ASTR/GEOL-2040-001: Search for Life in the Universe

Homework #3 (Wednesday Sep 27, 2017) model solutions

1. Evidence for life on Earth

   (i) O_2 was detected as a pronounced dip in the emission spectrum at near-infrared wavelengths around $0.76\,\mu$m. [2pts]

   (ii) The strength of the dip in the emission spectrum is deemed to be large and unique among the other worlds on the solar system (even by modern standards, after having visited many more worlds since then). The authors discuss that O_2 can also be produced abiogenically (=non-biologically) by dissociation of H_2O into O_2 and H_2, which is made irreversible by the escape of H_2 owing to its low molecular weight. They estimate that this process would take several times longer that the age of the Earth, so some other process must be at work. [2pts]

   (iii) The injection rate of CH_4 needed to compensate the rate of oxidation by O_2 is estimated to be $500\,\mathrm{Tg\,yr^{-1}}$, which is deemed implausible. (1 Teragram = 10^{12} g.) [2pts]

   (iv) N_2O is detected as relative minor dips in the spectrum at infrared wavelengths at 3.5, 4.05, and $4.5\,\mu$m. [2pts]

   (v) Abiogenic sources of N_2O include lightning, but this is a small effect compared with nitrogen fixing by biogenic means (bacteria and algae). [2pts]

The purpose of this exercise was to make you read a scientific article by a scientist what you might have known only from his public outreach activities.

2. **Metabolic reactions**. In the reaction $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$,

   - the energy comes from: molecules (reduction of carbon), so the relevant prefix is "chemo" [2pts]
   - the electron donor is: H_2, which is inorganic, so "litho" [2pts]
   - and the carbon source is: CO_2, which is inorganic, so "auto" [2pts]
   - and so it is a: chemolithoautotroph.
     → see `https://en.wikipedia.org/wiki/Methanogen` and `https://en.wikipedia.org/wiki/Chemosynthesis` for details. (Since organoautotrophs are either rare or don't exist, one often just talks about a chemoautotroph.) [2pts]

3. **Disentangling origin of life questions on Mars.** *Explain (a) the possibility of independent developments of life on both bodies, (b) panspermia from outside the solar system, (c) panspermia from Mars, and (d) contamination from Earth.*

   (i) **Martian DNA similar to that on Earth**:

      (a) The transition from non-living to living matter might be universal. One would then expect this to happen independently on different planets. "Primitive" microbial life (as opposed to intelligent life) is nowadays believed to be widespread. It would, however, be *surprising* if such independent origins produced the same sort of DNA, because we can easily envisage different base pairs than the four used in contemporary life (other bases have been synthesized in the lab). Also, the length of a word (codon) might not be three, and there are many other amino acids that some other DNA could code for.

(b) Panspermia means that (dormant) life in the form of spores could have migrated from elsewhere, for example through meteorites. *If* panspermia from another planetary system is really possible, i.e., if life could survive such a long journey, including the launch from another planet and the arrival on Mars or Earth, then it would *not be surprising* if it was based on the same DNA.

(c) Panspermia from Mars to Earth appears more feasible than possibility (b), because the journey is not that long, and we know of many meteorites that have come from Mars. Again, *if* life survives this, it would again *not be surprising* if it was based on the same DNA.

(d) Contamination from Earth to Mars is a possibility, in spite of all attempts to eliminate or reduce the risk by sterilizing the spacecraft. However, in the early years of space flight, not all spacecraft that flew to Mars were sterilized, so it may have already happened. However, the Martian environment is now hostile to life, so, only *well adapted* life forms could surive on Mars. Nevertheless, *if* life survives the journey to Mars and can even thrive there (which is hard to imagine), it should *not be surprising* if it was based on the same DNA.

[4pts]

(ii) **Opposite handedness of Martian biomolecules**:

(a) *If* it is true that the transition from non-living to living matter is universal, we would expect the biomolecules of life on Mars to be left- or right-handed with 50% probability, so it would then *not be surprising* (and yet amazing!) if it had the opposite handedness.

(b) If panspermia from another planetary system is possible, we would *not expect* it to have the opposite handedness (unless there was panspermia from two different sources with opposite handedness and different ones survived on the two planets).

(c) If life on Earth came from Mars, we would *not* expect it to have opposite handedness.

(d) Similarly, if life on Mars came from Earth (which is hard to imagine), we should *not* have the opposite handedness.

[4pts]