Name:______________________________
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1 Gases, Liquids and Ices in the Outer Solar System

1.1 Introduction

Water. You are familiar with water in all of its three forms: liquid, gaseous (steam), and solid (ice). Human life, and life on Earth itself, would be impossible without liquid water. Thus, NASA has used the goal of "Follow the Water" in searching for life elsewhere in our solar system. We have found that water exists in some form on just about all of the bodies in the solar system. On hot Mercury, there appears to be water ice located in the polar regions in permanently shadowed craters. The same is true for the Earth's moon. Even one of the driest bodies in our solar system, Venus, has a little bit of water vapor in its atmosphere, and probably has some water buried deep within its crust.

It is difficult to envision how any forms of life could survive on Mercury, Venus, or the Moon. The same is not true, however, as we go further out into the solar system. As you have learned in this class, the planet Mars has ample evidence that liquid water flowed on its surface in the past, as well as large deposits of ice at its poles, and frozen into the soil. The big question is whether there is liquid water *anywhere* on present-day Mars. As you also will find out this semester, several of the moons of the Jovian planets have evidence for liquid water. In fact, water ice is ubiquitous in the outer solar system–many of the solid surfaces found beyond the orbit of Mars have water ice as a major constituent.

Today we are going to investigate gases, liquids and ices. Since objects in the outer solar system are far from the Sun, they are cold, thus any liquid water on the surface will usually be frozen. To understand the conditions on Mars, or on one of the moons of the Jovian planets, we have to understand how water, and other substances, *behave at different temperatures and at different pressures.*

1.2 Water on Earth, and the Triple Point Diagram

All of you are experienced with how water behaves on the surface of Earth. If the temperature is above the freezing point, any water on the surface, or any that falls from the sky, will be a liquid. You know that this temperature is 32°F. This is the freezing point of water on the surface of the Earth. You are also aware that if you heat a pot of water on the stove for long enough, the water will boil, producing water vapor (steam). Steam is the gaseous form of water. The boiling point of water is 212°F *at sea level.*

Did you notice we added the "*at sea level*" in the previous sentence? If you are a cook, you might have noticed that many recipes (even frozen pizzas!) have different cooking times depending on altitude. Why? It is because the temperature at which water boils and becomes steam is dependent on the atmospheric pressure. For Las Cruces, our elevation is near 4,000 feet. Our air pressure is lower than at sea level, and thus the boiling point of water is lower: 204°F. It takes a little bit longer to cook spaghetti in Las Cruces, than if you lived in San Diego.

The first question you may have is "why does the atmospheric pressure drop with increasing altitude?" The answer is simple: atmospheric pressure is just the "weight" of all of the air above your head. As you climb in altitude, there is less air above you, so there is less pressure. At some altitude, there will be no atmosphere left, and thus no pressure: the vacuum of space. Most definitions of the end of the Earth's atmosphere put this altitude at 100 km.

The second question you should ask, or at least be thinking about, is "why does atmospheric pressure have anything to do with the boiling point of water?" This question is a little bit harder to answer. When you heat a substance (whether solid, liquid or gaseous), the molecules that make up that substance start vibrating. They are getting "excited" by the heat. As a liquid heats up, some of the molecules near the surface of the liquid have enough energy to jump out of the liquid, and try to escape. But the atmospheric pressure pushes back on them, and keeps them in the liquid. Eventually, however, these molecules acquire enough energy to overcome that atmospheric pressure, and the highest energy molecules can escape. Eventually, all of the molecules have enough energy to escape, and the liquid boils away.

Bell Jar Demo: We are going to demonstrate this effect in class today. To do this, a glass "bell jar" is connected to a strong pump. As we pump out the air, we lower the pressure. As the pressure drops, the water in the container will freeze—even though the temperature in the room is well above freezing! The pump, besides removing the air in the vessel, also removes the most "excited" water molecules. Thus, the water is also cooled.

Just about every substance in the Universe behaves this way. There are solid forms, liquid forms and gaseous forms of just about all substances. There is a complicated relationship between the boiling points and freezing points that depend on the local temperature and pressure. These relationships can be easily summarized in something called a triple point (or "phase") diagram. A simple version of such a plot is shown in Fig. 1.

1.3 Understanding the Triple Point Diagram for Water

For the first part of today's lab, we are going to be looking at the triple point diagram for water. In such a diagram, the temperature will be on one of the axes, while the pressure is on the other one. Note that sometimes temperature is on the x-axis, and sometimes it is on the y-axis. There is no rule.

