International Journal of Astrobiology 16 (1): 10–13 (2017)
doi:10.1017/S1473550415000427

Polypeptide formation on polar mineral surfaces: possibility of complete chirality

Malcolm E. Schrader

Institute of Chemistry, Hebrew University of Jerusalem, Jerusalem, Israel e-mail: schrader@mail.huji.ac.il

Abstract: In the present work, it is shown that thermodynamically feasible polymerization of cyanomethanol, which can be formed from formaldehyde and hydrogen cyanide, can lead to synthesis of polypeptides as well as to the previously reported synthesis of RNA. If the polymerization takes place on a one-dimensional feature of a mineral, such as for example a crack on its surface, the concept of quasi-chirality is introduced to describe the adsorbed polypeptide. This, in principle, would lead to formation of proteins that are completely homochiral in their alpha carbon groups. The concept of quasi-chirality can also be introduced in the condensation of glycine under similar conditions to form a polypeptide. This again leads to proteins completely chiral in their alpha carbon groups.

Received 11 August 2015, accepted 1 October 2015, first published online 23 November 2015

Key words: chirality, cyanomethanol, prebiotic synthesis, proteins, polypeptides, RNA.

Introduction

In addition to the synthesis of RNA (Schrader 2009), a cyanomethanol intermediate could also react along a different pathway, leading to the thermodynamically feasible synthesis of polypeptides, the backbone of protein molecules. The cyanomethanol intermediate was postulated as formed, with thermodynamic feasibility, from addition of HCHO and HCN (Schrader 2009). The latter two molecules, in turn, have been calculated as formed from photolysis of a 'slightly reducing' atmosphere to which HCN has been added (Mukhin 1974; Pinto *et al*. 1980; Zahnle 1986; Ferris 1992; Hennet *et al*. 1992) This synthesis of polypeptides could be regarded as one solution to the 'chicken and egg' problem, i.e. which originated first, RNA (Gilbert 1986; Ferris 2005) or proteins. The present hypothesis has them originating independently from the same molecule.

$$\begin{array}{c}\text{Adenosine} \rightarrow \text{RNA}\\ \uparrow\\ \text{Cyanomethanol}\\ \downarrow\\ \text{Polypeptides} \rightarrow \text{Proteins}\end{array} \qquad [1]$$

Results

Polypeptides from cyanomethanol

The cyanomethanol could reasonably react in one of two ways to yield a polypeptide, as follows.

$$\mathrm{N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH + N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH + N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH}$$

$$\downarrow \qquad [2a]$$

$$\mathrm{N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}\overset{O}{\overset{\|}{C}}{-}\underset{H}{N}{-}\overset{H}{\underset{H}{C_\alpha}}{-}\overset{O}{\overset{\|}{C}}{-}\underset{H}{N}{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH}$$

Here, in the first proposed mechanism, the carbon of the CN in the second molecule from the left detaches from its alpha carbon and unites with the alpha carbon of the molecule to the left, while picking up the O atom. The polymerization is straight addition, with no loss of water molecules.

In mechanism 2, the CN carbon in the second molecule from the left remains attached to the alpha carbon, while the N atom of that molecule detaches and enters the alpha carbon of the first molecule, whose oxygen then moves to the second molecule alpha carbon.

$$\mathrm{N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH \cdots N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH \cdots N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH}$$

$$\downarrow$$

$$\mathrm{N{\equiv}C{-}\overset{H}{\underset{H}{C_\alpha}}{-}\underset{H}{N}{-}\overset{O}{\overset{\|}{C}}{-}\overset{H}{\underset{H}{C_\alpha}}{-}\underset{H}{N}{-}\overset{O}{\overset{\|}{C}}{-}\overset{H}{\underset{H}{C_\alpha}}{-}OH} \qquad [2b]$$

In Tables 1 and 2, the energy required to break all bonds that disappear, and form new bonds that appear, during reaction, is compared for mechanism 1 as compared with mechanism 2. The difference between those disappearing and appearing should be the same in each case. However, the magnitudes of total breaking and forming could be different for each mechanism.

Thermodynamic feasibility

The total enthalpy change in Tables 1 and 2 are, as expected, the same within the accuracy of the method. Their negative value shows that the reactions are thermodynamically feasible in terms of enthalpy.

