

Solutions

1. What is the Copernican principle? Make a list of scientific discoveries that confirm it.

The Copernican principle is the idea that Earth and the Sun are in no way specially favored bodies in the universe. Several discoveries confirm this, including (in order of discovery) the following: Earth orbits the Sun and is not the center of our solar system, our Sun is one among billions of other stars in the Milky Way Galaxy and is not in any central position within the Galaxy, our Galaxy is one among billions of other galaxies in the universe, and planets are commonly found orbiting other stars. You could also discuss that the elements that make up most of Earth and the Sun are commonly found in other stars and other planets.

2. Where in the solar system (and beyond) have scientists found evidence of organic molecules?

Beyond our solar system, organic molecules have been found in giant clouds of dust and gas between stars (the “interstellar medium”) and in star-forming regions. In our solar system, besides Earth, organic molecules have been discovered on comets, in meteorites, on Saturn’s moon Titan, in the plumes of water expelled from Saturn’s moon Enceladus, and on Neptune’s moon Triton.

3. What is a biomarker? Give some possible examples of biomarkers we might look for beyond the solar system.

A biomarker is a feature—a chemical substance, a structure, or a signal—that could only have been formed by life. Beyond our solar system, we can only detect planet-scale biosignatures—biological impacts so great that they affect the way a planet appears in reflected or emitted electromagnetic radiation. An example of such an exoplanet biomarker would be unusual atmospheric composition, such as the mutual presence of methane and oxygen. While this would be a strong indication of life, it would not be unequivocal because methane and oxygen can be produced in the absence of life under special circumstances. Another possible example might be very short, very energetic pulses of visible light or infrared radiation or radio waves that are not just natural static, but are coded with information given off by huge structures in space built near or around stars. Both would be biomarkers of technologically advanced civilizations.

4. Why are Mars and Europa the top targets for the study of astrobiology?

Five decades of observation of our neighbor world, Mars, strongly suggest that in the distant past it had an environment (thicker atmosphere, running surface water, perhaps even lakes) that could have sustained life on its surface. Even if such life no longer survives on Mars, its “fossils” might still be found on the red planet. Life could also exist on modern Mars just below the surface, where liquid water is thought to exist. Europa is a top target because of the high likelihood of an extensive salty ocean under the thick ice shell that covers this moon of Jupiter. This ocean, substantially deeper than Earth’s ocean, is probably in contact with a rocky seabed and may be warmed by internal heat; thus the interaction of water and rocks could provide a chemical energy source for life.

5. Why is traveling between the stars (by creatures like us) difficult?

Interstellar travel is difficult for many reasons. The first is certainly the vast distances between the stars. Even at speeds very close to the speed of light, the maximum

theoretical speed achievable, it would require four years or more to travel between stars. At more realistic speeds, trips would take far longer than a human lifetime. And the faster you go, the more expensive (in fuel costs) the trip would be. Since we can't depend on fuel being available at our destination, such travel would require carrying all the fuel necessary for both the trip there and the return trip and require accelerating all that fuel to tremendous speeds—a truly gargantuan effort, and an extraordinarily expensive one. To be sure, those issues only come up if creatures like us are along on the trip. Travel by machines (such as robots, computers, or smartphones) could proceed much more slowly and less expensively. As this book went to press, a billionaire in Silicon Valley gave \$100 million to a project to find technology that could get a very tiny probe to the nearest star using laser propulsion. See: Project Breakthrough Star-shot: <https://breakthroughinitiatives.org/News/4>

6. What is the “cosmic haystack problem”? List as many of its components as you can think of.

Because so many factors go into detecting a signal from extraterrestrial intelligence, some astronomers have compared the effort to searching for a needle in a haystack. Some of the problem's components include the origin and direction of the signal containing the message from among all the possible directions one could “listen,” the frequency chosen for that signal from among the vast range of potential frequencies in the electromagnetic spectrum, the frequency width of that signal, the strength of that signal compared with background noise, the continuity of that signal (whether it's on all the time, or only sweeps over us periodically), the frequency drift of that signal (caused by the relative motion of the sources to Earth), the system used for encoding any message in that signal, and whether we would recognize the nature of the message, when it was coded by alien minds.

7. What is a habitable zone?

A habitable zone is the range of distances from a star where, if water existed on the surface of a planet, that water would likely be liquid.

8. Why is the simultaneous detection of methane and oxygen in an atmosphere a good indication of the existence of a biosphere on that planet?

Oxygen and methane chemically react with each other, so we would not see them together unless there are active sources for both. At least on Earth, biology is responsible for essentially all the oxygen and the majority of the methane in our atmosphere.

9. What are two characteristic properties of life that distinguish it from nonliving things?

Life extracts energy from its environment and has a means of encoding and replicating information in order to make faithful copies of itself.

10. What are the three requirements that scientists believe an environment needs to supply life with in order to be considered habitable?

The requirements are a solvent (water may be the best example), the biogenic elements (CHNOPS) in biologically accessible form, and energy.

11. Can you name five environmental conditions that, in their extremes, microbial life been challenged by and has learned to survive on Earth?

Five environmental conditions that microbial life has overcome are extreme temperature, pressure, salinity, acidity, and radiation.



12. Would a human have been possible during the first generation of stars that formed right after the Big Bang? Why or why not?