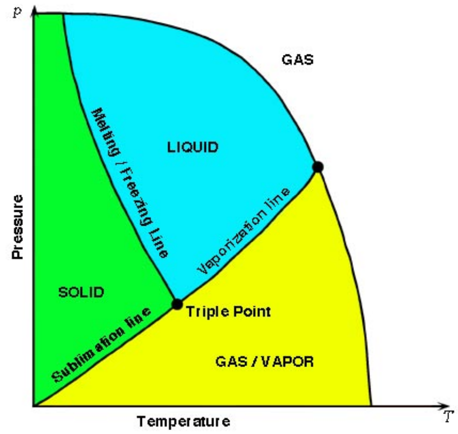

Figure 1: A simple triple point diagram. At certain temperatures and pressures a substance can be a solid, a liquid or a gas. **There is one place in "phase space" where all three states of matter simultaneously exist: the triple point.** In this version of the diagram, temperature is on the x-axis, and pressure on the y-axis (from http://www.kchemistry.com/Quizzes/triple_point_lg.jpg).

Before we begin, however, we must talk about the units we are going to be using in this lab. For the temperature, these diagrams are either in Celsius or Kelvin. Remember that the Celsius temperature scale was defined with respect to the behavior of water: 0°C is the freezing point of water (= 32°F), and 100°C (= 212°F) is the boiling point. In the Kelvin system 0°C = 273 K, and 100°C = 373 K (the zero of the Kelvin scale is something called "absolute zero", and is equivalent to -273 °C = -459°F). The three scales are compared in Fig. 2.

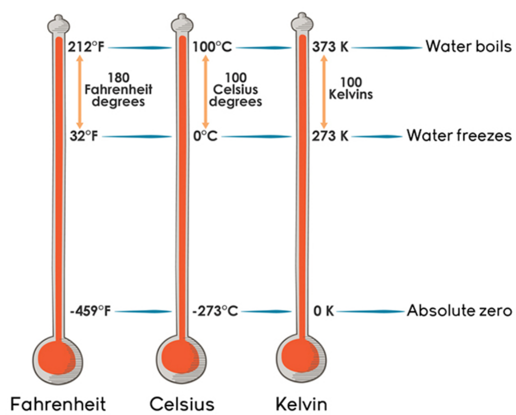

Figure 2: A comparison of the three temperature scales used by the public and by scientists: Fahrenheit, Celsius, and Kelvin (from https://www.learner.org/courses/chemistry/images/lrg_img/ThermometersFCK.jpg).

The other component of a triple point diagram is the pressure. There are several different units that can be used for pressure. In the US we use pounds per square inch. In countries on the metric system they may use kilograms per square centimeter. But these result in complicated numbers to memorize. The unit of pressure that we will be using is the "bar." One bar is the standard pressure at the Earth's surface, or "one unit of atmospheric pressure." If the pressure is 0.1 bar, this is equivalent to 10% of the pressure at the Earth's surface.

Now we are ready to look at a more realistic triple point diagram for water: Fig. 3. At one bar (the air pressure at sea level), the freezing point of water is at 0^{o}C, and the boiling point at 100^{o}C (or 273 K and 373 K, respectively). Note that the triple point of water is at 0^{o}C, but at a very low pressure: 6 millibars. On Earth, this corresponds to an altitude of 60 km! Notice that the range of temperatures and pressures at which water is a liquid is smaller than found for either ice or gas. Water ice can occur over a very wide range of temperatures and pressures. At high pressures, there can be forms of water ice that exist at temperatures above 1,000^{o}F! As this diagram delineates, there are various types of ice that are segregated by the shape of the ice crystals.