Comparing the details of 1 to 2, however, it is seen that stronger bonds must be broken for the reaction to proceed via mechanism 1 than mechanism 2. This implies that the activation

Table 1. *Bond energies of cyanomethanol polymerization for mechanism 1 (kJ mole^{-1})*

Breaking energy		Forming energy	
C−OH	376.2	CH_2−CO	301.0
C≡N	888.7	CO−NH	304.3
CH_2−OH	424.3	NH−CH_2	304.3
N≡C−CH_2	398.3	C=O	735.7
		N−H	413.0
		Amide resonance	83.6
Total	2087		2142

The bonds breaking or forming are denoted by a space on each side and the colour red.

energy for mechanism 2 is probably significantly lower than that for 1. Consequently, we assume that mechanism 2 holds true in all cases.

Adsorption to minerals

Background

The soup theory has been the most popular approach to initial formation of biopolymers from small atmospheric molecules (Oparin 1938; Miller 1953, 1955). This approach however, was, from its inception, considered to have a major flaw of the difficulty of condensation in a medium where hydrolysis is favoured. In fact, the free energy of the reaction of two amino acids to yield a peptide

$$2RCH(NH_2)COOH \rightarrow RCH(NH_2)COC(R)NH_2COOH + H_2O$$

has been estimated as high as 4 kcal per mole in favour of hydrolysis (Martin 1998; Rimola *et al*. 2004). The excess of water in the medium magnifies this effect.

To help overcome this and other problems in the soup approach, a parallel approach has been developing for over half a century. This approach has the soup in contact with a solid state adsorbent which can possibly catalyse the reactions, provide some protection from degradation from ultraviolet radiation (penetrating an atmosphere that did not as yet contain an ozone layer), and possibly provide chirality by some means. Goldschmidt, in 1945 (Hazen 2006) suggested adsorbing the monomers to right-and left-handed quartz crystals to resolve racemic mixtures into their enantiomers (Goldschmidt 1952). Bernal, in 1949 (Hazen 2006), suggested adsorption to clay minerals which have a large surface area and may act as catalysts for polymerization.

Lahav *et al.* (1978) found small amounts of biopolymers, resembling proteins, formed on clay minerals on exposure to amino acids. Ferris & Ertem (1993) brought about synthesis of RNA using clay as a substrate. Hill *et al.* (1998) investigated polymerization on rocks and obtained results indicating the reaction proceeded to some extent (Liu & Orgel, 1998). Schrader (2009) suggested carrying the concept, of exposure of monomers to solid adsorbents, to an extreme, by avoiding a soup altogether. The monomers were assumed to be carried by raindrops (Zahnle 1986) onto phosphate containing minerals (Schrader 2009) on Earth, which acted as a chromatographic column with RNA as the final result (Schrader 2009).

In addition to its other advantages, adsorption of monomers or polymers to mineral surfaces holds the possibility of establishing chirality in the adsorbate. Investigation along those lines has centred largely on the possibility of chirality in the substrate mineral, transferring its chirality to the biopolymer, by preferentially adsorbing one or another of the enantiomers from a racemic mixture.

Hazen states 'Thus, researchers have invoked two broad categories of symmetry-breaking phenomena to explain life's chiral excess (Bonner 1991, 1992, 1995; Palyi *et al*. 1999). Some authors claim that an important philosophical distinction exists between deterministic models of life's chirality (i.e. that some intrinsic feature of the Universe inevitably leads to preferential selection of left-handed amino acids) versus a chance local selection of left or right (i.e. life might have formed either way through local stochastic processes)'.

In this paper, I accept the stochastic explanation without ruling out the possibility of an intrinsic feature such as, for example, the counter clockwise rotation of objects in the Solar System.

Nevertheless, the traditional theoretical approach to evolution in its biological phase has often been insistence on a stochastic explanation. For example, Mayr (1982) states that the facts of biological evolution contain five requisites, one of which is that all bio-evolution emanates from a single source (Schrader 2006). Another example is the sudden evolutionary appearance of eukaryotes after a billion years or so of prokaryote domination. The origin of this has been attributed to a single-cell change (Lane 2011). This of course does not prove that the same principle must be present in chemical evolution, but it certainly must be considered. On this subject, Hazen states 'Advocates of mineral induced handedness suggest that life's origin was a local molecular event, not dictated by global averages'.

The nearly universal approach that utilizes the method of surface (adsorbent) chirality has been, until the present, to start with completely racemic products and from there on to engage in what is termed 'symmetry breaking'. For example, Hazen (2001) and Hazen & Sholl (2003) demonstrated small selective adsorption of D-and L-amino acids on the chiral 'scalenohedral {214} type crystal faces'. In nature, slight preference for l protein fragments over the d form has been found in the Murchison meteorite. Investigation of these approaches to the role of minerals in aiding the formation of chiral biological molecules is most worthwhile and should be continued.

