Orig Life Evol Biosph (2007) 37:303–307
DOI 10.1007/s11084-007-9104-3

Basic Questions About the Origins of Life: Proceedings of the Erice International School of Complexity (Fourth Course)

Pasquale Stano · Pier Luigi Luisi

Received: 16 April 2007 / Accepted: 16 April 2007 /
Published online: 30 June 2007

Keywords Origins of life · Evolution · Protocells · Theoretical models

Foreword

This Special Issue of Origins of Life and Evolution of Biospheres contains in more detailed form the oral contributions presented at the 4th Course of the International School of Complexity, hold in Erice (Italy) from 1 to 6 October 2006. Alan Schwartz generously offered this space to record the various "answers" to the Basic Questions on the Origins of Life, given by the participants. The Erice meeting was characterized by a novel format: speakers were not requested to illustrate their own work as is usually the case. On the contrary, it was expected that each speaker provides an answer or a comment to a specific question/statement, chosen from the list of nine given below. As with all innovations, the new format was only partially successful, but a considerable number of contributions matched well with the spirit of the event. Considering the originality of the format, we are pleased with the current collection of papers presented in this Special Issue, also in view of their scientific quality. Some of the questions/ statements were given in a provocative fashion, and in fact several authors actually contradicted them, often providing opposite viewpoints and arguments on the basis of theoretical or experimental findings. This Special Issue shows a considerable diversity both in form and length, but beyond this heterogeneity, the reading of it already gives an idea of the depth and complexity of the questions which are still unanswered in the field of the origin of life. To conclude this foreword, and before illustrating the Basic Questions proposed in Erice, we

P. Stano
Research Centre "Enrico Fermi",
Compendio del Viminale, 00184 Rome, Italy

P. Stano · P. L. Luisi (✉)
Department of Biology, University of RomaTre,
Viale G. Marconi 446, 00146 Rome, Italy
e-mail: luisi@mat.ethz.ch

P. Stano
e-mail: stano@uniroma3.it

would like to thank all the participants and the speakers. Thanks to their efforts and kindness, the Erice meeting was a profitable event to exchange ideas, comments, stimulating scientific discussion, and to build a community. We are also very grateful to the “Ettore Majorana” Foundation and Centre for the Scientific Culture, that has hosted and supported the meeting; Mrs. Fiorella Ruggiu, the Manager of the Centre, with all her team, is particularly acknowledged for her precious assistance in organizing the event.

Basic Questions About the Origins of Life

Below is a series of statements and/or questions related to the origin of life. Some of them are presented in a provocative form just to foster a more lively discussion. About 50 scientists (from 18 countries), most of them speakers, contributed to a fruitful debate, which – however – was not meant to find a definitive answer to each question, but only to elicit critical thinking. The outcome was a fruitful meeting, whose atmosphere improved by virtue of the nice framework of Erice.

Question 1. Basic Questions About the Origin of Life

1.1 On Prebiotic Low Molecular Weight Compounds

Many low molecular weight compounds have been produced under alleged prebiotic conditions. Generally, they can be considered products under thermodynamic control (formed by “spontaneous” reactions because they are the most stable products under the given conditions). The “free ticket” of thermodynamic control is however not sufficient: if a chemist is given all these compounds in any amount he wishes, he would be unable to make life. For making life, one needs a series of additional reactions and products under kinetic control – enzymes and nucleic acids are not with us because they are the most stable chains. Thus, the origin of life can be traced back to the origin of kinetic control. Do you agree with this statement; and how would you envisage the prebiotic evolutionary bridge between thermodynamic and kinetic control?

1.2 On Contingency vs. Determinism

The proteins (or nucleic acids) existing on our Earth correspond to an infinitesimal part of the theoretically possible sequences – the ratio between possible and existing structures corresponds more or less to the ratio between the space of the universe and the space occupied by one hydrogen atom. The above ratio can be interpreted as an indication that our “few” proteins have not been selected primarily because of distinctive properties (such as thermodynamic or thermal stability, solubility, particular kinetic processes of formation etc...) – but rather due to a most significant contribution of the vagaries of contingency. Do you agree with this statement, and with its corollary, that then life on our Earth, which is based on these “few” proteins, is not an obligatory pathway, but is largely based on contingency?

Question 2. On Astrobiology

2.1 What Do We Learn From Astrobiology?

The compounds found in meteorites and the cosmos correspond to thermodynamically stable products, synthesized under prebiotic conditions and are therefore of great significance to the origin of abiotic organic compounds on our Earth. The fact that, until now, no oligopeptides or nucleotides have been detected in cosmic material may signify that these oligomers do not tend to form spontaneously. Thus, what we learn from cosmic products is of limited interest regarding macromolecular prebiotic molecular evolution. Do you agree with this statement, and where would you see than the importance of astrobiology?

