Scientific and Technological Research for Development

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February 2005

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FOREWORD

Science and technology without doubt are an indispensable part of the developmental process. Nations with poor layouts in science cannot aspire to attain the living standards of the developed world. It is thus, important that a scholarly analysis be undertaken of the linkages between science, technology and development. Dr. Hameed Ahmed Khan has done a great service by manuscript compiling such undertaking and deserves the appreciation of all those who are interested in the promotion of science and technology and their impact on development. In the realm of science and technology, there is a virtual explosion and a strong synergy that exists between science and technology. New science results in newer technologies, which in turn help creation of new knowledge. This poses serious challenges for the science planners in the developing countries with limited resources as to how to keep abreast with the new advances and how to choose and prioritize areas that can address the national needs and develop and capacity-build in those areas.

Incorporating steps to promote relevant science and technology in national planning are not sufficient for either increasing the growth of the national output or eradicating poverty. Development requires not only science and technology but also modernization of politico-socio economic traditions and methods, which of course would be beyond the scope of this work. Dr. Khan has, however, very cleverly delineated a road map of what science and technology can do for development, once proper conditions are in place for deriving maximum benefit from both the classical and the latest scienctific applications.

In my opinion, the book has been very comprehensively structured, and a systematic sequencing of chapters and topics has been ensured. Starting from the description of major historic events in science and technology, the book includes thought-provoking discussion on the importance of basic and applied research for the developing countries in general, and Islamic countries in particular.

The recommendations made at the end of the book are meant to suggest ways and means through which these countries can formulate effective policy-frameworks for their science and technology for development. The essential idea that envelops the recommendations is that, without science and technology it is difficult to survive with dignity and respect in the comity of nations. In this age of ever expanding knowledge, the developing Islamic countries must redouble their efforts for a firmed commitment to science.

I have had a long association with Dr. Khan and have always admired his work: as a young laboratory scientist; a group leader of a research project; the director of a very large scientific research establishment and finally, the head of an important multi-governmental organization viz. COMSATS. With his rich experience, I hope that Dr. Khan, in addition to his other duties, will find time to continue to write more on the theme of science, technology and development.

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August 3, 2004

PREFACE

The world is experiencing a period of unprecedented advances in science. Today, more than ever, science and its applications in the form of technology are indispensable for development. Science has contributed immeasurably to the development of modern society, and the application of scientific knowledge continues to furnish powerful means for solving many of the challenges facing humanity, such as poverty eradication, provision of health care, food and safe drinking water. Jacob Bronowski once said, “the most remarkable discovery ever made by scientists was science itself”.

In an era where the standards and parameters for socio-economic development and prosperity are dynamically shaping, continued scientific research is perhaps the only constant that lies at the heart of sustainable development and progress in the modern world. Science and technology are undoubtedly the most explicitly utilized tools and techniques to alter the outlook of nations, societies, cultures, economies, environment and, more importantly, life. However, to foster continued improvement, refinement and enhancement in these fields of immense importance to mankind, scientific research is inevitable. Overall, it can be stated that scientific and technological research plays a pivotal and extremely crucial role in furthering the scientific revolution and transferring its benefits to the general society.

This monograph aims at bringing visibility to the nature of scientific and technological research, its historical importance and future implications for developed and developing countries alike. At the very outset, clear pictures of the different concepts of science and technology are highlighted, along with their mutual and exclusive attributes. With illustrations, examples and detailed accounts of success stories, the ultimate objective of this document is to underline the importance of scientific and technological research for sustained development and progress of any nation, in general, and developing nations, in particular, and to define strategies and plans of action for continued S&T research.

Taking a different approach to this subject, this book identifies the various myths that were associated with the phenomena under discussion and tries to quantify, in tangible terms, the benefits of the results attained so far. It also focuses on the different types of S&T research and categorizes their comparative importance to the developing and developed countries. A frame-work for mutual cooperation for development is also presented, keeping in view the prospective benefits and desired objectives. The consequent effects of neglecting this crucial tool for development have also been touched upon, while keeping in view the relatively different characteristics, needs and problems of the Muslim World and presenting a model for S&T research.

The endeavour has been to make the contents of the book easily comprehendible for readers and to evoke further interest in this important topic. Any mistakes are regretted and I would welcome comments and suggestions for modification and improvement.

Last but not least, I would like to thank Dr. M.M. Qurashi, Mr. Salman Malik, Miss Zainab Hussain Siddiqui, Mr. Irfan Hayee and Mr. Imran Chaudhry for their invaluable help in exploring the relevant material and also in the compilation of this book.

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Chapter-1

FUNDAMENTAL CHARACTERISTICS OF SCIENCE AND TECHNOLOGY

1. FUNDAMENTAL CHARACTERISTICS OF SCIENCE AND TECHNOLOGY

1.1 Science and Technology: Evolution

The modern era is characterized by innovations in all strata of life. Advancements have been made in almost all sectors of society, and human beings have been able to devise ways and means to improve the quality of their lives. Understandably though, this modernization has not occurred over a small period of time; indeed it has evolved over a time-frame of centuries rather than years (*Bragg M. & Gardiner R.; Physics World, 1999*).

Science and technology have been at the forefront of most revolutionizing changes, and it is only due to the progress in these fields that mankind has undergone a complete transformation from the stone-age to the current era marked by comfort and sophistication. Although changes and innovations have been observed throughout the history of mankind, we can for convenience, subdivide the eras of scientific and technological growth into various arbitrary phases as given in the following Tables-1.1 to 1.5 (the detailed form is given in the Appendix-I, while important developments of the 20th century are listed in *Appendix-I* and *Appendix-II*):

Mankind has embarked upon its journey of major research and development since the period before Christ. Starting from 6500 BC, with invention of the wheel, to the time of 250 BC when Archimedes presented the Principles of Buoyancy and Levers, this era can be termed as the foundation age of scientific and technological research.

Other major events of this era include the introduction of 365-day calendar, construction of the Pyramids and invention of black ink. The credit for all these significant developments goes to the Egyptians. Among the contributions by other nations and individuals during this period were the development of windmills by the Babylonians (1700 BC); demonstration of silk-weaving by the Chinese (1500 BC); Pythagoras' proposition of sound being a vibration of air and the suggestion of the Earth being a sphere rather than being flat; and Aristotle's discovery regarding "free fall" as a form of motion (Table-1.1).

With the spread of Islam in the mid seventh century and establishment of a large Islamic state by the eight century, the Arabs began to encourage learning of all kinds. At the same time, scholars were invited to their learning centres, i.e. Damascus and Baghdad. The old learning was thus infused with a new vigor, and the intellectual freedom of men of the desert stimulated the search for knowledge and science. The era 700 AD to 1500 AD, is marked with a number of scientific discoveries and breakthroughs. Especially in the early days of Islam, the Muslims were eager seekers of knowledge, and then Baghdad was the intellectual center of the world.

Table - 1.1: Scientific Discoveries and Breakthroughs (-6500 to -250 B.C.)

Year	Scientific & Technological Development
-6500	Sumerians invent the wheel
-4236	Egyptians institute the 365 day calendar
-4000	The first mines, where humans began extracting useful minerals such as iron ore, tin, gold and copper, appeared in the Middle East.
-3200	Egyptians invent black ink
-2800	Pyramids are built in Egypt
-2500	Iron age begins around this time
-1700	Windmills developed by Babylonians; they used to pump water for irrigation
-1500	Silk weaving demonstrated by the Chinese
-950	Leather is used for writing and scrolls
-550	Pythagoras proposes that sound is a vibration of air
-500	Pythagoras suggests that the Earth is a sphere and not flat, as had been previously assumed
-360	Aristotle discovers that free fall is an accelerated form of motion
-250	Archimedes develops the principles of buoyancy and levers

Historians have justly remarked that the school of Baghdad was characterized by a new scientific spirit. Jabir Ibn Hayyan; Mohammad Bin Musa Al-Khwarizmi; Al Razi Ibn Sina; Al Zahrawi; Ibn al Haytham and Abu Raihan Al-Biruni are some of the famous Muslim scientists, known for their contributions to physical and biological sciences during this period (*Qurashi M.M. & Rizvi S.S.H, 1996*), also see Table-1.2, after whom George Sarton has identified successive half-centuries in his History of science.

Jabir Ibn Hayyan (known as Geber in Latin) (803 A.D.) is well known for his contributions in the field of chemistry: he introduced experimental investigation into alchemy, which rapidly changed its character into modern chemistry and processing. His achievements in the field include: preparation of various metals; development of steel; dyeing of cloth and tanning of leather, varnishing of water-proof cloth, use of manganese dioxide in glass-making, prevention of rusting; letterring in gold; identification of paints; greases, etc. During the course of these practical endeavours, he also developed aqua regia to dissolve gold. Al-Khwarizmi (840 C.E), the founder of algebra, gave analytical solutions of linear and quadratic equations; explained the use of zero; perfected the geometric representation of conic sections and developed the calculus of two errors, which led him to the concept of differentiation. Another very well known Muslim scientist, Yaqub Ibn Ishaq Al-Kindi, on account of his scientific work, is reputed to be

Table - 1.2 : Muslim Scientists and thier Field(s) of Contribution

	Name & Period	Latin Name	Field of Contribution
1	Jabir Ibn Hayyan (d. 803)	Geber	Chemistry (pure & applied)
2	M. bin Musa Al-Khwarizmi (d. 840)	Algorism	Mathematics (Algebra)
3	M. Ibm Zakariya Al Razi (864-930)	Rhazes	Medicine & Chemistry
4	Abul Qasim Al Zahrawi (930-1013)	Abulcasis	Medicine & Surgery
5	Abu Ali Ibn Sina (980-1037)	Avicenna	Medicine, Mathematics & Physics
6	Ibn al Haytham (965-1040)	Albazen	Physics, esp. Optics, Densities, Analytical Geometry
7	Abu Raihan Al-Biruni (973-1048)	Alberuni	Geodesy & Mathematics
8	Umar Al-Khayyam (1044-1123)	(Omar Khayyam)	Mathematics
9	Ibn Rushd (1128-1198)	Averroes	Medicines, Music & Philosophy of Science
10	Ibn Al Baitar (d. 1248)	(Al Baitar)	Botany, Medicine & Surgery

Source: *Qurashi M.M. & Rizvi S.S.H, 1996, "History and Philosophy of Muslim Contributions to Science & Technology", Chapter 6 , Pakistan Academy of Sciences.*

the leading scientist of his time. He was author of 241 books in the areas of: Astronomy (16), Arithmetic (11), Geometry (32), Medicine (22), Physics (12), Philosophy (22), Logic (9), and moreover in Psychology (5) and Music (7). Like-wise, the list is full of such eminent scholars and Muslim scientists, more than a hundred of whom are included in Gillispie's sixteen volume Dictionary of Scientific Biography, because their contributions were sufficiently distinctive to make an identifiable contribution to the profession or community of knowledge.

During the same period, the Chinese invented porcelain (700 AD) (Table-1.3) and paper was made in Iraq (793 AD) (*Henry J.; Shapin S.*). Later on, while the first paper mill was established in Germany (1390), Galileo, with his pendulum experiments in 1583 AD, was able to demonstrate that the time of oscillation was independent of the amplitude; this was indeed a major scientific discovery. To round off this era, the Dutch developed glass lenses, which were subsequently used for the manufacturing of microscopes and telescopes.

Table - 1.3: Scientific Discoveries and Breakthroughs (1600-1860 A.D.)

Year	Scientific and Technological Development
1609	Galileo establishes the principle of falling bodies descending to Earth at the same speed
1609	Kepler publishes his first two laws of planetary motion
1613	Galileo observes sunspots
1665	Newton's law of universal gravitation
1666	Newton observes the effect of a prism on white light; the light separates into different colours
1668	Isaac Newton designs and constructs a reflecting telescope
1687	"Principia" published. Newton's great work includes his 3 laws of motion and also the law of universal gravitation
1714	Fahrenheit invents the mercury thermometer
1728	Speed of light newly estimated by Bradley to be 183,000 miles per second
1752	Benjamin Franklin performs his famous "kite experiments" and shows that lightning is a form of electricity
1769	James Watt invented the steam engine
1777	Lavoisier put forward the idea of chemical compounds composed of more than one element
1798	The mass of the Earth is determined by Cavendish
1800	Nicholson and Carlisle decomposed water into hydrogen and oxygen, via electrolysis
1801	The first steam-powered pumping station is built near Philadelphia to supply power
1803	Dalton publishes table of comparative atomic weights
1803	It is a rich year for the discovery of new elements, with the identification of cerium, rhodium, palladium, iridium and osmium
1808	Modern atomic theory is put forward by John Dalton
1821	Dynamo principle described by Faraday
1825	Faraday discovers benzene
1826	Faraday established empirical formula of natural rubber as C_5H_8
1827	Ohm's law of electrical resistance established
1827	Robert Brown observes what becomes known as Brownian motion
1831	Faraday discovers electromagnetic induction
1833	The electric telegraph is invented by Gauss
1848	First 'Science' magazine published
1849	French physicist Armand Fizeau measures the speed of light
1851	Kelvin proposes "absolute zero" of temperature

The next phase is between 1600 AD and 1850 AD. It was a period of time that was characterized by increased activity and major innovations in the fields of science and technology. Renowned scientists brought about major scientific discoveries and these innovations had a long-term impact on the future of human beings and their lives.

During this era, although innovations were made in all fields of science and technology, physicists took the leading role in developing and implementing scientific theories and products. Be it the names of Newton (for Laws of Gravitation, Laws of Motion, Construction of Telescope,

Table - 1.4: Scientific Discoveries and Breakthroughs (1860 - 1900 A.D)

Year	Scientific and Technological Development
1869	Celluloid is first produced from cellulose nitrate and camphor
1869	The first Periodic Table is formulated and published by Mendeleev
1869	First 'Nature' journal published
1873	Maxwell describes light as electromagnetic radiation
1877	Thomas Edison invents the phonograph for sound recording and transmission
1879	Thomas Edison invents the light bulb
1879	Speed of light calculated by Albert Michelson to be 186,350 miles per second (give or take 30 m/s) (or 299,792.458 km/s)
1883	First electric railway built at Brighton by Magnus Volks
1887	Hertz predicts the existence of radio waves - he successfully detects them a year later
1887	Hertz discovers the photoelectric effect
1895	Marconi pioneers the wireless telegram
1895	Rontgen discovers X-rays
1896	Radioactivity is discovered by Becquerel
1896	The "Zeeman effect", whereby the application of a magnetic field to a substance causes a spectral line to split into a series of closely-spaced lines, is first observed
1897	J. J. Thomson discovers that electrons are negatively charged particles with very tiny mass; this is the discovery of subatomic particles
1897	Synthesis of aspirin by Felix Hoffman
1897	Radio message sent by Marconi over a 20-mile distance from Isle of Wight to Poole, Dorset, England
1898	Rutherford discovered the two species (a- and b- particles) of radioactive radiations
1899	J. J. Thomson discovers the process of Ionization
1900	Gamma rays are discovered by Villard
1900	Max Planck puts forward his quantum theory

Table - 1.5: Scientific Discoveries and Breakthroughs (1900 - 1950 A.D)

Year	Scientific and Technological Development
1901	First Nobel Prizes awarded
1905	Einstein puts forward his special theory of relativity
1911	Rutherford makes the discovery of the nucleus from alpha scattering
1911	Kamelingh Onnes discovers Superconductivity
1912	Friedrich, Knipping and von Laue discover that X-ray diffraction establishes the periodic structure of solids
1913	W. L. Bragg and W. H. Bragg put forward Bragg's Law
1913	Bohr and Rutherford put forward the Nuclear Model of atom
1914	Rutherford discovers the proton
1916	Sommerfeld comes up with the atomic fine structure – 3 quantum numbers
1924	L. de Broglie discovers Matter Waves
1925	Discovery of the Pauli Exclusion Principle
1925	Uhlenbeck & Goudsmit: spin intrinsic angular momentum of the electron
1925	Heisenberg's Formulation of Quantum Mechanics
1926	Schrödinger's Formulation of Quantum Mechanics
1926	P.A.M. Dirac - Dirac equation & equivalence of Heisenberg & Schrödinger formulations
1926	First liquid-fuel rocket launched
1928	C. V. Raman comes forward with the Raman Effect in liquids
1937	Invention of the jet engine by Frank Whittle
1938	Discovery of Fission Process
1942	Manhattan Project is formed by leading scientists and Allied governments, to build an atomic bomb
1946	The first synchrocyclotron is built at Berkeley

Publication of "Principia", Observation of effects of a prism on white light), Galileo (for Principle of Falling Bodies, Observation of sunspots), Faraday (for Discovery of Benzene, Electromagnetic Induction, Dynamo Principle), or the likes of James Watt (for Steam Engine), Cavendish (for determining the mass of the Earth), Dalton (Table of Atomic Weights), the list seems endless with such names of immense knowledge and reputation.

The era of the mid nineteenth to the twentieth century is characterized by the revolutionary discoveries of Edison, Maxwell, Thompson, Rontgen, Rutherford and Villard. Important discoveries included the light bulb, the wireless telegraph system, sound transmitting and recording systems, the X-rays, radioactivity and the Gamma rays. The Quantum Theory, put

Table - 1.6: Scientific Discoveries and Breakthroughs (1950 - 2003 A.D)

Year	Scientific and Technological Development
1954	Invention of the transistor radio, which gains widespread usage in a very short time
1957	Formation of International Atomic Energy Agency (IAEA)
1971	Lunar rover vehicle driven on surface of the Moon
1980	Sony and Phillips invent the compact disc
1983	Research at CERN shows evidence of “weakons” (W and Z particles); this validates the link between weak nuclear force and electromagnetic force
1984	West German scientists create 3 atoms of element 108, now known as Hassium (Hs)
1986	First use of the world “Internet”
1992	CERN release their hypertext for physics system, the beginning of the World Wide Web
1994	Use of silicon technology in optoelectric devices
1996	Polymer wafer implants used to treat brain cancer; the technique is approved by the US Food and Drug Administration
1996	German scientists produced atoms of element 112 (ununbium), the heaviest ever created; this was achieved by fusing a lead atom with a zinc atom. The element decays in less than a thousandth of a second
2001	Evidence for a black hole at the centre of our galaxy is found
2003	Chinese successfully launch first manned space-flight, piloted by Yang Liwei

forth by Max Plank, is one of the most important theories of that time, which has today paved the way for dynamic and revolutionising discoveries. It was during this period of about fifty years that J.J. Thompson first discovered the process of ionization, Maxwell understood light as electromagnetic radiation and Hertz discovered the existence of radio waves and the photoelectric effect. In chemistry, the pharmaceutical industry benefited from the synthesis of aspirin, which was carried out by Felix Hoffman in the year 1897. Earlier, celluloid was produced for the first time by man from the ingredients of cellulose nitrate and camphor (*Henry J.; Shapin S.; David Peat F.; Weinberg S.*), as shown in Table-1.4.

The period of 1900 to 1950 marked the beginning of the prestigious Nobel Prize awarding tradition, which is awarded today in the disciplines of Chemistry, Physics, Medicine, Literature, Peace and Economics. Some of the most crucial discoveries of that era, which have paved the way for later magnificent discoveries and inventions, include Einstein’s revolutionary theory of relativity. This theory negated other theories of the past and presented a whole new dimension for the subject of Physics, in particular, and science in general. Onnes’s discovery of superconductivity was made as early as 1911, but its uses and significance materialized later. Meanwhile, Quantum Mechanics was an area of importance, on which Heisenberg and Schrödinger worked successfully during 1925-26. This era witnessed the discovery of the proton, the launching of the first liquid-fuel rocket, the invention of the jet engine and the construction of the first synchrocyclotron (*Levenson T.; Feyman Richard P.; Stachel J.; Bromley Allan D.*), as shown in Table-1.5.

The twentieth century saw more breakthroughs in technological advancements rather than in basic science. Nonetheless, the invention of the transistor radio in the early nineteen fifties, the invention of the compact disc, the use of silicon technology in optoelectric devices, the global usage of the Internet and the evidence for a black hole at the centre of our galaxy are just some of the remarkable discoveries and inventions of this era, which promise to pave way for further astonishing discoveries (*Feyman Richard P.; Bromley Allan D.*), as depicted in Table-1.6.

At the dawn of the 21st century, the universality of science and technology, as ever-growing and useful phenomena, is a globally accepted idea. As a vehicle for development and prosperity, science and technology have never deserted mankind. In fact, they have always provided humanity with the means to grow, through applicable and implementable solutions for complex problems, and have served continually as an instrument for building the prosperous world that we all live in today. Nonetheless, science and technology have also contributed to the current environmental, social and economic predicaments faced by humanity at the dawn of the 21st century; however, it is unanimously accepted that it is the careless *use of* science and technology and not S&T itself that has allowed these global challenges to come up. Needless to say, the importance and significance of science and technology, along with its pivotal role in the development, growth, productivity and prosperity of the world, cannot be underestimated at any stage.

1.2 The Foundations of Modern Science

> *"What is this thing called science. We start off confused and end up confused on a higher level" (**Alan Chalmers**)*

To find the foundations of science, we must look back to Greece about 600 BC. Science is rooted in the work of Thales of Miletus. He asked the question "Of what is it that all things are made?" (*Christophorou L.G, 2001*) Over the centuries, this question was followed by countless other questions that served to drive scientific exploration (*Bragg M. & Gardiner R.; Physics World, 1999; Collins H. & Pinch T.*).

The period from the beginning of the 17th century to the end of the 19th century (or beginning of the 20th century) can be considered as the time during which the foundations of modern science were laid. These were the 300 years that led from Newton to Einstein, from the macro-cosmos to the micro-cosmos, from classical to quantum physics. A period of critical observations, ingenious experiments, unique insight, incremental understanding, patient and often independent steps along tortuous paths that, in time, converged and led to brilliant syntheses and bold propositions. A time of gradual step-by-step steady evolution, occasionally interrupted by revolutionary discoveries and steep step-function-type advances. In this period, many of the fundamental fields of modern science were developed, in parallel or in tandem, cross-fertilizing and cross-breeding. Discovery bred discovery, innovation superseded innovation, and (in a chain-reaction like process) some of the broadest laws of science were established. Even a selective portion of this path, which led to the great discoveries in physics of the late 19th and early 20th century and to the galloping scientific advances beyond, will help mankind appreciate the way science progresses and the way it evolves.

By the end of this period, all pre-requisites for the transition from classical to quantum mechanics, from the macro-cosmic to the micro-cosmic universe, were essentially in place. Four fundamental constants dominated physics at the end of this period: the electron charge, e; the quantum of action known as the Planck constant, h; the gas constant per molecule, known as the Boltzmann constant, k; and the speed of light in vacuum, c.

1.3 Technology: Evolution and Contribution (*Christophorou L.G., 2001; Feibleman J.K., 1966; Ferguson E.S., 1977; Kranzberg M., and Pursell C.W. Jr., 1967; Dubois R., 1972; Forbes R.J., 1967; Collins H. and Pinch T.*)

As mentioned earlier, technology is the organization of knowledge for practical purposes. It meets man's need to do something; the word technology is derived from the Greek 'techne' – an art or a skill. It refers to something done by man. Specifically, it means industrial science and is usually associated with major activities, such as manufacturing, transportation and communication (Karle, 2000). In ancient Greek, 'technologica' referred to a systematic treatment of any subject, including grammar. It was only during the course of the l9th century that the word 'technology' became current in English, with its modern connotation. During the 18th century and soon after the Industrial Revolution, the term mechanical art was more commonly used for what we now call technology or engineering.

The benefits of technology are manifold; the overall aim being to take maximum advantage of the available opportunities, in order to cater to the physical needs of human beings. From the very beginning of human evolution, technology has been instrumental in providing solutions to the demands of mankind, be it the basic needs like shelter and clothing or the more advanced wishes like telecom-technology and automobiles.

It is argued that technology was seen in application much before science. According to this view, even in the absence of science, human beings always had at their disposal some kind of technology. Technology could be initially seen in the arts of clothing and cooking and even in the field of music. The artifacts of ancient times and the exemplary construction work provide us with admirable examples of various forms of technological use. The invention of wheeled vehicles (almost 7,000 years ago), that of plow machines (almost 5,000 years ago) and also of steam engines are some of the results of technological application, which had little or no help from scientific knowledge.

It was during the seventeenth century A.D that man actually started to learn and apply scientific knowledge in a systematic manner. Subsequently, it was also in the same era that human beings started to integrate their scientific knowledge with their technological know-how, thus bringing about the industrial revolution. The results could be seen in the invention of jet engines/airplanes, computer systems, mobile communication-devices and many more.

Overall, technology with the help of science has devised numerous ways and means to make life more comfortable and rewarding. The modern information-revolution has only made the process faster, and access to the knowledge and application of science and technology has become easier over time.

1.4 Science and Technology: Dissimilarities (*Christophorou L.G., 2001; Funder J., 1979; Mesthene E.G., 1969; Baruch J.J., 1984*)

Generally used as a single term, science and technology are two different, yet overlapping phenomena. Science is defined as a method for studying the natural world. Derived from the Latin word meaning ‘knowledge’, science uses observation and investigation to gain knowledge about events in nature. In science, men and women seek to collect facts or observations and look for patterns or regularities that are then deemed laws; they make hypothesis leading to experiments or predictions and ultimately build theories, which support (but never absolutely prove) and explain the foundational evidence. On the other hand, technology is the application of science or scientific knowledge to help people to produce something useful. Technology draws on science and also contributes to it.

Besides the obvious differences reflected in the definitions of the respective phenomena, science and technology differ in many other ways as well. An interesting comparison of both these terms is elaborated in the following Table-1.7:

Table - 1.7: Comparison between Science & Technology

Science	Technology
Derived from the Latin word meaning ‘knowledge’	Derived from the Greek word meaning ‘art or a skill’
A method for studying the natural world	The application of science
The product of human curiosity	The product of human ingenuity
A way of explaining the world	A way of adapting to the world

As mentioned in this table, science is the product of human curiosity. Since remotest times, man has looked at nature and tried to explain natural phenomena. Technology, however, is the product of human ingenuity: man has been perfecting his tools, the material with which they are made and the manufacturing techniques, for ages, in his struggle to survive (*Papa, 2002*).

Another way to put it is that science includes processes and a body of knowledge. Processes are the ways scientists investigate and communicate about the natural world. The body of knowledge includes concepts, principles, facts, laws, and theories. As Einstein said, "*The whole of science is nothing but a refinement of everyday life*". Technology, on the other hand, utilizes tools, techniques, and an applied understanding of science to design products and solve problems.

In the following words of some of the most famous scientists themselves, one can better judge the true meaning of science:

> *"Science cannot solve the ultimate mystery of Nature. And it is because, in the last analysis, we ourselves are the part of the mystery we are trying to solve"* ***(Max Planck)***
>
> *"Science is facts. Just as houses are made of stones, so is science made of facts. But a pile of stones is not a house and a collection of facts is not necessarily science"* ***(Henry Poincare)***
>
> *"Science must begin with myths and with criticism of myths".*
> *"Science may be described as the art of systematic oversimplification"* ***(Karl Popper)***

Among the various differences between science and technology, one can easily identify the core differentiating features in their respective methods, goals, and operation. Moreover, the difference of working in terms of methodology, objective and operation is also evident between the scientist and the engineer. Primarily, the basic functions of science and technology vary. As a matter of fact, science operates independently of the society, i.e. autonomously. In the case of technology, one can say that it also has a way of its own; however the working of technology is essentially laid out by the standards devised and enforced by the society in which it is operating. The demands that drive technology are extrinsic in nature; however the demands in science are usually derived intrinsically (*MacCormac, 1998*).

Another way to distinguish between science and technology is to understand that very occasionally is the methodology repeated while conducting science. On the contrary, the industry very frequently repeats over and over again a previously employed methodology. Moreover, science needs an intellectual environment to practice it, a setting largely determined by the organization or institution in which it is being conducted. For technology to be useful it has to be situated socially; however an intellectual setup is nonetheless required. Another distinguishing feature is that the community of science is the entire society, while that of technology is the customer whose specific needs and wants the technology is fulfilling.

