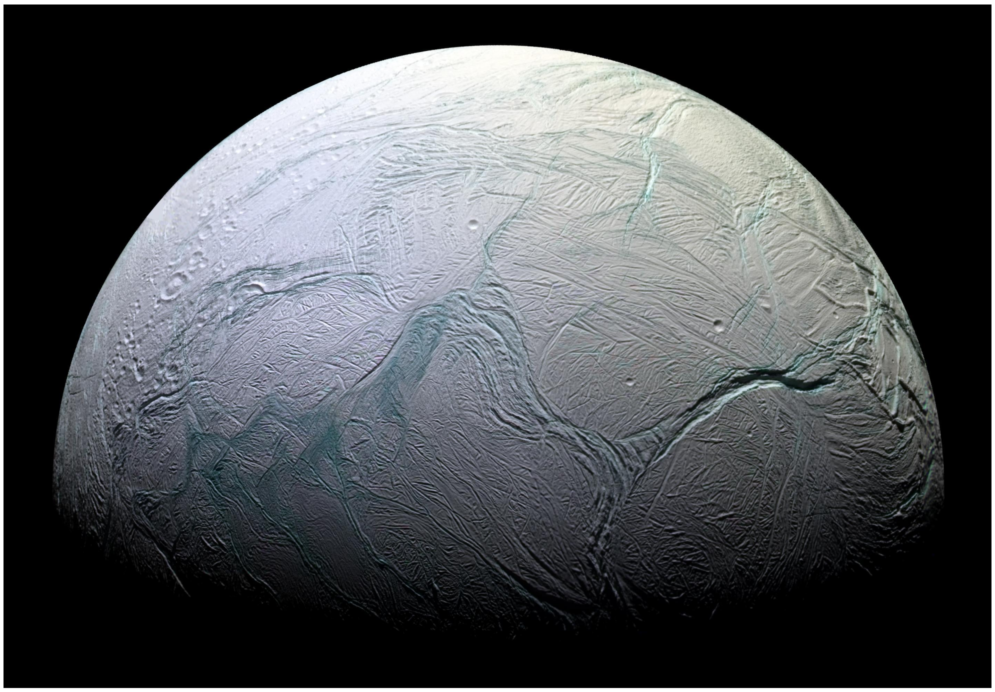
# Science Olympiad
# Solar System
# UT Invitational 2022

October 29, 2022
Austin, Texas



**Directions:**

- You are allowed to bring in one 8.5” × 11” sheet of paper with information on both sides.
- There is no penalty for wrong answers.
- Above all else, just believe!

**Written by:** Aditya Shah

# Section A [50 points]

**When applicable, use the Image Set to answer the following questions. Each part is worth 1 point.**

1. Order the following objects by their (average) distance from the Sun, from nearest to farthest: Enceladus, Venus, Mars, and Europa.
2. Order the following objects by their radius, from smallest to largest: Titan, Venus, 101955 Bennu, and Enceladus.
3. Order the objects shown in the following images by their (average) temperature, from coldest to hottest: Image 1, Image 2, Image 11, and Image 16.
4. (a) What moon is shown in Image 1?
   (b) Around which planet does this moon orbit?
   (c) What geologic feature is illustrated towards the bottom of the moon in Image 1?
5. (a) What planet is shown in Image 3? *Hint: it is outside of the Solar System.*
   (b) In your own words, describe the technique used to discover this planet.
   (c) Suppose you're part of a team of scientists searching for Earth-like planets. Is the technique from (b) better at discovering Earth-like planets in the habitable zones of high-mass or low-mass stars? Explain your answer, as well as any assumptions you make.
6. (a) What object is shown in Image 4?
   (b) Which of the following terms best describes this object? Choose from planet, moon, asteroid, or comet.
   (c) In 2018, this object was famously visited by a NASA mission. What was its name?
   (d) What other image shows this object?
7. (a) In what portion of the electromagnetic spectrum (e.g., ultraviolet, visible, infrared, etc.) was Image 5 taken?
   (b) What image shows this object pictured in visible light?
   (c) What spacecraft or telescope took both of these images?
   (d) What image shows an illustration of this spacecraft or telescope?
8. (a) Image 6 shows the distribution of a sulfur-containing compound over the surface of Europa. What compound is it?
   (b) How do scientists think this compound ended up on Europa's surface?
   (c) What image shows an illustration of the spacecraft or telescope that collected the data to make Image 6?
9. (a) Image 7 shows two "lakes" on Titan. Generally, what substance(s) are these lakes composed of?
   (b) What spacecraft or telescope took Image 7?
   (c) What instrument on this spacecraft or telescope collected the data for this image?
   (d) The lake on the right has lighter patches within it. Why might this be the case?

