16 Nanotechnology and its Applications

Observe well, the figure 16.1 given below.

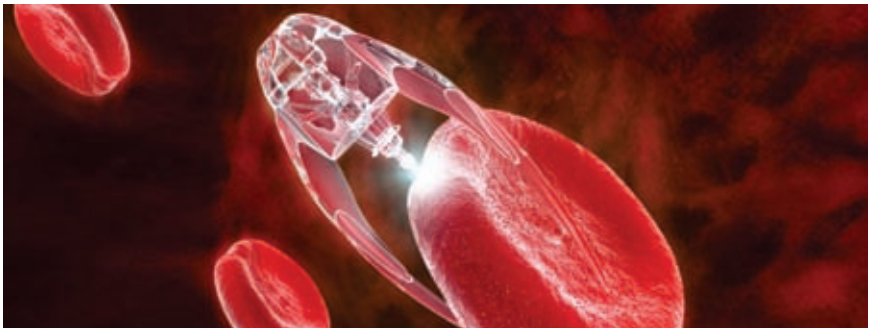


Figure 16.1 - How a red blood cell is being treated by a micro robot machine

In the above magnified figure, you observed how a human red blood cell is being treated by a micro robot machine. Machines which are dealing with such microscopic structures should be extremely small. How can such micro-machines be constructed? What is the technology used for this?

Science reached another important milestone in year 2016 with the award of the Nobel Prize in Chemistry to Jean-Pierre Sauvage, Sir J. Fraser Stoddart, and Bernard Feringa, three scientists whose groundbreaking work had spawned the idea of turning molecules into machines. Molecular Robots are not any more aliens to science.

Sir J. Fraser Stoddart Jean-Pierre Sauvage Bernard Feringa

Figure 16.2 - The scientists who won Nobel prize in Chemistry in year 2016

Now let us try to understand the science of tiny world which could do such miracles.

16.1 Nanometer

What is 'NANO'?

The word 'nano' is derived from Greek language, with the meaning dwarf. Therefore, nano refers to something very small. At this magic scale you'd not only see the atoms that everything is made from—you'd actually be able to move them around.

How small is 'NANO'?

It is a tiny world. It is quite hard to imagine a world that is small to see. We live on a scale of meters and kilometers. Nano means "billionth", so a nanometer is one billionth of a meter, i.e. 10^{-9} m.

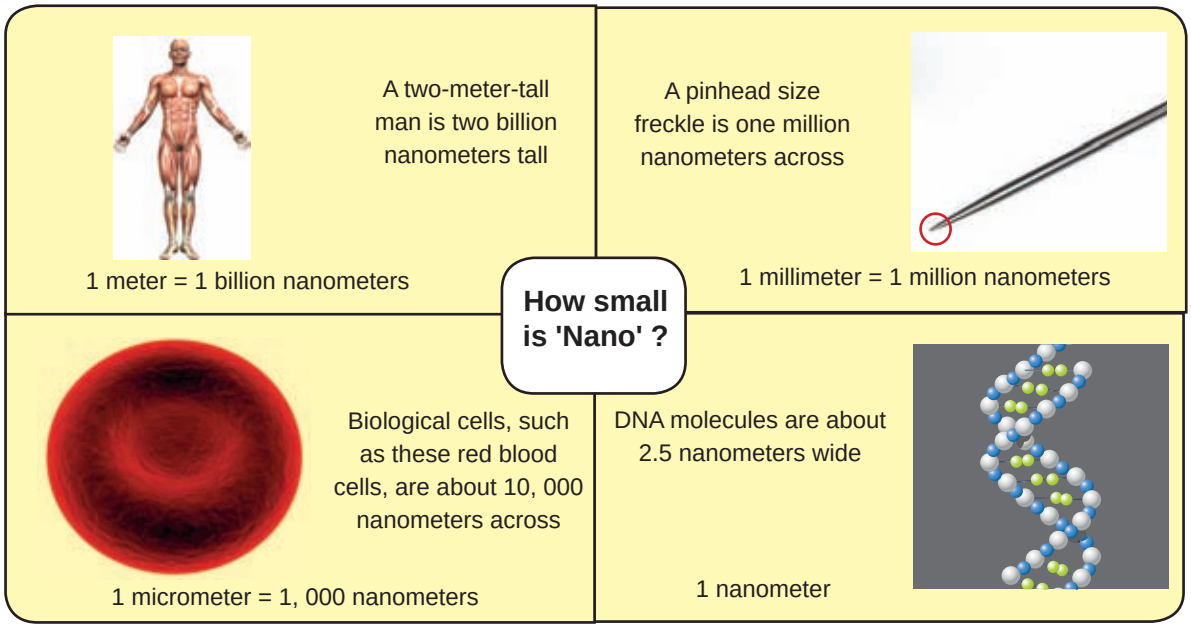


Figure 16.3 - Nano technology refers to inventions on the scale of small molecules or individual atoms