As is commonly known and understood, the end product of a scientific endeavor is knowledge, both in terms of the scientific papers and related literature. This produce of science is a public good, which is utilized in a mutual sharing fashion that most certainly implies that more for one does not translate into less for another. All in all, the entire human race benefits from the findings of scientific discovery, without having to pay an extra penny. On the other hand, the finished output of technology is usually a machine, a chemical or a process. The produce of technology is usually a consumer-based item, an additional item of which adds to the overall cost of production. Essentially, the goods of technology are what we can term as private, consumer-driven items.

A major difference between science and technology is that of their cultures. Within science, the outcomes of the research endeavors are considered to be free-of-cost goods. A scientist's basic search is usually discrete and investigators seldom share while competing against each other; however once the search is complete and the discovery has been made, the results are the property of the entire human race and are at the disposal of mankind without a cost. Usually, the scientific culture provokes the scientist to let everyone know of his work in any possible way that he can. On the contrary, technology is confidentially developed. The development of publications is unintentional and patents are usually used to protect the technology from becoming public property. The objective of the technologist is to prevent the spread of details of his technology.

The support for science and technology also differentiate the two, in that science pays for its conduct in an indirect fashion, while technology pays for itself in a direct way. The value of the work of the engineer is assessed directly from the output of his work. The value of a scientist's work, however, is assessed essentially from the presumed worth of his work's contribution to the society or the difference that his work makes to the foundations of a particular technology in its initial stage. It is nonetheless a fact that the produce of technology pays back more than the actual cost of scientific research.

Science and technology both need the freedom to work; however technology essentially requires more of this freedom than does science. It is a well known fact that, even in industrial research, success has come out through able workers who were left alone to do what they wanted to do i.e. uninterrupted. As we know, the technologist and the engineer are primarily motivated by the society, while the scientist's motivation is drawn from within. There is undoubtedly a profound difference between the working of the technologists and scientists and their skill, but there is also a fundamental relationship between the two, in the sense that they themselves and the effects of their work have changed and are continuing to change the life of mankind in a deep and long-lasting manner.

Table - 1.8: Identifying an endeavor as that of Science and/or Technology

Question	Science	Technology
• Rather than meeting a human need or opportunity, is the exhibit primarily driven by curiosity about something?	Yes	No
• Is the exhibit a response to a hypothesis?	Yes	No
• Is the exhibit a response to an identified human need or opportunity for a product, process or environment?	No	Yes
• Was some of the research aimed at confirming the validity of the original need or opportunity, and/or finding out the precise nature of the problem to which you are developing a solution?	No	Yes
• Has a theory been formulated to explain the observations?	Yes	No
Is the development of the identified product, process or environment the key element of the exhibit, including documentation with sufficient plans, models etc., to verify the development process?	No	Yes
• Was most of the research aimed at gathering new data, in response to an observation and/or hypothesis?	Yes	No
Did the gathering and processing of data ensure its validity and aim to determine its significance to causes of an effect?	Yes	No
• Was much of the research aimed at guiding the development and/or improving the performance of the product, process or environment?	No	Yes
• Is a design-process the core process?	Yes	Yes
• Is the scientific method the core process?	Yes	No
• Does the exhibit identify as important such attributes as: efficiency, optimization, reliability, cost-effectiveness, appropriateness of materials, ergonomics, aesthetics, etc?	No	Yes
• Does the exhibit show that the satisfaction of the end users of a product, process or environment was a key factor in guiding development?	No	Yes
• Is it concerned with something that could be mass-produced?	No	Yes
• Has an attempt been made to falsify a hypothesis?	Yes	No

Source: *www.lincoln.ac.nz/sciencefair/difference.htm*

As a further method of identifying a particular endeavor as strictly that of science or technology, one may refer to the following Table-1.8. It must be remembered however, that some activities can fall under both categories as well:

1.5 Science and Technology: Similarities (*Weinberg A.M., 1972; David E.E., 1971; R.Chalk, 1988*)

Knowing the various dissimilarities between science and technology, one cannot help but realize the obvious connection between the two. Science and technology are connected. Technological problems create a demand for scientific knowledge and modern technologies make it possible to discover new scientific knowledge. In a world shaped by science and technology, it is important for us to know how science and technology connect with all content-areas.

Since Galileo made his first telescope, science has used the most advanced available technical devices to collect experimental evidence to support or refute this or that theory. Furthermore, Maxwell's equations, aside from being beautiful, have generated lots of technologies. In fact, most branches of science - mechanics, thermodynamics, electromagnetism, optics, chemistry, medicine - have generated their industries. So, it is true that science and technology are activities that complement each other very well (*Papa, 2002*).

Richter, a modern technologist once said, "*Today's technology is based on yesterday's science; today's science is based on today's technology*". Science, which is revealing new discoveries expected to create new industries everyday, cannot be done without; for example, the lasers and computers that have been developed from previous science. The pace of progress in this direction is so fast that for a large number of high-tech industries, today's technology is based on today's science.

Science and technology are both considered as human activities. Science and technology are equally blamed for the unsustainable condition of the world today. Nonetheless, the nature of both of these concepts is complex, yet revolutionary. They both attempt to solve predicaments faced by humanity and, side by side, also generate new and complicated ones. It is their trait to open up new avenues of possibilities for the human race, which were non-existent otherwise. Undoubtedly, some of the new avenues that open up for the society are loved by it; for instance, Television, Microwaves, etc. Others are necessities such as synthetic materials, food preservation etc.

There is another category of this avenue which man needs but essentially does not want, such as nuclear power. Today, the conditions and environment for technology and science have changed equivalently. As an example, one may note that the development, improvement and potential use of nuclear technology is not a factor determined by the potential of science-based technology, but it is determined by the society's overall attitude towards it. This can be expressed in the words of Weinberg who said that ***"nuclear technology is limited by the society's inability to exert the eternal vigilance needed to ensure proper and safe operation of its nuclear energy-system".***

Given the noteworthy current advances in the realms of science-based technology, one cannot help but note that the human adjustment of his habitat, to his preferences, is as constrained as is his understanding and knowledge of physical reality through science. The laws of nature and the state of the art limit both science and technology. For example, deriving electric power from nuclear fusion sources would violate no law of nature, that is presently beyond the state of the art. Furthermore, they are also restricted by the structure of the society and the political/legal systems of its environment. Just like science, technology is limited by the inaccuracies of its practitioners and by the side-effects that are packaged with its benefits.

According to another approach by Earl R. MacCormac of the Duke University Medical Center, symmetry and asymmetry between science and technology relate in three distinct ways (*MacCormac, 1998*):

- One, science and technology possess similarities, which are symmetrical, and dissimilarities which are asymmetrical.
- On the other hand, each entity possesses internal mathematical symmetries and asymmetries.
- Lastly, the symmetries and asymmetries found within science and technology arise from symmetries and asymmetries found in the physical world—both natural and human-made. While science seeks to understand the nature of the physical universe, technology or engineering seeks to construct artifacts to modify the world. Engineers design structures and machines for human purposes, often largely independent of scientific theories.

MacCormac says that one way of discovering similarities and differences between science and technology is to examine the values held by each, and observe where they overlap and where they don't. Scientists often distinguish between the internal values which scientists assume and the external values which society imposes upon science. For example, scientists pursue knowledge of the physical world for its own sake, regardless of the consequences of that knowledge. This dedication to knowledge for its own sake is a value we may call internal. The consequence of that knowledge, however, is a value we may call external. Chemists who synthesize a new compound are excited about that scientific achievement and may also deny, side by side, any responsibility that this product may be used for chemical warfare in the battlefield. A reasonable premise for the defense of pursuing knowledge for its own sake is that if research would be limited due to its unexpected possibly harmful outcomes, then almost no scientific investigations could be undertaken. No one can tell in advance how the results of scientific knowledge will be used; however some commitments are made in order to justify the ongoing scientific research.

Furthermore, honesty, which can be termed as the commitment to the truth, exists as the most revered internal value of science. The ethical value of honesty is in the limelight of science as a field, because without trust, the experimental performance of the researcher cannot be acceptable. Beauty also infuses into science as that internal value, which assumes several forms of expression. Scientists claim beauty in the fit of their theories to the material world as established by experiments. Theories are called beautiful in terms of their internal structure, i.e. how the concepts interact with one other and how the concepts themselves find expression in equations and algorithms alike.

According to MacCormac, technology possesses similar internal values of a commitment to truth and expression of beauty as does science. But, the slight difference that exists is that technology does not pursue truth for its own sake because its nature depends upon a teleology which bleeds the difference between internal and external values. It is very rare that technological knowledge takes the form of pure investigation. Instead, technological knowledge exists as practical knowledge, which provides insight into how to build things, and knowledge of how those things will carry out their purpose and aim. For example, engineering knowledge about computers includes architectural design of hardware, along with knowledge of the possibilities of developing software to execute various functions like the solution of equations, word-processing packages, statistical packages, etc.

MacCormac concludes by saying that, basically, science and technology have different fundamental commitments. Science pursues knowledge alone and technology pursues knowledge for the purpose of improving human life and culture. Scientists try to live within the world of internal values, while engineers eagerly express their internal values of honesty and design in structures and machines that express external values.

Some salient features and observations regarding science and technology, their peculiar patterns and resultant outcomes, are captured in a nutshell as follows:

- Experience shows that today's technology is based on yesterday's science; today's science is based on today's technology;
- It has been discovered that the road from science to new technologies is not a straight highway but a kind of spiral of science enabling new technologies that, in turn, allow new science, which again creates new technologies and so forth;
- The process of development follows somewhat the following journey: Science enables industry to develop new technologies, and to reduce scientific discovery to practical application effectively and quickly. For this to happen, there must be a continual interaction between scientists in the laboratory and engineers in industry;
- This rather simple picture does not explain a kind of third dimension that shows how, in developing new technologies and products, results from many areas of science and technology usually must be combined. It is believed that, there is a kind of "double helix" in the interaction of science and technology. Science is one strand of the helix; the other

> strand is technology. The two are inextricably linked, and either can advance in the long run without advances in the other. Policymakers in government, who think that focusing on short-term applied work can increase economic competitiveness, ignore at their peril the implications of the science-technology double helix for long-term development. To advance along this double helix, fundamental science is necessary for developing new capabilities that benefit humanity.

Science and technology are activities that involve human values. The social, cultural, and environmental contexts within which they occur influence the conduct and content of science and technology. Vice versa, science and technology influence the social, cultural, and environmental contexts within which they occur. All in all, science and technology have reciprocal effects and their interrelationships vary from time to time and place to place. The following figure represents the three contexts of knowledge, in general, and scientific knowledge in particular, namely self, nature and social.

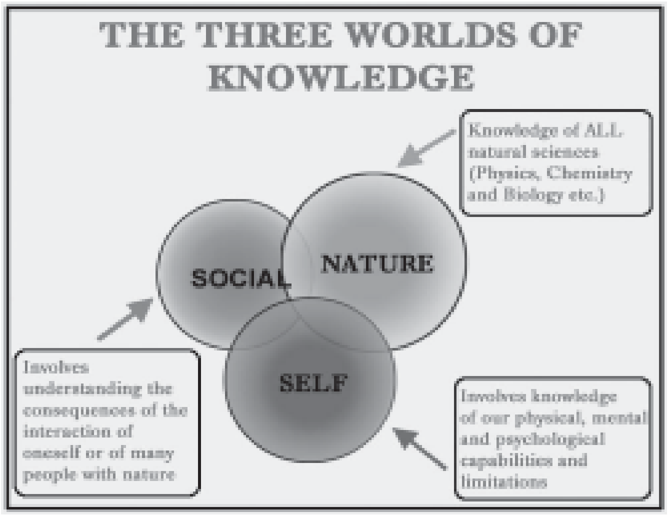
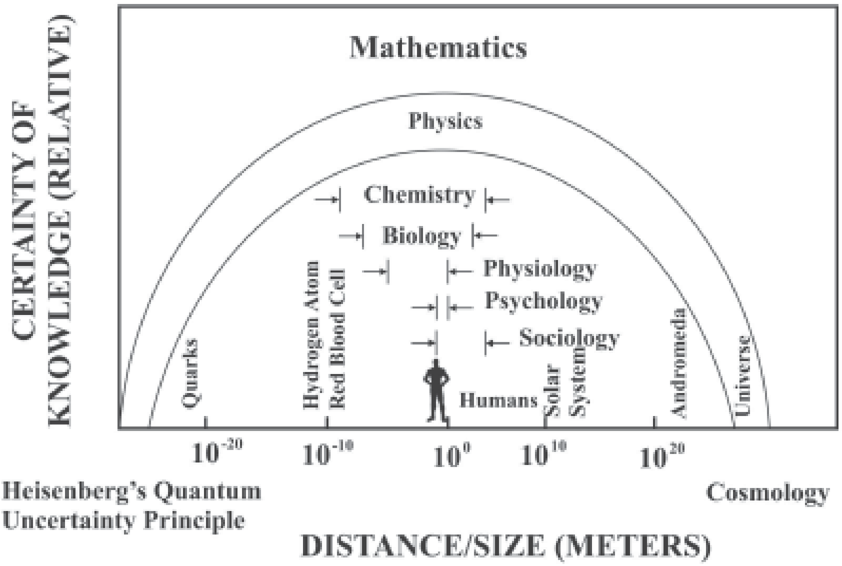


Figure - 1.1: The Three Worlds of Knowledge

In Figure-1.1, it is demonstrated that the frontiers of knowledge essentially exist at the boundaries of the worlds of nature, self and social. These frontiers are also present where each world of knowledge intersects another. Indeed the area where all the there intersect is the most critically important area as regards knowledge itself (*Larry L. Hench*).

A particular misconception about science that generally exists in the minds of certain people is that science creates certainty. This is quite an untrue notion, as knowledge is not a limitless phenomena. On the contrary, it is essentially limited by three key factors, namely distance, time and theory. Figure-1.2 and Figure-1.3 depict how time and distance influence the relative certainty of knowledge (*Larry L. Hench*).



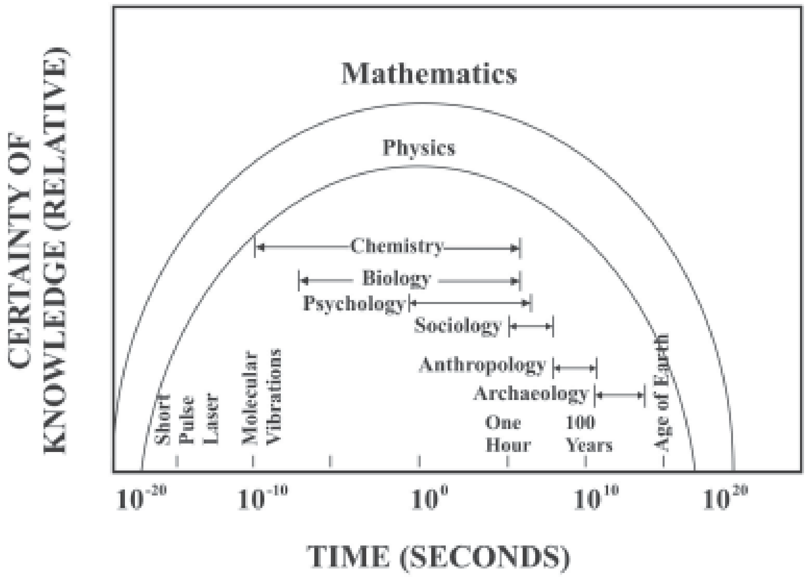
Source: *Larry L. Hench, "Science, Faith and Ethics", Imperial College Press.*

Figure - 1.2: Limits of Knowledge: Effects of Scale

Figure-1.2 demonstrates the level of certainty of scale, or distance as against the relative certainty of knowledge. This is essentially a hypothetical cross-section of the sphere of knowledge, as against an axis of distance expressed in metres. This figure essentially illustrates that the level of certainty depends upon knowledge. It says that the level of certainty of the realm of Physics is higher than that of Chemistry, which in turn is greater than that of Biology and Physiology and so on and so forth. Moreover, the certainty of knowledge of the behaviour of very large systems is limited. Although the behaviour of individual atoms is not certain, thermodynamic quantities can be defined, which are certain.

Heisenberg's uncertainty principle provides the theoretical base for much of modern physics, chemistry and biology and is a part of the foundation of quantum mechanics. This uncertainty principle states that one cannot simultaneously define the momentum and location of a particle. It further states that one cannot simultaneously establish both the energy and the time of a particle. Heisenberg's uncertainty principle shows that there is a limit to knowledge at the scales of the very small. The sphere of knowledge (Figure-1.2) demonstrates that there are at the least two other limits to man's ability to understand and forecast the world. These limits are invariably independent of observation and are known as the Gödel's incompleteness theorem and the Turing's non-computability theorem.

Gödel's incompleteness theorem states that "You may know it but you can't prove it". On a later stage, Gödel's theorems were extended by A.N. Turing whose non-computability theorem states that "You can't prove it by computing it".



Source: *Larry L. Hench, "Science, Faith and Ethics", Imperial College Press.*

Figure - 1.3: Limits of Knowledge: Effects of Time

The study of the nature of knowledge which is called epistemology, further exemplifies the fact that that there is a theoretical limit on certainty of what we know or can possibly know. The problem essentially lies in the process of defining the criterion for judging the truth and falseness of the manifestation of things.

Figure-1.3 essentially illustrates the effect of time on the certainty of knowledge (*Larry L. Hench*). It demonstrates that when the duration of time is in the scale of man's general perception, i.e. in seconds, minutes and hours, the certainty of both observation and knowledge is high. But given the circumstances, when we extrapolate backwards in time, i.e. the sphere of historians, archaeologists, geologists, etc, the level of certainty of knowledge decreases with the number of years of extrapolation.

A fascinating aspect of time itself is mankind's capability to extrapolate backwards and forwards. Cosmologists freely predict physical events in time backwards by 10^{17} seconds and forwards by equally sizeable increments. As per the figure, the level of certainty of these extrapolations is very low.

According to Hawking, time doesn't exist as a fundamental property of the universe. He says that we experience only transitory moments called 'nows'. Indeed, our brains incorporate the immediate 'nows' into what we assume as a continuous and non-stop flow of time, it on the contrary is just an illusion.

As a final thought, it can be said that there are essentially three limits on comprehending the universal nature of things. First, we must not put our trust in knowledge as such that we forget mortality. Secondly, we must always apply knowledge to achieve that which is good rather than that which is not. And lastly, we must not presume to attain the mysteries of God by studying nature itself.

1.6 The Debt of Science to Technology

The relationship between science and technology has been described by some as mutually dependent. Technology is said to be the mother and the daughter of science. Independent of the proper description of their relationship, there is a mutual debt and feedback between the two that grows with time. As mentioned earlier, one must realize that the road from science to new technologies is not a straight highway, but a kind of spiral of science, enabling new technologies that, in turn, allow new science that again creates new technologies and so forth (*Christophorou L.G., 2001; F.N. Magill, 1990*).

According to Harvey Brooks of the Harvard University, there are a variety of ways in which science has and can contribute to technological development. Science is the direct source of new technological ideas. Futuristically speaking, opportunities for meeting new social needs or previously identified social needs in new ways, are conceived as a direct follow-up to a scientific discovery made in the course of an exploration of natural phenomena undertaken with no potential application in mind (*Brooks, 1994*).

The clearest example of this is perhaps the discovery of uranium fission, leading to the concept of a nuclear chain-reaction and then the atomic bomb and nuclear power. Other examples include:

- The laser and its various applications
- The discoveries of X-rays and of artificial radioactivity and their applications in medicine and industry
- The discovery of nuclear magnetic resonance (NMR) and its vast applications in chemical analysis, biomedical research, and medical diagnosis, and
- Maser amplifiers and their applications in radioastronomy and communications (Brooks, 1994).

According to Brooks, when the exploration of a new field of science is purposely taken up, with a general anticipation that it has a high probability of leading to applications that may be useful, though there is no particular end-product in mind at that time, a more direct and genetic relationship between science and technology occurs. Work such as that at the Bell Telephone Laboratories, which eventually led to the famous invention of the transistor, is also an example of this relationship. The reason is that the group that was set up at the lab, to deeply examine the physics of Group IV semiconductors, such as germanium, was evidently driven by the expectation of discovering a method of making a solid-state amplifier to serve as an alternative to the use of vacuum tubes in repeaters for the transmission of telephone signals over long distances.

Science has also been serving as a source of engineering-design tools and techniques for humanity. The relationship between the two intimately related concepts of the process of design and the process of developing new knowledge of natural phenomena has become more and more important, as the cost of empirically testing and evaluating complex prototype technological systems has increased manifold. A lot of the technical knowledge, which is used in design, as well as the comparative analytical evaluation of alternative designs, is fundamentally developed as 'engineering science' by engineers, and is in fact the major activity comprising engineering research in academic engineering departments. Even though this is generally labeled as 'engineering' rather than 'science', such research is really another example of basic research (*Brooks, 1994*).

In the past couple of decades, humanity has witnessed a tremendous growth of interest and concern with predicting and controlling the social impact of technology (*Brooks, 1973*). In general, the assessment of technology requires a deeper and more fundamental scientific understanding of the basis of the technology than does its original creation. Moreover, for such an understanding, basic scientific knowledge, well outside the scope of the relevancies in the development of the technology, are often required. For example, the manufacture of a new chemical could involve disposal of wastes, which require knowledge of the groundwater hydrology of the manufacturing site. Therefore, it can be well anticipated that the need for more basic research knowledge (in relation to the technical knowledge required for original development) will grow, as the deployment and scope of technology widens and technology becomes complicated (*Brooks, 1994*).

Just as the issue of technology assessment is dependent on the contribution of basic science, the planning of the most efficient strategy of technological development is also quite often dependent on science. This accrued stock of existing scientific and technological knowledge helps to avoid dead-ends and hence wasteful developmental-spending. Much of this is old knowledge rather than new, but it is nonetheless important and requires people who know the field of relevant background science. Evidence of this ideology is the observation that very creative engineers and inventors tend to read very vastly and deeply, both in the history of science and technology, and about scientific developments that are the latest (*Brooks, 1994*).

1.7 Technology Contributes Towards Science (*Christophorou L.G., 2001; F.N. Magill, 1990*)

The contributions of science to technology are widely understood and recognized by the public, scientists and engineers alike. However, one cannot overlook the reciprocal dependence

of science on technology, both for its agenda and for most of its tools. These relationships are slight and subliminal and require a deeper investigation for discovery.
The debt of science to technology is manifold and multifaceted. It includes the contributions of technology to individual and specialized fields of science, its generic trans-disciplinary effect in the realms of physical science, as well as ideas that are originally generated in the field of technology and cross over to science.

In every step in the step-by-step process of science, one finds a multitude of particular technologies that enabled science to take the next step. For instance, critical steps forward in astronomy, physics, chemistry, and biology, more often than not, had as a prerequisite the previous existence of the required minimum technology. For instance:

- In astronomy, successive generations of telescopes, satellites, remote-sensing devices;
- In physics, spectrographs, accelerators, nuclear reactors, exotic materials;
- In chemistry, new chemicals, analytical instruments, spectrometers, and
- In biology, radioactive tracers, absorption, fluorescence and scintillation spectrographs.

The technologies of vacuum, light and the electron have particularly impacted science in a generic trans-disciplinary way, as described below:

1.7.1 Vacuum Technology (*Christophorou L.G., 2001*)

Scientists are fascinated by empty space and especially physicists love it. The primary reason for this fascination and attachment is that a vacuum is the most suitable environment, to study reacting species in complete isolation. Vacuum is essential for the realization of the reductionist approach of basic science. In the early science of gas discharges, the pumping-down of chambers to sub-atmospheric pressures was an essential tool. The development of high-vacuum technology, which is today one of the most essential requisites for study in advanced scientific fields of elements like particles, gases, surfaces and plasmas, was the result of the need-based endeavors of the electric-light industry and the manufacturers of radio tubes, among others. Vacuum technology itself has had astounding success in development. From vacuum levels of 10^{-3} Torr in the 1900's, it attained in 1970's levels of 10^{-11} Torr, and eventually todays levels of 10^{-16} Torr. Without the technology of vacuum, a great deal of science would not be possible. During the last 30 years or so, vacuum technology has evolved greatly to provide better operating conditions, especially for particle accelerators.

Today, specialists, engineers, physicists, surface scientists, chemists, electronic device specialists and materials-scientists, all are benefiting from the new developments in vacuum-technology. The developments include vacuum-pumping and instrumentation; vacuum measurement; advancements in the kinetic theory; gas-surface interactions; surface analysis, plasma and ion-surface interactions and etching; nanometer-scale processing; ion-implantation; surface-modification and coating industry; PVD; CVD and ion/plasma-assisted PVD/CVD.

1.7.2 Light Source Technology (*Christophorou L.G., 2001*)

It is a known fact that science as a discipline owes much of its advancement to the technology of light sources. The light-source technology is essentially science-based. It moved gradually and incrementally from primitive light-sources to advanced light-sources of varied intensities, durations, and spectral compositions, and to the laser and the synchrotron light, which is a doughnut-shaped microscope that produces incredibly intense light-beams, mainly as X-rays that can penetrate deep inside all kinds of matter, from proteins to plastics, and allows for the study of various materials.

Most of the advanced sciences, whether in physics, chemistry or biology, are benefiting from the rapid advancements and progress in light-source technologies. With regard to the duration of light-pulses, light-source technology equals the success of vacuum technology. It is worth mentioning that the duration of light-pulses has decreased from milliseconds (10^{-3}s) to femtoseconds (10^{-15}s) over the last forty years.

1.7.3 Electrical and Electronic Technologies (*Christophorou L.G., 2001*)

Science, especially the discipline of physics would not have commenced and enjoyed the status that it does today, had it not been for the evolution and development of the electrical technology. It is virtually impossible to imagine that the major discoveries in physics could have been made without the high-voltage power-supply, the current supply, the electrical instruments and power-conditioning instruments, which were developed for technology and were then quite cheaply available. It would have certainly been impossible to get and work with such complicated electronic devices that we have today in our laboratories, without the inexpensive and readily available parts, manufactured and produced originally for items such as the radio, TV, and computer.

Today, there exists an enormous array of electronic technologies that include electronics laboratory technology, electronics instrument technology, industrial electronics technology, aerospace electronics technology, and microwave/radar technology. Specific products of daily use include radios, televisions, business machines, appliances, computers, and others. Equipment is also being used in manufacturing and medical practices. Designers and engineers are deriving benefit from this very technology for the society by designing, developing, and testing circuits, automated systems, lasers and optical systems, and robots.

Table - 1.9: Nobel Prizes Awarded to Industrial Scientists

Industrial scientist(s)	Discovery/Contribution	Industrial laboratory
Fenn (J.B.) / Tanaka (K.)[a] / Wüthrich (K.) (Chemistry) – 2002	Development of methods for analyses of Biological Macromolecules	Shimadzu Corp. Kyoto, Japan
Lederman (L.M.) / Schwartz (M.)[b] / Steinberger (J.) (Physics) – 1988	Neutrino Beam Method and the discovery of the Muon Neutrino (Nuclear Physics)	Digital Pathways, Inc. Mountain View, CA, USA
Cram (D.J.) Lehn (J.M.) / Pedersen (C.J.)[c] (Chemistry) – 1987	Development of Molecules with structure-specific interactions of High Selectivity	Du Pont Wilmington, DE, USA
Muller (K.A.) / Bednorz (J.G.)[d](Physics) – 1987	High Temperature Superconductivity	IBM, Zurich Research Laboratory
Binning (G.)[e] / Rohrer (H.)(Physics) – 1986	Scanning Tunneling Microscopy	IBM, Zurich Research Laboratory
Penzias (A.A.) / Wilson (R.W.)(Physics) – 1978	Cosmic Background Radiation	Bell Telephone Laboratories, New Jersey, USA
Bardeen (J.)[f] / Brattain (W.H.) / Shockley (W.) (Physics) – 1956	Transistor	Bell Telephone Laboratories, New Jersey, USA
Langmuir (I.) (Chemistry) – 1932	Surface chemistry/ Electrical discharges/Atmospheric Physics	General Electric Research Laboratory, Schenectady, New York, USA

[a] Koichi Tanaka worked at Shimadzu Corp.
[b] Melvin Schwartz worked in Digital Pathways, Inc.
[c] J. Pedersen worked at Du Pont
[d] International Business Machines
[e] The third scientist who shared the Nobel prize (E. Ruska) was not at IBM
[f] Bardeen also shared the 1972 Nobel prize in Physics for his work on the theory of superconductivity.

