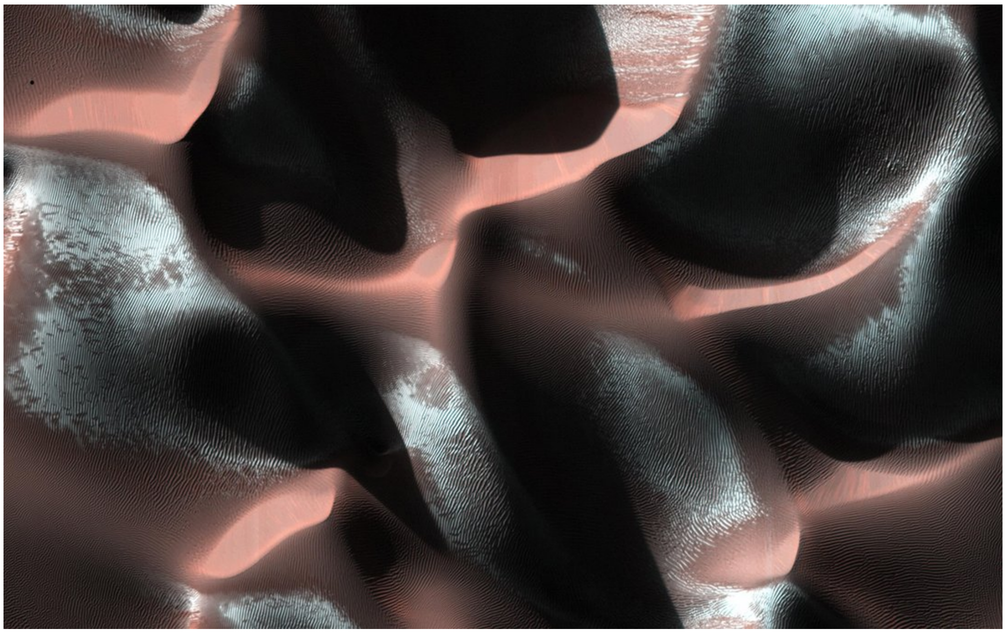
Science Olympiad
Solar System
UT Regional 2023

February 18, 2023
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 [40 points]

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

1. (a) What moon is shown in Image 1?
   (b) Around which planet does this moon orbit?
   (c) What image shows the planet this moon orbits around?
   (d) Is the moon's surface younger on the right side or left side of Image 1? How do you know?
2. (a) What is the name of the second planet from the Sun?
   (b) NASA is planning two missions to this planet over the coming decades. What are their names?
   (c) In your own words, gives a brief explanation of what each mission plans to study on this planet.
3. (a) What object is shown in Image 3?
   (b) What spacecraft or telescope took this image?
   (c) What type of object (e.g., planet, star, moon, comet, asteroid, etc.) is this?
4. (a) Image 4 shows a portion of one of Mars' poles. Is it the North Pole or the South Pole?
   (b) The dunes in this image have white stretches along them. What compound is this white material?
   (c) These white stretches are pockmarked with black spots, which are sometimes called "dalmatian spots". How do scientists think these spots were formed?
5. (a) What object is shown in Image 5?
   (b) What spacecraft or telescope collected the data used to create Image 5?
   (c) The prominent line going from (approximately) the top left to the bottom right of Image 5 has uneven blotches of darker, redder material which are more prominent in some locations than in others. What might this indicate about the geologic activity around this line?
6. (a) Image 8 shows evidence for water vapor plumes on a moon in the Solar System. Which moon?
   (b) What spacecraft or telescope collected the data shown in blue?
   (c) Is the data in blue a photograph? If not, what is it?
7. (a) What object is shown in Image 9?
   (b) In what portion of the electromagnetic spectrum was this image taken?
   (c) What is the name of the dark region in the center of the image?
   (d) What do scientists think this dark region is?
   (e) This region is the planned landing site of the *Dragonfly* spacecraft. In your own words, explain what type of spacecraft *Dragonfly* is (e.g., rover, orbiter, etc.).
8. (a) What image shows Cufa Dorsa?
   (b) What spacecraft or telescope took this image?
   (c) What object is this surface feature on?
   (d) In your own words, explain what a "dorsa" is.

