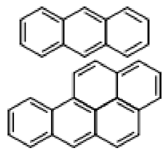
8.1.1: Astronomy- Mars Meteor and Extraterrestrial Life

The search for life elsewhere in the universe has centered on finding ***organic compounds*** because they are the stuff of all life on earth. Organic compounds are easily synthesized by abiotic (non-living) processes, however, so the search for extraterrestrial life has occasionally centered on other "biomarkers" (chemical structures that are typically found in living things).

ALH84001

A meteorite from Mars collided with the earth and was collected in 1984 from the Allan Hills region of Antarctica[1] and thus designated ALH84001. An asteroid probably collided with Mars, breaking off the chunk which circled the sun for eons before colliding with the earth as a meteorite. The meteorite contained PAHs (Polycyclic Aromatic Hydrocarbons) containing rings of six carbon atoms, fused together in arrays like those shown below. Benzo-α-pyrene is formed when meat is barbecued (it may be a carcinogen) and anthracene is found in coal as a relic of it's biological origin.

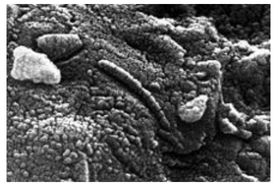


Two PAHs: (left) Anthracene and (right) Benzo-alpha-Pyrene

Note that these organic compounds have even numbers of carbon atoms (a sign of biotic origin). They are considered **organic** because they contains carbon chains and hydrogen atoms (H atoms are not shown in the figure by convention; organic chemists know that there must be hydrogen atoms where necessary to make a total of four bonds to each carbon). Carbon-carbon bonds are quite strong, allowing formation of long chains to which side branches and a variety of functional groups may be attached. Hence the number of molecular structures which can be adopted by organic compounds is extremely large. PAHs are ***hydrocarbons*** because they contain only carbon and hydrogen, like the simpler hydrocarbon ethane (shown below). Hydrocarbons are further categorized as alkanes, cycloalkanes, aromatic compounds, alkenes and alkynes,

Organic compounds often also contain oxygen, nitrogen, and small proportions of other elements. Addition elements other than carbon and hydrogen creates different classes of organic compounds. For example, alcohols contain the -OH group, as shown below in ethanol (drinking alcohol).

The meteorite ALH84001 also contained carbonate minerals (like $CaCO_3$), which are not organic, but are the stuff of stalactites formed when water dissolves carbon dioxide and passes through cracks in rocks. Since water may be a prerequisite of life, carbonates are considered a biomarker, especially in the shapes found on ALH84001, which are reminiscent of cell fossils. Carbonates are not considered organic, because they don't contain carbon atoms bonded to each other as described above. Carbonates are typical inorganic, ionic compounds.



ALH84001 Structures [4]

Several other types of evidence, including the structures shown in the figure, convinced David McKay and his NASA collaborators to claim "Although there are alternative explanations for each of these phenomena taken individually, when they are considered collectively, particularly in view of heir spatial association, we conclude that they are evidence for primitive life on early Mars."[5]

Many skeptics, notably paleontologist J. William Schopf, pointed out that "organic compounds" come from sources other than organisms (life), and are often created by abiotic processes, as are carbonate rocks. Furthermore, all meteorites, when carefully inspected, show signs of life, because they are almost immediately colonized by Earth's biota. In the end, the meteorite held no convincing evidence for life.

Abiotic Organic Compounds

There are several telltale markers that distinguish abiotic "organic" compounds, like those that are synthesized in the laboratory or under the extreme conditions found on most planets where life as we know it cannot survive: [6],

1. The presence of a smooth distribution of organic compounds in a sample, e.g., a balance of even versus odd numbers of carbon atoms in alkanes (living things produce mostly compounds with even numbers of carbons, due to the mechanism of biological synthesis).
2. The presence of all possible structures, patterns, isomers, and stereoisomers in a subset of compounds such as amino acids. (Living matter tends to select only certain amino acids (we need 20 essential amino acids, but hundreds are known)
3. A balance of observed enantiomers (life produces "left handed" molecules of some types (like amino acids), and or "right handed" molecules of others (like sugars).
4. The lack of depletion or enrichment of certain isotopes with respect to the isotopic ratio normally expected. (Living things normally concentrate the lower mass naturally occurring isotopes by the "kinetic isotope effect").

Other Biomarkers

Unique groupings of atoms like the -OH group in alcohols mentioned above, are called ***functional groups***. Functional groups determine the chemical and physical properties of organic molecules. Living things are characterized by involvement of molecules containing the carbonyl (-C=O) functional group [7] which appears in aldehydes and ketones as well as carboxylic acids and esters. Organic Nitrogen Compounds like amino acids and nucleotides are also nearly universally found in terran living things. Amino acids have been detected in comets [8].

Weird Life

It is possible that life elsewhere ("nonterran" life is NASA's term[9]) may be entirely different, and a NASA conference on "Weird Life" [10] explored other possibilities for what "organic" might mean elsewhere in the universe. Extraterrestrial life is studied by "Astrobiologists" or "Exobiologists" (working with astronomers at NASA [11]). Astronomers interested in nonterran life need to understand the types of organic molecules found on Earth, their properties that make them useful in living things, and how these properties differ from other classes of substances.

Physical Properties

Macroscopic physical properties such as melting and boiling points depend on the strengths of the forces which hold microscopic particles together. In the case of molecules whose atoms are connected by covalent bonds, such intermolecular forces may be of three types. All molecules are attracted together by weak London forces. These depend on instantaneous polarization and increase in strength with the size of the molecular electron cloud. When a molecule contains atoms whose electronegativities differ significantly and the resulting bond dipoles do not cancel each other’s effects, dipole forces occur. This results in higher melting and boiling points than for nonpolar substances.

The third type of intermolecular force, the hydrogen bond, occurs when one molecule contains a hydrogen atom connected to a highly electronegative partner. The other molecule must contain an electronegative atom, like fluorine, oxygen, or nitrogen, which has a lone pair. Although each hydrogen bond is weak compared with a covalent bond, large numbers of hydrogen bonds can have very significant effects. One example of this is in the properties of water. This highly unusual liquid plays a major role in making living systems and the earth’s environment behave as they do.

References

1. Hazen R.M. "**Genesis: The Scientific Quest for Life's Origin**", Joseph Henry Press, Washington, DC, 2007, p. 33
2. en.Wikipedia.org/wiki/Polycyclic_aromatic_hydrocarbon
3. en.Wikipedia.org/wiki/Polycyclic_aromatic_hydrocarbon
4. en.Wikipedia.org/wiki/Exobiology
5. Hazen R.M. "**Genesis: The Scientific Quest for Life's Origin**", Joseph Henry Press, Washington, DC, 2007, p. 35
6. "Exploring Organic Environments in the Solar System Exploring Organic Environments in the Solar System National Academies of Sciences, Engineering, and Medicine. 2007. Exploring Organic Environments in the Solar System [books.nap.edu]
7. The Limits of Organic Life in Planetary Systems (free download) astrobiology.nasa.gov/documents-and-reports/
8. astrobiology.nasa.gov/article...lock-in-comet/
9. The Limits of Organic Life in Planetary Systems (free download) astrobiology.nasa.gov/documents-and-reports/
10. The Limits of Organic Life in Planetary Systems (free download) astrobiology.nasa.gov/documents-and-reports/
11. NASA [astrobiology.nasa.gov]
12. CoreChem:Properties of Organic Compounds and Other Covalent Substances