SCIENCE AND SOCIETY IN THE 21ST CENTURY

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Karnataka Rajyotsava Extension Lecture
INSTITUTE FOR SOCIAL AND ECONOMIC CHANGE
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After passing through the Stone Age, the Bronze Age, the Age of Steam and Steel, humanity is now in the Age of Science and Science Based Technologies. The message that comes through all this development over the centuries is that the present is always built on the past. "Past is Prologue" is the very appropriate inscription below the very imposing oversized statue of a majestic lady sitting on a chair in front of the American Museum of Natural History in Washington D.C. Scientifically the future can be predicted only on the basis of a reasonable extrapolation of whatever has happened in the past upto the present. However, I must hasten to point out that any scientist howsoever eminent and erudite he may have been, would have made totally wrong predictions about the scope and nature of science and technology in the 20th Century, if he had been asked to do so around 1885. It so happened that over the 25 years 1885-1910, major discoveries of a totally unexpected nature were made that led to a basic transformation of many of the concepts of science and also led to entirely new range of technologies, that had profound influence on the lifestyles of the people of the 20th Century. Society is influenced by many other factors besides science and these also have their own measure of unpredictability.

Bearing fully in mind these limitations and uncertainties, I will make an attempt in this talk to portray the increasingly closer connection that is inevitably emerging between science and society and examine how this symbiosis is to be nurtured to influence the future of both in more effective ways. To set the perspective for discussion and to emphasise the rapidly changing pace of discoveries and the emergence of enabling technologies in the service of society, I will pick a few threads of major discoveries in the field of physical sciences with which I am more familiar, and discuss them in a historical setting.

Electricity, Radio, Television and Information Technology

Rudimentary ideal on electricity go back to much before 1600 A.D., when Gilbert started some investigations on the repulsive power of amber sticks rubbed on a piece of animal skin. Almost a hundred and fifty years later Benjamin Franklin suggested the idea in 1747 of an electric fluid that existed in all bodies and this led him to propose that lightning was due to the passage of electric current in the visible discharges between clouds and between clouds and the earth. In 1785, Henry Coulomb established the famous inverse square law of electricity and in 1800 the Italian physicist Volta made the first set of electrical storage batteries that became the source of electricity. Another quarter century later in 1827, Ohm discovered the famous Ohm's law connecting voltage, current and resistance. It is only in 1879, another half a century later, Edison made the first incandescent lamp - (the electrical bulb that we so commonly use to-day). In 1831, Faraday connected electricity with magnetism through his famous laws of magnetic induction and introduced the concept of lines of force. Thirty eight years later in 1869 Maxwell formulated his Electro-Magnetic Theory according to which any disturbance created by magnetic or electric changes would result in the production and propagation of Electro-Magnetic Waves. Maxwell had the brilliant foresight that ordinary light is just and electromagnetic wave. In 1887, Hertz produced electro-magnetic waves in the laboratory. This was the beginning of a new era in science - a new era in technology and a new era in society in general. While steam power was the first horse, electricity the second horse in the service of man, the electro-magnetic wave became undoubtedly the third horse.

Let us pursue the wonder "the electromagnetic wave" further. In 1895, another Italian, Marconi demonstrated the transmission of electro-magnetic waves across the Atlantic. It was good that Marconi did not have much formal training in science. Otherwise, he would not have ventured his experiment to send radio signals from Cornwall in England to Newfounland

in the North of America. The curvature of the earth results in a 150ft. high solid barrier that would forbid straightline transmission of radio waves. However, the experiment worked! The reasons for the success had to be found later - the theories of ground wave propagation and reflection of radiowaves by the Ionosphere. In 1902 Kenelly and Heaviside discovered that radio waves travel round the earth.

In 1897, the electron the elementary particle that has been in the service of man most, was discovered by J.J. Thomson in the electrical discharge of gases. In 1904 the vacuum diode and in 1906 the vacuum triode which constituted the heart of radio transmitters and receivers were discovered and the new field of Electronics came on the horizon, marking another watershed in the role of science in society. The vacuum tube reigned supreme in the field of electronics for almost half a century when in 1947 the solid state device, the 'transistor' was discovered. This resulted in remarkable miniaturisation of electronic devices, lowering of power requirements by orders of magnitude. The transistor was followed by the large scale integrated circuit (LSI) and then by the very large scale integrated circuit (VLSI) leading to the microchip - the minicomputer in 1971. In the 1950's a fairly sophisticated computer with electronic valves would require several racks filling a large room, with elaborate cooling systems and air conditioning. The first computer at MIT, Boston was called appropriately 'the Whirl Wind' because of the noise the installation generated. Today, a similar capability computer is a 'lap top' one perhaps with much more sophistication and facilities and choice of operation. The cost has also come down by several orders of Magnitude and most of the time such computers can be operated with chargeable batteries. The confluence of computers and satellite communications brought in the era of Telematics and Information Technology.

I have already referred to the fact that radio waves can travel round the earth and this is what enabled radio broadcasting. This long range transmission was because of a very helpful feature

of our atmoshpere which under the bombardment of the ultraviolet radiation from the sun gives rise to striated ionospheric layers and the radio waves suffer repeated relections between the earth and these ionospheric layers. The heights of these reflecting layers range from about 70 to 200 miles.

When Television arrived on the scene, it was realised that one needed a much higher bandwidth to transmit the visual details, the carrier frequencies had to be very much higher than required for radio broadcasting. But such high frequency waves would not be reflected by the ionospheric layers. The waves would just penetrate through. You might have seen in the old days the series of TV towers every few kilometers on which were mounted "repeaters" to extend the TV broadcast to longer distances. Oddly enough the same feature, namely the penetration of the carrier waves through the ionospheric layers came, as a boon for satellite communication and satellite TV. without communication facilities, the satellites would have been thoroughly useless for any practical purposes.

The objectives of Telematics, which is the new buz word is to provide a variety of services for a variety of customers which includes the public at large, the industrialist, the businessman, the student, the scientist, the engineer, the beaurocrat etc. The services offered are telephone, telex, fax, television, cellular phone, pager, e-mail, internet connections and access to the world wide web.

The implications and consequences of such a revolution in information services on society were forecast a couple, of decades ago by Alvin Toffler in his books 'The Future Shock' and 'The Third Wave'. It is perhaps appropriate to say that the future shock is already here and we are confronting the third wave. The amplitudes of these waves are of course, larger, in some of the advanced countries and they will spread soon to all parts of the world. This information technology revolution is a truly sociological and societal revolution, hopefully resulting in a global harmony on many issues.

Nuclear Physics, Atomic Energy and the Atom Bomb

Let me now take on another string of research and development activities which also have had enormous benefits to society and at the same time have created issues of international concern and debate. X-rays and Radioactivity were discovered in the years 1895 and 1896 respectively. The medical and industrial applications of these are so well known that I need not elaborate on them.

