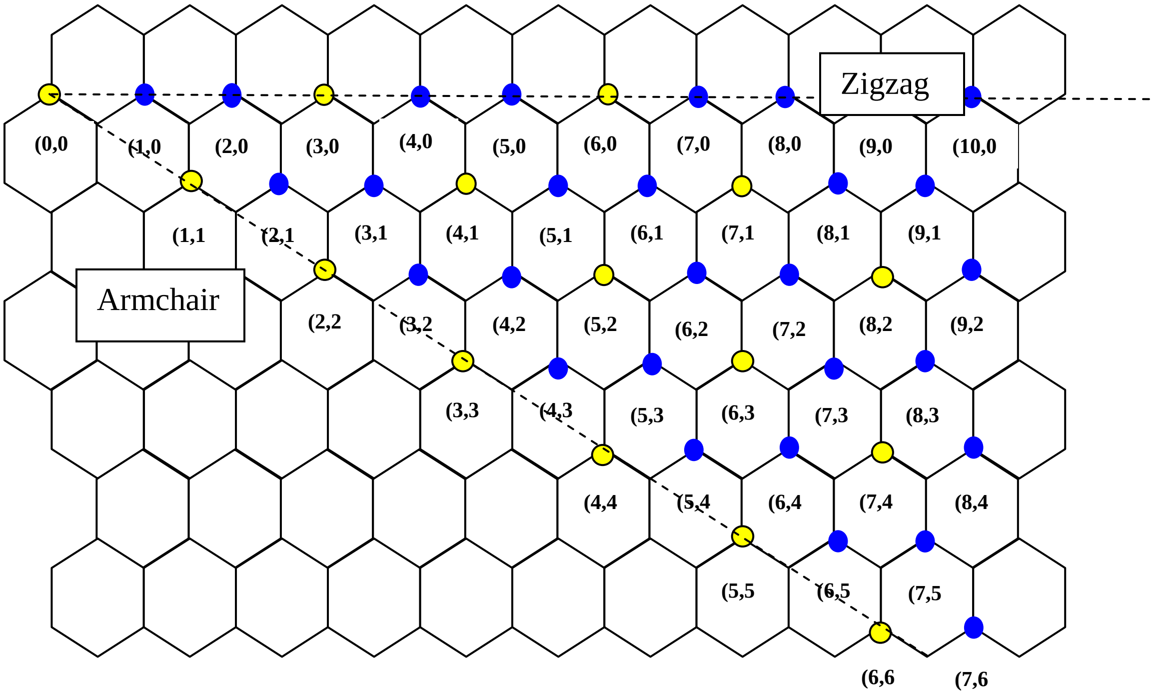


Figure18. All possible structures of SWNTs can be formed from chiral vectors lying in the range given by this figure.

There are a large variety of forms of each of the nanotubes identified by a two-digit sequence such as (4,0), (4,1), (4,2), (4,3), (4,4), etc.

- The first digit indicates how many carbon atoms around the tube.
- The second digit determines the offset where the nanotubes wrap around.

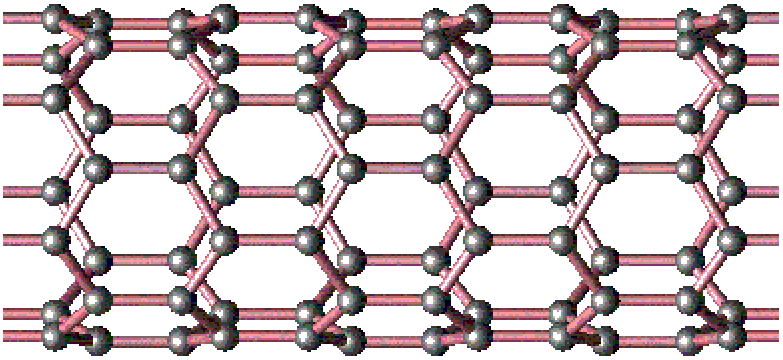
If the second digit is zero (m = 0), and the chiral angle θ = 30 then the naotube is called zigzag nanotube.

If both digits are the same (n = m) and (θ = 0°), then it is called an "Armchair" nanotube.

If 0 < θ < 30° then it is called a "chiral" nanotube.

Depending on details of their synthesis, carbon nanotubes can act like conducting metals or semiconductors, and have found use in elementary transistors and chemical sensors.

The structure of the nanotube (zigzag, armchair or chiral) affects its electric conducting properties. For example, (6, 0), (6, 6), (9, 0) and (9, 9) nanotubes are all excellent conductors. Carbon nanotube is seamless, with either open or capped ends.



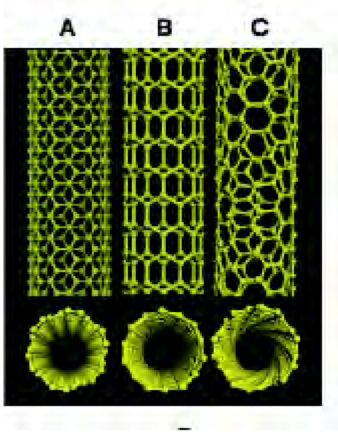


Figure19. Buckytube or carbon nanotube (A) armchair (B) zigzag (C) chiral SWNTs

The diameter of single-wall carbon nanotubes is 0.7 to 2 nm, 100,000 times thinner than a human hair. Buckytube lengths are 100 to 1,000 times their diameters [18]. Their large length (up to several millimeters) and small diameter (a few nanometers) result in a large aspect ratio. Nanotubes generally have a length to diameter ratio of about 1000 so they can be considered as nearly one-dimensional structures [23]. The SWNT can exist as bundles of many single walled nanotubes held together by Van der Waals force.

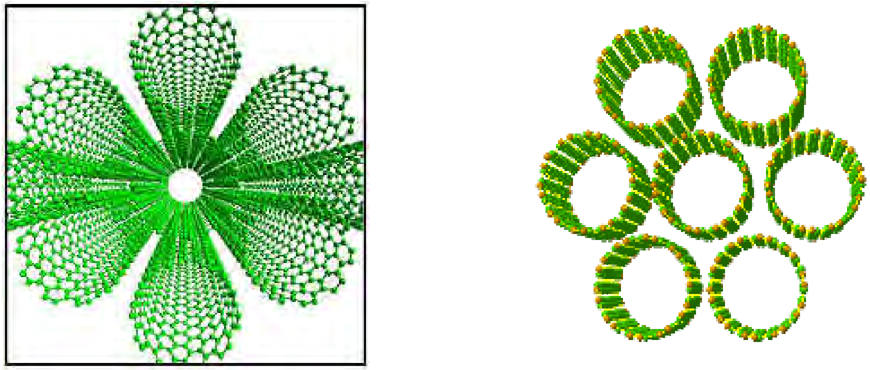


Figure20. Bundle of SWNTs

6.2.2 Multi-walled Carbon Nanotubes

Multi-walled carbon nanotubes are concentric cylindrical graphitic tubes [37]. They contain atomic layer planes of carbon, which form a nested series of concentric cylinders, much like the growth rings of on a tree. MWNTs have several characteristics: wall thickness, number of concentric cylinders, cylinder radius, and cylinder length [18].

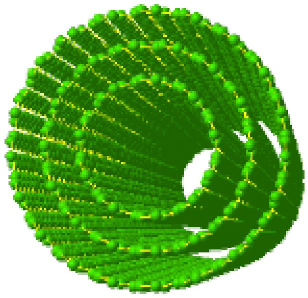


Figure21.Multi-walled carbon nanotubes

Multi-walled nanotubes are invariably produced with a high frequency of structural defects that they frequently contain regions of structural imperfection and the occurrence of defects that inevitably degrade the material properties of a substance, such as strength.

To sum up carbon nanotube classified in to two that are SWNT and MWNT, which have different structure. In chapter seven we will discuss briefly how to synthesize, technological important nonmaterial and called carbonnanotube.

CHAPTER SEVEN

7. Synthesis of Carbon Nanotube

Techniques have been developed to produce nanotubes in sizeable quantities, including arc discharge, laser ablation, chemical vapor deposition (CVD), water-assisted synthesis, and catalytic decomposition of hydrocarbons, electrolysis method and thermal pyrolysis of organometallic. Of these, the CVD method has shown the most promise in terms of its price/unit ratio. Fullerene and carbon nanotubes are not necessarily products of high-tech laboratories; they are commonly formed in such mundane places as candle flames. However, these naturally occurring varieties, due to the highly uncontrolled environment in which they are produced, are highly irregular in size and quality, lacking the high degree of uniformity necessary to meet the needs of both research and industry.

Here only three methods of synthesis of carbon nanotubes: arc-discharge, laser vaporization, chemical vapor deposition (CVD) will be considered as a prototype.