9. (a) Image 10 shows the distribution of atomic carbon, oxygen, and hydrogen around Mars. In what portion of the electromagnetic spectrum was this data collected?
   (b) Which spacecraft or telescope collected the data used to make this image?
   (c) If you look at the scale on the axes, you'll notice that atomic hydrogen is prevalent much further away from Mars than atomic carbon or oxygen. Why might that be the case?
10. (a) What image shows 67P/Churyumov–Gerasimenko?
   (b) Churyumov–Gerasimenko was visited by a mission led by the European Space Agency in 2014. What was the name of this mission?
   (c) Churyumov–Gerasimenko has a distinctive, two-lobe shape. How do scientists think it was formed?
11. (a) Image 13 shows shows a portion of Jezero Crater. What object is Jezero Crater on?
   (b) What spacecraft or telescope was used to collect the data used to create this image?
   (c) The map shows the distribution of minerals like olivine and pyroxene, which are commonly found in igneous rocks. In your own words, explain what an igneous rock is.
   (d) Many of the olivines found in a certain part of Jezero Crater contain magnesium-iron carbonate. How do scientists think this may have formed?
12. (a) Of the four extrasolar systems in the rules, which one is closest to the Solar System?
   (b) What detection method was used to find the planet(s) in this system?

Section B [45 points]

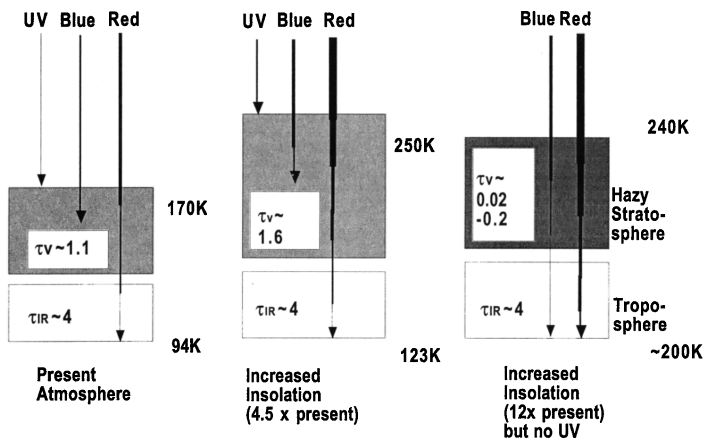
For each question, please explain your answer (even if it is a short explanation); it is not enough to give a one-word response like "faster" or "slower".

13. Recently, a team of researchers led by Emily Gilbert discovered a new planet in the TOI-700 system called TOI-700 e. To make this even more exciting, TOI-700 e is about the same size as Earth and is in the optimistic habitable zone of its parent star!
    (a) (3 points) TOI-700 e is one of two planets in this system that is in TOI-700's optimistic habitable zone. What is the name of the other, and how does it compare in size and insolation to TOI-700 e?
    (b) (2 points) What does it mean when we say these planets are in the habitable zone of their parent star? Does that mean they have life on them? Explain.
    (c) (2 points) Astronomers think TOI-700 e is tidally locked. What does that mean? Do you think it is more common for habitable planets to be tidally locked around a star like TOI-700 or the Sun?
    (d) (2 points) The planets in the TOI-700 system were discovered using the transit method. In your own words, explain how the transit method works.
    (e) (2 points) If you *only* have transit data, it is impossible to *exactly* calculate the mass (and with it, density) of a planet. However, in their discovery paper, Gilbert *et. al.* mention that TOI-700 e is "likely a rocky planet with a probability of 87%". How might astronomers be able to make an educated guess about the composition/density of the planet with only transit data? *Note: the percentage and the exact methodology the astronomers used don't matter for this question; think about whether there are any rough correlations/relationships between mass/density and radius for planets.*

