REPORT ON WORKSHOP ON CHEMICAL EVOLUTION, ORIGINS OF LIFE AND EVOLUTION OF LIFE PROCESSES*

Although the theme of evolution in all its cosmic ramifications and implications is part of India's ancient heritage, yet a scientific approach to the problem has not been actively pursued by its investigators using modern methods and techniques.

With a view to stimulate activity in an exciting field of science, a workshop was recently held at Hyderabad between Jan. 28-31, 1978 at which astronomers, physicists, chemists, biochemists and biologists participated. It was perhaps for the first time in this country that scientists from different disciplines discussed informally the all important probem 'HOW LIFE BEGAN ?'

The workshop was inaugurated by Dr. Raja Ramanna with a thought provoking address. He remarked that there has been a breakthrough in understanding the processes of life well within the laws of physics and chemistry as they exist now. After recounting aspects of Aristotelian logic and its limitations as brought out by advances in mathematics, especially the theory of infinite sets, transfinite numbers and Godel's theorem, he discussed the two laws of thermodynamics and the limitations of the second law in explaining life processes. Ramanna emphasised the importance of recent theories of Prigogine *et al.* which describe how new stable order can come about by spontaneous fluctuation. He said that "I do not have to stress on the importance of this discovery that just by fluctuation we can be led to thermodynamic conditions far from equilibrium and this can lead to higher order and to evolution in general". He concluded by saying, "I see in the development of non-linear non-equilibrium thermodynamics a great breakthrough for many of the unexplained problems in physics. It will certainly encompass the whole of chemistry and much of biology. It may even explain the nature of consciousness, only we may then have to associate probability with God and not a gambler."

Dr. Cyril Ponnamperuma of the University of Maryland delivered the keynote address dealing with Cosmochemistry and the origin of life. Ponnamperuma outlined the Oparin-Haldane hypothesis of chemical evolution and stated that much earlier Charles Darwin had forestalled the idea of chemical evolution in the letter which he wrote to his friend Hooker in which he described a warm little pond filled with ammonia, phosphoric salts etc from which a protein compound was formed ready to undergo still more complex changes.

According to Ponnamperuma, the origin of life on Earth would immediately lead to the consideration of life beyond Earth. The same sequence of events which took place on Earth would happen elsewhere in the universe. He added that the scientific investigation of a problem which appears to be transcendental in nature has been made possible due to advances in modern astronomy, recent developments in biochemistry and the triumph of Darwinian evolution which is the cornerstone of modern biology.

He discussed briefly the laboratory investigations, both synthetic and analytical, related to the origin of life. In the synthetic approach, convincing evidence has been obtained to show that starting with the raw materials of Earth's primitive atomosphere and the energy sources abundant in prebiotic times, the molecules necessary for life could be synthesised. Also, the next step has been demonstrated where these molecules may be put together to form marcromolecules.

In the analytical approach, the discovery of microfossils in sediments 3.5 billion years old was discussed, and current studies on sediments from the edge of Greenland Ice Cap which are 3.86 billion years old were also described.

Ponnamperuma presented the dramatic evidence for the presence of organic compunds (aliphatic and aromatic hydrocarbons and equal amounts of D and L amino acids) of biological interest in the Murchison meteorite which fell in Australia in 1969. He also discussed the importance of the discovery of nearly forty organic molecules by radio astronomers in the interstellar medium. These include molecules of critical imporatnce such as NH_3, HCN and HCHO, which are key intermediates in the synthesis of bases, sugars and amino acids.

He concluded by saying that "The results of our laboratory experiments, of our analysis of carbonaceous chondrites, and the microwave evidence for interstellar molecules lend us to the conclusion that "CHEMICAL EVOLUTION MUST BE A COSMIC PROCESS".