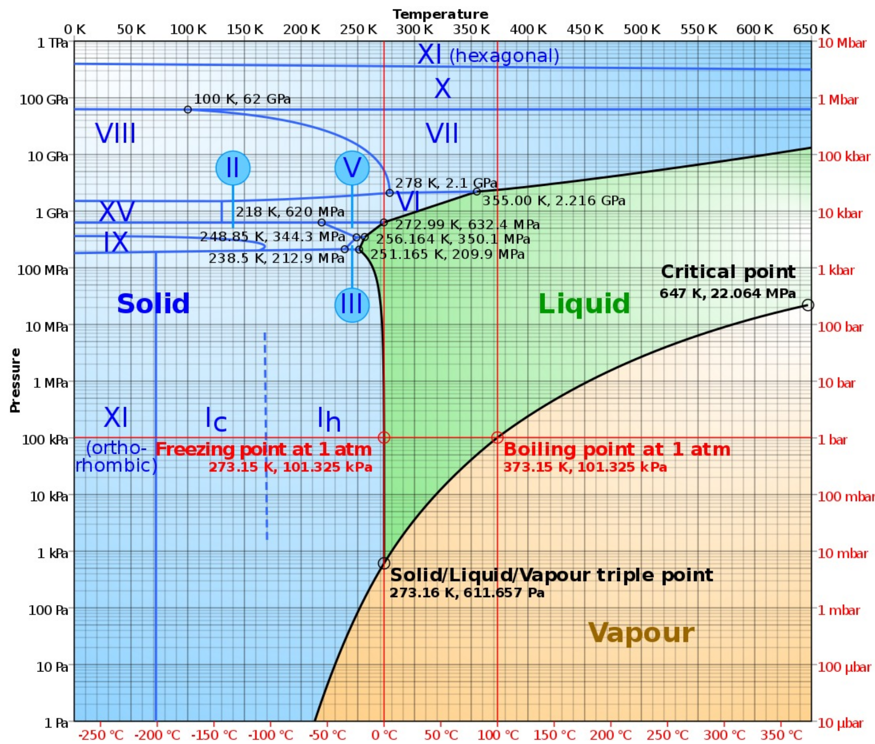

Figure 3: The triple point diagram for water. On the x-axis we have the temperature in Celsius, and on the top of the diagram, the temperature is in Kelvin. On the y-axis (right hand side) we have the pressure in units of bars. Note that this axis is plotted in powers of 10, or *logarithmically*. This allows us to plot the enormous range in pressures necessary to explore the triple point diagram of water. The left hand y-axis has the metric units of pressure in "Pascals," from 1 Pa, to 1 TPa (Terra Pascal = 1 trillion Pascals). 1 bar = 100,000 Pa. We will not be using Pascals in this lab! (From https://en.wikipedia.org/wiki/Triple_point.)

1. The (average) atmospheric surface pressure on Mars is 6 millibar (= mbar). This is very close to what special place in the phase diagram of water? What form(s) of water might we find at this pressure? (**2 points**).

Like on Earth, the temperatures at various locations on Mars depend on the season, and span the range from -140^{o}C in winter to 20^{o}C in the summer. Unlike the Earth, the atmospheric pressure on Mars spans a large range: from 4 mbar in winter to about 9 mbar in summer (more than a factor of two!).

2. Do we expect to find liquid water on the surface of Mars during the winter? Why? What form(s) or *phase(s)* of water can exist during the winter time on Mars? (**2 points**).

3. How about during the summer? What phases of water can exist during the summer time on Mars? (**2 points**).

It is clear that there is a very narrow window of temperatures and pressures that would allow for liquid water on the surface of Mars. Let's look at some other objects you have learned (or will learn) about in class. The Jovian planets Uranus and Neptune are also called "ice giants." This is not because they have icy surfaces, but because deep below the tops of the clouds there is a region of ice. The so-called "ice mantle," shown in Fig. 4.

4. If the temperature of the ice mantle in Uranus is 350^{o}C (= 623 K = 660^{o}F), and if it were composed entirely of water (not true), what must the pressure be in the ice mantle? (**2 points**)

1.4 Sublimation and Vaporization

Returning back to Fig. 1, there are some words in this diagram we need to become familiar with: sublimation, and vaporization. To these we add the word for the reverse of vaporization: condensation. Between the solid phase and the liquid phase, we have a line that marks the "Melting/Freezing" line. This term needs no explanation. As you lower the temperature (move to the left in Fig. 1), the liquid freezes. If you raise the temperature, the solid melts and becomes a liquid.

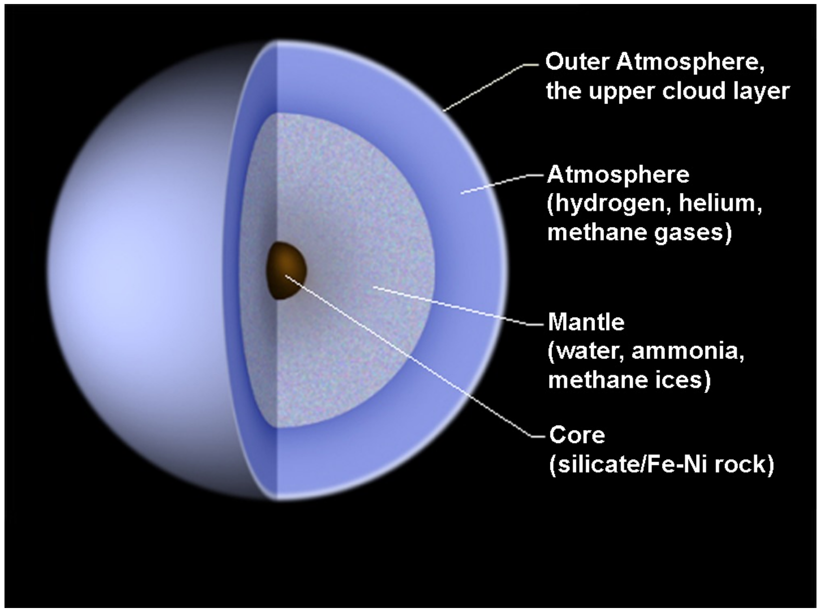

Figure 4: The interior structure of Uranus, showing that the "ice mantle" contains most of the mass of the planet. The ice mantle is made up of a mixture of water, ammonia, and methane ices. From https://en.wikipedia.org/wiki/Uranus.