7.1 Arc-discharge Method of Synthesis of Carbon Nanotubes

In this method of synthesis carbon nanotubes, two graphite rods are used as the cathode and anode, between which is arcing occurs when DC voltage power is supplied. A large quantity of electrons from the arc-discharge moves to the anode and collide into the anodic rod. Carbon clusters from the anodic graphite rod caused by the collision are cooled to low temperature and condensed on the surface of the cathode graphite rod. The graphite deposits condensed on the cathode contain carbon nanotubes, nanoparticles, and clusters.

In this method, the apparatus must be connected both to a vacuum line with a diffusion pump, and to a helium supply. The electrodes are two graphite rods, usually of high purity.

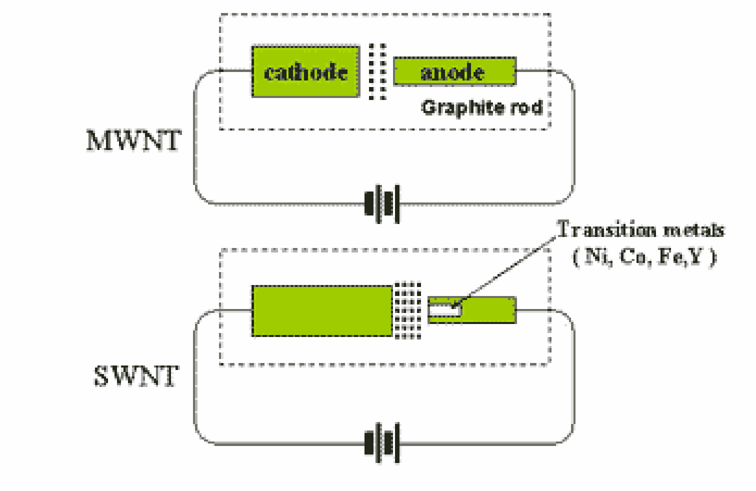


Figure22.Schematic diagram of arc-discharge apparatus

Carbon nanotubes synthesized by arc-discharge normally have multi-walled structures. After holes in the graphite rods are bored and filled with appropriately proportional composites of graphite powder and catalytic Co, Ni, Fe, and Y powder, SWNT can be synthesized by arc-discharge on the cathode.

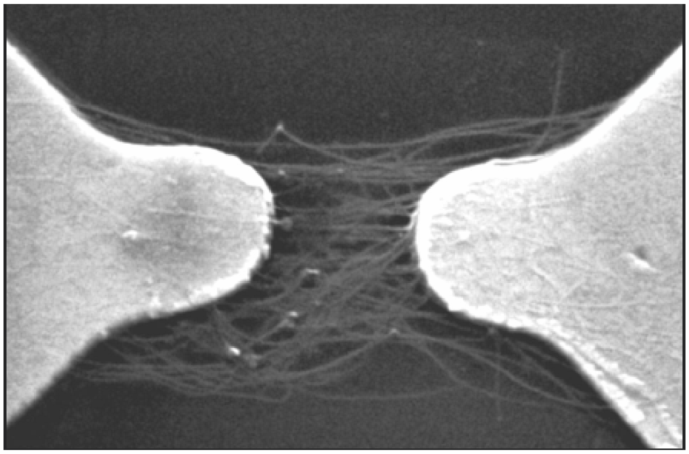


Figure 23.SEM image of nanotubes aligned between two electrodes

7.2 Laser vaporization Method of Synthesis of Carbon Nanotubes

In this technique of synthesis of carbon nanotubes a laser is used to vaporize a graphite target in an oven at 1200 0c. Then helium or argon gas is filled to keep the pressure in the oven at 500 Torr. Carbon clusters from the graphite target are cooled, adsorbed, and condensed on the Cu collector at a low temperature. The condensates obtained this way are mixed with carbon nanotubes and nanoparticles. MWNT would be synthesized in the case of pure graphite, but uniform SWNT could be synthesized if a graphite of a mixture of Co, Ni, Fe, or Y were used instead of pure graphite. SWNTs synthesized this way exist as ‘ropes’ [38].

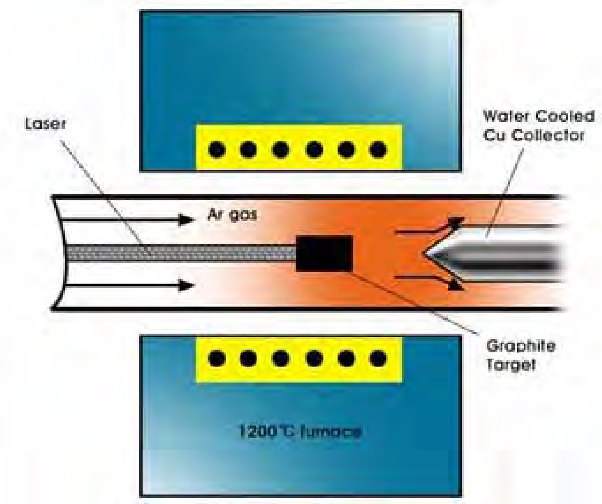


Figure24.Schematic diagram of laser vaporization apparatus for the synthesis of Multi-walled nanotubes

Laser vaporization is higher in yield than arc-discharge and can synthesize high quality single-walled nanotubes.

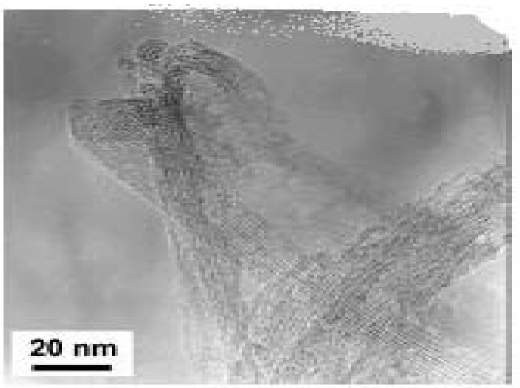


Figure25.TEM image of SWCNTs synthesized by laser evaporation method

7.3 Chemical Vapor Deposition (CVD)

Chemical vapor deposition (CVD) methods have been successful in making carbon fiber, filament and nanotube materials since more than 10–20 years ago. A schematic experimental setup for CVD growth is depicted in [Fig 26]. The growth process involves heating a catalyst material to high temperatures in a tube furnace and thereafter flow a hydrocarbon gas through the tube reactor for a period of time. Materials grown over the catalyst are collected upon cooling the system to room temperature. The key parameters in nanotube CVD growth are the hydrocarbons, catalysts and growth temperature. The active catalytic species are typically transition-metal nanoparticles formed on a support material such as silicon. The general nanotube growth mechanism [Fig 27] in a CVD process involves the dissociation of hydrocarbon molecules catalyzed by the transition metal, and dissolution and saturation of carbon atoms in the metal nanoparticle. The precipitation of carbon from the saturated metal particle leads to the formation of tubular carbon solids in sp2 structure. Tubule formation is favored over other forms of carbon such as graphitic sheets with open edges. This is because a tube contains no dangling bonds and therefore is in a low energy form. For MWNT growth, most of the CVD methods employ ethylene or acetylene as the carbon feedstock and the growth temperature is typically in the range of 550–750C. Iron, nickel or cobalt nanoparticles are often used as catalyst. The rationale for choosing these metals as catalyst for CVD growth of nanotubes lies in the phase diagrams [Fig 28] for the metals and carbon. At high temperatures, carbon has finite solubility in these metals, which leads to the formation of metal-carbon solutions and therefore mentioned growth mechanism. Noticeably, iron, cobalt, and nickel are also the favored catalytic metals used in laser ablation and arc- discharge.

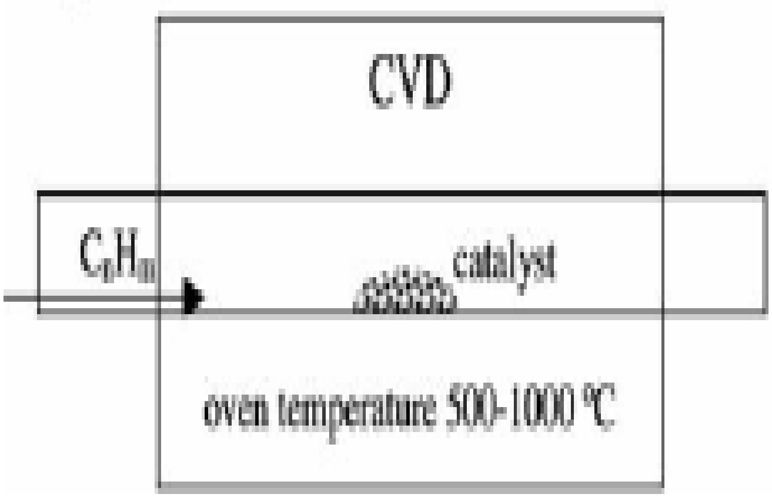


Figure 26: Schematic of CVD process [33]

A major pitfall for CVD grown MWNTs has been the high defect densities in their structures. The defective nature of CVD grown MWNTs remains to be thoroughly understood, but is most likely be due to the relatively low growth temperature, which does not provide sufficient thermal energy to anneal nanotubes into perfectly crystalline structures. Growing perfect MWNTs by CVD remains a challenge to this day.

