# Scientific Developments: A Vision

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Science has been undergoing an unusually long and intense revolution in the last 100 years, shaping itself and in turn reshaping the society, which makes it. There seems to be no stopping, as nature, which is being looked into collectively by an active eye of human society, seems inexhaustible, challenging, inviting and more importantly benefiting. It is hard to comprehend the current developments in modern science, in the present explosive mode. It is making unsuspected interconnections and becoming an expanding web. I will touch upon some on going developments in some corners of science that I am familiar with, where a kind of blurred vision may be possible. Global sharing of knowledge and in particular detailed knowledge of the on going revolution in science is possible almost free for every one, thanks to internet and communication revolution. Knowledge based industries, the central theme of the present meeting, can grow in imaginative ways and benefit and perhaps even contribute to science developments. I will make a speculative suggestion for 'knowledge based cottage industries'.

## Introduction

Science is in an exponential growth mode. It has been so for quite some time. It fosters new technologies and new comforts for humanity. It touches our every day life, directly and indirectly, and even the life of the fragile eco system in a way we fear and do not completely comprehend. While the innate 'nature' of human individuals have not been much affected directly, the nature of our society has got significantly modified by scientific developments in the last couple of centuries. Society, political establishments, world economy, inter country transactions, nature of conflicts, nature of wars, nature of revolutions and to some extent even value systems have got massively reorganized. It would have been impossible for any one to have even roughly imagined the state of changed society, political systems as well as science of the present times, two centuries ago.

Things continue to change. Modern science is a new power that humanity has acquired. It is important to understand how powerful it is. The power science possesses is also scary. It is important to understand how to use it. Finally we want a society that will be more happy than it is now, peacefully coexisting with the ecosystem and mother earth, of which we are an integral part.

This meeting is about knowledge based industries. There is a new scope in these industries, to use recent developments in science in imaginative ways. This applies to even countries which are not active participants in the actual revolution in science. This is possible because of the internet and communication revolution we are witnessing now. Global sharing of knowledge is possible and almost free. This is more true in the field of science, where there is a conscious attempt by the scientific community to keep their discoveries and developments as open as possible and as free as possible. One of the prime examples is the phenomena of open archives. Through this, almost the whole body of modern and to some extent old scientific knowledge is made freely accessible, in an unprecedented fashion. Knowledge based industries can surely benefit by this.

I will divide this article into four parts, having in mind professionals who are not scientists. I cursorily touch i) nature of science, ii) nature of scientific activity in modern times, iii) some active areas in science and my own blurred vision and iv) interfacing knowledge based industries with the ongoing scientific revolution.

## Nature of Science

Science is about the nature of material and not so material universe. The belief is that the complex and incomprehensible behavior of things around us, from the properties of atoms and molecules to the life of an ameaba, to questions such as birth of our universe can be studied and 'understood' in a framework, that involves systematic observation, organization, experimentation, conceptualization, use of logic, arguments, mathematical modeling etc. Science is about the big, the small and the complex. It seeks to find guiding principles, universal laws, that govern the bewilderingly many aspects of this wonderful material universe. There is no denying that science has had enormous success so far.

The faith of human beings in its own ability to comprehend things deep inside the materials around us, space, time and matter far separated from us, inaccessible to our five senses, is itself a miracle. While scientists have studied about evolution and maturing of thought and language, through various life forms during millions of years, the science of evolution of human mind is more complex than the science of material universe we are after.

Nature of scientific enquiry tends to be impersonal and to some extent value free. It is a search after some kind of irreducibel minimal 'truth', a framework. Economy of description is one of the basic tenents. It goes beyond what one observes or collection of facts available. It is very often guided by certain philosophical attitudes,that is not part of scientific teachings. This is well known if one looks at scientific career of men like Einstein. There is also something personal about science, the way art is. There are many styles and many ways of doing science, within its own rigor, norms and limits. There are heroes and followers, camps, biases and conflicts: after all science is a human enterprise. The strength of science, as it is practiced now, is that it has to be objective and nature is the final judge. It has to answer nature, which it is trying to explain. Its flow has to agree with nature's flow, otherwise it will be falsified. Sciences at any given time is falsifiable in principle, as it is an exploration of infinity. Science evolves and is very dynamical and ever ready for a new understanding and radical changes.

Scientific truth should be universal: understandable, testable, reproducible and provable by anybody given identical conditions. It is the human mind, through interaction with the material universe, that discovers science. However science, a product of mind, comes out of mind as something concrete that can be put on the table for every one to read, see and confirm by experiments. It avoids aspects of the very instrument of science, namely 'mind's eye', spirit and related enquiries, Because they are very personal and can not be shared and are deeply buried in one's own mental world. This is why non-scientists, who are often fascinated by analogies, metaphysics, issues of science and spirit etc. are annoyed by the very frigid attitudes of practicing scientists, who tend to be conservatives and avoid talking about 'issues of mind' and related speculation. This conservatism actually protects science and is its strength.