These discoveries along with that of the electron in 1897 and some crucial experiments carried out with light around the same period, led to the formulation of radically new theories 'Relativity' by Einstein and "Quantum Theory" by Max Planck. Classical physics that had been the friend, guide and philosopher of the scientist from the time of Newton, in explaining all natural phenomena in the inanimate world was overthrown. Entirely new and deeper aspects of the familiar concepts like space, time, matter, radiation, forces gradually unfolded. I will give you just a flavour of these developments and their consequences without going into details. The alpha-particle, one of the radiations from radioactive nuclei was used by Rutherford and his collaborators to study the structure of atoms. This simple study of scattering of alpha-particles by an extremely simple technique led to one of the most profound discoveries namely that the entire mass of the atom is contained in the "nucleus" which is almost a million times smaller than the atom itself. This discovery made in 1912 heralded the age of Nuclear Physics. While the proton had been discovered as the positively charged counterpart of the electron in the discharge of gases, but of much heavier mass, it took a decade to recognise that this was one of the constituents of the nucleus. In 1932 its companion in all nuclei heavier that hydrogen, the Neutron with almost the same mass was discovered.

In 1939, two German radiochemists Otto Hahn and Fritz Strassman found that when Uranium atom was bombarded by a neutron, instead of an isotope of Uranium being produced, there was evidence for the Formation of two separated radioactive nuclei

of lower mass. This anomalous result was interpreted by two other German physicists, Lise Meitner and Otto Frisch as evidence of the Fission of the Uranium nucleus. In this process and energy equivalent to 200 million electron volts was released, which was orders of magnitude more than what had been observed in earlier nuclear reactions and exothermic chemical reactions. Bohr and wheeler carried out detailed theoretical studies of the fission process which was published in the American Journal, The physical Review. This was the first and last comprehensive article on this subject in an open literature that was available to every one. Immediately after came the appalling realisation of what this fission process could lead to - making of an Atom Bomb. Fearing that the Germans would go ahead of the Allies, the top most scientists of the day outside Germany, Niels Bohr, Einstein, Szilard and others influenced the U.S. Government to initiate and hasten the project on the making of the Atom Bomb. The rest is well known history now. Science had led to the placing of the most devastating weapon in the hands of the military generals. The dilemma and the resolution of the dilemma in the minds of the scientists who worked on the bomb is reflected in the following words of Robert Oppenheimer, who was the man behind the first bomb and who later when the more devastating hydrogen bomb was being developed, tried his best to delay the project:

> "The scientist is not responsible for the laws of nature, but it is the scientists job to find out ways in which these laws can serve the human will. However, it is not the scientist's job to determine whether a hydrogen bomb should be used. This responsibility rests with the American people and their chosen representatives."

Oppenheimer was one among these who were excited by the technical challenge, but realised the moral repugnance of the whole issue.

While on this subject of moral and social responsibility of scientists, I must make a reference to the case of Wernher Von Braun who developed the V-2 rockets in the 1930's in Hitler's

Germany. He was reported as saying that the V-2 was not intended as a weapon of war. Because of this attitude, he was arrested by the Gestapo. As the war was ending and Germany was facing defeat, this great genius of a man manoeuvered to be captured by the American army so that he will have the opportunity of pursuing his life's ambition of space exploration. Von Braun was the man behind the first satellite that U.S. put into orbit in 1958.

Though the first public release of nuclear energy was through the explosion of the two bombs on Hiroshima and Nagasaki in August 1945, in the post war years power generation became the main objective and today the total installed nuclear electric capacity in the world is at the level of bout 17% of all electric capacity. France has the record of more than 70% of its electricity generated being nuclear. While it is true that no more than two atom bombs have been dropped so far as part of any war, the proliferation of the nuclear weapons with stock piles of tens of thousands by some of the countries and the anxiety of these countries not to lose their monopoly, has led to issues like NPT-the non-proliferation treaty and the CTBT - the comprehensive test ban treaty etc. Enough publicity has been given to these issues in recent months and sufficient awareness of the public has been built on these matters. In my opinion however, there are several others like the pollution of water by hazardous chemicals, the atmospheric pollution by industrial gases and the dangers consequent to the formation of the Ozone hole, indiscriminate use of pesticides, narcotic drugs need equal attention if not more since some of them can also be used as weapons and more importantly are silent killers of large population. Let me illustrate one example of a well documented case.

A couple of decades ago, one of the most industrially advanced countries, the United States was rocked by what came to be known as the Love Canal tragedy. In the residential area of Niagara Falls there was a dumpsite of toxic chemicals which polluted the surrounding bodies of water, generated toxic fumes which in turn resulted in a variety of health complications for the

citizens - kidney damage, respiratory ailments, and cancer in addition to high rate of birth-defective children. The investigations by the U.S. environmental agencies revealed that in the U.S. alone, there were more than 50,000 sites where hazardous chemicals were buried and in less than 7% of them proper precautions had been taken. The tragedy in Bhopal due to the negligence of Union Carbide, is still green in our memory. I think, I have said enough to emphasise that Science and Technology are not unmixed blessings.

The Indian Scenario in Science and Technology

The question has often been raised, why India and China which were on the top of civilization centuries ahead of Europe- or Greece which was the intellectual fountainhead much before Western Europe- did not become the centres in which modern science originated, took roots and flourished. In a very perceptive article entitled "Scientific tradition and other traditions" published in Current Science of July 1995, my former colleague at the TIFR, Prof. B.M. Udgaonkar has discussed this issue threadbare and I will summarise his analysis with which, I totally agree.

The Indian civilization is about 4500-5000 years old. (8000 years if the pre-Harappan findings in Baluchistan are included). Science based on observation and empirical methods did exist in ancient India and Indian contributions in these fields have begun to be documented to some extent and much more needs to be done-perhaps something on the lines of what Needham did in the case of China. Among the reasons that could have contributed for the lack of origination and development of modern science in India, Udgaonkar has listed the following:

(i) The other-worldliness of the Indian culture
(ii) Suppression of scientific spirit for political reasons
(iii) Conflict between science and religion
(iv) Belief that all knowledge is in the Vedas
(v) Tendency to accommodate conflicting opposites

(vi) Complacency developed during the period when Indians had attained high level of civilization

(vii) Rigidity of the caste system

(viii) Ban on foreign travel

(ix) Handicap of oral tradition

(x) Effect of invasions

(xi) Influence of Buddhism

After discussing in some detail the pros and cons of each of these possible causes, Udgaonkar makes the important point that it is necessary to take a unified view of the trio science, philosophy and culture before arriving at any conclusions regarding the past and a critical assessment of both external factors and internal failures have to be made from the point of view of the future. It is not clear however, how the conditions in Western Europe were congenial in the 17th Century for the birth of modern science, in preference to Greece. What is however, very clear is that the conditions for nurturing science were ideal in those countries especially since the renainssance.

