ASTR/GEOL-2040-001: Search for Life in the Universe
Homework #2 (Thursday Feb 2, 2017) model solutions

1. (i) Life produces *more order inside the cell*: it puts the various molecules or building blocks in the right places and the nucleotides and amino acids in the right order to make functional DNA and proteins.
(ii) Cells take in useful chemicals for their metabolism and expel other chemicals as waste. This waste does not obey any order, so the *disorder increases outside the cell.*
(iii) For the Universe as a whole, the second law of thermodynamics applies. This includes the cells with their order and the disorder elsewhere. Thus, by the second law of thermodynamics, *the disorder in the whole Universe increases.*

The purpose of this exercise is to make you aware that life still obeys the laws of physics in general and of thermodynamics in particular. The apparent puzzle with thermodynamics is resolved by realizing that a cell is an *open system* (it interacts with the environment), but the second law of thermodynamics only applies to a closed system.

2. (i) Methane (CH_4) appears symmetric from all angles with the carbon atom in the middle and the hydrogen atoms being symmetrically distributed around it.
(ii) Chemists draw a perspective view like so in the right panel of Fig. 1.
(iii) Because it is symmetric from all viewing angles, no particular polarity sticks out anywhere, so it is *apolar* or *non-polar*.
(iv) Water, by contrast, is polar, and since "like dissolves like", methane would not dissolve in water, so it is *hydrophobic*.

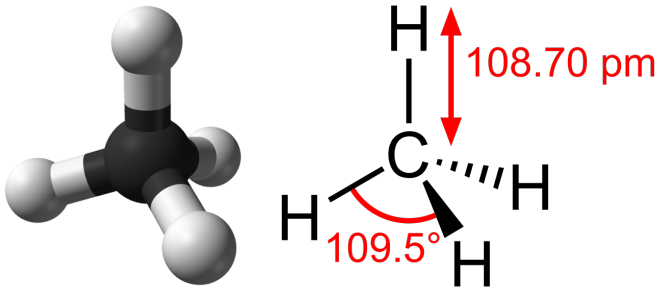

Figure 1: Perspective view of methane. Taken from Wikipedia.

3. Early genetic code speculations.

(i) As discussed in Lecture 4 (page 25), where I showed the 2014 Nature paper by Malyshev et al., there exist more than the 4 base pairs used in all living organisms on Earth. Thus, there is nothing special about those 4. Obviously, we need at least 2 bases that make a pair, so as to perform copying and transcription.

(ii) If we trim the 4-letter alphabet to a 2-letter alphabet, but keep the length of the word unchanged at 3 characters, the number of different words would be $2 \times 2 \times 2 = 2^3 = 8$, so in theory we could expect making up to 8 different amino acids.

(iii) With G and C bases, modern life codes for just 4 amino acids: glycine (Gly) with GGC and GGG, alanine (Ala) with GCC and GCG, proline (Pro) with CCC and CCG, and arginine (Arg) with CGC and CGG. Thus, there is redundancy and the last letter is ignored. The simplest expectation would be that the same would be true for early life.

(iv) Yes, it is reasonable to expect glycine to be one of the amino acids used by early life, because it is the simplest amino acid and it is readily synthesized under primitive conditions such as the Miller/Urey experiment.

Note: It is plausible that early life would have to have start and stop codons, and that the last letter of some of the 8 possible codons would not code for an amino acid but would correspond to a start or stop codon.