Modern Science is quantitative and that makes science very powerful and also brings in a new character of precision. It is sharp, objective and less vague compared to may other human endeavors. If one looks at a modern scientific instrument in the lab, such as the scanning electron microscope, which can locate the positions of foreign atoms on a graphite surface for example, the precision and the quantitative character at every stage becomes clear. Einstein's general theory of relativity predicted a tiny bending of light by gravity quantitatively. It was measured precisely and confirmed during an eclipse by Eddington. This sharpness, extends to being able to predict the current age of the universe ! Last years Nobel Prize in physics was partly for precise measurement of frequency of electromagnetic waves. This unprecedented precision is not just an academic curiosity, but has practical use in the modern world that is ruled by the communication revolution.

Experimentation, quantitative analysis and mathematics are various components of science. When mathematics enters science in a big way it becomes a hard science and progress is very rapid, one can say by leaps and bounds. Physics has been witnessing it from the time of Newton. Biology, believed to be a 'soft science' is witnessing it now, through powerful entry of very precise quantitative experimentation and some mathematics, thanks to a deep interaction with physics. Modern computer, once again a biproduct of modern science and technology, is repaying and making rapid progress in all branches of sciences and making science even more powerful than before.

Having made some statements about nature of science, it is important to make a brief statement about scientists. Practitioners of science, like the larger academic community to which they mostly belong, are often influenced by the very nature of their profession; they tend to be analytical, unbiased, question authorities, non-manipulative and (some times) naive to the annoyance of 'practical' people who manage things. In the process scientists like the general academic community, play an unrecognized role: they are one of the torchbearers and safeguards of some of the important values needed to keep the rapidly changing society honest. By the international character of scientific activity, scientists all over the world operate beyond man made and some times artificial, political and racial boundaries. In the process, without their own knowledge, like most academics, they also become messengers of peace and and an integrating agent of the world at large.

**Nature of Scientific activity and organization in Modern Times**

Science is a sophisticated outcome of interaction of human mind with the material and not so material unverse. In every thinking person there is a scientist. With practice it can be nurtured and one can become, what one calls a professional scientist, and join the game. It is like any other form of human activity.

Science has grown over centuries. The way science is done and practiced has also evolved. Scientific enterprise of Newton's times and even Raman's times are very different from the present one. What used to be a grand Natural Science has got fragmented by its own weight, into botony, zoology, molecular biology, physics, chemistry, etc. In the current explosive mode, while new connections are being made, it is also getting more and more partitioned and is becoming more of specialists activities.

Modern science is a highly organized activity. It is organized by governments, industries, societies, universities, laboratories etc. The growth of modern science is a remarkable interplay of individual talents and collective strength. Unlike the past, very few individuals are able to practice science in isolation and compete. There are exceptions in theoretical science such as mathematics. The collective aspect also makes interfacing with technology somewhat easy. Science flows to technology rather fast.

There are big sciences and small sciences. Big science is particularly common in physics and to some extent biology. Example are the powerful accelerators (based on international collaborations) that consume billions of dollars to discover a tiny little particle, for example a 'quark' that is believed to be inside a proton. There is big science in astrophysics and space programs. Our own country boasts of the powerful radio telescopes in Pune and Ooty. Big science is organized very differently from a laboratory in an unversity physics department.

Big science have had unexpected impacts in modern society. For example seeds of the idea and first implementation of what has become inevitable, as communication by email and the very 'world wide web' is a spin off of this kind of massive collaborative science activity.

Modern sciecen is expensive. The more advanced a country is, in terms of its GNP, the more it spends on science. For example USA spends, maximum amount of money for science. According to some statistics I heard recently, in absolute scale it spends about 100 times more than India.

Science is international, at the same time strongly western; west continue to set the agenda. It is slowly changing, as recently affluent Japan is spending more money and putting enormous efforts on science and has started setting the agenda in sub fields of science. We expect more such outcome from China, Korea, Taiwan in the coming decades, as they have started spending more money and there is a conscious effort to improve their science and become competitive. As far our own country, it is fair to say, we are yet to join the big race. It is heartening to hear about recent realization of this reality and desire to take some steps in government circles - but it should be put to action, in thoughtful and very serious ways.

**Some Active Areas of Science**

A large part of science, called basic science, is a result of sheer curiosity. It simply wants to understand nature as clearly as possible. It has no application in mind. Invariably there are spin offs and profound applications. In the field of mathematics, some of the discoveries of Ramanujan, related to prime numbers, for example Ramanujan's partition theorems have found application in modern cryptography, which apparently helps international banking, as well as secret communication in defense.

