Graphene and Nanotechnology Applications for Space Technology

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Space Environment and Kibo Utilization Workshop (SEKUW)
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National Nanotechnology Directorate
Ministry of Science, Technology & Innovation
MALAYSIA

How BIG is nano?

Macrosize
meters, decimeters, centimeters, millimeters

Child

10^{0}

A child is about 1 meter tall
1 meter = 1,000,000,000 nm
(1 billion nanometers)

Hand

10^{-1}

A hand is about 1 decimeter wide
1 decimeter = 100,000,000 nm
(100 million nanometers)

Pinky Finger

10^{-2}

A pinky finger is about
1 centimeter wide
1 centimeter = 10,000,000 nm
(10 million nanometers)

Freckle

10^{-3}

A freckle is about 1 millimeter wide
1 millimeter = 1,000,000 nm
(1 million nanometers)

Strand of Hair

10^{-4}

A hair is about one tenth of a
millimeter wide
0.1 millimeter = 100,000 nm
(100 thousand nanometers)

Microsize
micrometers

Red Blood Cell

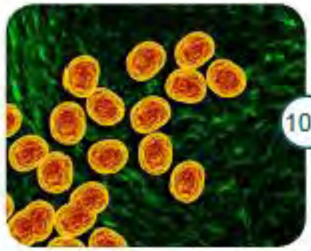
10^{-5}

A red blood cell is about
10 micrometers wide
10 micrometers = 10,000 nm
(10 thousand nanometers)

Bacteria

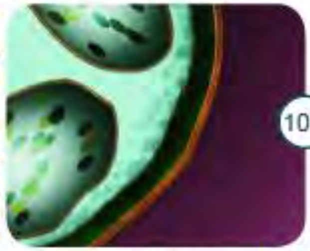
10^{-6}

A bacterium is about
1 micrometer wide
1 micrometer = 1,000 nm
(1 thousand nanometers)

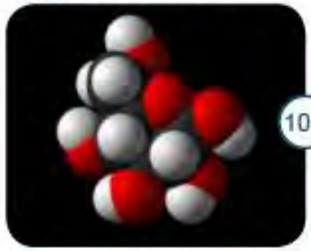
Virus

10^{-7}

A viron is about one tenth
of a micrometer wide
0.1 micrometer = 100 nm
(1 hundred nanometers)

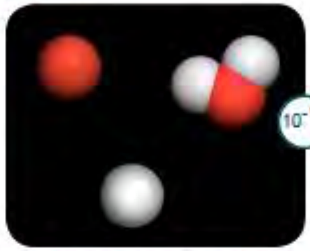
Nanosize
nanometers

Cell Membrane

10^{-8}

A cell membrane is about
10 nanometers wide
10 nanometers = 10 nm

Sugar Molecule

10^{-9}

A sugar molecule is about
1 nanometer wide
1 nanometer = 1 nm

Atom

10^{-10}

An atom is about one tenth
of a nanometer wide
0.1 nanometer = 0.1 nm

Nanoscale

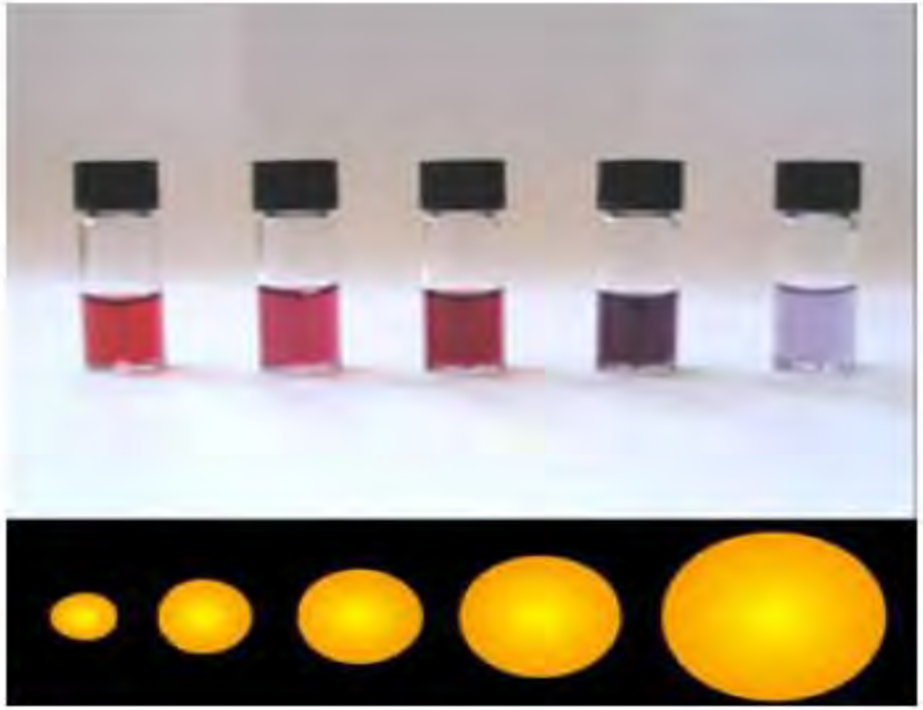
1 nanometer =
1 billionth (10^{-9}) of a meter

a marble

Why do we care?

Things behave differently at this scale

- Quantum mechanics plays a much more important role
- For example,
  - A brick of gold is shiny and "gold"-colored.
  - A vial of gold nanoparticles in solution can be a range of colors depending on the size of the nanoparticles.
  - This is because of a phenomenon know as quantum confinement.



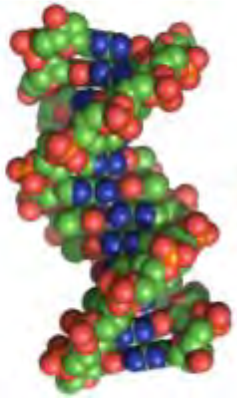
Suspensions of discrete (separated) gold nanoparticles in clear solution vary in color from pink to purple as the nanoparticle size gets bigger.

Image source: "Causes of Color", WebExhibits, http://www.webexhibits.org/causesofcolor/9.html

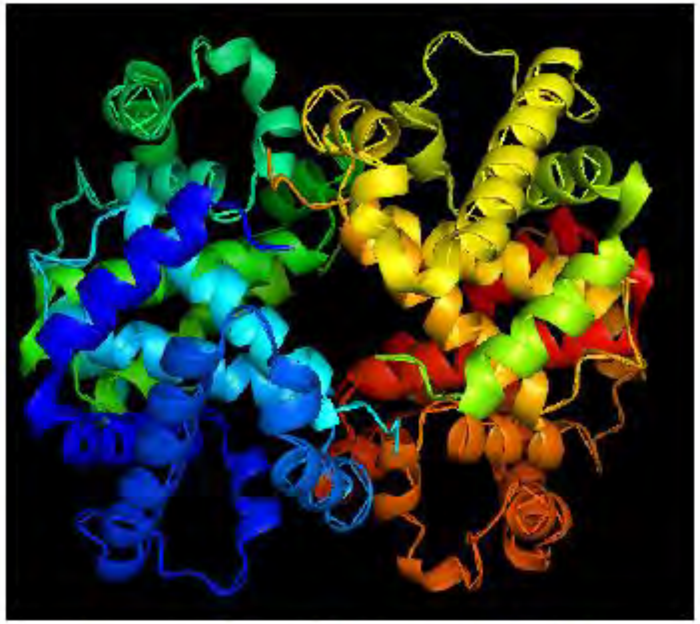
This is the scale of biological processes

- Human cells and bacteria have diameters around 1-10 *micro*meters

- Cellular machinery is on the *nano*scale
  - Diameter of DNA is ~2 nanometers
  - Hemoglobin, the protein that carries oxygen through the body, is 5.5 nanometers in diameter