14. Moons such as Europa, Enceladus, and Titan are some of the most promising places in the entire Solar System for life. However, understanding whether (and how) life could survive is complicated by these moons' extremely low temperatures.
    (a) (3 points) Catabolic reactions are used in biochemistry to break down molecules. Imagine a catabolic reaction ($\Delta H_{rxn} < 0$) on one of these moons. Assuming everything else is the same, will the lower temperature cause the equilibrium constant for this reaction to be higher, lower, or the same compared to what it would be on Earth?
    (b) (2 points) Looking at equilibrium tells us what happens if we give the reaction infinite time to run. However, we also care about how quickly reactions take place. Generally, if everything else is the same, reactions will be slower at lower temperatures than higher temperatures. Why is this the case?
    (c) (2 points) Chemical reactions can take place in a variety of phases. For example, on Enceladus or Europa, they may happen in the liquid/aqueous phases, due to their substantial subsurface oceans, while on Titan, they can also occur in the gaseous phase, since Titan has a substantial atmosphere. Reactions in the solid phase usually take place much more slowly than reactions in the gaseous, liquid, or aqueous phases. Why might that be the case?
    (d) (4 points) Determining rate constants and equilibrium constants can be difficult work, particularly at low temperatures. You are studying chemical reactions on Titan and your friend (who knows nothing about chemistry) suggests measuring these quantities at high temperatures in the lab, when all of the chemical species are in their gaseous forms, and then using a mathematical relationship to estimate what those values would be at 94 Kelvin, the surface temperature of Titan. What limitations may their plan have? *Hint: the boiling point of many hydrocarbons is around the surface temperature of Titan.*

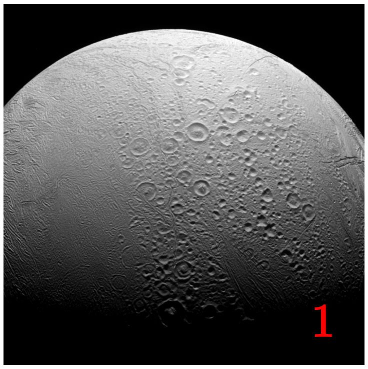
15. From the previous question, it's clear that temperature plays a big role in the chemistry we'd see in the Solar System. Interestingly, some scientists think that moons in the outer Solar System may become warmer in the future as the Sun evolves.
    (a) (4 points) When the Sun becomes a red giant, its temperature will (approximately) halve and its radius will (approximately) increase by a factor of 100. Assuming everything else stays constant, by what factor would we expect the equilibrium temperature of Enceladus to increase? Show your work, even if it's only one line.
    (b) (3 points) Determining the temperature of an object becomes much more complicated when that object has a substantial atmosphere, like Titan. Titan happens to have both a "greenhouse" effect and an "anti-greenhouse" effect due to its atmosphere. What causes each of these effects, and which one ("greenhouse" or "anti-greenhouse") affects the temperature more?

    As you may have guessed, it turns out that our assumption that everything else stays constant in part (a) is not likely to be accurate, especially for an object like Titan. Work done by Lorenz *et. al.* in 1997 presents the following evolution of Titan's atmosphere and temperature, which is shown in the figure below. The leftmost diagram shows Titan's atmosphere today, and moving to the right corresponds with going further into the future.