However, modern science, because of nature of funding, is more and more driven by governmental needs and societal needs. For example, during the last two world wars science saw an enormous progress, originating from certain heavy demands from defense and politics. Good examples are a rapid growth of nuclear science, radars and various pre semiconductor day electronics. In modern times, defense and defense industry, electronics industry, energy industry, oil industry, transportation industry, medicine technology and agriculture continue to fuel science. In advanced countries, as most of the basic needs are fulfilled, people are more conscious of their health, happiness, well being and conquering dreaded diseases. So health needs of advanced society drives science of biology and related areas.

However, it is fair to say, that once certain field of science is funded, whatever may be the reason behind, a serious study of that aspect of nature always leads to new discoveries and truths, that go beyond the original intentions.

**Micro and Nano Electronics - there is a Mansion at the bottom**

Richard Feynman, one of the premier theoretical physicists of last century, an universalist, to whom science had no boundaries, wrote an influential article titled 'There is more room at the bottom'. He was propounding use of objects of nano meter (one billionth of a meter) such as a molecule to be used as electronic components such as a transistor or a rectifier. He also realized that the new laws of physics called 'quantum mechanics' had to be used in a fundamental way in building and manipulations of these devices. I heard him at a colloquium at the then Bell Telephone laboratories, at Murray Hill, NJ, USA, back in 1984, where he discussed ways of 'wiring' these nano scale components. Feynman was ahead of his times. Feynman's dream is being realized now, partly. Feynman was modest. By looking at what is going on now, it wont' be an exaggeration to say that 'there is a mansion at the bottom'.

The field of nano electronics is in the forefront of science and technology. It has become an integral part of what is called, material science, nano science, molecular electronics, etc. Here, physics, with all its experimental, theoretical and computational power, has become a key player. It is one of the most active areas in modern physics. I will discuss in what follows this field from the point of view of further miniaturization, from micro to nano electronics and then possibility of altogether new computers called quantum computers.

Let me begin with the example of radio. During my school days, we used radios that had vacuum tubes (used to be called valves). They occupied a big space; it was a miracle still. Electromagnetic radiation (or radio waves), that was created in Tiruchi was picked up by my home radio at Madurai. If some one sings at Tiruchi it is impossible for me to hear him sitting at Madurai. Radio science and technology enabled one to pick up a feeble electromagnetic signal, amplify it, extract the voice or music and present it in audible form, nearly instantly ! If one sits near a calm pond and create a wave, by dropping a small stone, you will realize how feeble the height of the ripples become as they move farther and farther. The same happens to the electromagnetic ripples produced at Tiruchi, when they reach Madurai. The power of the then electronics was the ability to isolate it from among the enormous signals that is present at a given place at any given time and amplify it and so on.

Detecting feeble signals demanded very feeble objects, as receivers. It fact it is the feeble electrons in the metallic antenna that pick up the signals and produce tiny electrical currents. These electrical currents got amplified in vacuum tubes. In modern 'solid state radio', it is the same set of electrons that do the job; but valves are replaced by tiny pieces of 'doped' semiconductors, such as p-n junction and field effect transistors. So modern electronics got liberated from vacuum tubes; electron flow is controlled in small solid state components such as a tiny transistor. They have a size of one micron (compared to a few cm valve, it is about 1000 times smaller in size). It follows that in a volume occupied by one vacuum tube, we can pack 1000 x 1000 x 1000 ( = one billion or 100 crore) number of solid state transistors !

This is the power of miniaturization that lead to the emergence of what is called micro processors. What used to be one of the most powerful computer in India, IBM 360, occupying a big room in early 70's, which we used proudly as research students at IISc, Bangalore, has lost its importance, in terms of speed, memory etc., compared to a modern low end note book computer. Big telephone exchanges are replaced by tiny boxes, doing even more sophisticated and faster jobs.

This miniaturization involves use of physics at every stage. For example field effect transistor (FET), one of the common components in modern electronics, uses what is called quantum mechanical tunneling, that is unknown to classical physics. It is a pure quantum effect, a consequence of a wave property that tiny particles like electron posses. We will come back to it later.

As I said earlier, the field of nano science is very closely tied to what is called material science and nano material science or functional material science. One wants to create new type of materials and understand old materials. The idea is to make them do specific functions. One needs to do manipulation and obtain desired behavior, in the form of electrical, magnetic and mechanical responses at micro to nano meter scale. For example, memory storage in terms of large volumes (giga bite, to tera bite to peta bite ..) in small devices, and being able to read or change the contents are some of the key problems. Material and solid state science, with the plethora of phenomena that it has discovered in the last century, superconductivity, ferroelectricity, quantum magnetism, Josephson phenomena, etc., is able to come up with new ideas and new devices for memory and manipulations.