Structure of DNA
PDB ID: 1BNA

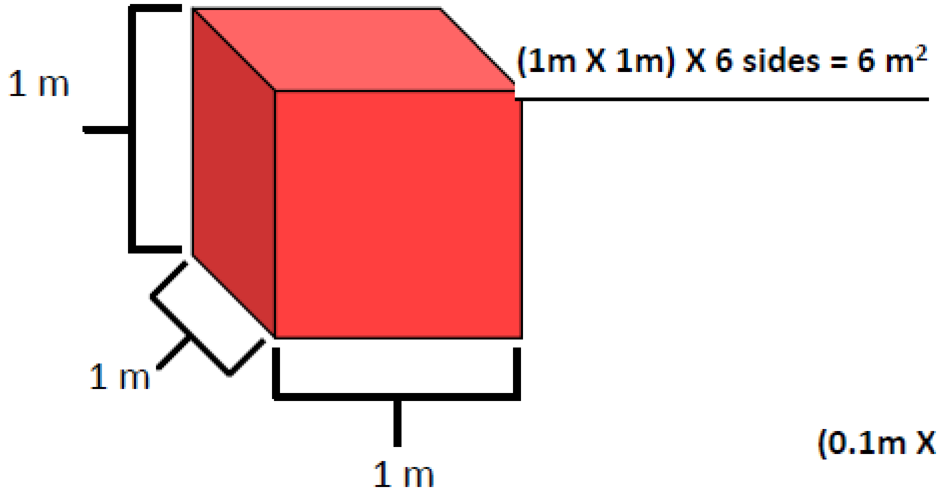


Structure of hemoglobin
PDB ID: 1BUW

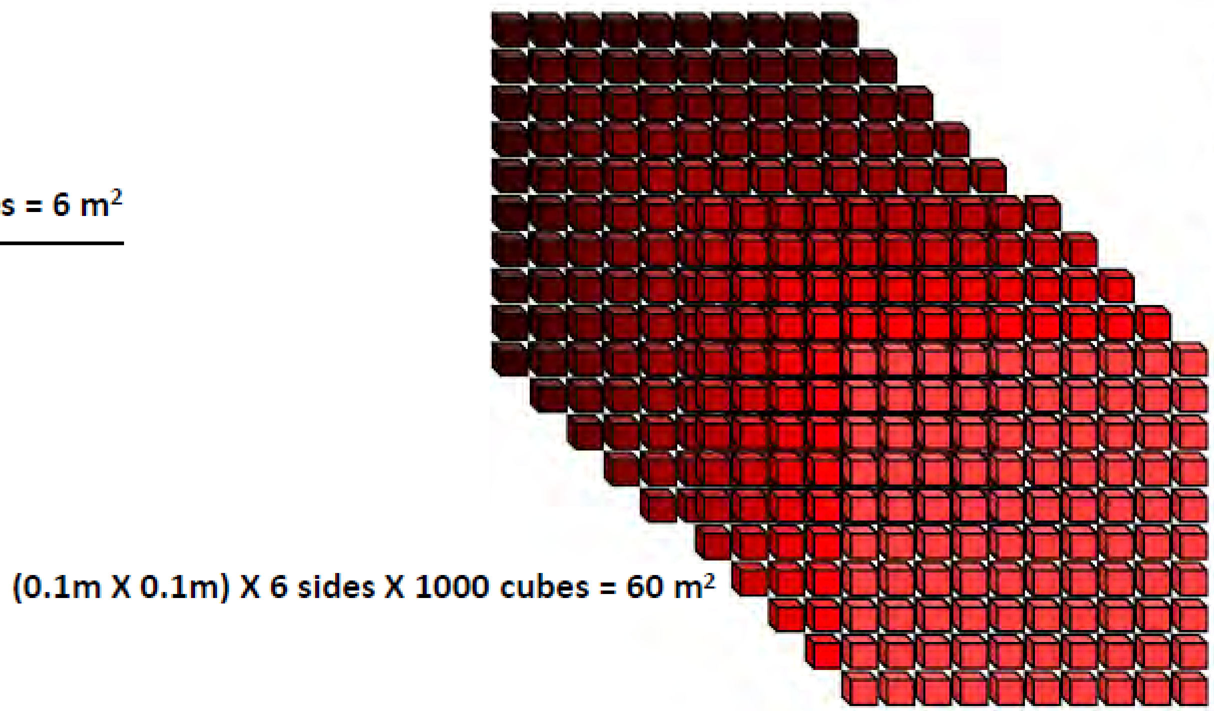
One more reason: surface area

Another reason nanomaterials behave differently from bulk materials of the same chemical is because of surface area – or the area of an object that is an exposed surface.

For this cube, each edge is 1 meter in length.



1m X 1m X 1m = 1 m^3



For these cubes, each edge is 0.1 meters in length, but there are 1000 cubes.

(0.1m X 0.1m X 0.1m) X 1000 cubes = 1 m^3

Surface Area and Reactions

- This increased surface area allows chemical reactions to go much faster.
- Think about it this way:

  Which dissolves faster in your coffee or tea, a sugar cube or a teaspoon of granulated sugar?

Answer: Granulated sugar

Nano-enabled Consumer Products

As of the March 10, 2011, there are over 1300 consumer products around the world that are manufacturer-identified as nanotechnology-based.

- Touch screens (iPhone)
- Sunscreens
- Cosmetics
- Tennis rackets
- Bicycles
- Fabric
- Computer memory
- Many more…

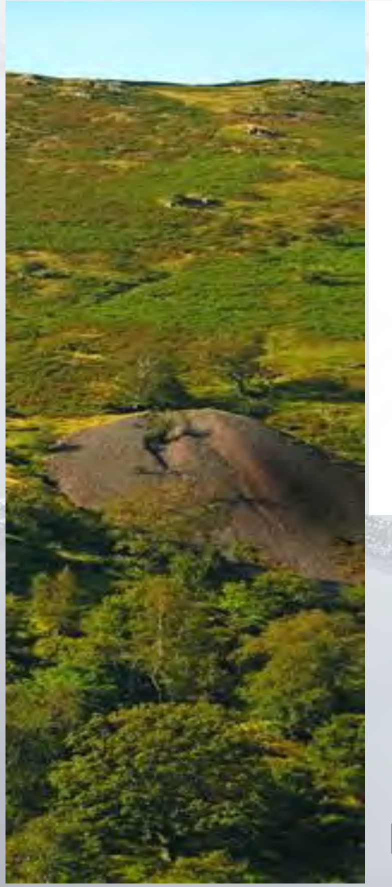
These products are here, ready to buy today!

Resources: The Project on Emerging Nanotechnologies website: http://www.nanotechproject.org/

What *is* graphene?

- It is a single layer of Graphite (pure crystaline carbon)

Graphite was discovered in 1564 at Seathwaite (Borrowdale), Northumberland



Oldest surviving pencil circa 17th Cent.

Left: Tall graphite mine,

near Seathwaite, England CA12 5XJ

‘Graphene’ **was first isolated in the lab by Professor Andre** Geim with former student Konstantin Novoselov at the University of Manchester, England in 2004

◄Sir Andre K. Geim, FRS

The University of

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1824

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konstantin.novoselov@manchester.ac.uk +44(0)161 275-4119
Schuster Building, Rooms 2.10 & 2.11

The School of Physics and Astronomy
The University of Manchester
Manchester, M13 9PL

Sir “Kostya” Novoselov, FRS►

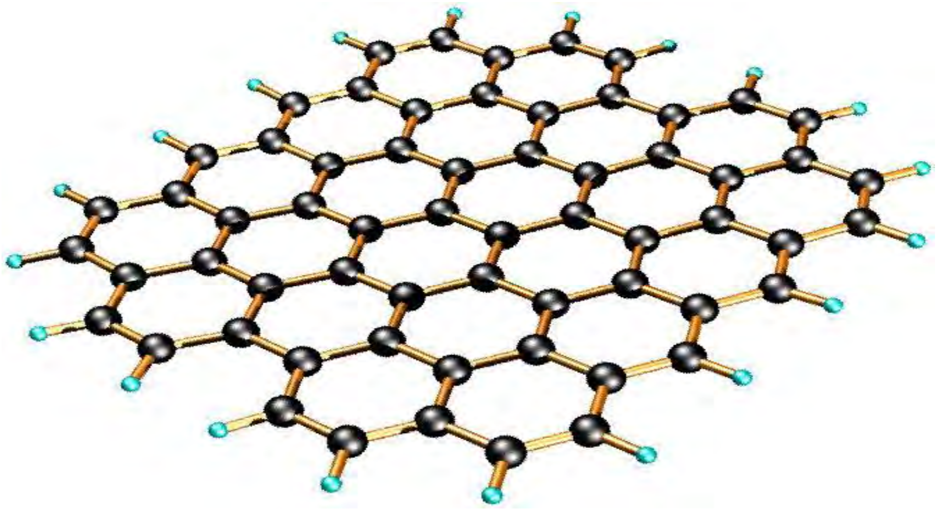
2010 Nobel Prize

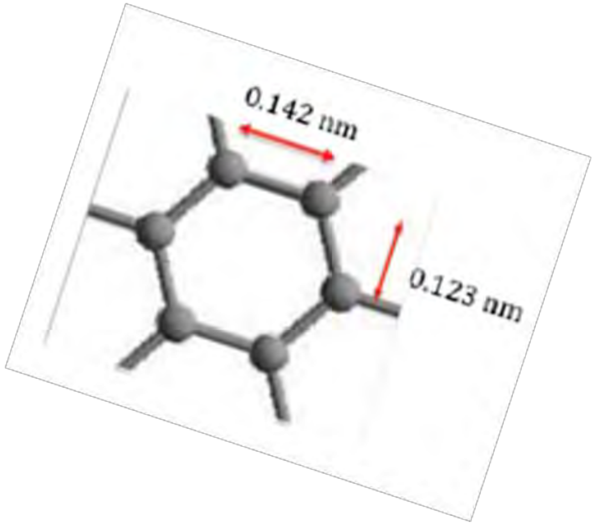
for **“groundbreaking experiments regarding the two-dimensional material graphene”**