    (c) (2 points) In the middle diagram, the insolation is increased by 350%, but the surface temperature of Titan only increases by about 30%. Why is the surface temperature increase going from the left to the middle diagram so small?
    (d) (3 points) In the rightmost diagram, we see that once the Sun stops producing a significant amount of UV light, the surface temperature increases much more substantially. Specifically, going from the middle to the right diagram, the insolation increases by 167%, and the surface temperature increases by about 67%. Why would removing the UV emission make the surface warm up more?
    (e) (3 points) In the rightmost diagram, the surface temperature of Titan is only about 200 Kelvin, which is far below the freezing point of water. Can you think of any ways the freezing point of water could be lowered so that some form of liquid water (even if it isn't pure) could exist on Titan's surface at this temperature? How would it work?
    (f) (3 points) Imagine you are part of a civilization of humans living on Titan in the (very) distant future, when the surface temperature is about 200 Kelvin. What are some of the challenges you and your friends may encounter? How might y'all solve them? Be as creative or imaginative as you want; this is intentionally written as a very open-ended question.

16. (5 points) When preparing for this event, you probably studied some concepts or objects that weren't covered explicitly (or in very much depth) on this exam. Choose one of them and tell me about it in as much detail as you can. *Note: this question will be the first tiebreaker.*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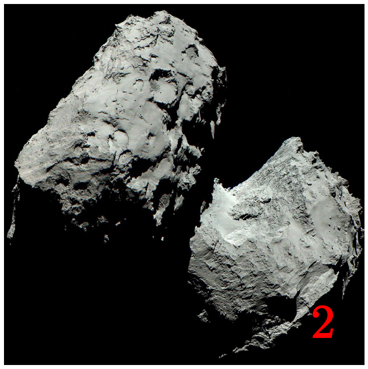
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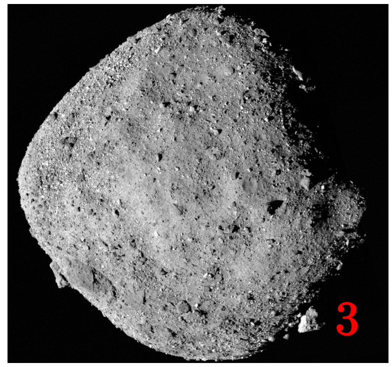
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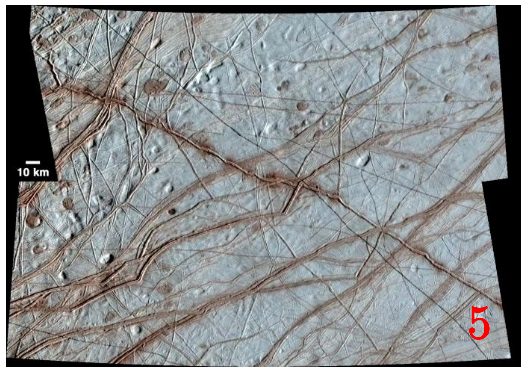
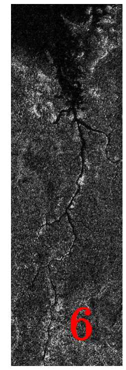