Any discussion on origin of life in the universe must start with the question of the origin of the universe iteself. In a session on this subject, J.V. Narlikar discussed 'The structure of the Universe and its Relation to Life Supporting Environment'. Narlikar gave an impressive set of numbers to bring home the fact that the universe is vast in terms of space, time and mass. He discussed the Hubble equation $V = HD$, where V represents the speeds with which the galaxies are receding from us proportional to distance (D) from us and H is Hubble's constant, H^{-1} being the time scale characteristic of the age of the universe. Einstein's general relativity provided models of the expanding universe. According to Narlikar, "All these models show the universe as originating in a big bang." It may either expand for ever or slow down and eventually contract. As yet the observations do not tell clearly which model is right. The observation of microwave background radiation at 2.7°K (black body temperature) is often quoted as the best evidence in support of a hot big bang.

Narlikar then discussed the philosophical question: To what extent is our presence (as observers) an accident? Is it related to the nature of the universe or to the laws of physics? He then discussed what is called "Anthropic Principle" and gave some examples of it. These were :

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(i) The ratio of carbon (C) to oxygen (O). The formation of carbon by α-process from He^4 via Be^8. The instability of Be^8 and the existence of resonant level of C^{12} to compensate for this instability. If this were not the case, life, as we know it, would not be possible. Since the abundance of carbon, oxygen etc would be vastly different from those presently observed.

(ii) The Sun will exhaust all its fuel in 10^{11} years. The fact that we exist means that the Sun is still producing energy. Thus the observed age of the universe should not be too different from 10^9-10^{10} years.

(iii) Carter's postulation regarding the convective or radiative transport of energy of stars and their effect on the likelihood of their having planets.

Narlikar concluded with the remarks that "Theoretically such considerations may put rather narrow limits on the type of universe we live in and the type of physical laws which are consistent with our existence."

S.M. Chitre followed with his talk on 'The Evolution of Stars and the Formation of Elements.' He started with the statement that stars are mainly responsible for the syntheses of heavy nuclei from He^4 upwards.

The formation of stars by the contraction of interstellar clouds was discussed. The limited phases of evolution of small stars (black dwarfs) and their inability to trigger thermonuclear reactions was also discussed.

In case of stars where temperatures are high enough (i.e. in the range $10^7 \leqslant T \leqslant 10^9$ °K to start with) the formation of elements with the following sequences was indicated.

$$H^1 \longrightarrow He^4 \longrightarrow C^{12} \longrightarrow O^{16} \longrightarrow Ne^{20} \longrightarrow Fe^{56}$$

Chitre discussed the effect of higher temperatures $\sim 10^{10} - 10^{11}$ °K that are produced in the shrinking inner core where the matter is neutronized and the core-bound shock ejects violently the infalling envelope. The fate of the ejected material was also discussed.

The role of supernova in triggering the process of star formation and the presence of Al^{26} in the Allende carbonaceous chondrite pointing to the occurrence of a supernova event a few million years before the solar system was also put forth.

Chitre concluded his talk with the sobering thought that "The Sun itself will become a red giant in a few billion years and will gobble up the Earth and inner planets. Jupiter may suck some of its material, as well as accrete material from the neighbourhood of the solar system and become a star! He asked the question "Will life be sustained under such changed circumstances".

The session on the Exploration of Outer Space was featured by U.R. Rao, Yash Pal and N.A. Narasimham.

Rao in his talk on outer space exploration stated that consideration of various factors such as orbit, eccentricity, mass, temperature distribution etc. lead to the conclusion that planetary systems around F and G stars are probably most conducive for life to grow, and Alpha Centauri and Barnard's star are the best candidates for detailed exploration.

Rao discussed the well known calculation by Drake for determining the possible number of technical civilisations in the universe which is :

$$N = R \; f_p \; n_p \; f_l \; f_i \; f_c \; L,$$

where R = rate of star formation,

f_p = fraction of stars with planets,

n_p = fraction of stars suitable for life,

f_l = fraction of stars where life has evolved,

f_i = fraction in which life has become intelligent

f_c = fraction in which life has become communicable,

and L = longevity of civilization.