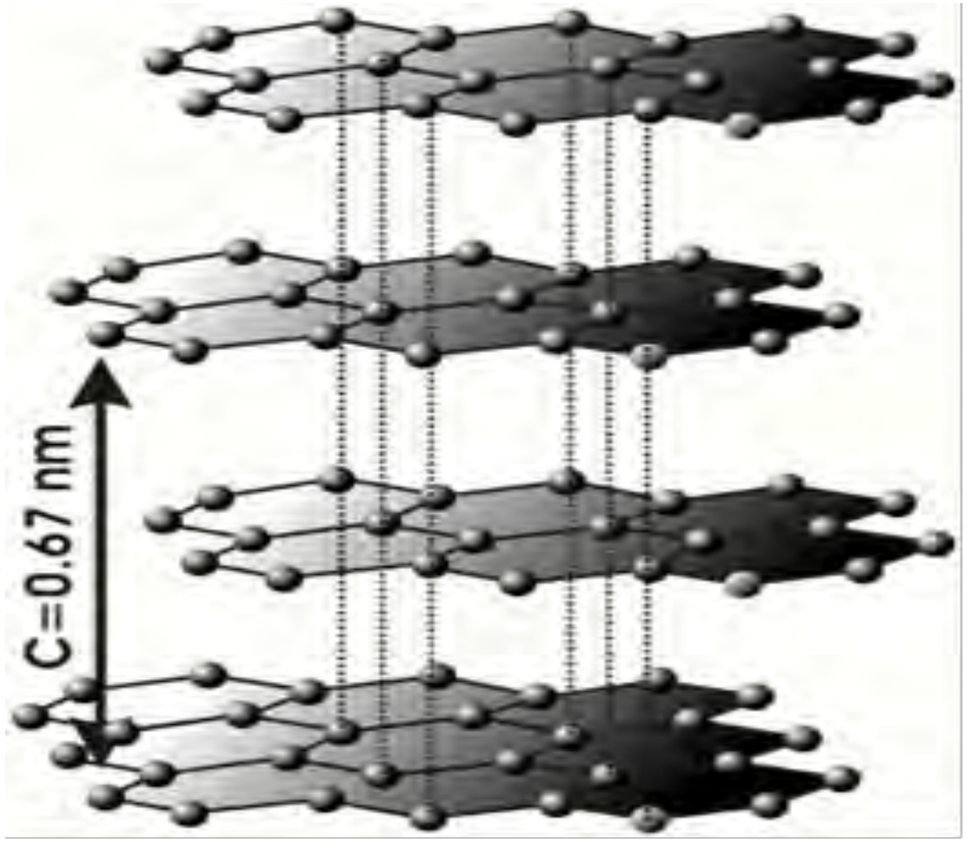
(Both were later Knighted, twice)

STRUCTURE

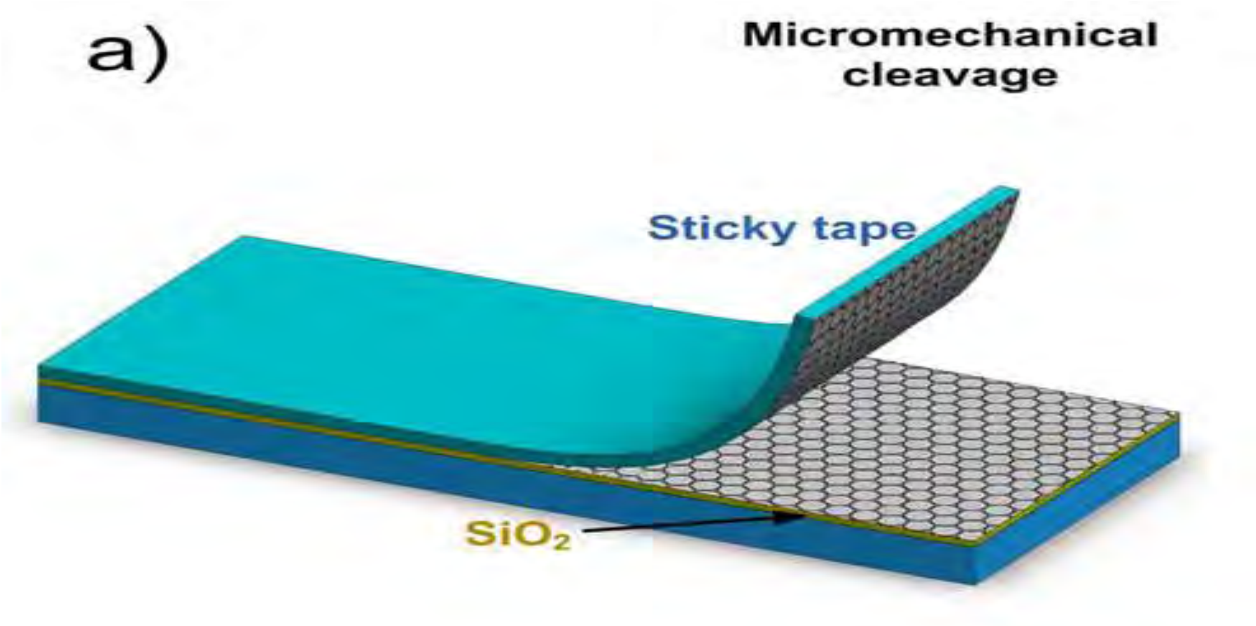
- It is the one-atom thick planar sheet of carbon atoms (graphite), which makes it the thinnest material ever discovered.
- 2-dimensional crystalline allotrope of carbon.
- C-C Bond length is 0.142 nm.
- Graphene Sheets interplanar spacing is of 0.335 nm.
- It is almost completely transparent, yet so dense that not even helium can pass through it.







- Andre Geim and Kostya Novoselov pulled graphene layers from graphite and transferred them onto thin SiO2 on a silicon wafer in a process called either micromechanical cleavage or the Scotch tape technique.