For a long time silicon (Si) was dominating the semiconductor industry. Now there are many viable alternatives, starting from ceramic oxides to carbon nano tubes to organic materials. Novel materials, inspired by highly functional molecules such as DNA, RNA and proteins are being synthesized and completely novel ideas have been proposed. The idea of self assembly of a circuit is a good example. As the circuit elements are too small to be handled, wired and assembled by our hands and forceps, what if we use the rules of DNA pairing conveniently and instruct them to create a circuit ? In fact it has been demonstrated. I was talking to Uri Sivan, who demonstrated this along with his colleages, once. He did all these things in a laboratory with a couple of rooms and relatively inexpensive instruments. This is a good example of small science that is idea driven. Material science seems to be in an ever expanding mode. There is plenty of scope for practical but imaginative ideas.

It has become a combinatorial game; in fact there is an active field in materials science called combinatorial materials science, where new materials are synthesized in tiny amounts using certain permutation combination logic, thereby making the search for new materials more exhaustive and fast. Of course, it is all computer controlled.

There is a new entry in this game called carbon nano tubes, which holds a lot of promise. According to one study, it is the most active sub branch in physics at the present time. I am familiar with this, as we do some theoretical work with this and related graphene. Graphite is an allotropic form of carbon. We know it too well - it is in our pencil tips. Strongly bonded carbon atoms form a two dimensional net or sheet called graphene. The carbon atom with their bonds form what is called a honey comb lattice, it looks like a beehive. The atomic net graphene is a metal. When you stack graphene layers, they bond weakly and you get graphite. It is because of this weak bonding when you write with pencil it is soft, and graphene layers get peeled off silently.

Under some growth conditions, graphene sheets role (like rolling a cigarette paper) and form a tube, whose diameter is of the order of nano meter, but length can be as large as a centimeter. Thy are robust. They are ideal candidates, because of their nano thickness, to become molecular wires that can connect molecular transistors in future electronics. Under some condition, they themselves can become transistors. Thanks to imaging methods in physics and ability to manipulate and study their electrical properties, we know a lot about them. They are going to be the future electronics. It will be safe to say that 10 years from now your cell radio will have components made of carbon nano tubes.

Tiny pieces of graphenes, that is a pice of mono atomic layer of carbon, of the size of one micro meter have been isolated (peeled) and one can essentially make electronic devices with them ! This is a new revolution in our field. This is going to feed to micro and nano electronics for sure. It has such wonderful physical properties, including some esoteric properties, that theoretical physicists have been dreaming of, like realization of a massles Dirac electron, Klein paradox, and certain genuine relativistic quantum field theory type effects such as a Lorenz boost (found by our student Vinu Lukose, colleague Shankar and myself) etc. This is one of the few systems, which gets equal attention from some of the theoretical physicists who live normally in their 21 dimensional world and material scientists who toil hard in the basement of their laboratory, to make nano materials, using crystal growth apparatus and furnaces. Like carbon nanotube, graphene is a safe bet, which should see useful applications sooner or later.

There are other competitors, organic molecules with what is called unpaired spins, that can do the job of a molecular transistor. There is a whole field called spintronics, where unusual 'spinning' property of electrons are used to create devices. This has a great future and it is likely carbon nanotube will get integrated with spintronics in future. Infact, in our own work, we have suggested some thing called 'Spinonics', where tiny packets of spinning objects in a sea of electrons do the job that an electrons do in the normal electronic devices. So there are many possibilities. Sky is the limit at the bottom there.

I have only touched upon the field of nano science. Literally dozens of key developments are taking place every year. It is safe to say that Moores law will be satisfied for a decade. Moore's Law is the empirical observation that the transistor density of integrated circuits, with respect to minimum component cost, doubles every 24 months. We are not going to hit a rock bottom. The bottom is soft and accommodating.

**Quantum Computers**

Our brain is often compared to a computer. It has nearly a billion neurons (similar to components of an electronic device) that are 'wired' as a complex network called neural network. It does wonders as we know very well. Modern day computers, with all their sophistication is yet to match the human brain. May be, one day, the collective effort of humanity will produce a machine that is as powerful as one human brain. What is remarkable is that there is a new computer, perhaps in the horizon already (?), that will do this job and perhaps more. This is the story of quantum computer I will very briefly tell. It is a remarkable story, where some of the finest creation of human mind in theoretical physics (may be all of science), that eludes philosophers and philosophies with all its strange and counter intuitive properties, are at work in making a miracle of a quantum computer. This is the realm of quantum theory, which once used to be an advanced topic, dreaded even by physics students. Now it is studied by some electrical engineers.

Quantum mechanics is strange - it is an understatement. It is a brain child of physicists of last century, starting from Planck, Einstein, Bohr, Schrodinger and so on. Phenomena in quantum physics defies our common sense and conventional wisdom. It is a miracle that human mind has been able to comprehend and find the existence of such a physics at atmic scales. Deep intuition of physicists together with clue from nature in the form of a variety of experimental results over decades, and more importantly help from mathematics has helped physicists to build a rich structure - quantum mechanics and quantum field theory in the last century. After having been constructed, it has succesfully explained a series of strange results and phenomena, happening in the world at nano and atomic scales. In has also predicted unusual and new phenomena, many of them have been confirmed. Quantum mechanics is so important - it is responsible for the very stability of matter, that you and me are made of. Without quantum mechanics, if the world were to use the laws of classical physics alone, matter will collapse and radiate into nothingness. All bonding that occurs in materials, biology are quantum mechanical. Biochemical reactions are fundamentally quantum mechanical. Photosynthesis, the very first support phenomena for life of plants on this earth, is a quantum phenomenon.