The existing estimates for N, which vary between 10^6 to 10^8 years, indicate that the distance between two technically advanced civilizations could be anywhere between 10 to 1000 parsecs, considering the known density of stars.

According to Rao, the search for life can be carried out, in principle, using either remote or *in situ* observations. Remote observations include optical (infrared, visual, uv) as well as radio techniques. A large (3 meter) telescope in space can detect planetary systems as far away as 17-20 ly. Radio technique is the most promising one to carry out remote exploration, particularly around 1400-1600 MHz, associated with the line emissions from hydrogen and OH radicals.

The first major study to carry out *in situ* observation is Project Daedalus which aims at accomplishing a fly-by mission to Barnard's star with a velocity of about 0.15 c. Various techniques like nuclear pulse propulsion, controlled fusion rockets, interstellar ramjets etc were discussed by Rao in sufficient detail.

Yash Pal discussed the problems of Interstellar Communication. He thought that the radio technique is probably the simplest one to detect extraterrestrial intelligence as advanced civilizations like ours elsewhere must be putting out a large amount of radio energy into space in the form of radio signals, TV, radar etc. According to Yash Pal, a 100 kW transmitter beaming from a distant planet 400 ly away can be detected easily by radio telescope such as the one at Arecibo.

He presented an examination of the radio noise spectrum and concluded that the region between 1 and 5 GHz seemed to be the only low noise region, the bulk of the noise in this region being contributed by the microwave background radiation at 3°K.

As the most abundant element hydrogen has its spectral line signature at 1420 MHz and the hydroxyl lines cluster around 1680 MHz, he felt that it was reasonable to expect that "Any intelligent civilization to choose. their transmission in this low noise narrow region of 1400-1600 MHz which is often termed as the "waterhole".

N.A. Narasimham discussed "Spectral Studies and Identification of Interstellar Molecules in the Optical and Microwave Regions".

He reviewed the early work of Dunham and Adams in characterising Na, Ca, K, Fe, Ca^+ and Ti^+ from the sharp interstellar absorption lines around 4000 Å.

The cosmic abundances of H, He, C, N and O suggest the presence of simple diatomic molecules such as CH and CN in the interstellar space and these were in fact detected very early.

Narasimham discussed the application of radio telescopes, in the discovery in the cm and mm wave-length regions of around forty interstellar molecules. This list consists of simple molecules like CO, CS, SO, HCN, H_2CO, HNCO and some more complex molecules. The role of laboratory studies in the microwave and the infrared was emphasised as this will help in providing data for comparison of still undiscovered interstellar molecules.

Narasimham concluded that "The optical telescope, both in the terrestrial observations and in the orbiting satellites can be equipped with Fourier transform spectrometer to scan the infrared region as well. This can become a good compliment to cm and mm wave spectroscopy for the identification of interstellar molecules".

In the session dealing with Composition of Planets and Meteorites, N. Bhandari spoke on 'Planetary Compositions and the Evolution of their Atmospheres', D. Lal on 'Volatiles in the Solar System' and C. Ponnamperuma on 'Organic Matter in Meteorities'.

Bhandari presented the recent information on the planetary compositions obtained from Venera missions to Venus, Viking Landers on Mars, Pioneer fly-by of Jupiter and samples returning from Apollo and Luna missions to moon. These have not only given details of planetary surface composition, geomorphology, atmospheric constituents and geological history but have also led to some definitive scheme of evolution of the solar system. Bhandari presented some of these in his discourse. He compared the biological evolution on Earth and its absence on Venus and particularly Mars which point to the fact that the geological evolution of these planets has been significantly different. He pointed out that several questions are crucial to the origin of life on planets, which are chemically similar to start with and are subjected to the same interplanetary processes but evolve differently depending upon several factors viz. temperature cycles, proximity to the Sun, gravitational escape tne of atmospheric constituents and volcanic activity. Bhandari liked to ask the questions:

1. Was there ever life on Mars?
2. Did life on earth have extraterrestrial precursors?
3. Can any of these planets now support life and if so of what kind?