Let us now examine the Indian scenario in the more recent past. Modern science came to India just about 150 years ago through the establishment of the three Universities at Calcutta, Madras and Bombay in 1850s. The Indian Association for the Cultivation of Science was founded by Mahendra Lal Sircar in 1876 and the Indian Institute of Science at Bangalore in 1910 by J.N. Tata. The names of Ramanujan, J.C. Bose, P.C.Ray, C.V.Raman, M.N.Saha, S.N.Bose, K.S.Krishnan and S.K.Mitra who put India on the map of "world science" is well known to all of us. There is no question that they were all very exceptional men of high intellectual calibre who educated themselves and made outstanding contributions at the highest international levels. Their greatness is all the more since they achieved all this at a time when the country was still very backward in the relevant areas of science and mathematics and journals and books so essential for pursuit of research had to come by sea with a delay of more than 6 months.

What is the post-independence scenario?

Our first Prime Minister Pandit Jawaharlal Nehru had written even before independence in his famous book "Discovery of India":

"It is science and science alone that can solve the problems of poverty, of insanitation, and illiteracy, of dreadening Customs and superstitions of a rich country inhabited by poor people."

Thanks to his foresight and the encouragement he gave as the Prime Minister and also to the very significant role played by some of the leading scientists immediately after independence, Bhatnagar, Saha, Krishnan, Bhabha, Sarabhai and others a chain of National Laboratories and high level research institutions came up in different parts of the country- the National Physical Laboratory at Delhi; the National Chemical Laboratory in Poona, the National Metallurgical Laboratory in Jamshedpur, the Central Food Technological Research Institute at Mysore, the Central Leather Research Laboratory at Madras and so on. Gradually, the scientific departments - Atomic Energy, Space, Electronics, Agriculture, Biotechnology, Ocean Development etc. came up, and some of them set up their own Laboratories. The number of Universities increased to more than a hundred. Five Institutes of Technology were set up. Considering all this one has to accept that higher education and research did get a large measure of support from the Government. Whether it could or should have been more is an issue which we will discuss later. The question that we should ask is whether the scientific community has lived up to the expectations of those that gave the support.

Well, as one who belongs precisely to the generation that should answer this question and also as one who was closely involved with one of the premier research institutions of the country namely the Tata Institute of Fundamental Research and had also connections with many other institutions in the country and abroad, my unhesitating answer is 'Yes' and 'No.' Unquestionably, there are areas in which India has made quite significant contributions

both in science and technology and of course there are also areas in which we have failed. Wherever the activities were built around young scientists of proven merit and ability trained within the country or abroad, and were given the necessary infrastructural support at the right time, success was guaranteed. This was so in the case of atomic energy and space programmes and in some of the areas of basic sciences. Among the areas of basis sciences, I am familiar with, I must mention the fields of cosmic rays, astronomies, ionospheric studies, solid state physics, solid state Chemistry, gravitation, liquid crystals and especially mathematics. I am sure there are similar success stories in many other areas too. In the areas of atomic energy and space, India has come to occupy a place among the front liners in the world. The new array of radio telescopes (the Giant Meter Wave Length Radio Telescope) that has been built near Poona by TIFR ranks as the largest telescopes in the world in the Meter Wave Band. It is a technological marvel and also is one from which we are expecting very fundamental results of cosmological significance to emerge in the coming decades. Among the technological areas where we have failed, the most glaring one is electronics. We are not even at the level of 0.5% of world production, when even Singapore is at the level of 5% or more. National goal oriented effort was totally lacking and commercial interests of other countries interfered in the earlier years and were not taken advantage of later.

Mediocrity stepping-in in the appointments of professors, Vice chancellors in the universities and merit not being the sole criterion in the admission of students was the main factor responsible for the deterioration of even the universities that had established themselves as good centres of research before independence. As you all know the conditions are worsening. The reason for the deterioration of the universities is not the setting up of National Laboratories immediately after independence. If these had not been set up, we would be no where in the world of science and technology. The priorities now should be to ensure that the universities correct themselves by giving the rightful place for merit and come back to the main stream of higher learning

and research. With the emphasis that is increasingly placed on all kinds of reservations, this seems to be a tall order and may be the most detrimental factor in our progress.

Changing Pattern of Research:

The discoveries of x-rays, Radioactivity and electrons, and those that followed were all made with very inexpensive experimental setups and just one or two scientists were involved in all aspects of these investigations. As we have seen these small efforts led to major technological fall outs. In India, the Raman effect that was discovered by C.V. Raman, Krishnan and Ramanathan in the late 20's also involved very simple, but an ingenious setup. While this style of research still persists in some rare corners of the world, by and large the present day pattern of scientific research has totally changed. Ofcourse, the types of investigations now being carried out necessarily require very high sophistication and large sums of many and team work. Let me give you a glimpse of an extreme cast - the discovery of one of the fundamental particles, called the TOP Quark, that hit the world headlines just a year ago.

Detailed investigations on the nature of Cosmic Rays in the period 1930-60 led to the discovery of a large number of particles known as mesons and hyperons. A peculiar characteristics of these particles was that they lived for extremely short intervals of time, much less than a millionth of a second, but still had a specific and important role in the stability of all matter. It was later discovered that they controlled many intricate phenomena in some of the celestial objects that exhibited exotic features. A veritable zoo of several hundred such particles were discovered by specially designed man made accelerators in the world in the period 1950 to 1990. A very elegant theory known as the Standard Model of particle physics was formulated to explain many properties of these particles and their interactions. The beauty of the standard model was that all the hundreds of particles could be looked upon as constituted of a few still more elementary particles known as

"quarks." This Standard Model predicted the existence of a rather heavy particle known as the Top Quark, which could be produced only in an accelerator of a particular kind.

Such an accelerator was built and has been functioning in Chicago since 1970's. The cost of construction of the accelerator itself was about a billion dollars. The discovery of Top Quark was made late in 1995 with this accelerator. The discovery paper had 493 authors hailing from dozens of institutions all over the world including India. It was truly an international effort. You can imagine the scale of effort that must have gone into the design, execution and analysis, of the results if so many institutions and scientists are involved. Behind the 493 authors there must have been atleast ten times more technicians, computer programmers and so on. Very sophisticated computers had to be deployed for control and analysis.

I would like to highlight one aspect of the construction of such an accelerator which was entirely for fundamental research with no immediate practical applications in sight. When the Director of the Fermi National Accelerator Laboratory was making efforts to raise the money for construction and had naturally approached the U.S. Government, one of the senators who was a member of the subcommittee that had been set up for examining the project for approval, asked Professor Wilson whether his accelerator would help in any way the defence of the United States. Professor Wilson is reported to have replied that he did not know about that, but it would certainly make the country worth defending. Prof. Wilson got the money. The Fermi Accelerator was constructed and produced a spate of discoveries of great significance. That is the kind of enlightened support that is necessary if India has to come to the forefront.