10 km
5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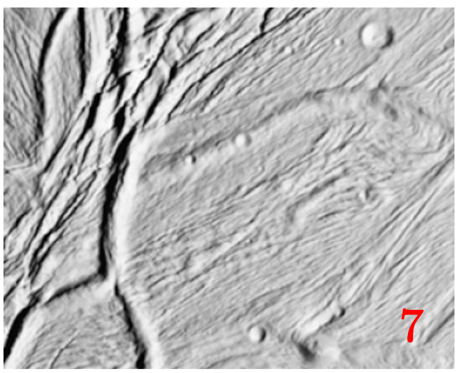
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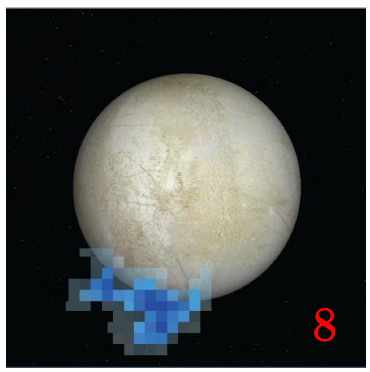
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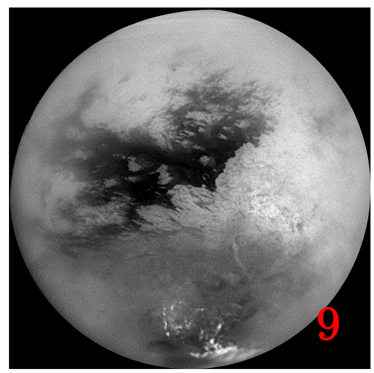
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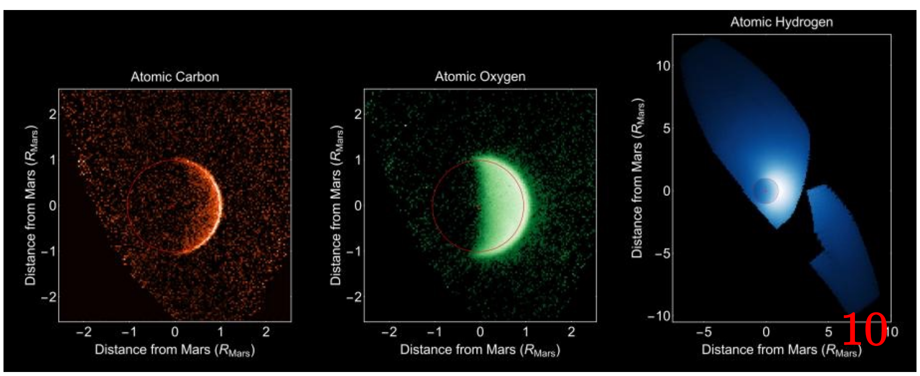
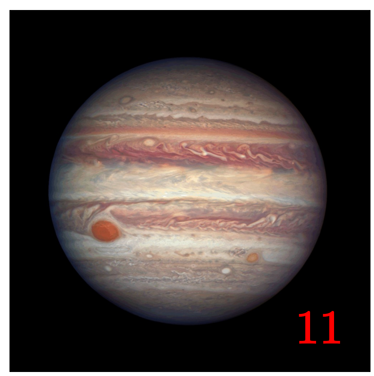

Atomic Carbon
Atomic Oxygen
Atomic Hydrogen
Distance from Mars (R_{Mars})
Distance from Mars (R_{Mars})
10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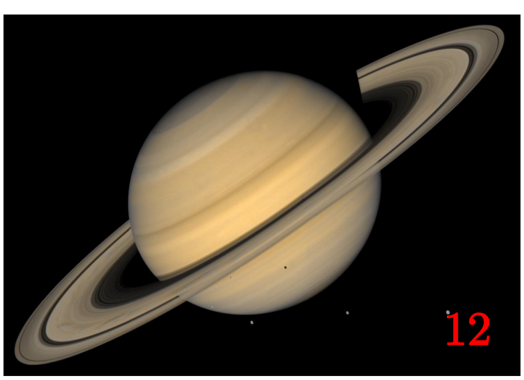
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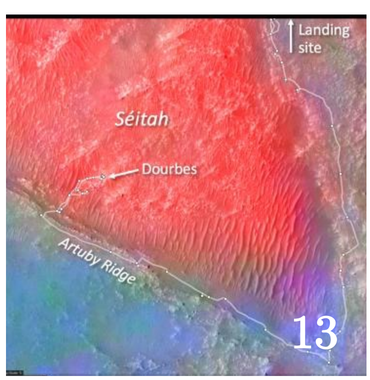
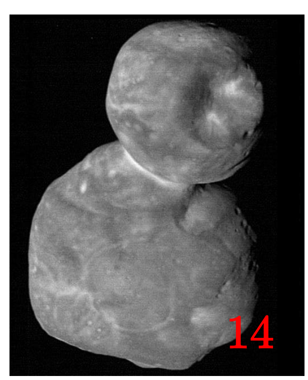

Landing site
Séítah
Dourbes
Artuby Ridge
13


14

Answer Sheet

Section A [40 points]

