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EDITORIAL

THERE'S PLENTY OF HOLES AT THE BOTTOM: THE OTHER SIDE OF 'nano'

"There's plenty of rooms at the bottom" was the title of the talk delivered by Richard P Feynman, Nobel Laureate physicist, about fifty years ago (on December 29, 1959) in the meeting of the American Physical Society at the California Institute of Technology. He introduced the subject of the talk saying "I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, "What are the strange particles?") but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications", long before the nanotechnology was imagined. Feynman did not christen any name for the subject. It is an MIT biologist Drexel who coined the name 'nanoscience' in the eighties ('nano' in Greek means dwarf).

Laws of physics do not prevent us from arranging atoms the way we want to, as Feynman professed. Feynman not only talked of many possibilities with very small atomic size objects but also talked about methods how to tackle such small scale situations. Many of the Feynman's possibilities are now reality. The wonders nanotechnology can do sound like science fiction and were discussed at various levels. What were not much discussed are the potential dangers and hazards it may bring in environment, privacy, economics or in general to the society. The countries where nanotechnology is pursuing in a big way, like in USA, Europe, Canada, Japan are seriously concerned about its societal and ethical issues. It is only very recently that India started paying attention to this subject. The purpose of this note is to discuss some of those issues.

What were not much discussed are the potential dangers and hazards it may bring in environment, privacy, economics or in general to the society. The countries where nanotechnology is pursuing in a big way, like in USA, Europe, Canada, Japan are seriously concerned about its societal and ethical issues. It is only very recently that India started paying attention to this subject.

Nanoscale science and technology is referred to science and engineering carried out at a nanometer scale i.e. a scale of 10^{-9} m. The size of an atom is about 10^{-10}m and therefore nanoscience and nanotechnology, in principle, works at the atomic and molecular level. Anything in the size range less than 100nm falls under the general area of nanoscience and nanotechnology. When one talks in an atomic scale i.e. working atom by atom, it is obvious that the distinction between different branches of science collapses. At this scale principles of physics, chemistry, biology, materials

science and engineering tend to converge and therefore have a far-reaching impact. The nanoscale is not just another step toward miniaturization, but at this scale, we expect new features dominated by quantum mechanics. These quantum effects fundamentally alter the optical, electrical and magnetic behaviour of materials and exposes entirely new fundamental areas scientists love to explore. To the technologists, this area is challenging to innovate how to handle such small scale situations.

Another important property is the large surface to volume ratio. In a 30 nm particle five percent of the atoms are on the surface, while in a 3 nm particle 50 percent of the atoms are on the surface. The atoms on the surface are more aggressive to react than those at the centre and this makes nano particle based materials extremely chemically reactive.

Nanotechnology is a new kind of human activity but it is interesting to note that nature is quite adept in handling nano-sized particles. Cells contain millions and millions of small structures which are being used to produce the larger structures. For example, the enzyme ATP synthase, which is of the size of about 10 nm produces ATP, is actually a tiny rotary motor attached to a nanoscale bar magnet made of nickel. Human mind is getting cue from the nature to build such structures. Nano particles exist in nature in the form of dust erupted in volcanic burst or in the form certain pollens. Gold and silver nano particles have been used in producing stained glass and ceramics as old as in 10th century A.D. In recent history, carbon nano particles (carbon black) were used as pigment in crayons, first introduced by Binney and Smith Co., New York, USA in 1903.

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Properties of a material depend on how the atoms are arranged in the material. By rearranging the arrangement of atoms in a material one can produce material with entirely different kind of characteristics. Coal, graphite and diamond are all basically made of carbon atoms, but they belong to different properties because the arrangements of carbon atoms are different in each material. It is easy to conceive that by rearranging the carbon atoms in the coal the same way as in diamond, we can get diamond, rearranging the atoms in sand and we can get computer chips. People say jokingly 'rearrange the atoms in dirt, water and air and you can get potatoes'. So nanotechnology talks about engineering done in atoms by atoms. Therefore if the arrangement of atoms or molecules could be done precisely the right way and repetitively, nanotechnology is an inexpensive way to produce products the way we like. We can think of producing diamonds of any size, can think of producing material which is stronger than steel yet lighter than rubber, can think of computer hardware of molecular dimension, can think of surgical instruments which can operate at a precision at a molecular level.

But manipulating atoms to place them at exact position is not an easy job and can not be done by the tools that we ordinarily use in our macroworld. As said, it is like trying to make things using LEGO blocks with boxing gloves on your hands. With boxing gloves in hand, you can not really hold them together and assemble the way you would like. However, there are instruments available such as scanning tunneling microscope or atomic force microscope which can handle atom by atom. This type of approach in which structures are built up atom by atom is commonly known as 'bottom up' in the literature. Molecules can also arrange themselves into ordered structures by chemical synthesis or self assembly. Our own body is produced from self assembly from molecules of carbon, oxygen, hydrogen, nitrogen and a few metals. In 'top down' approach traditional engineering techniques are used in a very small scale and therefore products produced are very small. Computer chips are getting smaller and smaller but with more electronic components crammed into it, producing electronic products very thin and small in size.

