

Honors Seminar 292 — cheat sheet for 9/11/2019 — Andrew Baker

Benner et al. (2004)

You should read all of this article. Key questions, which you may find useful to think about as you are reading and planning a potential discussion of the paper:

1. Why do the authors argue that life has each of a number of general biochemical requirements?
2. What are the three categories of explanations for why life on Earth has any given aspect of its observed biochemistry?
3. Could other worlds besides the Earth be *more* hospitable for different kinds of life than the Earth is for ours?

Below is a partial list of the scientific “key terms” that appear in the paper. Although the list is long, keep in mind that not all of the entries are *important* in the sense that they connect to the authors’ main ideas; one of your goals as a reader is to recognize which terms are central and which are more peripheral.

- **aerosol** = liquid droplet or small solid particle that is suspended in a gas (typically, the atmosphere).
- **alkyl** = chain of carbon and hydrogen atoms that can be attached to another molecule.
- **anion** = negatively charged ion (the opposite is “cation”).
- **biotin** = vitamin B₇, required for metabolism of fatty acids.
- **chiral** = adjective describing something (molecule, crystal, hand, etc.) that cannot be superimposed on its mirror image. In the case of molecules, the two mirror images are known as *enantiomers* of each other.
- **cofactor** = a substance that must be present, supplementing an enzyme, for a particular chemical reaction to occur.
- **conjugated system** = molecule in which the electrons involved in covalent bonding are not uniquely attached to a particular bond, but are delocalized.
- **covalent bond** = type of chemical bond formed when two atoms share one or more pairs of electrons; covalent bonds are stronger than “hydrogen bonds” (like those linking complementary nucleotides in a strand of DNA).
- **cytidine** = molecule formed by the combination of cytosine (the “C” base in RNA and DNA) and ribose.
- **deamination** = removal of an amine group (ammonia with one or more substitutions) from a molecule.

- **denaturation** = process by which a protein, RNA, or DNA unfolds and loses its preferred three-dimensional shape (a shape often required if it is to do what it's supposed to).
- **deoxyribose** = a sugar containing five carbon atoms that provides part of the “backbone” of DNA.
- **dihydrogen** = hydrogen that is bound together into H_2 molecules. (Beware of anyone who tries to alarm you with the news that the drinking supply has been contaminated with “dihydrogen monoxide”!)
- **formamide** = a particular example of an *amide* (a compound featuring a $C=O$ group bonded to a N atom) that has the formula $HCONH_2$.
- **Gibbs free energy** = Gibbs energy = the amount of useful work that can be extracted out of a thermodynamic system with uniform temperature and pressure. The *change* in Gibbs energy ΔG associated with a chemical reaction is negative if the reaction releases energy and positive if the reaction requires energy.
- **guanosine** = molecule formed by the combination of guanine (the “G” base in RNA and DNA) and ribose.
- **halogen** = an element from the next-to-last column of the periodic table (F, Cl, etc.).
- **homochiral** = adjective describing molecules that have the same chirality.
- **hydrolysis** = partial or complete breakdown of a molecule due to reactions driven by the H and OH that result from the splitting of a water molecule.
- **hypersurface** = the analog of a surface in more than three dimensions. In the context of this article, suppose that the sequence of a protein is described by exactly two parameters (call them x and y —granted, this is not very realistic!), and the ability to “confer fitness” is a function of these parameters $z = f(x, y)$. If we plot (x, y, z) , then we'll have a landscape of peaks, dips, ridges, valleys, and ripples. A hypersurface is the generalization of this landscape to more than two parameters.
- **isosteres** = two molecules with the same numbers of atoms and “valence” electrons (electrons in the outer shell that are important for chemical bonding).
- **liposome** = bubble whose surface is a double layer of lipid molecules, with their hydrophilic “heads” pointing outward and their hydrophobic “tails” pointing inward.
- **micelle** = sphere whose surface is a single layer of lipid molecules with their hydrophilic “heads” pointing outward and their hydrophobic “tails” pointing inward (unlike a liposome, a micelle does not enclose anything).
- **oligosilane** = a small number of silicon atoms chained together with hydrogen atoms attached to every other available bonding site. Silane (SiH_4) is analagous to methane (CH_4).