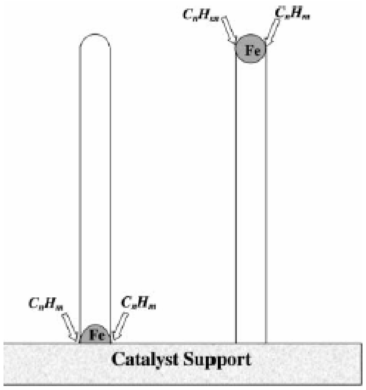


Figure 27.Growth process of CNT from nucleating spot [33]

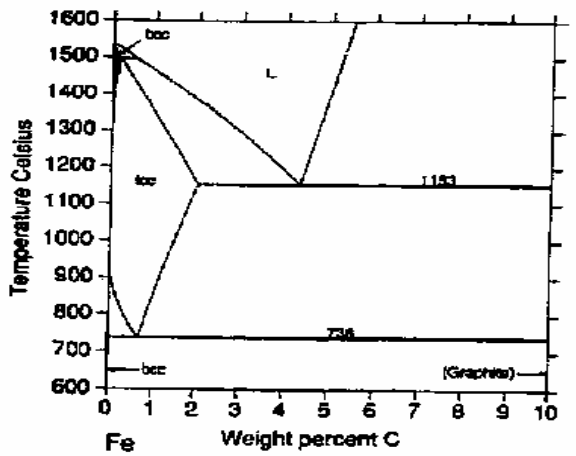
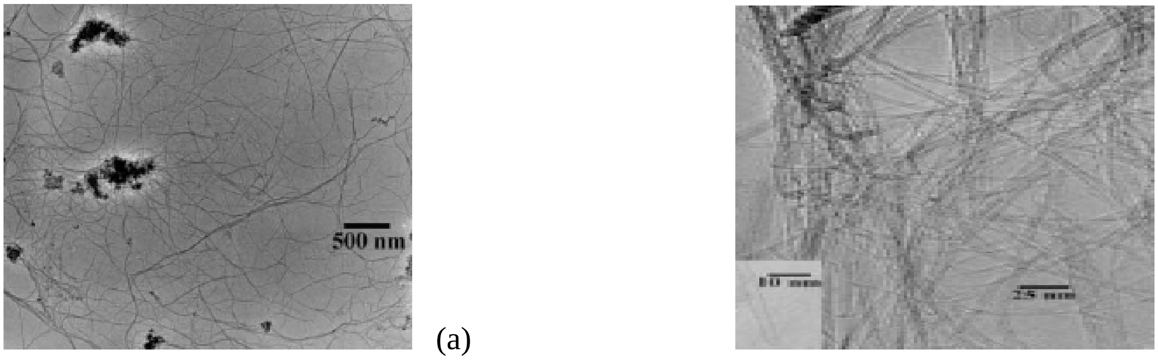


Figure28: Graph of wetting of Fe by carbon atoms [33].

a) Single-Walled Nanotube Growth and Optimization

For a long time, arc-discharge and laser-ablation have been the principal methods for obtaining nearly perfect single-walled nanotube materials. There are several issues concerning these approaches. First, both methods rely on evaporating carbon atoms from solid carbon sources at ≥ 3000C, which is not efficient and limits the scale-up of SWNTs. Secondly, the nanotubes synthesized by the evaporation methods are in tangled forms that are difficult to purify, manipulate and assemble for building addressable nanotube structures. Recently, growth of single-walled carbon nanotubes with structural perfection was enabled by CVD methods. For an example, it has been found that by using methane as carbon feedstock, reaction temperatures in the range of 850–1000C, suitable catalyst materials and flow conditions one can grow high quality SWNT materials by a simple CVD process. High temperature is necessary to form SWNTs that have small diameters and thus high strain energies, and allow for nearly-defect free crystalline nanotube structures. Among all hydrocarbon molecules, methane is the most stable at high temperatures against self-decomposition. Therefore, catalytic decomposition of methane by the transition-metal catalyst particles can be the dominant process in SWNT growth. The choice of carbon feedstock is thus one of the key elements to the growth of high quality SWNTs containing no defects and amorphous carbon over-coating. Smalley and coworkers who used ethylene as carbon feedstock and growth temperature around 800oC reported another CVD approach to SWNTs. In this case, low partial-pressure ethylene was employed in order to reduce amorphous carbon formation due to self-pyrolysis/dissociation of ethylene at the high growth temperature. Gaining an understanding of the chemistry involved in the catalyst and nanotube growth process is critical to enable materials scale-up by CVD .The choice of many of the parameters in CVD requires to be rationalized in order to optimize the materials growth. Within the methane CVD approach for SWNT growth, we have found that the chemical and textural properties of the catalyst materials dictate the yield and quality of SWNTs. This understanding has allowed optimization of the catalyst material and thus the synthesis of bulk quantities of high yield and quality SWNTs. Evident from the TEM image [Fig 29] is that the nanotubes are free of amorphous carbon coating throughout their lengths [33].



(a) (b)

Figure 29. Image of CNT generated by CVD process b) Directed Growth of Single-Walled Nanotubes

Ordered, single-walled nanotube structures can be directly grown by methane CVD on catalytically patterned substrates. A method has been devised to grow suspended SWNT networks with directionality on substrates containing lithographically patterned silicon pillars. Contact printing is used to transfer catalyst materials onto the tops of pillars selectively [Fig 30]. CVD of methane using the substrates leads to suspended SWNTs forming nearly ordered networks with the nanotube orientations directed by the pattern of pillars [36].

Figure30. a) Structured pattern of SiO2 on Si wafer b) Directed growth of CNTs [33]

As mentioned above CNT can synthsised in different techniques, but now we shoed answer why we need mass production of CNT.In chapter eight we will investigate magical properties of carbon nanotube.

CHAPTER EIGHT

8. How Carbon Nanotubes Become Extraordinary?

The very important properties of carbon nanotubes have exceptionally high material properties such as extremely very high tensile strength, lightweight, thermal stability, chemically inertness, field emission, electric conductivity have potential applications [24]. Some of the bonding properties of carbon atoms in CNTs are given in the figure and table 2 below.

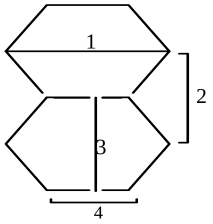


Fig.31. Bonding in graphite structure

Equilibrium Structure	Property
Average diameter of SWNTs	1.2-1.4 nm
Distance from opposite carbon atoms (line 1)	0.283 nm
Analogous carbon atom separation (line 2)	0.246 nm
Parallel carbon bond separation (line 3)	0.245 nm
Carbon bond length (line 4)	1.42 nm
C-C bonding overlap energy	2.5 eV

Table 4 some properties of CNTs

8.1 Mechanical Properties of Carbon Nanotubes

Carbon nanotubes are one of the strongest materials known to man, both in terms of tensile strength and elastic modulus. This strength results from the covalent sp2 bonds formed between the individual carbon atoms. In 2000, an MWNT was tested to have a tensile strength of 63GPa. In comparison, high-carbon steel has a tensile strength of approximately 1.2 GPa. CNTs also have very high elastic modulus in the order of 1 TPa. Since carbon nanotubes have a low density for a solid of 1.3-1.4, its specific strength is the best of known materials [18,27,37].

Under excessive tensile strain, the tubes will undergo plastic deformation, which means the deformation is permanent. This deformation begins at strains of approximately 5% and can increase the maximum strain the tube undergoes before fracture by releasing strain energy. CNTs are not nearly as strong under compression. Due to their hollow structure, they tend to undergo buckling when placed under compressive, torsional or bending stress [18,27,37].

The carbon atoms of a single sheet of graphite form a planar honeycomb lattice in which each atom is connected via a strong chemical bond to three neighbors' atoms. The basal-plane elastic modulus of graphite is one of the largest of any known material. For this reason, carbon nanotubes are expected to be the ultimate high-strength fibers. In our laboratory in Lausanne, we developed a simple method for measuring the mechanical properties of single nanotubes. The technique involves depositing nanotubes from a suspension in a suitable liquid onto well- polished alumina ultra filtration membranes with a pore size of about 200 nm (See fig. 32). Carbon nanotubes strongly adhere to alumina, but occasionally span the pores by chance. The deflection of such a supported tube is then deduced from AFM images recorded at various normal loading forces. The measured deflection is inversely proportional to the Young's modulus. It is found to be approximately 0.8 TPa for arc-discharge grown nanotubes, while for the catalytically grown tubes a much lower - by one to two orders of magnitudes - modulus was found. This result demonstrates that only highly ordered and well graphitised nanotubes have stiffness comparable to graphite. In contrast, MWNTs grown by catalytic decomposition still contain many defects.