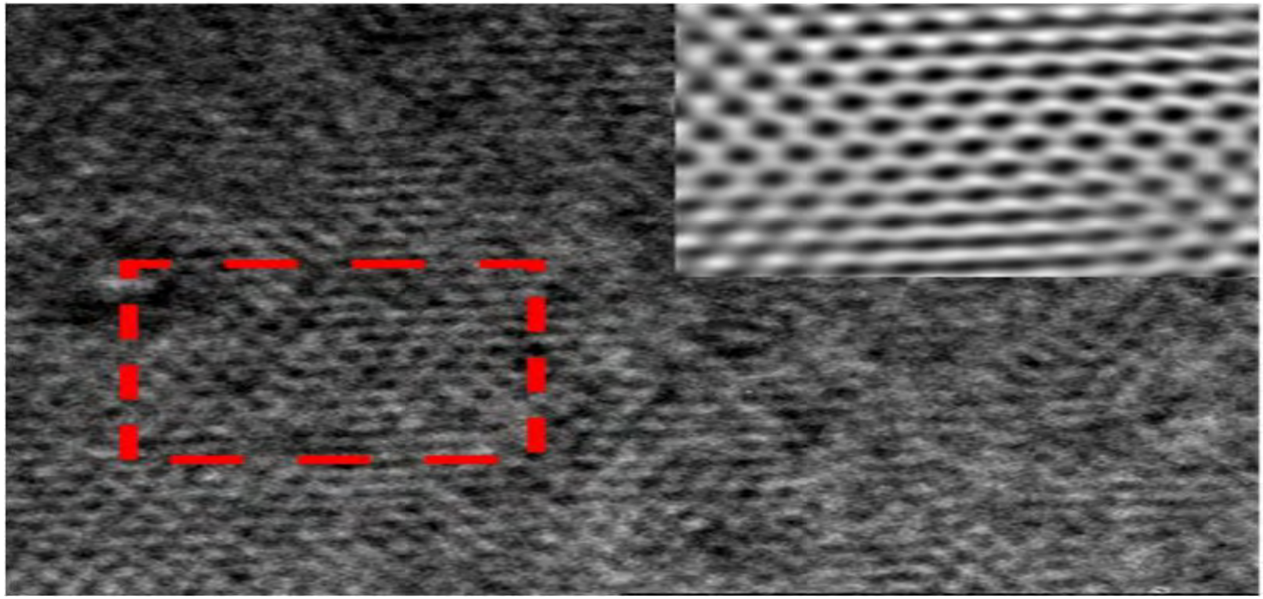


Graphene can be seen with help of

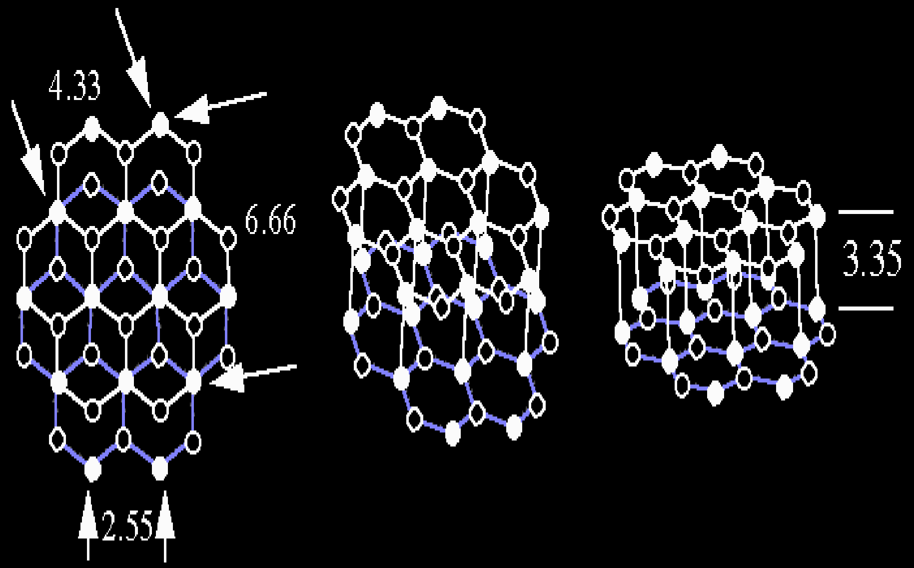
1.Transmission electron microscopy.

2.Electron microscopy

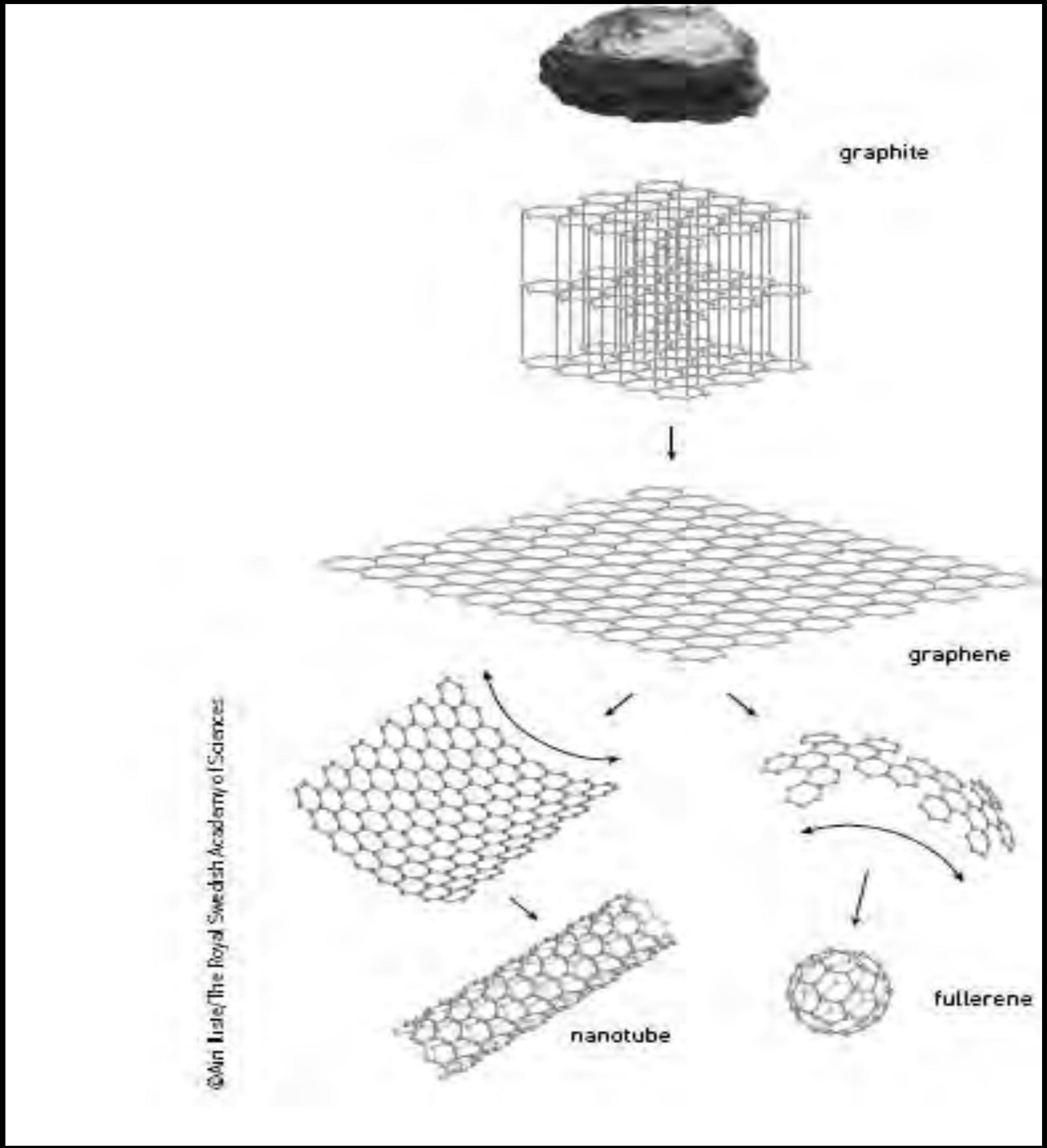
3.Optical microscope



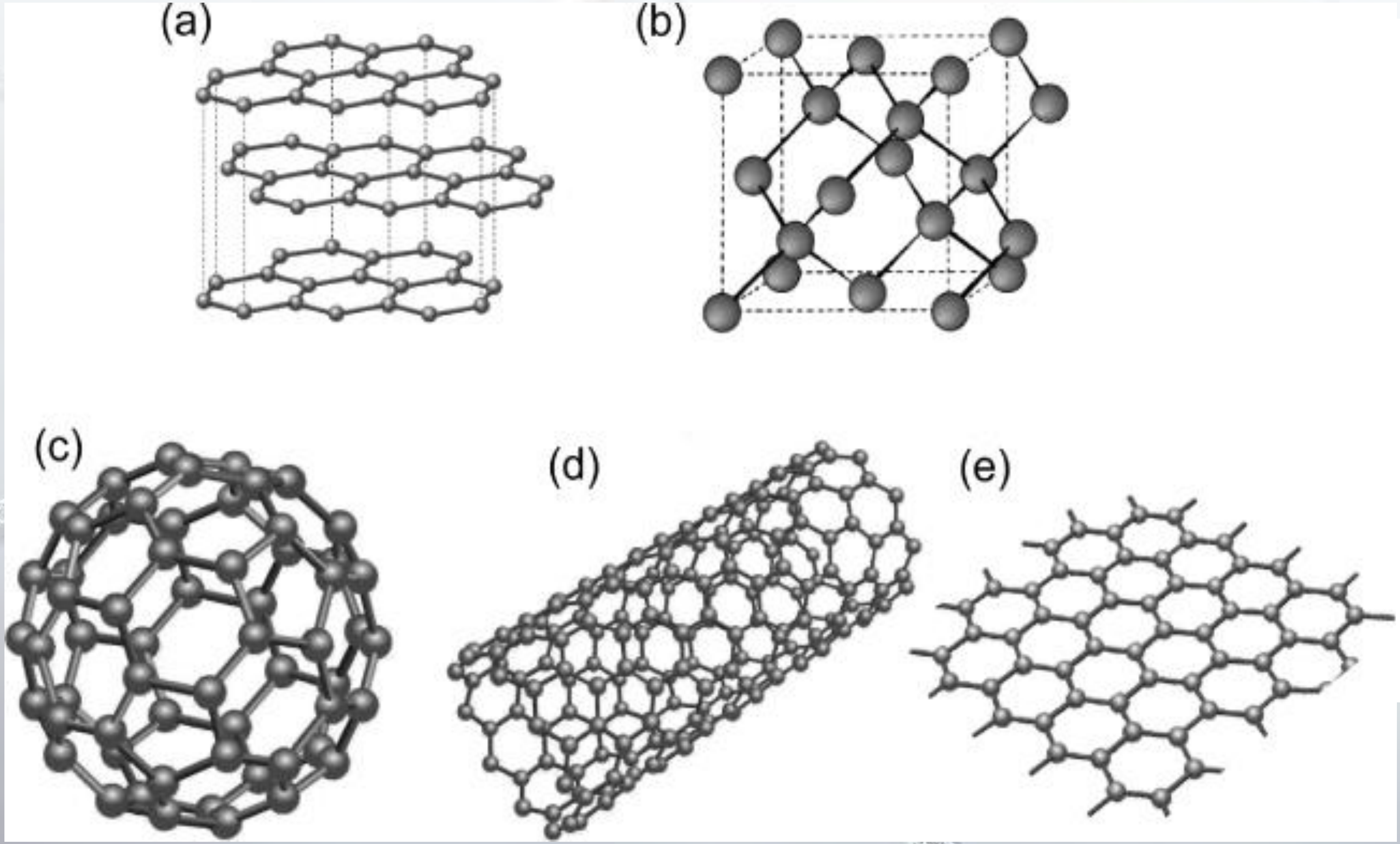
STRUCTURE OF GRAPHENE



Sheets of graphene are bonded by loose bond in graphite. These bonds are broken and sheets are isolated to form graphene. These isolated hexagonal sheets are graphene.



