SLAC-PUB-1957
June 1977
(T/E)

ON THE ORIGIN OF BIOLOGICAL CHIRALITY VIA NATURAL BETA-DECAY*†

H. Pierre Noyes
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

William A. Bonner
Department of Chemistry
Stanford University, Stanford, California 94305

J. A. Tomlin
Department of Operations Research
Stanford University, Stanford, California 94305

(To be published in Origins of Life)

*Work supported in part by the National Aeronautics and Space Administration and by the Energy Research and Development Administration.

†This work was described in part at the Third College Park Symposium on Chemical Evolution, University of Maryland, September 1976.

Abstract

Experimental evidence that longitudinally polarized electrons having the handedness characteristic of terrestrial beta-decay electrons preferentially remove D-leucine from a racemic mixture, coupled with the probable presence of ^{14}C in pre-biotic molecules, offers a plausible hypothesis for the origin of biomolecular handedness.

Shortly after the discovery (Wu et al., 1957) that beta-decay electrons are chiral, Vester et al. (1957) and Ulbricht (1959) speculated that this phenomenon might explain the specific chirality of biological molecules. Direct experimental attack on the problem originally achieved negative or inconclusive results (Bonner et al., 1972, 1974, 1975a). Although Garay (1973) has claimed an asymmetric effect using chiral positrons from a radioactive source, the symmetry check using positrons of opposite chirality has yet to be performed and the connection of a positron emitter with a plausible biopoetic mechanism remains to be established. Recently, it has been shown (Bonner et al., 1975b) that longitudinally polarized electrons with an initial energy of 120 keV produce a significant asymmetric decomposition of DL-leucine. Although independent experimental confirmation of this result is still lacking, the fact that the result reverses quantitatively with the chirality of the incident electrons and is over three standard deviations from results obtained with a non-irradiated sample,

encourages us to accept the experiments as reliable.

Starting from this result, Keszthelyi (1976) has pointed out that the preferential degradation of D-leucine with respect to L-leucine by electrons with a chirality characteristic of the terrestrial environment (i.e. for electron-proton-neutron atoms rather than positron-antiproton-antineutron atoms) is consistent with the invariable occurrence of L-leucine in terrestrial organisms. If the terrestrial environment could thus in general provide more L- than D-amino acids, any biopoetic process leading to life based on amino acids will be biased to produce the chirality now observed due to the action of natural selection at the molecular level. Keszthelyi (1976) further emphasizes that ^{40}K is a natural beta-emitter common on the earth's surface which yields chiral electrons in the energy range around 120 keV where asymmetric degradation has been observed (Bonner et al., 1975b). We add the remark that potassium is ubiquitous in the physiology of terrestrial organisms, which strengthens the case for an early association between this element and the dominant C, N, O, H composition of protein molecules.

Although Keszthelyi (1976) makes an interesting case for ^{40}K beta-decay as the source of biomolecular chirality, he points out that the short range (ca. 1 cm) of ^{40}K betas requires us to assume an early and quite intimate association between the prebiotic amino acids and potassium. To make his mechanism plausible therefore requires more knowledge than we now possess about the actual paths which biopoesis followed. Fortunately there is a ready alternative which does not suffer from this disadvantage, namely, ^{14}C. This isotope could provide a source of chiral betas within the prebiotic molecules themselves. The end-point energy of the electrons from this pure beta-emitter, though lower than that for ^{40}K (155 rather than 1320 keV), still provides us with many chiral betas in the energy range where the asymmetric effect has been observed (Bonner et al., 1975b).

The first question to ask is whether ^{14}C would have been available some 4.5 aeons ago. Although ^{14}C has a half-life of only about 5000 years, it is continuously replenished by the action of neutron secondaries from the "cosmic radiation" via the $^{14}N(n,p)^{14}C$ reaction in the upper atmosphere (Libby, 1952). Since the atmosphere of our earth has presumably always been predominantly nitrogenous, the only question as to the presence of ^{14}C on the primitive earth involves the prevalence of energetic extra-terrestrial radiation striking the atmosphere and producing the neutrons. Current discussions (Meyer, 1969) of cosmic ray origin focus on mechanisms all of which were operating aeons before the formation of our solar system. Solar proton flux could only have increased the amount of ^{14}C available during the critical period of biopoesis. Atmospheric mixing would then guarantee that the ^{14}C, once formed, would be rapidly incorporated into the molecular environment from which biopoesis took off.

