

LIFE IN THE UNIVERSE – PROBLEMS

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This compilation of test questions is provided to students of MSE 2101 and AST 1078 at Villanova University to help prepare for the in-class tests.

1. Nomenclature is a crucial part of every science – we need to define precisely what we are talking about. Using your notes and/or other available sources, provide precise definitions of the following astronomical terms: *star*, *planet*, *natural satellite*, *asteroid*, *meteor*, *meteorite*, *nebula*, *open cluster*, *globular cluster*, *galaxy*, *galaxy cluster*.
2. Recap the structure of the universe; start from the smallest building blocks and work your way to the large scale structure.
3. How do we define life in scientific terms?
4. Explain Drake's equation in detail and plug in the numbers that you find reasonable. What is the number of expected concurrent civilizations in our Galaxy?
5. Based on your prior knowledge and convictions, speculate whether there is intelligent life beyond Earth. Justify your answer thoroughly.
6. Click your way to wikipedia (or, better yet, flip the pages of an actual encyclopaedia) and summarize (in 2-3 sentences) the contribution to science of major Greek philosophers: Thales, Anaximander, Pythagora, Plato, Aristotle, Aristarchus, Eratosthenes, Ptolomy, Democritus and Epicurus.
7. Explain how did the geocentric model get overturned by *scientific* methods.
8. Science and religion are often claimed to be in conflict. Do you believe this conflict is real and hence irreconcilable, or is it a result of misunderstanding the differing natures of science and religion? Defend your opinion.
9. The dwarf planet Eris, which is slightly larger than Pluto, orbits the Sun every 560 years. What is its average distance (semi-major axis) from the Sun? How does its average distance compare to that of Pluto?
10. Orbital periods for the planets in our Solar system are provided below.
 - a) Determine the distance of each planet from the Sun using Kepler's 3rd law.

- b) Determine the distance of each planet from the simple power law called the Titius-Bode formula: $a = 0.4 + 0.3 \times 2^m$, where $m = -\infty, 0, 1, 2, \dots$ for Mercury, Venus, Earth, etc. Note that you need to count the asteroid belt as well. This formula effectively states that each planet is predicted to be roughly twice as far away from the Sun as the previous planet.
- c) Compute the percent error of the Titius-Bode prediction for each planet.

| Planet: | Mercury | Venus | Earth | Mars | Belt | Jupiter | Saturn | Uranus | Neptune |
|----------------|---------|-------|-------|------|------|---------|--------|--------|---------|
| Period [yrs] | 0.24 | 0.62 | 1.0 | 1.88 | | 11.86 | 29.46 | 84.01 | 164.8 |
| Distance [au] | | | | | | | | | |
| Titius-Bode: | | | | | | | | | |
| Percent error: | | | | | | | | | |

- In recent years, the Vatican has devoted a lot of resources to learning more about the trial of Galileo and understanding past actions of the Church in the Galileo case. Learn more about such studies, and write a short report about the current Vatican view of the case.
- What makes up a scientific *theory* and how is a theory different from a *hypothesis*?
- What is Occam's razor and how does it apply to Ptolomeic vs. Galileian model, and how does it apply to Newton's theory of gravity vs. Einstein's theory of relativity?
- How does the Goldilocks theorem apply to science? Find examples from real life *and* from science and explain why the Goldilocks theorem applies.
- Recap the nebular formation theory of the solar system and comment on its current challenges.
- What is our best guess at how the universe began and what it consists of? What are the *scientific* arguments that support that guess? Based on that, should Big Bang be called a theory or a model? (hint: this is a difficult question without a clear answer; read up on it online before you provide your own opinion; remember that argumentation is key, and following the key points of scientific writing is crucial).
- You are hired as this class's personal detective to figure out how the extrasolar planetary systems compare to our own. Find (and cite!) authoritative sources and describe the orbits, masses, sizes and other properties of discovered extrasolar planets. Do your findings have any implications to life in the universe?