1. (a)
   (b)
   (c)
   (d)
2. (a)
   (b)
   (c)
3. (a)
   (b)
   (c)
4. (a)
   (b)
   (c)
5. (a)
   (b)
   (c)
6. (a)
   (b)
   (c)
7. (a)
   (b)
   (c)
   (d)
   (e)
8. (a)
   (b)
   (c)
   (d)
9. (a)
   (b)
   (c)
10. (a)
    (b)
    (c)
11. (a)
    (b)
    (c)
    (d)
12. (a)
    (b)

Section B [45 points]

13. (a)

(b)

(c)

(d)

(e)

14. (a)

(b)

(c)

(d)

15. (a)

(b)

(c)

(d)

(e)

(f)

16.

Answer Key

Section A [40 points]

1. (a) Enceladus
   (b) Saturn
   (c) Image 12
   (d) Younger on the left, since it has fewer craters.
2. (a) Venus
   (b) DAVINCI and VERITAS
   (c) DAVINCI will orbit Venus to learn more about its atmosphere (and also send a probe through Venus' atmosphere). VERITAS will also orbit Venus, but it will focus on understanding Venus' surface and interior.
3. (a) 101955 Bennu
   (b) OSIRIS-REx
   (c) Asteroid
4. (a) North Pole
   (b) Dry ice (carbon dioxide ice)
   (c) They are explosive marks left behind from carbon dioxide sublimation/avalanches
5. (a) Europa
   (b) Galileo
   (c) It is (or recently was) geologically active
6. (a) Europa
   (b) Hubble Space Telescope
   (c) It is not a photograph. Instead, HST "spectroscopically detected auroral emissions from oxygen and hydrogen", which is thought to be a proxy for the plumes themselves.
7. (a) Titan
   (b) Infrared
   (c) Shangri-La
   (d) Broadly speaking, scientists think it is an immense sand sea of dark, organic material of unclear origin/composition.
   (e) *Dragonfly* is a rotocraft lander (answers like "helicopter" will also be accepted).
8. (a) Image 7
   (b) Cassini
   (c) Enceladus
   (d) It's a ridge, not unlike the ones found on Europa
9. (a) Ultraviolet
   (b) MAVEN
   (c) Hydrogen is much lighter than carbon or oxygen
10. (a) Image 2
    (b) Rosetta
    (c) Two objects slowly came into contact due to their mutual gravitational attraction - this is called a "contact binary".
11. (a) Mars
    (b) Perseverance
    (c) Igneous rocks are rocks that are formed due to lava or magma cooling and solidifying
    (d) Contact with liquid water rich in carbon dioxide
12. (a) Proxima Centauri
    (b) Radial velocity

Section B [45 points]

13. (a) (3 points) TOI-700 d is the other planet in the habitable zone (+1). TOI-700 d is slightly larger (+1) and receives less light from TOI-700 (+1) than TOI-700 e.

    (b) (2 points) Generally speaking, "habitable zones" refer to a range of distances where scientists think the temperature of a planet would be able to support liquid water (assuming a suitable pressure). They usually include a bit a variation due to assumptions about atmospheres, heat distribution, albedo, etc. (+1). Being in a habitable zone does *not* mean that a planet has life on it (+1).

    (c) (2 points) Tidally locked planets always have the same side facing the parent star. As a result, one side of the planet is always experiencing daytime, while the other is experiencing nighttime (+1). It is more common for planets in the habitable zone of their parent stars to be tidally locked around red dwarfs than the Sun, since red dwarfs are much dimmer, forcing the planets to be closer, where tidal forces are stronger (+1).

    (d) (2 points) Planets cross in front of their parent star as viewed by us. This causes the star to appear slightly less bright, since the planet is blocking some of its light. We measure the dip in the star's brightness to estimate how large the planet is (+2).