Individual atoms such as hydrogen, are only a few tenths of a nanometer in diameter.

For extra knowledge

Thickness of human hair is about 80 000 nm.

A paper has a thickness of about 100 000 nm.

16.2 Nanotechnology

Nanoscale science investigates the matter at the **critical range on 1 - 100 nm**. Making new things on this incredibly small scale is called nanotechnology and it's one of the most exciting and fast-moving areas of science and technology today. Nanotechnology is an enabling technology which has applications in a diverse areas from biology to aerospace.

History of nanotechnology

Nanoscience and technology are not new concepts to the nature. There are many natural phenomena based on nanotechnology. However, the American physicist Richard Feynman (1918–1988) is credited with kick-starting modern interest in nanotechnology. In 1959, in his after-dinner speech called "There's plenty of room at the bottom," Feynman speculated about an public speaking incredibly tiny world where people could use atoms and molecules as tools to make things. In 1974, Japanese engineering professor Norio Taniguchi named this field "**nanotechnology**."

Nanotechnology truly took off in the 1980s. That was when nanotech-evangelist Dr. K. Eric Drexler first published his groundbreaking book “Engines of Creation: The Coming Era of Nanotechnology”. Nanotechnology could not really took off until the electron microscopy became popular. It was also the decade when microscopes that were capable of manipulating atoms and molecules on the nanoscale were discovered.

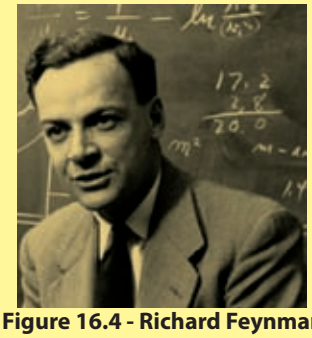


Figure 16.4 - Richard Feynman

There's plenty of room at the bottom - Richard Feynman

Likewise nanotechnology will, once it gets under way, depend on the tools we have then and our ability to use them, and not on the steps that got us there. - Eric Drexler

Figure 16.5 - Eric Drexler

Natural Nano-concepts

Nature has created things of nano scale. Let us do the activity 16.1 to get an idea of such things and their functioning.

Activity 16.1

You will need :- Untorn lotus or alocasia leaf

Method :-

- Put few drops of water on the leaf and observe.
- Record your observations.

Did you see that water droplets roll on the leaf without sticking and spreading on it? What can be the reason for this?

Fig. 16.6 - How water droplets are retained on a lotus/alocasia leaf

Lotus effect

The self cleansing activity of lotus leaves because of the hydrophobic condition on its surface is known as lotus effect. This hydrophobic nature on the lotus leaf is due to the fine arrangement of the particles of nano scale. Because of this, water, dirt and micro-organisms that fall on the leaf are automatically removed. Lotus effect can be seen on wings of insects like dragon flies.

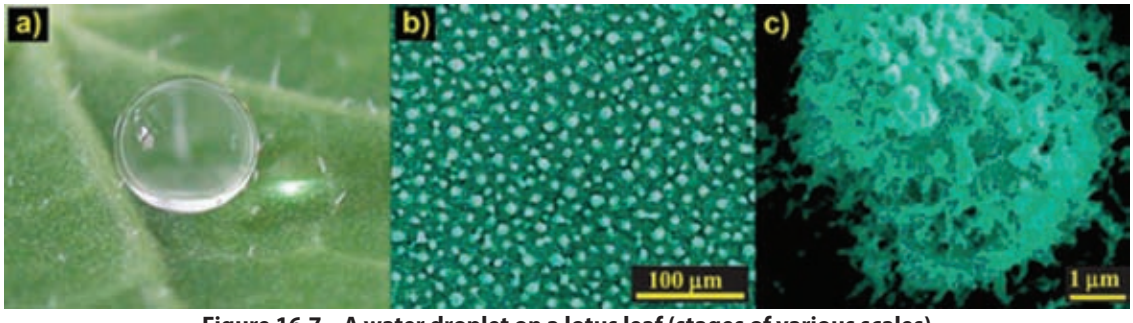


Figure 16.7 – A water droplet on a lotus leaf (stages of various scales)