He concluded his talk with the remaks. : "The origin of meteorites, comets, protoplanets and the processes responsible for condensation of solar nebula, together with constraints imposed by absence of life bearing or generating molecules, when understood, will lead us to see the existence of life elsewhere in the universe in the correct perspective".

Lal examined the questions relating to the origin of volatiles (and organic matter) in the solar system.

He discussed the recent results from the examination of meteorites and lunar samples and from the reconnaisance of planets. The carbonaceous chondrites, the most primitive component of the solar system, contain refractory high temperature condensates which have exciting isotopic anomalies, e.g., the presence of nucleosynthetic Al^{26} along with decay product Mg^{26}.

Lal discussed the complexity of processes leading to the formation of carbonaceous chondrites and also presented the classification of some of the important asteroids.

He then compared the volatiles in Mars and Earth and concluded that Mars like Earth may have received its volatiles in the final stages of accretion.

Lal concluded his presentation with the following remarks :

"Considering the above facts and the recent speculation made by Whipple, comets and asteroids may, in fact, be the most important source of life giving elements and water on Earth. The early atmospheres of Earth and inner planets may have been blown away by the solar "gale" in the T-Tauri phase of the Sun".

"It is therefore not known at present whether volatiles including water and the organic compounds were added to the solar nebula along with the "presolar" grains and whether Earth and Mars received appreciable amounts of these from comets. It seems that elucidation of sources of volatiles on the earth may provide important clues to the early life processes".

Cyril Ponnamperuma concluded the session on Composition of Planets and Meteorites by a discussion on the Organic Matter of Meteorites much of which was based on studies from his own laboratory.

He first reviewed the meteorites in the collections around the world, highlighting some of the more recent falls and finds. Of the total collection of over 2000 meteorities, 36 fall into the carbonaceous chondrite category, where the organic matter ranges from 0.5% to 5%.

Ponnamperuma discussed as to how the techniques developed during lunar programme became a boon when samples of Murchison meteorite became available soon after its fall in Australia in 1969. As a result, using techniques like gas chromatography—mass spectrometry unequivocal identification of D and L amino acids in equal amounts and also non-protein amino acids was obtained in the organic matter extracted from the Murchison meteorite. The presence of non-biological aliphatic and aromatic amino acids and the heavy C^{13} value showed conclusively that the Murchison contained organic matter of non-terrestrial origin. There was also a marked similarity with the amino acids synthesised by a spark discharge experiment. Results from Murray and Mighei were also presented which were qualitatively similar to Murchison.

Ponnamperuma suggested that, "The origin of the organic matter in the meteorites may have occurred before the formation of the solar system. Fischer-Tropsch type and other prebiotic processes may have accounted for the synthesis of organic compunds. This mechanism may be a method of preserving organic matter for the planets for further processes".

The next session dealt with laboratory simulation studies related to the "Evolution of Organic Monomers and Polymers under Abiotic Conditions".

M.S. Chadha spoke on Prebiological Synthesis of Oragnic Molecules : Possible Role of Aminonitriles in Chemical Evolution. He reviewed the experimental studies carried out by a number of investigators during the last 20 years which have revealed clearly that under simulated primitive terrestrial conditions a large majority of building blocks (amino acids, bases, sugars) of important biomolecules can be synthesised. From his own experimental work on simulated Jovian atmosphere, he discussed the products which were characterised, resulting from the passage of electric discharge through a mixture of CH_4 and NH_3. The products formed were HCN, ammonium cyanide, alkylnitriles, aminoacetonitrile and its C and N methyl homologs, together with dark red coloured polymeric material. There was strong indication that the monomeric nitriles had participated in the formation of polymeric products. Evidence for the formation of alkylaminopropionitriles, some pyridyl and pyrimidyl type heterocyclics was also obtained, the latter showed resemblance with the heterocyclics found in some carbonaceous chondrites.