Question 3. On Macromolecular Sequences

3.1 How to Make Prebiotically Long Hetero-Peptides or Hetero-Nucleotides?

There are no or rather scanty reports in the literature on how to make under prebiotic conditions long – say 30 residues – specific sequences of co-oligopolypeptides (or polynucleotides) in many identical copies containing say five to six different amino acid residues or three to four bases (the Merrifield method cannot be considered a prebiotic method). Methods for homo-polypeptides (chains containing only one type of residue) have been described, but they are in principle not valid for mixtures of different amino acids – as all rules of copolymeration teach us. Random polymerisation of mixtures of amino acids (which we also we do not know how to make under prebiotic conditions) would produce a wild mixture of different chains, with a circa zero probability to make two identical chains. Do you agree then that we do not know – neither conceptually nor experimentally – how to make macromolecular sequences in many identical copies under prebiotic conditions? And if it so, would you not conclude that the bottom-up approach to the origin of "our" life is made impossible by the very definition of contingency?

Question 4. On Chirality

4.1 No Longer a Problem?

The origin of homochirality in nature is usually debated in terms of two opposite views. According to a deterministic (ex-lege) approach, one of the two enantiomers has a lower intrinsic energy and therefore a greater probability of occurrence. The alternative is a stochastic process, according to which the selection of one enantiomer over the other out of a racemate was determined by contingency. From recent experiments, it appears that the breaking of symmetry may be achieved rather easily in the laboratory, possibly under prebiotic conditions. Do you agree then with the view, that the origin of homochirality in nature "is no longer a problem"?

4.2 Prior to the Onset of Macromolecules, or After?

Was homochirality in nature implemented originally at the level of bio-monomers; or only after, namely at the level of the separation of diastereomeric macromolecules originated from racemic bio-monomers? (some authors assert that it is easier to physically separate diastereomeric macromolecules than enantiomeric monomers).

Question 5. On the RNA-World

5.1 On the Impact of the RNA-World on the Origin of Life

There is little doubt that the RNA-world has written some of the most significant and outstanding pages of modern molecular biology – and also, quite generally, shows the importance of macromolecular evolution. However, the importance and success of the RNA-world is restricted to the field of synthetic biology, whereas its impact in the field of the origin of life it is negligible. The question “who/what made RNA?” is in fact still unanswered and, presently, no generally accepted routes to the prebiotic synthesis of mononucleotides have been described, nor their prebiotic 3′–5′ stereospecific polymerisation, let alone the question of the prebiotic synthesis of specific long RNA sequences in many identical copies. Do you agree with these statements, and in general with the point, that we have learned very little or nothing about the origin of life from the RNA-world?

5.2 On the Chemical Reality of the RNA-World

There is a lot of emphasis in the RNA literature about a possible self-replicating RNA as the primary motor for the origin of life. However, when one puts chemical constraints to this view, one realizes that self-replication cannot be achieved by one single molecule (it needs at least two), and generally for any workable chemical system one needs RNA local concentrations of at least femtomoles – which still means billions of identical copies of this compounds (and larger concentrations of the mono-nucleotides). Do you agree with this statement, and with the corollary that even in such a hypothetical scenario, such amounts of RNA can only come from an active previous cellular metabolism?

Question 6. On the Genetic Code

We have not yet reached a generally accepted view on how the genetic code might have originated. Models that have been presented are generally theoretical scenarios without reliable experimental proof. It appears indeed to be a very complex machinery. On the other hand, some recent studies may indicate that the genetic code may be as old as 4 billion years. Is there anything solid that we can actually state at the moment, on the origin of the genetic code? Has it sense to invoke a genetic code prior to the onset of cellular life?

Question 7. On Early Cells

The simplest cells on our Earth contain at least 500–600 genes, and more generally several thousand. This observation elicits the question, whether this high complexity is really necessary for the simplest form of cellular life, also in view of the fact that early cells in the origin of life and evolution could not have been as complex as modern cells. This would imply that the first early cells were alive (although perhaps in a kind of “limping” life form) with a much smaller number of genes. This, in turn, results in a the possibility of constructing in the laboratory, models of early cells, displaying a kind of primitive cellular life (self-maintenance + self-reproduction + evolvability), based on a number of genes which is one order of magnitude smaller than the present day simplest cells. Say a living cell with 30–40 genes. Do you believe that this is indeed a possibility?

Question 8. On Theoretical Models of the Origin of Life

There are many theoretical models of the origin of life which are based on notions of complexity. Particularly well known, and very often cited, is, for example, the model developed by Stuart Kauffman on the spontaneous origin of catalytic networks. One can say, however, that this and other theoretical models have had very little influence on the experimentalists in the field of the origin of life, mostly due to the fact that they have never been observed in the real world of organic chemistry. Do you agree?

Question 9. On Artificial Life

Artificial life deals with life as it might have been, and researchers involved in this field aim to create forms of life which are different from "our" life based on DNA and proteins. Up until now these efforts have not been very successful, and it almost appears that there are no forms of life simpler that "our" life. Do you have data to counteract such a (rather negative) statement; and do you accept the notion that alternative forms of life (still within the general category of metabolism + self-reproduction + evolvability) may be possible with different chemical systems?