Nature made nanomaterials

The best example is the functions taking place inside the cell, which is the structural and functional unit of living organisms (Remember the size of the cell is not at nano size). In a cell, a large number of nanoscale biological processes like respiration, excretion, nutrition, growth and photosynthesis are taking place continuously. Cell organelles, specially adopted for those biological functions can be considered as machines of nano scale.

Why 'Nano'? size matters!

Substances behave differently in the world of atoms and molecules. Both physical and chemical properties of matter substantially changes when the size reaches 100 nm or below although it is the same bulk material. For example, physical properties such as optical, mechanical, electrical and magnetic properties, change at the nano-scale while chemical reactivity significantly changes.

e.g.

- Metal copper is transparent on the nanoscale while gold, demonstrates a range of colours depending on the size and shape at the nanoscales.
- Chemically inert gold become highly reactive at the sizes below 100 nm.
- Carbon can be converted into resistance free conducting materials at nano-level.
- Strength of carbon nanomaterials could be several times higher than steel.

Figure 16.8 - Various colours are observed in gold nanoparticles when the size of particles are below 100 nm

Surface area of nano particles

The main reason for such changes in physical and chemical properties is the increase in the surface area (A) to volume (V) ratio (A/V) when the particles size decreases.

As an example let us consider a 1 cm length cube made of silver. The volume of the cube is 1 cm^3 and surface area will be 6 cm^2. This 6 cm^2 surface area is equal to the surface area of a stick of gum (chewing gum). But, if that volume of 1 cm^3 is filled with cubes of 1 mm length, that surface area of total cubes will be equal to the surface area of a single page in an exercise book. When the 1 cm^3 of volume is filled with 1 nm sized cubes, total cubes needed, have a surface area which is about one third of a football court. Nanoscale materials have far large surface areas than similar masses of large scale materials. As surface area per mass of a material increase, a greater amount of the material can come into contact with surrounding materials thus affecting reactivity (Figure 16.9).

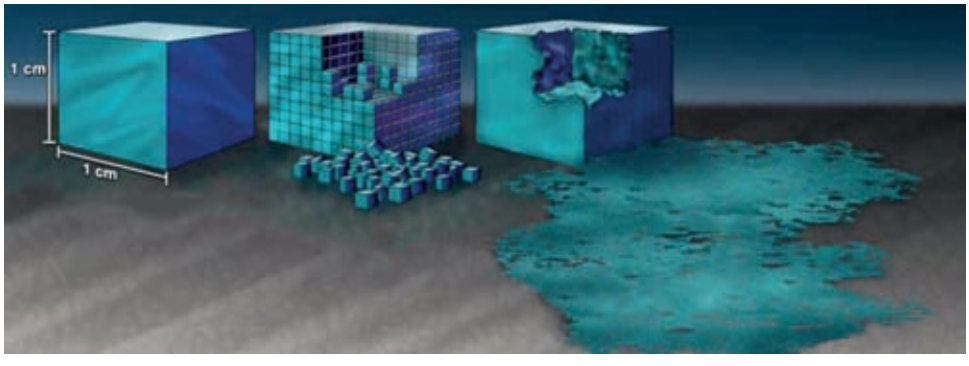


Figure 16.9

How to see the nano-scale?

Your fingers are millions of nanometers long, so it's no good trying to pick up atoms and molecules and move them around with your bare hands or see them using a common optical microscope. That would be like trying to eat your dinner with a fork 300 km long.

Scientists have developed electron microscopes that allow us to "see" things on the nanoscale and also manipulate them. They are;

- Atomic Force Microscopes (AFMs)
- Scanning Probe Microscopes (SPMs)
- Scanning Tunneling Microscopes (STMs)

Figure 16.10 - Electron Microscope

Figure 16.11 - Atomic Force Microscope

Nanomaterials

Key to developments related to nanotechnology innovations, are based on the availability of nanomaterials.