An innovative variation of the above approaches has been the suggestion of J.V. Smith (1998), who invokes the principle of low dimensionality to propagate L or D forms into biomolecules. He assumes that the monomers are all hydrophobic and require a hydrophobic, or as he states it, an organophilic, mineral surface for adsorption of the monomer. For this purpose, he suggests a molecular sieve called silicalite, who's surfaces consist of Si–O–Si groups which are hydrophobic (Schrader & Yariv 1990; Yariv 1992), i.e. organophilic (Schrader 1968). This sieve contains numerous channels, some of which are tenths of a nanometre in diameter, with

https://doi.org/10.1017/S1473550415000427 Published online by Cambridge University Press

Table 2. *Bond energies of cyanomethanol polymerization for mechanism 2 (kJ mole^{-1})*

Breaking energy		Forming energy	
H_2C-OH	376.6	O=C	736.3
$N\equiv C-CH_2$	889.5	O=C−NH	304.6
CH_2O-H	424.7	N−H	413.4
		H_2C-NH	304.6
		Amide resonance	83.6
Total	1690.8	Total	1796.6

The bonds breaking or forming are denoted by a space on each side and the colour red.

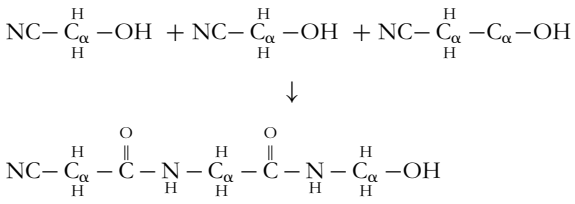
hydrophobic walls. He states, without going into details, that monomers adsorbed in these channels should propagate L or D biopolymers.

With respect to the problem of propagation from a single site, he states 'Although all biochemical life might have developed from a single left-handed chance event that has essentially zero probability in terms of conventional ideas for chemical synthesis, multiple events of high probability are preferred, of which one event may have been the actual trigger.'

The quasi-chiral approach

I present in this paper, an alternative low-dimensional approach which describes molecular adsorption on a mineral surface which can lead to complete L or D chirality for all proteins. Instead of channels such as in zeolite, a crack on a solid mineral surface is sufficient. The mineral surface should have polar groups, such as in phosphate minerals, and the monomers have polar groups, such as CN and OH of cyanomethanol, or NH_2 and COOH of glycine.

The ubiquitous chirality of proteins is present in the alpha carbon group of each segment, which in this approach, is already present in the monomer. To explain this, I introduce the concept of the quasi-chiral monomer. The principle of this method, is to start with a non-chiral molecule such as $CH_2(CN)OH$ (cyanomethanol), or alternatively $HCHNH_2COOH$ (glycine) either one of which on adsorption becomes a quasi-chiral molecule. The reason they can fulfil this function, is that each alpha carbon has two hydrogens that, after adsorption, are no longer equivalent. One H is attached to the surface, while the other projects outward. The polypeptide formed is now quasi-chiral due to non-equivalence of H atoms. Ultimately, after formation of the long-chain polypeptide, each protruding H is replaced by an R group to form a real adsorbed protein where all the alpha carbons have the same chirality. The R groups can be of a wide variety and can be different for each alpha carbon. Equations depicting this phenomenon can be written as follows:



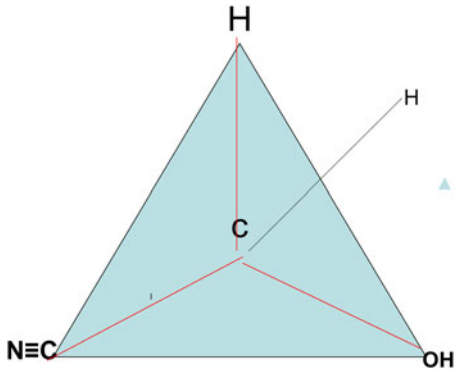


Fig. 1. Adsorbed cyanomethanol.

A detailed look at the adsorption, diagrammatically (Fig. 1), is as follows: The monomer is a tetrahedron, a triangle side of which rests on a surface, with a group or atom in each of the three corners of the triangle and a fourth corner perpendicular to the plane of the surface. A carbon atom is in the middle above the plane of the surface.