Graphene is among several allotropes (forms) of carbon



Forms of carbon:

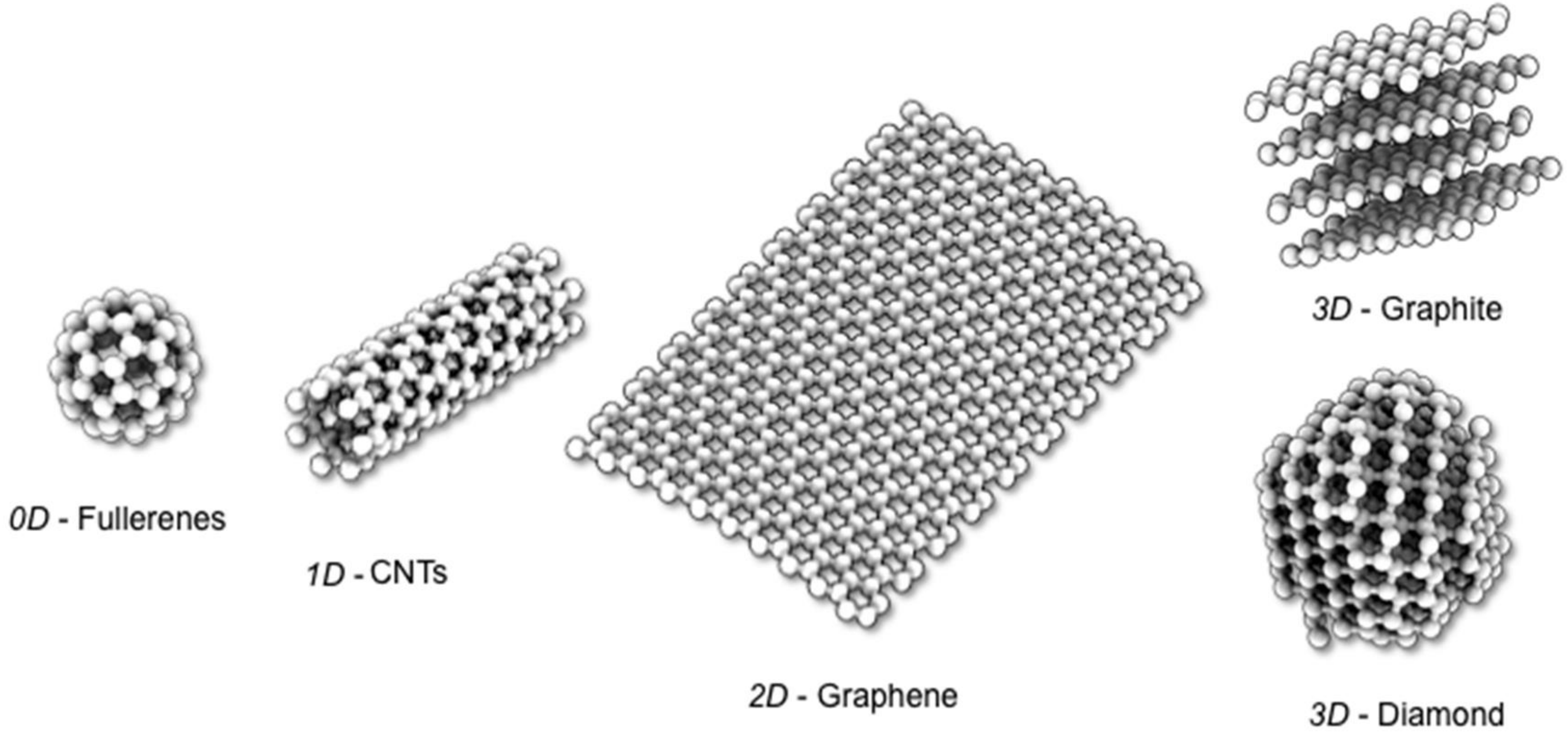
a) graphite 3D

b) diamond 3D

c) Buckminsterfullerene
"Buckyballs" 0D

d) carbon nanotube 1D

e) graphene 2D


0D - Fullerenes
1D - CNTs
2D - Graphene
3D - Graphite
3D - Diamond

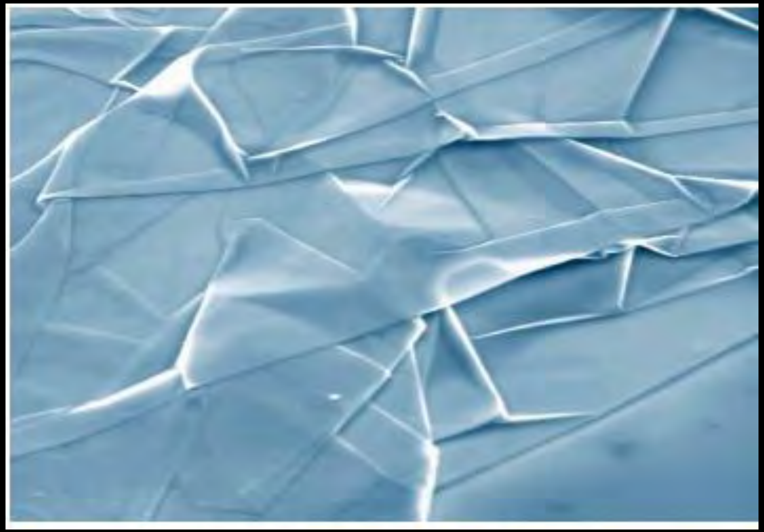
Physical properties of Graphene

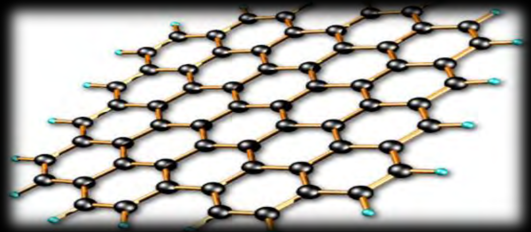
- Density- density of graphene 0.77 mg/m2.

Strength- With its breaking strength 42 N/m it is 1000 times stronger than steel

Optical transparency- graphene is almost transparent with its ability of absorb just 2.3% of light falling on it.