Carbon based nanomaterials

Out of the many available nanostructures, carbon based nanostructures are among the most exciting of nanomaterials. They can be rod shape, a foot ball shape or thin sheets.

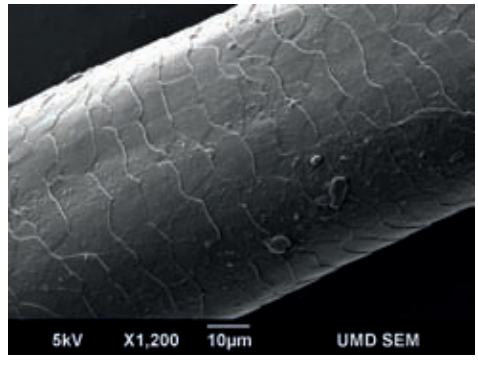


Figure 16.12 - Image of human hair under electron microscope

Forms of Carbon

Carbon exists as two distinct polymorphs, carbon graphite and carbon diamonds.

Activity 16.2

- Collect the information about carbon, graphite and diamond. Discuss them in classroom.

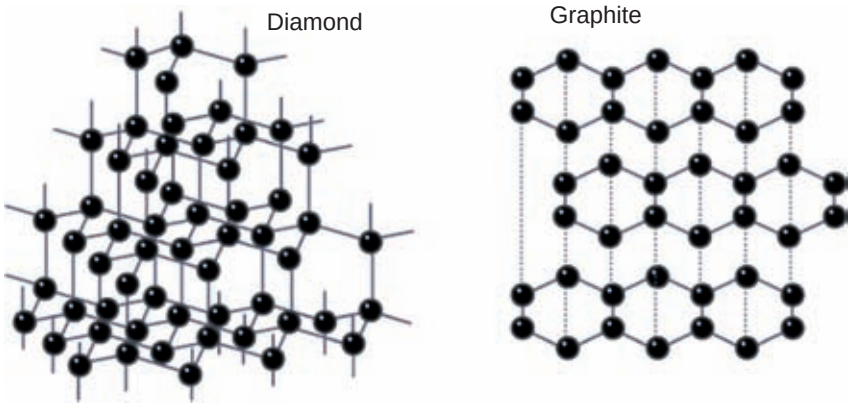


Figure 16.13 - Structures of diamond and graphite

Graphene

Figure 16.14 - Two scientists, Andre Geim and Konstantin Novoselov

Graphite has a layered structure and scientists have attempted to separate a single layer from the structure for several decades. It was one of the significant achievement of science when single layer of graphite was pealed off by two scientists, Andre Geim and Konstantin Novoselov from University of Manchester. They received the Nobel prize for physics in 2011 for this ground breaking innovation. It was a serendipity event in the history where they needed only a scotch tape and a piece of graphite for this innovation.

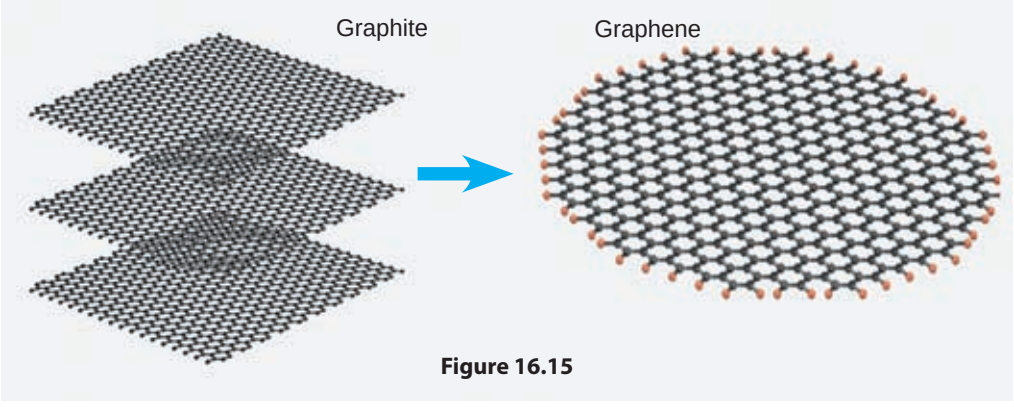


Figure 16.15

Graphene is a single layer thick graphite sheet (0.5 nm thickness) and has unique properties due to high surface area (figure 16.15). It is highly flexible while demonstrating very high mechanical properties. It also shows unexpected electronic and electrical properties. It is considered as the material that has the potential for revolutionizing the next generation flexible electronics.