- **oxidant** = a substance that gains electrons in oxidation-reduction reactions (see definition of “redox” below).
- **phenol** = carboic acid = compound consisting of an OH group bonded to a phenyl ring (i.e., benzene with OH tacked on).
- **phosphorylation** = addition of a phosphate group (PO_4) to an existing molecule.
- **pKa** = negative logarithm of the acid dissociation constant K_a . Since K_a is higher when an acid (e.g., HCl) is more easily dissociated into its constituents (e.g., H and Cl^-), an acid with a *larger* value of pKa is *weaker*.
- **polar** = a molecule with an asymmetric distribution of charge (water is polar; methane is not).
- **pyridoxal** = vitamin B₆.
- **racemic** = adjective describing a mixture that contains equal amounts of left-handed and right-handed enantiomers of a chiral molecule.
- **reductant** = a substance that loses electrons in oxidation-reduction reactions (see definition of “redox” below).
- **ribose** = a sugar containing five carbon atoms that provides part of the “backbone” of RNA (most compounds whose names end in “ose” are sugars/carbohydrates).
- **ribosome** = one of many RNA/protein complexes within a cell that “translates” the instructions from a DNA sequence (conveyed via a “messenger RNA” molecule) into a protein.
- **sulfone** = chemical compound containing a O=S=O group attached to two carbon atoms.
- **thermodynamic equilibrium** = the state of a system whose temperature, pressure, and chemical composition don’t change, and which (for constant temperature and pressure) has a minimum Gibbs free energy.
- **thioester** = one of a family of chemical compounds that include sulfur atoms.

Schulze-Makuch et al. (2015)

You should read all of this article. Key questions:

1. What are some of the adaptations that terran life forms have developed to survive and/or grow in extreme environments? In what circumstances do these adaptations need to be permanent, and in what circumstances can they be temporary?
2. What are some of the challenges that terran life forms would face on Mars and/or Titan? (Keep in mind that organisms need to have at least one source of energy and be able to maintain the integrity of their bodies.)

3. What are the key features of the authors' "hypothetical organism" that would be well adapted to Mars, and of their "hypothetical organism" that would be well adapted to Titan?

Key terms (you may also wish to refer to the glossary for Benner et al. (2004) above):

- **acetylene** = simple hydrocarbon compound with the chemical formula C_2H_2 .
- **amphiphilic** = adjective describing a molecule that has sub-units that are hydrophilic ("water-loving") and lipophilic ("fat-loving") in terms of what other molecules they are drawn to.
- **anhydrobiosis** = a form of cryptobiosis triggered by a severe lack of water.
- **apoptosis** = death of cells that occurs as a regular step in the growth or development of an organism.
- **azotosome** = hypothetical cell membrane built out of nitrogen-rich compounds that could function in liquid methane in the same way that a liposome functions in liquid water.
- **cnidarian** = organism that belongs to the phylum *Cnidaria*, which includes jellyfish, anemones, and corals.
- **cryptobiosis** = the state achieved by some living organisms in which all metabolic processes shut down (often in response to a severe environmental stress).
- **endolith** = organism that lives inside rock or a similarly hard substance (e.g., animal shell or coral).
- **endothermic** = adjective describing a chemical reaction that requires the absorption of heat.
- **gonochoric** = term describing organisms that only have one of two sexes present in an individual (more frequently the case for terran animals than for plants).
- **heterotroph** = a type of organism that does not produce its own food, but rather consumes it from other forms of life.
- **hygroscopic** = able to absorb moisture from the air.
- **hyperthermophilic** = adjective describing an organism that thrives in environments with high temperatures
- **induction** = the process by which one structure in a developing organism triggers (i.e., induces) the formation of another structure; this process can involve self-transformation of cells (i.e., endogenous induction) or involve non-genetic influences on gene expression (i.e., epigenetic induction).
- **methanogenic** = adjective describing an organism that produces methane

- **NAD** = nicotinamide adenine dinucleotide, a compound found in all living cells that is involved in redox reactions that are important for metabolism.
- **ontogenetic** = term describing the usual direction of an organism's development, e.g., from a fertilized egg to an adult form.
- **perchlorate** = chemical compound containing one chlorine and four oxygen atoms.
- **photoautotrophic** = adjective describing an organism that can produce its own food using light as an energy source.
- **proteome** = the full set of proteins that a cell, tissue, or organism *can* produce.
- **redox** = shorthand term for "reduction/oxidation," describing chemical reactions in which an atom's "oxidation state" decreases (often due to gain of electrons), a.k.a. reduction, or in which it increases (often due to loss of electrons), a.k.a. oxidation. Redox reactions are discussed in B&S §9.4.
- **serpentinization** = geological process in which various types of precursor rock are converted to serpentinite under the influence of heat and water.
- **silane** = either SiH_4 , or a general term for a compound that consists of silicon atoms chained together with hydrogen atoms attached to every other available bonding site.
- **thermolabile** = adjective describing a substance that can be destroyed, decomposed, or significantly modified by heat.
- **water activity** = a property of a substance defined as the ratio of the partial vapor pressure of water *in the substance* to the partial vapor pressure of water *by itself* (a higher number is more supportive of life).