18. Following the discussion in class and after reading Feynman's *Atoms in Motion*, explain what our material world is made of. What did you think of Feynman's essay?
19. What is spectroscopy and how do we determine the chemical composition of an observed substance with it?
20. Which three thermodynamical quantities determine the phase state of matter? Give an example of what happens with water as you change any of the three quantities.
21. What is radioactive decay, and how do we determine geological ages using radiometric dating?
22. Name the three structural types of rock and find at least 3 examples of common rocks for each type. If you attach thumbnail pictures next to them, that might make me extra-credit happy.
23. Print out a periodic table of elements and spend some quality time with it. Learn and explain how the table is organized. Where are the atomic and mass numbers given? What other information is given?
24. How much would a 70-kg person weigh on the Moon, on Jupiter and on the Sun (if he could stand on the latter two)? Look up the masses and radii of these three celestial bodies. The value of the universal gravitational constant is $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{s}^2$.
25. Sedna is a dwarf planet that orbits the Sun at an average distance of 518 astronomical units. What is its orbital period? Google for it and check that it's correct.
26. One light year is the distance traveled by light in one year at a speed of 300,000 km/s.
 - a) What is this distance in km?
 - b) Convert one light day, one light hour, one light minute and one light second to km.
27. How does quadrupling the distance between two objects affect the gravitational force between them?
28. Determine the half-life of potassium-40 if you know that there is ~9% of primordial potassium left from the time Earth was created 4.5 billion years ago.
29. The half-life of carbon-14 is about 5700 years. Is this a good tracer for dating fossils that are ~1 million years old? Explain why.

30. Uranium-238 has a half-life of ~ 4.5 billion years. A rock from lunar highlands shows that 45% of the original uranium decayed into lead. A rock from the lunar maria shows that 37% of the original uranium decayed into lead. Determine the ages of these two rocks; how do they compare? Explain why this makes sense.
31. According to the Titius-Bode rule, at what distance should a planet past Neptune be? What would be its orbital period?
32. What is the most optimistic number of currently living communication-capable civilizations in our Galaxy if you take that, on average, there are 5 planets around every star? What is the most pessimistic number?
33. What is the difference between a necessary condition and the sufficient condition? Give three examples from science and three examples from everyday life.
34. List the 6 criteria that we use to define life and find weak points for each individually – properties of non-living matter that allow it to pass the test. Then try to think of something non-living that adheres to all 6 tests together. Would you say that the 6-prong test is adequate for defining life?
35. What is entropy and how does it relate to our discussion on order and structure?
36. How does natural selection work?
37. Explain what are carbohydrates, lipids, proteins and nucleic acids.
38. Look up online some possibilities of non-carbon based life. What basic elements are the main contenders and why? Based on that, speculate what might such non-carbon based life look like.
39. Flip through Chapter 5 in the book – and by *flip* I mean: read carefully – and find *all* the hints that point to a common ancestor for all life on Earth. Present them in bulleted form.
40. In the previous homework you were asked to explain the principles of natural selection as Darwin saw them. Now that you learned about DNA, give a molecular biologist's perspective on natural selection.
41. What are extremophiles? Find at least 10 cases of extremophiles online, be stupendously amazed, and present their living habitats in a sentence per extremophile. Then comment on any implications of finding such a variety of extremophiles for life elsewhere.
42. Explain how is heredity encoded in the DNA. What is a gene, what is a genome, and what is genetic code?

43. Imagine you were a lucrative farmer who lived several centuries ago, and owned a herd of cows. If you wanted to boost the production of milk via artificial selection, how would you go about it?
44. Go online and find alternatives to the evolution theory. Are those alternatives scientific? If so, what makes them scientific? If not, what makes them *non*-scientific?
45. In class we discussed the evolution of life all the way up to the K-T boundary. Then Earth got struck and the mammals took over the reign of land. Read up on the subsequent evolution of primates and recap how *Homo sapiens* evolved.
46. What clues do we have that life on Earth commenced within the first few hundred million years of its creation?
47. Explain how cellular symbiosis with bacteria lead to a modern cell.
48. How do we explain the offset of sudden diversification during the Cambrian explosion?
49. Google for extinctions before the K-T boundary and determine their frequency; other than impacts, are there other phenomena that can cause massive extinctions?
50. Dr Kenneth Miller is a professor of biology at Brown University. He is the recipient of the Mendel Medal from Villanova in 2009. Google for his talk on youtube titled "Darwinian Grandeur" and invest one hour of your life for watching it. It really is spectacular. Then write a thoughtful reflection based on your own perception of his ideas.
51. What is the story of water on Mars? List all the evidence that indicates the presence of water now and throughout its history.
52. List the three environmental requirements for life and explain what makes water the most suitable medium for life to evolve.
53. What are the prospects for life on: (a) Moon and Mercury; (b) Venus; (c) Mars; (d) Jovian planets; (e) Jovian moons; (f) other minor bodies?
54. What are the 4 experiments that were conducted by Viking and how do they address the question of life on Mars?
55. Google for the rovers currently on Mars and list their major achievements.
56. Curiosity is our latest rover on the surface of Mars. Find and recap the press releases made in 2013 associated with Curiosity and comment on the success of the mission.

