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CHEMISTRY IN THE SERVICE OF HUMANITY*

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I DEEM it a great privilege and honour to be invited to present the Gandhi Memorial Lecture this year. I am deeply grateful to the Raman Research Institute for the opportunity it has provided me to pay my humble tribute in this fashion to the memory of Mahatma Gandhi whose thought and action have influenced every aspect of life in modern India. It is also particularly apt to pay this tribute under the auspices of the Raman Institute, founded by Raman, who combined his genius with an unbounding enthusiasm for science. True independence, and, pride in being an Indian have been instilled by the political and moral values enshrined in the teachings of Mahatma Gandhi. Raman has inspired Indians to practice science and to aspire for its greatest heights and has endowed them with pride in their achievements and confidence in their potential to excel. I had the privilege of being associated with Professor T. R. Seshadri who received in his studies on chemical sciences, great encouragement and support from Professor Raman. Because of this fortunate association, I had many opportunities to listen to Professor Raman and I welcome, therefore, this opportunity to commemorate his lasting influence on Indian Science.

Chemistry has been concerned with molecular transformations and the production of materials. Study of the molecular architecture of materials has been the abiding interest to chemists. Through understanding of natural materials, chemists have altered them and fashioned entirely new materials with new properties to meet the varied needs of human society. Increasing attention is also being paid to the energy changes involved in chemical transformations and the ways in which energy is stored in chemical molecules and released or absorbed during transformations.

Man is almost unique among living systems, in the abilities he has developed for using materials for housing, clothing, weapons for protection against natural elements, and, transport. Natural materials include wood, stone, horn, ivory, bone, shell, hides, leather, feathers, wool, silk as well as jute, cotton and linen, many of which are used also as structural materials. He has also learnt to produce many metals through chemical changes, such as iron, copper, lead and tin as well as many alloys such as brass, bronze and steel. The ages of man are known by the advances in civilization made through the use of such structural materials. Other materials available include fired clay, bricks, glass, pottery and ceramics.

Man is also unique in his ability to use many natural materials for non-structural applications such as surface coating, colours, drugs, insecticides, poisons, perfumes, flavours, washing agents, emulsifiers, plant nutrients and explosives. He also uses energy, derived by the burning of oil, wood and coal. There is an intimate connection between his use of materials and the energy derived from the sun through photosynthesis in green plants leading to stored energy in starch, sugar, protein and fat. These are utilised by animal system through the Krebs Cycle for the production of energy for body heat and movement. Animal and plant materials under certain circumstances, over long periods are transformed into fossil fuels such as coal and petroleum which today form the largest source of energy. To meet the increasing needs of nutrient nitrogen for plants in recent times, man has devised means of production of ammonia using fossil fuels. Finally, through synthetic organic chemistry, a whole variety

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* Gandhi Memorial Lecture delivered at the Raman Research Institute, Bangalore, on October 2, 1980.

of structural polymeric materials as well as a myriad of non-structural substances have also been produced. Today we are familiar with synthetic drugs, detergents, insecticides, adhesives, perfumes, solvents and colours. Without these, the security, health and the quality of life, that is now obtained, would not have been possible.

The extent of use of non-renewable hydrocarbon resources is large amounting to nearly 6,000 million tonnes per annum in oil equivalent (Table I). We are also familiar with the many new synthetic polymeric materials such as polyethylene, polypropylene, polystyrene, polyvinylchloride, polybutadiene, rubber, polyurethanes, polycarbonate, polyvinyl alcohol and acetate as well as many copolymers which have special applications. We are equally familiar with many synthetic fibre materials such as polyesters, nylon and acrylics. As the need for using natural resources for improved production increases and our aspirations for new properties grow, there has been increasing use of synthetic materials to supplement, complement and replace natural materials as well as paper, glass, metals and alloys. World production of polymers is approximately 100 million tonnes per annum today and is expected to increase further since energy requirements for production of such materials are considerably lower than those required for many conventional materials. (Table II).

TABLE I

Use of non-renewable hydrocarbon resources, coal natural gas and liquid petroleum

(in million tonne oil equivalent)

	World	U.S.A.	India (1980)	India (1990)
Energy	5000	2200	100	200
Nutrient nitrogen	60	30	3	8
Carbon chemical feedstock	500	250	2	4
Per capita consumption of organic polymers (kg per annum)	..	55	0·3	..

