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Nanoscience and its applications

... think scientifically, act scientifically... think scientifically, act scientifically... think scientifically, act...

Nanoscience and its applications

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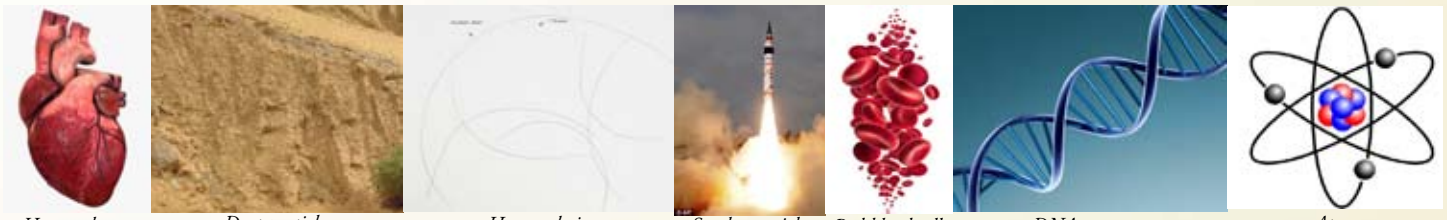
In our day-to-day life, the unit for measurement of length is the metre. We use kilogram as the unit for measurement of mass while for measuring time, second is used. This is known as 'metre, kilogram, second' or MKS system. But if the distance or size involved is too small then we use units much smaller than a metre. Nanometre is a unit of this kind. Very small length is measured in nanometre, miniscule mass is measured in nanogram and extremely small time is measured in nanoseconds. One nanometre is a billionth of a metre. In metric system, it is written as 10^{-9} m. Its minuteness may be gauged from the fact that if ten atoms of hydrogen are laid side by side then together they will constitute a length of one nanometre. One thousandth of a metre is one millimetre (1 mm = 1m/1000) and one thousandth of a millimetre is one micrometre (1µm = 1 mm/1000). The chips used in computers are fabricated on this scale. One thousandth of a micrometre is one nanometre (1nm = 1µ/1000). The science related to 'nano' is called nanoscience.

A nanometre can span about 5 to 6 carbon atoms. A DNA molecule is about 2.2-2.6 nanometres in size, and a red blood cell has a size of 6,000 – 8,000 nanometres; whereas a human hair has a thickness of around 80,000 nanometres or 80 microns.

Is nano indeed a new concept?

Nanoscience is now pervading almost every field of our day-to-day life and day-by-day it is expanding in its scope. However, this field of science based on the measurement, study and application of minuteness is not entirely new. In terms of its application, it is very old. Nevertheless, only research and development carried out during recent years has opened up new vistas in the study of this science. The credit for the very first application of nanoscience goes to Rome. The multi-coloured glass cups made in Rome in fourth century, called Lycurgus cups, look very attractive even today. Gold and silver nanoparticles were used to colour the transparent glass for making of these cups. These cups appear green in reflected light during the daylight due to the presence of nanoparticles. However, when light is transmitted through the glass, the cups appear red.



Lycurgus cup

As another ancient application of nanoscience, mention may be made of soot (*kajal*). The use of soot for decorating the eye has been in vogue since ancient times. In villages or rural areas people use traditional method for making soot. They take an earthen lamp (*diya*) containing mustard oil or pure ghee with a wick of cotton wool. When a cold metal plate is kept over the earthen lamp touching the flame, fine particles of unburnt carbon are deposited as soot, a part of which is known to be made up of carbon nanoparticles.

The famous Samurai swords of Japan belonging to medieval period present yet another example of nanotechnology. These Samurai swords had a special significance in ancient Japanese warfare. The 'Forge and fold' technique was used for fabrication of these swords, which were known for their sharpness and strength. The technique involves beating the steel when it is red hot. The beaten steel is then folded. After several repetitions the thickness of the steel surface

Japanese Samurai sword

Gold thread work on Banarasi saree

or the sword blade becomes extremely thin (about 50 nm) which consequently is endowed with great strength. Analysis has shown that the extreme strength of Samurai swords comes from the presence of carbon nanotubes in the steel.

