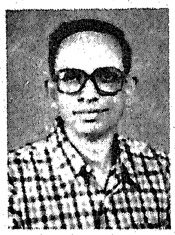
Life : Complexity and Diversity

1. A World in Flux

Madhav Gadgil



Madhav Gadgil is with the Centre for Ecological Sciences, Indian Institute of Science and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. His fascination for the diversity of life has prompted him to study a whole range of life forms from paper wasps to anchovies, mynas to elephants, goldenrods to bamboos.

Evolving patterns of matter and energy gave rise to the cosmos. The earth, itself a dynamic entity, is inhabited by living organisms that have a dialectical relationship with the world around them.

Cosmic Dance

We live in a world in flux. In a world of ever changing patterns. Patterns that change with the time of the day, the season of the year. Patterns that change from place to place. Patterns that have been in flux ever since the cosmos originated with a big bang fifteen billion years ago. In the beginning was pure energy concentrated in an infinitesimally small space. As the cosmos expanded, matter began to crystallize out of this cauldron. First as tiny elementary particles, each on its own, each dancing separately. As things cooled down, the particles linked arms to form atoms. Initially smaller ones, like hydrogen, helium, oxygen, later larger ones, such as iron or nickel. With time these atoms began to form complexes, molecules like those of water, as well as larger entities like crystals and metals.

Slowly matter condensed to form heavenly bodies: nebulae, stars, planets, meteorites. All the while atoms were bumping into each other, linking together to form bigger and bigger molecules. Of all the variety of atoms, carbon and silicon are best at holding hands with each other, and with those of other kinds as well. Like Brahma and Vishnu, our gods of creation and maintenance, they have four arms each. So not only can they form long carbon or silicon chains, but a variety of side chains, with hydrogen, oxygen, nitrogen, even iron or manganese. The chains so formed can twist and wrap around each other, forming balls with a multitude of projections and indentations. Thus is formed an incredible diversity of carbon-containing, or organic, molecules. Molecules predominantly composed of silicon tend to form more regular sheets and three dimensional structures, giving rise to particles of sand and crystals of quartz.

But atoms can hold hands with each other only when the surroundings are cool enough. When things heat up too much they delink, preferring to dance on their own. At extreme temperatures they even lose their shells of electrons - the tiny particles that whirr around the nucleus of each atom. As a result, a large variety of carbon containing molecules can only be formed at moderate temperatures, indeed just such temperatures as we enjoy at the surface of the earth. Not that the rest of the cosmos has no organic molecules; in fact there are some even in the wide open spaces between the stars. Some pretty large organic molecules also occur on meteorites called carbonaceous chondrites. But earth has in abundance one other substance that makes all the difference. This is liquid water. This is because organic molecules move around with the greatest ease when immersed in water. Then they can twist and turn, taking on myriad shapes. And they can really play with each other, zipping and unzipping chains, chopping off a piece here, adding on a piece there. Swimming in water, the organic molecules have let themselves go, eventually coming together to form the truly marvellous structures that living organisms are. Life thus owes its origin to the great good fortune that on the surface of the earth prevail temperatures that permit water to remain for much of the time in its liquid form.

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Dynamic Earth

The earth on which this dance of organic molecules is in progress, is itself a dynamic entity. On it the water is forever in flux, passing between its liquid and vapour forms; giving rise to clouds and rain, rivers and seas. More than two thirds of the earth's surface is today covered by the seas; seas that have been there a long, long time. An average cloud on the other hand survives no more than

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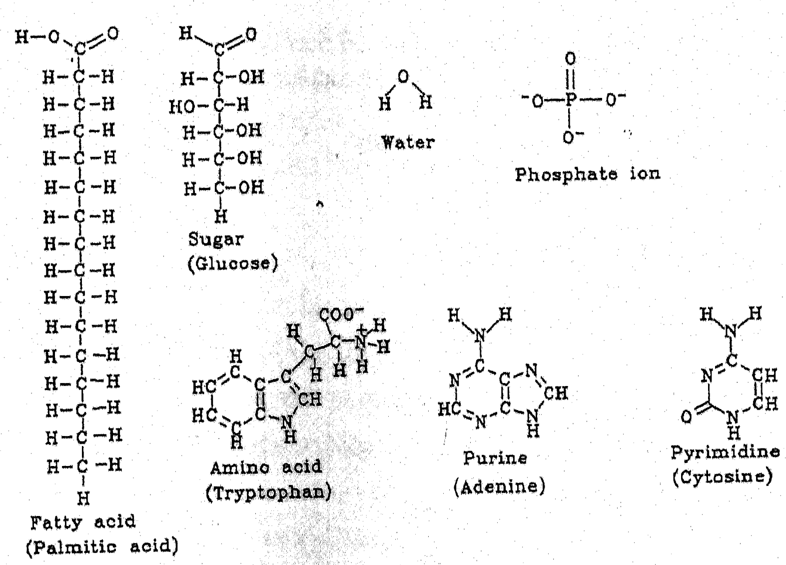
an hour or so; larger collections of clouds persist for at most a few days. But we now know that seas and islands, continents and mountains are also subject to change, albeit on a much slower time scale. For, the continual barrage of rain and wind on the surface wears the land down; and the flux of hot molten rocks in the interior of the earth raises it back again. Even more significantly, this flux of hot molten rocks in the bowels of the earth drives around whole plates of land and ocean floor, so that continents go on forming, splitting, reforming, albeit on a time scale of hundreds of millions of years.