There are books written about the strange behavior of quantum mechanics. From mathematical point of view it is a sheer beauty, Hilbert space, matrix mechanics, operator algebra, Fock space, Pauli principle and so on. From phenomena point of view, apart from what I said before, superconductivity, the magnetism that you and me are familiar in standard magnets, notions of electrons, holes in semiconductor devices, p-n junctions etc. are quantum mechanical.

Let us come to quantum computers. Laws of quantum mechanics allows for a strange state of matter, called a 'quantum superposed state'. Imagine a molecule made of two atoms, where one electron is rattling between two atoms or shared between two atoms. This happens in hydrogen molecule we are familiar with; here, two electrons are rattling between two protons.But if you look at it quantum mechanically, it is a strange state in which an electron is simultaneously there in both atoms ! It is as good as saying that I am simultaneously present inside this hall and outside this hall. This possibility of simultaneous existence does not stop there. It allows for an infinite number of different possibilities of simultaneous existence, which can be easily written down very precisely mathematically. But physically, it is quite counter intuitive. It is true however, because this alone can explain the experimental observations. Further, this idea also predicts many new effects which are also observed experimentally. So there is no way of escaping quantum mechanics at the atomic scale !

Starting from Richard Feynman, people wondered whether such a strange quantum state that is realized in atomic scale can be used to our advantage and used in computers and develop new quantum mechanics-based algorithms. After all, in a computer there are basic elements called switches or bits, that make what are called elementary gates (AND, OR, NOT, NAND etc.) that perform elementary logical operations. Standard gates can be in two states called on or off (mathematically a binary state, 0 or 1 ). If only you can construct these switches or bits, using an electron or an atom (that obeys laws of quantum mechanics) you can create strange switches that are on and off simultaneously and that too in infinite number of possible states. Since these bits obey laws of quantum mechanics they are called 'qubits'. It is a different problem how qubits will communicate among themselves and really work as a computer. That is going to be the problems of nano scientists and nano engineers.

The very possibility of realizing a qubit is tantalizing and opens new windows into a new world of quantum computers. Deutsch (1985), following Feynmans suggestion (1981) suggested an algorithm now called Deutsch algorithm, where qubits do jobs faster than their classical counterparts. This was proof of a principle, not building of a quantum computer. But this was a key step, beginning of a revolution. This and later works by Shor (1994), who proposed a quantum computation algorithm for prime number factorization and a search algorithm by Luv Grover, essentially showed that a computer that operates on quantum states can perform tasks that are beyond the capability of any conceivable classical computer.

Why are quantum computers better than classical computers, assuming they have the same number of components for example. This is related to a massive parallelism that quantum states offer. I can not go into the details. It is technical. But the statement we made earlier, that in a given qubit infinite states 'superposition' states are realized gets multiplied each time you add a qubit. The end result is that quantum computer starts having a massive parallelism. A well known example is called a travelling salesman. There are 200 cities, which a salesman wants to visit (each only once) and of course he wishes to find the shortest route. He can not fnd it as the total number of routes, if you count is about 2 to the power of 200 ( a large number ! ). Even a modern computer will find it hard to enumerate all paths and choose the shortest one. A quantum computer can apparently do the job very efficiently. What the quantum computer will do, in principle, is to enumerate all the paths simultaneously ! There is a massive parallelism in its internal state dynamics. This is not like a present day paralellel computers that we are familiar with. The above task of finding the path of least distance can not be done by the most powerful computer on earth today, with its millions of components in a finite time, when the city is as large 200. However a quantum computer with less than 1100 elements can do this job. It is said that the theoretical capacity of a quantum computer that has a few hundreds of qubits will overwhelm the computing powers of all the present day computers of the world put together.

Such is the power of quantum computers. No wonder Microsoft Research, a research wing of Microsoft corporation, has invested money and have established a center called 'Station Q' at University of California, Santa Barbara, California, USA, which is headed by a renowned mathematician, Freedman, a Fields Medalist (equivalent of Nobel Prize in Science). The mathematical challenges posed by quantum computers have invited very eminent minds into this game, including persons like Freedman. It is a remarkable field where pure mathematicians and condensed matter physicists like me work together. These theoretical developments have opened up whole new fields called theory of quantum computation, quantum communication theory, quantum cryptography, where many physicists are active. In our own Institute group of Rajiah Simon and Sibashish Ghosh are involved in key fundamental issues such as quantum entanglement and quantum information processing. A deep understanding of the structure of quantum mechanics, both physical and mathematical, is necessary.