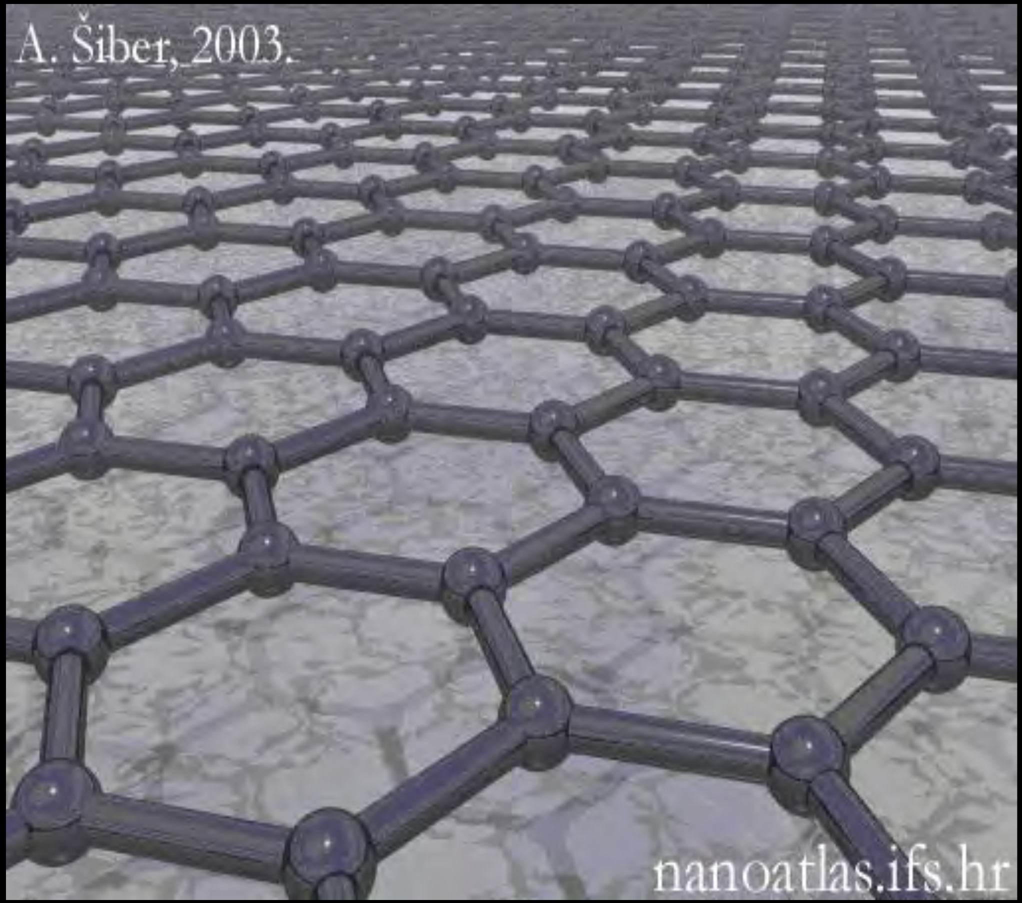
Thinnest possible material





Electrical properties

- Different electronic structure.
- High electrical conductivity.
- Conductivity further can be increased by applying electric field.
- electrical conductivity of sheets are 10 times that of copper.
- Best known conductor till now



Electronic properties

- Graphene differs from most conventional three-dimensional materials.
- Graphene has a remarkably high electron mobility at room temperature
.
The mobility is nearly independent of temperature between 10 K and 100 K
Resistivity of the graphene sheet would be 10^{-6} Ω·cm.

Optical properties

Unexpectedly high opacity for an atomic monolayer

This is "a consequence of the unusual low-energy electronic structure of monolayer graphene

It is further confirmed that such unique absorption could become saturated when the input optical intensity is above a threshold value

Due to this special property, graphene has wide application in ultrafast photonics

Thermal properties

- The near-room temperature thermal conductivity of graphene was recently measured to be between (4.84±0.44) $\times 10^3$ to (5.30±0.48) $\times 10^3$ $Wm^{-1}K^{-1}$.

Mechanical properties

As of 2009, graphene appears to be one of the strongest materials ever tested.

Bulk strength is 130GPa

2200 times greater than steel

Graphene sheets, held together by van der Waals forces

What makes Graphene different from others???

- Unique structure.
- All in one properties.
- Low cost.
- Abundant element.
- Simple fabrication techniques.
- Chemically inert.
- Thermal stability.

It conducts electricity and heat better than any other material.

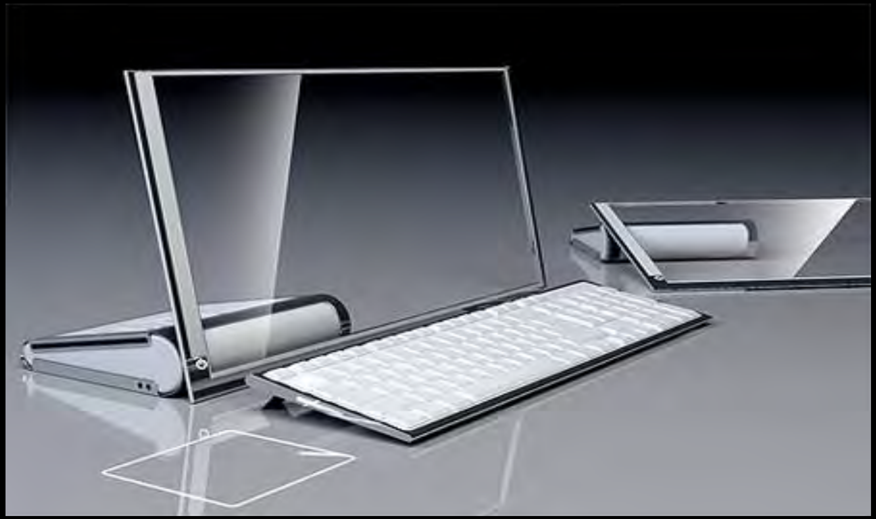
And allows nothing to pass through it except water.

Applications

- Graphene makes experiments possible that give new twists to the phenomena in quantum physics.
- Applications in electrical engineering.
- Mechanical engineering.
- Most important in electronics engineering as component material.
- As a superconducting material.
- Micro electronics.
- Transparent conducting electrode.
- Solar cells
- Graphene bio devices.

Electronics Engineering

- Will definitely replace silicon and germanium as device material.
- Conducting material on PCBs.
- Single molecule sensors
- Touchscreens
- Graphene transistor.
- Graphene integrated circuits.
- Graphene chips.



Fabrication of electronic devices

- Graphene when converted into nanoribbon and nanotubes will replace silicon as semiconducting material.
- Due to its high electronic quality, graphene has also attracted the interest of technologists who see it as a way of constructing ballistic transistors. Graphene exhibits a pronounced response to perpendicular external electric fields, allowing one to build FETs.
- Graphene has excellent properties to be a vital component of integrated circuits
- Graphene transistors are conceivable and are ready to replace silicon transistors
- In 2009 researchers demonstrated four different types of logic gates, each consisting of a single graphene transistor
- It is capable of taking an incoming electrical signal of a certain frequency and an producing output signal that is a multiple of that frequency
- A recent publication has described a process for producing gram-quantities of graphene, by the reduction of ethanol by sodium metal, followed by pyrolysis of the ethoxide product, and washing with water to remove sodium salts

Electrical engineering

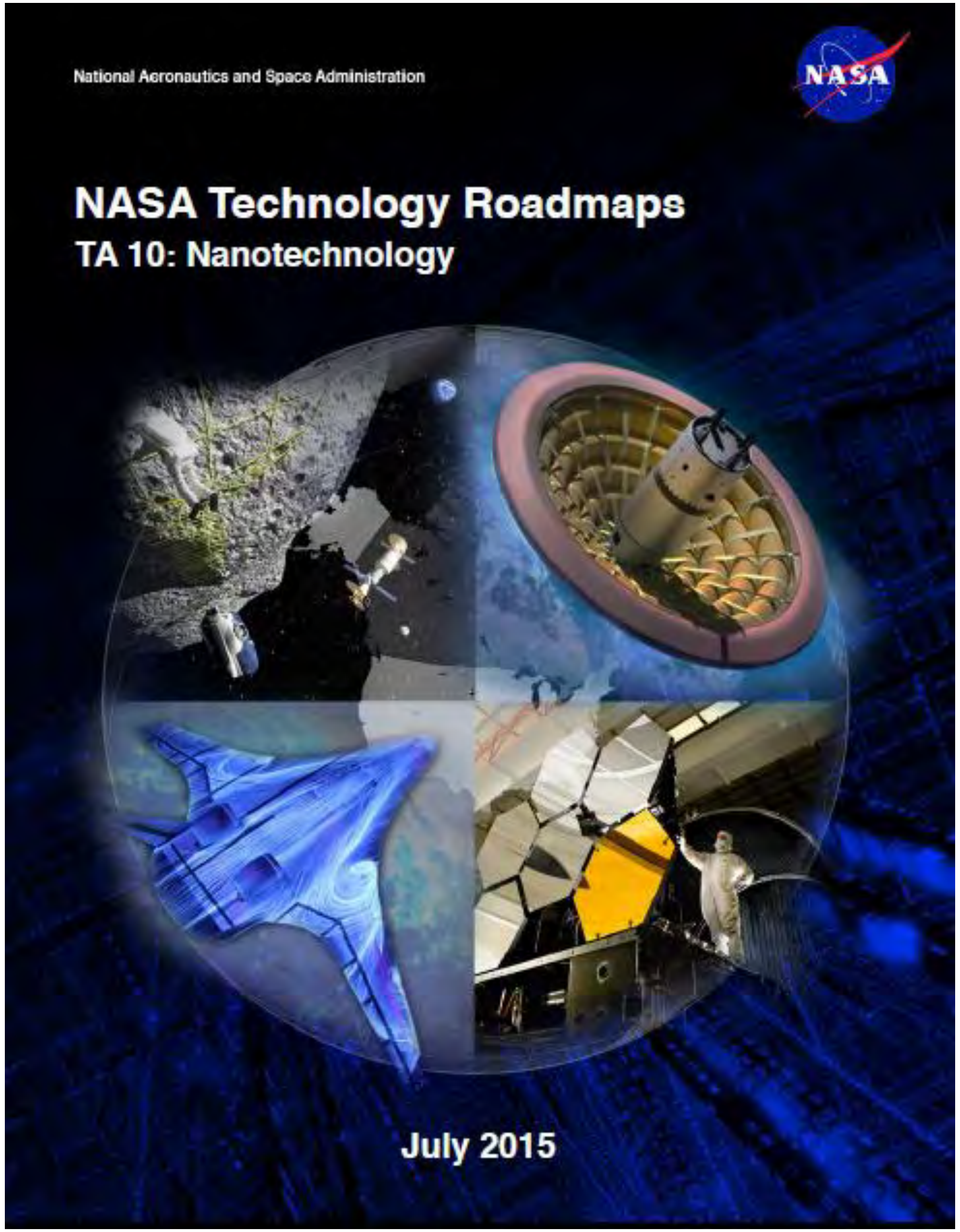
- Can replace graphite in brushes of motors.
- Can be construction material for various electrical devices.
- When mixed with plastic can be used as conductor with higher strength.
- It will replace copper as conducting material.