10. (a) What image shows the hottest planet in the Solar System?
    (b) In what portion of the electromagnetic spectrum (e.g., ultraviolet, visible, infrared, etc.) was this image taken?
    (c) What spacecraft or telescope took this image?
    (d) This planet is much hotter than its planetary equilibrium temperature. Why is that the case?
11. (a) What image shows Martian permafrost?
    (b) What spacecraft or telescope took this image?
    (c) Mars also has water in the form of equatorial glaciers. What image shows these?
12. (a) What object is shown in Image 13?
    (b) What spacecraft or telescope took this image?
    (c) From a chemistry perspective, what is the difference between the white-blue areas and the red-orange areas?
13. (a) Image 17 shows "chaos terrain" on Europa. In your own words, briefly explain what this is.
    (b) Does the existence of chaos terrain imply that Europa's crust is thin, thick, or some combination of the two? Explain why.
    (c) This region of chaos terrain is so well-known that it has a specific name. What is it?
    (d) Image 2 shows a geological feature on Europa closely related to chaos terrain. What are the "dots" in this image called?
    (e) How do scientists think these dots were formed?
14. (a) There is one comet on this year's rules. What is its name?
    (b) What image shows this comet?
    (c) In order to learn more about water in the Solar System, scientists measured the ratio of deuterium to hydrogen in the water vapor surrounding this comet. In your own words, what is deuterium?
    (d) Measurements have shown that the ratio of deuterium to hydrogen in the water vapor surrounding this comet is significantly higher than that of water on Earth. Based on this information, do you think it is likely that the water on Earth came from comets like this? Explain why.
15. (a) Image 20 shows Chasma Boreale, a large canyon in Mars's north polar ice cap. What spacecraft or telescope took this image?
    (b) What instrument on this spacecraft or telescope collected the data for this image?
    (c) The darker areas in this image are thought to be dust. How might the presence of dust affect whether (and how quickly) material is melted compared to areas without dust?
16. (a) What object is shown in Image 21?
    (b) What is the name of the surface feature shown in Image 21? Be as specific as possible.
    (c) This image shows how the temperature varies near this surface feature. In what portion of the electromagnetic spectrum (e.g., ultraviolet, visible, infrared, etc.) would we find this thermal radiation?
    (d) Scientists have measured temperatures as high as 180-200 Kelvin in this area of the object, which is much higher than expected. What process (or property of Enceladus) is leading to the extra heat flow to sustain these high temperatures?

# Section B [45 points]

**For each question, please explain your answer (even if it is a short explanation); it is not enough to give a one-word response like "faster" or "slower".**

17. (16 points) All of the exoplanets in this year's rules orbit red dwarfs, which are smaller, less massive, and dimmer than the Sun. In this question, we'll explore some of the ways red dwarfs can impact the habitability of planets around them.

    (a) (2 points) Compared to our Sun's habitable zone, would the habitable zone around a red dwarf be closer or farther away? Justify your answer by either writing a few short sentences or referencing the equation for planetary equilibrium temperature.

    (b) (3 points) Planets in the habitable zone of red dwarfs have a significant likelihood of being tidally locked to their parent star, but none of the planets in are Solar System are tidally locked to the Sun. Building off your answer to the previous part, why might planets in the habitable zones of red dwarfs be more susceptible to being tidally locked? *Hint: think about the shape (and especially slope) of the function* $f(r) = 1/r^2$ *at both large and small values of* $r$.

    (c) (4 points) *Challenge:* Consider an alternate universe in which the force of gravity scales with $1/r^3$ instead of $1/r^2$. Do you think objects would get tidally locked faster or slower than in our universe?

    (d) (3 points) A tidally locked planet would have one side facing its parent star at all times, while the other side is in constant darkness. What are some ways life could survive in such an environment? Are there any ways that the planet could redistribute the heat? *Note: this is intentionally written as an open-ended question, and you are encouraged to be creative (and imaginative) in your response. A variety of answers will be accepted.*

    (e) (2 points) Red dwarfs emit a significant amount of ultraviolet radiation. Photons in this portion of the electromagnetic spectrum have energies comparable to the energy stored in chemical bonds, like the ones that make up proteins or DNA. Do you think this presence of this radiation would help or hinder the development of life around red dwarfs?

    (f) (2 points) Red dwarfs also "live" much longer than our Sun. Based on your knowledge of how (biological) life evolves, do you think this extra time would help or hinder the development of life around red dwarfs?

18. (12 points) Liquid water is thought to be essential for life as we know it. However, in order for water to exist as a liquid in a stable form, the pressure must be higher than 611.66 Pa. At some point Mars had an atmosphere substantial enough to support such a pressure, but most of it has since disappeared.