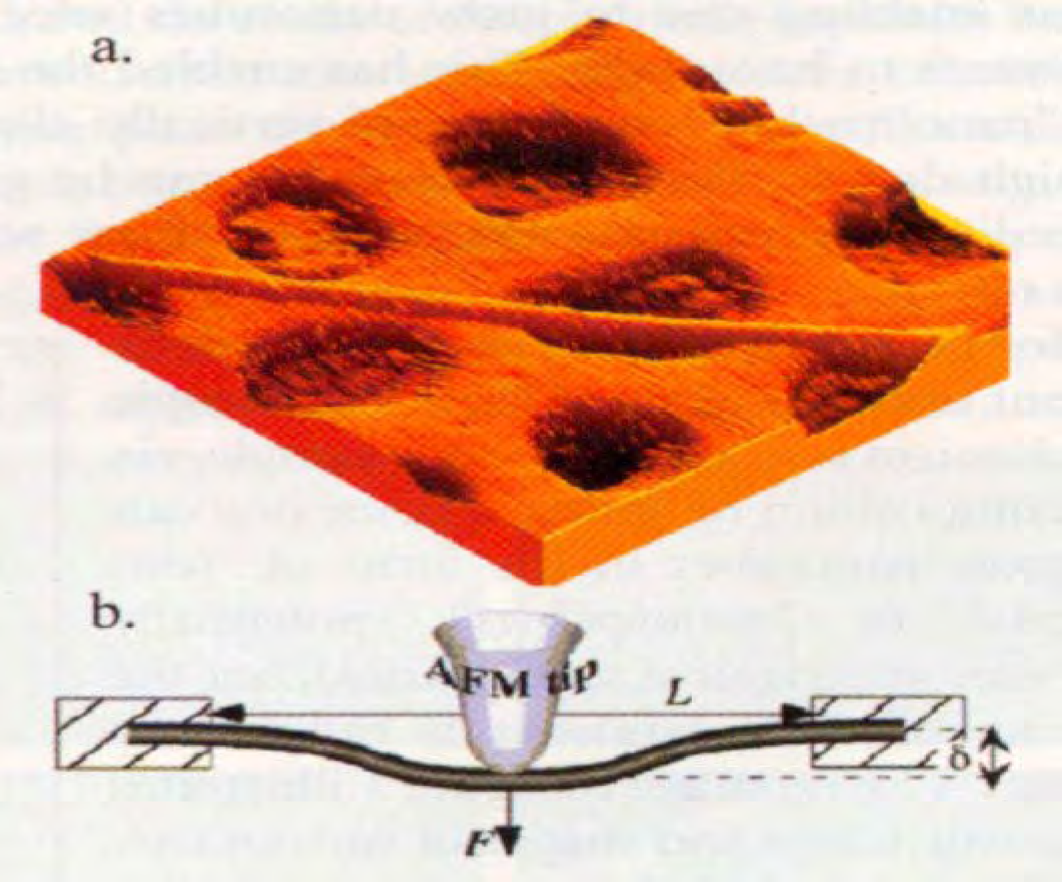


Figure 32 (a) 3D rendering of an AFM image of a SWNT bundle (or a single MWNT), adhered to an alumina ultrafiltration membrane, leading to a clamped beam configuration for mechanical testing. (b) Schematic representation of the measurement: the AFM tip applies a load, F, to the portion with a suspended length of L, and the maximum deflection d at the center of the beam is directly recorded from the topographic image; d versus F is proportional to the Young's modulus of the nanotube.

Besides their high strength nanotubes behave magically with respect to high loads. If the applied force exceeds the bending strength, a MWNT first bends over surprisingly large angles, start to ripple on the compressed side, and eventually develops kinks, as well. The amazing thing is that all these deformations are elastic, i.e. disappear completely if the load is removed. If one would employ nanotubes as mechanical springs, these springs would be very stiff for small loads, but would turn into soft ones for larger loads allowing for longer extensions without breaking. One could then dream of making objects which after severe deformations relax into their initial form once the load is released [39].

8.2 Dynamic Properties

Multi-walled carbon nanotubes, multiple concentric nanotubes precisely nested within one another, exhibit a striking telescoping property whereby an inner nanotube core may slide, almost without friction, within its outer nanotube shell thus creating an atomically perfect linear or rotational bearing. This is one of the first true examples of molecular nanotechnology, the precise positioning of atoms to create useful machines. Already this property has been utilized to create the world's smallest rotational motor and a nanorheostat. Future applications such as a gigahertz mechanical oscillator are envisioned [18, 27 37].

8.3 Electrical Properties

Due to the symmetry and unique electronic structure of graphene, the structure of a nanotube strongly affects its electrical properties. For a given (n, m) nanotube, if 2n + m=3q (where q is an integer), then the nanotube is metallic, otherwise the nanotube is a semiconductor. Thus all armchair (n=m) nanotubes are metallic, and nanotubes (5, 0), (6, 4), (9, 1), etc. are semi conducting. In theory, metallic nanotubes can have an electrical current density more than 1,000 times stronger than metals such as silver and copper [18,27,37].

One can view carbon nanotubes as giant conjugated molecular wires with a conjugation length corresponding to the whole length of the tube. In order to understand their electronic structure, we have to start with graphene, a single sheet of graphite. Carbon has four valence electrons of which three are strongly bound to neighbor atoms giving graphene its very high in-plane rigidity. The fourth electron is delocalised and shared by all the atoms, thus allowing for electronic current transport. However, because of its particular structure graphene is electronically between a semiconductor and a metal. It is a semimetal or a "zero-gap" semiconductor.

This peculiarity renders the electronic states very sensitive to additional boundary conditions, such as that created by a single shell of a carbon nanotube. A stationary electron wave can only develop, if the circumference of the tube is a multiple of the electron wavelength. This condition removes the zero gap property of graphene and turns a nanotubes into either a true metal or a semiconductor, depending on how the graphene sheet is rolled up, in other words, depending on its helicity. (For MWNTs one expects a more complicated situation, because of a possible additional electronic coupling between adjacent shells). The helicity gives a fascinating richness for the engineering of electronic properties of SWNTs. However, for the time being, we can control neither the diameter nor nanotubes' helicity during the synthesis, and at the present this "richness" is rather a drawback than an advantage. For each nanotube one has to find out first its conduction characteristics. In order words, we do not study what we want, but what we get.

The electronic properties of one-dimensional (1d) conductors have generated much interest. The reason for this excitement lies in their very rich phase diagram and the prediction that in a 1d system the Coulomb interaction should lead to a strongly correlated electron gas, called a Luttinger liquid instead of the weakly interacting quasi-particles described as a Fermi-liquid in conventional metals. This issue is still controversial. There are experimental results both for SWNTs and MWNTs, which speak in favour of either exotic Luttinger- liquid or conventional Fermi-liquid behaviors.

A perfect metallic nanotube with uncorrelated electrons, is supposed to be a ballistic conductor, i.e. the best (normal electron) conductor an engineer can dream of, only surpassed by a superconductor. If an electron is injected from a contact into a ballistic wire with ideal contacts, the electron will emerge with certainty at the drain contact. There is no backscattering in the wire, which is the source of intrinsic electric resistance and leads to Ohm's law. For a perfect ballistic tube theory predicts not one, but the existence of two propagating eigenmodes independent of the diameter. The electric conductance (the inverse of the resistance) is then expected to be twice the fundamental conductance unit G0 = 2e2/h =1/13 k . Note, the resistance is not zero, as it would be for a superconductor but in contrast to classical resistors and to Ohm's law, the resistance is independent of the length of the wire. Data suggesting that MWNTs are indeed ballistic conductors even at room temperature are highlighted in fig. 33, although the observed conductance quantum appears to be G0.