1.7.4 Computers and Data-Processing Technologies (*Christophorou L.G., 2001; F.N. Magill, 1990*)

As the reality spells out for itself, computer and data-processing technologies have undoubtedly made possible the current capabilities and capacities of mankind in the realms of acquisition, processing, and storage of scientific-data. In its progression, it has managed to facilitate effective communication in science, and has allowed for extraordinary dissemination and compression of information. Its unique capabilities enable the scientist to manage the proliferation of his semantic environment, in one way or the other.

Computers have revolutionized the way scientists analyze and assess information for complex objectives, which may include those of basic research. All scientific disciplines are benefiting from the revolutionary data-processing technologies and are adding more innovation to these technological breakthroughs of modern times.

Lastly, technology has impacted science by donating ideas. As an example, we are reminded of the industrial scientists who were awarded the Nobel prize in physics or chemistry for the work they did in industrial laboratories, as reported by (*Christophorou L.G., 2001*), and shown in Table-1.9.

Chapter-2

SCIENTIFIC RESEARCH: ITS IMPORTANCE AND TYPES

2. SCIENTIFIC RESEARCH: ITS IMPORTANCE AND TYPES

The explosive growth of scientific knowledge and continuing developments in technology are transforming society today; while we are hailing the advent of the *Information Age*, it is a well-known fact that it is the breakthroughs in the fields of computer-science and communication-science that knocked open the gate to this age. The important role that scientific research has played in the development of human society has been universally recognized (*Christophorou L.G., 2001*). The whole world is emphasizing knowledge and consequently the role of science and technology, as the primary productive forces has increased manifold.

Scientific research is the cardinal tool for mankind to know and reform nature. Activities of scientific research date back to the early stages of human society. Scientists today continuously get familiarized with the universe, understand its physical laws by thinking and practice, and apply the knowledge they have acquired in guiding the practice, creation and invention. The remarkable accomplishments of the human race are the monuments of scientific research activities of the past. As Albert Einstein said:

“The process of scientific discovery is, in effect, a continual flight from wonder”

The progressive development of human society has placed an ever-increasing demand on scientific research. On the one hand, the issues for scientific research have become accentuated and complex in an unprecedented manner. Nowadays, the forefront of scientific research is marching towards the untouched areas in leap and bounds, both in micro and macro-scopic directions. Whether with micro-scopic particles and nanometer technology in physics, or with chromosome and gene in bioscience, scientific research has now advanced to create a complex and abstract world, which in turn raises new formidable tasks for scientific research to overcome. All in all, the development of science and technology has given impetus to social progress. Meanwhile, the contents and methods of scientific research have also been innovated continuously (*Mianheng, 2002*). A wise man once said:

"Scientific discovery makes invention possible."

A similar idea was floated by Sir Isaac Newton, who said that:

“Whoever has undergone the intense experience of successful advances made in science, is moved by profound reverence for the rationality made manifest in existence”

Today, scientific research is a highly controversial issue. Many scientists, technologists, industrialists, planners and policy-makers are commenting on and questioning the value of various types of scientific research. Some of the issues being debated are:

- Who should be paying for basic research?
- Should governments spend less of the taxpayer's money on basic research, in order to concentrate more funding on research projects that have potential economic value?
- Should public funds be used to subsidize applied research being carried out by private industrial companies?
- Is basic research viable and necessary, especially when it comes to the developing and underdeveloped countries?
- Should the impetus be to harness and conduct applied research or basic research, and what should be the balance, if any?

As is clear from the crux of the debate, the issue is primarily focused on the two branches of scientific research, namely basic and applied. However, before one attempts to answer these important questions, one needs to get a better and deeper understanding of the meaning and value of not only basic and applied research, but also the other types of scientific research[1] contributing to development and making an impact on today's technology.

Scientific research can be broadly categorized as follows (*Christophorou L.G., 2001*):

1. Basic Research
2. Applied Research
3. Mission-Oriented Research
4. Problem-Oriented Research
5. Industrial Research

2.1 Basic Research (*Christophorou L.G., 2001; Brooks H., 1971*)

Basic and Applied research shall be touched upon in detail in the forthcoming chapter. Here, it is sufficient to give their definitions.

Very briefly, basic research is the extension of scientific and technical knowledge, without necessarily being justified by industrial and commercial intentions. Basic research provides us the necessary knowledge of the intricate mechanisms that sustain life and is at the heart of nearly every major discovery known to man (*MMRL, 2002*). It is that kind of activity, the output of which is used as an informational input into other inventive activities. It is the attempt of a researcher to access the frontiers of knowledge for the sake of knowledge alone. Nevertheless, ultimately it is the knowledge created by pure research that provides the intellectual material for formulating the applications, which we today deploy as technology (*Okpaku, 2000*).

Basic research is said to be the component of knowledge-enterprise most distant from immediate or foreseen commercialization. The discovery of new knowledge and the desire to

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[1] The word 'research' encompasses in itself a multitude of connotations; however in this book the term would be used more in the sense of development, which is how academic scientists describe it, rather than in the sense of innovation with existing technology, which is how it is defined in the industry.

solve problems is at the core of all research, and basic research is at the core of knowledge-creation. In layman's terms, a researcher carries out basic research when he or she thinks that the activity is the best use of his or her time, that the research has value in its own right and that it offers the best prospects of discovering something presently unknown about the natural universe (*Lukasik, 2000*).

The importance of basic research is not assessed by the importance of the work being carried out, as the ultimate outcome of the endeavor is not fully known at the initiation of the research. However, assessing the likelihood of the research's contribution towards important unsolved scientific questions – more specifically known as the 'needs' of science -- may be helpful.

2.2 Applied Research (*Bromberg J., 1988*)

Contrary to basic research, applied research may entail creation of new knowledge and applications of existing knowledge, but is addressed to clearly defined problems (usually, but not always, of companies or industries) and leads to products or services that may be exploited in the near future.

Applied research is carried out to find practical solutions for current pressing needs. In essence, the problems of society in general, and industry in particular, are assessed and addressed by applied research, which results in the improvement of a product or a system. Such research is primarily done because the performer expects to benefit from it in some direct way, such as through a future business-return or a direct financial interest (*Lukasik, 2000*).

In other words, applied research is work that translates into products, goods, or services that contribute to the GNP. It is the investigation of some phenomenon to discover whether its properties are appropriate to a particular need or want. It aims to answer real-world questions and not just abstract and theoretical ones. Its focus is on solving problems, evaluating projects and making policy or managerial decisions and planning and forecasting. All in all, applied research is that kind of activity whose informational output is an input for the production of commodities.

2.3 Mission-Oriented Research (*Weinberg A.M., 1967*)

A simple definition is as follows:

"A broad-based research, carried out in support of a particular Mission or the achievement of a certain Technological Goal".

The 'mission' or the 'technological goal' could be any broad-based programme aimed at the developmental work for a certain scientific system or establishment of a proper infrastructure/ know-how, necessary to make the project '*Critical*' and workable for the aim with which it was initially started. It may consist of different combinations/phases of "basic" and "applied" research project/sub-projects.

Some of the examples of "Mission-Oriented Research" are:

1. Development and Establishment of Nuclear-Energy Programme
2. Research leading to the Development of Radar System, Missile Programme, Space Exploration, etc.
3. Research aimed at cure of Cancer.
4. Research aimed at
    - Development of X-ray lasers.
    - Understanding the Effects of Radiation on Matter.
    - Development of a cure for cancer, aids, etc.
    - Controlled Fusion/thermonuclear reactions

Mission-oriented research focuses on developing new knowledge of direct relevance.It is interesting to note that Mission-oriented research does not deal with only applied research, but has also greatly contributed in the advancement of basic research, with the development of new gadgetry helpful for the generation of new and high-level basic knowledge. Some of the relevant examples are:

1. Basic research in superconductivity greatly benefited from the programme carried out for the development/advancement of new energy sources.
2. The Space-programme helped (and vice versa) in securing handsome government grants for the advancement of atomic and molecular physics.
3. Basic research in atomic & molecular radiation, and radiological physics, for example, draw valuable support from Organizations carrying out extensive research/programmes in studying the effects of different types of radiations on living cells.

As mentioned earlier, Mission-oriented research, in many ways, has contributed enormously to the further improvement/progress in the domain of Basic Research by developing new and advanced methodologies, processes, experimental techniques and instrumentation. Some typical examples are as follows:

1. Mission-oriented research in defense-related projects resulted in tremendous progress/ development in computer science/technology. This remarkable development could not take place if carried out for doing basic research alone. It needed the "impetus" and "support" given by the Missions of "Defence" and "Space Race".
2. Nixon's programme dealing with cancer was started with the mission of finding a cure for cancer. The mission did not succeed as such. However, it gave a tremendous boost to

the advancement of "Biotechnology".

3. Reagan 's "Stars War" initiative was taken with the objective of realizing a "protective shield" against a possible "nuclear attack" The work so carried out did not help in achieving this objective. However, surprisingly, it resulted in useful research-output in the field of new materials and yielded valuable insight in light-sources such as X-ray lasers.

It is, thus, clear that in Mission-Oriented research, the benefit is mutual, i.e. the applied and basic research help each other. Experience shows that this mutual benefit was a maximum when the interpretation of "Mission Relatedness" of "basic research was not narrowly defined".

2.4 Problem-Oriented Research (*Christophorou L.G., 2001*)

Problem-oriented research is simply defined as 'research work carried out to solve a specific problem arising during a certain research programme'.

This is a relatively narrow research activity aimed at some difficulty or hurdle faced during a broad research activity. It can also be aimed at resolving certain technical fixes. In certain cases it may be carried out to find out a quick / immediate (on relative time-scale) solution to meet certain societal needs. Some specific examples may be as follows:

- Problems relating to public health, pollution, etc.; other immediate public-concern problems, such as water, energy, transportation, waste disposal.
- Suitable replacement of useful but hazardous materials – such as PCBs (polychlorinated biphenyls), CFCs (chlorofluorocarbons).

Problem-oriented research is primarily concerned with current issues and problems, as well as the relevant social actors and stakeholders. The primary objective of this type of research is to analyze perceptions of the problems at hand, related models for action and means of knowledge and then to transform these into scientific questions and research-strategies. This research claims to bridge the gap between natural sciences, humanities and social sciences, and uses the impetus on predicaments to reach interdisciplinary and/or transdisciplinary approaches. The fundamental goal is to amalgamate scientific analysis with action, keeping in mind the interests of societal decision-makers and stakeholders (*ITAS, 2000*).

To achieve the goal of problem-oriented research, the scientific, technical and sociological theories, methodologies and data must be methodically interlinked with the visions of sustainable development or recycling economy, or more specifically visions of a technological nature or those related to ethical standards. By doing this, problem-oriented research focuses more on the relationship between normative determinations and empirical analysis of results. What lies at the heart of problem-oriented research is essentially the integration of social reflection and the dynamism of scientific knowledge into decision-maker's strategies for action (*ITAS, 2000*).

Problem-oriented research develops out of the specific requirements of the business-world and public authorities, but also out of needs which arise in new areas with growth potential. It is implemented on the basis of cooperation between the actors involved in carrying out research and the actors who need the results and skills that emerge from the research process, including scientific methods of solving problems. From a scientific perspective, problem-oriented research can be both basic research and so-called applied research.

In order for problem-oriented research to produce innovations and sustainable growth, there must be high standards of scientific quality and on-going cooperation between the various actors involved, in order to promote mutual interaction and learning. When a satisfactory level of interaction is reached, need-based research can produce internationally outstanding scientific results, effective innovation-processes and growth.

2.5 Industrial Research (*Schon D.A., 1971*)

Scientific discoveries coupled with technological developments enable the industrial sector to convert the new knowledge, so gained, to practical applications in an effective manner. Such a conversion of new knowledge to industrial products should preferably take place as early as possible, if an effective edge over other competing industrial set-ups is to be achieved. In addition to this, industry carries out its own research-programme. This research, carried out by industry, under its own programme, is generally known as *Industrial Research*.

Industrial research predates invention, involves highly knowledgeable men of vision and is aimed at obtaining knowledge and new ways that facilitate the emergence of new technology. It is, therefore, clear that it is extremely important to get new and good ideas, which enable the industry to: (a) improve the quality and usefulness of its products, and (b) make them relatively more durable and inexpensive. It clearly indicates that many industrial set-ups are well aware of the importance of new/basic knowledge, because it acts as the seed for obtaining a better and more efficient product, which will ultimately result in increased profit and more financial gains for the industry concerned.

Experience shows that there seem to exist (a) "time continuums" from fundamental knowledge to usable/marketable industrial products, and (b) "diffusion time", a period necessary for the diffusion of "technological innovations". It is interesting to note that both of these durations seem to be getting shorter and shorter with the passage of time. For example:

- The time continuum for the Principle of Photography was 200 years, while the diffusion time for the same was only 40-50 years.
- In the case of Liquid Crystals, it took 80 years until the fundamental knowledge was

actually converted into products, while it took the Electrical Motor only 40 years.

- The time continuum for Nuclear Power and the Transistor is the same i.e. only 5 years, while the diffusion time for the Transistor is an unexpected 15 years
- Transparent Plastics took only 2 years to move from basic knowledge to marketable items.
- The time continuum for nylon was 10 years.

Superconductivity is also one such area for which Theodore H. Geballe said:

> ***"It took half a century to understand Kamerlingh Onne's discovery, and another quarter to make it useful. Presumably, we wont have to wait that long to make practical use of the new high-temperature superconductors."***

2.6 Contribution of Industry to Research

Research and development is an important element of technological innovation, because it helps generate superior products, processes and services that can give a company a competitive edge. For R & D to lead to profitable growth, it must lead to a technical advance, which in turn must be translated into profits in the world markets. R & D is a prerequisite for

Table - 2.1: Top 10 Countries and Top 10 Companies in the R&D Scoreboard 1999

Country	**Number of Companies (in Top 300)**	**R&D Investment (£M) by these Companies**	**Company**	**R&D Investment (£M)**
USA	130	65,284	General Motors (US)	4,748
Japan	79	36,658	Ford Motors (US)	3,786
Germany	23	18,103	Daimler Chrysler (Germany)	3,508
France	19	8,932	Siemens (Germany)	3,279
UK	16	6,315	IBM (US)	3,183
Switzerland	9	5,555	Lucent Technologies (US)	3,061
Canada	2	3,672	Compaq Computers (US)	2,734
Sweden	5	3,173	Hitachi (Japan)	2,722
Netherlands	4	2,191	Matsushita (Japan)	2,560
Italy	6	1,831	Northern Telecom (Canada)	2,529
Others	7	2,769		
Total	**300**	**152,491**		

Source: *Tubbs M., 1999, "Industry and R&D", Physics World October 1999, pp 32-36.*

innovation, which is essential for companies to remain competitive in the global village of today (*Tubbs, 1999*).

The Table-2.1 elaborates the R&D spending of the top 10 countries and their investment in R&D in the year 1999.

However, innovation and the resultant technological change do not just happen – they must be paid for, through expenditures on research and development. How R&D funds are spent helps determine how scientific knowledge will accumulate and how technological change will be manifested. In other words, total R&D expenditures reveal the perceived economic importance of R&D relative to all other economic activities of a nation. Of course, R&D data alone are not sufficient to analyze the future growth of a field of study or an industrial sector, but they may well be an important input into such analysis (*NSB, 2000*).

Most of a nation's civilian research and development is carried out in industry, while "development" has always been the major aim of industrial R&D, industry has made many critically important contributions to "research". But competitive pressures have forced industry to shift R&D efforts toward work with shorter time-horizons. Relatively little industrial R&D now has an anticipated time-to-application of longer than five to seven years. This is the case even at Bell Labs and IBM. Hence, government support for long-term R&D is now *more important than ever*.

Examining the return on investment in R&D shows that the rate of return to industry is around 20%, while the societal rate of return is considerably higher, around 50% (since technology spreads from the firm that introduced it). It is also found that academic research is of great importance in underpinning industrial innovation.

Examples of the industries' contribution to research can be drawn from a variety of industries, such as the pharmaceutical, manufacturing, and so on. However, the contribution of industry to information technology as a field and discipline are extremely important. As Tom Theis and Paul Horn of the IBM Corp's *Thomas J. Watson Research Center, US*, elaborate, the incorporation of GMR sensors into hard-disk drives is a good example of just how quickly a new and unexpected scientific discovery can energize an entire industry. The effect, when first observed in 1988, was significant only at cryogenic temperatures, and the costly process of molecular-beam epitaxy was needed to grow the layered metal structures with atomic precision. Stuart Parkin, a remarkable experimental physicist at IBM Corp, was well-versed in the technological issues of magnetic recording, and resultantly foresaw a potential new technology. To his credit is also the observation that low-cost sputter deposition techniques could be used to rapidly explore the enormous combinatorial space of possible layered magnetic structures and materials. Consequently, Parkin and other scientists across the globe clarified the underlying physics and were able to produce practical room-temperature GMR magnetic sensors. At a later stage, groups of scientists and engineers worked together, to reveal and solve many problems of materials-compatibility, device reliability, manufacturing process-control, and so on and so forth.

The first commercial GMR devices were magnetic field sensors, which were sold in 1995. IBM introduced GMR read-heads to hard-disk drives in 1997, and all competing manufacturers also followed quickly in this direction. Consequently, a collective quantum behavior became an essential component of the billions of computers that have been and are manufactured – a behavior which was unheard of a couple of decades ago (*Theis et al., 2003*).

Let us look at another example for elaboration. In the early 1980s, Bernard Meyerson and his colleagues at IBM conducted fundamental studies of the gas-phase chemistry of organic compounds containing Silicon (Si). Meyerson had seen prospective benefits for the epitaxial growth of Si crystals in a previously unexplored low-temperature, low-pressure regime. The subsequent invention of Meyerson, called the ultra high-vacuum Si epitaxy, consequently led to the fabrication of electronic devices that set a string of records for high-frequency performance. In an attempt to solve the developmental and manufacturing problems associated with it, several groups of scientists and engineers worked jointly and enabled IBM's microelectronics division to offer new products for communications. Today, the world witnesses rapid commercialization of applications and devices produced using Meyerson's methods, which also include devices based on silicon-germanium electronics (*Theis et al., 2003*).

Moving out of the IT industry, one can analyze another example. Fundamental studies of nonlinear optical processes at Lucent, Technologies Bell Laboratories, led to the invention of optical fibers, engineered for greatly reduced chromatic dispersion, . Introduced to the market in 1994, Lucent's True-Wave optical fiber has become an industrial standard for multiplex data transmission, involving multiple wavelengths, simultaneously carried on a single fiber. Similarly, studies (at Bell Labs) of the optical properties of rare-earth ions in glass hosts led to high-power erbium-doped fiber amplifiers. And studies of soliton dynamics led to pulse-shaping techniques for transmitting data, without repeaters, over very long distances (*Theis et al., 2003*).

There are countless examples of industry's contribution to research, which prove the significance of this contribution and its continued positive impact in the realms of scientific and technological research of modern and futuristic times. The society continues to get benefit from the valuable input of the industry towards research.

2.7 The Scientific and Industrial Revolutions

Although, as Snow put it, dating the scientific revolution is "a matter of taste", the middle of the 17th century may well be regarded as its beginning. This period also may be taken as the beginning of the systematic investigation of major areas of the universe, in spite of the fact that it was not until the 19th century that the fruit of this revolution ripened, as can be seen from **Appendix II**, which lists a sample of the outstanding scientific discoveries which occurred during the latter part of the 19th century.

From the beginning of the scientific revolution there were calls for emphasis on the application of science to the solution of social problems and the practical needs of man. Francis Bacon was an early advocate of this view. Thus, the scientific revolution unavoidably led to the industrial revolution. The latter had arisen from wider human interactions and has had far-reaching social consequences. In the 18th century the specific interrelationships between science and technology were minimal, but they increased considerably by the end of the 19th century. For instance, basic investigations in chemistry were triggered, in response to needs for bleaching and dying of cloth, while the discovery of urea by Wohler in 1828 opened up the way for the synthesis of medicaments and dyestuffs. Watt's steam engine (around 1765) signifies perhaps truly the onset of the industrial revolution. **Initially, the basis of this revolution was invention and not science**, but by the close of the 19th century the interplay between scientific discovery and industrial innovation began to emerge, as can be seen from the **Appendix-I,** where some technological advances are listed.

Ultimately, this interlocking of basic discovery and technological innovation led to the emergence of the chemical, the engineering, the electrical, the electronics and the transportation industries, as well as many industrial uses of atomic particles. In this way, technologies were established as systematic disciplines, to be taught and learned, and science began to reorient progressively a larger part of itself towards feeding the new technologies.

2.8 Fundamental and Strategic Research

Besides the kinds of scientific research listed and described above, Richter came out with an even more simple classification of scientific research. According to him scientific research can broadly be divided into two generic areas: "Fundamental Research" and "Strategic

Table - 2.2: Distinction between Four Categories of Research (Fundamental, Strategic, Basic and Applied) in the Case of Lasers

Gerneric Research	Type of Research	Examples of Research
Fundamental	Basic	Quantum Mechanics (the Einstein A and B coefficients for light absorption and emission)
	Applied	Laser
Strategic	Basic	Interaction of Materials with light
	Applied	Optical Fibers

Research”. These two types of research have both “Basic and Applied Components”. Table 2.2 summarizes two examples of generic, basic and applied research for the case of Lasers: The generic research category of fundamental research in the subject table exemplifies that, according to Richter, basic research can be identified by the work of Albert Einstein in the field of Quantum Mechanics (*Richter B., 1995*). In 1905 Einstein examined the photoelectric effect. The electromagnetic theory of light gives results at odds with experimental evidence. Einstein proposed a quantum theory of light to resolve the difficulty and then he realised that Plank's theory made implicit use of the light quantum hypothesis. By 1906, Einstein had correctly guessed that energy changes occur, in a quantum material-oscillator, in changes or jumps which are multiples of $h\upsilon$ where ‘h’ is Planck's constant and ‘υ‘ is the frequency. Einstein received the 1921 Nobel Prize for Physics, in 1922 and for his work on the photoelectric effect. This work, inclusive of Einstein’s A and B coefficients for absorption and emission of light, is an example of fundamental basic research.

On the other hand, the research that led to the development of lasers is strictly fundamental applied research. It finds its roots in Einstein’s theory of ‘photons’ and Planck’s concept of ‘quantums’. The invention of the LASER (which stands for Light Amplification by Stimulated Emission of Radiation), was the work of Schawlow and Townes, which can, however, be traced back to the 1940s and early 50s and their interest in the field of microwave spectroscopy, which had emerged as a powerful tool for puzzling out the characteristics of a wide variety of molecules. Neither man was planning on inventing a device that would revolutionize a number of industries, from communications to medicine. On the contrary, they had something more straightforward in mind, i.e. to develop a device to help them study molecular structures (*LT, 1998*). In Richter’s eyes, such research is fundamental applied research.

The strategic basic research, as explained by Richter, is synonymous with the discovery of the phenomenon of material interaction with light. On the other hand, the research that led to the development of Optical Fibers, which are flexible, transparent fibers, usually made of extremely pure glass, and designed and manufactured to guide rays of light, can be termed as strategic applied research work.

All in all, Richter (*Richter B., 1995*) aimed to draw a line between the various categories of applied and basic research by further categorizing them through generic classifications of fundamental and strategic research – a different approach to understanding the fine line of difference altogether.

Chapter-3

BASIC AND APPLIED RESEARCH: ISSUES AND CHALLENGES

3. BASIC AND APPLIED RESEARCH: ISSUES AND CHALLENGES

3.1 Introduction

The debate about the relative importance of basic research over applied research or vice versa has always received significant attention among the scientific community. Opinions differ on the issue. Some would value applied research more than its basic counterpart, while referring to its application that has led to a large number of inventions and solved many a problem in almost every walk of life. Others tend to disagree and place more value on basic research, considering it the foundation on which every invention is based. It is true that applied research has gained prominence, since people seek in it solutions to major global problems, e.g., over-population, global warming or environmental degradation. Sometimes application has come first and understanding later, but there is no denying the fact that, in a majority of cases, it is the basic research that precedes any modern invention or technological innovation (*Christophorou L.G., 2001, Brooks H., 1971*).

Basic research is driven by the curiosity of a scientist who does not have any technological discovery in his/her mind while at work; the purpose is to augment scientific knowledge, introduce new aspects of already researched issues or discover an entirely new phenomenon. The results are hardly predictable when a scientist is doing basic research and it is only during or after the research that a new phenomenon is hit upon or a discovery is made. Basic research, thus provides a foundation upon which technological innovations and inventions are often based.

This chapter shall highlight both types of research—applied and basic—while the focus shall remain on the nature and importance of basic research. It will draw upon examples from various scientific fields, such as electronics, physics, and bio-medicine, to show that the importance of basic research is as relevant as it was in the past, and applied research has not diminished it in any way. It has rather provided a practical end to it, in the form of numerous scientific inventions for the benefit of mankind.

3.2 Applied Research

Applied research is designed to solve practical problems of the modern world, rather than to acquire knowledge for the sake of knowledge. The focus of applied research is on defined outcomes, i.e. to solve problems, to make decisions and to predict and/or control. It is primarily carried out to achieve certain goals and convert the findings of basic research into practical applications (*Bromberg J., 1988*).

The three predominant characteristics of applied research include:

- Potential for contributing to the development of theory;
- The researcher has access/control over phenomena being studied;

- Generation of knowledge that will influence or improve clinical practice.

Applied Research is aimed at gaining the knowledge or understanding to meet a specific, recognized need. General examples of applied research would include using bacteria to inoculate plants against particular diseases, developing computer-models of the atmosphere to improve weather-forecasting, and creating drug therapies for brain-related illnesses (*AAU, 2002*).

Further examples of what applied researchers may investigate, include ways to:

- improve agricultural crop-production,
- treat or cure a specific disease, and
- improve the energy-efficiency of homes, offices, or modes of transportation.

All in all, applied research is an original research, just like basic research, but is driven by very specific, practical objectives. Examples are: the research for the formulation of public policy (education, health, economic, environmental, etc); research into how industrial development can take place, with simultaneous protection of the environment; research into the provision of adequate, cheap housing; and research around finding cures for diseases.

3.2.1 Importance of Applied Research

As mentioned, applied research is aimed at gaining the knowledge or understanding to meet a specific, recognized need, or to solve a specific problem. It includes investigations oriented to discovering new scientific knowledge that has specific objectives, for example with respect to systems, products, processes, or services. Finding a better treatment or diagnostic for a disease, is also an example of the applied research.

Many of the modern scientists are arguing about the viability, significance and importance of applied research against basic research. This argument is augmented by the premise that global overpopulation, pollution and the overuse of natural resources is consistently generating complex problems for the human race, and science should now be directed towards improving the human condition by providing pragmatic solutions, rather than indulging in knowledge-seeking endeavours only, which have no immediate direction in sight.