Carbon Nanotube

A nanotube is formed when a single layer or few layers of graphene is rolled into a tube. When a single layer is rolled it is known as Single Wall Carbon Nano Tube (SWCNT) while few layers rolling into a tube leads to formation of Multi Wall Carbon Nano Tube (MWCNT).

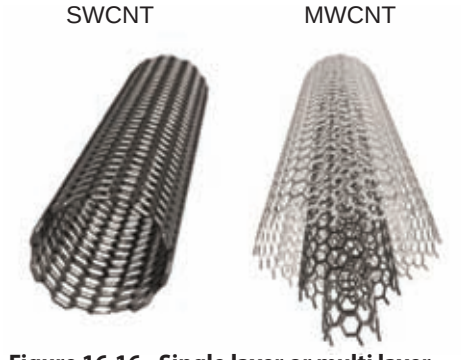


Figure 16.16 - Single layer or multi layer nanotubes

For extra knowledge

One of the worlds best graphite deposits is found in Bogala and Kahatagaha, Sri Lanka. Sri Lanka exports large tonnage of graphite without any further value addition at a very cheaper price. The price of graphene is $ 100 per gram while the price of carbon nanotube varies from $ 25 -100 in the global market.

Fullerene

One of the other forms of nano carbon is fullerene. Fullerene is a molecule which consists of about 60 carbon atoms arranged in a shape of a football. Its diameter is about 1 nm.

Let us engage in activity 16.4 to make a model of fullerene.

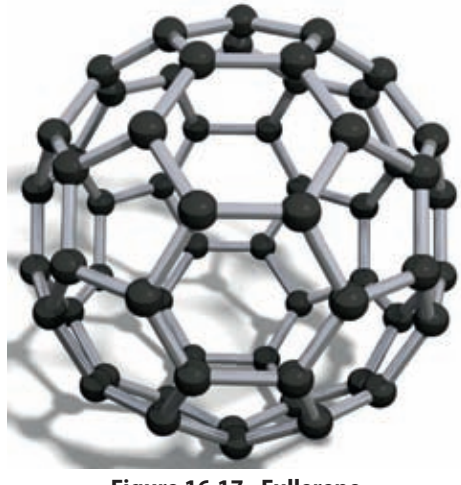


Figure 16.17 - Fullerene

Activity 16.4

You will need :- Bristol board, glue, a pair of scissors

Method :-

- Take a photocopy of the picture in figure 16.18. Paste it on a bristol board and cut the block.
- Join the letters together A-A, B-B, C-C and D-D, using glue on the foil-out tabs.
- You wiil end up having a ring and 2 caps.
- Stick the five flaps of each cap onto the 5 hexagon edges of the ring.
- Repeat on the other side.

