Self-assessment questions for *An Introduction to Astrobiology*

Question 1

This question relates to Chapter 1.

(a) List some of the unique properties of carbon that enable it to play a vital role in supporting life. (*4 or 5 sentences*)

(b) Define chirality and discuss the links between chirality and life, taking into consideration the role played by the ultraviolet circularly polarized light (UVCPL) in star-forming regions. (*About 100 words*)

(c) Briefly comment on the key roles that minerals could have played in the origin of life. (*About 100 words*)

Question 2

This question relates mainly to Chapter 2.

(a) If the total power radiated by a planet is 1.19×10^{18} W then calculate the effective temperature (T_e) of the planet (in K) using Equation 1 (Eq. 1) below. Show your working and report your results in the correct units and to three significant figures.

$$T_e^4 = \frac{L}{4\pi R^2 s} \qquad \text{(Eq. 1)}$$

Where:
L is the total power radiated in Watts (W),
$\pi = 3.14$
$R = 6.30 \times 10^3$ km
$s = 5.67 \times 10^{-8}$ W m^{-2} K^{-4} the Stefan-Boltzmann constant (see IA Appendix B2)
(Note: you met the concept of effective temperature, and this equation, on p. 176 of ISS and in Box 2.1 on p. 46 of IA.)

(b) Outline three competing views for the origin of the Earth's water and cite appropriate examples that can help to distinguish between different options, taking into account any limitations or gaps in our current knowledge. (*About 250 words*)

(c) The level of solar luminosity was lower in the early Solar System than it is today. Outline the key aspects of plate tectonics on the early Earth which are believed to have played a crucial role in regulating the Earth's surface temperature and in bringing about the habitability of the planet. (*About 100 words*)

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Question 3

This question relates mainly to Chapter 3.

(a) Describe the Viking life detection instrument package and GCMS. Critically evaluate the results obtained from these experiments and explain why these results remained inconclusive for detecting life on Mars. (*About 400 words*)

(b) What were the main objections that were raised against the biogenic origin for 'microfossils' in Martian meteorite ALH 84001? (*About 250 words*)

(c) Give some of the factors that would counter the development of life on the surface of Mars even if water was present on the planet. What are the main considerations for landing site selection for any future space missions designed to search for Martian life? (*About 250 words*)

Question 4

This question relates to Chapter 4.

Europa has an icy surface with a noontime temperature at its equator of only 130 K, and yet it has become a prime target for the search for life beyond the Earth.

(a) Outline the *observational* evidence, including that from spacecraft, that has made Europa seem so significant in this regard. *(4 or 5 sentences)*

(b) Explain how hydrothermal vents could harbour life on Europa, and how the most fundamental organisms in a Europan vent community (the 'primary producers') could derive their energy. *(4 or 5 sentences)*

Question 5

This question relates mainly to Chapters 2, 3 and 8.

The following text is based on a NASA Press Release published in January 2009 on a NASA website, announcing the discovery of methane in the atmosphere of Mars. Read this text before answering (a) and (b), bearing in mind what you have learned about both Mars and methane in the course materials.

> **Discovery of Methane Reveals Mars Is Not a Dead Planet**
> WASHINGTON -- A team of NASA and university scientists has achieved the first definitive detection of methane in the atmosphere of Mars. This discovery indicates the planet is either biologically or geologically active.
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> The team found methane in the Martian atmosphere by carefully observing the planet throughout several Mars years with NASA's Infrared Telescope Facility and the W.M. Keck telescope, both at Mauna Kea, Hawaii. The team used spectrometers on the telescopes to spread the light into its component colors, as a prism separates white light into a rainbow. The team detected three spectral features called absorption lines that together are a definitive signature of methane.
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> "Methane is quickly destroyed in the Martian atmosphere in a variety of ways, so our discovery of substantial plumes of methane in the northern hemisphere of Mars in 2003 indicates some ongoing process is releasing the gas," said Michael Mumma of NASA's

Goddard Space Flight Center in Greenbelt, Md. "At northern mid-summer, methane is released at a rate comparable to that of the massive hydrocarbon seep at Coal Oil Point in Santa Barbara, Calif." Mumma is lead author of a paper describing this research that will appear in Science Express on Thursday.

Methane, four atoms of hydrogen bound to a carbon atom, is the main component of natural gas on Earth. Astrobiologists are interested in these data because organisms release much of Earth's methane as they digest nutrients. However, other purely geological processes, like oxidation of iron, also release methane.

"Right now, we do not have enough information to tell whether biology or geology -- or both -- is producing the methane on Mars," Mumma said. "But it does tell us the planet is still alive, at least in a geologic sense. It is as if Mars is challenging us, saying, 'hey, find out what this means.' "

If microscopic Martian life is producing the methane, it likely resides far below the surface where it is warm enough for liquid water to exist. Liquid water is necessary for all known forms of life, as are energy sources and a supply of carbon.