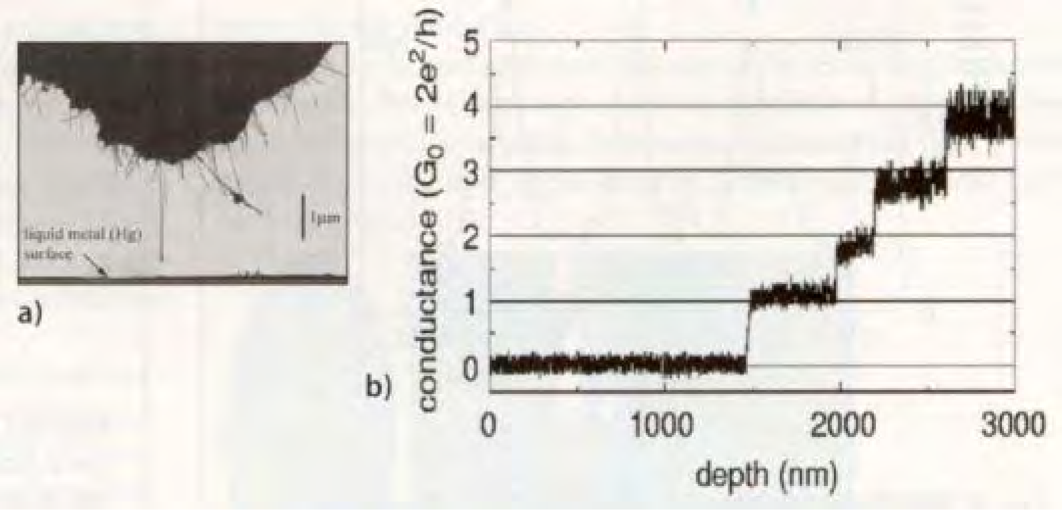


Figure 33 a) Electron microscope image of an ensemble of MWNTs mounted on a motion stage realized by de Heer and coworkers at Georgia Tech. The MWNT sticking out most is progressively dipped into liquid mercury, which serves as a second electrode. As the individual nanotubes enter the metal, they contribute G0=2e2/h to the overall quantum conductance, which appears to be ballistic, i.e. independent of length on each plateau.

Investigations have proven that studying electric transport in MWNTs is somewhat similar to studying transport in a large diameter SWNT using lithographically deposited metal contacts in various configurations to connect electrical wires to the tubes (Figure 34).

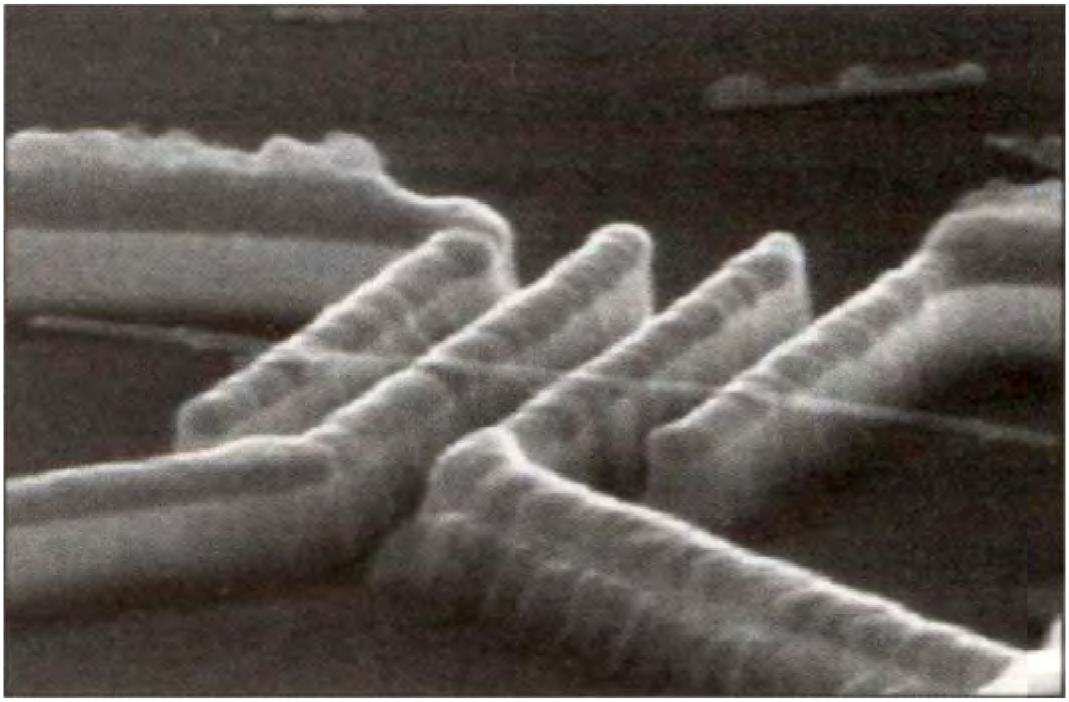


Figure 34. Scanning Electron Microscopy image of an individual multiwalled carbon nanotube contacted by four electric leads for resistivity measurements. In order to check the influence of the substrate, the SiO2 was etched away from below the nanotube.

The current mainly flows on the external cylinder, the nanotube core solely acting as a mechanical support for the electrically active outermost shell. (Note, this were no longer true, if we could find a way to contact the core, or even to selectively address inner shells). MWNTs have certain specific advantages over SWNTs: their large diameter favors low-ohmic contacts, because of the larger contact area. Furthermore, the large diameter of MWNTs enables one to investigate quantum-interference phenomena in a magnetic field. The most profound quantum-interference effect is the Aharonov-Bohm (AB) effect that not only reveals that electrons are waves, but also demonstrates that the vector potential not the magnetic field plays a basic role. For the study of this phenomenon, a magnetic field of several Tesla is applied along the nanotube axis. Our electrical resistance measurements showed pronounced oscillations with a period of h/2e, h being Planck's constant, and e the electronic charge (Fig. 35)

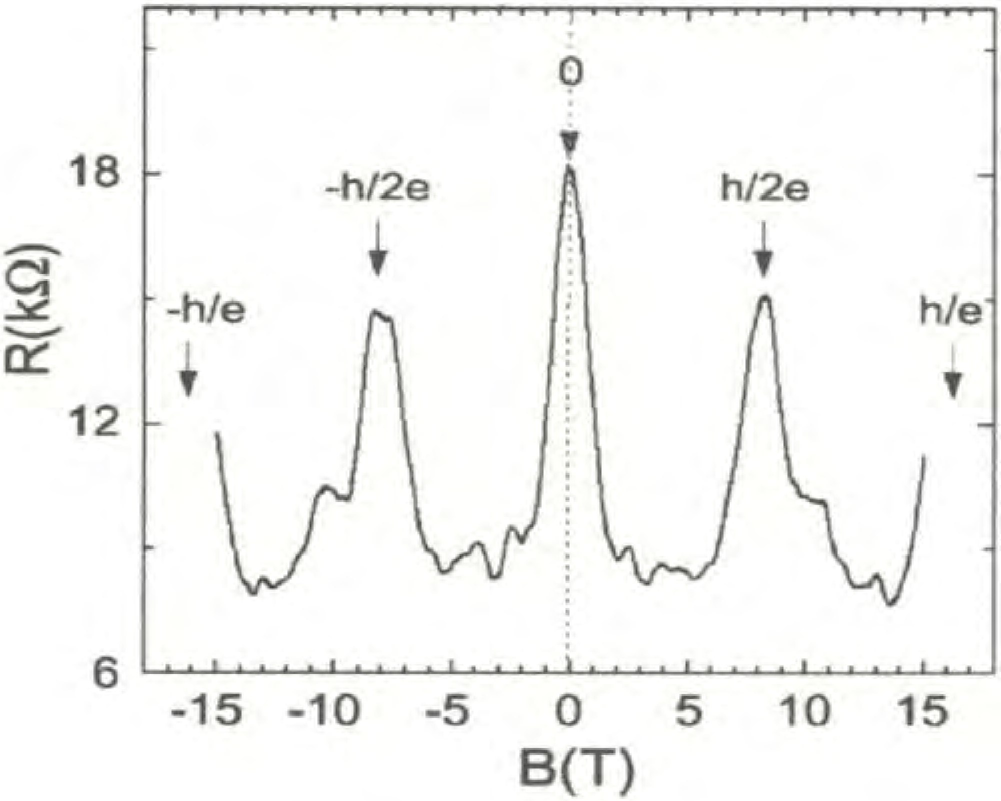


Figure 35. Electrical resistance R as a function of magnetic field B of a MWNT aligned parallel to B. The resistance oscillation is due to the Aharonov-Bohm effect. Arrows denote the resistance maxima corresponding to multiples of h/2e of the magnetic flux through the nanotube outer perimeter, thus indicating that the current flows in the outer most shell.

The oscillations are associated with the "weak localization", a quantum-mechanical manifestation of coherent backscattering of electrons, which arises from interference contributions adding up constructively in zero fields. Backscattering is thereby enhanced, leading to a resistance larger than the classical Drude resistance. This observation has given compelling evidence that the phase coherence length can exceed the circumference of the tube. But because the h/2e period (as opposed to h/e) requires backscattering on the scale of the diameter of the MWNT, this implies that these nanotubes are not ballistic, but rather diffusive. Nevertheless, most scattering processes are elastic, i.e. the coherence of electron waves is maintained over a large distance.

In our opinion contradictory results, ballistic contra diffusive transport, Luttinger contra Fermi liquid behavior, do not mean that one experiment is right and the other is wrong, but rather show us that we still do not have control of all experimental parameters, and that more decisive results are yet to come [39].

