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The Challenges at the Frontiers of Science and Technology*

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Thank you for the introduction Dr Murthy. I concede that the title of the talk is rather onerous. To some extent I am an omnivorous reader and one of the books which had come from DESIDOC—Frontiers in Science—fascinated me. Following this, came several articles in *Scientific American* and *New Scientist* discussing the trends and challenges in science. So I thought that it would not be out of place to share some of the ideas and information with you, especially on this occasion of Science Day Lectures. At the outset I have a confession to make, I do not understand most of the subjects I am going to present. I am already building a defence for not answering any questions that may come from the audience.

During the next 30 to 45 minutes I am going to share with you some of the information I have collected on the challenges and frontiers in science. Though I am going to cover several topics, most of them do not have much implication on technology. None seems to have relevance to DRDO and indeed some of them are not even topics of active research in India. Yet they are fascinating in themselves and I thought that it would not be inappropriate to expose you to this fascinating world of challenges and frontiers of science and technology—not much about technology but mostly science.

Over the last several years, if not several decades, serious debate is raging between scientists and philosophers. Scientists feel that they are converging on to the truths about many of the mysteries of the universe and that they may have answers for most. Perhaps the forthcoming books by Steven Weinberg entitled 'Dream of the final theory' and Paul Davies 'The mind of God' illustrate this euphoria. On the other hand philosophers, I do not mean classical philosophers but scientific philosophers, like Karl Popper do not share this opinion of the scientists. They tend to think that science is diverging and, in fact, it has become very esoteric and fractious and that we will not arrive at a coherent vision of the truth. Already they have conducted a seminar at the University of Minnesota under the title 'The End of Science', or death of science. Predicting the death of science is nothing new. In fact, Lord Kelvin is believed to have once said that all the major work on science has ended and all that future science was going to do was to add only a few decimal points to the universal constants. If that statement was true we know how sadly he was mistaken for two of the most brilliant theories—Einstein's theory and quantum mechanics—were just round the corner. Is all science about theories? Karl Popper once wrote, "All theories are only provisional. No theory can be proved. They can only be disproved." Such debates between scientists and philosophers continue *ad infinitum*. It may also be true, as Popper said, "Irrespective of what we are doing in science, science is never going to answer three fundamental issues: origin, purpose and destiny of universe and mankind". However, I submit that we have come a long way. We may not be able to answer Popper's three questions but we, and science, are close enough to solve and answer other mysteries of nature.

I will first consider certain issues and research in cosmology and astrophysics. Recently, cosmologist have found very powerful sources which seem to consume millions of stars and have radiation equivalent to the radiation emitted by billions of suns. They call

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it active galatic nucleus. These are supposed to be made of black holes with a very large spiralling cloud of gas. The gravitational pull sucks in the gas. And the gravitational force is so high that the friction generates immense heat and hence the heavy radiation. Indeed the particles being sucked in reach nearly the speed of light. Is this evidence for the existence of black holes predicted by Albert Einstein and Stephen Hawking? In fact, Stephen Hawking, if you have read his 'Brief history of time,' tries to take a peep into the event horizon of the black hole even though nobody has physical evidence for such mystical objects and he has developed a new theory of evaporation of black holes. Identification of black holes and then arriving at the earliest phases of the creation of the universe is one of the major challenges for the science.

Another very important issue is to provide clear justification for acceptance or rejection of the big bang theory. An important evidence for the big bang theory is the existence of what is called background radiation, the remnant of the big bang at a temperature of 2.7 K. When this theory was propounded, Prof Alan Guth of MIT proposed what is called the inflationary universe/cosmology according to which the universe was supposed to have expanded exponentially in the early micro seconds, and then settled down to a steady expansion. With such a theory many of the cosmologists felt that there should be variation in the background radiation. One of the recent experiments—the cosmic background experiment—did point out such ripples. Stephen Hawking called this as the greatest discovery of not only of this century, but of science itself.

With all this research and information are we ready to predict, when did it all begin? Let me touch on one more aspect. Astrophysist Edwin Hubble proposed the theory of expanding universe by defining cosmic red shift and calculating the speed at which galaxies are flying away from each other and thus calculating the life of the universe. This red shift theory is now being challenged. Now Tift, Arizona State University, has made some measurements indicating that the cosmic red shifts are quantized. With the quantization of the cosmic red shift justification of the big bang theory itself is under some doubt. The extent of the universe, 10 or 15 billion years, depends on this issue.