TABLE II

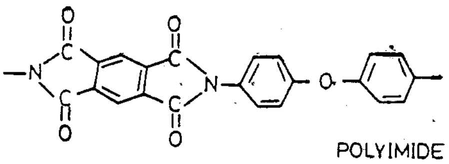
Energy requirement in manufacture of materials

Materials	Tonnes of oil per tonne of material	Kilo-calories/ cubic cm
Aluminium	5·6	158
Steel	1·0	82
Copper	1·2	112
Paper	1·4	12
Cellophane	4·4	17
Polystyrene	3·2	36
Polyvinylchloride	1·9	28
Low density polyethylene	2·2	22
High density polyethylene	3·2	24
Polypropylene	2·5	24

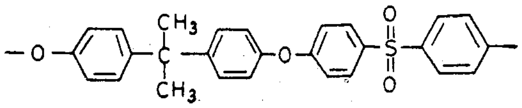
These materials, however, are no longer sufficient in their range of properties to meet the growing special needs. A range of new synthetic engineering polymers are becoming available and these include polyamide-imide, polyaryl sulphone, polyphenylene sulphide, polyaryl ether, polyacetal and polyester (Fig. 1).

FIG. 1

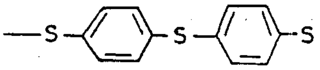
Engineering Polymers



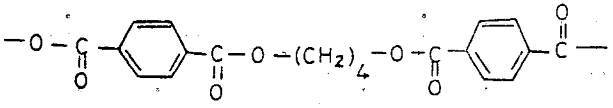
POLYIMIDE (KAPTON)



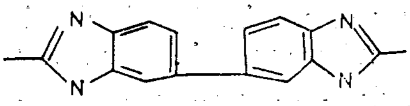
POLYSULPHONE



POLYSULPHIDE (RYTON)



POLYESTER (PBT)



POLYBENZIMIDAZOLE

The world production of such polymers amounts to already 2·5 million tonnes per annum. The characteristic properties required of these materials are as follows :

High strength
Corrosion resistance
Light weight
High and low temperature resistance
Elasticity
Rigidity
Strength under stress
Low wear by friction
Low friction
Transparency
Ease in shaping
Low or specific permeability
Insulation
Continuous film formation.

Engineering plastics find applications in products such as automobiles, aircraft, textile and engineering machinery, electronic and communication appliances, electrical power generation and transmission equipment and increasingly in buildings, household materials as well as special scientific instruments. Their ability to withstand variations in temperature, light weight, transparency, immunity to corrosion, thermal and electrical insulating properties and above all, their ease in shaping into a variety of forms contribute to their increasing range of use.

Yet another area of considerable activity in the production of new light weight material is the use of synthetic fibre for the reinforcement of rigid structures. These reinforced materials meet the requirements of very high modulus and strength, perfect bonding with matrix, low specific gravity and good machineability required in applications for fast running machines, aircraft, boats, cars and spacecraft. Some typical properties of fibre reinforced materials are summarised in Table III.

Large need also exists for high strength materials which can be transformed into films and membranes. For applications in electronics, very thin and totally uniform films, less than 1 micron in thickness without any pinholes and possessing very good insulation properties (resistivity 10–15 ohm/cm resistance) in a wide temperature range (2° K to above 200° C) and special resistance, to oxygen and ozone for several years are needed. Similar materials are also required for applications requiring continuous exposure to sunlight and in the fabrication of special membranes for separation of liquids and purification of water. The many engineering polymers already listed are able to meet such requirements. Special applications include cord materials for landing tyres for supersonic aircraft and for earth moving equipment as well as in fast moving transport belts. Such applications require high adherence of the plastic to elastomer and resistance to chemicals and these are obtained by using tough filaments of materials such as aromatic polyamides (Aramid).

TABLE III

Key properties of fibre reinforced materials

Material	Modulus PSI × 10^6	Tensile strength PSI × 10^3
Carbon fibre/aromatic polyester	40-80	300–400
Aramid fibre/epoxy	9	180
Carbon fibre/epoxy	26	160
Glass fibre/epoxy	5	120
Alumina fibre	50	350
UTRC glass	20	770
Aluminum	10	80
Steel	28	200

NEW CHALLENGES

The enormous growth of chemical conversion processes and their applications have come primarily from the use of non-renewable resources such as ores, minerals and oil and using large amounts of energy in effecting such transformations. The known reserves of oil in the world will begin to deplete rapidly within the next 20 years and the technologies developed in the past are unlikely to be valid for a much longer time in future in their entirety. There is therefore a great deal of attention, being paid entirely to new areas of chemical transformation and new methods based on the use of light from the sun and renewable resources available through photosynthesis. Furthermore, there is also concern, in the widespread use of new synthetic substances whether they are drugs or pesticides or preservatives due to the possibility of side effects or long range toxicity or teratogenicity. Although much good has been realised through their applications, a new understanding of the mechanism of their production is now emerging. These are apparent in the new research areas, aimed at taking us in future to a world without serious concern for the diminishing fossil fuels.