Since the surface and its crack, are polar, both the CN and OH groups, which are polar, will be in the triangle adsorbed to the surface crack. Thus, the third corner in the crack of the surface is occupied by an H atom, and the other H atom, its bond described by a dotted line, is perpendicular to the surface. In terms of future reaction then, one H is on the surface relatively inaccessible, while the other protrudes and is accessible. Therefore, the two hydrogens are no longer equivalent. The adsorbed cyanomethanol monomer is then here called quasi-chiral.

In more detail, the following is a possible configuration:

Consider a partially opened book. The interface between the two exposed pages represents a more or less one-dimensional space. Now, cut one of the page segments in half, horizontally. This portrays a crevice in a mineral surface, given diagrammatically in Fig. 2.

The two polar groups in cyanomethnol will now adsorb to the bottom of the crevice. The H of the triangle containing the adsorbed polar groups may now be assumed to lean back to the long side of the joined surfaces which form the crevice. The other surface forming the crevice is short, and the H perpendicular to the triangle protrudes, and is available for reaction. Or, alternatively, the bottom of the crevice is regarded

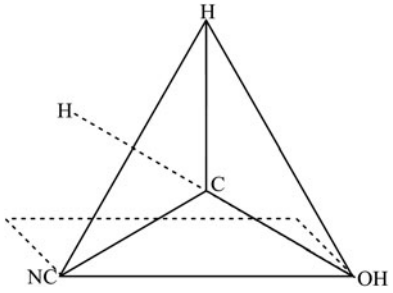
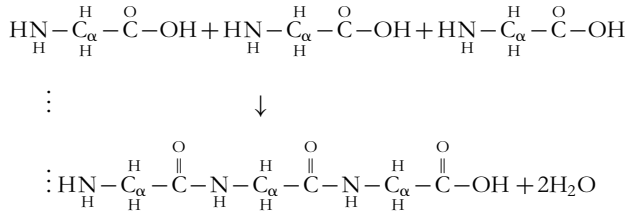


Fig. 2. Adsorption in crevice.

https://doi.org/10.1017/S1473550415000427 Published online by Cambridge University Press

as flat, its walls small, and the perpendicular H extends out of the crevice. Ultimately, R (organic) groups replace the protruding H's, and the alpha carbons all remain completely L or D.

The same considerations may be applied to the conventional proposed mechanism of repeated condensation of amino acids, provided that the condensing monomer is glycine and the condensation takes place in a crevice where removal of the H_2O product can take place. The equations are as follows:



[3]

The polar groups of the monomer are now COOH of glycine instead of the OH of cyanomethanol and the NH_2 of glycine instead of the CN of cyanomethanol.

Conclusions

It is shown that the reaction leading to RNA synthesis via cyanomethanol, can branch off to form polypeptides by the polymerization of cyanomethanol.

The same result can be obtained from condensation of an amino acid provided that the amino acid is glycine.

If the polymerization of cyanomethanol (or condensation of glycine) occurs in a crack on a polar surface, then the resulting polypeptide can be completely chiral in the alpha carbons. This ultimately can lead to chiral proteins in the alpha carbons for any reaction with side chains.

The mechanism subscribes to the approach that life's origin was a local molecular event, in line with the traditional approach of evolutionary theory that requires single source origin. Thus, even for chemical evolution, as well as subsequent biological evolution, many factors must fall into place, spatially and temporally, for it to succeed. A low probability may therefore have to be assigned for its occurrence, even on an Earth-like planet.

Acknowledgements

This paper was presented in part at the 27th Annual Meeting of the Israel Society for Astrobiology and the Study of the Origin of Life, 1 December, 2013. The author thanks Professor Shmuel Yariv and Dr Isaak Lapides for their support.

References

Bonner, W.A. (1991). The origin and amplification of biomolecular chirality. *Orig. Life Evol. Biosph.* **21**, 59–111.

Bonner, W.A. (1992). Terrestrial and extraterrestrial sources of molecular homochirality. *Orig. Life Evol. Biosph.* **21**, 407–420.

Bonner, W.A. (1995). Chirality and life. *Orig. Life Evol. Biosph.* **25**, 59–111.

Ferris, J.P. (1992). Chemical markers of prebiotic chemistry in hydrothermal systems. *Orig. Life Evol. Biosph.* **22**, 109–134.

Ferris, J.P. (2005). Mineral catalysis and prebiotic synthesis: montmorillonite-catalyzed formation of RNA. *Elements* **1**, 145–149.