8.4 Thermal Properties

All nanotubes are expected to be very good thermal conductors along the tube, exhibiting a property known as" ballistic conduction", but good insulators laterally to the tube axis. Prior to Carbon nanotubes, diamond was the best thermal conductor. Carbon nanotubes have now been shown to have a thermal conductivity at least twice that of diamond. The high-frequency carbon-carbon bond vibrations provide an intrinsic thermal conductivity higher than even diamond. Unlike bulk diamond, however, whose thermal conductivity is the same in all directions, buckytubes conduct heat far better down the tube axis than sideways from tube to tube [24,37].

Nanotechnology is predicted to spark a series of industrial revolutions in the next two decades that will transform our lives to a far greater extent than silicon microelectronics did in the 20th century. Carbon nanotubes could play a pivotal role in this upcoming revolution if their remarkable electrical and mechanical properties can be exploited.

Since the first measurements were made in 1997, these rolled up sheets of graphite have captured the imagination of researchers around the world. Progress in understanding the basic physics and chemistry of nanotubes has advanced at a phenomenal rate - and shows no signs of slowing.

Nanotubes have an impressive list of attributes. They can behave like metals or semiconductors, can conduct electricity better than copper, can transmit heat better than diamond, and they rank among the strongest materials known - not bad for structures that are just a few nanometers across. Several decades from now we may see integrated circuits with components and wires made from nanotubes, and may be even buildings that can snap back into shape after an earthquake. In chapter nine we will see technological dominant application and its future direction.

CHAPTER NINE

9. Recent Researches, Application and Future Direction

Because of the interesting electrical properties of Carbon nanotubes, it can both a metal, semi metal and semi conductor. Therefore, it can be used to make logic gates and transistors, which are the building blocks of modern computers. Because of their small size, they will fit a higher magnitude of transistors and therefore create faster, smaller computers that will replace their silicon counterparts. Figure 36 below shows a nanotube molecule with respect to a silicon-based transistor.

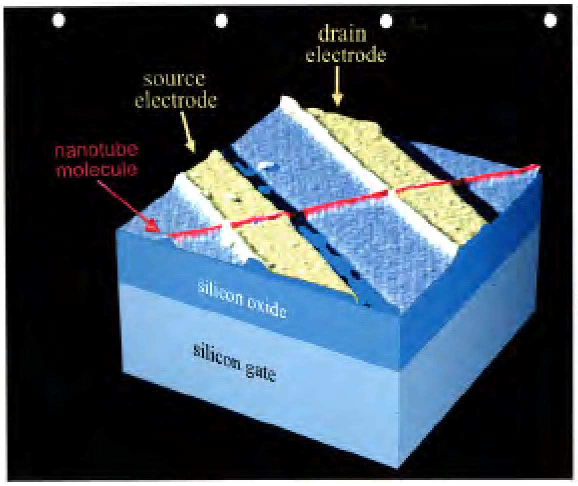


Figure 36.Diagram of a transistor constructed from a carbon nanotube [40]

NASA is currently researching the possible us of Carbon Nanotubes. Atomically precise manipulation of matter is becoming increasingly common in laboratories around the world. As this control moves into aerospace systems, huge improvements in computer, high-strength low-weight materials for aircraft and launch vehicles, and other systems are expected.

9.1 Aerospace Transportation -Launch Vehicles and Interplanetary Travel

It is estimated that a four passenger SSTO weighing three tons including fuel could be built using a mature nanotechnology. Using McKendree's cost model, such a vehicle would cost about $60,000 to purchase -- the cost of today's high-end luxury automobiles.

It may be possible to develop excellent structural materials using carbon nanotubes. Carbon nanotubes have a Young's modulus of approximately one Terapascal comparable to diamond. Below is a figure (Figure 37) outlining a few possible uses of Carbon nanotube technology?

Figure 37-Conception of space transport made from carbon nanotubes [41].

9.2 Active Materials

Today, the smallest feature size in production systems is about 250 nanometers the smallest feature size in computer chips. Since atoms are an angstrom or so across and carbon nanotubes have a diameter as small as 0.7 nanometers, atomically precise molecular machines can be smaller than current MEMS devices by two to three orders of magnitude in each dimension, or six to nine orders of magnitude smaller in volume (and mass).

To make active materials, a material might be filled with nano-scale sensors, computers, and actuators so the material can probe its environment, compute a response, and act.

9.3 Swarms

Active materials can theoretically be made entirely of machines. These are sometimes called swarms since they consist of large numbers of identical simple machines that grasp and release each other and exchange power and information to achieve complex goals. Swarms change shape and exert force on their environment under software control. Although some physical prototypes have been built, at least one patent issued, and many simulations run, swarm potential capabilities are not well analyzed or understood. The swarm components are implicitly synchronized so there is no clock signal. Component design, power distribution and control software are significant challenges for swarm development. Consider that with 10-micron components a cubic meter of swarm would contain about 1015 devices, each with an internal computer communicating with its neighbors to accomplish a global task.

All of NASA's enterprises should benefit significantly from molecular nanotechnology. Although the time may be measured in decades and the precise path to molecular nanotechnology is unclear, all paths will require very substantial computation. However, the intermediate goals are to develop Ames' computational molecular nanotechnology capabilities, design and computationally test atomically precise electronic, mechanical, and other components as well as work with experimentalists to advance physical capabilities.

9.4 Computational Nanotechnology

Using the NAS Facility’s computing resources; researchers at NAS can run classical atomistic simulations and quantum molecular dynamics simulations involving large numbers of atoms. By simulating systems of 1000 atoms or more, it is possible to investigate the behavior of lightweight, high-strength materials for structural applications, nanoelectronics for future information technology hardware, and nanoscale sensors, actuators, and motors. Using these techniques, NAS researchers have demonstrated the feasibility of nanotechnology devices never before conceived, such as transistors made from carbon nanotubes [27].

9.5 Carbon Nanotubes in Electrical Circuits

Nanotubes exhibit varying electrical properties depending on the way the graphite structure spirals (or their 'twist') around the tube and other factors, can be insulating, semi conducting or conducting or metallic. Metallic, semi-conducting or a combination of the two depends on whether it is made from one or many layers of graphite and on the angle of the roll. They could be very useful to applications in nanoelectronics. An electronic device known as a diode can be form by joining two nanoscale carbon nanotubes with different electronic properties [11, 27]. Carbon nanotube is now the top candidate to replace silicon when current chip features cannot be made any smaller in 10-15 years' time.

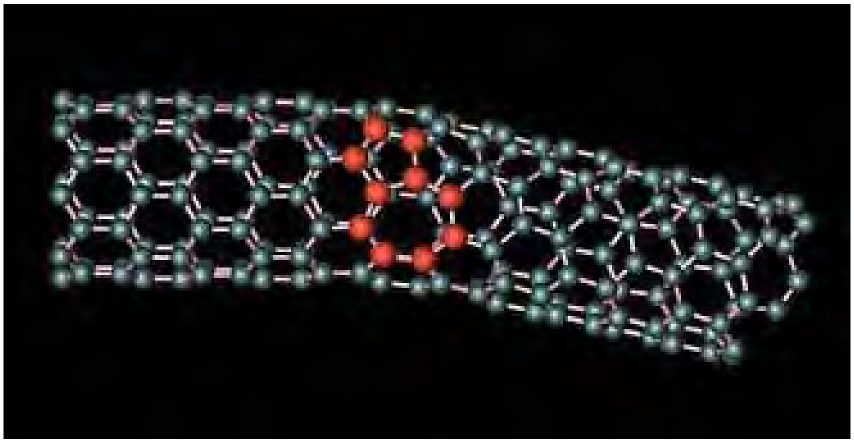


Figure.38.Making of a diode by joining hexagonal and pentagonal ends of CNT

Existing computer chips and the devices they hold are made principally of silicon. A new way of building computers involves the world's strongest material in the form of carbon nanotube. In theory, computer chips an inch square could hold billions, even trillions, of such molecular-scale switches. Today's Pentium-style chips could be reduced to the size of a needle tip [27].

9.6 Conductive Plastics

Plastics are famously good electrical insulators. This deficiency is overcome by loading plastics up with conductive fillers, such as carbon black and graphite. The loading required to provide the necessary conductivity is typically high, however, resulting in heavy parts, and more importantly, plastic parts whose structural properties are highly degraded. Buckytubes are ideal in this sense, since they have the highest aspect ratio of any carbon fiber. Individual tubes are about 1 nm in diameter (about half the diameter of DNA, and about 1/10,000th the diameter of graphite fibres), and 100-1000 nm in length. Thus, the aspect ratio of buckytubes is around 100-1000, compared with about 1 for carbon black particles. In addition, their natural tendency to form ropes provides inherently very long conductive pathways even at ultra-low loadings [18,20].