"On Earth, microorganisms thrive about 1.2 to 1.9 miles beneath the Witwatersrand basin of South Africa, where natural radioactivity splits water molecules into molecular hydrogen and oxygen," Mumma said. "The organisms use the hydrogen for energy. It might be possible for similar organisms to survive for billions of years below the permafrost layer on Mars, where water is liquid, radiation supplies energy, and carbon dioxide provides carbon. Gases, like methane, accumulated in such underground zones might be released into the atmosphere if pores or fissures open during the warm seasons, connecting the deep zones to the atmosphere at crater walls or canyons."

It is possible a geologic process produced the Martian methane, either now or eons ago. On Earth, the conversion of iron oxide into the serpentine group of minerals creates methane, and on Mars this process could proceed using water, carbon dioxide and the planet's internal heat. Although there is no evidence of active volcanism on Mars today, ancient methane trapped in ice cages called clathrates might be released now.

"We observed and mapped multiple plumes of methane on Mars, one of which released about 19,000 metric tons of methane," said co-author Geronimo Villanueva of the Catholic University of America in Washington. "The plumes were emitted during the warmer seasons, spring and summer, perhaps because ice blocking cracks and fissures vaporized, allowing methane to seep into the Martian air."

According to the team, the plumes were seen over areas that show evidence of ancient ground ice or flowing water. Plumes appeared over the Martian northern hemisphere regions such as east of Arabia Terra, the Nili Fossae region, and the south-east quadrant of Syrtis Major, an ancient volcano about 745 miles across.

One method to test whether life produced this methane is by measuring isotope ratios. Isotopes of an element have slightly different chemical properties, and life prefers to use the lighter isotopes. A chemical called deuterium is a heavier version of hydrogen. Methane and water released on Mars should show distinctive ratios for isotopes of hydrogen and carbon if life was responsible for methane production. It will take future missions, like NASA's Mars Science Laboratory, to discover the origin of the Martian methane.

(a) Explain what is particularly suitable about one or both of the telescopes and their instrumentation used in this study for the detection of methane in the atmosphere of Mars. (*1 or 2 sentences*)

(b) Bearing in mind the gas species known in Mars's troposphere according to *An Introduction to Astrobiology* Table 3.2, why is the presence of methane particularly significant as evidence of life? What non-biological explanation for methane is offered as an alternative in the Press Release, and how might the biological origin of methane be established by a future mission? (*4 or 5 sentences*)

(c) Summarise observations reported in the Press Release about the spatial and temporal distribution of methane in Mars's atmosphere? What release mechanism does the Press Release suggest for the methane? (*2 or 3 sentences*)

(d) Bearing in mind the likely location suggested in the Press Release for methane-producing Martian organisms, discuss the categorization of these organisms on the basis of IA Table 2.2. (*2 or 3 sentences*)

Question 6

This question relates mainly to Chapter 6 but also to Chapters 7 and 8.
The star HD212301 seen from Earth has a magnitude (apparent magnitude) of 7.77. Its distance is 1.63×10^{18} m. The radial velocity method has revealed a planet in orbit about this star, designated HD212301b. Its orbit has a semi-major axis of 0.036 AU. M$\sin i$ for this planet is 0.45 M_J (where M_J is the mass of Jupiter).

(a) Explain why it would be reasonable to assume that the actual mass (M) for HD212301b is approximately two thirds M_J. (*3 or 4 sentences*)

(b) Calculate (i) the brightness (seen from Earth) and (ii) the luminosity of HD212301. (M*ake it clear which equations from* An Introduction to Astrobiology *you are using. Show your working, and include units at every stage*)

(c) Assuming that HD212301b has the same size and albedo as Jupiter, calculate (i) its luminosity (when at its average distance from the star) and (ii) its brightness (seen from Earth). (*Make it clear which equations from* An Introduction to Astrobiology *you are using*)

(d) Discuss the factors that would make it difficult to image HD212301b in the visible spectrum. (*3 or 4 sentences, supported by calculations*)

(e) With reference to Figure 7.6 on page 244 of *An Introduction to Astrobiology* comment on the ease of detectability of HD212301b by the radial velocity method. (Note that HD212301b is not plotted on this Figure). (*2 or 3 sentences*)

Question 7

This question relates to Chapters 6 and 9
(a) Describe the Drake equation, showing how it can be used to argue that intelligent life ought not to be rare in our Galaxy, and how this then gives rise to the Fermi paradox (*about 150 words*).

(b) Describe the Fermi paradox, and suggest possible ways in which it may be explained (*about 100 words*).

Question 8

This question relates to Chapter 9

(*a*) Define SETI and CETI. (*1 sentence each*)

(*b*) Hydrogen atoms emit at a characteristic frequency of 1420 MHz. Explain why, if wishing to *broadcast* a signal for the attention of an extraterrestrial civilization it would be appropriate to transmit at 452 MHz or 4461 MHz. (*5 or 6 sentences)*

(*c*) If *searching* for an artificial signal, discuss whether a signal received at 4462 MHz would be equally promising as one received at 4461 MHz. (*2 or 3 sentences)*