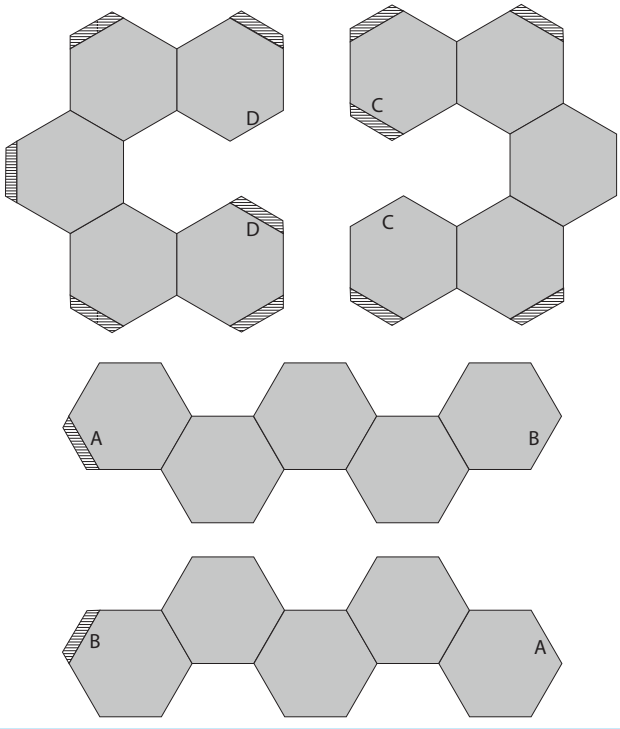


Figure 16.18

Active carbon with pores of nanoscale

Active carbon is processed using charcoal, coconut shell coal, coal, peat etc. as raw materials. The specialty of active carbon is, the presence of nanoscale pores. These pores of nanoscale in active carbon provide a large surface area. One gram of active carbon has a surface area in excess of 3 000 m^2. The pores in active carbon has high adsorption capacity.

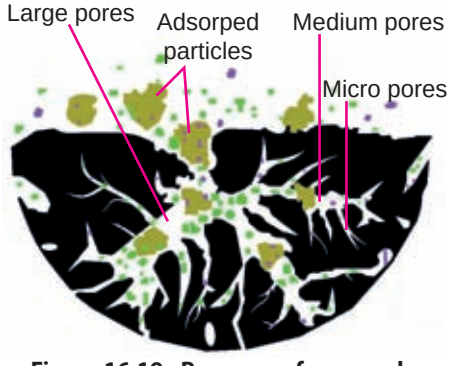


Figure 16.19 - Presence of nanoscale pores in active carbon

Due to these high adsorption capacity, it is used to purify water. Nanotechnology is applied in various fields such as medicine, agriculture, electronics, polymers, cosmetics, food and textile.

16.3 Applications of nanotechnology

According to the researches carried out for a long time, there are expected as well as unexpected uses of nanotechnology. Nanotechnology has contributed towards a revolutionary development in the fields of security, communication, energy, food, medicine, transportation, agriculture, textile, polymers, cosmetics, electronic science etc. Few of them are described below.

Field of medicine

- Diagnostic tools are considered by using nanotechnology. Thus the therapeutic efficiency can be increased. Nanotechnology is being used to diagnose and treat ailments like atherosclerosis. One way of doing this is the introduction of nano particles which are similar to HDL, a type of favourable cholesterol, to remove lipid deposits in blood vessels.

Figure 16.20 - Nanorobots with diagnostic and therapeutic ability used to treat ailments

- Clinical methods to treat directly to cancer cells, without damaging healthy tissues, is being developed using nanotechnology.
- Treatment to replenish bone tissues and nerve tissues are being developed using nanotechnology.
- Nanotechnology is used to inject drugs without using injection needles and also to introduce common vaccines for frequent diseases like common cold.
- Nanoparticles are introduced to skin ointments which are used to protect skin from harmful solar radiation, to increase their quality.
- Nanotechnology is used to detect the amount of sugar and cholesterol in blood.

Field of transport

- Very light and fuel economic motor vehicles, air crafts, boats and space crafts can be manufactured using nanotechnology.
- Nanotechnology is used in the industry of motor vehicles. Items like heavy duty rechargeable batteries, heat controllable electronic devices, wear-resistant tires, thin solar panels and very efficient and cheap sensors are some vehicle parts manufactured using nanotechnology.