9.7 Carbon Nanotube Flat Display Devices

Due to their high electrical conductivity and the sharpness of their tip (the sharper the tip, the more concentrated will be an electric field, leading to field emission; this is the same reason lightening rods are sharp), carbon nanotubes are one of the best-known field emitters. Carbon nanotubes produce can produce streams of electrons very efficiently, which can be used to create light in displays for televisions or computers, or even in domestic lighting, and they can enhance the fluorescence of materials they are close to, an important fact for building electrical devices that utilize this feature [37]. One of the many promising types of applications of this behavior receiving considerable interest is in field emission flat-panel display. Instead of a single electron gun, as in a traditional cathode ray tube display, are bulky and heavy, here there is a separate electron gun (or many) for each pixel in the display. This could be could be used as miniature cathode ray tubes in thin high-brightness low-energy low-weight displays. This type of display would consist of a group of many tiny cathode ray tubes, each providing the electrons to hit the phosphor instead of having one giant cathode ray tube whose electrons are aimed using electric and magnetic field. These displays are known as field emission displays (FEDs). FEDs are a new type of flat panel display device, which is currently being developed. They combine the high image quality and low power consumption [37, 27].

9.8 Filling of Carbon Nanotubes With Other Substances

Carbon nanotubes can be opened and filled with a variety of materials including biological molecules raising the possibility of application in biotechnology. The very large surface area provided by the highly porous nature of nanotubes means that atoms of gases are readily adsorbed into the tubes. Therefore, it can be storage medium for hydrogen-powered vehicles. Hydrogen adsorbed in to nanotubes can be stored in a volume much smaller than that required storing the gas. When carbon nanotubes are heated in the presence of either lead or bismuth the closed ends are opened and the metal is sucked into the nanotubes [11].

9.9 Nanomedicine

Imagine a medical device that travels through the human body to seek out and destroy small clusters of cancerous cells before they can spread [15]. Nanomedicine is the preservation and improvement of human health using molecular tools and molecular knowledge of the human body [12]. Medical nano-robots will also make possible the convenient correction of genetic defects, and can help to ensure a greatly expanded health span. However, mechanical medical nano devices will not be allowed (or designed) to self-replicate inside the human body, nor will medical nano robots have any needed for self-replication themselves [11]. One of the most important applications of molecular nanotechnology will be medical Nanorobotics or Nanomedicine. The ability to design, build, and deploy large numbers of medical nanorobots will make possible the rapid elimination of disease and the reliable and relatively painless recovery from physical trauma [3]. It covers areas such as nanoparticle drug delivery and possible future applications of molecular nanotechnology (MNT). Since current cancer treatments like radiation therapy and chemotherapy often might avoid side effects and allergic reactions by coming in generic, biocompatible housings; becoming active only upon reaching their ultimate destinations; and attaining end up destroying more healthy cells than cancerous ones, nanomedicine would make use of nano robots, introduced into the body, to repair or detect damages and infections. For example, these nanorobots would search out cancer-affected cells using certain molecular markers. Medical nanorobots would then destroy these cells, and only these cells. Carbon nanotubes would be the primary structures used to build these nanorobots due to the inherent strength and other characteristics [2].

One application of nanotechnology is the development of so-called smart material. This term refers to any sort of material designed and engineered at the nanometer scale to perform a specific task. Smart pharmaceuticals could be essentially programmable machines with a range of "sensory," "decision-making," and "effector’s" capabilities. They almost complete specificity of action. One example is materials designed to respond differently to various molecules; such a capability could lead, for example, to artificial drugs, which would recognize and render inert specific viruses [11].

9.10 Carbon Nanotube Fiber & Film

One application for nanotubes that is currently being researched is high tensile strength fibers. Two methods are currently being tested for the manufacture of such fibers. A French team has developed a liquid spun system that involves pulling a fiber of nanotubes from a bath, which yields a product that is approximately 60% nanotube. The other method, which is simpler but produces weaker fiber elastic modulus beers, uses traditional melt-drawn polymer fiber techniques with nanotubes mixed in the polymer. After drawing, the fibers can have the polymer component burn out of them leaving only the nanotube or they can be left as they are [11, 17].

To sum up Carbon nanotubes are unique nanostructures with remarkable electronic and mechanical properties. Interest from the research community first focused on their exotic electronic properties, since nanotubes can be considered as prototypes for a one-dimensional quantum wire. As other useful properties have been discovered, particularly strength, interest has grown in potential applications.

This hexagonal network of carbon atoms, which has been rolled up to make a seamless cylinder, Just a nanometer across, the cylinder can be tens of microns long, and each end is "capped" with half of a fullerene molecule. Single-wall nanotubes can be thought of as the fundamental cylindrical structure, and these form the building blocks of both multi-wall nanotubes and the ordered arrays of single-wall nanotubes called ropes. Many theoretical studies have predicted the properties of single-wall nanotubes.

Because this material is exceptionally new, it is still in a research phase. However, it has properties which make it useful to perform certain tasks, but not on a commercial level. As research into this material slowly extends in the aspects of synthesis and utility, practical applications for this material become more apparent and will slowly begin to appear in scientific use. Possible present uses include

- Semiconductors, Transistors and Logic gates
- Metals, quantum wire
- Semimetals

Structural material Future Prospects include

- Active Materials
- Swarms or materials made of machines
- Supercomputers (smaller and faster)
- Improved interplanetary transportation
- Space elevator
- Launch Vehicles
- Advanced data storage

We can see that this exciting new technology can replace conventional technology with astounding results. The implications of this technology and new materials will change the way computers; structural and mechanical materials are made and used.

CHAPTER TEN

10. Analytical Nanoscopy

The light or optical microscopes utilize light as a source of illumination. The highest effective magnification of light microscopes is about 1,000×; at magnifications beyond this no further detail in the image is acquired. The best possible theoretical resolution of light microscope is 0.25 micron. Therefore, common analytical optical instruments do not analyze nanomaterials. Therefore, better resolution (the discrimination of fine detail in the image) instruments have been developed one of this kind is electron microscope [9].

10.1 Scanning probe Microscopy

Scanning probe microscopy is an important technique for both characterization and synthesis of nanomaterials. Scanning probe microscopy is the umbrella term for all kinds of microscopy techniques, where the sample is not imaged at once, but scanned line by line. The best-established modes are:

EM: electron microscope
TEM: transmission electron microscope
AFM: atomic force microscope
STM: scanning tunneling microscope
SEM: scanning electron microscope

Nanotechnology received it greatest momentum with the invention of scanning electron microscope in 1985 by Binnig and Rohrer and latter the most important atomic force microscope was developed in 1986 by Binnig, Rohrer and Gerber [1, 9].

These instruments belong to a broad category of particle beam instruments. Electron probe microanalysis (EPMA) is generally considered micro-analytical techniques, which are able to image or analyze materials we cannot generally observe with the resolution offered by visible techniques. Imaging, here, means photograph an object much smaller than it can be seen, even with the aid of an optical microscope. High-resolution electron microscopy is an essential tool for the characterization of the nanotubes and annostructres [42, 43].

All of these microscopes work by measuring a local property- such as height, optical absorption, or magnetism- with a probe (or "tip" like a stylus) placed very close to the sample. The small probe sample separation (on the order of the instrument's resolution) makes it possible to take measurements over a small area. To acquire an image the microscope raster-scans the probe over the sample while measure in the local property in question. The resulting image resembles the image on a television screen in that both consist of many rows or lines of information placed one above the other [43].

The main advantage of the scanning technique is, that the resolution of the microscopes is not limited by diffraction and unlike the traditional microscopes, scanned-probe systems do not use lenses, so the resolution of limited by the size of the probe rather than the diffraction effects.

10.1.1 Electron Microscope

Ernest Ruska and Max Knoll at the Berlin Technische Hochschule built the first electron microscope in 1931. The advantage of an electron beam is that it has a much shorter wavelength (due to wave-particle duality of electrons), which allows a higher resolution. Light microscope allows a resolution of about 0.25 μm, whereas electron microscopes can have resolutions as low as 0.1 nm.

Electron microscope, EM, uses a beam of electrons as its source of illumination. In this case a material is bombarded with electrons which have high energies because they have mass and because they have been accelerated with tens of thousands of volts. As the effective wavelength of this electron beam is shorter than that of light then resolution is improved. Therefore, the image in an EM may be magnified up to about 500,000× to elucidate much finer details in the specimen observed [42].