It is apparent that in all the energy transformations in nature, water and its constituents, hydrogen and oxygen play the major part in natural photosynthesis. Light energy is used essentially to form hydrogen for combination with carbon dioxide and produce carbohydrates. It is estimated that the annual production of carbon by photo synthesis on land is 20,000 million tonnes and 180,000 million tonnes on sea surface. All carbon dioxide is cycled once in 300 years. This enormous activity is rendered possible by light photon of wavelength 380–680 millimicrons, which in the presence of chlorophyll *a* and chlorophyll *b* produces within 10–12 seconds. Adenosine Triphosphate (ATP), the biological energy source molecule, which in turn is instrumental in converting carbon dioxide into carbohydrate in the Calvin photosynthetic cycle. Much attention is now being paid to a fuller understanding of the function of light in this process and the catalytic systems that are required for achieving a high efficiency in the light induced production of hydrogen. Professor Calvin has recently demonstrated hydrogen production in a non-biological photo reaction system. It can therefore be assumed that a study of reactions by use of light will be a major concern. In addition to natural light, it is increasingly possible to use very specific pure light from lasers. Laser induces chemical reactions with high orders of specificity in transfer, and, would also be an area of much activity. Our greater understanding in theoretical chemistry, mathematical modelling and in the use of computer would promote this approach. With the precision available in exact wavelength and power of light, it may be possible to perform specific steps in chemical transformation with very high efficiency.

It is known that while the type of chemistry that has been practised hitherto in laboratories and industries requires high pressure, high temperature and non-aqueous media or media with very high acidity or alkalinity, biological transformations take place in a facile manner in aqueous media under neutral conditions, at normally ambient temperature without using very high pressures. Our studies in biological chemistry have now given us a very considerable undetstanding of these biological transformations in minute detail. Nevertheless, we lack as yet a fuller picture of catalytic activity by enzymes and especially of the very rapid reactions through successive involvement of many enzymes. Therefore, these allosteric transformations would receive very much greater attention.

In this effort, new tools such as Low Energy Electron Diffraction, Electron Spectroscopy for Chemical Analysis, Secondary Ion Mass spectroscopy, Laser Excited and Fourier Transform spectroscopy are augmenting the already established methods like infrared, ultraviolet, Raman and X-ray spectroscopy. Furthermore, the availability of modern micro processors and high capacity computers enable the deployment of a multitude of such techniques simultaneously to bear upon a single problem and the emergence of a hypothesis and solution compatible with experimental observation. The rate of advance in the future, therefore, is likely to be extremely rapid through the combination of excellent theory verified rapidly by observation and experiment. A major concern of new chemistry would also be of a greater specificity achieved in biological processes and controlled mechanisms. Work during the last 30 years is providing a greater understanding of the very chemical and physical basis of biological structure and sub-structure and the detailed intricate mechanisms and controlled processes governing the modes of transformation at each level. The availability of observational tools such as the electron microscope and new capabilities in organ, tissue and cell culture have provided us opportunities for the study of dynamics of isolated parts or whole systems. The complex puzzles which remained mysterious are being resolved through a combination of theory and experiments. New understanding of biological phenomena based on laws of physics and chemistry is being obtained. This new insight, in chemical terms, of life processes, is likely to produce extraordinarily high benefits in many areas such as health, nutrition and medicine as entirely new technologies for improved and higher production without concomitant adverse effects on the environment. Such new applications are likely to need little energy usage and may be based on the constantly renewable resources.

A major possibility in chemical studies related to biology is the production of entirely new drugs, which are capable of simulating natural control mechanisms. There are developments of endogenous opiates which act on specific brain sites and greatly alleviate pain or alter biological states. There are also new modified natural hormones and immune suppressants which are likely to have effects on fertility and in the conquest of virus diseases and in diminishing the effects of ageing process and communicable diseases. Modern advances in the determination of chemical structure using very tiny quantities will play a great part in these advances.