Whatever the argument, one cannot neglect the importance and significance of applied research, be it yesterday, today or tomorrow. Applied research leads to inventions. This process is usually spread over a large span of time and, normally, a large number of people are involved in attaining the invention stage. There have been many historic examples in which applied research has had a major impact on our daily lives. In many cases, the application was derived long before scientists had a good, basic understanding of their underlying science. This phenomenon may be illustrated by envisioning a scientist saying to himself, "I know it works; I just don't really know how it works!"

The invention of the transistor was also a revolutionary application of scientific research and proved to be a major milestone for the electronics industry all over the world. It also proved to be a starting point for the design and manufacture of integrated circuits (ICs). Before this discovery, vacuum tubes were used as the only means (as triodes) in electrical devices (*Bindloss, 2003*).

Scientific research and experiments also led to many other noteworthy developments in various other fields, such as health and medicine. These included developing of vaccines for polio (1953), rabies vaccine (1885), and pencillium (20th Century).

Although interlinked, basic and applied research have a different orientation from each other. Yet it is the way basic research leads and supports applied research that determines the necessity and usefulness of both kinds of research.

3.3 Basic Research

Basic, fundamental or pure research is driven by a scientist's curiosity or interest in a scientific question. The main motivation is to expand man's knowledge, not to create or invent something. It can be further defined as a scientific research, performed without any practical end in mind.

One of the most distinguishing characteristics of basic research is that it cannot be easily defined operationally and cannot be tested in advance for utility. In this type of research, the process of innovation is interwoven with the production of new knowledge. Consequently, basic research is rightly termed as the 'mother of all inventions', because it provides the requisite 'scientific capital' (new scientific knowledge and understanding) needed for technological breakthroughs and for finding solutions to important practical problems.

Basic Research is aimed at gaining more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. Some general examples of basic research include research on the chemical properties of bacteria, analysis of the interaction of the oceans with the atmosphere, and investigation of neural pathways in the human brain (*AAU, 2002*). Another way to describe the concept is to say that objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. In industry, basic research is the research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest. Understanding how a protein folds or how a specific molecule elicits a particular biological response are also examples of basic research.

More examples of the questions which basic science investigations probe for answers include:

- How did the universe begin?
- What are protons, neutrons, and electrons composed of?

- How do slime molds reproduce?
- What is the specific genetic code of the human being? [*LBNL (online)*]

Basic research is that component of knowledge, which does not involve any immediate or foreseen commercialization or commercial viability. The ultimate objective is therefore not to serve any pressing need or attend to a current problem, but to aim at discovering knowledge with a universal perspective and a broader horizon. This trait of basic research allows many an invention and technology to stem from the reservoir of accumulated knowledge built through continued basic research.

Informational input attained from conducting basic research is the essence for instigating inventive activities. More specifically, answers to scientific questions are the building blocks for technological innovation and further scientific development, and basic research undoubtedly is the essential means of gathering such answers.

3.3.1 Importance of Basic Research

Over 200 years ago, at the beginning of 1782, the German physicist and philosopher Christof Lichtenberg wrote in his diary referring to the planet Uranus, which was discovered in 1781:

> ***"To invent an infallible remedy against toothache, which would take it away in a moment, might be as valuable and more than to discover a new planet... but I do not know how to start the diary of this year with a more important topic than the news of the new planet".***

The question Lichtenberg unreservedly raised, of the relative importance of looking for technical solutions to specific problems, and of searching for new fundamental knowledge, is even more relevant and significant today than it was in his times (*Smith, 1998*).

It is inevitably true that the search for fundamental knowledge, motivated by curiosity, is as useful as the search for solutions to specific problems. “Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science” (*LBNL [online]*). One of the fundamental reason as to why today we have computers and did not have them about 100 years ago is because of discoveries in fundamental physics, which formed the basis of modern electronics, developments in mathematical logic, and the need of nuclear physicists in the 1930s to develop ways of counting particles. Assuredly, it had nothing to do with the need to develop computers (*Smith, 1998*). Today, it is truer than ever that basic research is the pacemaker of technological progress (*LBNL [online]*). Technologies upon technologies originates from fundamental discoveries, often unforeseen and unpredicted.

Careful studies indicate that basic research serves as a foundation of modern technology. The following important contributions in this regard are worth noting:

1. It provides the required basic knowledge or acts as a “Scientific Capital” necessary for making the application a reality. It is firmly believed that industrial development would eventually stagnate in the absence of the supporting basic research. This stage is felt only when the “Scientific Capital” runs out.
2. Broad-based basic research is a prerequisite for solutions to different problems. Solutions are not forced or obtained abruptly. They are preceded by necessary knowledge, often obtained by basic research.
3. Basic research provides the foundation of education and basis of training the people working in industry and technological setups.
4. It cultivates scientific climate conducive to understanding the objectives of technology.
5. Basic research serves as a source of intellectual standards for applied research.
6. It is the net exporter of techniques to industry. Techniques such as, vacuum technology, cryogenics, X-ray diffraction, radioisotopes, with their origin as techniques of basic research, are commonly used in industry these days.
7. Basic research, therefore, must not be taken as a peripheral activity or be forced to provide short-term solutions under excessive pressure and/or limited support.

Fundamental research has been well supported by many leading scientists of the world. As Alistar M. Glass notes in his article on fiber optics:

> ***“Fundamental research in glass science, optics and quantum mechanics has matured into a technology that is now driving a communication revolution”***

Subjects of great technological and medical importance that originated from basic physical research include, among many, nuclear magnetic resonance, semiconductors, nano-structures, superconductors and medical cyclotrons.

There is a strong view among experts regarding the output of research. The proponents of one view suggest that it is the targeted, goal-oriented research that brings about useful products and innovations. Examples from daily life are also cited to support this claim, but it should be kept in mind that numerous examples could also be found, which indicate that many a product were developed as a result of basic and fundamental research. Also, funds these days are allocated more towards goal-oriented research and less emphasis is put on basic research. Still, the importance and usefulness of basic research cannot be denied and sustainability of results can only be achieved with an optimal distribution of resources between applied and basic research.

It is a proven fact, which history has repeatedly demonstrated that it is not possible to predict which efforts in fundamental research will lead to critical insights about how to address a particular problem. It is therefore, essential to support a certain critical number of worthwhile projects in basic research, so that key opportunities do not go unrealized or wasted. As there is no doubt that basic researchers aim to complete the blanks in mankind's understanding of how life-processes work, there is also no skepticism about the enormously beneficial results that basic research has led to, in terms of its practical applications. The society today reaps enormous benefits from basic research and its applications, which in the form of technologies have saved millions of lives and made many others far more comfortable and meaningful than ever before.

Dr. Allan Bromley of the Atomic Energy of Canada says that the unprecedented boom in the American economy had little to do with new approaches to fiscal management, and all to do with past investments in science. Federal investments in science produce cutting-edge ideas and a highly skilled work-force. Two simple discoveries – the transistor and the fibre optic cable – are at the root of this boom. He added that,

"Anyone skeptical of this should turn off the computer for a day and see how much work gets done."

In a nutshell, the importance of basic science can be expressed in the words of Dr. George Smoot of the Lawrence Berkeley National Laboratory:

"People cannot foresee the future well enough to predict what's going to develop from basic research. If we only did applied research, we would still be making better spears."

3.3.2 The Unpredictable Nature of Basic Research (*Christophorou L.G., 2001; Braben D., 1994; Ziman J., 1976*)

As discussed earlier, the results of most of the basic research work contained unexpected practical applications in store. Such is the uncertain future impact of basic research work that some entirely wrong predictions were made regarding their practical utilization. History of scientific research contains a number of such instances. The following are a few illustrative and interesting examples:

- According to Rutherford, "the energy produced by the breaking of the atom would be a very poor kind of thing". Later developments showed the extent to which he underestimated this great source of energy.
- It is surprising that even Einstein could not possibly foresee how his mass-energy relationship would lead to the release of nuclear energy. He said in the year 1932, "there

is not the slightest indication that nuclear energy will ever be obtainable. It would mean that the atom would have to be shattered at will". Yet nuclear power-generation became a reality quite some time ago, and has since then been playing an important role in meeting the demands of the modern world, proving Albert Einstein's statement wrong.

- Faraday, on the other hand, could covertly foresee the practical usefulness and future applied nature of his work on electricity and magnetism. It is said that around 1850, Mr. William Glandstone (the then Chancellor of Exchequer and later Prime Minister) visited Faraday's laboratory and asked him, "This is all very interesting, but what good is it?" Faraday replied, "Sir, I do not know, but some day you will tax it". Faraday's reply was a visionary one.
- A decade ago everyone regarded superconductivity as a dead field. But in 1987, Alexs Muller and Georg Bednorz were awarded the Nobel Prize in Physics for the discovery of new kinds of superconducting material with much higher transition temperatures, and it did not fit the model of the Bardeen-Cooper-Schrieffer theory. We still do no fully understand how these materials work, but applications have already begun.
- Charles H. Duell, of the Office of Patents, said in the year 1899 that, "everything that can be invented has been invented". Obviously, he seriously misjudged the potential of basic and applied science/research.
- Popular Mechanics said in the year 1949 that, "computers may weigh no more than 1.5 tons". Pocket computers and other compact computer types evidently nullify the validity of this statement.
- Another such statement was issued by Ken Olson, President of Digital Equipment Corporation, who said in 1977 that "there is no reason anyone would want a computer in their home". Today, there is hardly a reason why one wouldn't want to have a computer at home.
- "This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us." This is a piece of text from the Western Union internal memo issued in 1876, which seriously underestimated the utility of a device that is an integral part of the conduct of modern livelihood.
- "The wireless music box has no imaginable commercial value. Who would pay for a message sent to nobody in particular?" This statement was made by David Sarnoff's associates in response to his urgings for investment in radio in the 1920s.
- "Heavier-than-air flying machines are impossible." Lord Kelvin, President of the Royal Society said this in 1895, which the Wright Brothers disproved in the 1903.
- "No flying machine will ever fly from New York to Paris." Orville Wright made this comment, unaware of the potential his work would acquire in the later years.
- "So we went to Atari and said, 'Hey, we've got this amazing thing, even built with some of your parts, and what do you think about funding us? Or we'll give it to you. We just want to do it. Pay our salary; we'll come work for you.' And they said, 'No'! So then we went to Hewlett-Packard, and they said, 'Hey, we don't need you. You haven't got through college

yet"."A recollection of events narrated by Steve Jobs, founder of Apple Computer Inc. when he attempted to get Atari and HP interested in his and Steve Wozniak's personal computer.

- "Professor Goddard does not know the relation between action and reaction and the need to have something better than a vacuum against which to react. He seems to lack the basic knowledge ladled out daily in high schools."… 1921 New York Times editorial about Robert Goddard's revolutionary rocket work.
- "Airplanes are interesting toys, but of no military value." Statement of Marechal Ferdinand Foch, Professor of Strategy at the Ecole Superieure de Guerre.
- "Louis Pasteur's theory of germs is ridiculous fiction". Statement made by Pierre Pachet, Professor of Physiology, at Toulouse in the year 1872

The uncertain/unpredictable nature of research work based on the curiosity-drive (i.e. concerning product/practical/main field/area of the final impact) is further illustrated by some more examples summarized in the Table-3.1 below (*Christophorou L.G., 2001*):

Table – 3.1: Scientific Fields and Technological Areas Benefiting From Fundamental Research in Diverse/Unrelated Subjects

Original Research Work or the Basic Emphasis and/or the field of interest)	**Field/Area which Finally Benefitted or the Final Product Resulting from the Research Work so Carried Out**
Fundamental research in glass science, optics and quantum mechanics	**Fibre** Optics – Revolutionary Technology in communications
Basic Research on Tetrafluoroethylene aimed at preparing new refrigerants	**Teflon** – A material with extremely useful industrial application
Research work on drug AZT was carried out to find a remedy against cancer	**Useful** Progress made in obtaining Anti-AIDS drug
Rosenberg's research on the potential effects of electric fields on cell division	**Discovery** of an important drug against cancer
Kendall's work on the harmones of the adrenal gland	**Resulted** in the identification/ formation of an anti-inflammatory substance
Carothers' research work on giant molecules	**Led** to the invention of Nylon
Block and Purcell's fundamental research work on the absorption of radio frequency by atomic nucleus in a magnetic field	**The** research work led to a very important technique of magnetic /medical resource imaging (MRI)

(Continue...)

(Contd...)

Rabi's work on Nuclear magnetic Moments (1938)	**Magnetic** / Medical Resource Imaging (MRI) (1980s)
Cohen and Boyer's work on the development of gene splicing	**Produced** better insulin, along with other useful products
Haagen – Smit's work on air pollution	**Spawned** the catalytic converter.
Reinitzer's important work on the discovery of liquid crystals	**Important** contribution in further development of computers (particularly flat-panel television screen) and the discovery of laser. Laser, which was initially a laboratory curiosity has found important applications, such as the reattachment of a detached retina and the reading of bar-codes in supermarkets.
Various projects carried out in "Basic Physical Research"	**Subjects** of great technological and medical importance, such as: Nuclear magnetic resonance Semiconductors Nanostructures Super conductors Making useful … applications Carrying out medical applications
Fundamental Basic Work in Condensed Matter Physics (1920s – 1930s)	**Development** of Transistors (1950s)

It is also interesting to note that applied form of research (the products that are developed) can somehow be linked to the fundamental research; examples can be given in this regard: the transistor was developed as a result of research in condensed matter physics, and Magnetic Resource Imaging technology was developed due to investigations in nuclear magnetic moments. A conversation between Socrates and Glaucon can be used to support the claim:

Socrates: Shall we set down astronomy among the subjects of study?

Glaucon: I think so, to know something about the seasons, the month and the years is of use for the military purposes, as well as for agriculture and for navigation.

Socrates: It amuses me to see how afraid you are, lest the people should accuse you of recommending useless studies.

More recently, Frances W. Clarke of the U.S. Geological Survey, in a speech also protested that:

"Every true investigator in the domain of pure science is met with monotonously recurrent questions as to the practical purport of his studies; and rarely can he find an answer expressible in terms of commerce. If utility is not immediately in sight, he is pitied as a dreamer, or blamed as a spendthrift."

The return on investment in basic research is not often so immediate. However, over the long term, it can impact substantially, and often as least expected. Indeed, investment in basic research produces a multifarious payback, a clear example of which is the creation of an entire new economy, based on information-technology (*Birgeneau, 2001*).

3.3.3 The Technological Value of Basic Research (*Christophorou L.G., 2001*)

It is an established fact that there has always been apprehension regarding the emphasis upon and investment in basic research. This is mainly due to the uncertainty attached to the focus and expected results of basic research.

The time-line of science and technology indicates that there are certain periods in history where a lot of activity and innovation took place. In this regard, the twentieth century has been a century that can be identified as an era of fast-paced and high-tech innovations. Interestingly enough, this rapid developmental activity of 20th century was seen in almost all areas of science and technology. Be it the field of nuclear physics, organic chemistry, or biotechnology, the world has seen very significant changes in terms of scientific and technological research and their respective applications. During this time-span, space vehicles were introduced, power plants revolutionized the energy sector, atomic physics experienced the most dynamic results (at times destructive), and biological sciences were also marked by significant developments. All in all, there is an unending list of activities and the world actually saw unprecedented changes due to research in science and technology.

3.4 Revolutionizing the World through Basic Discoveries (*Christophorou L.G., 2001*)

The importance of basic research in human civilization cannot be emphasized enough. Starting from daily appliances and systems and going onto complex industrial and scientific equipment, systems, disciplines and fields – all owe their celebrated utilization in the modern times to basic research.

The link between science and technology can be further illustrated by a number of scientific discoveries that have changed the world. Examples of science-based technologies that trace to such discoveries in the fields of electricity and electronics, energy, radiation, chemistry, biomedicine, laser and photonics, and materials are briefly given in the following paragraphs:

3.4.1 ***Electrical and Electronic Technologies*** (*Christophorou L.G., 2001*)

About thirty-five years after Faraday's basic scientific discovery of electromagnetic induction (1831), we found the development of the first commercial electric generator (1866-67). With that development, electricity during the latter part of the 19th century was transforming not merely the study of physics but also European and American society. In an unprecedented manner, electricity bridged the gap between pure science and useful applications. It showed the utilitarian character of physics, just as chemistry's utility had already been demonstrated in agriculture and industry. Hence, electrical engineering emerged as the first important activity to be developed from the very beginning on scientific principles. Since then, the science of electricity has given society electric-discharge tubes; electric lights; electric motors; telephones; radios; televisions; and clean, reliable technology-tailored electric power, without which there would be no computers and no communication-system industry, as we now know them.

The electronics industry came after the discovery of the electron, the induction coils in motor cars came after the *Laws of Induction;* the electromagnetic wave and communications came after their discovery by Maxwell and Hertz; and the transistor came after the basic research in condensed matter and quantum theory of solids. Similarly, basic circuits in computers originated in nuclear-physics research in the 1930's and was done by scientists who needed to count nuclear particles. The impact of scientific discovery in this field on advanced technology continues with the miniaturization of electronic devices and computer microprocessing.

3.4.2 ***Energy Technologies*** (*Christophorou L.G., 2001*)

Man's most important energy-sources are science-based. They will become more so in the future. Nuclear-power came after, and not before, nuclear physics. Energy from controlled fusion is not yet available to man, because basic science in plasma physics is not yet sufficient to allow technology to proceed. It was not technology but basic science that formulated the understanding and identified the critical reactions in both fission and fusion, which man can harvest for useful energy-production. Plasma physics is central to thermonuclear research and to the applied science, which is needed to enlarge mankind's energy resources.

In the field of energy, it is a widely held view that spending on R&D is an important precursor to the technological advances required to secure sufficient, safe and environmentally acceptable energy-supplies, and to use them more efficiently. Nevertheless, energy-technologies have many aspects. They not only involve energy-production, but also use of energy, energy conservation, energy conditioning, and energy transmission and distribution. Especially in the last area, there is a great potential for superconductivity. The power loss in a superconducting transmission line would be virtually zero because the electrical resistance of a superconductor is virtually zero. Power transmission by superconductors will become commercially attractive when (1) the savings on power-loss exceed the cost of refrigeration of the line, but (2) more so when room-temperature superconductors are discovered and developed.

The continuing development of superconducting alloys with higher working temperatures provides hope that the economic crossover may soon occur, thus allowing economic long-line transmission of power from distant hydroelectric or other type of power-plants. Another important application of superconductivity is in very high-field electromagnets. Such magnets are needed in plasma containment, a key element in the development of a controlled thermonuclear reactor. Technologies based on high-temperature superconductors are not here yet because basic science has not yet developed an understanding of the phenomenon that would allow applied research to provide the complete answers, needed for their technological development. This technology too will follow and will not precede science. Industry or society did not dream up superconductors; science discovered the phenomenon, struggles to understand it thoroughly, and when it does, the application will follow and so will the superconducting transmission lines and the high-field electromagnets.

The need today, however, is to ensure that progress in advanced fossil-fuel technologies, in non-fossil fuel technologies, and in energy-efficient technologies is maintained and accelerated. This is widely accepted in the energy sector as one of the key responses to the challenges of environmental degradation to warrant sustainable development.

3.4.3 Radiation - Based Technologies

Here again we have several beautiful examples of scientific discoveries that led to new technologies. For instance:

3.4.3.1 X-rays

X-rays are electromagnetic waves of short wavelength, capable of penetrating some thickness of matter. In 1895, Wilhelm Conrad Röntgen accidentally discovered an image cast from his cathode-ray generator, projected far beyond the possible range of the cathode rays. Further investigation showed that the rays were generated at the point of contact of the cathode ray beam on the interior of the vacuum tube, that they were not deflected by magnetic fields, and they penetrated many kinds of matter. Roentgen’s research on electrical discharge in gases, at the end of the 19th century, led to the discovery of X-rays and, with it, to a multitude of technologies in medicine and elsewhere. The latter followed the former.

3.4.3.2 Radioactive tracers

Radioctive tracers came from nuclear physics and profoundly impacted society via the many technologies in medicine (nuclear medicine for instance) and biochemistry. Many advances in molecular biology would not have been possible without radioactive tracers. These have been used for many purposes. For instance, doctors use minute amounts of radioactive substances to diagnose the presence of tumors, ulcers, or nonfunctioning organs; biologists use tracers to follow the path of nutrients through the food chain; earth scientists use tracers to follow the path of rainwater, as it moves through the groundwater to lakes, rivers, and reservoirs.

3.4.3.3 Radio-isotopes

These are widely used throughout science, technology, and medicine. The ability to detect, measure, understand, and safely use ionizing radiation came from science too. It has even revolutionized archaeology by making it possible to date, more precisely, human artifacts and other remains.

3.4.3.4 Magnetic Resonance Imaging (MRI)

Developed in the 1980's it came from fundamental work on nuclear magnetic moments in the late 1930's. The MRI provides a deeper insight into the human body by creating a magnetic field around it. This instrument is now in standard use in all hospitals for diagnosing complex medical problems especially related to orthopaedics and brain diseases.

3.4.4 Chemistry-Based Technologies (*Maugh T.H., 1978*)

It has correctly been said that of all the branches of science, chemistry is the closest to industry. Indeed, the strong coupling of chemical science to technology is responsible for today's chemical environment.

Chemical synthesis delivers annually about a quarter of a million new compounds, more than 1,000 of which reach the market place. It has given society biodegradable detergents, agricultural, industrial, and medical substances, along with penicillin, vitamins, and hormones. It gave birth to biotechnology and hopefully, by synthesizing the organic and inorganic superconducting materials, to a superconductor industry.

Chemistry-based technologies handed to society plastics, fibers, rubbers, coatings, adhesives, items, and polymers. Out of basic research in theoretical, structural, quantum, and computational chemistry on simple, complex, and polymeric molecules, and through the use of a broad spectrum of experimental techniques, grew the industry of plastics (e.g., Polythene, Lustrex, Lexan, Zytel), artificial fibers (e.g., Nylon, Fortrel, Orlon, Dynel, Rayon, Dacron), and synthetic rubber (e.g., Natsun, Neoprene, Hypalon). The impact upon the standard of living of society of these comparatively inexpensive materials has been immeasurable, and there is more to come. From basic research in chemical dynamics comes the understanding of the mechanisms of enzymatic action, controlling the chemistry of life; and from quantum and computational chemistry come powerful new tools for pharmacology and emerges an understanding of the interactions with the body of drugs, chemical carcinogens, metals, and other dangerous toxic substances. From basic scientific research emerges a new generation of chemical technology, capable of microprobing life at the cellular level.

Through the data provided by scientific research and with the aid of the computer, chemistry has built databases, which make possible the fingerprinting of complex biostructures. And through extra-sensitive analytical instruments rooted in scientific research, it is now possible to detect (at the parts per trillion level) and to characterize trace-chemicals in diverse environments, whether these are environmental pollutants, dangerous biochemicals responsible for rare diseases, or explosives used by terrorists.

Nanotechnology-related chemical research-activities are also making significant progress in the modern times. Such contemporary research areas include topics on colloidal nanocrystals, inorganic/organic hybrid materials, nanoporous and catalysts, supramolecular chemistry, and molecular electronics. Synthesis, characterization, and applications of nanomaterials are considered to be important issues in chemistry of materials chemistry because they have special characteristics that are different from bulk phases. For instance, by changing their size and shape in nanometer scale, their band-gap due to quantum confined band-structure can be tuned and increasing surface/volume ratio of nanocrystals leads to novel catalytic effects. The unique properties and characteristics of chemistry based nanomaterial science and technology, assuredly promise new and novel knowledge, along with expanded horizons of application in the times to come (*Cheon et al., 2002*).

Table – 3.2: The Conversion of Basic Science into Chemical-Based Technological Knowledge

Basic Research	Knowledge Output/Industry Applications
Basic Research in Chemical Dynamics	**Understanding** of the mechanisms of enzymatic action, containing the chemistry of life.
Quantum and Computational Chemistry	**Powerful** new tools for pharmacology and an understanding emerges of the interactions (with the body) of drugs, chemical carcinogens metals and other dangerous toxic substances.
Basic Scientific Research	**Emerges** a new generation of chemical technology, capable of microprobing life at cellular level.
Scientific Research with the Aid of Computer Technology	**Helped** in building databases, which make possible the finger-printing of complex bio-structures.
Extra Sensitive Analytical Instruments Rooted in Scientific Research	Detection at Parts per trillion level and to characterize trace-chemicals in diverse environments (helpful in determining whether the source is environmental pollution, dangerous biochemicals responsible for rare diseases or explosives used in terrorism.

Currently, the chemical research activities, related to nanotechnology, are also making significant headway. Some examples of current research areas include: topics on colloidal nanocrystals; inorganic/organic hybrid materials; nanoporous and catalysts; supramolecular chemistry; and molecular electronics. Synthesis, characterization, and applications of nanomaterials are important issues in materials-chemistry because of their special characteristics different from bulk phases. For example, by changing the size and shape in nanometer scale, their band-gap due to quantum confined band-structure can be tuned and increasing surface/volume ratio of nanocrystals leads to novel catalytic effects. The novel properties of chemistry-based nanomaterials science and technology, promise new and unique knowledge and application in the near future. The Table-3.2 represents the conversion of basic science into chemical-based technological knowledge for the industry.

3.4.5 Physics-Based Technologies

Physics has enormously contributed to the process of development and refinement of not only currently utilized technologies, but also those potentially utilizable technologies, which are termed as the *Future Technologies*. Physics is considered to be the most basic of the natural sciences. It deals with the fundamental constituents of matter and their interactions, as well as the nature of atoms and the build-up of molecules and condensed matter. It tries to give unified descriptions of the behavior of matter, as well as of radiation, covering as many types of phenomena as possible.

Some of the contributions of Physics in this regard include:
- Improvement in accuracy of data and its processing
- Miniaturization of physical and chemical servicing-devices in health care
- Real-time imaging and analysis
- Designing and development of lighter and more robust devices
- Developments of in-vivo robotic systems, tools for endoscopic surgery and intelligent implants.
- Physics-based surface-engineering in clinical advances (i.e. use of plasmas to improve artificial body parts)
- To reduce the prices, where possible

As is evident from the illustrations, in some of its applications, physics comes close to the classical areas of chemistry, and in others there is a clear connection with the phenomena traditionally studied by astronomers. Present trends are even pointing toward a closer approach of some areas of physics and microbiology.

Fundamental research in physics requires both quality and quantity of resources (financial and human) and infrastructure. For the initiation of any such research, a definite vision, along with a formidable mandate is extremely necessary. Technical capabilities, coupled with the dedication of directors/managers and other important people at the helm of affairs, is also crucial. The results of such a research include short-term products, such as publications and patents, as well as human resource development/training of technical manpower and helping individuals/research institutes. The impact of this research on outcomes, in terms of long-term and broader benefits of research, include production of new knowledge, human resource development, contribution in enhanced and better agricultural products. The results may also help in the development of better health-conditions, help in environmental protection, aid in the development of new industrial products and thereby contribute to the country's economy and defence. All in all, the advantages range from financial, political and economic benefits to defence-related returns.

It is unanimously agreed that the computer, the transistor, and the World-Wide Web are among the greatest inventions of modern times. We all know that today's global economy is strongly reliant and linked to applications of these technologies. It is a true fact that the day-to-day lives of millions of people across the globe would be profoundly different without the presence of these technologies to facilitate them. The present status of the USA, as an economic superpower, is primarily due to its dominance in the realms of computer and information technology. Moreover, high figures of GDP in Japan, Taiwan, countries in Western Europe, and others are also partly due to their acceptance of, and contribution to, the era of the information age. Interesting to note is the fact that physicists invented the computer, the transistor, the laser, and even the World-Wide Web (*Bindloss, 2003*).

In the world of today it is a fact that man knows more fundamental physics than he knows how to use it presently. The application of this available knowledge to integral fields, such as condensed matter physics, chemistry, biology, and the associated technologies, such as material science, electronics, photonics, nanotechnology, and biotechnology, is perhaps the only way to make easy progress now. By doing so, the physicists of the world may well be able to lay the foundation for a new and higher level of fundamental experimental physics (Baez, 1999).