All the above developments are what are called theoretical developments. Showing a way to experimentalists that such a thing is possible if only one can build a quantum computer in the laboratory. These theoretical developments have kindled the imagination of theoretical and experimental physicists who want to create physical realization of qubits. There is an intense search all over the world. Unfortunately, I know of no groups in India involved in this fertile and inviting field. There is sufficient expertise available, if only one can put together a team it can do wonders.

There is no free lunch, as they say. There are many hurdles in the practical realization of qubits. Many of them are very skeptical and are of the opinion that the hurdles are unsurmountable. Quantum computers are only nice game that theorists will keep playing for a while, till they get tired. But there are optimists. I am one of those optimists for no logical reason, it is simply a gut feeling. One of the chief hurdles is called decoherence, the quantum state that is offered by a qubit should be protected from disturbance from environment. Otherwise, the qubit will get 'entangled' with the environment and loose its 'purity', which is necessary to do a quantum computation.

There has been many imaginative proposals to overcome this hurdle. One of the promising candidate, chiefly inspired by work by Kitaev is called 'Topological quantum computation'. Strange are the ways connections are made in modern science. In a very different context, in the field of quantum solid state physics, strange states of matter such as topological excitations in polyacetylene, high temperature superconductors, spin-charge separation, fractional charge in quantum Hall states, were happening. This become very popular with the discovery of high temperature superconductivity in 1986 in some ceramics. My own work has been in this front in the context of high temperature superconductors, beginning with my early collaborataion with P.W. Anderson, another universalist, a Nobel laurage from Princeton, also a founder of Santa Fe Institute, which has inspired creation of the current 'Forum for Global Knowledge Sharing', which is conducting the present International Seminar.

What was found in these 'strongly correlated electron systems' was that certain quantum mechanical objects emerge, have strange and unexpected robustness, which kept showing in various experimental results. Their quantumn character is protected by certain internal quantum mechanical rigidity that emerges in these systems. They do not decohere easily. Kitaev used this in imaginative ways and along with others became responsible for the beginning of the field of topological quantm computation. This holds a great promise. There is an upsurge of activity in this particular branch of quantum computation in the last few years. Because people have suggested that topological quantum computers could be in principle constructed from strongly correlated electron systems that I alluded to earlier. One of the primary candidate is certain objects called fractional charges in quantum Hall states, intensely studied by Shankar Das Sharma of Maryland and collaborators. Another candidate is vortex states of a strange superconductor called strontium ruthenate. It is heartening that, when Rice and Sigrist and I independently predicted this strange superconducting state of strontiuam suthenate, during 1996, we had no inkling that it will be considered a candidate for quantum computers ! Kitaev himself constructed a model for topological quantum computation, now popularly known as Kitaev model that realized some of the dreams we had in the context of high temperature superconductors. This model has again become important, because there has been suggestions that it could be experimentally realized in what is called cold atom optical lattices. Our own group at Matscience (Saptarshi Mandal, Shankar and I) have recently found interesting results in this model.

The field of quantum computation continues to be one of the most active fields in physics in modern times. Breakthrough in both theory and experiments are expected. Will there be quantum computers of reasonable size 10 years from now ? As I said earlier, I have no logical arguments or vision arising from deep insights. But a country like India should bravely invest in these efforts.

**Molecular Biology and Genetics**

DNA is the genetic basis and blue print for of all known forms of life, that we are familiar with on this earth. After the discovery of the structure of DNA in the mid 1950's by Watson and Crick, the field of biology got completely transformed. As DNA and an associated protein machinery orchestrates the phenomena of 'life' with all its splendour, the attention of biology and even chemistry, physics and mathematics has turned into understanding this wonderful 'strings of life'. Sophisticated instrumentations from physics, starting from x-ray crystallography to recently optical tweezers has helped revolutionize the field of molecular biology and genetics.

Key phenomena in life have their basis in set of molecules and thousands of different proteins. Understanding of biological functions on molecular and structural basis is the general field of molecular biology. Never before in the history of humanity, so much intellectual effort has been vested by so many minds collectively and individually on one problem. The results in the last 5 decades or so has been rewarding. We know a lot about molecular biology and genetics. Dozens of Nobel Prizes have been awarded. Still our understanding of the phenomena of life is far from complete. It is a challenging problem and many aspects are formidable because of the sheer complexity. We do not have a full understanding of even the simplest form of life, namely a single cell ameaba. We are getting there. What was thought of as an impossible task, namely finding the full genetic code of human DNA, called Human Genome Project, has been completed before time. It was a monumental international effort, another example of what international collaboration can do when researchers put their mind together. Finding the genetic sequence is the beginning of a whole set of problems. Completing the human genome project was only the tip of the iceberg. There is so much underneath and there is so much in the code.