Mechanical engineering

- In Manufacturing process as Manufacturing material.
- As a composite material for machines ,cars.
- Defense.
- Airplanes, space shuttles , satellite.

GRAPHENE IN ADVANCED COMMUNICATION TECHNOLOGY

- Flexibility and Slim
- Graphene based phones are very easily placed in the pocket
- Graphene based phones are slimmer as compared to the smart phones.
- Graphene based phones are thinner like floppy disc.
- Graphene based phones can be worn as wristwatches.


National Aeronautics and Space Administration
NASA
NASA Technology Roadmaps
TA 10: Nanotechnology
July 2015


TA 1 LAUNCH PROPULSION SYSTEMS
TA 2 IN-SPACE PROPULSION TECHNOLOGIES
TA 3 SPACE POWER AND ENERGY STORAGE
TA 4 ROBOTICS AND AUTONOMOUS SYSTEMS
TA 5 COMMUNICATIONS, NAVIGATION, AND ORBITAL DEBRIS TRACKING AND CHARACTERIZATION SYSTEMS
TA 6 HUMAN HEALTH, LIFE SUPPORT, AND HABITATION SYSTEMS
TA 7 HUMAN EXPLORATION DESTINATION SYSTEMS
TA 8 SCIENCE INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS
TA 9 ENTRY, DESCENT, AND LANDING SYSTEMS
TA 10 NANOTECHNOLOGY
TA 11 MODELING, SIMULATION, INFORMATION TECHNOLOGY, AND PROCESSING
TA 12 MATERIALS, STRUCTURES, MECHANICAL SYSTEMS, AND MANUFACTURING
TA 13 GROUND AND LAUNCH SYSTEMS
TA 14 THERMAL MANAGEMENT SYSTEMS
TA 15 AERONAUTICS

Nanotechnology

Engineered Materials & Structures
Lead: Mia Siochi

- Lightweight Structures
  - Fibers/Textiles
  - Membranes/Gossamer
  - Adaptive
  - Multifunctional
- Damage Tolerant Systems
  - Self-repairing materials
  - Self-diagnosing materials
  - Radiation Protection
  - EMI Protection
  - Antimicrobial
- Coatings
- Adhesives
- Thermal Protection and Control
  - TPS
  - Cryoinsulation

Energy Generation and Storage
Leads: Brad Files, Dan Powell

- Energy Storage
  - Batteries
  - Ultracapacitors
  - Flywheels
  - Hydrogen storage
- Energy Generation
  - Fuel Cells
  - Photovoltaics
  - Thermophotovoltaics
  - Thermoelectrics
  - Piezoelectrics
  - Energy Harvesting

Propulsion
Leads: Mike Meador, Harish Manohara

- Propellants
  - Monopropellants
  - Nanogelled propellants
  - Hydrogen storage
- Propulsion Components
- In-Space
  - Electric
  - Solar Sails
  - Tethers

Sensors, Electronics, and Devices
Leads: Jing Li, Harish Manohara

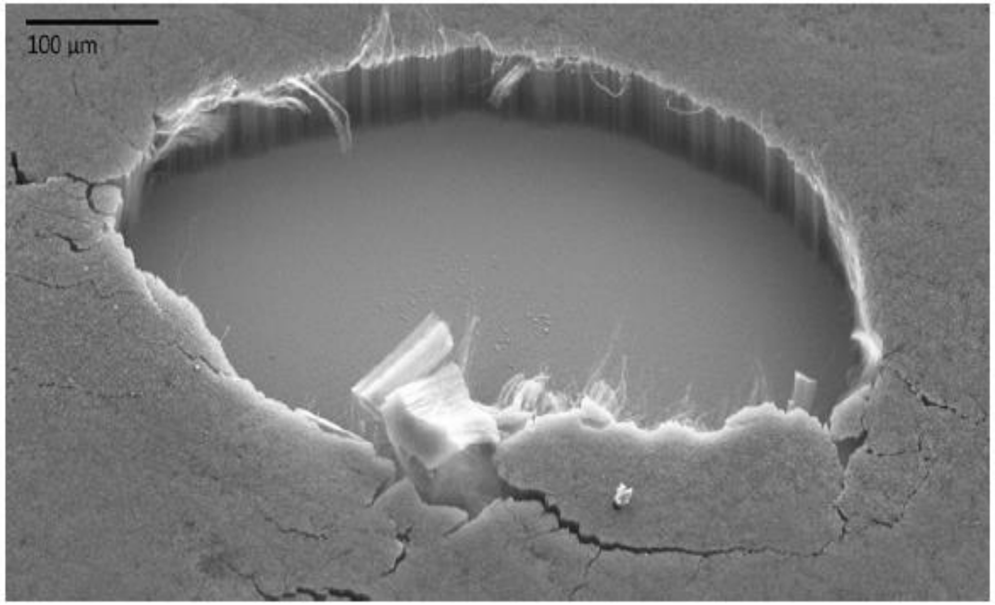
- Sensors and Actuators
  - Chemical
  - Biological
  - State
  - Astronaut Health Management
- Nanoelectronics
  - Graphene
  - Interconnects
  - Radiation Hardening
- Miniature Instruments
  - Emission Sources
  - Detectors
  - Spectrometers

NASA Develops Super Black Material That Absorbs Light Across Multiple Wavelength Bands - straylight suppression

NASA engineers have produced a material that absorbs on average more than 99 percent of the ultraviolet, visible, infrared, and far infra red light that hits it ------ a development that promises to open new frontiers in space technology.

The technology would allow scientists to gather hard-to-obtain measurements of objects so distant in the universe that astronomers no longer can see them in visible light or those in high contrast areas, including planets in orbit around other stars,

Earth scientists studying the oceans and atmosphere also would benefit. More than 90 percent of the light Earth monitoring instruments gather comes from the atmosphere, overwhelming the faint signal they are trying to retrieve.



This closeup view (only about 0.03 inches wide) shows the internal structure of a carbonnanotube coating that absorbs about 99 percent of the ultraviolet, visible, infrared, and farinfrared light that strikes it. A section of the coating, which was grown on smooth silicon, was purposely removed to show the tubes' vertical alignment. (Credit:Stephanie Getty, NASA Goddard)

New Spacecrafts and Spacesuits Using Nanotechnology

New materials, nanosensors and miniaturized robots could improve the performance of spaceships.

Anticipated advances in space travel thanks to nanotechnology

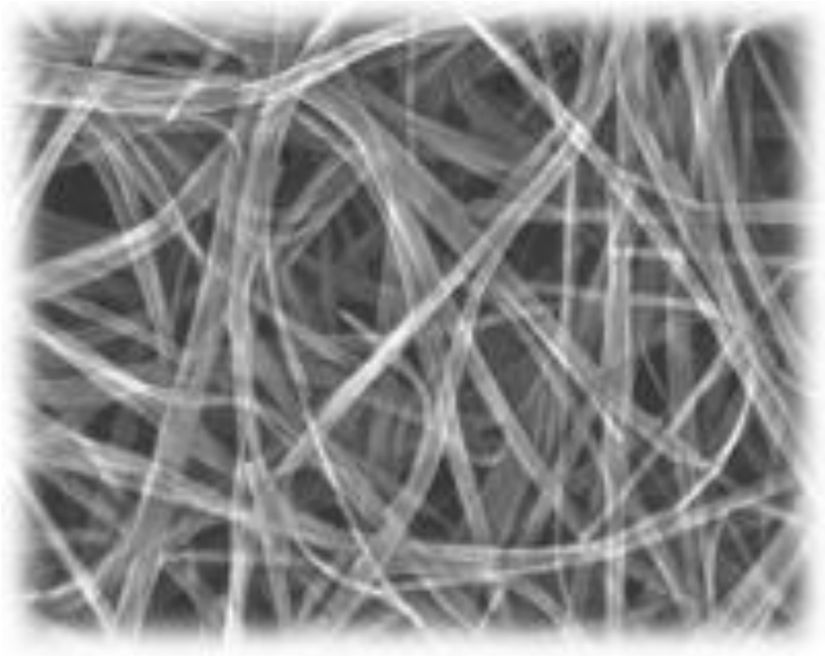
- Ultra-small sensors, power sources, as well as communication, navigation, and propulsion systems with very low mass, volume and power consumption could be developed using nanotechnology.
- Developments in electronics at the nanoscale are leading to autonomous, "thinking" spacecraft.
- Networks of ultra-small probes can investigate planetary surfaces.
- Micro-rovers should be able to drive, hop, fly, and burrow.
- Micro-spacecraft will be able to make a variety of measurements.