3.4.6 Science-Based Biomedical Technologies (*Maugh T.H., 1978; Peterson J.I., & Vurek G.G., 1984; Waidelich W. (Ed.) 1982; Berns M. W. et al., 1981; Jasny B.R. & Miller L.J., 1993*)

As mentioned earlier, basic research has had a ground-breaking effect on all fields of life, and the same can be said about positive developments in healthcare. Numerous examples can be given to substantiate the effects of basic research in this field: immunization from diseases that were once life-threatening, introduction of pain killers, and diagnosis and treatment of ailments of various kinds. In addition, it is also the result of basic research that instruments, processes and methods have been developed to facilitate medical care. At the moment, the most advanced methods are being employed and innovations are being made in areas like genetic engineering, laser technologies, scanning devices, etc.

Comparing the advancements in the fields of medicine and healthcare today to that of nearly five decades ago, candidly gives man an idea of the rapid pace of development. Scientific research is to be given full credit for the ease with which man can today handle risky and highly technical procedures, such as open-heart surgery. The same is true for laser beams and radio-frequency capable techniques, which are being used in modern times for complex procedures, such as tumor vaporization, destruction of parts of the heart that are problematic, opening up of clogged blood-vessels and destruction of brain-tumors via remote- control mechanisms. Today, new and improved medicines are available for dealing with a multitude of diseases and illnesses that include hypertension, cancer and heart diseases. The production of drugs in large quantities, to avoid scarcity and unavailability is now possible through the use of *Recombinant DNA Technology*. Moreover, remarkable cures of congenital and other diseases are also in the process of discovery through the procedure of gene-therapy. Nonetheless, the very ability of man to infuse healthy and normal genes into the human body, and replace the defective ones with them, has applications beyond imagination (*MMRL, 2002*).

In most cases, basic biomedical scientists seek to add to the basic reservoir of knowledge by explaining how processes in living organisms develop and function. Knowing how a life-process functions normally, would essentially mean understanding how to recognize and treat it, when it functions abnormally (*NCABR, 1998*). Therefore, basic research has immense applications in biomedical technological innovation. Proving this fact quantitatively is the work of Comroe and Dripps, who found, in their study of top 10 developments in cardiovascular and pulmonary medicine, that over 40 per cent of the research needed to realize a particular advancement, was actually conducted by a scientist, whose goal at the time was unrelated to the medical advancement (*Comroe et al., 1976*).

The following examples of basic research contributing to the study and understanding of one of the world's most frightening threats, AIDS, are still true and important to further improvement in the knowledge of this area (*The Scientist, June 28, 1993, p.7*):

- biologists studying the structure of CD4 (a protein embedded in the cell surface of helper T-lymphocytes) found that HIV invades cells by first attaching to the CD4 molecule (CD4 receptor)
- immunologists asking basic questions about T-cells (also known as T lymphocytes; a thymus-derived white blood-cell that participates in a variety of cell-mediated immune reactions)
- geneticists manipulating genes that the virus uses to replicate
- scientists conducting basic research in the molecular structure of the virus
- virologists conducting basic research in the genetics of the virus (*NCABR, 1998*).

The importance of basic research to the control of imminent and re-emerging diseases cannot be over emphasised. Research on emerging diseases, encompasses and engulfs many disciplines, fields and research advances that fall under it, the research will be pertinent not only to specific diseases being studied, but also to a wide array of disciplines, such as vaccinology, immunology, and drug development. Subsequently, research in these areas is crucial to advances in emerging and re-emerging diseases (*Fauci, 1998*).

Following is a table representing the conversion of basic science into biomedical technological knowledge:

Table – 3.3: The Conversion of Basic Science into Biomedical Technological Knowledge

SCIENCE/RESEARCH	BIOMEDICAL TECHNOLOGIES/ INSTRUMENTS
Fundamental/Basic Research	**Immunization**, Pain Killers, Chemically Controlled Body-Changes, Electrical Recordings from Brain/Heart, Control of Fertility.
Fundamental/Basic Research	***Developed*** *Instruments & Methods, such as:* Instruments for the measurement of electric Current and Voltage. Instruments for the measurement of Magnetism, Photon Fluxes/energies, etc. Technologies dealing with x-rays, r-rays Particle beam sources, Radioactive Isotopes, Medical Scintillation spectrometers, Microscopes (Optical & Electron), Cryogenic. Equipment, Fiber-Optic Sensors. Laser beams to repair detached retinas, seal leakly blood-vessels in the eye, treat ulcers, skin tumors, microsurgical operations on single cells, etc.
Using the Techniques from Physics and Chemistry	**Scientific** discovery in Biology Facilitated New Biological Engineering Technologies and, through them, new biological-based therapies such as genome therapy, manipulation of the immune system and defects in tissues or organs originated.

3.4.7 Laser-Based Technologies (*D.C., O'Shea, Callen W.R., & Rhodes W.T. 1978; Glass A.M. 1993; Physics Today, 1993; Richardson M., 1981*)

This is an example of scientific knowledge lying dormant until scientific advances in neighbouring areas and technological needs in neighbouring fields made its development inevitable. The name LASER is an acronym for Light Amplification by the Stimulated Emission of Radiation. Indeed, the process of stimulated emission of radiation had been shown to be possible in 1917 by Einstein and, thus since that time, light amplification and the invention of the laser were in principle possible (*Bellis [online])*. The laser however, was not invented until after WW-II when, as a result of the development of radar, during World War-II and the extension of that work to higher microwave frequencies, conditions were explored under which laser action can be achieved. Thus, in the early 1950's came the invention of the MASER (Microwave Amplification by Stimulated Emission of Radiation) and in the late 1950's the extension of maser principles to the optical region of the electromagnetic spectrum. By 1960, a number of groups were investigating systems that might work as the basis for the optical maser or laser.

Today, materials for lasers are many and include gases, liquids and solids. Lasers come in many varieties, power levels, wavelengths (infrared, visible, ultraviolet, and possibly also X-ray), and types (continuous or pulsed). In a layman's term, lasers are currently being used in daily examples, such as to cut precise patterns in glass and metal and to reshape corneas to correct poor vision. They are also being used in supermarket checkout lines, CD players, and for the transmission of most telephone signals. Among other utilities, they are also used in scientific experiments, to provide intense heat in controlled fusion experiments.

Lasers led to new technology which, in turn, facilitated new science, which again led to new technology and yet again to new science—a continuous interplay that is still unfolding. High-quality lasers and hardware can now be purchased readily, enabling laser-based technology to be used in virtually everything; industry (e.g., cutting, welding), communications (e.g., via satellite, fiber optic, or laser printing), weapons (e.g., directed energy weapons), information storage (laser recording, optical disk storage), remote sensing, and so on.

Laser-based technologies are also used in microstructure engineering, microfabrication, semiconductor processing, material deposition and etching, and a host of methods for altering the morphology of a solid surface with special resolution, down to the nanometer scale. Very high power lasers have a potential application in fusion-energy sources, and short-duration laser pulses are basic to man's ability to modify and/or switch material properties.

3.4.8 Science-Based Materials Technologies (*Christophorou L.G., 2001*)

If we use the term "materials" to refer to solids, needed by man to manufacture the things he wants, then it can be said that all man needs to do today, is to specify the property of the material he needs and science will find the chemical or physical method to get the best improvement in whatever property it is sought. Materials science is primarily an applied science, which is concerned with the relationship of the structure and properties of materials, whether artificial or natural. Those chemists who are involved in the practical work of this field, essentially study how different combinations of molecules and materials result in different properties. Afterwards, they use this newfound knowledge to synthesize new materials with special and distinct properties (*TST, 2002*). Science-based technology gave man the electric light-bulb filament, the transistor, the solid-state laser, composites, ceramics, metals, alloys, and polymers.

The discovery of new techniques for producing and processing materials continues unabated and is joined by new capabilities towards the development of new multi-property materials. For instance, materials that depict unique physical properties: conductivity, superconductivity, optical effects, magnetism, heat sensitivity, and so forth, or materials that can be made to change their properties, for instance, from insulators to conductors and from conductors to insulators when they are exposed to physical insults such as laser light, or still materials whose three-dimensional structure would allow information-processing to occur in bulk, rather than surfacially as in the silicon chip. The applications of materials technologies include electronics, aerospace, medical, motor vehicles, bridges and houses. Even small things, such as our clothes and shoes, which have a range of natural and synthetic materials involved in their construction, or for that matter used in the manufacture of computers, cameras, hi-tech equipment and other household goods! The list is extensive and includes various metals and their alloys; ceramic materials such as glasses, bricks and porcelain insulators; polymers, such as plastics and rubbers; together with semiconducting and composite materials (*TST, 2002*).

Today, materials science is an exciting and rapidly expanding field of technology whose importance is being duly recognised by the world.

3.5 Basic Research and its Applications: The First Step

Since basic science is now very much a part of developing technologies, the term co-evolution of science and society implies the co-evolution of both basic science and industrial science with society. Advances in technology are generally accompanied by social changes as a consequence of changing economies and ways of carrying out life's various activities. An important issue to discuss is how basic scientific discoveries eventually lead to new technologies and what that may mean to the rational support of basic research and the future of science and technology in the world (*Karle, 2000*).

There are tremendous uncertainties in the process that starts with basic research and ends with an economically successful technology. The successful discovery of a new development in research that appears to have technological significance does not ensure the economic success of technologies that may be based on it. Nathan Rosenberg of Stanford University said in this regard that there are great uncertainties regarding the economic success of a technology, even in research that is specifically directed towards a particular technological objective (*Karle, 2000*). Uncertainties derive from many sources, such as:

- The failure to appreciate the extent to which a market may expand from future improvement of the technology,
- The fact that technologies arise with characteristics that are not immediately appreciated, and
- Failure to comprehend the significance of improvements in complementary inventions, that is inventions that enhance the potential of the original technology.

It is important to note that many new technological systems take many years before they replace an established technology, and that technological revolutions are never completed overnight. They require a long gestation period. Initially it is very difficult to conceptualize the nature of entirely new systems that develop by evolving over time (*Karle, 2000*).

The road that leads from basic research to application can be illustrated by many examples. We may describe this by two examples of basic scientific findings in a small field of Little Science, namely, low-energy electron collision physics. These examples involve the development of efficient CO_2 lasers and the development of gaseous dielectric materials for the transmission and distribution of electricity. These and innumerable other examples, of the translation of scientific findings into technological products, allow us to conclude: what is good science can be good technology.

Looking from another angle, one realizes that laboratory techniques or analytical methods used in basic research, particularly in physics, often find their way either directly, or indirectly via other disciplines, into industrial processes and process-controls largely unrelated either to their original use or to the concepts and results of the research for which they were originally devised. According to Rosenberg (1991):

> ***“This involves the movement of new instrumentation technologies... from the status of a tool of basic research, often in universities, to the status of a production tool, or capital good, in private industry.”***

Examples are numerous and include electron diffraction, the scanning electron microscope (SEM), ion implantation, synchrotron radiation sources, phase-shifted lithography, high-vacuum technology, industrial cryogenics, superconducting magnets (originally developed for cloud-chamber observations in particle physics, then commercialized for ‘magnetic resonance imaging’ (MRI) in medicine). In Rosenberg’s words:

“The common denominator running through and connecting all these experiences is that instrumentation that was developed in the pursuit of scientific knowledge eventually had direct applications as part of a manufacturing process.”

Also, in considering the potential economic benefits of science, as Rosenberg says: “There is no obvious reason for failing to examine the hardware consequences of even the most fundamental scientific research.”

One can also envision ultimate industrial process applications from many other techniques now restricted to the research laboratory. One example might be techniques for creating selective chemical reactions, using molecular beams.

Clearly, the reciprocal feedback between science and technology is overpopulating the earth with offsprings. This process will undoubtedly continue and along with it the shrinking of the time that is required to go from basic research to application. It would appear that this time may be decreasing to virtually zero. Indeed, this may already be happening in the information and computation technology!

Chapter-4

ISLAMIC COUNTRIES AND SCIENTIFIC RESEARCH

4. ISLAMIC COUNTRIES AND SCIENTIFIC RESEARCH

Though the increasing gap between the socio-economic development of developed countries and most Muslim countries can be attributed to a number of factors, the role of scientific and technological research, in this regard, cannot be overlooked. The results have indicated that allocation of funds towards R & D has been one of the primary reasons for the overall development and achievement of long-term objectives by the developed nations.

Developed countries of the world have been directing substantial funds and resources towards scientific research and development, which has resulted in their current positions of economic strength. This trend has been missing in the case of Muslim countries. A good sign, however, is that there now is an increasing awareness, amongst the experts in these countries that technological and industrial research has an extremely important bearing on the sustainability of programmes and policies at the national and international levels. In the current global context, which is characterized by rapid technological changes and innovations and an ever-growing industrial application, lack of attention towards applied research in industry and technology is bound to have a negative impact on the growth and development of Muslim countries.

4.1 Alarming Gap between the Muslim and Developed Countries

The current level of efforts in science and technology in Muslim countries is much below than required. The scientific and technological gap between Muslim and the developed countries is widening with every passing day. There is not enough emphasis on basic and applied research, whereas developed countries like USA have been allocating substantial funds towards the same, and there has been a growing importance attached to develop and transfer industry-relevant knowledge. According to estimates a few years back, there were more than 50 such active centers, involving about 1,000 faculty members, about 10,000 graduate students and 78 universities in the United States of America (*Karle, 2000*). More than 700 organizations sponsored these centers, including government agencies, national laboratories and about 500 industrial firms. There was an available list of 55 research topics, covering a broad array of technologies. The encouraging factor was the success-rate shown by these centers, which came out to be almost 94%. Therefore the need of the hour for Muslim countries is to learn lessons from such success stories and formulate policies that aim at streamlining research efforts, both in the public and private sector. There is a critical need for close coordination and cooperation between the public and the private sector, both at the stage of identification and solicitation of ideas, as well as at the implementation-stage.

It is imperative, for Muslim countries, to realize the importance and long-term impact of scientific research, in order to overcome the threat of exclusion from the race for economic prosperity. It is also very important to encourage and involve the Muslim youth in the research process, thereby harnessing their tremendous potential. In the words quoted by the Nobel Laureate, Prof. Dr. Abdus Salam, "*in the condition of modern life, the rule is absolute: the race which does not value trained intelligence is doomed….today we maintain ourselves, tomorrow science will have moved over one step and there will be no appeal from the judgment, which will be pronounced…on the uneducated. We must arouse the spiritual energies, particularly of the younger generation, for science and technology*".

4.2 Scientific and Technological Research: Need-Identification, Facts and Figures

It is generally agreed that search for development has to make use of the research in science and technology, for achievement of the objectives. Scientific and technological research should not be seen merely as something having an impact on one or a few areas; in essence, the research bears results that carry solutions to problems of varied natures, like social, cultural and economic issues. As Albert Einstein rightly said:

"Science without religion is lame, religion without science is blind"

As the current global environment is characterized by the element of change, therefore, Muslim countries ought to appreciate that in order to adapt to change, they not only need to be flexible in their approach, but are also required to reconsider their rigid and static view about the global scenario and its requirements.

The figures from UN sources indicate the critical state of Muslim countries and the comparison between Muslim countries and developed countries does not depict a rosy picture. According to UN sources, (*Abbasi R., http://www.maxwell.syr.edu*), only six Islamic countries fall in the high Human Development Index (HDI), 22 in the medium, and as many as 23 in low HDI category. The highest ranking Islamic country is 36th, while the lowest is 173rd, in the HDI list of 178 countries. The total GNP of the 56 OIC member countries together is only $1.1 trillion, less than that of France with $1.5 trillion and only one fifth that of Japan. Japan solely has a GNP of $ 5.1 trillion, with no natural resources, but it has 1000 universities, including 120 in Tokyo alone. The total number of universities in OIC countries is 328, against 120 of Tokyo alone!

The OIC region, as a whole, needs at least 12,000 universities, i.e. 40 times the present number. The entire Muslim world constituting one-fifth of humanity, contributes barely 1,000 research articles, out of 100,000 science books and 2,000,000 research articles published annually. While the West has an average of 3,000 science Ph.Ds per million population, our number is so dismally small that even the precise statistic was not available!

This situation is a valid way of understanding the seriousness of the issues and requires immediate thinking on the part of policy makers in Muslim countries. It has also been established that 95 % of new science in the world is created in the countries comprising only 20% of the world's population, while the remaining 80 % contributes only 5% towards it.

These figures sound even more alarming when one considers that almost two-third of the total population living in the developing countries lives in conditions of extreme poverty, and one of the main reasons for this is the lack of technical knowledge and ignorance of the requirements of modern times. Lack of emphasis on scientific and technological research only compounds the problem.

4.3 The Diverse Nature of Confronted Challenges

The question that arises, after considering the above-mentioned dismal and bleak scientific and technological scenario of the Muslim countries, is ‘what are the possible reasons for this continued downfall’? The answer is evident; Muslim countries have been richly endowed with natural resources; however, they are incapable of fully exploiting them to their advantage and, therefore, lag in progress. This incapacity is primarily due to the ill-defined priority areas of these nations, who fail to realize the importance of science and technology as an important engine for growth. The continuous under-emphasis of the significance and practicality of research, coupled with the absence of a contextual approach towards science and technology, have paved the way for the continual deterioration of the economic situation in Muslim countries.

From a more intricate perspective, the reasons why the Muslims of the world stopped making any considerable advancement in the scientific arena during the last four or five hundred years, can be divided into four main categories:

Firstly, soon after their early progress and triumphant march, the Muslims became preoccupied with the enjoyment of the luxuries brought about by the conquest of nature, as well as of other nations. The habits of an easy-going life averted them from toiling intellectually and physically. As long as there was no competition for them, they could set their own pace; but after the European countries emerged from the lurches of the dark ages and rejuvenated their stance through the renaissance, they learnt all they could from the Muslims and thus, challenged their supremacy. Sadly, the Muslims by this hour had become too easy-going and were unable to resist the vigorous competition stirred up by the West.

The *second* reason for the downfall of the Muslims was that they made the mistake of arranging for short-range defense only, not realizing that the acquisition and creation of knowledge is the real source of power and the best method of long-range defense. In essence, they threw away the best weapon that they had, without realizing its worth. Every scientific activity of good quality requires extended concentration and enduring hard work, without any prospects of immediate gain or return. In a society which was dominated by an easy-going life-style and principles of immediate personal gain, the spirit of scientific enquiry could not possibly survive.

Another very important reason for the downfall of Muslims was and is the generation of a defeatist mentality and a fatalistic tendency, following the loss of global supremacy. The pain of subjugation gave rise to the misconception that since everything is pre-determined, according to the ideology of Taqdir and Qismat, there was no point in making an effort against the divine will.

Finally, the last and most important factor that led to the demise of the Muslim reign was that they had started attaching more importance to worldly power and wealth than to scientific exploration and discovery. As the misconception about 'Taqdir' ideology flourished, Muslims craved only for the immediate satisfaction of the senses rather than intellectual growth. Resultantly, the learned scholars were at the mercy of petty officials and were never given the respect and patronage that they deserved in the society. It was, therefore, inevitable that the best brains shifted to business, law and civil services, rather than pursuing a scientific career.

Today, one can see very little change in the scientific scenario. It is evident that, generally, technology is adopted in its actual form, rather than according to the country-specific requirements, which leads to early obsolescence and unrealized goals. Scientific education does not get its due importance in the national policy-framework of Muslim countries, which allows the vicious cycle of knowledge-gap to churn time after time. On the other hand, the qualified Muslim youth finds itself frustrated because of not finding enough growth-opportunities and encouragement to undertake research in science and technology. The role of scientists is highly limited in policy-formulation at the national level in Muslim countries, which allows for isolation to creep in amongst societal stakeholders and causes disjointed scientific, technological, industrial and educational policies to evolve.

The relative importance of basic and applied research and the respective allocation of already scarce budget is also a debated issue in the Muslim countries. The bias of these countries towards practicing applied research for short-term quick results has reduced the availability of scientific capital/knowledge, earnestly required for continued R&D. Even more perturbing is the fact that most of the emphases are laid on performing R&D without creativity and innovation, rather than on utilizing the already generated R&D results of the production sector. Consequently, increased dependency on the transfer of appropriate technologies from other countries, instead of the available technologies, poses serious challenges to the Muslim World.

Summing up the above discussion, the following **major issues** related to Muslim countries must be addressed:

4.3.1 Identifying the Appropriateness of the Type of Research

An issue which has invited views from various schools of thought is that of the relative importance of different kinds of researches; whether goal-oriented and targeted research needs emphasis or the curiosity-driven basic research. As Muslim countries embark on a mission to employ research for their developmental objectives, it is indeed worth considering as to what kind of research is more beneficial for their cause.

On the one hand, it is argued that due to various impediments, focus should be on the goal-oriented research with clear objectives. While on the other hand, it is believed that the major developments in the fields of science and technology derive from curiosity-driven research, and these have had a major impact on the national interests, such as development of new industries and also in making long-term contributions to other strata of societal development.

An interesting element to note is the linkage between the basic and industrial research. For example, evidence indicates that a considerable majority of scientists, involved in the study and treatment of common human diseases, work closely with the clinical scientists; this results in the overall progression of research efforts and in the improvement of results. The co-evolution persists and since basic research has proved to be a part and parcel of technology development, therefore, the term co-evolution of science and society in essence means the co-evolution of both the basic, as well as, the industrial science, with society. Advancements in technology are invariably accompanied by the social changes, as a consequence of changing economies and ways of carrying out various activities of life.

4.3.2 Scientific Research and the Issues of Funding

Experts in Muslim countries have been voicing their concern over lack of funding for scientific and technological research. Compared to the allocation of resources for the field in the developed countries, Muslim countries have been unable to direct any substantial funds for the advancement in S&T research. It has been observed that governments and other sources of funding in Muslim countries, are reluctant to invest in research that does not have clearly defined goals, and it is usually preferred to allocate funds and resources in target-oriented research. In such a scenario, it does make sense to create and manage a diversified portfolio of research options, which includes both types of research projects, i.e. basic and industrial research projects. In this way, not only can risk be lessened but an optimal balance can be maintained.

There is, however, a positive change in this regard, as various Muslim countries now have a greater understanding of the potential and usefulness of scientific and technological research. Example of Paksitan can be taken for instance, where there has been a record increase in the budget for science and technology and it is hoped that this would be on a consistent basis. Other Muslim countries ought to follow suit and seek ways and means to give this sector its due importance.

It is also argued that allocation of funds and other resources should be made on the basis of relative importance for the country. Research may also be oriented towards making maximum use of the country's natural resources and aimed at harnessing the potential of human resources.

4.3.3 Need for sharing of Information and Resources

At a national level, Muslim countries have been able to show some encouraging results on the scientific and technological fronts, but the need still remains for mutual cooperation and sharing of information, resources and expertise.

While noticing the national-level developments in the Muslim countries, it can be observed that Turkey has been able to achieve the objective of integrating the efforts of its public and private sectors, in various fields of science and technology. Malaysia, which has been making a vigorous applied research effort, has achieved considerable success, especially in the high-tech areas. Indonesia has also been following a research policy that aims at encouraging research in the high-tech areas. Pakistan has recently started putting a well-directed research effort, but there is a considerable need for improvement, especially in the pace of implementation and in cost-efficiency. Other Muslim countries, notably United Arab Emirates, Kuwait and Saudi Arabia, have all been investing heavily in research and development, but the overall quality of research has been questionable at times, because of the non-achievement of desired output.

The basic lesson that the Muslim countries can learn from each other's experience is that it is in their interest to ensure mutual cooperation and assistance that can benefit all of them. If one country is doing well in Nuclear Technology (e.g., Pakistan) and another in some high-tech areas (e.g., Malaysia), collaboration with each other can be of considerable mutual benefit. Be it the areas of information dissemination, transfer of technology, exchange of scientists, or any other field, it is an imperative step to strengthen partnerships and thus, develop in various fields of science and technology.

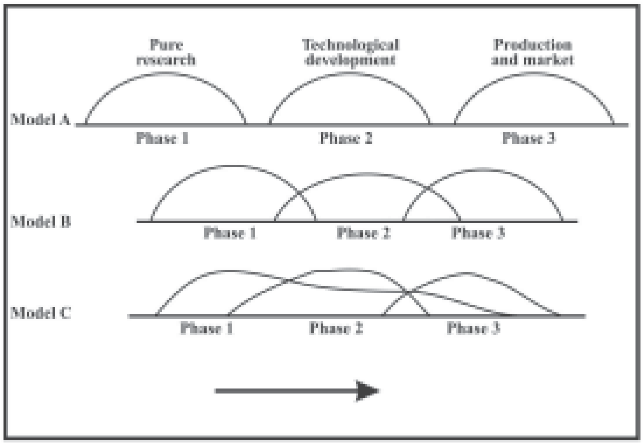
4.4 Directions for the Muslim World

Learning from lessons of the deadly Second World War, Muslim countries like Pakistan and Iraq embarked on gigantic project-type enterprise development in the fields of electronics nuclear energy, pharmaceuticals and space research, so that they could leapfrog from the level of low development in their respective countries. They pursued this type of development with vigour and started nuclear programmes that mobilized thousands of technicians and cost millions of dollars, but failed to meet the basic power-demands of the people. This is a clear example of the failure of scientists and policy-makers alike, as they have misunderstood the fact that development does not necessarily coincide with the possession of nuclear weapons or the capability to launch satellites. On the contrary, the prerequisites of the process of development are modern agriculture, industrial systems, and education. The misconception that nuclear-energy and satellite space-programmes would convert countries into high-tech industrialized states proved wrong, when they had to bear heavy economic and political costs. The lesson learnt is that Muslim countries should not expect to follow the research model that led to the scientific revolution in developed countries like the United States.

Instead, Muslim countries must first adapt and develop relevant technologies, appropriate to their own local needs and conditions, so that they may strengthen their system of education, expand their roles as advisors, both in the government and the industry (*Goldemberg, 1998*).

To understand the various concepts, which are applied and are applicable to the developing countries, regarding the relationship between science and development, three models are briefly discussed (refer to Figure-4.1).

The technical elite of many Muslim countries find themselves entangled in the misconception that pure research invariability and directly leads to technological development and then to products that open new markets or conquer existing ones. This is what is known as the ***'linear theory'*** approach to science and development, which started off from the USA and was later copied all across the globe (Model-A). This approach however has its flaws, as it fails to stress the interaction that should occur among various phases. As one moves from pure research to technological development and then to production and marketing, unanticipated problems arise, which need to be re-examined and solved at the earlier stages. Models-B and Model-C have been found to be closer to reality. Model-B generally corresponds to *current* practices in the USA, where some overlapping exists between the succeeding stages. Model-C, on the other hand, illustrates the Japanese practice of having the three phases more completely superimposed (*Goldenberg, 1998*). Broadly speaking, these two



Source: *Goldemberg J., 1998, "What is the Role of Science in Developing Countries?", Science 20th Feb., 1998, Vol. 279, AAAS, pp 1140-1141.*

Figure – 4.1: Three Models for the Relationship Between Science and Development

(Model-B and-C) are the more realistic models, which Muslim countries need to follow, if they desire to integrate and enjoy the right mix of benefits from both pure and applied research and development.

It can be said with confidence that no matter how overwhelming the challenge, Muslim countries must reconsider and redirect their policies and actions towards benefiting from science and technology. Religion itself is no hindrance to the promotion and development of S&T, as P.D. Oupenski once said:

"A religion contradicting science and a science contradicting religion are equally false"

Scientific and technological research is considered as one of the most important tools of development in the modern age and if the Muslim Comity does not realize and reap its advantages in the near future, irreversible retardation in progress may well be its fate. The Muslim World must develop a broader perspective towards S&T – closer to the one that Christian Huygens had:

"The world is my country, science is my religion"

Chapter-5

COOPERATION IN SCIENCE AND TECHNOLOGY: CHALLENGES AND PROSPECTS FOR DEVELOPING COUNTRIES

5. COOPERATION IN SCIENCE AND TECHNOLOGY: CHALLENGES AND PROSPECTS FOR DEVELOPING COUNTRIES

It is a known fact that rapid globalization and the emergence of a technology-driven economy have notably changed the world. The developing countries of the South have entered the third millennium, facing mammoth challenges hindering their efforts to advance towards economic progress and sustainable development. Issues such as, the worldwide lowering of trade-barriers; integrating the capital-markets, decentralizing production-processes, and the extraordinary advances in information and communication technology, merge to suggest a very different agenda for international development-cooperation, whether South-South or North-South.