The 20th Century Boons and Horrors:

The 20th Century is undoubtedly characterized by a mixture of very beneficial developments and at the same time the most devastating fallouts of science and technology.

On the positive side, we can list the following:

- The release of energy of the atom, development of nulcear power, production of radio isotopes.
- Development of rockets, satellites, satellite communication remote sensing of the earth resources
- Electronics, radio, television, telecommunication computers, lasers, liquid crystal displays, neon signs, optical fibres, xerox, x-ray machines.
- Automobiles, civilian and military aircrafts, jumbo-jets
- Genetic engineering, heart, kidney, lever transplants
- Wonder materials, nylon, teflon, plastics, matalics, ceramic composites, dyes
- Eradication of infectious diseases - small pox, cholera, plague, antibiotics, cancer diagnosis and treatment, (CT Scan, NMR and PET)

On the negative side we have:

- The atom bomb, the hydrogen bomb, the neutron bomb
- Missiles, ICBM's (Intercontinental ballistic missiles)
- Star Wars, Spy Satellites
- Pollution of food stuffs, water and air by toxic chemicals, radioactive leakages
- Noise pollution by factories, vehicles, air craft
- Uncontrolled growth of cities, sky scrapers, slums

The century is also characterized by fundamental research that has given deeper insights into many aspects of working of Nature and of the Universe at large. In particular, we have now very detailed understanding of

- Ultimate constituents of all matter and radiation - the forces operating in the various domains and the underlying unity behind diversity.

- The immensity of the universe - the existence of celestial bodies whose characteristics are very different from the near by objects - neutron stars, black holes
- Possible scenarios of creation of the universe - the Big Bang, the details of physical and chemical evolution that has preceded the biological evolution.
- The constitution of the human body in all its details, the biochemical operations that go on in each cell of the human and animal bodies, many aspects of the nervous system and its connection with the brain.
- The causes and cures of a variety of diseases

This is surely a partial list and is biased by my lack of familiarity with many fields of science and technology. Nevertheless, it gives a general picture of the role that science and technology have played in the Century that is coming to an end.

What next?

The 21st Century:

One can say with some confidence what the main directions of development will be, atleast in the early part of the 21st Century:

- Information Technology (IT) with all its ramifications on all aspects of society - trade, commerce, education, industrialisation, patterns of administration will be the front runner.
- IT will be aided further by newer developments in materials - Nano - technologies as they are called, further miniaturisation of electronic devices, optoelectronics and photonics
- High temperature super conducting materials which are on the threashold of realisation for commercial purposes, will revolutionize transportation, power transmission
- Nano-technologies, Nano-electronic materials will bring in era of micro-satellites which may replace the Geostationary satellites for communication

- Developments in the field of cancer research and cancer treatment may lead to the cure and eradication of this dreaded disease
- The employment of the newer techniques of tomography - the NMR, the PET etc.,. may lead to much deeper understanding of the neuronal networks and the functioning of the brain., which may help in the treatment of mental disorders.
- There will be increased efforts in searching for extraterrestrial intelligence, as well as in creating in the laboratory artificial intelligence.
- Much greater emphasis on research and utilisation of solar Energy because of dwindling conventional energy sources and reservations on nuclear energy.
- Off-shore and Deep Sea Mining from the point of view of mobilizing more resources

Society and Science:

Almost all of the accomplishments of science and technology that I have highlighted so far are due to the efforts of a few countries of the world though many of the benefits (and evils) have been shared by practically all countries of the world. While India has all the potential it has not been a major player so far, while much smaller countries which were considerably backward when India got its independence, have forged ahead. This is essentially because

(i) We have fallen behind in our educational system at all levels, especially at the advanced levels so necessary for nurturing high level Research and Development.

(ii) Large number of young bright students are leaving the country for better education and prospects abroad.

(iii) We have no system by which exceptional opportunity is provided for exceptional talent. It is a recognised fact that

in the long run the progress of a nation depends on the outstanding performance of a few.

(iv) The outlay on higher education and research is hopelessly inadequate. The countries which were behind us have marched ahead because of much higher level of investment in science and technology.

(v) While one can understand the difficulties of the government for enhancing the financial outlays for the Research and Development because of other needs and compulsions, there is no reason why the industrialists who are the direct beneficiaries of higher education, technical education and Research and Development should not be enlightened enough and come to the rescue of the nation by contributing liberally towards education and research.

As we come close to stepping into the 21st Century, the message for us in India is loud and clear. We have to reorganize ourselves in the rapidly changing context of the world scenario in science and technology and instead of continuing to be at the receiving end should become aggressive contributors to the world reservoir of scientific knowledge and become dominant exporters of technology. Now is the time to encourage the local talent to the maximum and bring back the experts who have migrated to other countries. This calls for an enlightened approach where merit and performance should be sole criteria for judgement and unrestricted support. A better quality of life for all is the primary concern of any democracy.

This is possible only if the country becomes sufficiently affluent, the per capita income goes up and the environment is protected and made congenial for disease free living. Several countries have proved in the recent past that all this is possible in a reasonably short time through progressive policies and liberal support of science and technology. It is time we wake up to these realities. This is the primary responsibility of the Indian Society. Perhaps, I have over-emphasised the role of modern science and technology in influencing and controlling the quality of life of the

Indian Society in the future without giving sufficient weightage to its inheritance of a rich culture, its deep-rooted philosophical moorings and religious tolerances - in short the eastern wisdom that has tempered the society from becoming too materialistic in its outlook. In fact one may wonder whether one cannot go back to those golden days of prosperity that were prevalent long before the advent of modern science. The answer is clearly not because of several irreversible happenings. Compared to a thousand years ago the population has increased atleast twenty fold, the resources haved dwindled and even to meet the minimal requirements of food, water and shelter, one needs the services of modern technology. Also, it is no longer feasible to isolate ourselves from the rest of the world. Clearly a strategy has to be worked out by which we preserve the best of our tradition and at the same time utilise the power and benefits of modern technology.

I would like to end this talk by quoting a renowned scientist, educator and statesman, K.T.Compton, who was the President of the Massachusetts Institute of Technology, Boston:

"..... Truly the urge to live is basic: it is a feature of biological behaviour of cells and tissues, of the instinctive reactions of all animals and of the conscious planning and effort of human beings. But though mankind shares with all other forms of life the urge to live, there seems to be another urge which is peculiar to man and distinguishes him from all other animals and other living things. It is the urge to live better.

It is man alone, of all living things, who has consciously and to a staggering degree changed his ways of living ... Man has employed imagination and logic, he has invented, he has developed new skills, he has created new concepts of values, he has manipulated the materials and forces of nature for his purpose. He has done all these things because of his urge to live better. While it is occasionally pleasant to think back, it is far more profitable to think ahead. Adventure and progress and exhibition of achievement always lie in the future, and their planning should be the concern of the present."