Finding meaning in the one dimensional genetic code that is made of just four different letters A, T, G and C (standing for four nucleotides Adenine, etc.) is a daunting task. The sequence is too long, more than a billion letters. It is the blueprint of a life of a blue whale or a butter fly. Mathematicians, statisticians, computer scientists, engineers, chemists, theoretical and experimental physicists and others are contributing to the real understanding of the mysterious code. My own young theoretical physics colleagues like Rahul Siddharthan are putting their might into understanding these mysterious codes. They tell me that significant progress is being made on monthly basis. But the end is nowhere near. Perhaps this is not the way to approach or solve the problem of life ? Decades of efforts has lead us to this, of a molecular basis of understanding life . We have to solve the problem. It is fair to say many small problems of practical relevance are getting solved on the way. That is why the whole field of biotechnology, drug design etc. are alive and making rapid progress; it is a big part of the knowledge-based industry we are talking about.

An outsider like me can smell the excitement, when I talk to these colleagues and read papers in journals like Nature or Science. Much progress will be made in the future. Dreaded disease like cancer, where certain types are already under control, is likely to be overcome. The time is not too far. Many good things are likely to happey for a healthy society.

**Open Archives, Knowedge Based Cottage Industries etc.**

Most popular knowledge based industries seem to be software, communication, biotechnology and drugs. But availability of internet, a platform for free sharing of Global Knowledge creates new opportunities, as it is well recognized. Our imagination alone limits what one can achieve with it. In this last section I will discuss how, all of a sudden, the wealth of scientific results and detailed informations, that can take you to the very frontiers of various developments in modern science are available for free and also easily accessible. Second I will speculate on how one can imagine Knowledge Based Cottage Industries, using this accessible knowledge from science.

I have talked to various people, including teachers in colleges, about ‘Open Archives’. Unfortunately many are not familiar with this new phenomena. So I take this opportunity to proudly talk about this phenomena, which started as a creation of handful well meaning scientists. It has ignited a phenomena of free sharing of scientific knowledge, that can not be stopped. It is feared by the billion dollar publishing industry. In fact, one of the aims of our forum ‘Forum for Global Knowledge Sharing’ is to get in this activity in a serious way.

When I was a Ph.D. student in the early 70’s and even later, source of new results on latest scientific developments are research journals. Being expensive, research journals were not subscribed in most libraries in the universities. (This is true even now). You could in principle write to the authors and request for a preprint or a reprint. It will be received in a couple of months, if the author posts a bulky paper by surface mail. It took effort and one had to wait. We also used to do literature survey, through voluminous abstact journals such as Physics Abstracts and so on. Even at that time, high energy physics friends from Stanforld Linear Accelerators in the USA had already started a free and useful service. They requested the authors to send one copy of their latest preprints to one central place. They collect them and send the titles of new preprints in the field of high energy physics, once in a weak. It was already a great source of excitements for my colleagues, as you could get this list personally by air mail. Then you can contact the authors for preprint and so on.

As I said Research journals, annual review volumes and research monographs are very expensive. In ‘Open Archive’ system, to begin with, high energy physics friends, decided to make use of internet and place their full preprints for the scientific public to read, instead of sending a finite number of copies to your own professional friends and colleagues. You can go to the web site xxx.arXiv.org, a very popular website for physicists and mathematicians now. For example, in my field, called condensed matter physics, a part of physics, every day from all over the world about 30 research articles are submitted by email to this archiv. It displays titles and names of authors. If you wish you can click and read the abstract; you can also download the entire paper as a PDF or post script file, or even the source Word or TeX files. This archiving is done in about dozen fields of physics, also mathematics, non-linear science and quantitative biology. You get excellent review articles, general science articles and full thesis from all over the world. Not only knowledge is available free, you can also put your own research papers and make them known to the world.

Participation of active researchers in areas of physics is nearly 100 percent. For example, in high energy physics, every one submits their papers to the archive even before they send it for publication to research journals. In other fields the partipation varies. For example, in my field I will say that the participation is more than 50 percent. In subfields of my discipline such as superconductivity, it is nearely hundred percent.

When this phenomena started I was little apprehensive, and thought that this new possibility of putting papers before reviewing is bad and all kind of junk articles will appear and dilute the quality of the archive. I was wrong. It is remarkable that the authors are more conscious of the quality of the paper they submit it to the archive than when thy submit to a second rate journal. Because, active and young scientific community from your sub field, all over the world from Alabama to Zambia reads your abstract, if not the article, the next day after you submit to the archive. This feeling that you are being read, is not only gives you a feeling of gratification, but also makes you quality conscious. Reading archive, as a matter or routine every morning, for about half hour, is very easy compared to looking through published journals, which most of the times are not available in your library any way.

The authors, independently pursue publishing these articles in refereed journals, which takes its own time, depending on the journal and get accepted or rejected for reasons of the standrads of the journal, etc. As soon as the article gets published the author can send a note to the archiv. It will display this information along with the journal reference. So other authors, who follow your work knows the reference of your article in journals. So need for the journals are completely avoided in some sense ! It has happened. I hardly go to the library for reading journals these days. Because papers come to my computer window every day, including very important articles.