Yet another fundamental issue in research today is that of the unification of the last two forces. Most of you are familiar with four different forces of the universe viz., electromagnetic, weak nuclear, strong nuclear and gravitational forces. Salam-Glashow-Weinberg theory puts together the weak nuclear force and the electromagnetic force to form the electro-weak theory. The so called grand unified theory (GUT), is for combining the electro-weak force with the strong nuclear force. One of the ideas of building super conducting supercollider is towards amalgamating all the nuclear forces. Ultimate goal is to integrate this amalgamated force with the gravitational forces and arrive at the theory of everything (TOE). There are many theories of super-symmetry, super-strings, universe of more than four dimensions and as to how the dimensions get rolled up finally exposing only the four dimensions. Perhaps one of these days we shall find the answer to all these. Indeed some feel this may well happen in the early part of the 21st century. Then we may peek beyond the Planck time -10^{-49} s from the cataclysmic event we call bing bang. A ....jority of the scientists, especially physicists and cosmologists believe that the ultimate challenge of science has to be this, the unravelling the mystery of creation or else we may agree with Robert Frost:

"You are searching Joe
For things that don't exist
I mean beginnings
Ends and beginnings
Ends and beginnings
There are no such things
There are only middles".

After having talked about the beginning or creation of the universe, what do we know about the beginning of the mankind itself? Sometime in the early eighties, an anthropologist and paleontologist, Allen Wilson of Berkley put forward a theory. He talked about what is called a mitochondrial DNA, which he used as a biological clock. This mitochondrial DNA is passed on only from mother to a child. Studying the mutation of every independently variable gene, he talks about number of years for each transition. Based on them and looking at a single prototype, he started constructing a tree backwards. And after constructing this tree, his argument was that the longest branch of this tree should be the branch where all humanity must have originated. And he traced it back to 200,000 years to a single African woman—an African Eve—and concluded that she was the mother of all humans. Of course, this was something which was not going to be easily accepted. Immediately,

a number of people challenged this African Eve theory. It is true that this dating through mitochondrial gene has already been used to find out when we separated from chimpanzees five million years ago approximately. An aspect of this challenge is that 200,000 years is too short a period for the diversity we have amongst the human race. So, either Wilson's timing must be different or, as Tempelton of Washington University argues, either Wilson's computer modelling itself is wrong or the statistical data being used is incorrect. Single regional theories of the origin of mankind is not acceptable to many who are putting forward multiregional theories of Africa, China and Europe. But some kind of consensus is that the origin took place in Africa, but much earlier than 200,000 years to provide for the diversity of human race. Another aspect is that some people think may be mitochondrial DNA is not the correct genetic loci to use. Why not Y-chromosome itself which all of us carry. Challenges and counter challenges continue, and the issue is far from resolution. Final theories must be acceptable to biologists, anthropologists and paleontologists and must also bear the phylogenetic reconstruction tests. The ultimate challenges still remain. Fascinating isn't it!

Now, I come to another topic. A few months back we all read that in 2126 Swift-Tuttle meteor is going to collide with the Earth and thus the life on Earth is going to come to an end. Is it a far-fetched idea? Many people think such extinctions have indeed taken place earlier too. We have identified five such extinctions, the last one having occurred 60 million years ago at what is called KT boundary—Cretaceous-Tertiary boundary—when all the dinosaurs are supposed to have been killed and mammals started evolving. Later, Signor from University of California started looking at the possibility of a sixth extinction which is supposed to have happened 510 million years ago in the early Cambrian period. He claimed that 80 per cent of the genera (echinoderms, bronchiopods, etc) became extinct at that stage. When we talk about the five extinctions, these are supposed to have been caused by either volcanic erruptions or actual meteoritic collisions, the latter being the more acceptable one. The evidence for the meteoritic collisions comes from the presence of large proportion of iridium in the rocks and iridium is not an element which is generally found in these proportions on earth and meteors contain a large proportion of iridium. Signor talks about sea-level rises through plate tectonic movement for the Cambrian extinction. So sea-level rises can cause mass extinction. In our present context, will depletion of ozone layer, the green house effect cause sea-level changes and cause further extinction?

Let me now go to another area which I consider as one of the most important challenge in science. I am going to talk about two or three topics which have great implications in medical science; first is on cancer research. Scientists have identified two particular genes—p53 and Rb—as the most important ones in fighting cancer. The experiments conducted to date is to knock out these genes in mice and see what happens to the animals' development. Even after knocking out gene p53 which was considered to be important for growth, they found that the mice had no problem in development. However, they had developed tumours. So, among the many genes they had explored, they have identified p53 and Rb genes as master genes. The question being asked now is: Are these the genes which control cancer? Clearly, if you do not have p53, the tendency to develop tumours seems to be more. If you do not have the Rb genes, the tendency to develop retinoblastoma is also very large (the research so far has been restricted to mice only). What is the importance of such a fundamental research? The pre-disposition to cancer is high when one does not have p53 and Rb. If they are identified as truly master genes (are there other master genes? p53 and Rb indicate pre-dispostion to certain type of cancers only), it might also indicate a method of treating cancer—a right combination between radiation and chemotherapy. This is clearly a challenging field of research and hopefully, one of these days scientists will meet with success in curing all types of cancers.