SCINCE AND SOCIETY IN THE 21ST CENTURY

B.V. Sreekantan*

After passing through the Stone Age, the Bronze Age, the Age of Steam and Steel, humanity is now in the Age of Science and Science Based Technologies. The message that comes through all this development over the centuries is that the present is always built on the past. "Past is Prologue" is the very appropriate inscription below the very imposing oversized statue of a majestic lady sitting on a chair in front of the American Museum of Natural History in Washington D.C. Scientifically the future can be predicted only on the basis of a reasonable extrapolation of whatever has happened in the past upto the present. However, I must hasten to point out that any scientist howsoever eminent and erudite he may have been, would have made totally wrong predictions about the scope and nature of sceince and technology in the 20th Century, if he had been asked to do so around 1885. It so happened that over the 25 years 1885-1910, major discoveries of a totally unexpected nature were made that led to a basic transformation of many of the concepts of science and also led to entirely new range of technologies, that had profound influence on the lifestyles of the people of the

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20th Century. Society is influenced by many other factors besides science and these also have their own measure of unpredictability.

Bearing fully in mind these limitations and uncertainties, I will make an attempt in this talk to portray the increasingly closer connection that is inevitably emerging between science and society and examine how this symbiosis is to be nurtured to influence the future of both in more effective ways. To set the perspective for discussion and to emphasise the rapidly changing pace of discoveries and the emergence of enabling technologies in the service of society, I will pick a few threads of major discoveries in the field of physical sciences with which I am more familiar, and discuss them in a historical setting.

Electricity, Radio, Television and Information Technology.

Rudimentary ideas on electricity go back to much before 1600 A.D., when Gilbert started some investigations on the repulsive power of amber sticks rubbed on a piece of animal skin. Almost a hundred and fifty years later Benjamin Franklin suggested the idea in 1747 of an electric fluid that existed in all bodies and this led him to propose that lightning was due to the passage of electric current in the visible discharges between clouds and between clouds and the earth. In 1785, Henry Coulomb established the famous inverse square law of electricity and in 1800 the Italian physicist Volta made the first set of electrical storage batteries that

became the source of electricity. Another quarter century later in 1827, Ohm discovered the famous Ohm's law connecting voltage, current and resistance. It is only in 1879, another half a century later, Edison made the first incandescent lamp - (the electrical bulb that we so commonly use to-day). In 1831, Faraday connected electricity with magnetism through his famous laws of magnetic induction and introduced the concept of 'lines of force.' Thirty eight years later in 1869 Maxwell formulated his Electro-Magnetic Theory according to which any disturbance created by magnetic or electric changes would result in the production and propagation of Electro-Magnetic Waves. Maxwell had the brilliant foresight that ordinary light is just an electromagnetic wave. In 1887, Hertz produced electro-magnetic waves in the laboratory. This was the beginning of a new era in science - a new era in technology and a new era in society in general. While steam power was the first horse, electricity the second horse in the service of man, the electro-magnetic wave became undoubtedly the third horse.

Let us pursue the wonder "the electromagnetic wave" further. In 1895, another Italian, Marconi demonstrated the transmission of electro-magnetic waves across the Atlantic. It was good that Marconi did not have much formal training in science. Otherwise, he would not have ventured his experiment to send radio signals from Cornwall in England to Newfounland in the North of America. The curvature of the earth results in a 150 ft. high solid barrier that would

forbid straightline transmission of radio waves. However, the experiment worked ! The reasons for the success had to be found later - the theories of ground wave propagation and reflection of radiowaves by the Ionosphere. In 1902 Kenelly and Heaviside discovered that radio waves travel round the earth.

In 1897, the electron the elementary particle that has been in the service of man most, was discovered by J.J. Thomson in the electrical discharge of gases. In 1904 the vacuum diode and in 1906 the vacuum triode which constituted the heart of radio transmitters and receivers were discovered and the new field of Electronics came on the horizon, marking another watershed in the role of science in society. The vacuum tube reigned supreme in the field of electronics for almost half a century when in 1947 the solid state device, the 'transistor' was discovered. This resulted in remarkable miniaturisation of electronic devices, lowering of power requirements by orders of magnitude. The transistor was followed by the large scale integrated circuit (LSI) and then by the very large scale integrated circuit (VLSI) leading to the microchip - the minicomputer in 1971. In the 1950's a fairly sophisticated computer with electronic valves would require several racks filling a large room, with elaborate cooling systems and air conditioning. The first computer at MIT, Boston was called appropriately 'the Whirl Wind' because of the noise the installation generated. Today, a similar capability computer is a 'lap top' one perhaps with much more

sophistication and facilities and choice of operation. The cost has also come down by several orders of magnitude and most of the time such computers can be operated with chargeable batteries. The confluence of computers and satellite communications brought in the era of Telematics and Information Technology.

I have already referred to the fact that radio waves can travel round the earth and this is what enabled radio broadcasting. This long range transmission was because of a very helpful feature of our atmosphere which under the bombardment of the ultraviolet radiation from the sun gives rise to striated ionospheric layers and the radio waves suffer repeated relections between the earth and these ionospheric layers. The heights of these reflecting layers range from about 70 to 200 miles.

When Television arrived on the scene, it was realised that one needed a much higher bandwidth to transmit the visual details, the carrier frequencies had to be very much higher than required for radio braoadcasting. But such high frequency waves would not be reflected by the ionospheric layers. The waves would just penetrate through. You might have seen in the old days the series of TV towers every few kilometers on which were mounted "repeaters" to extend the TV broadcast to longer distances. Oddly enough the same feature, namely the penetration of the carrier waves through the ionospheric layers came, as a boon for satellite

communication and satellite TV. Without communication facilities, the satellites would have been thoroughly useless for any practical purposes.

The objectives of Telematics, which is the new buz word is to provide a variety of services for a variety of customers which includes the public at large, the industrialist, the businessman, the student, the scientist, the engineer, the beaurocrat etc. The services offered are telephone, telex, fax, television, cellular phone, pager, e-mail, internet connections and access to the world wide web.

The implications and consequences of such a revolution in information services on society were forecast a couple, of decades ago by Alvin Toffler in his books 'The Future Shock' and 'The Third Wave.' It is perhaps appropriate to say that the future Shock is already here and we are confronting the third wave. The amplitudes of these waves are ofcourse, larger in some of the advanced countries and they will spread soon to all parts of the world. This information technology revolution is a truly sociological and societal revolution, hopefully resulting in a global harmony on many issues.

Nuclear Physics, Atomic Energy and the Atom Bomb

Let me now take on another string of research and development activities which also have had enormous benefits

to society and at the same time have created issues of international concern and debate. X-rays and Raioactivity were discovered in the years 1895 and 1896 respectively. The medical and industrial applications of these are so well known that I need not elaborate on them.