Science and technology are now the principal tools for bringing about the changes needed to meet the ever-increasing requirements of the human-race. These are also considered to be the major factors that will assist in dictating the new world-orders of the future. Advancement in science and technology depends on the broad sharing of information and knowledge. It is, therefore, essential that the flow and exchanges of information or experiences be maintained on research methods and results, so that the advancement and dissemination of knowledge may be promoted, alongside the improvement in the relations and understanding among various people.

Science is a component of the organized knowledge that has existed in all societies since time immemorial. Similarly, technology, which is the mix of knowledge, organization, procedures, standards, equipment and human skills, combined appropriately to produce socially desired products, has also existed in the same fashion. Today, the only thing new is the *systematic* pursuit of scientific knowledge and its rapid use in meeting the pressing human needs. The S&T ‘haves’ and ‘have-nots’ in the developing countries of the South have raised the need for alliances, strategies and mechanisms needed to harness S&T for development, especially in the developing world. Equally important is the need to identify the challenges, possibilities and possible plans of action, in building meaningful cooperation among the developing countries and between the developing and developed countries.

5.1 The Rationale behind South-South Cooperation

It is a well-known fact that the developing world contributes meagrely to modern science and technology. Yet, if acquired and utilized appropriately, the new trends in science and technology offer tremendous potential for solving many of the problems hampering economic progress in the developing world. It is, therefore, crucial that the developing countries utilize science and technology in a manner that addresses their own pressing needs. It is also necessary to promote scientific and technological cooperation in the regional and international arena, and more importantly, among developing countries for the following reasons (*Kane, 2000*):

1. There is a need to avoid the duplication of human, material and financial resources in crisis-situations or in the cases of under-development, which are impediments for optimally realizing the scientific and technological potential of developing countries and ensuring the optimization of this potential. This is an ailment, common to most of the developing countries, and can be reduced or eliminated through mutual collaboration.

2. There are quite a number of similarities in the environmental conditions of the various developing countries, which give rise to general developmental problems that are similar in several critical sectors of their respective economies. **These common predicaments should pave the way for mutual collaboration**. The existence of common problems within the South is undoubtedly the most important reason for cooperation in S&T. Science and technology are considered to be the likely key-factors in solving critical problems of the South, such as food-security and diseases. Some of these issues have little express-impact on the countries of the North, and are thus unlikely to be given high priority in the S&T research agenda of the North. Cooperation of developing countries, in such areas, could be very beneficial in discovering and disseminating effective solutions.

3. Globalization and liberalization of the world economy, followed by the tremendous advances in new Information and Communication Technologies (ICTs) and, most importantly, self-interest in safeguarding the trade-agreements and blocs, are such phenomena that must be tackled by the developing countries, in a collective manner. This is extremely important because, individually, these countries do not stand a chance. While literally all developing countries have been adapting their domestic policies to the new global trade and economic dictation in the recent years, their capacity to protect their own interests in a global epoch, remains restricted due to the lack of capability for institutional and technological innovation - and this is where the role of mutual cooperation comes in. One aspect of globalisation, in its present form, is that it forces developing countries, in need of international financial support, to accept imposed conditionalities with respect to the macro-and micro-economic conditions, under which they operate. This often leads to reduction in government expenditure, with associated pressure on the budgets of the spending ministries, including that of education. Thus, structural adjustment, whether imposed or voluntarily adopted, has put pressure on public funds available for science in these countries.

4. There are several large and complex problems, such as environmental degradation and natural disasters, whose solutions can only be found through a collective approach by the entire global scientific community. This calls for greater cooperation on the international front.

For these reasons, there is real exigency for developing countries to closely work together and build their innovative and creative capacities. As mentioned earlier, no developing country on its own has the capacity to shape the processes that can inspire the development of global economy. However, in adapting local institutional systems to the requirements of the global economic order, every developing country has a lot to gain by cooperating with one another. Particularly, those countries that are technologically disconnected can gain from those that have recently transcended to the level of technological innovators. The basis of cooperation amongst developing countries is that, when the wealth of knowledge and capacity in them is systematically assembled and channeled, effective participation between developing countries can be facilitated in the global economy (*Kane, 2000*).

5.2 Need for North-South Cooperation

As mentioned earlier, the capacity to generate new scientific and technological knowledge is concentrated in the countries of the North and is mainly utilized to address their own material needs. Not much of the new knowledge, gained by developed countries, has been used to address the critical predicaments of poor and developing countries:

"All the rich-country research on rich-country ailments, such as cardiovascular diseases and cancer, will not solve the problems of malaria. Nor will the biotechnology advances in temperate-zone crops easily transfer to the conditions of tropical agriculture... rich and poor countries should direct their urgent attention to the mobilization of science and technology for poor-country problems." (*Sachs, 1999, p. 18.*)

According to Mohamed H. A. Hassan of the Third World Academy of Sciences (TWAS), North-South partnerships can be of great benefit to South-South cooperation-strategies, especially when such partnerships help develop and sustain indigenous capacities in science and technology. A good example in this regard is that of the development of Brazil's space-programme and satellite technology. Brazil set up a National Space Commission in 1961, in order to develop its satellite technology. In 1993, Brazil launched its first resource data-collecting satellite from Kennedy Space Center, Florida, with the assistance of a private US space firm. Ever since, Brazil has pursued two inter-related space programmes. One is the Brazilian Space Mission and the other is the China-Brazil Earth-Resource Satellites programme. These ventures use satellite-technology to address down-to-earth concerns, which include changes in temperature, humidity and carbon-dioxide concentrations in the atmosphere, as well as real-time data on alterations in quality of soil and water. More importantly, the information collected from these satellites has been shared with scientists in other developing countries, through more than 300 Earth-data collecting platforms in Brazil and neighboring countries. Brazil has also offered access to the data, to countries of Africa. Brazil's surfacing space-programme is a premier example of how North-South cooperation can be utilized to further South-South cooperation. This endeavor began with the training of young Brazilian scientists and technicians, primarily in US universities and R&D laboratories. The primary building-blocks of the programme were laid with the help of private firms and public institutions in the North, not to mention the fact that Brazil's first satellite was launched from the soil of United States.

The knowledge and technical skills that Brazilian space scientists and technologists have attained is currently being put to meaningful use via critical examination of environmental problems, for the benefit of nations throughout the developing world. Simultaneously, the initiative has raised the standard and level of Brazil's overall scientific skills and facilities. Today, a cooperative partnership with China has allowed the country to further advance in the fields of satellite earth-observing, data-collection and communication. Such examples carry the promise of permitting researchers in the South to become partners with the scientists of the North, in projects devoted to global scientific issues (*Hassan, 2000*).

Research performed according to the traditional concepts results in augmentation of the knowledge-base, but not necessarily in innovation or sustainable development. This should not be the case anyhow because the objective of generating scientific knowledge is extremely worthwhile itself. A linear direct linkage amongst the three will, without a doubt, create problems. However, there is still a wide belief that innovation is restricted to the North and to large corporations making 'inventions' in the classical sense, which is not true for today (*Velho, 2000*).

Innovation essentially implies the knowledge that is put to work by creative people and which leads to economic and social development. Innovation can essentially be achieved everywhere, at varying levels and in varying ways. It takes place at the crossroads of the development of formal science and technology and economic activity in an institutional manner. Therefore, innovation denies the supremacy of both knowledge-creation and/or the role of enterprises (*Velho, 2001*).

Information exchange and creation of innovative ideas have become possible with the help of information and communication technology, which is harnessed by the partnerships between various types of actors. Information, if not put to use, is useless. Only its creative use among interacting actors can lead to results. In this context, this interaction is focused on researchers from the North and the South, and on the policies of funding agencies. Conclusively, it can be said that for defining future modes of North-South collaboration, especially in areas of R&D, innovative systems will play a critical role.

Research efforts must be directed towards critical global issues, as identified through the valuable input of the scientific community. In the long run, the whole global scientific community, whether that of the North or the South, would undoubtedly enjoy the benefits that are likely to come from the use of scientific data and knowledge, utilized to solve pressing problems, especially those of the Third World.

5.3 Specific Challenges Confronted by the Developing World

Developing countries must overcome challenges confronting them on the social, economic and environmental grounds, to effectively participate in the knowledge-race of today. It is essential to describe some of the problems faced by these countries, so that a clearer picture of the future course of action, for a cohesive and result-oriented policy may come up. According to John F.E. Ohiorhenuan of UNDP and Amitav Rath of the Policy Research International, Canada, the specific challenges confronted by the developing world are of the following four major types (*Ohiorhenuan et al., 2000*):

5.3.1 The Poverty Issue

The vast majority of the poor live in developing countries. More than one billion people in developing countries are living in absolute poverty, with per-capita incomes below US$1 per day, and no access to clean water and sufficient food to sustain their energy.

A rapidly expanding economy is necessary, though it is not the only condition necessary for the fulfillment of the needs and wants of the masses. It is imperative that a suitable developmental strategy be put in place, which would have the capacity to provide employment-opportunities for the growing labor-force of the developing countries, and subsequently, allow for the creation of requisite resources to provide for basic needs, such as food, shelter, health, and education. This does not go to say that the South should follow the same development-path of industrialization, which the North readily took up. Undoubtedly, growth can reduce poverty, but only if it is complemented and supported by specific economic and social policies, which should include determined efforts to manage population-growth and develop human-resources, through imparting high-quality education, particularly in science and technology.

Achieving higher developmental goals necessarily translates into the improved welfare of the people of the South. A welfare improvement strategy in this regard must be directed towards an increase in the capacity of people to earn a decent standard of livelihood. This reasonable standard requires the creation of new and productive employment-opportunities, in rural and urban areas alike. The majority of population in the developing countries of the South lives in rural areas. Therefore, increased agricultural productivity and intensive use of bio-resources, are critical areas of concern and require special attention. In the coming years, the population of the developing countries will increase manifold and shall migrate in large numbers, to urban centres. Consequently, this increased and migrated population will need basic necessities of life, such as jobs, shelter, energy, water, sewerage, and transportation. If this issue is not tackled in a mature and pre-planned fashion, the urban localities will soon be marred by mayhem, pollution and a dysfunctional social setup.

A sector of the South's economy, which has great potential for stimulating and generating economic activity and growth is the Small and Medium-size Enterprises (SMEs) sector. This sector has the ability to provide substantial employment opportunities to the locals, with a comparatively low investment-influx and relatively high utilization of local raw-materials and inputs. Past experiences show that SMEs have played a significant role in stimulating the process of industrialization in market-economies. It is observed that in some Asian countries, SMEs created more jobs per unit of invested-capital, as compared to larger enterprises. Moreover, they have the potential to contribute substantially to improving living standards in urban and rural localities alike. The performance and efficiency of SMEs can now be improved through the use of many new technologies. Some other technologies also allow for the generation of new economic activities that could potentially be undertaken by SMEs. Nevertheless, recognizing the potential of SMEs for job-creation, is an aspect that the countries of the South must consider, in conjunction with the fact that SMEs are just one aspect of a nation's endeavor towards successfully industrializing itself.

5.3.2 Absence of Basic Health and Education Facilities

The population of the entire world, in general, and the developing world, in particular, are being troubled by old and new diseases alike. No doubt, the intensity of the spread of disease is far more severe and recurrent in the South, where those diseases are proving to be deadly, which no longer exist or are extremely rare in the developed world. Malaria, for example, is estimated to kill millions of people per year and is predominantly concentrated in poor tropical countries. It is also true that the development of a malaria vaccine is not very high on the international agenda of global disease-control and prevention. As the multinational pharmaceutical companies of the North believe that there virtually are no markets for malaria vaccine, they feel that the development of a malaria vaccine could be costly and may not produce sufficient financial returns if other companies or international firms started producing the same. Individually, developing countries do not have the means or capacity to develop such a vaccine; however, this capacity can be augmented by greater international cooperation, which could ultimately lead to the successful production of much needed vaccines. An estimated two-thirds of the 33 million people infected with AIDS reside in developing countries. The available drug-treatments being used to control AIDS in the developed countries are extremely expensive for the poor countries of the South to afford. The current vaccine-research is predominantly concerned with the specific viral patterns, which are prevalent in North America and Europe, while those few instances of research, which do specifically focus on the peculiar patterns of the South, are severely under-funded. It is therefore, imperative that the countries of the South should not completely rely on the AIDS-research conducted in the North. They must also ensure their own individual and collective efforts in this regard.

On the educational front, it is ironic to note that the 21st century is being called the age of knowledge, but there are more than 130 million children of primary-school age in developing countries of the South that have absolutely no access to basic education (*Ohiorhenuan et al., 2000*). According to a study of the UNICEF, nearly one billion people are currently unable to read or even sign their names. Of these one billion, two-thirds are women. The figures show the negligible percentage of people who are computer-literate or, for that matter, even know how to fill a requisition form or a questionnaire (*Ohiorhenuan et al., 2000*). All these facts imply inadvertently that any effort to bridge the gap of the digital divide, through innovation-capacity enhancement and diffusion of technology, must begin with the provision of rudimentary education to the people of the South.

5.3.3 Connectivity Challenges and Issues

The reliance of nations on knowledge-generation and effective processing has increased manifold due to globalization. It is now a well-known fact that countries and firms that lack access to modern telecommunication-systems cannot take part in the new and emerging global economy. The reason for this is that telecommunications aptly facilitate market-entry, improve customer-service, reduce costs, and help increase productivity, to allow firms and nations to compete effectively in the present global setup of the world economy.

The need for telecommunications is evident in all spheres of economy, starting from financial services, commodity markets, media, and transportation, as well as wholesale and retail businesses. There is no doubt that access to information-resource is imperative for bringing about desirable socio-economic change; however, the growing trend to privatize information-services, markets and telecommunication-channels, inevitably widens the gap between the North and the South. Representation of statistics reveals the poor state of affairs that at least 80 per cent of the world's entire population lacks the most basic telecommunication-facilities.

A good number of developing countries are making substantive efforts to access the world of knowledge and information on the Internet, but the high cost of doing so hampers many, as it costs three to four times more to surf the net in Africa than it does in the United States or Western Europe. On the contrary, very cheap Internet charges in other countries, such as Pakistan and India, provide a viable opportunity for initiating mutual collaboration in this field of immense significance and importance.

5.3.4 Environmental Degradation

Environmental hazards faced by developing countries are countless and grave. Some of the most significant environmental dangers include:

- Continuous degradation of cultivated land;
- Desertification in arid and semi-arid zones;
- Tropical deforestation;
- Unabated pollution in large and industrialized cities; and
- The discharge of toxic gases and untreated industrial effluents into the natural environment.

As the population-explosion in the South continues to spread, coupled with increasing levels of wealth and consumption, the heightened pressures on the fragile ecology cannot be avoided. The increasing environmental pressures are due to various factors. Shortening of traditional crop-rotation cycles has been introduced in various countries of the South, so that they may be able to meet the growing food-needs of their respective increasing populations; however this has resulted in the cultivation of land without respite, causing the soil to be depleted. For fulfilling the requirement of more land and new sources of timber, deforestation has become a pardonable excuse.

As in the industrialized world, economic growth and industrialization are the key elements responsible for the evident and looming environmental dangers in the South. A growing problem is that of air pollution and water-contamination, which are being caused respectively by emissions from fossil-fuel combustion and uncontrolled disposal of industrial wastes. The continuous and unabated migration of population in the countries of the South from rural to urban localities will inevitably result in greater demands for housing, transport, energy, etc, which essentially require substantial amounts of resources. It is therefore urgently required that innovative methods of providing such needed services be introduced by the developing countries, to lessen the financial and environmental burden.

A collective action within the South is needed to manage shared resources and deal with collective environmental problems, for the reason that proper environmental strategies need to be chalked out with consideration of the consequences of domestic actions on adjoining countries. Such common and shared areas of concern, which could allow close cooperation to flourish, include: the management of shared water-resources; irrigation systems; energy-generation and conservation; and the prevention of floods and erosion, amongst many others. The sharing of requisite knowledge and pertinent experiences, especially in areas of resource-management, could be beneficial to countries facing similar problems and enjoying similar ecosystems. Other areas of relevance, in terms of cooperation are pollution-control, offshore-oil exploration, management and assessment of natural resources through improved technologies.

The energy-sector is a vital area for cooperation between the countries of the South. The sustained supply of grid-electricity is an unstable and sometimes even nonexistent facility for the people of the developing world. Industrial and economic development is dependent on the ready availability of energy. Keeping this scenario in mind, it must be considered that the growing consensus on the negative role of fossil-fuels in enhancing global warming will most likely create new pressures on the South. It will be vital for developing countries to enhance their energy-supply from renewable sources, in order to allow for sustainable long-term development. This would also require improved energy-efficiency in all sectors. Countries like Brazil, China, India, Mauritius, Nepal and South Africa, are now front-runners in the field of renewable energy, proving that the South has significant capacities in the energy-sector as a whole. Significant benefits for all stakeholders could be gained through pooling resources of the South, especially in the fields of energy-research and development.

It is a sad reality that the developing countries have let the North take up environmental problems and propose necessary actions in this regard as well. It is imperative that the countries of the South develop a collective and strong position on the issues of environment and development, so that they may ensure adequate representation of their interests in the global environmental agenda. Negotiations with the North can also prove fruitful especially if a common stance is adopted for more effective participation on the developmental issues and sharing of technologies for energy-conservation and pollution-control.

5.4 Challenges to be Met in Forging Cooperation

To increase the cooperation amongst developing countries and between developed and developing countries, several challenges must be met. The primary challenge is the trouble that international community confronts while attempting to mobilize the requisite resources. Two strong trends have compounded this predicament. For one, cutthroat competition in technological invention and innovation has evolved due to the uprising *New World Order*, which is essentially technology-oriented and calls to bestow economic power on and honor nations, which are technologically advanced. Therefore, technology essentially became an element which was strictly protected, thus causing cooperation to subside. Secondly, the emergence of private multinational companies (MNCs) resulted due to liberalization, loosing of state control with subsequent privatization affecting the entire world. These multinationals are equipped with their own research centres and are engaged in financing public research teams. They are, however, primarily concerned with their own materialistic gains, rather than with cohesion or for that matter with the sharing of scientific and technological knowledge. All in all, it is nevertheless an intimidating task to bridge the enormous gap between the North and the South, especially in the production and utilization of scientific and technological knowledge (*Kane, 2000*).

Other challenges, as identified by Ousmane Kane of the African Regional Centre for Technology, Senegal, that affect scientific and technological cooperation at the inter-regional and international levels include:

- The establishment of distinct structures of higher education and research within various countries due to the blind pursuit of selfish scientific and technological development policies under the flag of nationalism: even though these structures lacked the bare minimum resources required for proper functioning, they were still created.
- The scientific and technological policies that are being pursued in most countries, when assessed from a practical approach, usually turn out to be steps taken in isolation. Moreover, these initiatives are neither entirely integrated into national economic and social development plans, nor into bilateral and multilateral cooperation programmes.
- Barriers of language and international travel, coupled with the difficulty to travel and communicate, besides the dubious nature of financially challenged publishing facilities, allow for isolation to spread.
- There is a dearth of reliable data on the existing and projected scientific and technological potential of many countries. Additionally, duplication, overlapping mission and under-

optimization along with irrational mismanagement of resources at hand, and the failure to clearly define national objectives are also pertinent reasons.

5.5 S&T Cooperation: New Possibilities, Prospects and Opportunities

Despite the seemingly unconquerable challenges, there is no doubt that science and technology cooperation amongst developing country and between developed and developing countries has bright prospects. Some of the opportunities in this regard are as follows (*Ohiorhenuan et al., 2000*):

5.5.1 Technical Innovations and the Leapfrogging Phenomena

The needs of the developing countries demand optimal efforts, on one hand, and on the other, opportunities for creating additional capacities and new developments related to science and technology. Key areas in this regard include biotechnology, microelectronics and new materials, where jointly undertaking the scientific and research and technological innovation would greatly benefit the developing countries. Indeed, the development of such new technologies is a painstaking and expensive process; yet their assimilation, adoption and application to the production would be cost-effective. However, this has to be done through leapfrogging over immediate levels of technology.

This methodology would allow developing countries to achieve accelerated economic growth through the use of cleaner and more effective technologies that would also allow comparative advantages, and at lesser cost, particularly in comparison to the technologies developed in the recent past.

Many areas of technology, traditional as well as newer, offer opportunities for leapfrogging. These cover areas of traditional importance, such as energy-production; pulp and paper; wireless and satellite communications, microelectronics and environmental technologies, amongst the latest ones. Today the South is better placed in adopting technological options between environment and development, which were not available to the North during their industrialization process. Thus the developing countries are well placed to adapt cleaner and energy-efficient technologies, at a much faster pace.

Nevertheless, in order to implement the strategy, these countries require access to networks of technological knowledge, not restricted to appropriate infrastructure and administrative capacities, but also extended to effective institutional mechanisms to achieve the desired results of technological changes. These technological improvements have a multiplier effect on promotion of high-tech economic and industrial activities. One must take caution, however, that undertaking new advances in S&T while offering promising opportunities also poses major challenges due to backwash of technological developments being undertaken simultaneously in other regions.

5.5.2 Increased Investments in Research & Development

Financial and intellectual resources for S&T are scanty, especially in the South. On the other hand, the requisite knowledge-base for effective competition is expanding. This disparity presets an opportunity for South-South cooperation in the S&T arena so that efficient use of their resources could be possible. Of course, the continued importance of North-South collaboration cannot be subsided either. Nevertheless, integral activities, such as R&D, must enjoy South-South cooperation on a larger scale, as these require a critical mass of knowledge and expertise for effective functioning.

A sustained mechanism of sharing research-resources could bring developing countries much closer to their target of maintaining a critical minimum of investment required. This would also allow for duplication the minimizing of effort in some other areas as well. The South Centre further suggests in this regard that, “with the increasing importance of economies of scale and expenditure on research and development, South-South cooperation may well become the most cost-effective means for the South to reach the new frontiers of science and technology”.

5.5.3 Exchange of Experiences in Fundamentally Critical Areas

The developing regions of the South enjoy common environmental and thermohygrometric conditions. Due to these similarities, specialized technical know-how in the fields of agriculture and agro-foods can be vastly shared. Moreover, common solutions to common problems in the exploration of prospects in different sectors can also be expanded. Effective collaboration of these countries in areas of water-resource management, key crop-production, and enhancement of functional, nutritional and commercial viability in agro-based products can be realized.

Energy is another such field that holds key significance. The unabated use of timber as source of fuel has allowed green pastures to become deserts in countries of Africa, Latin America and Asia, which already suffer from heightened petroleum import bills. Another area of importance is the energy sector. Hopes are high that the energy needs of these countries could be met in an ecologically sustainable fashion, if cooperation amongst them could be evoked. Collectively, they can channel their competencies to develop the filed of renewable energy, especially solar, biogas, biomass, water and wind energy. It is imperative that they work in close collaboration, especially on research endeavors, so that investment costs may be reduced and the application and maintenance of pertinent technologies improved.

The South suffers from a high mortality rate, along with increasing incidences of diseases such as malaria, cholera etc. it would be extremely beneficial for the developing countries suffering from health-issues to exchange experiences on diagnosis and treatments,

5.5.4 Exploring the Frontiers of Biotechnology

Rapid growth of population and rising food-demand are the two most eminent menaces the countries of the South can expect in the coming years. This could eventually lead to decreasing agri-land per person and heightened pressure on the existing cultivable land. As biotechnology has the potential to:

- Improve productivity of the farming systems of the South,
- Reduce the quantity of chemicals used in agriculture,
- Lower the cost of raw materials, and
- Reduce some of the negative environmental impacts of conventional production-methods, it may well be critical for ensuring sustainable food security.

It can be said that the key areas for cooperation between the countries of the South are biotechnology and agricultural research. As these regions face many common problems, the results of the research attained may have a wider application and could help more than one country. As research in the realms of the stated fields is complicated and expensive, it is advised that the concerned countries should share their resources and work collectively on endeavors of mutual interest.

Several challenges are brought about by the development and application of biotechnology. To ensure the commercialization of biotechnology increased capacities and capabilities must be developed, especially when it comes to the knowledge of biosafety and IPR issues. It is thus, quite obvious that the path that developing countries must adapt should be:

- The establishment of an appropriate regulatory system
- Assessment and management of health and environmental hazards of biotech products, and
- Dealing with the problem of public education.

5.5.5 The Role of Micro-electronics and ICTs for Cooperation

An efficient, rapid and cost-effective information-flow can increase the speed of industrialization, especially now as the advances in information and communication technologies (ICTs), have greatly complimented and harnessed their potential. Spreading out production-plants to many locations, and unbundling production processes, can be made possible today due to the ease and low cost of assimilating and transferring information. A new window of opportunity thereby opens for large corporations to subcontract production-processes or parts to small and medium enterprises in the countries of the South.

The emerging ICTs are playing a dominant role in improving performance in critical sectors of the economy and society. ICTs, being predominantly conceptualized and developed in the North, confront the South with the risk of increased and sustained dependence on the North in terms of technical know-how and technological expertise. In order to strengthen existing capacities relating especially to the production of software and hardware, close South-South collaboration is needed. This will consequently allow these countries to bridge the gap between them and those of the North, while simultaneously being more sensitive to the particular nature of their own needs.

Progress in the field of IT has also allowed information about available and prospective technology-choices easier and quicker to acquire. Better access to technologies and their complete and comprehensive assessment, while already in the public domain, can be made possible through electronic knowledge-networking. This also permits the dissemination of information on standards in energy-technology, pollution control, and clean manufacturing, besides other areas.

There are many examples of the rapidly industrializing countries of the South, now competing actively with the North in areas of software development and data-management techniques. Examples of India, China and Korea are well-known and pertinent. It can therefore be concluded that random capabilities utilized for a single objective can prove worthwhile, while isolation reaps no results, and this is precisely what the South must *not* engage in.

5.5.6 Exploiting the Share of Natural Resources

The developing countries of the world possess ample natural resources. They are endowed with most of the world's unique and substantial biodiversity, besides the deeply rooted traditional knowledge that is associated with it. Sadly, the South has been unable to fully utilize these natural gifts of nature to its fullest advantage. To protect and exploit these gifts of nature, through the use of ecologically sound scientific and technological resources, is an area where the developing countries lack requisites. It is however no secret, that for gaining a reasonable competitive edge in the world economy, which is being dominated by globalization, natural resources are perhaps the most important weapon in the armory of the countries of the South.

5.6 Strategy for Cooperation and Future Direction

Any strategy for future cooperation, amongst the countries of the South, must be initiated with the resolve that they posses and will continue with, the political will to rise to the challenges which they have identified for themselves. For this, the concerned countries must:

- Adopt and pursue policies of non-secrecy to other parts of the developing world,
- Show their willingness to propagate and further the local and regional South-South

collaboration in science and technology, and
- Commit to solidarity in the collective augmentation of capacities and acquiring of necessary technologies.