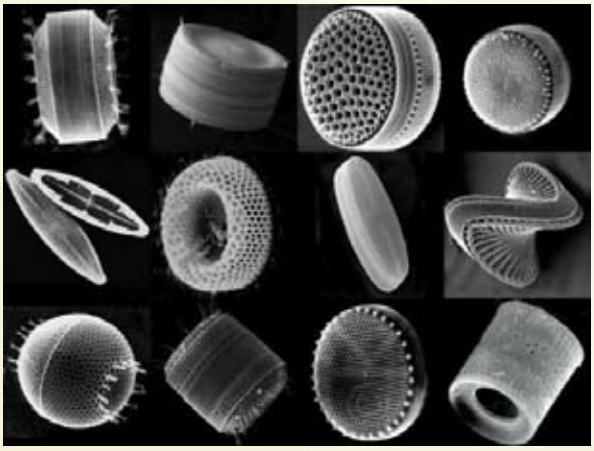
Another promising example of nanotechnology is offered by the traditional sarees of Benaras which have a history dating back a few centuries. As we all know, thread made of gold is used in the making of these sarees. Of all materials on Earth, gold has the maximum ductility. So, just 1 gram of gold can be drawn into about 2-kilometres of thin gold wire. The thickness of these gold threads is about five microns or 5,000 nm. Benaras sarees get their pretty and fabulous look because of the use of these gold wires.

Although today we know about these age-old applications of nanotechnology, the people who used these materials did not have any idea of their true nature or scientific significance. We have started getting scientifically acquainted with the world of nano only recently. We have only been seized of the scientific aspects of nanotechnology in the wake of research and scientific developments that have taken place in recent years.

Examples of nanostructures in nature

Thus far we got familiarised with examples of man-made nano products. However, many unique examples of nano are also found in nature. Mention may be made of a tiny single-celled marine organism called *Emiliania huxleyi* having a shell with a diameter of about 2.5 microns, or 2,500 nm, which is made up of calcium carbonate (calcite) crystals. It has pores and designs of nano size which constitute its unique characteristics. Inspired by these designs and structures, nanocrystals of calcium carbonate were developed artificially in the laboratory. However, these lab-grown crystals were very different from the natural nanocrystals of calcium carbonate. Another example is that of unicellular sea creatures, called diatoms. Their specialty is that they have porous shells made of silicon oxide. These pores may be of nanometre size.

It may be pertinent to refer to the very fine structure of bones as an apt example of nanostructure. Bones are primarily made of hydroxyapatite, which made up of a group of minerals. Pores of nano-size may be seen in the fine minute structure of bones. Due to these pores, bones are spongy inside, which reduces their weight drastically. These structures, which have come into existence after a billion of years of bio-evolution and adaptation are unique examples of nature's artistry.

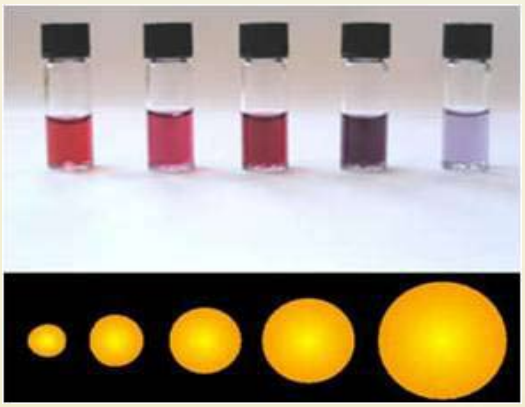


Diatoms

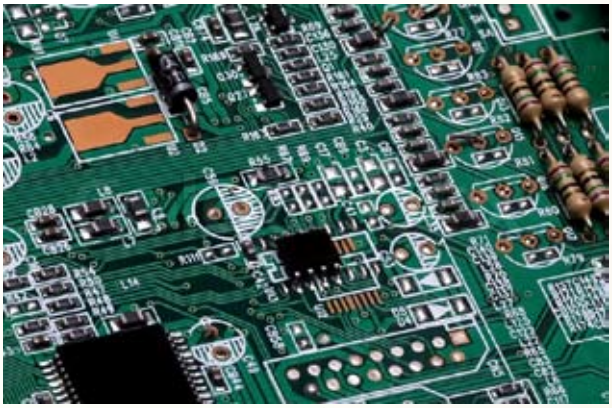
Properties of matter at nanoscale

There are myriad reasons behind possibilities of the technological applications of nanotechnology. This is because the basic properties of matter undergo sea change at the nano-level. At the nanoscale, remarkable changes are seen in the colour, reactivity, electrical properties, etc., of matter. As these changes are different from the basic properties, they can be used under controlled conditions for development of seemingly unusual applications. These properties of nanomaterials have many unique applications. For instance, turning a opaque material into transparent material (copper); an inert material into a highly reactive material that can be used as a catalyst (platinum, gold); an incombustible material into a combustible material (aluminium); a solid material at normal temperature into a fluid (gold); an insulating material into a conductor (silicon); and many others. The example of colloidal solution of gold may also be given. The normal colour of gold particles is yellow but a colloidal solution of nano-sized gold particles may appear red in colour.