57. Recap the prospects for life on Mars inferred from the study of the martian meteorite ALH84001.
58. How do large jovian moons differ from small jovian moons, and how does the formation process explain those differences?
59. Describe the cause of tides on Earth, why they lead to tidal friction, and how tidal friction affects Earth's rotation and the orbit of the Moon.
60. What is tidal heating and how does orbital resonance play into it? What consequence does it have on Io?
61. Describe the evidence for subsurface oceans on Europa.
62. Although Europa is a promising place to look for life, penetrating its thick icy crust will be difficult. Suggest a possible way of making a spacecraft that could enter the european ocean. If it is technically feasible, do you think we should do it soon, or wait until we have further evidence of life? Defend your opinion.
63. What is the habitable zone? How are the inner and the outer boundary defined and how do they change in time?
64. What are the main arguments of subsurface liquid water on Ganymede and Callisto?
65. How does Titan compare to Earth in terms of surface features? What similarities are there between the two celestial bodies? Is the chemistry equally similar?
66. Has Earth been *continuously* habitable? Explain the concept of continuous habitability and provide an estimate of when will Earth stop being habitable.
67. Is global warming a scientific fact? Comment on the statements that "continued CO₂ emission caused by mankind will trigger a runaway greenhouse effect by 2025", and that "severe winters are the clear indication that global warming is a myth".
68. Read up on the exploration of Venus. How do we know about its history and how did we conclude that runaway greenhouse effect can describe the appearance of Venus today?
69. Would it make sense to expect that many extra-solar systems are similar to ours? Argue carefully.
70. Explain in detail how ancient Greek philosophy gave rise to scientific thought. Name the most important thinkers of that time.

71. The apparent retrograde motion of the planets is what ultimately proved the geocentric system wrong. Explain how. Make sure that you precisely state what retrograde motion *is*.
72. What drives plate tectonics in the Earth's lithosphere? Name three types of plate interactions and provide at least one example for each.
73. In his novel *Off on a Comet*, Jules Verne described the comet called Gallia. He stated that its orbital period is 2 years and that its distance from the Sun is 820 million km. Does that make sense?
74. In contrast to cool gas that produces absorption lines in the spectrum, the very hot glowing objects also feature *emission* lines. Speculate what causes emission lines on the atomic level.
75. Should personal testimony be accepted as valid scientific evidence? Argue carefully.
76. Explain in detail how the renaissance brought down the geocentric model. Name the most important thinkers of that time.
77. What evidence makes scientists think that our universe is made mostly of dark matter and dark energy?
78. Name the three hypotheses for the origin of the Moon and the scientific arguments that proved them false. What is the currently adopted model and why does it make sense?
79. Using the Titius-Bode rule, determine the distance of the asteroid belt from the Sun. If the asteroid belt were a planet, what would its orbital period around the Sun be?
80. Imagine an Earth-size extra-solar planet that orbits a star similar to the Sun at 1.4 au. Can such a planet be habitable? If so, what would its atmosphere need to be like when compared to Earth?
81. Quote the sentence about life outside Earth that Epicurus is most famous for. Do you agree with him? Argue carefully.
82. Describe in detail Kepler's laws of planetary motion.
83. According to the nebular theory, how do minor bodies form? Make a clear distinction between rocky planets, gaseous planets, and other small bodies (dwarf planets, asteroids, comets).
84. How did Earth get oceans and an atmosphere? How did Mars lose its oceans and its atmosphere?
85. Suppose Earth were moved to one-third of its current distance from the Sun.