    (a) (2 points) 611.66 Pa is a very specific number, and it comes from a famous "point" on the pressure-temperature phase diagram for water. What is it? *Hint: In case this number is more recognizable in other units, 611.66 Pa is equivalent to 6.1166 mbar or 0.0060366 atm.*

    There are many ways that an atmosphere can lose molecules. One involves the wide distribution of speeds gas molecules can have in the atmosphere. even if the average speed of the gas molecules is much less than the escape velocity around the planet/moon

    (b) (2 points) At a given temperature, do you think it is easier for light molecules (like hydrogen) or heavier molecules (like carbon dioxide) to escape from the atmosphere through this processes?

    (c) (2 points) For a given molecule, do you think it is easier for it to escape at high temperatures or low temperatures through this process?

    (d) (3 points) It turns out that this thermal process can only explain why Mars lost its hydrogen and helium. What do scientists think caused the other compounds to escape?

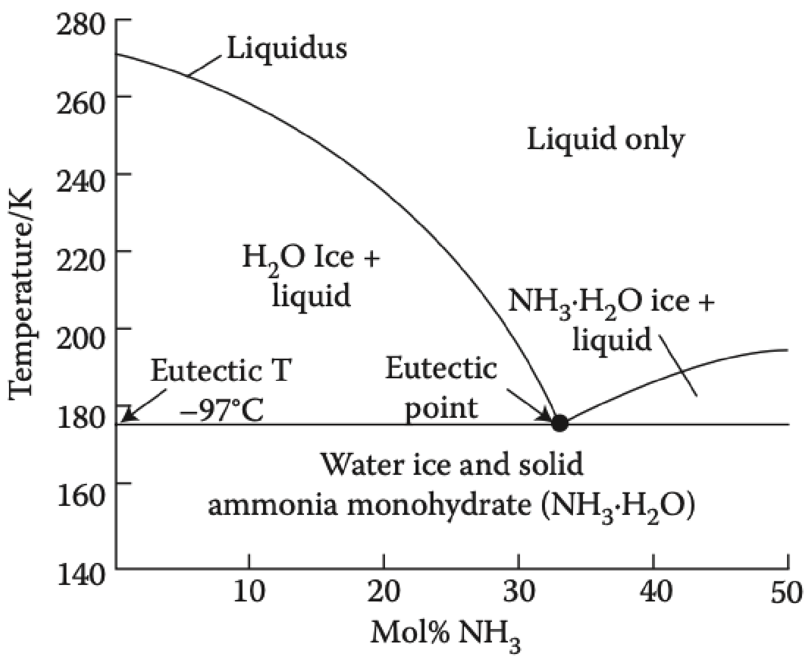
    (e) (3 points) One of the ways scientists supported this theory was by studying the relative abundances of two isotopes of argon, which is a Noble gas. From a chemistry perspective, why would they choose to focus on a Noble gas?

19. (12 points) In addition to having stable bodies of liquid on its surface, Titan is also thought to have a subsurface ocean consisting primarily of liquid water. In this question, we'll begin by examining some of the evidence for a subsurface ocean on Titan before thinking more about how such a subsurface ocean could remain liquid even when Titan is so cold.

   (a) (2 points) Radar mapping carried out by the Cassini mission has shown geologic features on the surface of Titan changing positions by tens of kilometers over the course of only a few years. Why might this support the idea of a subsurface ocean?

   (b) (2 points) Furthermore, the Huygens lander detected extremely low-frequency radio waves during its descent. Why would the detection of these radio waves support the idea of a subsurface ocean?

   Titan is extremely cold, and if the subsurface ocean was purely water, it would be difficult for it to stay liquid. However, if the ocean is a mixture of water and ammonia, the freezing point can drop significantly, as shown in the binary phase diagram of a water-ammonia mixture below.




   (c) (5 points) *Challenge:* From a thermodynamics perspective, why would adding ammonia decrease the freezing point of water? Frame your answer in terms of the entropic barrier that arises when the mixture starts to freeze.

      i. *Hint #1: when the mixture starts to freeze, the water will freeze first, increasing the concentration of the ammonia in the volume of water that is still liquid.*

      ii. *Hint #2: freezing is a process in which $\Delta H < 0$ and $\Delta S < 0$, and for a process to be spontaneous, $\Delta G = \Delta H - T\Delta S < 0$.*

   (d) (3 points) What is the lowest temperature the freezing point can go in this water-ammonia system? At this temperature, what percent of the subsurface ocean will consist of ammonia, by mole?

20. (5 points) When preparing for this event, you probably studied some concepts that weren't covered explicitly on this exam, simply because this exam can't be infinitely long. Choose one of them and talk about it in as much detail as you can. *Note: this question will be the first tiebreaker.*