Ferris, J.P. & Ertem, G. (1993). Montmorillonite catalysis of RNA oligomer formation in aqueus solution- a model for the prebiotic formation of RNA. *J. Am. Chem. Soc.* **115**, 12270–12275.

Gilbert, W. (1986). The RNA world. *Nature* **319**, 618.

Goldschmidt, V.M. (1952). Geochemical aspects of the origin of complex organic molecules on the earth, as precursors to organic life. *New Biol.* **12**, 97–105.

Hazen, R.M. (2001). Life's rocky start. *Sci. Am.* **284**(4), 63–71.

Hazen, R.M. (2006). Mineral surfaces and the prebiotic selection and organization of biomolecules. *Am. Mineral.* **91**, 1715–1729.

Hazen, R.M. & Sholl, D.S. (2003). Chiral selection on inorganic crystalline surfaces. *Nat. Mater.* **2**, 367–374.

Hennet, R.J.-C., Holm, N.G. & Engel, M.H. (1992). Abiotic synthesis of amino acids under hydrothermal conditions and the origin of life: a perpetual phenomenon. *Naturwissenschaften* **79**, 361–365.

Hill, A.R. Jr., Bohler, C. & Orgel, L.E. (1998). Polymerization on the rocks: negatively charged amino acids. *Orig. Life Evol. Biosph.* **28**, 227.

Liu, R. & Orgel, L.E. (1998). Polymerization on the rocks: beta amino acids and arginine. *Orig. Life Evol. Biosph.* **28**, 245–257.

Lahav, N., White, D. & Chang, S. (1978). Peptide formation in the prebiotic era. Thermal condensation of glycine in fluctuating clay environment. *Science* **201**, 67–69.

Lane, N. (2011). Energetics and genetics across the prokaryote-eukaryote divide. *Biol. Direct.* **6,** 35.

Martin, R.B. (1998). Free energies and equilibria of peptide bond hydrolysis and formation. *Biopolymers* **45**, 351–353.

Mayr, E. (1982). *The Growth of Biological Thought*. Harvard University Press, Cambridge.

Miller, S.L. (1953). A production of amino acids under possible primitive earth conditions. *Science* **117**, 528.

Miller, S.L. (1955). Production of some organic compounds under possible primitive earth conditions. *J. Am. Chem. Soc.* **77**, 2351–2361.

Mukhin, L.M. (1974). Evolution of organic compounds in volcanic regions. *Nature* **251**, 50–51.

Oparin, A.I. (1938). *The Origin of Life*, Macmillan, NY. S. Morgulis (trans.).

Palyi, G., Zucchi, C. & Caglioti, L. (eds) (1999). *Advances Biochirality*, Elsevier, NY.

Pinto Joseph, P., Gladstone, G.R. & Yung, Y.L. (1980). Photochemical production of formaldehyde in earth's primitive atmosphere. *Science* **210**, 183–185.

Rimola, A., Ugliengo, P. & Sodupe, M. (2004). Formation versus hydrolysis of the peptide bond from a quantum mechanical viewpoint: the role of mineral surfaces and implications for the origin of life. *Int. J. Mol. Sci.* **10**(3) 746–760.

Schrader, M.E. (1968). Ultrahigh vacuum techniques in the measurement of contact angles. Methylene iodide on glass. *J. Colloid Interface Sci.* **27**, 743–750.

Schrader, M. E. (2006). Is life on Earth accidental? Natural selection and the second law of thermodynamics. In: *Life as We Know it*, ed. Seckback, J., Springer, Dordrecht, pp. 163–178.

Schrader, M.E. (2009). The RNA world: conditions for prebiotic synthesis. *J. Geophys. Res.* **114**, D15305.

Schrader, M.E. & Yariv, S. (1990). Wettability of clay minerals. *J. Colloid Interface Sci.* **136**, 85–94.

Smith, J.V. (1998). Biochemical evolution. 1. Polymerization on internal organophilic silica surfaces of dealuminated zeolites and feldspars. *Proc. Natl. Acad. Sci. USA* **95**, 3370–3375.

Yariv, S. (1992). Wettability of clay minerals. In *Modern Approaches to Wettability: Theory and Applications*, ed. Schrader, M. E. & Loeb, G. I., Plenum Press, NY.

Zahnle, K.J. (1986). Photochemistry of methane and the formation of hydrocyanic acid (HCN) in the Earth's early atmosphere. *J. Geophys. Res.* **91**, 2819–2834.