No. Humans are composed primarily of the elements carbon, oxygen, hydrogen, and nitrogen, and we live on a planet that is made mostly of silicon, iron, and oxygen. Of these elements, only hydrogen was formed in the Big Bang. The others had to be built up via nuclear fusion in the cores of hot stars, and subsequently ejected into space, before they were available to form a second or third generation of stars with planets around them.



13. What are some answers to the Fermi paradox? Can you think of some that are not discussed in this chapter?

Answers to the Fermi paradox discussed in the text (the question of why, if planets like ours and life out there is common, no one has contacted us) are as follows: intelligence out there is rare, a network of intelligent civilizations has not yet had time to develop, we are not aware of the communications from advanced aliens streaming by us, advanced civilizations do not want to interfere with the development of immature races like us, and advanced civilizations don't last a long time after developing technology that can destroy them or their world. Other ideas include the notion that civilizations might exist and not want to get in touch; that intelligence does not necessarily lead to technology; or that they may first send probes or machines to "scout" what's out there, and these may be much harder to find. A good book on this topic is Stephen Webb's *If the Universe Is Teeming with Aliens . . . Where Is Everybody? Fifty Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life* (2002). The Wikipedia entry on the Fermi paradox also has a good list of suggestions.

14. Why is there so little evidence of Earth's earliest history and therefore the period when life first began on our planet?

Earth efficiently recycles rocks through plate tectonics (and all the accompanying process that erase what is on our planet's surface), so very few rocks (which would record information about environmental conditions) have survived this process.

15. Why was the development of photosynthesis a major milestone in the evolution of life?

Photosynthesis allowed life to take advantage of a much more abundant source of energy than was previously available (the Sun). In addition, the by-product (the chemical "waste") of photosynthesis, oxygen, led to a complete revolution in our planet's ability to host complex life, such as humans. Oxygen in the air, in turn, led to the formation of ozone, which protected the planet's surface from harmful ultraviolet radiation, allowing life to thrive on the land and not just the oceans.

16. Does all life on Earth require sunshine?

No. Many organisms on Earth utilize chemical energy. While some of those (including us) require oxygen that ultimately comes from photosynthesis (oxygen is the by-product of photosynthesis in plants), others – including life on the deep ocean bottom -- require neither light nor the products of photosynthesis and live on energy sources provided by Earth itself.

17. Why is life unlikely to be found on the surface of Mars today?

Mars' present-day atmosphere is very thin. Low temperatures and pressures make liquid water unstable at the surface. Harsh solar UV radiation and challenging soil chemistry make matters worse.

18. In this chapter, we identify these characteristic properties of life: life extracts energy from its environment, and has a means of encoding and replicating information in order to make faithful copies of itself. Does this definition fully capture what we think of as "life"? How might our definition be biased by our terrestrial environment?

It could be argued that fire and computer viruses (both of which we consider nonliving) meet both of these properties, while sterile living species (like mules) fail the second property. Because our planet has solid land and liquid water, we might falsely consider these things necessary for life. The subjectivity in our definition of



life, as well as our terrestrial bias, might make it even more difficult to recognize alien life.



19. Given that no sunlight can penetrate Europa's ice shell, what would be the type of energy that could make some form of European life possible?

Chemical energy resulting from the reaction of rocky mantle with ocean water coupled with oxidizing chemicals could make life possible.

20. Why is Saturn's moon Enceladus such an exciting place to send a mission?

Its plumes of saltwater steam suggest that a liquid water ocean is present beneath the ice. The geysers provide a way of collecting samples of that ocean that would not require (very expensive and challenging) landing and drilling, as would be the case on Europa.

21. In addition to an atmosphere dominated by nitrogen, how else is Saturn's moon Titan similar to Earth?

It rains, although it's not water that falls from the sky, but hydrocarbons like liquid methane and ethane. These also collect into rivers and pool into lakes and seas. Another way to say this is that Titan's surface is at the triple point of methane (it can exist as gas, liquid, or solid,) just as the Earth is at the triple point of water. Other ways Titan resembles Earth is that it is a solid world, that it has clouds and smog in its atmosphere, and that it has hard "rocks" amid the liquid methane—although those rocks are made of water ice, frozen at Titan's temperatures to be as hard as rock is on Earth.

22. How can a planet's atmosphere affect the width of the habitable zone in its planetary system?

The width is affected via the greenhouse effect, in which certain atmospheric gases like water vapor and carbon dioxide trap heat and make the surface warmer than it would be from the star's radiation alone. This can move the inner and outer edges of the habitable zone farther out for planets with thick atmospheres.

23. The light a planet receives from the Sun (per square meter of planet surface) decreases with the square of the distance from the Sun. So a planet that is twice as far from the Sun as Earth receives $(1/2)^2 = 0.25$ times (25%) as much light and a planet that is three times as far from the Sun receives $(1/3)^2 = 0.11$ times (11%) as much light. How much light is received by the moons of Jupiter and Saturn (compared to Earth), worlds which orbit 5.2 and 9.5 times farther from the Sun than Earth?

Jupiter's moons receive $(1/5.2)^2 = 0.037$ times (3.7%) as much light. Saturn's moons receive $(1/9.5)^2 = 0.011$ times (1.1%) as much light.