These discoveries along with that of the electron in 1897 and some crucial experiments carried out with light around the same period, led to the formulation of radically new theories 'Relativity' by Einstein and "Quantum Theory" by Max Planck. Classical physics that had been the friend, guide and philosopher of the scientist from the time of Newton, in explaining all natural phenomena in the inanimate world was overthrown. Entirely new and deeper aspects of the familiar concepts like space, time, matter, radiation, forces gradually unfolded. I will give you just a flavour of these developments and their consequences without going into details. The alpha-particle, one of the radiations from radioactive nuclei was used by Rutherford and his collaborators to study the structure of atoms. This simple study of scattering of alpha-particles by an extremely simple technnique led to one of the most profound discoveries namely that the entire mass of the atom is contained in the "nucleus" which is almost a million times smaller than the atom itself. This discovery made in 1912 heralded the age of Nuclear Physics. While the proton had been discovered as the positively charged counterpart of the electron in the discharge of gases, but of much heavier mass, it took a

decade to recognise that this was one of the constituents of the nucleus. In 1932 its companion in all nuclei heavier than hydrogen, the Neutron with almost the same mass was discovered.

In 1939, two German radiochemists Otto Hahn and Fritz Strassman found that when Uranium atom was bombarded by a neutron, instead of an isotope of Uranium being produced, there was evidence for the formation of two separate radioactive nuclei of lower mass. This anomalous result was interpreted by two other German physicists, Lise Meitner and Otto Frisch as evidence of the Fission of the Uranium nucleus. In this process an energy equivalent to 200 million electron volts was released, which was orders of magnitude more than what had been observed in earlier nuclear reactions and exothermic chemical reactions. Bohr and Wheeler carried out detailed theoretical studies of the fission process which was published in the American Journal, The Physical Review. This was the first and last comprehensive article on this subject in an open literature that was available to every one. Immediately after came the appalling realisation of what this fission process could lead to - making of an Atom Bomb. Fearing that the Germans would go ahead of the Allies, the top most scientists of the day outside Germany, Niels Bohr, Einstein, Szilard and others influenced the U.S. Government to initiate and hasten the project on the making of the Atom Bomb. The rest is well known history now. Science had led to the placing of the most devastating weapon

in the hands of the military generals. The dilemma and the resolution of the dilemma in the minds of the scientists who worked on the bomb is reflected in the following words of Robert Oppenheimer, who was the man behind the first bomb and who later when the more devastating hydrogen bomb was being developed, tried his best to delay the project:

> " The scientist is not responsible for the laws of nature, but it is the scientists job to find out ways in which these laws can serve the human will. However, it is not the scientist's job to determine whether a hydrogen bomb should be used. This responsibility rests with the American people and their chosen representatives."

Oppenheimer was one among these who were excited by the technical challenge, but realised the moral repugnance of the whole issue.

While on this subject of moral and social responsibility of scientists, I must make a reference to the case of Wernher Von Braun who developed the V-2 rockets in the 1930's in Hitler's Germany. He was reported as saying that the V-2 was not intended as a weapon of war. Because of this attitude, he was arrested by the Gestapo. As the war was ending and Germany was facing defeat, this great genius of a man manoeuvered to be captured by the American army so that he will have the opportunity of pursuing his life's ambition of space exploration. Von Braun was the man behind the first satellite that U.S. put into orbit in 1958.

Though the first public release of nuclear energy was through the explosion of the two bombs on Hiroshima and Nagasaki in August 1945, in the post war years power generation became the main objective and today the total installed nuclear electric capacity in the world is at the level of about 17% of all electric capacity. France has the record of more than 70% of its electricity generated being nuclear. While it is true that no more than two atom bombs have been dropped so far as part of any war, the proliferation of the nuclear weapons with stock piles of tens of thousands by some of the countries and the anxiety of these countries not to lose their monopoly, has led to issues like NPT - the non-proliferation treaty and the CTBT - the comprehensive test ban treaty etc. Enough publicity has been given to these issues in recent months and sufficient awareness of the public has been built on these matters. In my opnion however, there are several others like the pollution of water by hazardous chemicals, the atmospheric pollution by industrial gases and the dangers consequent to the formation of the Ozone hole, indiscriminate use of pesticides, narcotic drugs need equal attention if not more since some of them can also be used as weapons and more importantly are silent killers of large population. Let me illustrate one example of a well documented case.

A couple of decades ago, one of the most industrially advanced countries, the United States was rocked by what came to be knwon as the Love Canal tragedy. In the

residential area of Niagara Falls there was a dumpsite of toxic chemicals which polluted the sorrounding bodies of water, generated toxic fumes which in turn resulted in a variety of health complications for the citizens - kidney damage, respiratory ailments, and cancer in addition to high rate of birth-defective children. The investigations by the U.S. environmental agencies revealed that in the U.S. alone, there were more than 50,000 sites where hazardous chemicals were buried and in less than 7% of them proper precautions had been taken. The tragedy in Bhopal due to the negligence of Union Carbide, is still greeen in our memory. I think, I have said enough to emphasise that Science and Technology are not unmixed blessings.

The Indian Scenario in Science and Technology

The question has often been raised, why India and China which were on the top of civilization centuries ahead of Europe - or Greece which was the intellectual fountainhead much before Western Europe - did not become the centres in which modern science originated, took roots and flourished. In a very perceptive article entitled "Scientific tradition and other traditions" published in Current Science of July 1995, my former colleague at the TIFR, Prof. B.M.Udgaonkar has discussed this issue threadbare and I will summarise his analysis with which, I totally agree.

The Indian civilization is about 4500-5000 years old.

(8000 years if the pre-Harappan findings in Baluchistan are included). Science based on observation and empirical methods did exist in ancient India and Indian contributions in these fields have begun to be documented to some extent and much more needs to be done - perhaps something on the lines of what Needham did in the case of China. Among the reasons that could have contributed for the lack of origination and development of modern science in India, Udgaonkar has listed the following:

(i) The other-worldliness of the Indian culture

(ii) Suppression of scientific spirit for political reasons

(iii) Conflict between science and religion

(iv) Belief that all knowledge is in the Vedas

(v) Tendency to accommodate conflicting opposites

(vi) Complacency developed during the period when Indians had attained high level of civilization

(vii) Rigidity of the caste system

(viii) Ban on foreign travel

(ix) Handicap of oral tradition

(x) Effect of invasions

(xi) Influence of Buddhism

After discussing in some detail the pros and cons of each of these possible causes, Udgaonkar makes the important point that it is necessary to take a unified view of the trio science, philosophy and culture before arriving at any conclusions regarding the past and a critical assessment of both external factors and internal failures have to be made

from the point of view of the future. It is not clear however, how the conditions in Western Europe were congenial in the 17th Century for the birth of modern science, in preference to Greece. What is however, very clear is that the conditions for nurturing science were ideal in those countries especially since the renainssance.