New developments in enzyme engineering and in catalysis are likely to be directed to the better use of natural materials. A major requirement is the transformation of 'one carbon' molecule to 'two carbon' and longer chain materials. Methane still remains an abundant source both from natural as well as from microbiological transformations of biomass. It is currently used mainly as a fuel and in the production of ammonia and new reactions could greatly enhance its value for production of other organic chemicals and polymers. There is now a technological process for the production of microbiological products such as proteins from methanol. The abundantly available cellulose and lignin in nature are not used generally as a source of carbon for chemicals. There is much interest in the chemical/microbiological degradation of cellulosic bio-mass into glucose and other fermentable materials, which, in turn, can produce ethanol and ethylene. Immediate attention is necessary for a study of this process. It is also possible that partially degraded natural polymers like cellulose could be grafted on to a matrix of synthetic polymers, so that, future structural materials could be derived from renewable resources. There is much interest in producing structural materials from filled polymers containing chalk, sawdust and talc. Electrochemical deposition from inorganic soluble materials to produce structures not dissimilar to natural bone and dental polymers would also be future areas for investigations.

The chemical industry and technology depend on a large measure on the use of techniques of separation such as distillation, solvent extraction and crystallization at each stage. All these require large energy inputs. It is estimated that even in petroleum refineries, approximately 6 to 8% of the total petroleum is used up as energy in the production of various fractions. Application of newer principles of chemical engineering and mathematical modelling could lead to high efficiency separation processes with greater energy conservation leading to a reduction of this to 2 per cent. Similarly, the development of newer techniques of separation such as reverse osmosis, membrane separation, extractive distillation, preferential absorption and desorption could all lead to substantial energy reduction. Increasing specificity would reduce the production of mixtures in products and would therefore eliminate to a great extent the need for a separation. There may be, therefore, greater emphasis on homogeneous catalysis. There may also be chemical reactions carried out with the continuous removal of reaction products so that high yields are obtained. There are also possibilities of the use of Inclusion Compounds which would provide a favourable environment for reactions to take place in a preferential way. There will certainly be very much greater need for studying coupled oxidation reduction reactions for energy conservation for avoidance of waste products. New catalysis may well depend upon the use of commonly available metals instead of scarce metals such as platinum, palladium, molybdenum or cobalt. Products such as carbon dioxide and carbon monoxide which are considered waste products or end products could well become important sources of carbon for recycling.

There may also be need for developing new mechanism for chemical energy storage, such as hydrogen or ammonia. There will also be substantial emphasis on the study of chemical reaction such as polymerisation in aqueous media.

If it were possible to develop normal pressure, ambient temperature, chemical transformations, there may also be very good possibility of small scale low capital technology which could be applied to locally available material to produce goods for local use and any energy required for this transformation could be supplied from natural sunlight or from relatively easily available renewable materials.

CONCLUSIONS

It is clear that chemical sciences therefore provide an understanding of biological as well as technological processes to serve humanity in innumerable ways. Chemical sciences offer enormous scope for exciting new avenues for exploration.

There are many research areas wide open for investigation and there is enormous new opportunity for meeting human needs in entirely original and novel ways, assimilating and learning from nature and sometimes improving upon it. Ultimately, much of chemistry is dependent on the study and understanding of natural resources like earth, water, air and light. Water with its unique quality to take part in the many transformations of carbon in the carbon cycle in life process and its uniqueness in providing media for chemical ionic transformations of minerals remains a central figure in chemical studies. Water is therefore *Life* and the mysteries of its transformations are not yet fully known to us.

We may recall that Mahatma Gandhi was anxious that humanity should be able to use the wealth of the elements in simple and clear ways. His belief on the right of individuals to use the elements such as water and salt from the sea and of natural materials such as cotton are expressions of his faith on the relationship between Man and Nature. Raman was ever fascinated by the elements and unravelled their mysteries and transformations by a study of interaction of matter with light. A scientist practising in the area of chemical sciences will continue to be concerned with the use of light in its many forms as a source of energy and as an analytical tool in understanding the complex architecture of materials, and the inter-play of this architecture in effecting chemical transformations on the surface and in the bulk. Let us hope that man's concern for the biosphere will now lead him on to finding new ways of living in harmony with nature and with greater security, peace and enjoyment, providing ever greater opportunities for his creative instincts to be utilised in the well-being of his fellowmen.