In 1857, Michael Faraday prepared a colloidal solution of gold. This solution comprising nanoparticles of gold was different in many ways. This suspension of gold nanoparticles in solution was totally transparent in some lighting, but in other lighting conditions could produce differently coloured solutions of 'ruby, green, violet or blue'. The most unique characteristic property of this solution is that after passage of so many years it has remained unchanged. This way Faraday proved that it is possible to make permanent colloidal solutions using nanoparticles. In the same vein, by bringing down copper to nanoscale its ductility at room temperature is increased so much that wires with length fifty times as much compared to normal copper can be drawn. At nanoscale, zinc oxide, which is white, becomes transparent; and aluminium when brought to the nanoscale ignites spontaneously. Platinum is chemically a very inert element, but in finely divided nanoparticle form it becomes extremely reactive.



Gold solutions of different nanosizes. The difference in the size is the cause of difference in colour



Integrated circuit

Commercial nanomaterials

At present, most of the commercial applications of nanoparticles refer to elements like titanium, silver, etc. These include use of titanium dioxide nanoparticles in cosmetics, use of silver nanoparticles in packaging of food products, use of zinc oxide nanoparticles in textiles, germicides, domestic appliances and cosmetic products, and use of cerium oxide nanoparticles in paints and varnishes for furniture.

The titanium particles present in high quality paint and thermal spray coatings are actually nanoparticles. In the same vein, decorative shapes in glass and ceramic tiles and sanitary products are made up of nanoparticles. Advanced catalysts obtained through nanotechnology are being used in chemical and related industries. The catalysts that are used these days in catalytic converters of vehicles to mitigate pollution are actually nanostructured. Thinking is also going on in the direction of increasing the efficiency of fuel by dissolving nanoliquids in the fuel of automobiles. As initial step in this direction, scientists have used aluminium nanoparticles. Attempts are being made to develop brake fluids made of nanoliquids in place of brake oil. On the basis of preliminary investigations, copper oxide and aluminium oxide nanofluids have been used which have produced good experimental results. Nanoporous materials (zeolites) are being used in the purification of crude oil.

One aspect of nanoscience also encapsulates modern technology. The current age is also known as the 'silicon age'. We are able to witness information revolution through silicon. Silicon is a semiconductor the application of which is seen in all electronic circuits. At present, a single silicon chip contains about a million silicon devices and the size of each of these devices is about 500 nm. It is hoped that in the next two decades this size will be reduced to 1-10 nm. The increase in the computational abilities of computers was achieved by using greater and greater numbers of transistors in an integrated circuit (IC). These days, transistors measuring 200-300 nm can be found in state-of-the-art ICs. In future, computer chips will be made of graphene instead of silicon. This will increase the computational speed of the computers and also reduce their size. Scientists are considering using optical fibres combined with graphene photodetectors to increase the internet speed by up to 100 times. It has been found that when graphene is incorporated into nanostructure made of noble metals it can convert light energy into electrical energy with almost 20 per cent efficiency.

Applications of nanotechnology in the field of energy

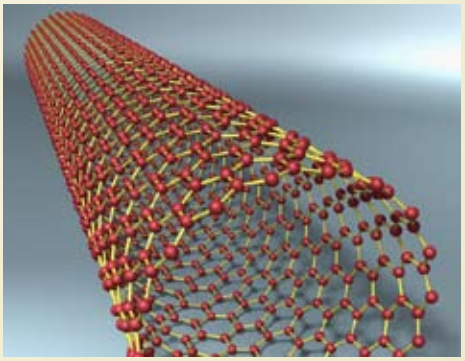
Keeping in view the global energy crisis, nanoparticles of lanthanum, cerium, strontium and manganese are being used in many solid oxide fuel cells. In fuel cells, platinum, which is a very expensive material, is used as a catalyst. Platinum in large quantity is chemically inert, but in nano powder form it becomes reactive. Companies are using platinum nanoparticles with a view to reducing the quantity of this expensive material used without reducing the reactive surface area. Nanoparticles of lithium titanate and tantalum are being used in lithium-ion batteries to produce much advanced next generation batteries.