There are some catches, which are getting solved. Some journals like Nature and Science did not allow authors to submit their papers to archives, before their papers got published. If you have already put your paper in the archives there is no way it can get published in these journals, however important they are ! I believe they are becoming lineant, because of pressure from scientific community. I have told you only part of the story. There are various wonderful things that is happening in this front. If you want more information you can get information from the internet. Further people in India can contact Prof S Arunachalam, a Distinguished Fellow at M S Swamination Research Foundation, who is actively campaigning for availability of scientific knowledge and open archives and open sources. His grievence is that countries like ours, which will actually benefit immensely by these developments, are not actively participating in these developments.

Even more interesting things are happening. I see it particularly in the field of biology. Active labs and group display all their published works in their home page. You could download the PDF files free. Apparently, as long as the authors declare and put a note that downloading should not be done for commercial purposes, all journals allow this. I do not know how true it is. But I have downloaded some recent papers that were published in expensive journals, not easily available in libraries at Chennai.

Thanks to email, if you can manage to find the email address of one of the authors of a paper you want, send him an email, and say how excited you are by his paper. You will get the PDF file next morning ! So young researchers in a third world country for example can in principle get an article next day and can be in the forefront as far as technical informations, like a graduate student sitting in an affluent University in Germany or Japan.

The above new facility is being effectively used by many college college teachers and many university researches these days, who are keen to pursue their and who have no library or journal access. A visit to a neighboring internet cafe for 3 to four hours a week, which is affordable, keeps them abreast as far latest happenings in their fields, including detaild technical information.

What is more impressive is that important colloquia and seminars in many Institutes and universities in USA are archived and are available in their home pages. A popular example in theoretical physics is the Kavli Institute of Theoretical Physics at University of California, Santa Barbara, USA. You can view the entire lecture online, at your leisure. For a few years now, many outstanding undergraduate and graduate level course materials are freely available online. My fried Arunachalman tells me that University of California at Berkeley in USA has decided to put all their course lectures, across all departments on line. It is remarkable. You can listen to some of the best teachers and leading authorities teach you elementary physics along with demonstrations, sitting here at Meerut or Karnool. If you are a researcher you can listen to the latest research seminar in your field, by a leading authority. In fact some of the Institutes in India, including our own Institute at Chennai are trying to make our lectures available on the net.

It is left to our imagination how to make use of the above scientific knowledge in knowledge based industries. This is where the possibility of Knowledge Based Cottage Industries notion come. Let me give one concrete possibility, which I was contemplating, when the historic tsunami hit in December 2004 and took a big toll.

The sea bed below Andaman and the neighborhood is prone for major earth quakes that can cause tsunami. The frequency of major tsunami such as the one happened in 2004 is less frequent, may be once in 60 years. But that is only statistics. Unlike the unfortunate Andaman islands and Indonesian islands nearby, tsunami takes about 2 hours to reach east coast of India. One person, who knows basic geography and some knowledge of tsunami wants to setup a knowledge based cottage industry to help a government agency involved in tsunami warning, for some nominal annual fee. I may be naive, as I have no experience in business or industry. This person owns a PC and has standard internet facility available. He employs 4 persons, each at work for 6 hours a day, to work round the clock. The employees are young M.Sc. or B.E. students, who are on their career path. This job can be a stop gap arrangement. What they do is a boring job of constantly watching an USA Web site, www.USGS.gov, which provides detailed information about the earth quake activity all over the world on line. Within 10 seconds of a small or major earth quake, the website will display all details of the earth quake, rough magnitude, very accurate location, depth information, and whether an under ocean earth quake is capable of causing a tsunami or not. The employee, while he is watching this sit, can do his other job of his choice. He can even, put some program in his PC, which automatically gives him a signal, when the earthquake web site is updated, for example. There can be many imaginative ways of doing this job.

The point is that one does need an organization to do this job. They can do other things. One can imagine this type of cottage industry in a variety of things, in various fields that affect people and society directly, using the latest scientific information in the field of agriculture, electronics, atmospheric physics, health physics, medicine etc. etc. There seems to be lot of scope.

**Conclusion**

I have briefly reviewed the nature of modern science and given a cursory glimpse of some of the important on going developments in nano science, quantum computers and molecular biology. It is an attempt to give the spirit of the ongoing revolution. My article has a character of a myopic vision. Further, details, including references are missing. But there is the internet that can fill the details and supply you the references. Global sharing of knowledge, that has become possible through the modern internet revolution, allows a larger participation of all nations on this globe, indpendent of wealth, in this exciting scientific revolution. What is interesting is that knowledge based industries can grow even in countries which are not major actors in science. Further, growth of knowledge based industries are likely to feed back and nurture science in that country; enlightened industries always nurtured science.