The formation of some peptides from amino nitriles was also discussed. In conclusion Chadha said that 'There is now convincing evidence for the formation of a large number of natural and unnatural amino acids, some peptides, nucleic acid bases, nucleosides, nucleotides and oligonucleotides under primitive terrestrial conditions'.

A.S.U. Choughuley then discussed the Role of Formaldehyde and Formic Acid in Chemical Evolution. Formaldehyde and formic acid have both been shown to be formed in simulated probiotic experiments and both have been detected in interstellar space by microwave spectroscopy. The importance of these two molecules in chemical evolution studies was presented.

The importance of HCHO in Strecker synthesis together with NH_3 and HCN to give aminoacetonitrile is well known. Aminoacetonitrile further reacts with HCHO to give methyleneaminoacetonitrile. These aminonitriles on mild alkaline hydrolysis, yield amino acids such as glycine, serine, hydroxymethylserine, iminodiacetic acid, sarcosine and alanine and di-, tri-and tetraglycine.

The formation of sugars and fatty acids during the alkaline condensation of formaldehyde was reviewed and the role of formaldehyde in the formation of imidazole derivatives which are good catalysts in oligomerization of nucleotides and polymerisation of amino acids was also discussed. Evidence for the role of formaldehyde and formic acid in the conversion of glycine to alanine and uracil to thymine was also presented.

This session was concluded by Cyril Ponnamperuma with a discussion on "Condensation Reactions under Prebiotic Conditions". He gave a historical background to the theoretical and experimental studies that have led to the belief that life may be the result of an evolutionary sequence in the universe. The accumulation of organic matter and the generation of replicating molecules are the two factors of prime importance in this sequence. According to Ponnamperuma this must have happened step by step going from the simple to the more complex.

He discussed the results of condensation reactions leading to the formation of macromolecules. Evidence for the synthesis of nucleic acid bases and sugars, of nucleosides, nucleotides and oligonucleotides in his laboratory were presented. The role which various condensing agents may play in condensation polymerization reactions was discussed and the prime importance which polyphosphates and the hydrogen cyanide tetramer may hold in this connection was clearly brought forth.

His concluding remarks hold the key to the type of work which needs to be carried out in future. He said, "Aside from seeking to obtain synthesis of biologically important molecules under conditions which can rationally be called primordial, the general areas of importance are the stability and accumulation of these materials and their eventual organisation into self-replicating macromolecules. Of paramount importance, therefore, is the problem of precellular organisation as it bridges the gap between chemical evolution and biological evolution".

"The problem of precellular organisation still retains its importance and will continue to be one of the most fascinating areas of future investigation. The purpose of further investigation in this area should be to develop rational models for precellular organisation, and devise experiments to test their feasibility under prebiological conditions".

Eigen's recently proposed 'hypercycle' concept on self-organisation of matter and the evolution of macromolecules which may prove to be the cornerstone in our understanding of precellular organisation was discussed in separate sessions by G. Venkataraman, U.N. Singh and N. Parikh respectively.

Venkataraman explained that in Eigen's 'hypercycle' the input consists of chemical and structural information, irreversible thermodynamics and information theory. The output is a possible model for the selection and evolution of information-rich sequences of 'organized' matter from the original 'soup' of energy rich monomers (phosphates, etc.).

The first step is the construction of coupled rate equations of information bearing sequences of digits (nucleotide, or in the next stage, amino acids). These equations take account of formation, survival and mutability (due to errors in template copying). Once the physical constraint of constant total organisation is imposed, the equations become highly nonlinear and exhibit unusual features such as *selection*. If the more realistic constraint of constant influx of basic digits and constant flow of reactants is imposed, the system also exhibits *evolution*. Finally, the theory is refined by taking into account fluctuations, or the inherent stochastic nature of the basic microscopic processes.

Venkataraman concluded by saying that, "The important point is that closed 'hypercycle' of biochemical reactions involving nucleic acids and proteins may well be the clue to actual self-organization. The nucleic acids would provide the code and the complementary instruction for replication, while the proteins provide the required specificity of catalytic coupling, recognition, etc. Such a hypercycle can be shown to possess very sharp selection properties, and to evolve very quickly, in addition to preserving the universality of the code as well as reproducibility. A theory of self-organization that is consistent with the laws of irreversible thermodynamics and that quantifies the concept of information value is thus obtained".