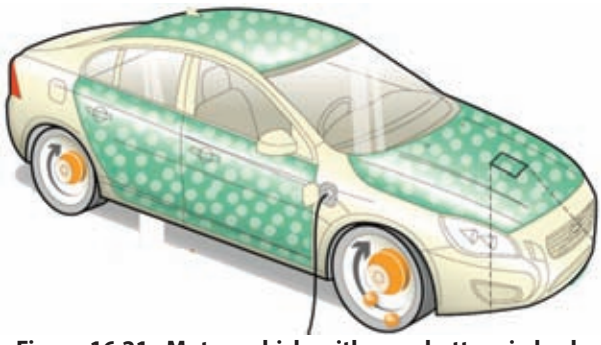


Figure 16.21 - Motor vehicle with nanobattery in body panels

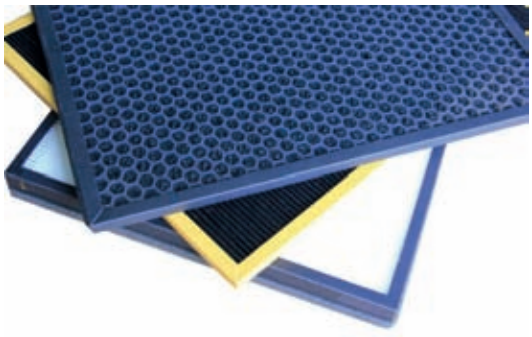


Figure 16.22 - Nanotechnology used in air filters in motor vehicles

Power generation

- Cellulose in saw dust, corn stem and grass can be converted to ethanol, which can be used as a fuel, with the help of enzymes produced by nanotechnology.
- Resistance and tension can be minimized by using wire codes which are made of carbon nanotubes to transmit electricity.
- Nanotechnology is used to manufacture efficient and inexpensive solar panels. Future solar panels may be flexible and are printable (paintable) like papers.
- Very thin solar panels can be made using nanotechnology to stick on computer covers and cloths. They can generate electricity using light, friction and body heat.

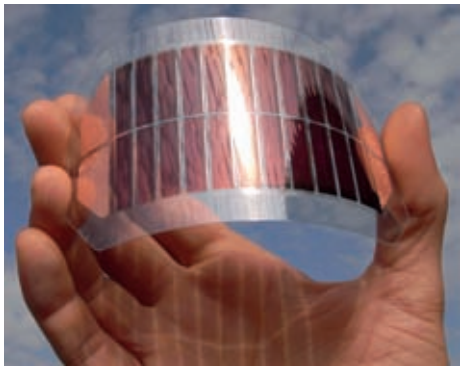


Figure 16.23 - Flexible solar panel

Electronic science

- Minute and speedy transistors in computers can be manufactured using nanotechnology. The size of an ordinary transistor is 130 nm – 250 nm. This size decreased down to 14 nm by 2014 and further decreased to 7 nm by 2015.
- Flexible, foldable, windable, stretchable and washable electronic components which are powered by solar energy can be made using nanotechnology. Therefore, it is possible to manufacture very thin, light, unbreakable, durable and smart electronic equipment.

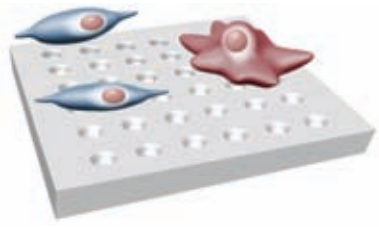
- Nanotechnology is used to manufacture memory chips, audio equipment, keyboards with antibacterial covers and mobile phone covers.

Flexible smart phone | Mobile phone covers | Memory chips

Figure 16.24

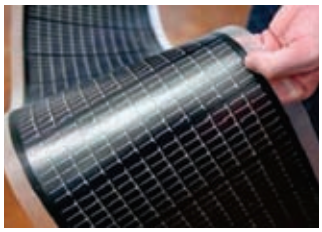
Producing consumer goods

- Eye spectacles, computer and television screen, door and window glasses made of nanotechnology are resistant to ultraviolet and infrared radiations. They do not retain water or micro-organisms and have the ability of auto cleaning.
- Nanopolymers are used to manufacture very light, hard and durable sports items, head gear, bicycles, vehicle spare parts and weapons.
- Household items like high quality detergents and bleaching agents, air filters, water filters, antiseptics, stain and dirt resistant paints can be manufactured using nanotechnology.
- Wearing off and cracking of machine parts can be minimized and life time of them can be considerably increased by using nanostructured ceramic coatings and lubricants made using nanotechnology.
- Textiles and cloths which are resistant to dust, dirt and oil particles are manufactured.
- Nanotechnology can be used in water purification plants to purify water economically and efficiently. Very thin filter membranes are used for this purpose.
- Air filters with pores of nanoscale are used to filter dust and micro-organisms in places like cockpits of air planes.
- Products like aluminum, steel, tar, concrete and cement which are durable, flexible and have a fine finish are manufactured using nanotechnology.



A surface with nanoplating

Piece of glass with nanotechnology



Keyboards with antibacterial covers

Figure 16.25

Assignment 16.1

Collect information on nanotechnology using books, media and internet. Present the information, thus collected, creatively as a booklet.

16.4 Future condition that may arise because of nanotechnology

As in any technical application, nanotechnology also may have adverse effects. These ill-effects may increase with the progress and usage of nanotechnology. Some such effects are mentioned below.