The rich kaleidoscope of patterns of nature that we witness all around us, every moment of our lives, is then a dance of organic molecules, in a watery medium, set in a theatre that is itself changing slowly but irrevocably, all the time. The dance patterns have been changing in all of the four and a half billion years that the planet earth has been in existence. The pace of change quickened a little when life first appeared on the scene three and a half billion years ago. It accelerated further when life invaded land four hundred million years ago. When tool-using ancestors of humans first appeared on the scene two million years ago, there was little reason to believe that the world was getting set for a dramatic increase in the rate of change in the manifold patterns of nature. But that has come to pass, and today we humans are a dominant force governing the variegated mosaic of nature.

Molecules of Life

The most fascinating, the most complex, the most diverse of patterns of nature are the handiwork of living organisms. Living organisms might be thought of as co-operative teams of complex organic molecules that take in matter and energy from their surroundings, and use these to keep themselves in good repair as well as to make more copies of themselves. The set of complex molecules constituting these co-operative teams is ultimately fashioned out of a small number, a few hundred basic building blocks. These include water, phosphate ions and four main types

Building Blocks of Life



of organic molecules: sugars, fatty acids, amino acids and purine and pyrimidine bases. Some of these organic molecules, such as adenine or ribose have 15 to 20 atoms, while others such as palmitic or stearic acid have 50 to 60 atoms. Each such building block is made up of at least three elements, carbon, hydrogen and oxygen and may additionally include nitrogen, phosphorus or sulphur. But these small numbers of a limited variety of atoms are linked to each other in very specific orders. That gives rise to the possibilities of fabricating a great diversity of molecules, sometimes differing only slightly from each other. Thus in amino acids one of the carbon atoms is linked to four distinct entities: H, NH_3^+, COO^- and a longer residue. This allows the formation of two forms which although identical in composition are mirror images of each other *(Figure 1)*. Notably enough all amino acids in living organisms exhibit only one of the mirror images, the L-form. These building blocks can of course be further linked together to form larger, more complex formations. Thus proteins, amongst the most vital of the larger molecules of life, are formed by linking together several amino acids in long chains. Now consider the great variety of such chains that may be formed by choosing one out of twenty amino acids in each position. With just

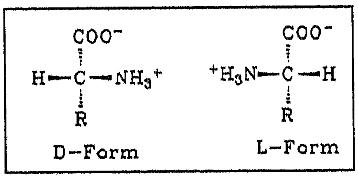


***Figure 1** The D-form and L-form of amino acids are identical in composition but mirror images of each other. All living organisms exhibit only the L-form.*

Table 1 Chemical composition of cells of living organisms

Constituent	Number of atoms per molecule	Estimated number of varieties of each molecule	
		Bacteria	Mammals
Water	3	1	1
Inorganic ions	1-5	20	20
Sugars and precursors	10-30	200	200
Amino acids and precursors	10-30	100	100
Nucleotides and precursors	30-50	200	200
Lipids and precursors	~ 50	50	50
Other small molecules	~ 100	200	200
Polysaccharides	> 1000	100	1000
Proteins	1000- 5000	4000	100000
rRNA	3200- 96000	6	6
tRNA	~ 5000	20	20
mRNA	2500-25000	1000	100000
DNA	10^9-10^{12}	1	20*

**This number varies from species to species.*

two amino acids linked together there are 20 x 20 or 400 possibilities. With three, 400 x 20 or 8000, with four, 8000 x 20 or one lakh sixty thousand. Proteins in fact are made up of tens, if not hundreds of amino acids, making possible millions upon millions of different combinations. The chains of proteins thus formed do not remain as long strings. They fold up, forming complex globular, ovoidal bodies. The shapes of these bodies are governed by the sequence of amino acids in the chain, so that a whole variety of intricate shapes can be generated by just varying the order in which the amino acids are linked one after another. And not only do these larger molecules come in many different, elaborate shapes, they bear on their surfaces intricate patterns of positive and negative electrical charges. Like proteins, other building blocks of life are also linked together in many different ways, but

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each in some precise order to form larger molecules. Thus many sugar molecules form polysaccharides, starches, cellulose, fatty acid molecules to constitute lipids, or along with sugars and phosphates glycolipids or phospholipids. Purine and pyrimidine bases are joined to sugar and phosphate to constitute nucleotides and nucleotides are linked into long chains to constitute nucleic acids.

Each of these molecules, large and small, play a particular role in the co-operative team of the molecules to allow the team to take in matter and energy in appropriate forms, to keep the team in good repair and to make more copies of themselves. This is an elaborate exercise which requires the co-operation of thousands of different molecules. *Table 1* looks at the composition of such teams for one of the most ancient forms of life, bacteria, and one of the most recent, mammals. The diversity of simpler building blocks is essentially the same for bacteria and mammals. The larger molecules however, are markedly more diverse, by one or two orders of magnitude in the case of mammals.

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Once triggered off in the hoary old times three and a half billion years ago, the dance of life has become more and more elaborate, drawing in an ever larger number and variety of actors. And the stage over which they have been dancing has also gone on expanding, beginning with shallow seas, invading depths of ocean, land, air and finally outer space.

Suggested Reading

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