As yet we have no direct experimental evidence that longitudinally polarized electrons of "natural" handedness will produce asymmetric decomposition leading to terrestrial chirality in any amino acid other than leucine. The physical mechanism by which such chiral decomposition occurs has yet to be elaborated (Yearian et al., 1976). But leucine is coded for in the RNA code for protein synthesis not only by the first two letters in its codon, independent of the third letter (i.e. CUU, CUC, CUG, CUA), but also has two additional codons (UUG and UUA) out of the 64 available for the 20 amino acids. This reinforces the claim that leucine was "in at the start" in biopoesis (Jukes and Gatlin, 1971). Given a chiral bias for L-leucine in the prebiotic environment, natural selection at the molecular level would then guarantee the eventual evolution of the specific biological handedness now observed.

Although we have indicated that beta-radiation from ^{14}C could have

provided just that handed bias of the correct chirality needed to explain the puzzle first encountered by Pasteur (1948), We are far from being able to prove that it did so. Indeed, the only experiment (Bernstein et al., 1972) bearing precisely on the question - the self-radiolysis of ^{14}C-labeled amino acids - has so far yielded only negative results (possibly due to insufficient degradation and/or analytical sensitivity). Nevertheless, all other terrestrial beta-decays act in a direction which would reinforce any ^{14}C effect. Whether such combined effects are quantitatively strong enough to overcome either racemizing influences or more local handed effects which could be of either chirality will be difficult to establish (Noyes and Bonner, 1975; Bonner and Kavasmaneck, 1976). Even worse, we have positive experimental evidence only for incident beta rays of 120 keV energy. These could initiate more complicated chiral secondary processes of lower energy (Yearian et al., 1976), which in turn might provide mechanisms leading to a reversal of the observed (Bonner et al., 1975b) chiral effect.

Although the specific ^{14}C mechanism which we here propose appears plausible, there is obviously an acute need for much more detailed experimental and theoretical work in this challenging area of research.

References

Bernstein, W. J., Lemmon, R. M. and Calvin, M.: 1972, in Molecular Evolution, edit. by Rohlfing, L. and Oparin, A. I., Plenum, New York.

Bonner, W. A.: 1972, "Origins of Molecular Chirality" in Exobiology, edit. by Ponnamperuma, C., North-Holland, Amsterdam, pp. 170-234.

Bonner, W. A.: 1974, J. Molec. Evol. 4, 23.

Bonner, W. A. and Flores, J. J.: 1975a, Origins of Life 6, 187.

Bonner, W. A., Van Dort, M. A. and Yearian, M. R.: 1975b, Nature 258, 419.

Bonner, W. A. and Kavasmaneck, P. R.: 1976, J. Org. Chem. 41, 2225.

Garay, A. S.: 1973, Chem. Phys. Lett. 23, 549.

Jukes, T. H. and Gatlin, L.: 1971, Progress in Nucleic Acid Research and Molecular Biology, 11, 303.

Keszthelyi, L.: 1976, private communication to W.A.B.

Libby, W. F.: 1952, Radiocarbon Dating, Univ. of Chicago Press, Chicago.

Meyer, P.: 1969, Ann. Rev. of Astronomy and Astrophysics, 7, 1; 13th International Cosmic Ray Conference, Denver, 1973, Vol. I, Sessions OG 11, 12, pp. 562-651.

Noyes, H. P. and Bonner, W. A.: 1975, J. Molec. Evol. 6, 91.

Pasteur, L.: 1848, Ann. Chim. Phys. 24(3), 442.

Ulbricht, T. L. V.: 1959, Quart. Rev. 13, 48.

Vester, F., Ulbricht, T. L. V. and Krauch, H.: 1957, Naturwiss, 46, 68.

Wu, C. S., Ambler, E., Hayward, R. W., Hoppes, D. D. and Hudson, R. P.: 1957, Phys. Rev. 105, 1413.

Yearian, M. R., Bonner, W. A., Van Dort, M. A. and Noyes, H. P.: 1976, Nature (in press).