Let us now examine the Indian scenario in the more recent past. Modern science came to India just about 150 years ago through the establishment of the three Universities at Calcutta, Madras and Bombay in 1850's. The Indian Association for the Cultivation of Science was founded by Mahendra Lal Sircar in 1876 and the Indian Institute of Science at Bangalore in 1910 by J.N. Tata. The names of Ramanujan, J.C. Bose, P.C. Ray, C.V. Raman, M.N.Saha, S.N. Bose, K.S. Krishnan and S.K. Mitra who put India on the map of "world science" is well known to all of us. There is no question that they were all very exceptional men of high intellectual calibre who educated themselves and made outstanding contributions at the highest international levels. Their greatness is all the more since they achieved all this at a time when the country was still very backward in the relavant areas of science and mathematics and journals and books so essential for pursuit of research had to come by sea with a delay of more than 6 months.

What is the post-independence scenario ?

Our first Prime Minister Pandit Jawaharlal Nehru had written even before independence in his famous book

"Discovery of India":

"It is science and science alone that can solve the problems of poverty, of insanitation, and illiteracy, of dreadening customs and superstitions of a rich country inhabited by poor people."

Thanks to his foresight and the encouragement he gave as the Prime Minister and also to the very significant role played by some of the leading scientists immediately after independence, Bhatnagar, Saha, Krishnan, Bhabha, Sarabhai and others a chain of National Laboratories and high level research institutions came up in different parts of the country - the National Physical Laboratory at Delhi; the Natioinal Chemical Laboratory in Poona, the National Metallurgical Laboratory in Jamshedpur, the Central Food Technological Research Institute at Mysore, the Central Leather Research Laboratory at Madras and so on. Gradually, the scientific departments - Atomic Energy, Space, Electronics, Agriculture, Biotechnology, Ocean Development etc. came up, and some of them set up their own Laboratories. The number of Universities increased to more than a hundred. Five Institutes of Technology were set up. Considering all this one has to accept that higher education and research did get a large measure of support from the government. Whether it could or should have been more is an issue which we will discuss later. The question that we should ask is whether the scientific community has lived up to the expectations of

those that gave the support.

Well, as one who belongs precisely to the generation that should answer this question and also as one who was closely involved with one of the premier research institutions of the country namely the Tata Institute of Fundamental Research and had also connections with many other institutions in the country and abroad, my unhesitating answer is 'yes' and 'No.' Unquestionably, there are areas in which India has made quite significant contributions both in science and technology and ofcourse there are also areas in which we have failed. Wherever the activities were built around young scientists of proven merit and ability trained within the country or abroad, and were given the necessary infrastructural support at the right time, success was guaranteed. This was so in the case of atomic energy and space programmes and in some of the areas of basic sciences. Among the areas of basis sciences, I am familiar with, I must mention the fields of cosmic rays, astronomies, ionospheric studies, solid state physics, solid state chemistry, gravitation, liquid crystals and especially mathematics. I am sure there are similar success stories in many other areas too. In the areas of atomic energy and space, India has come to occupy a place among the front liners in the world. The new array of radio telescfopes (the Giant Meter Wave Length Radio Telescope) that has been built near Poona by TIFR ranks as the largest telescopes in the world in the Meter Wave Band. It is a technological marvel and also is one from

which we are expecting very fundamental results of cosmological significance to emerge in the coming decades. Among the technological areas where we have failed, the most glaring one is electronics. We are not even at the level of 0.5% of world production, when even Singapore is at the level of 5% or more. National goal oriented effort was totally lacking and commercial interests of other countries interfered in the earlier years and were not taken advantage of later.

Mediocrity stepping-in in the appointments of Professors, Vice Chancellors in the universities and merit not being the sole criterion in the admission of students was the main factor responsible for the deterioration of even the universities that had established themselves as good centres of research before independence. As you all know the conditions are worsening. The reason for the deterioration of the unversities is not the setting up of National Laboratories immediately after independence. If these had not been set up, we would be no where in the world of science and technology. The priorities now should be to ensure that the universities correct themselves by giving the rightful place for merit and come back to the main stream of higher learning and research. With the emphasis that is increasingly placed on all kinds of reservations, this seems to be a tall order and may be the most detrimental factor in our progress.

Changing Pattern of Research:

The discoveries of X-rays, Radioactivity and electrons, and those that followed were all made with very inexpensive experimental set ups and just one or two scientists were involved in all aspects of these investigations. As we have seen these small efforts led to major technological fall outs. In India, the Raman effect that was discovered by C.V. Raman, Krishnan and Ramanathan in the late 20's also involved very simple, but an ingenious set up. While this style of research still persists in some rare corners of the world, by and large the present day pattern of scientific research has totally changed. Ofcourse, the types of investigations now being carried out necessarily require very high sophistication and large sums of many and team work. Let me give you a glimpse of an extreme case - the discovery of one of the fundamental particles, called the TOP Quark, that hit the world headlines just a year ago.

Detailed investigations on the nature of Cosmic Rays in the period 1930-60 led to the discovery of a large number of particles known as mesons and hyperons. A peculiar characteristics of these particles was that they lived for extremely short intervals of time, much less than a millionth of a second, but still had a specific and important role in the stability of all matter. It was later discovered that they controlled many intricate phenomena in some of the celestial objects that exhibited exotic features. A veritable Zoo of several hundred such particles were

discovered by specially designed man made accelerators in the world in the period 1950 to 1990. A very elegant theory known as the Standard Model of particle physics was formulated to explain many properties of these particles and their interactions. The beauty of the standard model was that all the hundreds of particles could be looked upon as constituted of a few still more elementary particles known as "quarks." This Standard Model predicted the existence of a rather heavy particle known as the Top Quark, which could be produced only in an accelerator of a particular kind.

Such an accelerator was built and has been functioning in Chicago since 1970's. The cost of construction of the accelerator itself was about a billion dollars. The discovery of Top Quark was made late in 1995 with this accelerator. The discovery paper had 493 authors hailing from dozens of institutions all over the world including India. It was truly an international effort. You can imagine the scale of effort that must have gone into the design, execution and analysis, of the results if so many institutions and scientists are involved. Behind the 493 authors there must have been atleast ten times more technicians, computer programmers and so on. Very sophisticated computers had to be deployed for control and analysis.

I would like to highlight one aspect of the construction of such an accelerator which was entirely for

fundamental research with no immediate practical applicatons in sight. When the Director of the Fermi National Accelerator Laboratory was making efforts to raise the money for construction and had naturally approached the U.S. Government, one of the senators who was a member of the subcommittee that had been set up for examining the project for approval, asked Professor Wilson whether his accelerator would hlep in any way the defence of the United States. Professor Wilson is reported to have replied that he did not know about that, but it would certainly make the country worth defending. Prof. Wilson got the money. The Fermi Accelerator was constructed and produced a spate of discoveries of great significance. That is the kind of enlightened support that is necessary if India has to come to the forefront.