Nanotechnology has many potential applications in the field of agriculture. For slow absorption of water and fertilisers by plants and for providing sufficient nutrients to plants, zeolites with nanopores can be used. Groundwater has been very heavily polluted due to the rapid industrialisation, use of pesticides in the agriculture, and presence of nitrates, and heavy metals like lead, etc. Recent research has shown that iron nanoparticles can be used for purification of groundwater. Using nanotechnology it will be possible to develop materials in the fabrication of which no waste products will be formed. This will help mitigate environmental pollution.

Research in the field of nanotechnology is being used for making light-weight uniform for the military. It will be possible to endow this uniform with the specialty of changing colour according to the surroundings. In addition, the use of zinc and silver nanoparticles in soaps, textiles and polymers such as plastics, can enhance their quality manifold. The same nanoparticles can be used in anti-microbial, anti-bacterial, antibiotic, and anti-fungal creams. In this way, articles and products of day-to-day use can be made more useful and efficacious.

Applications in the field of medicine

In the field of medicine and biotechnology too, nanotechnology is helping in the diagnosis of many ailments which was not possible earlier. For instance, using nanocrystals of calcium phosphate, material resembling artificial bone has been developed which has a quality similar to natural bone. Attempts are already going on for the diagnosis and treatment of cancer using nanoparticles. Nano drug-delivery system is being used for which nano-gel and gold plated nanoparticles are employed. These nanoparticles carry different types of biological markers and medicines so that they can straightaway reach the cancerous cells



Carbon nanotube

and destroy the ailing cells while keeping the healthy cells intact.

Nanoscientists have also been successful in creating fluorescent nanoparticles which glow during diagnostic procedure such as MRI/CT scan. This helps in finding the exact location of cancer in the body. In future, nanomaterial will be used as oxygen carrier like haemoglobin. Nanorobots, called

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labeled as "sugar free", "sugar less", "no added sugars", etc., maybe misleading, as it only means sucrose is not added to the product. But food ingredients containing sugar include not just sucrose but other names also like "high fructose corn syrup", "invert sugar", "glucose", "dextrose", "maltodextrin", "honey", "molasses", and "lactose", which are commonly used types of sugar in processed foods and have a cariogenic effect too. It is better to avoid foods with high sugar content.

18. The practice of concluding meals with foods that do not promote tooth decay like raw salads, fresh fibrous fruits instead of sweets and rich desserts may help in preventing tooth and gum problems.
19. Chewing gum sweetened with artificial sweetener xylitol actually promotes dental health. Therefore, one must replace regular chewing gum with chewing gum containing xylitol.

Studies have shown a link between gum diseases and heart disease along with other systemic disorders because bleeding gums are likely to serve as an entry port for bacteria and viruses. Women with dental and gum problems are more likely to give birth to premature babies. Since, oral health is linked with other serious disorders, one must adopt healthy eating habits and lifestyle practices to ward off other diseases as well. A healthy well-balanced diet consisting of fresh fruits and vegetables, milk and milk products, pulses, beans and legumes, whole grains, meat, fish and poultry ensures good oral health. Maintaining good oral hygiene by regular brushing of teeth, using fluoride toothpaste or mouthwash, drinking fluoridated water and regular visits to a dentist for removal of dental plaque and any needed repairs keep the teeth and gums healthy and long lasting.

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nanobots, are also being used in the field of medicine. These nanobots are extremely minuscule robots, made up of carbon nanotubes, which have dimensions of 1-100 nm. These nanorobots can easily be made to enter the bloodstream and free the body of pathogens without the aid of antibodies.

In industry, nanoscopic filtration membranes are being used. On a large scale, this is used in the purification of water and air and in various industrial processes which include purification of drugs and enzymes, separation of oil from water and waste removal. In particular, nanotechnology is capable of removing any kind of pollutants from water. Filters made out of nanofibres can be used to remove viruses and other pollutants from water. For removing metal ions, there is plan to develop dendrimer-aided ultrafiltration as a marvellous process of water purification. (Dendrimers are highly branched, star-shaped macromolecules with nanometre-scale dimensions.)

From the aforesaid we can clearly see that the reach of nanoscience and nanotechnology in our life is increasing day-by-day. With their use, myriad devices and methods are likely to be developed in future which on the whole will prove to be very useful for the betterment of human life.

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(Translation: Abhas Mukherjee) ■