- Air, water and soil can be polluted by releasing particles of nanoscale, which are used in nanotechnology, to the environment. This is known as nano pollution.
- Health problems can arise because of the collection of nanoparticles in human and animal bodies.
- Calamitous situations in the society may increase because of the abundance of nanoscale equipment.
- Severe disasters can occur because of the production of chemical and biological armaments of nanoscale.

Figure 16.26 - Imaginary nano armaments

Various precautionary measures can be suggested to minimize the ill effects of nanotechnology.

- Release of nanoscale air pollutants with effluent smoke can be filtered using nanofilters.

- Natural pollutants like arsenic can be removed from the environment by using nanoscale particles.
- Unfavourable gases can be removed by using nanosensors which are sensitive to those gases.
- Judicial security can be provided by imposing new legislations to prevent ill uses of nanotechnology.

Further information on nanotechnology and applications can be obtained from Sri Lanka Institute of Nanotechnology. The address of this institute is Mahenwatta, Pitipana, Homagama.

Telephone – 011 4 650 500

Figure 16.27 - Sri Lanka Institute of Nanotechnology

Summary

- One billionth of a meter is the nanometer (nm).
- Manufacturing of materials and components using particles of nanoscale and their usage in known as nanotechnology.
- The best natural nanosystem is the cell, which is the structural and functional unit of organisms.
- The self cleansing ability of lotus leaves because of the hydrophobic condition on its surface is known as lotus effect.
- Non-wettable clothes, self-cleansing glass, self-cleansing paints are some items produced using lotus effect.
- High standard productions are made in nanotechnology by positioning atoms appropriately.
- Nanotechnology has contributed to a revolutionary development in various fields.
- Misuse of nanotechnology can results in adverse effects.

Exercises

(01) Select the correct or most suitable answer.

1. A nanometer is considered as;

   1. 10^{-3} m 2. 10^{-6} m 3. 10^{-9} m 4. 10^{-12} m

2. What are the instances below, that lotus effect is in action?

   a - Water does not retain on lotus leaves.
   b - Water does not retain on insect wings.
   c - Dirt does not retain on surfaces painted with self cleaning paints.

   1. a only 2. a and b only
   3. a and c only 4. a, b and c all

3. The particles that are used in nanotechnology are;

   1. The particles of 1 nm scale.
   2. The particles of 1 nm to 10 nm scale.
   3. The particles of 1 nm to 100 nm scale.
   4. The particles of 1 nm to 1000 nm scale.

4. Who put forward the idea of nanotechnology to the world?

   1. Eric Dexler 2. Albert Einstein
   3. Francis Bacon 4. Richard Faynman

5. Which of the following, is not considered as a measure to be taken to minimize the ill-effects caused by nanotechnology?

   1. Limiting the use of nanotechnology.
   2. Minimizing the spreading of nanoparticles using nanofilters
   3. Acting against production of nano armaments
   4. Testing the amount of nanoparticles in air using nanosensors.

(02) Fill in the blanks.

1. Nanometer is ..... of a meter.
2. What is the term used to describe the auto cleansing ability caused by the presence of hydrophobic nature on a lotus leaf ? .....
3. Mention two fields where nanotechnology is used .....
4. Name two products in day-to-day life that are made using nanotechnology. .....
5. Mention two obstacles that come across, when a country is to use nanotechnology .....

(03) Outbreak of nanotechnology is considered as the fifth industrial revolution. This technology is not fully used up to date.

1. Identify what nanotechnology is.
2. Who introduced nanotechnology to the world?
3. Name two natural nanosystems found in the environment.
4. Describe lotus effect.
5. Name two products made, using lotus effect.
6. What is the element mainly used for nanotechnology activities?

Technical Terms

Nanometer	-	නැනෝමීටරය	-	நனோ மீற்றர்
Nanotechnology	-	නැනෝ තාක්ෂණය	-	நனோ தொழில்நுட்பம்
Nanoparticle	-	නැනෝ අංශු	-	நனோ துணிக்கைகள்
Lotus effect	-	ලෝටස් ආචරණය	-	லோட்டஸ் விளைவு
Activated carbon	-	සක්‍රීය කාබන්	-	தொழிற்படும் காபன்
Fullerene	-	ෆුලරීන්	-	புளரீன்
Graphene	-	ග්‍රැෆීන්	-	கிரபீன்