Nanotechnologies have potentials to touch every aspect of our lives. Nano particles are being used in cosmetics (in sun screens) to have better penetration. Nanoparticles are now considered to be used as a medium of gene and drug delivery. Wound dressings with antimicrobial properties of nanocrystalline silver are available on the US market. Nanotubes fabricated recently have excellent mechanical, electrical, magnetic and optical properties. Nanotubes are 100 times stronger than steel, yet six times lighter than it. Nanotubes conduct heat and electricity much better than copper and are being used in polymers to introduce conductivity and in anti-static packaging. Application of nano particles to purify water

will be extremely useful tool for developing countries. Nanopolymers with embedded enzymes to detect and break down chemical and biological warfare agents are being developed which will be sprayed on the body of a soldier to produce a seamless suit. The nano-battlesuit is under development at Massachusetts Institute of Technology.

Although nanotechnology is still in its infancy because only a few preliminary nanostructures have been able to produce with control and repeatability, but with the increased research and technical developments it seems it will soon change dramatically of our perception of science and technology.

In spite of potential benefits of the nanoparticles, greatest fear is the possibility of damaging environment. We do not know yet whether nano particles and macroparticles behave similarly and if they behave differently, the chances of which are believed to be reasonable, we have to proceed with extreme caution when dealing with nano particles. Our knowledge about the effects of macro particles on people and environment may not be valid in estimating the effect due to nano particles. Nanoparticles will easily become airborne and spread through the atmosphere, or will contaminate environments. For example, if nano particles enter our lungs through breathing, we do not know what effect it may occur to our health. What we know is that they can be taken up by cells in the lung, triggering inflammation, but they can also get into the bloodstream, and transport of nanoparticles through nerve tissue to the brain. Nanoparticles have been found to get absorbed by livers of research animals and found to cause brain damage in fish exposed to them.

Increasingly popular carbon nanotubes resemble asbestos fibres, which are known to produce cancers in workers who breathed in an asbestos-laden atmosphere**.** As with nanoparticles, new research is needed on their possible effects, but again early signs are that they might pose a threat to health. More dangerously, as they are carbon-based they may get absorbed in the body without producing any usual alarm in the body when foreign particles enter, making them difficult to enter. Although very little is known about the fate of nanoparticles in the environment, or their impact on living systems, but some preliminary research suggests that carbon nanoparticles can harm fish. One difficulty in studying the effect of nano particles is the lack of measuring instruments to monitor. A recent survey to assess the perception of the benefit and danger of nanotechnology amongst the nanoscientists and public revealed that nanoscientists are more optimistic about its benefit than the public while public in general are more concerned about the perceived risks than nanoscientists except in two areas that nano particles can cause more pollution and new health problems.

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Ethical issues like 'who will benefit', 'who will lose', 'whether gains and losses are shared equally', 'whether benefit overpowers the harm', 'how technologies affect us as people and the society' always surfaced whenever any new technology starting from discovery of electricity to biotechnology appear. So there are enough (loop)holes at the bottom one has to investigate while developing nanotechnology. What we need is a debate between academics from all walks of life from science, social science, humanities, industry, and more importantly socially responsible public to plug the holes. Initiation has already started a few years back and now we have a journal called *Nanoethics* to address all such issues by scientists, sociologists, economists and others who want to contribute in this debate. Media and scientific organizations can also play an important role to set the stage for a scientist-public interaction to aware the public about the real threat without being left them to decide by a handful of ill-equipped information.

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In order to move ahead responsibly with this powerful technology (we have learnt lessons from biotechnology), it is required to seriously consider all the negative possibilities to ensure a real safeguard for the people and the society. I am not ashamed if the article has a tone of pessimism. According to contemporary philosophers optimism seems to be more immoral than pessimism, because pessimism warns us about possible danger while optimism lulls into false security. ❐

S. C. Roy

Letters to the Editor

30th November, 2008

Dear Prof. Roy,

I would like to congratulate you for enriching the standard of the journal 'Science and Culture' through your sincere effort and constant supervision. I am very glad to note that the journal is now indexed in the "Current Contents". The special issue on Acharya J. C. Bose is praise worthy; however, my personal feeling is, it would have been more appreciated if you let this issue excluded from research communications that are not relevant to the Acharya's own work.

Quality of the photographs has also improved over the period of your Editorship, yet it may be further improved through reviewer's help, e.g. photographs in Vol. 74 (11-12), 2008, pg. 743 are out of focus.

I convey my best regards to you and looking forward to your sincere endeavour to make the journal 'Science and Culture' to become one of the bests.

Yours sincerely,

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December 29, 2008

Dear Prof. Roy,

I receive Science and Culture regularly and greatly appreciate it. The recent special issue on J. C. Bose is excellent. It is obvious that you spend a great deal of time on this and the magazine (*read journal-Ed.*) is a labour of your love. You should be commended. Congratulations on this excellent job and my best wishes for a Happy New Year.

Sincerely yours,

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