The 20th Century Boons and Horrors:

The 20th Century is undoubtedly characterized by a mixture of very beneficial developments and at the same time the most devastating fallouts of science and technology.

On the positive side, we can list the following:

- The release of energy of the atom, development of nulcear power, production of radio isotopes.
- Development of rockets, satellites, satellite communication remote sensing of the earth resources
- Electronics, radio, television, telecommunication, computers, lasers, liquid crystal displays, neon signs, optical fibres, xerox, x-ray machines.

- Automobiles, civilian and military aircrafts, jumbo-jets
- Genetic engineering, heart, kidney, lever transplants
- Wonder materials, nylon, teflon, plastics, matalics, ceramic composites, dyes
- Eradication of infectious diseases - small pox, cholera, plague, antibiotics, cancer diagnosis and treatment, (CT Scan, NMR and PET)

On the negative side we have :

- The atom bomb, the hydrogen bomb, the neutron bomb
- Missiles, ICBM's (Intercontinental ballistic missiles)
- Star Wars, Spy Satellites
- Pollution of food stuffs, water and air by toxic chemicals, radioactive leakages
- Noise pollution by factories, vehicles, air craft
- Uncontrolled growth of cities, sky scrapers, slums

The century is also characterized by fundamental research that has given deeper insights into many aspects of working of Nature and of the Universe at large. In particular, we have now very detailed understanding of

- Ultimate constituents of all matter and radiation - the forces operating in the various domains and the underlying unity behind diversity.
- The immensity of the universe - the existence of celestial bodies whose characteristics are very different from the near by objects - neutron stars, balck holes
- Possible scenarios of creation of the universe - the Big Bang, the details of physical and chemical evolution that

has precedeed the biological evolution.

- The constitution of the human body in all its details, the biochemical operations that go on in each cell of the human and animal bodies, many aspects of the nervous system and its connection with the brain.
- The causes and cures of a variety of diseases

This is surely a partial list and is biased by my lack of familiarity with many fields of science and technology. Nevertheless, it gives a general picture of the role that science and technology have played in the century that is coming to an end.

What next ?

The 21st Century:

One can say with some confidence what the main directions of development will be, atleast in the early part of the 21st Century:

- Information Technology (IT) with all its ramifications on all aspects of society - trade, commerce, education, industrialisation, patterns of administration will be the front runner.
- IT will be aided further by newer developments in materials - Nano - technologies as they are called, further miniaturisation of electronic devices, opto-electronics and photonics
- High temperature superconducting materials which are on the threashold of realisation for commercial purposes,

will revolutionize transportation, power transmission

- Nano-technologies, Nano-electronic materials will bring in era of micro-satellites which may replace the Geo-stationary satellites for communication
- Developments in the field of cancer research and cancer treatment may lead to the cure and eradication of this dreaded disease
- The employment of the newer techniques of tomography - the NMR, the PET etc. may lead to much deeper understanding of the neuronal networks and the functioning of the brain., which may help in the treatment of mental disorders.
- There will be increased efforts in searching for extra-terrestrial intelligence, as well as in creating in the laboratory artificial intelligence.
- Much greater emphasis on research and utilisation of Solar Energy because of dwindling conventional energy sources and reservations on nuclear energy.
- Off-shore and Deep Sea Mining from the point of view of mobilizing more resources

Society and Science:

Almost all of the accomplishments of science and technology that I have highlighted so far are due to the efforts of a few countries of the world though many of the benefits (and evils) have been shared by pratically all countries of the world. While India has all the potential it

has not been a major player so far, while much smaller countries which were considerably backward when India got its independence, have forged ahead. This is essentially because

(i) We have fallen behind in our educational system at all levels, especially at the advanced levels so necessary for nurturing high level Research and Development

(ii) Large number of young bright students are leaving the country for better education and prospects abroad.

(iii) We have no system by which exceptional opportunity is provided for exceptional talent. It is a recognised fact that in the long run the progress of a nation depends on the outstanding performance of a few.

(iv) The outlay on higher education and research is hopelessly inadequate. The countries which were behind us have marched ahead because of much higher level of investment in science and technology.

(v) While one can understand the difficulties of the government for enhancing the financial outlays for the Research and Development because of other needs and compulsions, there is no reason why the industrialists who are the direct beneficiaries of higher education, technical education and Research and Development should not be enlightened

enough and come to the rescue of the nation by contributing liberally towards education and research.

As we come close to stepping into the 21st century, the message for us in India is loud and clear. We have to reorganize ourselves in the rapidly changing context of the world scenario in science and technology and instead of continuiing to be at the receiving end should become aggressive contributors to the world reservoir of scientific knowledge and become dominant exporters of technology. Now is the time to encourage the local talent to the maximum and bring back the experts who have migrated to other countries. This calls for an enlightened approach where merit and performance should be sole criteria for judgement and unrestricted support. A better quality of life for all is the primary concern of any democracy. This is possible only if the country becomes sufficiently affluent, the per capita income goes up and the environment is protected and made congenial for disease free living. Several countries have proved in the recent past that all this is possible in a reasonably short time through progressive policies and liberal support of science and technology. It is time we wake up to these realities. This is the primary responsibility of the Indian Society.

Perhaps, I have over-emphasised the role of modern science and technology in influencing and conrolling the quality of life of the Indian Society in the future without

giving sufficient weightage to its inheritance of a rich culture, its deep-rooted philosophical moorings and religious tolerances - in short the 'eastern wisdom' that has tempered the society from becoming too materialistic in its outlook. In fact one may wonder whether one cannot go back to those golden days of prosperity that were prevalent long before the advent of modern science. The answer is clearly 'not' because of several irreversible happenings. Compared to a thousand years ago the population has increased atleast twenty fold, the resources haved dwindled and even to meet the minimal requirements of food, water and shelter, one needs the services of modern technology. Also, it is no longer feasible to isolate ourselves from the rest of the world. Clearly a strategy has to be worked out by which we preserve the best of our tradition and at the same time utilise the power and benefits of modern technology.

I would like to end this talk by quoting a renowned scientist, educator and statesman, K.T. Compton, who was the President of the Massachusetts Institute of Technology, Boston:

"..... Truly the urge to live is basic; it is a feature of biological behaviour of cells and tissues, of the instinctive reactions of all animals and of the conscious planning and effort of human beings. But though mankind shares with all other forms of life the urge to live, there seems to be another urge which is peculiar to man and distringuishes him from all other animals and other living

things. It is the urge to live better.

It is man alone, of all living things, who has consciously and to a staggering degree changed his ways of living ..... Man has employed imagination and logic, he has invented, he has developed new skills, he has created new concepts of values, he has manipulated the materials and forces of nature for his purpose. He has done all these things because of his urge to live better.

While it is occasionally pleasant to think back, it is far more profitable to think ahead. Adventure and progress and exhibition of achievement always lie in the future, and their planning should be the concern of the present."