**Amino acids in space: How meteors may have affected amino acid chirality on Earth**

Emily Boggs

Life on Earth is exclusively left-handed – that is, not in the traditional motor-coordination sense, but with respect to the chirality of the amino acids used by life. All proteinogenic, or protein-building amino acids used by cells, with the exception of glycine, exhibit one or more chiral centers, giving rise to either D- or L- enantiomers (not to be confused with dextro- or levorotary configurations). Curiously, all amino acids used by biological systems are exclusively of the L configuration. Biological systems seemed to have evolved to work exclusively with L amino acids – accompanying enzymes, amino acid precursors, and products are synthesized to work specifically with this configuration. The system is so hardwired that the presence of D enantiomers in humans is often the cause of pathology, and has been linked to serious conditions like Alzheimer’s and multiple sclerosis [1]. Why this bias?

 It makes sense that a biological system would evolve to accommodate only one configuration: having to make separate pathways for different enantiomers sounds messy and redundant. The question is then, why L? Why not D? Clearly, the humble beginnings of life on Earth resided in a primordial soup of L-configured amino acids. How did it get to be that way?

 While amino acids were likely formed on a pre-life Earth by abiotic processes (which would have resulted in racemic mixtures of enantiomers), some researchers have posited that the high frequency of meteorite impacts during this time may have delivered space-faring amino acids to the planet’s surface. Like amino acids found in meteors today, these extraterrestrial amino acids would have been functionally identical to their earthbound cousins and did not arrive in perfectly racemic mixtures (also like present-day meteorite-bound amino acids). These deliveries may have been frequent enough to tip the racemic balance in favor of one configuration [2].

 Then why are there configurational biases in meteors? Strecker synthesis of amino acids, the abiotic process that is likely responsible for the formation of amino acids in meteors (and pre-life Earth), produces a racemic mixture. Therefore, when researchers crack meteorites open to examine the amino acids within, they should theoretically expect to see a 50-50 split between L and D enantiomers. They don’t, though. For certain amino acids a very large enantiomeric excess of the L configuration (Lee) is present; for others, the amounts are almost perfectly racemic. These results have been baffling researchers for years, but one group has posited an excellent hypothesis.

 Shortly after the beginning of the new millennium in January 2000, a large meteor exploded over British Columbia, scattering meteorite chunks over a wide area, including the surface of the frozen Tagish Lake. Since the huge fireball produced by the meteor’s entry into the upper atmosphere was a very noticeable occurrence (particularly to individuals with still-simmering fears of Y2K), the arrival of what was to become the Tagish Lake meteorite was witnessed by many people and widely publicized. As a result of this meteor’s notoriety, researchers learned of it shortly after it fell and were able to collect and preserve relatively uncontaminated samples (a factor which, as soon to be explained, is extremely important in the analysis of meteorites). Some of the samples were taken to the nearby University of Alberta and placed in the care of a Dr. Christopher Herd. It was these samples that were made available to NASA researchers under Dr. David Glavin, along with other researchers at the University of Alberta.

 The tests performed fell into two categories: one set of tests was used to determine the relative amounts of amino acids (including enantiomers) in the meteorite samples. The other set was used to measure the amount of carbon-13 present in these amino acids.

 Tagish Lake meteorite samples were crushed into powder, and extracted at reflux. The water supernatant, which contained any peptides present in the sample, was dried out by rotoevaporation. Half of each sample was then subjected to acid hydrolysis before being derivatized for high pressure liquid chromatography and (HPLC) and mass spectroscopy. Acid hydrolysis of peptides breaks them into their component amino acids; by only hydrolyzing one half of each sample, the amounts of unbound or “free” amino acids could be determined after mass spectroscopy. The data obtained by this procedure had little impact on the final conclusions made by Glavin et al; this is likely a process performed on most meteor samples.

 Before HPLC and mass spectroscopy, the amino acids were derivatized using OPA/NAC (o-phthaldialdehyde/N-acetyl-L-cysteine). During this process, the OPA/NAC molecules were attached to the ends of the amino acids, producing larger diastereomers (depending on chirality of the amino acid in question) [3]. This was done because diastereomers exhibit different chemical properties that can be picked up by HPLC, while enantiomers do not. These amino acid derivatives were then run through HPLC; to match the UV fluorescence peaks and elution times with specific amino acids, an amino acid standard was also run through for comparison. The derivatives also underwent time-of-flight mass spectroscopy to further confirm their identities through molecular mass.

 Carbon-13 testing included derivatizing amino acids with trifluoroacetic anhydride (TFAA) and running the samples through an instrument with tandem mass spectroscopy and isotopic ratio mass spectrometry capabilities (MS/MAT 253 IRMS). This meant that amino acid samples could be injected and analyzed for structural and isotopic information. Isotopic ratio mass spectroscopy was performed by oxidizing amino acids to form CO2 and then comparing the mass to a CO2 standard.