    (e) (2 points) Based on our current understanding of planet formation and structure, we know that certain types of planets tend to be a certain mass or radius, and different things (e.g., solid accretion, gas accretion, self-compression, etc.) affect their size. In other words, mass and radius are closely related to each other (planets don't exist with random combinations of them). As a result, we can use mass-radius relationships for planets of different classes (e.g., rocky planets, Neptune-like planets, etc.) to empirically correlate a radius to a mass. See Chen and Kipping (2017) for more details if you're interested.

14. (a) (3 points) The equilibrium constant will be higher (+1). There are a couple of ways to rationalize this; let's examine it from the perspective of Le Chatelier's Principle. Catabolic reactions release energy in the form of heat, so we can think of heat as a "product" of the reaction. Decreasing the temperature removes heat, so the equilibrium will shift to produce more heat. This corresponds with an increase in the equilibrium constant (+2).

    (b) (2 points) This part can be understood using collision theory. At higher temperatures, molecules will be moving around more (and faster), leading to more collisions. Molecules need to collide to react with each other, so more collisions give them more chances to react (+1). Additionally, the molecules need to have a certain amount of energy (called an *activation energy*) in order to actually react. So, when the temperature is increased, the molecules collide with more energy, and a larger proportion of them have enough energy to get over the activation energy barrier (+1).

    (c) (2 points) Atoms or molecules in a solid are typically "locked" into position and cannot move around very easily (+1). As a result, it makes it very difficult for them to react with each other, since collisions between molecules are rarer than they are in gases or liquids (or solutions). Furthermore, in a reaction between two solids, the reaction can usually only take place at the interface between the two solids (and a little more, depending on the solubilities of the solids in each other). However, in a liquid or gas, the molecules can easily mix (+1).

(d) (4 points) This is a nice idea if the properties of the compounds and reaction stay (relatively) constant throughout the entire reaction. Scientists use relations like the van 't Hoff equation and the Arrhenius relation to do this stuff. However, on the surface of Titan, the temperatures are low enough such that some of these hydrocarbons may condense or even freeze. These phase changes completely change what the reaction would be like, so the data you collect from the reaction where everything is a gas would not be very useful. (+4).

15. (a) (4 points) The equation for equilibrium temperature is:

$$T = T_{star}\sqrt{\frac{R_{star}}{2a}}(1-\alpha)^{1/4} \tag{1}$$

We assume that T_{star} and R_{star} are the only variables that are changing. So,

$$\frac{T_{new}}{T_{old}} = \frac{0.5 \times T_{star}}{T_{star}}\sqrt{\frac{100 \times R_{star}}{R_{star}}} = 0.5 \times 10 = \boxed{5} \tag{2}$$

(b) (3 points) The greenhouse effect is caused by methane (+1), while the anti-greenhouse effect is caused by haze in the atmosphere reflecting incident light back (+1). Overall, the greenhouse effect is stronger (+1). Specifically, it increases Titan's temperature by about 21 Kelvin, while the anti-greenhouse effect decreases Titan's temperature by only 9 Kelvin.

(c) (2 points) The atmosphere becomes much thicker (+1) due to the mechanics of haze production on Titan. This makes it harder to light to get through to the surface of Titan (+1).

(d) (3 points) Haze is produced by UV radiation (and other highly energetic particles) hitting molecules in Titan's atmosphere (+1), leading to complicated chemical reactions. If the UV radiation goes away, then the haze production will drop significantly (+1). Since haze contributes to the anti-greenhouse effect, less haze will help warm up the moon, and it will make the haze layer less optically thick (+1).

(e) (3 points) You could add another substance (e.g., ammonia) to the water (+1), which would decrease the freezing point. The addition of a solute to the water will make the act of freezing less favorable from an entropy-perspective, which will drive the freezing point down (+2).

(f) (3 points) Answers will vary. Graded entirely based on effort, level of detail, and accuracy.

16. (5 points) Answers will vary. Graded entirely based on effort, level of detail, and accuracy.