- a) What would happen to the gravitational force between Earth and the Sun?
 - b) What would be the orbital period of Earth?
86. Explain the internal structure of Earth; speculate what would happen if the core were much smaller. How would that impact its habitability?
 87. What was Lamarck's idea of evolution and why did it not work? Explain carefully.
 88. Explain the difference between the top-down and bottom-up approach to artificial life and give an example for each.
 89. Why do we believe that water is an absolute requirement for life? Name the three properties that distinguish water from other liquids.
 90. How does a genome "store" all information on a species? Make sure to explain the structure, pairing and genetic code in the DNA.
 91. *When* did the first major diversity between organisms occur and why?
 92. Small meteorites (< 1 kg) fall onto Earth approximately once a week, completely randomly. Assuming that the cross-section of an average human is ~ 0.5 m², compute the probability of a person being hit by a meteorite in the course of 10 years. *Hint:* the probability of a single meteorite hitting a person will be the area occupied by all humans divided by the total area of Earth. The radius of Earth is $R = 6400$ km and the area of a sphere is $A = 4\pi R^2$.
 93. Does creationism constitute a viable scientific alternative to evolution? Explain carefully.
 94. What is the difference between natural and artificial selection? Name at least three cases of each.
 95. Name the three basic requirements for life and explain where in the solar system can we hope to find all three fulfilled.
 96. What is the difference between RNA and DNA and how do we explain that we live in the DNA-dominated world today?
 97. *When* did the second major diversity between organisms occur and why?
 98. Suppose that a particular bacterial colony replicates each minute, and it started at 12:00. Further suppose that the bacterial growth completely fills the bottle exactly 1 hour after the first bacterium replicated.
 - a) At what time was the bottle half full?

- b) A clever bacterium figures out the impending disaster at 12:55. Will anyone believe the warnings?
 - c) Just before the disaster, a bacterial space program discovers 3 other bottles in the lab. With an immediate and massive population distribution among the original and 3 new bottles, how much more time will bacteria buy?
99. How do we explain the volcanic nature of Jupiter's moon Io? Why is it an issue in the first place?
 100. Methane can be found in notable traces in the Martian atmosphere. What are the two possibilities for the origin of this methane and why is this relevant to the question of life on Mars?
 101. Why do we believe that the meteorite ALH84001 found in Antarctica originated from Mars and how can we tell its geological history?
 102. List at least 3 arguments for liquid (or at least slushy) water on Europa.
 103. Comment on the habitability of Titan. Make sure you address all three requirements for life.
 104. Assuming that the effects of tidal interaction between Earth and the Moon did not change over time, estimate the rotational period of Earth about its axis at the time of creation, ~ 4.3 billion years ago.
 105. The *canals* of Mars brought forth the idea of intelligent life on the red planet. Who was the main protagonist of this idea and how did his argument deviate from the scientific method? Explain carefully.
 106. What is the main driver of Martian weather? What is the dominant feature of Martian seasons?
 107. What are the objections to the claim that the meteorite ALH84001 is proof for life on Mars? Should we hope to find a "better" meteorite to answer that question?
 108. How does the habitable zone depend on the spectral type of the host star, and how does it evolve with time?
 109. Comment on the habitability of Europa. Make sure you address all three requirements for life.
 110. Assuming that the effects of tidal interaction between Earth and the Moon did not change over time, estimate the distance of the Moon at the time of capture, ~ 4.1 billion years ago. The distance to the Moon today is 384,000 km.
 111. Discuss the "hallmarks" of the scientific method. How do they pertain to the search for life in the universe?

112. Can artificial intelligence be considered *alive*? Discuss it in the context of how we define life and argument your opinion precisely.
113. What are the most important factors (biological, chemical, environmental) that allowed for the evolution of complex species here on Earth? Where is all this complexity stored and how?
114. How did we learn what we know about Mars and the possible habitability on Mars? Name some of the important missions and their outcomes.
115. Confront Venus and Earth in terms of their physical properties, orbital properties, habitability and future prospects for life.
116. An A-type star is $\sim 25\times$ more luminous than the Sun.
 - a) At what average distance should a planet orbit the host star for the conditions on its surface to be equivalent to those on Earth?
 - b) What is that planet's orbital period if the mass of the host star is 2.5 times the mass of the Sun?
 - c) Make an educated guess at the range of distances that would bound the habitable zone around that star.
117. Discuss the evolution of the scientific method in ancient Greece. How does it pertain to the search for life in the universe?
118. Looking for life elsewhere, why do we think that, out of all building blocks, carbon is best, and out of all liquids, water is best?
119. What are the most important factors (biological, chemical, environmental) that allowed for the evolution of the first primitive organisms here on Earth? Where does chemistry end and biology begins?
120. How did we learn what we know about Europa and the possible habitability on Europa? Name some of the important missions and their outcomes.
121. Confront Earth and Mars in terms of their physical properties, orbital properties, habitability and future prospects for life.
122. To date the ALH84001 meteorite, a radioactive isotope of ^{238}U was used. The measurements show that 60% of uranium decayed into lead.
 - a) If the half-life of ^{238}U is 4.5 billion years, how old is the meteorite?
 - b) Would ^{40}K or ^{14}C have been better? Their half-life times are 1.25 billion years and 5700 years, respectively.