 Carbon-13 content was measured as an insurance against accusations that the Tagish Lake meteorite samples contained significant amounts of terrestrial contamination. Since the vast majority of Earth’s amino acids are of the L configuration, a suspiciously high Lee found in a meteor sample may have been due to the influx of terrestrial amino acids shortly after impact. However, space-faring amino acids exhibit a much larger enrichment in carbon-13 than their terrestrial cousins, so finding a higher concentration of C13 present in a meteorite’s amino acids (particularly in an isolated Lee sample) can verify their extraterrestrial pedigree.

 Of the three samples taken from the Lake Tagish meteorite, two (the enigmatically named 5b and 11h samples) showed excessive Lees for aspartic acid, glutamic acid, serine, and threonine (the third sample was not tested for enantiomeric excess due to its low amino acid count) [Table 1]. All three samples also exhibited carbon-13 content consistent with extraterrestrial origins.

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|  Table 1 |   | 5b |   |   | 11h |   |   | Racemic Standard |   |
|   |  | Lee% | Error | *n* | Lee% | Error | *n* | Lee% | Error | *n* |
| Aspartic acid |  | 43.1 | ±8.6 | 8 | 45.5 | ±5.2 | 8 | 6.6 | ±2.9 | 9 |
| Glutamic acid |  | 51.0 | ±1.5 | 6 | 55.1 | ±3.6 | 6 | -2.6 | ±2.3 | 9 |
| Serine |  | 80.5 | ±3.9 | 6 | 55.5 | ±3.6 | 6 | 3.3 | ±1.5 | 9 |
| Threonine |  | 89.2 | ±4.9 | 6 | 99.4 | ±0.3 | 6 | 0.3 | ±2.1 | 9 |
|   |  |   |  |  |   |  |  |   |  |   |
| Alanine |   | -4.8 | ±5.5 | 9 | -3.2 | ±6.7 | 9 | 1.0 | ±1.6 | 9 |

For the amino acid alanine, however, an almost racemic mixture was observed. Based on these results, Glavin et al. hypothesized that the amino acids’ crystallization behavior was the cause of Lee in some but not others. Specifically, aspartic acid and alanine were compared because of their consistent Lee results and common presence on Earth.

 Aspartic acid amino acids, when present in saturated solutions, tend to precipitate out as conglomerate crystals (crystals composed completely of one enantiomer), while alanine forms racemic crystals. Glutamic acid and threonine have also been observed making conglomerate crystals.

 The process by which these mixtures are created rests solely on the observations that racemization between enantiomers only occurs in solution and larger crystals are more stable than smaller ones. The formation of a large Lee occurs with a sort of runaway snowball effect: the predisposition of aspartic acid residues to form enantiopure crystals. If a slight initial excess of one enantiomer over the other is present, this excess will accumulate into larger crystals; the minor enantiomer will form smaller crystals which will be more likely to dissolve back into solution and undergo racemization into the major enantiomer.

 For the production of racemic crystals, the process is more balanced. An excess in one enantiomer will cause the precipitation of racemic crystals. Enantiopure crystals are more soluble than their racemic counterparts – thus, an enantiopure crystal made of an excess configuration will be more likely to dissolve back into solution, and the excess enantiomers, being in solution, will be more likely to racemize into the opposite enantiomer. The question that remains is, if the runaway snowball effect that caused a large Lee in aspartic acid was initiated by a small excess, where did this initial excess come from?

 It has been reported that circular polarized light, when applied to amino acids and precursor aldehydes can have a selective effect on their chirality. Circular polarized light (CPL) is extremely common in star-formation areas of space, but may occur wherever there is linearly polarized light from stars that interacts with debris or magnetic fields [4]. Right-handed circular polarized light (RCPL) has the effect of degrading L configurations, while left-handed circular polarized light (LCPL) affects R configurations [5], [6]. If a meteoroid passes through an area of space high in LCPL then, a modest excess of L enantiomers may be selected for.

 However, though this disappointing conclusion was not at all mentioned in the *ScienceDaily* news article, Glavin et al. are not convinced that CPL had an effect on amino acids in the Tagish Lake meteorite. With respect to aspartic acid, the residue with the highest Lee, the team ruled out the possibility of precursor enantiomer selection, as the aldehyde that forms aspartic acid, 3-oxopropanoic acid, is achiral. Furthermore, the residues themselves were too far into the interior of the meteorite to have been directly affected by CPL. Though the mechanism given here for the process of enantiomer excess propagation is plausible and experimentally supported, the initial tipping factor that nudged Earth’s amino acids into L configurations is still unknown.

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