Amino Acid Racemization and Homochirality on Earth and Elsewhere. *Jeffrey L. Bada[1] and H. J. Cleaves[2], [1]Scripps Insitution of Oceanography, University of California at San Diego, La Jolla, CA (2024-0212 jbada@ucsd.edu, [2] Earth-Life Science Institute, Tokyo Institute of Technology, Tokyo, 152-8550, Japan; and Institute for Advanced Study, Princeton, NJ 08540*

Introduction: Did amino acid homochirality originate before, during or after the origin of life on Earth? Some researchers consider homochirality to be an inevitable consequence of universal fundamental physical processes that took place either in extraterrestrial environments or directly on the early Earth. Others consider that without molecular homochirality there could be no origin of life. An alternative view is that biochemistry itself played a more important role than abiotic chemical or physical processes, and thus biomolecular homochirality is a consequence of life, rather than a prerequisite for life [1].

In modern terrestrial organisms, amino acid homochirality is important because proteins cannot fold into bioactive configurations such as the α-helix if the amino acids are racemic. Enzymes could not have been efficient catalysts in early organisms if they were composed of racemic amino acids. However, enzymes made up of only D-amino acids function just as well as those made up of only L-amino acids, but the two enzymes react with the opposite stereoisomeric substrates [2]. There is no biochemical reason why L-amino acids would have been favored over D-amino acids.

The one example of terrestrial biological amino acid homochirality is inadequate to ascertain how widespread this example of mirror symmetry breaking is in the universe. Physical explanations such as those based the parity violation energy differences (PVED) between enantiomers predict that wherever life exists, the molecular handedness should be the same as on Earth. The biotic origins scenario predicts that life throughout the universe would be equally divided with respect to left and right molecular handedness. During the next couple of decades we will explore Mars and possibly Europa for evidence of extinct or extant life. The discovery of D-amino acid based life would eliminate the PVED-based arguments for the origin of biomolecular homochirality.

Racemization: When an organism dies, its amino acids begin to racemize at a rate which is dependent on the particular amino acid, the temperature, and the chemical environment [3]. Racemization reactions are rapid on the terrestrial geologic time scale and even at deep ocean temperatures (2°C), amino acids are totally racemized (D/L = 1.0) in <5-10 million years [3]. This should also be the case for any homochiral amino acids in the putative Europan Oceans. When biogenic amino acids are completely racemized, they would be indistinguishable from a chirality point-of-view from the racemic amino acids produced by abiotic organic synthesis or those derived from exogenous sources. Small L-enantiomric excesses in α-dialkyl amino acids with a chiral center have been found in some carbonaceous meteorites [4] and these amino acids are highly resistant to racemization [1]. These are not generally found in the proteins of terrestrial organisms, however.

By whatever process, or from whatever source a chiral excess or homochirality of amino acids was generated, it could only be maintained if the rate of formation, or addition, of the chiral amino acids was faster than their rate of racemization.

Using kinetic data, we have estimated the racemization half-lives and times for total racemization of protein amino acids under conditions relevant to the surface history of Mars [5]. Amino acids from an extinct martian biota maintained in a dry, cold (<250°K) environment would not have racemized significantly over the lifetime of the planet. Racemization would have taken place in environments where liquid water was present even for time period of only a few million years following biotic extinction.

Investigations of amino acid enantiomeric ratios should thus be a central component of future planetary astrobiology missions in order to help answer the 150 year old question of how amino acid homochirality originated on Earth.

References: [1] Bada JL and Miller SL (1987) *Biosystems* 20, 21-26 [2] Milton, RC D et al. (1992) *Science* 256, 1445-1448. [3] Bada JL (1991) Phil. Trans. Royal Soc. London Series B, 333, 349-358 [3] Pizzarello S, et al, [2003] *Geochim. Cosmochim. Acta* 67, 1589-1595 [5] Bada JL and McDonald GD (1995) Icarus, 114, 139-143.