The next important topic is the scourge of humanity—AIDS. How are we going to solve the problems of AIDS? Right now, the major medicines being tried for AIDS are AZT and DCI. These produce antibody response to human immunodeficiency virus (HIV) which is supposed to be causative of AIDS. If we develop antibodies for HIV, then there is perhaps a possibility of at least retarding AIDS. Of late, you might have read, that they are trying a number of combinations of these and other drugs. But even people like Salk, the inventor of polio vaccine, do not feel that this is the right approach to AIDS. Many like Salk believe that the only way to stop AIDS or to have a preventive for AIDS is not to generate antibodies at all

by altering the fundamental operation of cell itself. Can cellular performance be altered to control AIDS? At present it is noticed that AIDS virus gets attached to CD4 receptors of helper T-cells and kills them. As the body produces killer T-cells with CD8 receptors and helper T-cells in certain proportion, over the course of the disease the ratio of killer T-cells (CD8 receptors) to help T-cells (CD4 receptors) changes drastically. Is this the reason for failure of any treatment to AIDS? Only time will tell. Clearly prevention of and curing AIDS is the most important challenge being faced by immunologists.

The next topic I want to briefly touch is neural conduction and modelling of brain itself. Neural transmission takes place through neurotransmitters—you must have heard of acytylcholine, noradrenaline, etc. But of late two or three other compounds including the toxic nitric oxide have received attention. Nitric oxide is a toxic agent. And the effect of nitric oxide on neurotransmission has only recently been recognized. Unlike the other neurotransmitters *NO* is produced only on demand and has profound effect on long term potentiation (LTP) or long term memory. If *NO* production is inhibited, LTP is affected. The other lately discovered neurotransmitter is ATP (adenosine triphosphate). It is found that this is effective both in central and peripheral nervous system and is effective bothways. The third candidate is carbon monoxide; carbon monoxide as a neurotransmitter. Another area of neurophysiology which is receiving considerable attention is the models of brain itself. Here is where doctors, scientists and engineers are coming together to model the lost frontier in human physiology with a view to understand perception, memory, emotion and finally the consciousness itself. Francis Crick of the DNA fame believes that the physical mechanism giving rise to these neural phenomenon will eventually be unravelled. Many scientists do believe that the ultimate challenge of science is in biology and it could well be this neurophysiological research which is the ultimate to the ultimate.

Still another area which is throwing challenges is that of seismology. One of the most infamous or famous faults, whichever way you want to consider, is the San Andreas Fault in California, making California as one of the most earthquake-prone areas, atleast theoretically. Earthquake prediction can save lives and property. How does one predict the earthquake? We study plate tectonics and see how the stress concentration occurs along faults. And if the stress concentration exceeds a particular level, there is a possibility that it will rupture and release the stress energy. Can we detect this moment? Can we artificially release this energy and prevent earthquakes? The amount of instrumentation that has been used in the Los Angeles—San Francisco area is phenomenal. Yet we have been unable to predict the occurrance of an earthquake. May be we must finally agree with Charles Richter, "Only fools, liers and charlatans will ever predict earthquakes". May be or may be not! Clearly a challenge to science and scientists!

Next topic I want to indicate, brings us a little bit closer to technology. The topic is superconductivity, and that too, high temperature superconductivity. How does it happen? Many theories have been propounded. We know that the HT superconductors have copper oxide layers and also include rare-earth material. It has been possible to obtain a transition temperature of 130 K with thallium-based compunds. Yet, we do not clearly know how they work. Is the old theory of superconductivity viz., BCS theory—Bardeen, Cooper and Schrieffer theory applicable? You may recall that in BCS theory phonons—lattice vibrations—bond two electrons to form Cooper pair and these slip through lattice to induce superconductivity. Philip Anderson of Princeton, who himself is a Nobel Laureate, does not agree that BCS theory is suitable for HTS. He has developed a new theory based on quasi-particles—spinions and holons. Spinion is a particle which has only a spin and no charge while holon is a particle which has only a positive charge and no spin. The spinion-holon fluid which flows through the layers of copper oxide is the one responsible for superconductivity. In fact, he has gone further on to indicate that the T_C depends on the number of the layers and how tightly the layers are coupled. He predicts that the highest temperature that we are ever going to get in superconductivity is at 160 K. For this to happen, the copper oxide layers must be identical and there should be a certain minimum number of layers. Is it possible to synthesize compounds with a specified number of parallel and well coupled layers? The technological implications of HTS are profound.