Any cooperation, thus envisioned must be founded on a medium to long-term vision, based on a choice of the priority-sectors and on mutually agreed specific actions, to be taken to attain the stated objectives. There are primarily eight broad categories for inter-regional and international cooperation between the countries of the South, to improve their scientific and technological capacities in the identified priority-sectors and according to the requirements as laid out by each region. The areas for action include:

1. Establishment of a science and technology policy;
2. Human resources development;
3. Institutional capacity-building;
4. Information exchanges;
5. Identifying Clusters of Common Interests;
6. Involving the North in collaborative efforts;
7. Identifying and involving the stakeholders; and
8. The Classical Approach to Cooperation

As a matter of fundamental focus, it is imperative that the focus must remain on regional centres for the encouragement of science and technology in the concerned countries. Such centres, if utilized as genuine centres of excellence, would not only reduce the brain-drain in these countries, but will also enjoy the benefits of assistance from expatriate experts of developing countries who are residing outside their native lands. Such international consultative forums can also be used to augment South-South cooperation in S&T and include organizations, such as UNESCO, UNIDO, FAO, UNCTAD and EU-ACP, as a part of this structure (*Kane, 2000*).

5.6.1 Science and Technology Policy

One of the most critical challenges in realizing South-South collaboration is to help countries develop a meaningful and concrete science and technology policy that may be closely tied to their overall economic goals in the broader perspective. Any such policy must include strategy of technological innovation, which should be effective and clear regarding its future goals. A sound S&T policy must lead to:

- Establishment of a framework for practically complimenting science and technology endeavors in the country.
- Strengthening of capacities and capabilities in the fields of training, research and information-systems, and add value to technological innovations.

- Instituting an interactive partnership between governments, R&D organizations, manufacturing concerns, financing agencies and the civil society, in order to ensure consistency in experience-exchanges and sharing of relevant documents.

The integration of science and technology into the national developmental strategy requires individual national effort. This must be done with prudently determined sector-wise priorities, which must be supported by requisite and sufficient resource-allocation. It is also imperative that heightened expenditure on research and development endeavors be improved alongside greater priority and emphasis to educational activities, especially in basic sciences. Introduction of effective research-systems, strengthened linkages amongst manufacturing concerns and R&D institutions, and creation of facilities, such as venture-capital funds for supporting new technologies, will also support the integration of S&T into the national plan of action (*Kane, 2000*).

5.6.2 Human Resource Development

For conducting scientific and technological training activities in a bilateral or multilateral framework, exchange programmes between universities and R&D institutes from the different countries of the South could prove worthwhile. It is equally necessary that womenfolk of these regions play a participative role, in the generation and utilization of technological products. Such mutual programmes may offer scholarships and fellowships, and could be coordinated by the special units dealing with national expatriate expertise-exchange and regional institutions, working for the development and propagation of science and technology.

Such collaboration could engage the concerned countries in activities that may include formal academic training in basic scientific and technological disciplines alongside advanced training and specialized courses in all realms of S&T, such as generalized national level scientific and technological policy formulating and implementing skills or more specific focus on areas such as R&D in biotechnology, new synthesis technologies, alternative energy, etc. Seminars and training-workshops also promote the exchange of ideas, experiences and information on a single platform. They allow for debate and consequent understanding of specific problems and issues of common and individual interests, and would assuredly help the cause of South-South collaboration. Bilateral and multilateral cooperation will also encourage study-trips of budding and professional scholars, who will be permitted to gain first-hand knowledge of the experience of others, and could therefore, establish direct contacts and explore new horizons for cooperation. Last but not the least, the establishment of linkages through the use of teleconferencing and distance- learning methodology could also be promoted on this platform (*Kane, 2000*).

5.6.3 Strengthening Institutional Capacities

Knowledge today is the dictator of the pace of development in any region or economy. Human-development and economic growth are now increasingly dependent on knowledge and human-capital, rather than traditional natural and man-made forms of capital. Due to the increasing importance of knowledge itself, development and acquisition of knowledge-generation techniques and systems are priority-areas for developing and developed nations alike. Globalization, drastic technological changes and the growing disparities between various countries of the world, in terms of access to knowledge and potential to create it, have changed the standards of development and economic sustainability. The question now is exactly how the knowledge-systems of tomorrow will function.

Changes in the socio-economic and political environment require specialized institutions, to function on levels that are comprehensive and encompass a much wider domain of knowledge. Essentially, knowledge-generation is dependent on scale. In fact, economies of scale can be realized through a practical approach towards partnerships, which may include national and international-level partnerships alike. The centres of research in the South could come together not only as institutions in need of assistance from each other and their counterparts in the North, but essentially as genuine research centres who have their own objectives, competencies and comparative merits and demerits. Besides other benefits, this would create a sense of identity and belonging to the institution.

It is no secret that the South is desperately constrained when it comes to the much needed resources for conducting science and technology as well as R&D. Institutional augmentation would therefore require the establishment of regional centres of excellence for the critical economic, scientific and technological sectors identified. Existing regional centres would also provide for the requisite support and expand their missions and vision to incorporate South-South cooperation for S&T and R&D capacity-building. In this regard, major programmes would encompass the following areas:

- General technological needs of the region under consideration.
- Formulation, implementation and evaluation skills regarding national-level policies for technological innovation. Effective partnerships between the State, R&D community, and business setups (manufacturing concerns or otherwise) and particularly the small and medium-sized enterprises could help realize the objectives of this programme.
- Advanced training in cutting-edge technologies. This may be achieved by specific coordination of various centres within the South, particularly if collaborative projects in research and development are initiated.
- High-performance information-system development. Such areas would include the development of databases on specific sectoral information, regarding institutions, national and international experts, available and potential technological options, etc. Such information must be coherent with the needs of researchers, economists, government officials and

the general masses. Publications will essentially serve as the source of basic information for these databases. This information-system would primarily be an information-provider and would allow for the effective communication and technological monitoring of worldwide options and prospects.

- Establishment of sectoral and institutional regional networks of associations.
- Development of dissemination-programme for research result development via establishment of pilot demonstration-units and technology-based business incubators.
- Value-appraisal and propagation of traditional and region-specific knowledge. This would allow institutions and nations, in a broader spectrum, to easily adapt to the imperatives of modern day knowledge. Furthermore, this will enhance cooperation between modern and traditional knowledge-promoters and practitioners, besides creating a suitable environment for dialogue on mutually beneficial matters.
- Development of Programme for motivation and encouragement of talented inventors and technology-innovators through awards, prizes and monetary incentives.
- Devising a methodology for acquisition and transfer of environment-benign technologies, among different regions. This could also include advisory services on the available and prospective technological alternatives.
- Certification of Technological product, as well as, maintenance and calibration of scientific and technological equipment, through a systematic methodology.
- Partnerships with donor and development agencies. This will allow for the effective implementation of ongoing and newly initiated technological projects.
- Expert-exchange programmes of expatriate nationals serving and residing in other countries, especially those of the North. Such a programme will not only benefit the country itself, but will also give the expatriates an opportunity to relate and contribute to the development of their country and will satisfy their patriotic thirst. (*Kane 2000*).

5.6.4 Information-Exchange

As mentioned earlier, knowledge is the driving force of competition in the modern era. Therefore, it is imperative that a sound mechanism for the sharing of scientific and technological information be established. In this regard, the information-systems of the centres of excellence can serve as the appropriate sources.

Information-exchange amongst the countries of the South, should essentially be need-based and should focus on the practical application of science and technology, to solve pressing problems and meet identified needs. In this respect, effort should be channeled towards identifying those fundamental areas of S&T research that are of pressing importance to the countries of the South, and in which collaborative activity would potentially instigate concrete, short-and long-term benefits. Already established areas of such key-concern include agriculture, renewable energy, diseases and healthcare, biotechnology, and information and communications technologies. Any strategy for information-exchange must keep focus on the growth and development of links within the South, especially in the realms of education.

Emphasis however, must be on scientific, technical, managerial and vocational education. To achieve the above-stated, the following actions may be undertaken:

- Interactive access and provision of connectivity for information-sharing through databases.
- Exchange of publications and issuance of joint publications, to establish a concrete and continuous link between various regional centres of excellence, working in common fields of interest.
- Effective documentation and record-maintenance of the success and failure cases of collaboration amongst various stakeholders, so that a thorough understanding of the prospective hindrances and means of overcoming them may be anticipated beforehand (Kane, 2000).

5.6.5 Identifying Clusters of Common Interests

It seems rational for developing countries to build upon joint activities and programmes, in order to strengthen their mutual ties as well as, streamline their respective economic strategies. In this regard, rather than embarking on totally new initiatives, developing countries might find it more useful to focus on the existing, albeit smaller programmes. South-South cooperation can get a much-required boost if some successful examples could be presented.

It is also noteworthy that as all developing countries do not have the same priority-areas, therefore, a prudent strategy for such countries would be to identify areas of common interest. This would imply that these countries, not only embark upon a strategy for mutual sharing of information and resources, but also carry out joint research activities in such priority areas.

A major advantage of jointly working, in those areas that have mutual significance for developing countries, is that each country gets the benefit and that too at a much lesser cost, as compared to the situation in which they have to undertake the programmes on their own. Policy makers also find it convenient to identify and allocate resources, from a budgetary perspective. On the basis of all these factors, the need to use and share research for the overall benefit of developing countries seems more imperative and beneficial for all concerned (*Ohiorhenuan et al., 2000*).

5.6.6 Involving the North in Collaborative Efforts

In addition to South-South cooperation, an effective mechanism of partnership ought to be devised between countries of the North and those of the South. The increasing gap between developed and developing countries is a major concern for the global cause. This situation calls for participation and support by the more advanced and developed countries in the development-process of the less developed ones.

North-South collaboration should not be restricted to only a few areas. In essence, the areas of support need to be matched with country-specific requirements. The extent and scope of support also would vary from one country to the other. There is, however, a growing importance being attached to the creation of networks, in different fields, so as to have relevant expertise for sharing of skills and potential.

Although various examples can be cited in terms of practical models for collaborating networks, an excellent example of this network-approach is the programme for Research and Training in Tropical Diseases, launched by the World Health Organization (WHO) in 1974, to deal with major diseases endemic to tropical countries. Important networks have also been established under international organizations, such as the United Nations Educational, Scientific and Cultural Organization (UNESCO); the International Council for Science (ICSU) and the World Meteorological Organization (WMO). Their networks include the World Climate Research Programme (WCRP), Man and Biosphere Programme (MAB), International Geosphere-Biosphere Programme (IGBP), and International Research Programme on the Structure and Function of Biological Diversity (DIVERSITAS). All of these efforts show the important role that UN-affiliated and other well-established international organizations play in global efforts, to address critical public health and environmental issues (*Hassan, 2000*).

5.6.7 Identifying and Involving Stakeholders

In an era when economic reforms increasingly prefer and encourage the role of the private-sector, it is imperative that South-South cooperation expand and integrate those stakeholders who are primarily market-driven. New stakeholders must now be involved in collaborative programmes – those who had earlier been left out of the development and collaboration process. The promotion of technical change, enterprise-development and technological innovation, through public and private enterprises, help reduce the knowledge-disparity of the South. Areas of prospective focus can be (*Ohiorhenuan et al., 2000*):

- Initiation of collaborative R&D efforts through international corporation and with the help of institutions from the countries of the North and South,
- Small and medium enterprise development-strategies for harnessing employment-generation and invigorating technological innovation,
- Evolving a platform for the provision of consultancy that might be beneficial and integral for many developing countries, both individually and collectively, and
- Establishing a methodology for the promotion of effective linkages amongst research institutions and manufacturing concerns, especially those that are productive, so that the commercial viability of research findings may be ensured.

5.6.8 The Classical Approach to Cooperation

It is not always necessary to pursue high-end technologies only. On the contrary, relatively low-end areas of S&T collaboration can also be explored, which would comprise an amalgamation of older technologies with low-science inputs. This can be the first step towards the classical approach to cooperation. Later on, cooperation can be followed up by doing applied sciences, provided the necessary capacities are available in basic sciences before hand. The last area for cooperation as a final stage, in this classical approach, can be the typically science-based high-end technology cooperation, which is comparatively more difficult and costly to pursue (*Ohiorhenuan et al., 2000*).

It can be said that, given the similarities of economic and environmental conditions in most of the developing countries, South-South cooperation in the realms of science and technology assuredly has the potential to produce the desired results. However, the focus must always remain on identifying critical areas of collaboration, which may include sectors of common interest, such as food and agriculture, new and renewable energies, public health and information and communication technologies. In this regard, priority-areas demanding concrete and urgent actions include: science and technology policies, human-resource development; institutional capacity-building; the promotion of exchange of information, identification of stakeholders, involving the North in collaborative efforts; identification of clusters of common interest, and maintaining impetus on the classical approach to cooperation. The role of the centres of excellence in minimizing brain-drain could be pivotal and effective; however it must be realized that any South-South or North-South collaboration must initially overcome the financial constraints restraining the realization of cooperation in its true spirit. No headway can be achieved in cooperation unless the political will and determination is present, to share and mobilize their resources for greater cooperation in science and technology, for sustained development. (*Kane 2000*)

Undoubtedly, a much more elaborate follow-up, monitoring and evaluation system of the cooperative activities of South-South and North-South collaboration must be introduced and assessed. Projects and programmes must be practically assessed, so that reasonable clarity as to the identified objectives and their corresponding results may be attained. Efforts must also be channeled towards the promotion of the need for South-South and North-South cooperation, supported by the success-stories of various organizations, enterprises, institutions, countries and regions.

Chapter-6

CONCLUSIONS AND RECOMMENDATIONS

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In the twenty-first century, science must become a shared asset, benefiting all people on the basis of solidarity only. Science is a powerful resource for understanding natural and social phenomena and its role promises to be even greater in the future, as the understanding of mankind regarding the growing complexity of the relationship between society and the environment becomes deeper. The continuously increasing need for scientific knowledge in both public and private decision-making, including the significant role of science in the formulation of policy and regulatory decisions, should be adequately emphasized and ascertained. It is also agreed and understood that scientific research is a major driving force in all fields of critical importance to mankind and that greater use of scientific knowledge is a prerequisite for development.

Deciphering the facts given in this book, it is clear that there is an urgent need to reduce the gap between the developing and developed countries, by improving scientific capacity and infrastructure in developing countries. Giving importance to scientific research and education and to the need for full and open access to information-resources are also basic considerations. It is, therefore, necessary that a new relationship between science and society be contemplated, so that humanity in general may cope with the pressing global problems, such as poverty, environmental degradation, inadequate public healthcare, food and water-scarcity and population explosion. There is a need for a strong commitment to science, on the part of governments, civil society and the productive sector, as well as, an equally strong commitment of scientists to the well-being of society.

Pure and Applied Research: As is clear from the above discussions, basic research is performed without much thought of practical ends and it results in knowledge, as well as the understanding of nature and its laws, whereas applied research aims at giving complete and specific answers to important practical problems [*LBNL (online)*]. In essence, basic research is motivated by curiosity, while applied research is designed to answer specific questions. J.J. Thomson, the discoverer of the electron, explicitly outlined the difference between basic and applied research in a speech delivered in 1916:

> ***"By research in pure science I mean research made without any idea of application to industrial matters, but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the "utility" of this kind of research, one that has been brought into great prominence by the World War-I mean the use of X-rays in surgery..."***

“Now how was this method discovered? It was not the result of a research in applied science starting to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of electricity… “

“Applied science leads to reforms, pure science leads to revolutions; and revolutions, political or scientific, are powerful things if you are on the winning side".

The relative importance of ‘Basic’ and ‘Applied’ Research is a widely discussed topic of today. It is equally important to note that applied research does not always follow basic research, as was the case in the development of large Radar Antennas for applied purposes, which led to basic research in Radar Science and Radio Astronomy, as well as the case of the development of pure materials for technological applications, which stimulated fundamental investigations in Solid State Physics, but the loop does not necessarily end there. This is not always a one-way street.

People such as James Watt, who was an applied researcher in the field of steam engines, contributed considerably to the basic fields of mathematics and physics. Virtually, the whole basic field of thermodynamics was developed by applied science. Lavoisier, the founder of modern chemistry, started his career by undertaking two applied projects: lighting the streets of Paris and developing a new process to produce saltpeter. It were these projects that led to and funded his later experiments, in which he proved the conservation of mass, and discovered how Oxygen functions in combustion. Carnot's work on engines led to the discovery of the *Second Law of Thermodynamics*. Clausius, building on Carnot's work, proposed the property of entropy. Kelvin's work on engines led to the concept of *Available Energy*. Again, working with simple engines, Joule bridged the gap between heat and physical work. Gibbs, combining all of these insights, published Signal Works in Chemistry, widely renowned as fundamental ‘basic’ discoveries in chemistry.

Evidently, there is a very impressive example of applied work on engines, leading to Gibb's insights on Chemical Equilibria and Chemical Thermodynamics, including Free Energies, Energies of Formation, and all of the mathematical techniques that underlie virtually all of the modern physical chemistry. It is therefore important to note that discoveries do not necessarily take the route from basic to applied.

It is also important to make it clear that every research has objectives, and that every research is aimed at usable results. It may well be that basic research sets its targets within the world of research itself, whereas applied research is aimed at objectives and applications outside the world of research. But the boundaries are not at all clear. Much of the basic research eventually turns out to be applicable, and applied research has often made frequent contributions to the development of research as such.

The generally accepted view is that basic research is primarily conducted in universities, whereas applied research is an area of activity of research institutes and private companies. In fact, there is a good deal of applied research in universities, and also basic research in the outside world.

It is impossible to say anything about the importance, quality or degree of difficulty of research, merely by describing it as either basic or applied. Every research activity must be judged by its results, and by the degree to which it achieves its objectives. Hence, it is necessary to know the objectives, even if one does not wish to label the research in question, in one way or the another.

It may also be emphasized at this juncture that experience shows that best results in applied research are obtained in cases where the scientists, given the task to carry it out, are knowledgeable and have a sound background in ‘Basic Sciences’. If their knowledge in basic sciences is limited and/or narrowly channeled, the ‘applied product’ is expected to have limited utilization. It is, therefore, strongly advisable that ‘applied science’ be coupled with ‘basic science’ or ‘basic little-science’.

It is hoped that through science-based technology, a route to a brighter and prosperous future is made that would improve the condition and overall life of humans. Interwoven with this premise are two important elements that need stressing. First, whether science-based technology will provide the necessary answers for all of the Earth’s people and make the Earth a more equitable place! The answer to this question will depend more on man’s values and less on his knowledge of science and technology. On the other hand, man must become knowledgeable, wise, unselfish and brave enough, to forego technologically brilliant ideas, when they are more damaging than beneficial. As Bertolt Brecht, Galileo once said:

“***Science knows only one commandment: contribute to science”***

Recommendations

Strategic recommendations for the developing, as well as Muslim countries, for effectively carrying out scientific and technological research for socio-economic stability and development, are as follows:

- The developing countries must understand and realize the importance of science and technology for development and utilize it optimally for their sustained progress and prosperity. For this, the government, as well as, the masses must be educated and apprised of the pivotal role of S&T.

- They should integrate and incorporate new sciences into education. This is one of the prerequisites for sustainable development and for the provision of a well trained and well-equipped workforce. High-quality education must, therefore, be put in place early in the developmental process.

- On the one hand, developing nations must re-think their scientific and technological priorities, in the face of growing economic constraints and new political and ethical realities, while on the other, they must strive to build the capacities necessary for effective teaching and research in science. Education and research represent long-term investments in human capital that yield large returns in economic growth.

- They should aim to adapt technologies to local circumstances, if these are imported from abroad, because customization is necessary to make imported technologies function according to the desired standards.

- The input of scientists, along with industrialists, educationist and technologists, must be inducted in the policy-making process, so that long-term strategies may include the factor of scientific benefit within them. Developing countries would simultaneously have to make a special effort, to push science and technology to the forefront of their domestic policy agenda.

- They must realize and understand the relative importance and benefits of basic and applied research, and they must strike a balance between them at the overall national/ government level, and not only at an agency-to-agency level.

- There must be a closer linkage between basic research and national goals, which should be the criterion for research support.

- For the distribution of basic research funds, all proven performers should be adequately funded. Investment should also be made in areas that offer results of the broadest applicability across other scientific disciplines. The support for young scientists must be provided for the generation of new ideas and support should also continue for centres of excellence, so that the necessary scientific infrastructure could be provided, which could serve a greater number of investigators.

- It is also recommended that the planning authorities in the government, industry and research institutions identify priorities and establish national R&D programmes to serve the industrial strategies for the development of technology-domains. This will allow for concentrated efforts, towards improving the overall economic situation of the particular country.

- As industrial contributions to long-term R&D are decreasing, the governments of developing and developed countries alike, should remedy the situation by maintaining or increasing their long-term commitments to fund allocation.

- Cooperation is an integral element for sustained progress, both at the individual and collective levels. It is, therefore, suggested that engineers, scientists and other experts, who are both ‘applied thinkers’ and ‘basic thinkers’, must work together as a team, and their efforts must be synergized to produce desired results.

- The building of scientific capacity should be supported by regional and international cooperation, to ensure both equitable development and the spread and utilization of human creativity, without discrimination of any kind, against any countries, groups or individuals. Assurance must be made that cooperation be carried out in conformity with the principles of full and open access to information, equity and mutual benefit.

- Mutual cooperation, especially in the fields of science and technology; economy and trade; and information and culture, must be provided on a larger scale, so that conjoined efforts could help achieve the mutually desired result of sustainable development.

- The technological gap, however daunting and grave, still offers new opportunities for newcomers and investment in R&D and, at this stage, has great possibilities for economic returns from improved technologies. On the other hand, the supply aspect of the national industrial R&D system must be improved, to ensure continued effectiveness.

- They must avoid the lure of costly and ineffective research programmes and establish a system that rewards solving practical problems.

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APPENDIX-I: Outlined Chronology of S&T - Uptill 19th Century

Period Before Christ

-20000	Oil-based torches may have been used
-12000	Glass beads produced by ancients
-10000	The discovery and use of silver, gold, carbon, copper, tin, iron, mercury, sulphur and lead
-9000	Plants and animals are domesticated
-6500	Sumerians invent the wheel
-6000	First reported use of bricks on Iranian Plateau
-6000	Copper artifacts are common in the Middle East
-4800	First evidence of astronomical calendar stones near the Egypt-Sudan border
-4236	Egyptians institute the 365 day calendar
-4000	The first mines where humans began extracting useful minerals, such as iron ore, tin, gold and copper, appeared in the Middle East.
-4000	Light wooden plows are used in Mesopotamia
-3500	Sumerians make envelopes and tablets from clay
-3500	Kiln-fired bricks and pots are made in Mesopotamia
-3200	Egyptians invent a black ink
-3000	Invention of potter’s wheel
-3000	Square-sailed ships used in Egypt
-3000	Egyptians and Chinese independently developed binding materials similar to mortar and cement to aid construction
-2800	Pyramids are built in Egypt
-2500	Iron age begins around this time
-2500	In Asia, animal skins are used for scrolls
-2350	En Hedu’anna, an Egyptian priestess, traced the history and progressions of the Moon and stars
-2300	Chinese astronomers start to observe the sky, and in 2296 BC, a comet is observed for the first time
-1800	Babylonians begin to keep observational records
-1800	In the Middle East and Asia Minor the smelting of iron ore was developed for making tools and weapons
-1700	Windmills developed by Babylonians; they are used to pump water for irrigation
-1600	Chaldean astronomers identify the zodiac
-1500	Silk weaving demonstrated by Chinese
-1450	Egyptians use the sundial to measure time
-1300	Invention of steel
-950	Greeks and Syrians start glass production
-950	Leather is used for writing and scrolls
-763	Solar eclipse observed and recorded by Babylonians

-600	Greek philosophers describe magnetic properties of lodestones (ferric ferrite)
-600	Static electricity effects generated by rubbing amber with fur recorded by Greek philosopher Aristophanes
-550	Pythagoras proposes that sound is a vibration of air
-540	Xenophanes describes fossil fish and shells found in deposits on high mountains. Herodotus (490 BC) and Aristotle (384-322 BC) also noticed similar fossils
-512	Cast iron produced from blast furnaces by Chinese
-500	Pythagoras suggests that the Earth is a sphere and not flat, as had been previously assumed
-480	Parmenides stated his belief that the world was spherical
-450	The Greek philosopher Empedocles announces that all matter is formed from four base elements - earth, air, fire and water
-440	Leucippus of Miletus introduces the concept of the atom, an indivisible unit of matter
-400	Democritus develops the theory that matter is actually composed of tiny indivisible particles, which he terms “atomos”
-370	“Optica” published by Euclid
-360	Aristotle discovers that free fall is an accelerated form of motion
-330	Heraclides suggests that the Earth rotates on its axis, and that neighbouring planets also move round the Sun in spherical orbits
-300	Euclid’s “Elements” published, putting together mathematical and philosophical thinking
-280	The Egyptians build Pharos of Alexandria, the world’s first lighthouse
-270	Aristarchus says that the Sun is at the centre of the Solar System; this is generally dismissed
-250	Archimedes develops the principles of buoyancy and levers
-240	Eratosthenes made an accurate measurement of the circumference of the Earth.
-196	The Rosetta stone was created, on which identical text was engraved in Egyptian demotic and hieroglyphic scripts, and Greek letters
-130	Star charts and measurements developed by Hipparchus
-50	Phoenicians develop advanced glassblowing techniques

On the other hand, the events that characterize scientific and technological revolution in the A.D. era are:

105	Tsai Lun invents paper by mixing hemp, mulberry bark and rags with water
140	Ptolemy’s geocentric theory of the Solar System is published in the “Algamest” and widely accepted
271	Magnetic compass invented by Chinese scientists
517	Philoponus described “impetus” and showed that all objects fall with the same acceleration
673	“Greek fire”, an inflammable mix of sulphur, naptha and lime, was used by the

	Muslims in the siege of Constantinople
700	The Chinese invent porcelain
793	Paper, believed to have first originated in China, is made in Baghdad, Iraq
800	Jabir ibn Hayyen (Geber) devised a chemical system based on sulphur and mercury
850	An early form of copper electroplating is developed by Spanish Moors
1150	Bhaskara is one of the first to describe a “perpetual motion” machine
1175	Compass mechanism first described by English monk Alexander Neckem
1220	Nemorarius publishes “Mechanica”, which contains the law of levers and the law of composition of movements
1250	Magnus discovers arsenic
1250	Roger Bacon first applies geometry to the study of optics, and emphasises the use of lenses for magnification
1264	Albertus Magnus writes ‘De mineralibus’
1270	“Perspectiva”, a treatise of optics, refraction, reflection and geometrical optics, is published by Witelo
1390	First paper mill established in Germany
1400	Leonardo da Vinci described fossil shells and put forward a theory that these remains of once-living organisms and that changes had occurred in the relationship between sea and land
1444	Cusa refuted the belief that Earth is at the centre of the Universe
1568	Barbaro publishes an account of the use of a convex lens to sharpen the image recorded by a camera obscura
1583	Galileo’s pendulum experiments, which showed that the time of oscillation was independent of the amplitude
1586	Stevinus notes that two items of different weights dropped at the same time strike the ground together - first real observations of gravity
1590	Dutch develop glass lenses, which are then used in microscopes and telescopes
1592	Galileo develops the thermo scope
1596	Abraham Orteliu, a cartographer, was the first to suggest the possibility of continental drift
1596	David Fabricius records the first non-nova, non-supernova variable star discovered; it is named Mira
1600	William Gilbert publishes “De Magnete”, in which he describes the Earth’s magnetism
1600	Dominican monk and philosopher Giordano Bruno is executed by the inquisition for failing to recant his belief in a Copernican heliocentric Solar system
1604	Major work on optics published by Kepler
1608	Hans Lippershey invents the telescope
1609	Galileo also establishes the principle of falling bodies descending to Earth at the same speed
1609	Kepler publishes his first two laws of planetary motion
1613	Galileo observes sunspots