Magic membranes Flakes of graphene oxide could be used to separate water from other liquids.

Materials That Reduce Weight and Cost of Components

It costs about $10,000 per pound to lift anything into Earth's orbit, and $100,000 per pound to carry anything when distant planets are the destination. Space exploration experts agree that miniaturization of everything onboard spacecraft is essential to making space travel affordable, without giving up anything in terms of functionality. In fact, better performance and lower weight is always the goal.

Some of the best-known applications of nanotechnology in space are those that deal with this issue. Using materials constructed with carbon nanotubes can reduce the weight of space vehicles significantly while maintaining or even increasing structural integrity.



State of the art for lightweight structures, purified carbon nanotubes.

Power Distribution

Energy distribution systems constitute a significant fraction of the mass of an aerospace vehicle. There are over 4,000 pounds of copper wiring in a Boeing 777. The Space Shuttle had over 200 miles of data and power cables. Significant weight savings can be realized by replacing metallic conductors in data and power cables with lighter weight wiring from nanomaterials, such as CNTs and graphene.

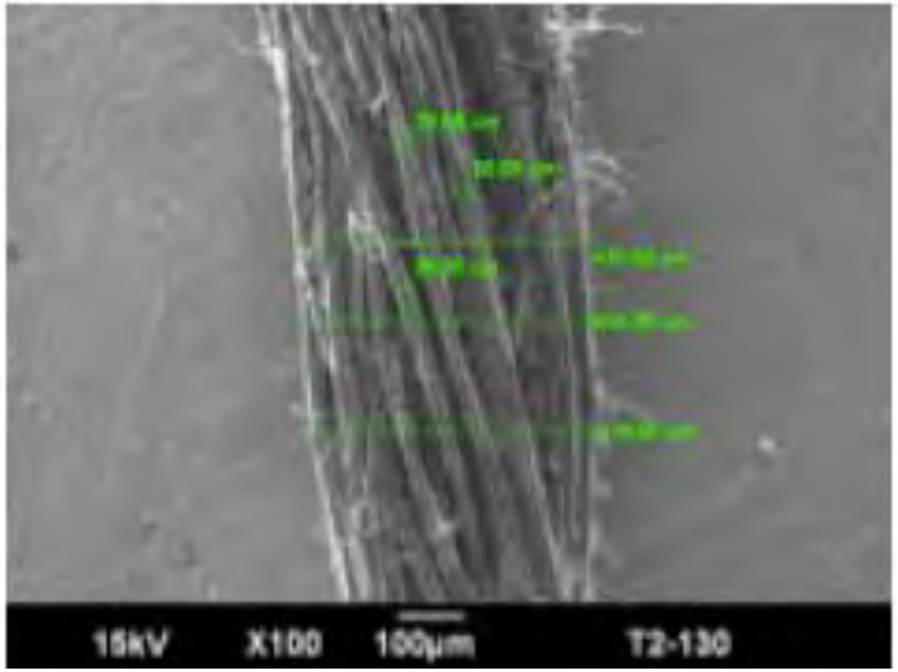


Image of CNT yarn being developed for wiring **Image of CNT yarn being developed for wiring**

Sensors and Actuators

Nanochemsensor flown on the ISS

Nanotechnology-based sensor system in space, was capable of detecting trace amounts of nitrogen dioxide.

Compact trace gas sensor system comprised of a main nanoparticle-impregnated polymer sensor and an auxiliary CNT-based chemical sensor on the International Space Station (ISS). It is anticipated that such sensor systems can achieve sensitivity in the parts per billion level with precise selectivity through the use of appropriate chemical functionalization.

Engineered Materials and Structures: Damage tolerant systems

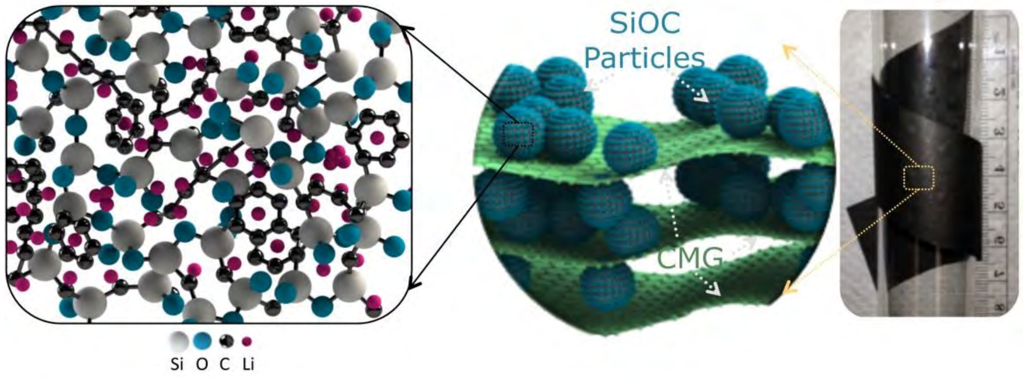
Schematic of nanostitching
from the Wardle laboratory.

In the laboratory of MIT Professor Brian L. Wardle, they are trying to make more durable materials through a technique called nanostitching.

- "The advanced materials currently used for many aerospace applications are composed of layers, or plies, of carbon fibers that in turn are held together with a polymer glue. But that glue can crack and otherwise result in the carbon-fiber plies coming apart."

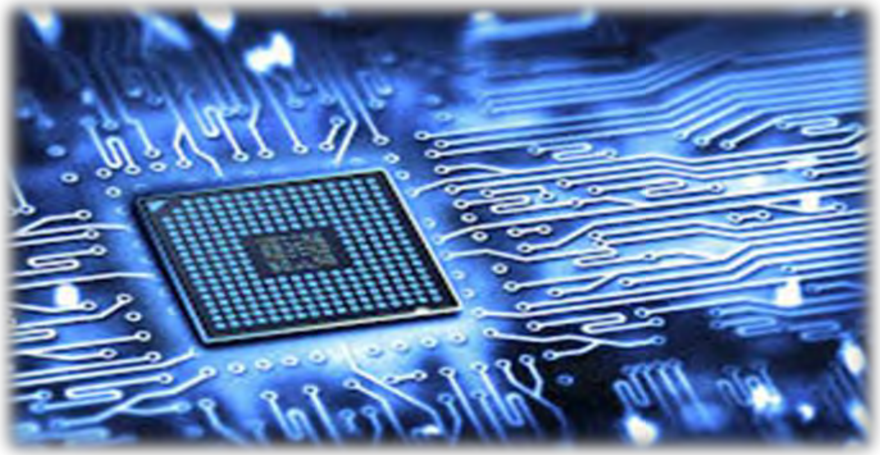
- To combat this problem, the Wardle group reinforces the glue with multiwalled carbon nanotubes that are grown parallel to each other. These nanotubes "bridge the crack" between layers of carbon fibers which results in composites that are 2.5-3 times tougher.

A paper like battery electrode developed by a Kansas State University engineer may improve tools for space exploration or unmanned aerial vehicles



- It is more than 10 percent lighter than other
- battery electrodes.
- It has close to 100 percent cycling efficiency for more than 1000 charge discharge cycles.
- It is made of low-cost materials that are byproducts of the silicone industry.
- It functins at temperatures as low as minus 15 degrees C, which gives it numerous aerial and space applicatons.

Miniature Instruments and Instrument Components



Nanotechnology in Space

- Nanotechnology may hold the key to making space flight more practical. Advancements in nanomaterials make lightweight solar sails and a cable for the space elevator possible.
- By significantly reducing the amount of rocket fuel required, these advances could lower the cost of reaching orbit and traveling in space.
- In addition, new materials combined with nanosensors and nanorobots could improve the performance of spaceships, spacesuits, and the equipment used to explore planets and moons, making nanotechnology an important part of the 'final frontier.'