Honors Seminar 256 — cheat sheet for 9/13/2011 — Andrew Baker

Benner et al. (2004)

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 B_7, 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** = carbolic 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 consitutents (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 B_6.
- **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 & Irwin (2006)

You should read all of this article *except* the "Life on the surface of Titan?" section on pages 167–169 (we'll come back to this material in a future class). Key questions:

1. The authors identify "the chemical components of the system, the solvent in which they interact, and the forms of energy that flow through the system" as three important aspects that characterize life. How would we characterize terran life in these terms?
2. For life on an Earth-like planet around another star, how likely would it be for the biochemistry to be (a) carbon-based and exactly like ours, (b) carbon-based but different from ours, or (c) silicon-based?

3. How well does water satisfy the criteria of being a "good solvent" for life, and in what respect(s) is it not ideal?

4. What are the advantages and disadvantages for life on other worlds of solvents other than water, and what sorts of conditions would be necessary for them to work well as solvents? What does Figure 1 imply about the viability of possible alternative solvents?

5. What sources of energy do the authors propose might support life that are not used by terran organisms?

6. If life currently exists in the atmosphere of Venus, what can we say about how it probably got there (given that the *surface* of Venus currently has prohibitively high temperature and pressure)?

7. In the atmosphere of Venus (among other environments), what are the costs and benefits for a living organism of exposure to strong ultraviolet radiation?

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

- **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.
- **aromatic** = adjective describing an organic molecule that contains a benzene ring.
- **buffer** = a substance in a solution that tends to neutralize changes in pH caused by the introduction of a strong acid or base.
- **carboxylic acid** = acid containing a carboxyl (COOH) group.
- **carotenoid** = an organic pigment that can absorb light; found (among other places) in plants and in human eyes.
- **chemotropic** = term describing an organism that relies on chemical reactions rather than (directly or indirectly) on solar radiation as a source of energy.
- **conformation** = a molecule's three-dimensional shape.
- **denitrification** = chemical process that reduces (see "redox" below) nitrates, often helped along by specialized bacteria.
- **dipole moment** = quantity characterizing how far a molecule's center of charge is from its center of mass.
- **glycine** = the smallest of the amino acids that are used in terran proteins, and a compound that has been successfully detected in interstellar space.
- **halophilic** = adjective describing an organism that thrives in a very salty environment.

- **heat capacity** = how much heat you have to apply to a substance to make its temperature increase by a fixed amount. Substances with high heat capacity don't melt or boil very quickly.
- **hypertonic** = adjective describing the solution with *higher* concentration in a system with an osmotic gradient (the opposite is "hypotonic").
- **immiscible** = term describing two liquids that do not form an evenly mixed solution.
- **induction** = generation of an electrical current by a changing magnetic field.
- **Langmuir oscillation** = oscillation of the electron density in a conducting medium.
- **ligand** = ion or molecule that binds to a metal atom.
- **membrane transduction** = passage of a signal across a cell membrane, through one of several mechanisms.
- **osmotic gradient** = difference in solute concentration; if there is a difference across a membrane that allows the solvent but not the solute to pass through, there will be *osmotic pressure* as solvent molecules are driven across the membrane to equalize the concentrations.
- **peptide bond** = a type of covalent bond in which a carboxyl group of one molecule attaches to the amino group of a different molecule, and a water molecule is released when the bond forms.
- **pi-conjugated system** = conjugated system in which the function describing the behavior of the bonding electrons (i.e., the "molecular orbital) has a particular kind of symmetry labelled "π." (A sigma-conjugated system has orbitals with "σ" symmetry.)
- **polar** = adjective describing a molecule in which there is a net separation of electrical charge from one side of the molecule to the other ("non-polar" describes a molecule where there is no such separation).
- **polyamide** = a chain of amides (compounds containing a C=O group and a nitrogen atom) linked by peptide bonds; silk and wool are examples.
- **potential** = in the context of physics or biophysics, the "electric potential" is the electric potential energy at a particular location divided by the charge at that location, defined so that it is *only* a characteristic of the local electrical field. A large potential difference between two locations means that a charged particle will feel a strong force along a line connecting the two locations.
- **phospoester** = chemical compound that includes a five-carbon-ring sugar connected to a phosphate (PO_4) group.
- **polypeptide** = chain of amino acids.

- **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. Note that in the third paragraph on page 157, when the authors write "valence" they effectively mean oxidation state. Redox reactions are discussed in B&S §9.4.

- **respiration** = chemical process that releases energy by combining sugar with oxygen.

- **serpentization** = 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.

- **silanol** = either SiH_3OH, or a general term for a compound that contains silane units and one OH functional group.

- **silsesquioxane** = chemical compound that contains at least one unit of the form SiO_2 or SiO_3 and lends itself to the formation of a cage-like structure.

- sp^2 = hybrid of one s-type orbital and two p-type orbitals in characterizing the bonding behavior of an atom (sp^3 is analogous).

- **stoichiometry** = in the context of the "Thermal energy gradients" discussion on page 163: the relative quantities of molecules involved in a reaction.

- **sulfonamide** = chemical compound that contains a sulfonyl (SO_2NH_2) group connected to an amine group.

- **supercritical fluid** = a substance existing at such a high temperature and pressure that the distinction between gas and liquid no longer exists.

- **super-rotation** = phenomenon in which a planet's winds blow faster than the rate at which the planet itself rotates.

- **thermotropic phase transition** = phenomenon whereby a liquid crystal– a substance that has properties intermediate between those of a liquid and a solid– undergoes a temperature-dependent transition in those properties. Cell membranes can be liquid crystals and exhibit just such transitions.