1616	Early form of reflecting telescope developed by Italian astronomer Zucchi
1619	Kepler publishes his third law of planetary motion
1621	Snell's Law of refraction of light
1632	First official observatory is established at Leiden (Netherlands)
1641	René Descartes in his "Principles of Philosophy" argues that the Universe is governed by simple laws and that natural processes might have shaped the Earth
1642	Principles of hydraulics published by Pascal
1643	Torricelli invents the mercury barometer and observes the first vacuum
1652	Fluid pressure laws determined by Pascal
1654	Invention of vacuum pump by Guericke
1656	The pendulum clock is invented by Christiaan Huygens
1658	Hooke's invention of the balance spring for watches
1658	Fermat's theory of "least time" - a ray of light will travel a route, so as take the shortest possible time to reach its intended destination
1660	Static electricity generator invented by von Guericke
1662	Boyle's Law published, stating that the pressure and volume of a gas are inversely proportional
1663	Gregory's "The Advance of Optics" describes the first practical reflecting telescope
1665	Newton's law of universal gravitation
1666	Newton observes the effect of a prism on white light; the light separates into different colours
1668	Isaac Newton designs and constructs a reflecting telescope
1669	The concept of double refraction discovered by Danish physicist Bartholin
1676	Hooke's Law
1676	Speed of light estimated at 140,000 miles per second by Danish physicist and mathematician Ole Roemer
1687	"Principia" published; Newton's great work includes his 3 laws of motion and also the law of universal gravitation
1695	Grew discovers Epsom salts (magnesium sulphate)
1704	Isaac Newton put forward the corpuscular theory of light in his publication "Opticks"
1705	Hauksbee invented neon lighting
1709	Abraham Darby introduces coke smelting
1714	Fahrenheit invents the mercury thermometer
1728	Speed of light newly estimated by Bradley to be 183,000 miles per second
1730	First compound magnet produced by Savery
1732	Gray publishes his theory of electrical induction, which he had discovered three years earlier
1735	German explorer Johann Gmelin discovers permafrost
1735	Ulloa discovers platinum
1738	Laws of fluid mechanics put forward by Bernoulli
1742	Anders Celsius invents the temperature scale named after him
1745	Comte de Buffon proposes that Earth was formed when a comet collided with the

	Sun
1745	The "Leyden jar", an electric capacitor, invented independently by van Musschenbroek and Kleist
1748	Lomonosov formulates the laws of conservation of mass and conservation of energy
1750	First production of wrought iron by Abraham Darby
1751	Nickel is identified by Cronstedt
1752	Benjamin Franklin performs his famous "kite experiments" and shows that lightning is a form of electricity
1754	The heliometer, a device designed to measure the diameter of the Sun, is invented by John Dollond. It is also used to measure distances between stars
1755	Joseph Black discovers carbon dioxide
1761	Latent heat and specific heat described by Joseph Black
1769	James Watt invented the steam engine
1772	Rutherford describes "residual air" (nitrogen)
1774	Scheele identified chlorine
1774	Bergman, Scheele and Gahn identify manganese; it was isolated from its dioxide (pyrolusite) via reduction with carbon. It is named from the Latin magnes (magnet), owing to the magnetic properties of the mineral pyrolusite.
1777	Lavoisier put forward the idea of chemical compounds, composed of more than one element
1783	Montgolfier and Michel invented the hot air balloon, and flew it to an altitude of over 1 mile
1787	Charles' Law established (gases)
1789	Klaproth discovers uranium
1791	Gregor identified titanium
1798	Rumford discovers the link between heat and friction
1798	The mass of the Earth is determined by Cavendish
1799	Proust put forward the Law of Definite Proportions, which presented the concept of stoichiometry
1800	The voltaic cell is invented by Alessandro Volta
1800	Nicholson and Carlisle decomposed water into hydrogen and oxygen via electrolysis
1800	Lamarck publishes a theory of evolution
1801	Dalton presents his Law of Partial Pressures
1801	The first asteroid is discovered when Giuseppe Piazzi identifies Ceres
1801	Thomas Young discovers interference of light
1801	The discovery of vanadium by del Rios.
1801	Henry's Law established for gases
1801	The first steam-powered pumping station is built near Philadelphia to supply power
1803	Dalton publishes table of comparative atomic weights
1803	It is a rich year for the discovery of new elements, with the identification of cerium, rhodium, palladium, iridium and osmium

1805	Gay-Lussac proves that water is composed of two parts hydrogen to one part oxygen by volume
1807	Davy discovers the alkali metals sodium and potassium
1808	Modern atomic theory is put forward by John Dalton
1811	Avogadro's Law published
1811	Iodine is identified by Courtois
1813	Berzelius develops the chemical symbols and formulae used today
1815	Humphry Davy invents the safety lamp for use by miners
1816	Fresnel explains the refraction of light
1817	The identification of three new elements occurred in this year: Arfvedson discovered lithium, Stromeyer found cadmium, while selenium was identified by Berzelius
1819	Hans Orsted discovers electromagnetism
1820	The laws of electrodynamics established by Andre Ampere
1821	Dynamo principle described by Faraday
1821	Seebeck invents the thermocouple
1824	Berzelius identified silicon, the second most abundant element in the Earth's crust
1825	Metallic aluminium produced by Hans Orsted
1825	Faraday discovers benzene
1826	Faraday established empirical formula of natural rubber as C_5H_8
1826	Ampere publishes electrodynamics theory
1827	Ohm's law of electrical resistance established
1827	Robert Brown observes what becomes known as Brownian motion
1827	The phosphorus match is developed by John Walker
1828	Paul Erman measures the magnetic field of the Earth; his measurements become the basis for Gauss's theory of Earth's magnetic field
1829	Graham's Law of gaseous diffusion
1829	Louis Braille invented embossed typing for the blind reader which bears his name
1831	Faraday discovers electromagnetic induction
1833	Faraday introduces the laws of electrolysis and coins terms such as electrode, anode, cathode, ion, cation, anion, and electrolyte
1833	The electric telegraph is invented by Gauss
1834	Wheatstone measures the speed of electricity using revolving mirrors and several miles of wire
1834	First use of the term scientist, coined by William Whewell
1837	Invention of the telegraph
1838	Friedrich Bessel makes the first measurement of the distance of a star from the Earth, calculating the distance of 61 Cygni to be approximately 6 light years away; the true value is later calculated as approximately 12 light years
1838	Samuel Morse makes the first public demonstration of Morse Code
1839	Ozone discovered by Christian Swann
1840	Englishman Charles Babbage invents the first mechanical computer
1842	Doppler effect discovered

1842	Principle of conservation of energy put forward by Julius Mayer
1843	Joule describes the mechanical equivalent of heat
1846	Law of diffusion expressed by Thomas Graham
1846	Lord Kelvin uses the temperature of Earth to calculate that Earth is about 100 million years old. He does not take into account heat from radioactivity, which made his estimate very short of the true age
1846	The 8th planet, Neptune, is discovered by Johann Galle
1847	von Helmholtz proposed the Law of Conservation of Energy
1848	‘Science’ magazine first published
1849	French physicist Armand Fizeau measures the speed of light
1849	Brewster builds the first model stereoscope
1850	Seebeck discovers thermoelectricity, where the application of heat to a metal junction generates electric current
1851	Foucault demonstrates the rotation of the Earth
1851	Kelvin proposes “absolute zero”
1852	George Stokes devised a method for the artificial production of what he termed “fluorescence”
1859	Plucker invents the cathode ray tube
1860	Kirchoff’s Law published
1861	The discovery of osmosis
1861	First colour photograph put together by James Clerk Maxwell
1869	Celluloid is first produced from cellulose nitrate and camphor
1869	The first Periodic Table is formulated and published by Mendeleev
1869	‘Nature’ journal first published
1873	Maxwell describes light as electromagnetic radiation
1877	Thomas Edison invents the phonograph for sound recording and transmission
1879	Thomas Edison invents the light bulb
1879	Speed of light calculated by Albert Michelson to be 186,350 miles per second (give or take 30 m/s)
1879	Properties of cathode rays discovered by William Crookes
1880	John Milne invents the modern seismograph for measuring earthquakes waves
1881	American scientist Michelson invents the interferometer
1883	First solar cells invented by Charles Fritts using selenium wafers
1883	First electric railway built at Brighton by Magnus Volks
1884	Charles Parsons builds a turbine; this technology would become widespread in power generation
1884	Le Chatelier’s Principle established for chemical reactions
1887	Hertz predicts the existence of radio waves - he successfully detects them a year later
1887	The theory of electrolytic dissociation is put forward by Arrhenius
1887	Hertz discovers the photoelectric effect
1888	Nikola Tesla designs alternating current (AC) power generator

1892 Electron theory published by Dutch physicist Hendrik Lorentz
1894 Ramsey and Rayleigh discover the first inert gas, argon
1895 Marconi pioneers the wireless telegram
1895 Rontgen discovers X-rays
1896 Radioactivity is discovered by Becquerel
1896 The “Zeeman effect”, whereby the application of a magnetic field to a substance causes a spectral line to split into a series of closely-spaced lines, is first observed
1897 J. J. Thomson discovers that electrons are negatively charged particles with very tiny mass; this is the discovery of subatomic particles
1897 Synthesis of aspirin by Felix Hoffman
1897 Radio message sent by Marconi over 20 mile distance from Isle of Wight to Poole, Dorset, England
1899 Thomas Chrowder Chamberlin criticizes William Thomson’s argument that the Earth is only about 100 million years old. He notices that the ice age was actually a number of smaller ice ages broken up by warmer weather

Note: *Scientific and Technological discoveries from 1900 onwards are listed in Appendix II*

APPENDIX-II: Outlined Chronology of S&T - 20th Century Onwards

1900

- Max Planck: Energy is emitted in discrete parcels, which he calls quanta, rather than continuously (Proves to be the basis for the quantum theory).
- Reed establishes a cause-effect link between yellow fever virus and mosquito bites
- Transmission of first speech through wireless
- Gamma rays are discovered by Villard
- Soddy observed the spontaneous disintegration of radioactive elements into isotopes - discovery of “half life” of elements

1901

- 1st Nobel Prizes for science are awarded to Roentgen (Physics, X-rays) Hoffman (Chemistry) and Behring (Physiology or Medicine)
- Hutchinson makes the first electric hearing aid
- Planck’s Laws of Radiation published
- Johann Elster and Hans Geitel demonstrate radioactivity in rocks
- First practical vacuum-cleaner invented

1902

- Fischer gets a Nobel prize in Chemistry, due to his special services related with synthetic experiments on the sugar and purine groups of substances
- Lorentz and Zeeman get Nobel Prizes for their research regarding the impact of magnetism upon radiation phenomena.
- Ross is awarded Nobel Prize for his work on malaria.

1903

- Nobel Prize for Physics is shared by Marie and Pierre Curie with Becquerel
- Rutherford shows that alpha particles are positively charged
- 1st Harley-Davidson motorcycle is made
- Wright Brothers achieved first manned flight
- Nagaoka put forward the idea of a positive nucleus orbited by rings of electrons
- Charles Curtis and William Emmet develop the steam turbine generator and the steam turbine, respectively

1904

- A thermionic valve is developed by Fleming; this allows electricity to flow in one direction but not the other

1905
- Einstein publishes three papers which are significant for 20th century science; the first presents the special theory of relativity, in which he argues from the absolute speed of light that energy and mass are equivalent; the second elucidates Brownian motion (the random movement of molecules in a liquid); the third explains the photoelectric effect. Last two papers have a crucial effect on the development of quantum theory
- The London underground railroad system is completely electrified.
- Arrhenius predicts that carbon dioxide emissions will lead to global warming

1906
- The term “allergy” is introduced by Pirquet.
- Nobel Prize for Physics is awarded to Thomson for his discovery of the electron.

1908
- “Quantum” theory of light is introduced by Einstein

1909
- pH scales of acidity is invented by Sorensen.
- Germany become the place to install the first automatic telephone exchange

1910
- High-pressure steam turbine is made by Ljundsttrom.
- Frahm introduces an anti-rolling device for ships.
- Jacques Brandenberger invents cellophane

1911
- The phenomenon of superconductivity at very low temperatures is observed by Onnes.
- Electric starter motor for automobiles invented by Charles Kettering

1912
- Funk introduces the term “vitamin”.
- Einstein devises the law of photochemical equivalence.
- Invention of crystal diode by Pickard

1913
- Lorin presents the basic principle of jet propulsion.
- Gyroscope stabilizer for aircraft is made by Sperry.
- Coolidge creates a hot-cathode X-ray tube.
- Behring produces diphtheria vaccine.
- the behaviorist approach to psychology is presented by Watson.
- Vitamins A and B in cow’s milk are discovered by McCollum and Davis.

1914

- Successful treatment of cancer is done with radium.

- Radio transmitter triode modulation is discovered.
- A cargo ship is constructed with a turboelectric engine.
- Carrel carries out the first successful heart wurgery on a dog is performed.
- Rutherford determines the proton.
- Duden and Hess produces acetic acid (Vitamin C).

1915

- General theory of relativity, by Einstein, is published, in which it is envisaged that space is curved
- Hugo Junkers develops the first all-metal aircraft (Ger)
- J. Goldberger shows that vitamin deficiency causes pellagra.
- Discovery of Proxima Centauri, the nearest star to the Earth (except the Sun)
- Sonar developed by Frenchman Langevin

1916

- The phenomenon of chemical bonding and valence of chemical elements is explained by Lewis; he also shows that the number of electrons in compounds is nearly always seven
- Fisher constructs the prototype of agitator washing machines.
- Vitamins A and B, identified in cow's milk in 1913, are declared essential for growth.
- Idea of covalent bonding put forward by Lewis

1917

- Equations used to predict the existence of black holes are presented by Schwarzchild .
- the importance of calorie consumption in producing energy is explained by Lusk and Anerson

1918

- The superheterodyne circuit for radio is devised by Armstrong

1919

- Eccles and Jordan construct the flip-flop electronic switching circuit, a vital feature of future digital computers.
- Joseph Larmor put forward a theory explaining the magnetic fields of Earth and the Sun by assuming circular motion in those bodies functioning as a self-exciting dynamo

1920

- Marconi establishes the first public radio station

1921
- First medium wave wireless broadcast

- Bronsted and Hevesy successfully separate isotopes
- Ear specialists use a microscope for the first time in ear operations.
- It is suggested by Morgan that chromosomes are the carriers of hereditary information in a living cell
- Western Union send the first electronically-transmitted photograph
- Ethyl gasoline introduced.

1922
- Technicolor, the first successful color process for films, is developed by Kalmus
- Insulin, isolated by Banting and Best , is used to administer to diabetic patients.
- The possibility of an expanding Universe is predicted by general relativity

1923
- Trucks with diesel engines are produced by Benz, a German company.
- Souttar is the first one to conduct cardiac surgery by attempting to widen a constricted mitral valve
- Ramon develops a new tetanus vaccine
- First electric refrigerator produced by Electrolux Company

1924
- Edwin Hubble proves that galaxies are systems independent of the Milky Way
- Pyrex invented by scientists at Corning
- Hermann Oberth demonstrates that rockets could generate enough thrust to escape the gravitation pull of the Earth

1925
- Rabbits are used by Lazzarini in his experiments in bone transplants
- Discovery of the Pauli Exclusion Principle

1926
- “Electrola”, a new recording technique, is developed
- Schrodinger explains his Schrodinger wave equation
- First liquid-fuel rocket launched

1927
- Lemaitre initiates the concept of the expanding universe to explain the red shift in the spectra from distant galaxies, a theory that is eventually developed into the “Big bang” theory.
- Bohr states the notion of complementarity.

- Ramon and Zoellar are the pioneers immunize human beings against tetanus.

1928

- Geiger and Mullur devise the “Geiger counter”, an instrument for measuring radioactive radiation
- Penicillin is discovered by Fleming, when a chance mold appears on a Petri dish and destroys bacteria.

1929

- A connection between high blood pressure and fatal heart disease is established by Levine.
- Frank Whittle invented jet propulsion

1930

- A vaccine against yellow fever Theiler is developed

1931

- E., Ruedenberg develops electron microscope
- Lawrence develops the cyclotron, an important development in the study of the nuclear structure of atoms.
- Rossi shows that cosmic rays are powerful enough to penetrate a meter or more into solid lead.
- The first teleprinter exchange goes into operation.

1932

- The use of vitallium, a non-corrosive metal, revolutionizes joint surgery
- Chadwick works out the existence of the neutron

1933

- Marriott and Kekwick recommend a continuous drip technique for transfusing a large quantity of blood (UK).
- Pure vitamin C is produced by Reichestein
- Polyethene is manufactured by Fawcett and Gibson. Melamine also first produced.
- Invention of frequency modulation (FM) by Edwin Howard Armstrong.

1934

- Beckman constructs the first pH meter
- Tritium discovered by Oliphant
- Coiled-coil electric light bulb invented; this increases the amount of radiated light
- Electronic hearing aid developed

1935
- Watt pioneers first practical aerial radar
- Hearing aids using a discrete battery and a small radio tube are invented.
- Richter introduces the “Richter scale” of earthquake strength
- Development of triacetate film, used as a base for photographic film

1936
- Alexis Carrel develops a form of artificial heart that is used during cardiac surgery (Fr).

1937
- Vitamin A is discovered by Elvehjem
- Yellow fever vaccine is made
- Invention of Radar (Radio Detection And Ranging)
- Field-emission microscope invented by Muller
- Invention of the jet engine by Frank Whittle
- Hand-held vacuum cleaner introduced

1938
- Discovery of Fission process
- The radio altimeter is developed
- Karrer develops Vitamin E
- Polytetrafluoroethylene (PTFE) discovered

1939
- First helicopter designed for mass production is built by Sikorsky
- Bohr puts forward a liquid-drop model of the atomic nucleus
- Oppenheimer discovers the properties of what is later known as a ‘black hole”
- Atanasoff develops the first electronic computer

1940
- Canadian scientist Martin Kamen discovers carbon-14
- Jeffreys and Bullen published the "J-B tables" for the travel times of P and S seismic waves through Earth
- Uranium 235 is isolated from the heavier isotope uranium 238

1941
- The first plastic lithographic plates are developed, followed by presensitized plastic plates.
- The term “antibiotic” is coined by Wakeman to describe substances that kill bacteria without injuring other forms of life
- Flerov discovers spontaneous fission of uranium

1942
- Manhattan Project is formed by leading scientists and Allied governments to build an atomic bomb.

1943
- Kolff develops the first kidney dialysis machine
- Penicillin is first used to treat chronic illnesses.

1944
- Quinine is synthesized successfully for the first time
- Mark 1, the first automatic general-purpose digital computer, goes into operation

1945
- The first radar signals are reflected from the moon
- Hiroshima and Nagasaki bombed using the first nuclear fission bombs

1946
- The Atomic Energy Commission is established by the United Nations.
- The first synchrocyclotron is built at Berkeley
- ENIAC (Electronic Numerical Integrator and Computer), the first electronic digital calculator, launched

1947
- Land invents instant photography

1948
- Gamow, Alpher and Herman develop the “Big Bang” theory of the origin of the universe
- Hench ascertains that cortisone can be used to treat rheumatoid arthritis

1949
- Britain produces plutonium for the first gas-turbine car

1950
- Neumann, makes the first 24-hour computerized weather forecast

1951
- Using a field ion microscope, scientists are able to observe single atoms for the first time

1952

- Wilkins discovers the first tranquilizer, reserpine, which was earlier used to treat high blood pressure.
- A hearing aid using transistors instead of vacuum tubes is launched.

1953

- Scientists identify the polio virus
- Sanger establishes the structure of the protein insulin.
- Townes develops the maser (Microwave Amplification by the Stimulated Emission of Radiation), forerunner of the laser.
- The first open-heart surgery with a hearth-lung machine is performed by Gibbon

1954

- The prototype of the Boeing 707 makes its maiden flight
- CERN, the Centre Europeen de Recherche Nucleaire, is founded at Geneva.
- Texas Instruments develop the use of silicon in transistors in place of germanium
- The Nautilus, the first nuclear-powered submarine, is built
- Invention of the transistor radio, which gains widespread usage in a very short time

1955

- F. Sanger established the structure of the molecule of insulin
- Kapary makes first optical fibers

1956

- FORTRAN, the first computer programming language, is made
- Calder Hall, Cumbria, UK, is the site of the world's first large-scale nuclear power station
- Norman Bier invents plastic contact lenses

1957

- The first European particle accelerator opens in Geneva
- Russians launch Sputnik I, the first artificial satellite, and take the lead in the space race
- The law of conservation of parity is partially overturned
- The US government founds the Advanced Research Agency (ARPA) as a direct response to the Soviet launch of Sputnik
- Formation of International Atomic Energy Agency (IAEA)
- Publication of 'Synthesis of the Elements in Stars' by Margaret Burbidge, Geoffrey Burbidge, William Fowler, and Fred Hoyle (B2FH); this landmark paper suggested that stellar elements are formed by nuclear reactions
- Female physicist Chien Shiung Wu disproves the law of conservation of parity, a fundamental physics assumption

1958
- Enders prepares an effective vaccine against measles
- Kilby and Noyce develop the integrated circuit, the cornerstone of the modern electronics industry

1959
- The first photographs of the Far Side of the Moon are taken by Soviet satellite Luna III
- Russian spacecraft Luna II reaches and impacts on the Moon

1960
- US physicist Maiman develops the first optical maser or “laser”
- Harry Hammond Hess develops the theory of seafloor spreading

1961
- The silicon chip is patented by Texas Instruments
- Heat-resistant "super-polymers" introduced

1962
- Lasers are initially employed in the process of eye surgery
- The first X-ray source is discovered in Scorpius

1963
- An artificial heart is used during cardiac surgery by Bakey.
- The first human lung transplant is performed by Hardy
- Moore and Starzl perform the first ever procedure of liver transplant.
- UK becomes the first country to have developed carbon fiber.
- 5 years of research yields a commercial vaccine for measles
- Valentina Tereshkova becomes the first woman in space

1964
- Cosmic radiation is detected by Penzias and Wilson, which paves way for the providing decisive evidence for the “Big Bang” theory
- The UK and USA introduce the process of home kidney dialysis.
- Emerging computer giant IBM develop the first mass-produced operating system for the computer, OS/360

1965
- A vaccine against measles is introduced

1966
- A live virus vaccine against rubella is developed by Meyer and Parman.

- France becomes the first and only nation to reject heart stoppage as the clinical definition of death and adopts brain inactivity instead.
- UK develops fuel injection for automobile engines.
- Japan develops laser radar.

1967
- The announcement of explosion of its first hydrogen bomb comes from the Communist China.
- Barnard performs the world's first heart transplant on Washkansky, who later dies on 21 Dec.
- Bell and Hewish discover the first pulsar
- In a bid to improve vehicle safety, Pontiac develop bumpers which partially absorb the energy of a collision

1968
- A vaccine against meningitis is developed by Arnstein.
- Ted Hoff invents the microprocessor
- Nuclear Nonproliferation Treaty (NPT) signed to prevent widespread production of nuclear weapons

1969
- The announcement of the structure of insulin comes from Hodgkin.
- Hoff successfully constructs the first silicon microprocessor.
- Cooley and Liotta make the first artificial heart implant.
- ARPANET, the first computer network, is set up

1970
- China successfully launches its first satellite.
- Lasers to be used in eye operations are developed.
- A successful attempt of nerve transplant is made.

1971
- Invention of Kevlar, a fibre five times stronger than steel
- Lunar rover vehicle driven on surface of the Moon

1972
- Discovery of 2 million year old humanlike fossil
- On January 1st, Coordinated Universal Time (UTC) was adopted worldwide

1973
- The longest eclipse of the sun lasting 195 minutes occurs in some parts of the world after 1,500 years.

- Nuclear magnetic resonator (NMR) is introduced to form images of soft body tissues.

1976
- Cray-1 supercomputer developed for rapid computation of mathematical and scientific problems
- IBM develop ink-jet printing technology

1977
- The lassa fever virus is discovered.
- The Apple II personal computer is launched

1978
- Using NMR (nuclear magnetic resonance) scanning, EMI produces the first brain scans.
- A form of moldable and recyclable natural rubber is developed in the UK.
- The first demonstration of Compact discs is held.
- Pioneer 1 and 2 reach Venus
- Fossilized human footprints dating from approximately 3.5 million years ago are discovered by Mary Leaky

1979
- After an elaborate campaign lasting 22 years and costing $100 million, smallpox is declared eradicated by the WHO.
- Provost and Hilleman culture the hepatitis virus.
- A leprosy vaccine is developed by Rees.
- Cronin and Fitch discover asymmetry of elementary particles

1980
- Guth proposes a variation to the Big Bang theory, which came to be known as the inflationary universe theory.
- Scanning tunneling microscope is developed by Roher and Binnig.
- Insulin, which is produced by genetically engineered bacteria, is tested in diabetic human patients for the first time.
- Sony and Phillips invent the compact disc

1981
- AIDS, which is the Acquired Immune Deficiency Syndrome, is recognized officially for the first time.
- IBM release their first personal computer, complete with a Microsoft operating system

1982
- Severe infectious hepatitis is treated successfully with interferon.

- The first virus implicated in human cancer known as the Epstein-barr virus is identified by Epstein.

1983
- The first personal computer with hard disk memory devices called PC-XT is introduced by IBM.
- A comprehensive methodology is devised, based on chemical changes in obsidian, for dating ancient objects.
- The virus from which AIDS can result called the HIV retrovirus, is identified.
- The first artificial chromosome is created by Murray and Szostak.
- Research at CERN shows evidence of "weakons" (W and Z particles); this validates the link between weak nuclear force and electromagnetic force

1984
- The successful cloning of sheep is done by Willadsen
- West German scientists create 3 atoms of element 108, now known as hassium (Hs)
- Apple Macintosh computer launched
- Russian Svetlana Savitskaya becomes the first woman to walk in space

1985
- After a detailed radio map of the galaxy is made by US radio telescopes, it is established that there is a black hole at the centre of the galaxy, accelerating stars and dust towards itself.
- Clogged arteries are cleaned for the first time with lasers.

1986
- The AIDS virus is witnessed by the electronic microscope for the first time.
- First use of the world "Internet"

1987
- Digital audio tape cassettes are introduced

1988
- The process of embryo cloning of dairy cattle is developed.
- It is estimated that 10 million chemical compounds have been recorded to date

1989
- Genetically engineered white blood cells, used to attack tumors, are transferred into cancer patients for the first time.
- The first test conducted with the LEP particle accelerator in Geneva produces Z particles.

- The announcement of the successful development of a new technique for making antibodies and fragments of antibodies able to carry out some of the functions of complete antibodies is made by Winter and his team. This technique avoids the use of animals and makes them more cheaply and quickly.

1990
- The discovery of the gene is reported by Chambon and his colleague. This discovery may be crucial in the spread of breast cancer
- Canadian scientists discover that killer whales speak a multitude of dialects and languages.

1991
- A new and low-cost process for producing solar cells is announced by Texas Instruments and South California Edison.
- US and European researchers announce that they have isolated the gene responsible for the most common cause of mental handicap, called the fragile-X syndrome.

1992
- CERN release their hypertext for physics system, the beginning of the World Wide Web

1993
- Development of the Mosaic browser system as a graphical interface to the World Wide Web

1994
- Use of silicon technology in optoelectric devices
- Cave paintings dating to more than 30,000 BC are discovered at Chauvet Cave, France

1995
- First extrasolar planet detected by Mayor and Queloz, using the "wobble technique"

1996
- Polymer wafer implants used to treat brain-cancer; the technique is approved by the US Food and Drug Administration

- German scientists produced atoms of element 112 (ununbium), the heaviest ever created; this was achieved by fusing a lead atom with a zinc atom. The element decays in less than a thousandth of a second

1997
- First direct evidence of the "tau neutrino" published

1998

- Supernova observations suggest that the universe is expanding at an increased rate

2000

- Work by separate research groups establishes that quasars are black holes "in development"
- World's first commercial wave-power station opens at Islay, Scotland

2001

- Evidence for a black hole at the centre of our galaxy is found
- First detection of X-ray emissions from Venus and Mars

2003

- Chinese successfully launch first manned space flight, piloted by Yang Liwei