U.N. Singh speaking on the same theme said that "The Eigen's 'hypercycle' concept comprising of (i) information carrier molecules (nucleic acids), (ii) a primitive translational machinary and (iii) a serially coupled closed cycle has been a major breakthrough in the visualization of a primitive *self-reproducing system* exhibiting the Darwinian selection at the molecular level. The relaxation of the stringent constraint demanding high fidelity of the translational machinary in Eigen's model was discussed in the light of nucleic acid-protein interaction as an obligatory selection mechanism".

In the foregoing, a summary of proceedings at the workshop which dealt with astronomy, exploration of outer space, meteorology, chemical evolution and Eigen's concept of selforganisation of matter is given. The rest of the workshop dealt with problems related with chemical, biochemical and biological aspects of evolution of life processes, which will be reviewed elsewhere.

However, the concluding talk of the workshop was by Cyril Ponnamperuma who discussed some aspects of Exobiology. Excerpts from his talk are reproduced below :

If chemical evolution is cosmic in occurrence, indeed it must have led to life beyond Earth. To answer the question "Are we alone in the universe?", two approaches are currently available to us (1) to land a man or an instrument somewhere in the universe and examine the planetary surface for life. With our present technology this would be restricted to our own solar system; (2) to listen to signals from outer space. This approach is based on the idea that there may be civilizations as advanced or more advanced than we are.

In the first instance, our research has been directed to the planet Mars. Preliminary data indicated that although the conditions were hostile and extreme by terrestrial standards, we could not exclude the possibility that microbial life could have adapted itself to the extreme conditions.

The Viking Mission was designed to search for life on Mars. Although some ambiguous results came to us from the three biology experiments, it was clear that there was no organic matter on Mars. One had to conclude reluctantly that the apparent positive results were nothing else but the result of Martain surface mimicking microbial activity.

The Viking Mission gave us an opportunity of testing for the first time a hypothesis. The negative results should not discourage us. Where Mars is concerned, perhaps we should ask the question, not "Is there life on Mars ?", but rather "Was there life on Mars?".

There is no question that sooner or later we have reluctantly to conclude that in our solar system, the Earth is the only place where there is life. However, we have the tools for the further exploration of the universe. Although we cannot as yet pinpoint a planet moving around another sun to be targetted by one of our spacecraft, we can listen to intelligent signals from outer space. Radio astronomy may provide the means of detecting our celestial neighbours. The number of civilizations present in our Galaxy is estimated to be about a million. The various parameters brought together in the equation $N = R f_p n_p f_l f_i f_c L$ to give the number of civilizations has been discussed by Dr. U.R. Rao.

Not all the parameters in this equation are on solid ground since our deductions have to be made from the single example of life which we know - namely terrestrial life. However, careful study of factors such as the origin of intelligence, the evolution of communication and the sociological factors leading to survival of civilizations may give us some solid scientific grounds for a firm assessment of the number of communicable civilizations in our Galaxy.

Ten searches are on the way—six in the United States and four in the Soviet Union. Project Cyclops—a design for a giant array of antenna is on the cards. Before long from someone somewhere in space will come that single word which will become the triumph of exobiology.

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ERRATUM

STUDY OF THE GALACTIC CLUSTER NGC 581 by Ram Sagar and U.C. Joshi

(*Bull. Astron. Soc. India*, **6**, 12, 1978)

p. 12, 1, line 12	**for** of Mermilliod **read** cf. Mermilliod
p. 14, 1, line 12	**for** isted **read** listed
p. 14, 1, last line	**for** hot **read** not
p. 14, 2, Table 3	interchange α and δ in the left upper corner box
P. 16, Table 4, col. 3	**for** $\psi(M_V)$ **read** $\phi(M_V)$