Now let me come to topics which seems to be receiving some attention—artificial photosynthesis, molecular batteries and bug power. Photosynthesis is a thermodynamically uphill reaction, in the sense that

you have got to supply energy to drive the fixation of carbon. It has two steps, photophosphorylation and Calvin cycle. These are redox (reduction-oxidation) reactions. The amount of energy that is taken out by chlorophyll in a year is 10^{17} kcal/mol, equivalent to continuous production of 13,000 MW of energy over a year. In doing this, it is said to consume 10^{10} tons of carbon dioxide. Photosynthesis takes place in the thylacoid membrane which, because of photo-phosphorylation, creates a charge gradient and this gradient drives the second reaction, the Calvin cycle, to form sugar from carbon dioxide. The redox reaction (and these two-stage processes of utilising sunlight, water and CO_2 to fix carbon and release O_2 to the atmosphere), is a two electron process and the most fundamental of reactions providing food for the world. Of course, green chlorophyl is not necessary for photosynthesis. There are algae which are not green but they still go through photosynthesis; they utilize light at different wave-lengths, like UV-green and so on. Can we mimic photosynthesis? Can we build artificial systems which absorb CO_2 from the atmosphere and in the presence of sunlight convert it to some useful product (and at the same time solving the problems of over-abundance of CO_2 in the atmosphere and perhaps help solve the greenhouse effect). There are umpteen articles these days on this subject in science magazines.

If we are looking for artificial sources of energy that also reduce the carbon dioxide in the atmosphere, through artificial photosynthesis, we must be able to produce something other than sugar, something which is more useful. The artificial process also involves two steps. The first one is similar to the photophosphorylation. And the second—Sabatier reaction— produces methane, a useful fuel. The entire process accomplishes photosynthesis of methane from carbon dioxide and water. This eight electron transfer process requires a consumption of 198.3 kcal/mole. The process also uses ruthenium catalyst dispersed onto titanium dioxide (a semiconductor). Most artificial systems work on the same principle: a donor which can donate electrons; an initiator which photocleaves electrons from the donor utilising sunlight; an acceptor which absorbs the electrons cleaved from the donor by the initiator. The reaction may take place through a semiconductor membrane rather than a biological membrane, chromophore attached to this membrane harvesting the sunlight. This photodriven charge separation has also been demonstrated by a group of scientists, the work being coordinated by Arizona State University. This artificial bio-solar convertor uses porphyrin (a close relative of chlorophyll) which captures sunlight and cleaves electrons from quinone, the donor, and transfers it to the acceptor, carotene. Porphyrin, quinone and carotene are all ring structured organic compounds.

One of the problems encountered in all these processes is the short-lived nature of the cleaved electron before it recombines and we must be able to store it or conduct it away. Utilizing similar principle a 'bio-battery' has been tested in laboratories. This particular one uses a halide-viologen complex trapped in an inorganic matrix which can store solar optical energy. The actual battery is a sandwich structure of viologen, an aceptor, in a zirconium phosphonate matrix, halides acting as the donor.

After having talked about artificial photosynthesis-based energy extraction methods, the last topic I want to touch is biotechnology where the cleavage of electron is done by a microbe. One of the ideas is to use either a monosaccharide like glucose or bisaccharide like sucrose as the biofuel and a particular bacterium which cleaves electrons from the fuel. For example if glucose is used, then the bacterium employed is *E.coli* or yeast. Of course mediators are required to aid the reaction and to help transfer of electrons. The mediators for glucose-*E.coli* bug battery are thionine or resorufin (all ring structured organic compounds) which themselves undergo redox reaction. In passing I have to mention that transfer of electrons from one chemical to another involves the reduction of chemical the receiving the electrons and oxidation of the chemical donating the electron. Redox reactions generally occur together and are electrochemical in nature (indeed it is now recognized that almost all biochemical reactions in the human body are all electrochemical reactions). This idea of biofuel cells is not new and the same is being pursued rigorously in many countries. We should not consider these frontier areas as far fetched and scientific fiction. Many such researches are at various stages of laboratory experimentation and the prospects are interesting and challenging. It is possible that by 2025 AD you drive your car with bug batteries to a station for a bug exchange.

I could have talked about other topics like smart materials, SETI and ESP (parapsychology). As far back as 20 years, major American universities like Stanford, Princeton did carry out a project on communication through ESP channels. I am not talking about Uri Geller and aspects like psychokinesis to bend spoons and so on, but hardcore scientific research. In America there is another research area, a frontier one at that, on SETI—search for extra-terresterial intelligence—indicating that there are several who believe that we are not alone. Surely one could argue that there is no need for such activities and whether these will help the development of technology. With technology we can look at the utilitarian aspects of science. On the other hand, if we are going to talk about science as an intellectual pursuit, some of these frontiers and challenges are to be pursued as we move into the 21st century. You might ask, in view of the debate between the scientists and the philosophers, whether we are going to become any wiser? I am sure we do. However, we must be humble enough to accept as John Wheeler of Princeton puts it "We live on an island of knowledge, surrounded by a sea of ignorance. As our knowledge grows, so does the shore of our ignorance".