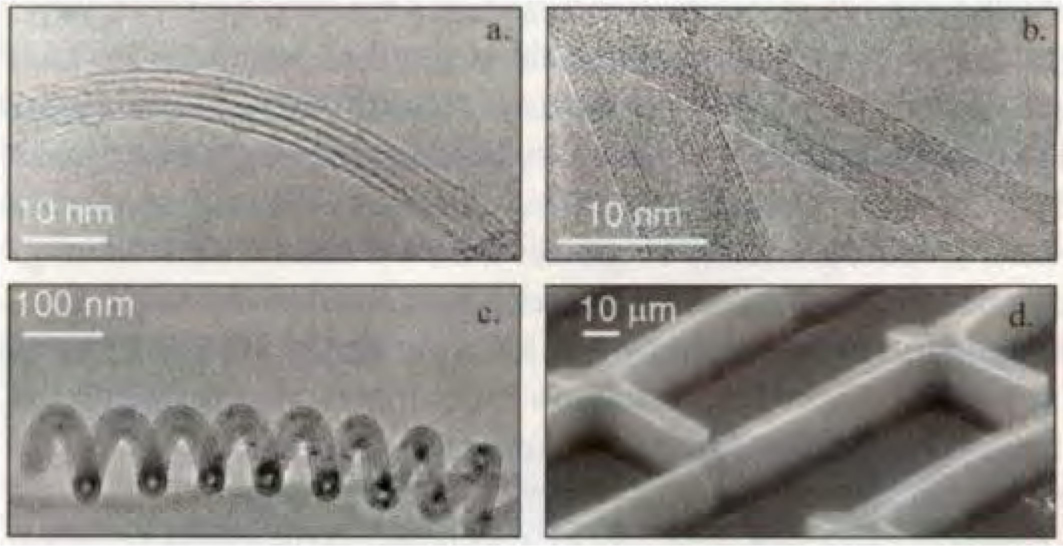


Figure 39 Montage of electron microscope images of various carbon nanotubes: a) SWNT rope prepared by laser ablation technique; b) MWNTs synthesized by the arc-discharge method; c) MWNT coil formed in the thermal decomposition of hydrocarbons in the presence of catalytic particles; d) patterns of oriented nanotube bundles grown on pre-structured deposits of catalytic particles by soft lithography [39].

11.1.2 Transmission Electron Microscope

The basic principle of transmission electron microscope, TEM, is as its name suggests - transmits electrons through the specimen (as light is transmitted through a specimen in an optical microscope). The source of electron is a filament (a thin piece of tungsten wire which is drawn out to a point). The filament is heated up by the application of a high voltage and electrons are literally boiled off the tip of the tungsten wire; this is termed as thermo ionic emission. The filament is housed within an assembly, which acts as a cathode gun and below this is an anode plate (which has a potential difference with respect to the cathode) so that electrons attracted to it. A small hole (aperture) in the anode plate allows the electrons to pass through and down through the rest of the TEM column. The whole TEM column is maintained under vacuum because the electrons do not have sufficient energy to pass through gas or water molecules. The limited energy of the electron beam requires that the specimen sections have to be very thin, typically around 100 nm. In contrast to the optical microscope glass eyepiece lenses, electron microscope use electromagnetic projector lenses which project the focused image onto a fluorescent screen; as the can not see electrons, they are projected onto a phosphor coated fluorescent screen the resultant fluorescent is visible [9].

11.1.3 Atomic Force Microscope

The atomic force microscope (AFM) is a very powerful. Besides imaging it is also one of the foremost tools for the manipulation of matter at the nanoscale by moving atoms around. AFM measures topography of a sample with a force probe. AFM has sensitive detection system, flexible cantilevers with sharp tips at its end.

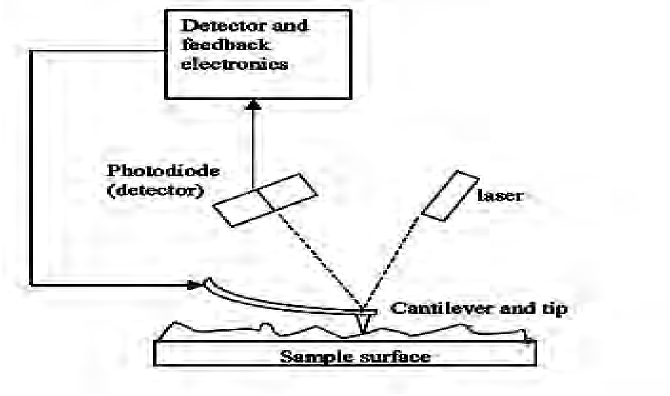


Figure 40.Block diagram of atomic force microscope

The tip is brought into close proximity of a sample surface, the force between the tip and the sample leads to a deflection of the cantilever. Typically, the deflection is measured using a laser spot reflected from the top of the cantilever high resolution tip-sample positioning, and force feedback [44].

Fig.41.Schematic illustration of the AFM with a tip attached to a spring

AFM can achieve a resolution of 10 pm and provides a true three-dimensional surface profile unlike electron microscope

11.1.4 Scanning Tunneling Microscope

Binnig discovered the scanning tunneling microscope, STM, and Heinrch Rohrer Who shared half of the Nobel Prize in physics in 1986 for their achievement

The other half went to Ernest Ruska for his fundamental work in electron optics, and for the design of the first electron microscope. TM is the most powerful microscope ever built. It is used to obtain images of conductive surfaces at an atomic scale 0.2 nm. It can also be used to alter the observed material by manipulating individual atoms, triggering chemical reactions, and creating ions by removing individual electrons from atoms and then reverting them to atoms by replacing the electrons.

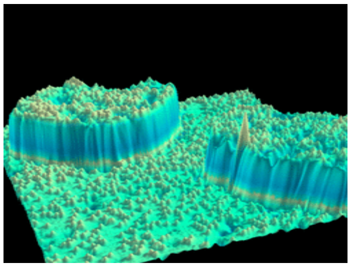


Figure 41. Image of substitution Cr impurities (small bumps) in the Fe surface

The STM is a non-optical microscope that employs principles of Quantum mechanics. A very fine probe is moved over the surface of the material under study, and a voltage is applied between probe and the surface. Depending on the voltage and its characteristics electrons will "tunnel" (this is a quantum-mechanical effect) or jump from the probe to the surface (or vice-versa depending on the polarity), resulting in a weak electric current. The size of this current is highly dependent on the distance between probe and the surface. By scanning the probe over the surface and measuring the current, one can thus reconstruct the surface structure of the material under study. Scanning tunneling microscopy can produce images similar to or at least suggestive of the actual structure such as chiral angel diameter of nanotubes in sample can be determined. [9].

EPILOG

The last decade of the last century in condensed matter physics has been marked by the revival of carbon-based materials. Besides the conventional forms of carbon, the graphite and the diamond, new forms of carbon have been discovered: fullerenes, carbon nanotubes, Although the parent compound of fullerenes, the C60 molecule was discovered in 1985 by Kroto, Smalley and co-workers, the full expansion of the activity concerning this material did not truly begin until Krätschmer and Huffman invented the mass production of fullerenes. The great euphoria in the fullerene research started with the discovery of "high temperature superconductivity" in 1991, exceeding a critical temperature of 30 K upon alkali metal doping. The search for new carbon nanostructures, higher mass fullerenes has strongly motivated chemists and physicists. Sumio Iijima discovered the multi-walled carbon nanotubes in the same year, which was considered at the beginning as a giant fullerene. In 1993 the single walled nanotubes were synthesized giving carbon structures of 1.4 nm in diameter and several microns in length. At the beginning, while the production and purification of these structures were not sufficiently elaborated, the research mainly consisted of "photography", which of spectacular images obtained by high-resolution transmission electron microscopy (HRTEM). Around 1994 some of these problems were solved, and the study of the physical properties began.

Today, carbon nanotubes are driving scientific research. This field has several important directions in basic research, including chemistry, electronic transport, and mechanical and field emission properties. Furthermore, the perspectives for applications are very challenging and exciting. The main avenues of potential applications of carbon nanotubes are: ultimate reinforcement fibers for composites (high strength, high aspect ratio, high thermal and chemical stability); conducting nanowires; field emitters (individual nanotube field emitters, large area flat panel displays,); nanotools (tips for Scanning Tunneling, Atomic Force, Magnetic Resonance Force and Scanning Nearfield Optical, Chemical/Biological Force Microscope tips, nanomanipulators, nanotweezers)

The discovery of Fullerene and Carbon Nanotubes, have a great potential to revolutionize the future trends owing to some of its unique properties.

If nanotechnology is practiced as predicted, then nanoscience and nanotechnology revolution will change the nature of almost every human object's and activities; the societal impact of this revolution will be greater than that of the first industrial revolution.

The activities are still limited only to the developed nation. Nation like ours greatly demands for it. It is inevitable in the future to remain away from such a flourishing field that would affect every part of our life in near future. The aim of my project was exactly to nurture the young scientists and practitioners to focus on this field to contribute so that Ethiopia can get benefit out of it. We should continue with this kind of research and developmental activities for future growth.

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