There are two other types of transitions in the triple point diagram. The first is sublimation: this is when a gas can become a solid, or a solid can become a gas, without first becoming a liquid. If the pressure is low enough, the water molecules that form ice can instantly become vapor if they can absorb a little heat—such as if the sun shines on the frozen ice. The other type of transition is the change from liquid to gas, called vaporization. This is essentially "boiling," where the liquid turns into a gas. The reverse is also possible, called "condensation," depending on the change in temperature *or* pressure. Condensation is what happens when you take a glass containing a cold drink outside—water suddenly collects on the side of the glass. It is also why clouds form.

5. Astronomers have found that there is always water vapor (gaseous water) present in the atmosphere of Mars (we see clouds!). How is this possible if there is no liquid water on the surface? (**3 points**)

1.5 The Triple Point Diagram for Carbon Dioxide

Now we are going to change substances, from water (H_2O) to carbon dioxide (CO_2). The triple point diagram for carbon dioxide is shown in Fig. 5. It is quite a bit simpler than that for water. Note where the triple point is located in this diagram: 5.2 bar, −56°C.

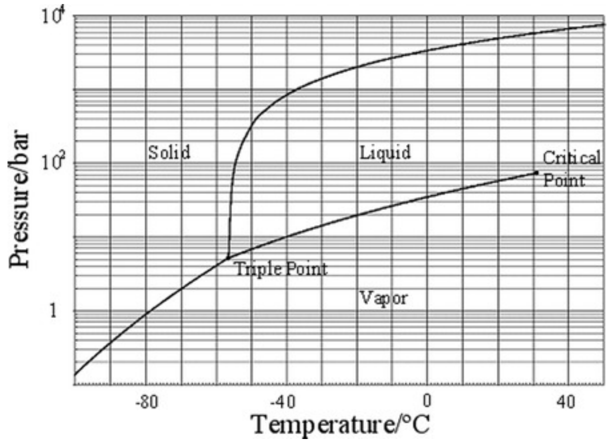

Figure 5: The triple point diagram for carbon dioxide. Note the units for pressure on the y-axis: $10^2 = 100$ bar. The mid-way point between 1 and 100 bar is of course 10 bar (the tickmarks in a log plot are not evenly spaced, but still run from 1 to 10, or 10 to 100, etc.).

6. Can liquid or solid carbon dioxide ever exist on the Earth's surface? What if you were told that the coldest temperature ever recorded on Earth (in Antarctica, of course), was −94.7°C? (**2 points**).

7. Predict how carbon dioxide will behave on Mars as we pass from winter into summer. How might this influence that change in atmospheric pressure we noted earlier? (**4 points**)

Experiment #1: Solid Carbon Dioxide. Your TA is going to give you a small chunk of frozen carbon dioxide (dry ice) inside a ziploc bag. Zip up the baggie for a few minutes.

8. Describe what is happening. What process is occurring here? Why is frozen carbon dioxide called "dry ice?" (**4 points**).

Now, unzip the baggie, but leave the dry ice in it, and move it to the side.

Experiment #2: Liquid Carbon Dioxide. We are now going to see if we can make liquid carbon dioxide at room temperature. Look back at the triple point diagram for carbon dioxide. How can we make liquid CO_2 at temperatures well above the triple point?

9. What do we need to increase in order to get liquid carbon dioxide to be stable at warmer temperatures? (**1 point**)

Your TA is going to give everyone safety goggles, a small amount of finely crushed dry ice in a paper towel, a plastic pipet, like used in chemistry and biology labs, a small funnel (a piece of wire to help convince the dry ice to go through the funnel), and a pair of pliers. We have cut off the tip of pipet so you can fit the funnel into it. Use the paper towel to pour the dry ice into the funnel so that **THE DRY ICE FILLS THE PIPET BULB BY ABOUT ONE THIRD!** Now, take the pliers and bend over the tip of the pipet, and clamp it–we need to create a good, tight seal–we do not want the CO_2 gas to escape, we need to increase the pressure! One member of the group needs to start timing: After about 90 seconds or so, you should begin to see liquid CO_2 form. As soon as all of the dry ice turns to liquid, release the pressure: **Warning: there is going to be a small pop! IF YOU WAIT TOO LONG THERE WILL BE A BIG POP—THE PIPET WILL EXPLODE!**

10. Explain what happened in this demo. What allowed us to form the liquid CO_2? What happened when you released the pressure? Into what phase did the liquid CO_2 return? Why? (**4 points**).

1.6 The Importance of Density in Shaping the Surfaces of Objects in the Outer Solar System

Earlier this semester you might have had a lab on density. As a reminder, density is simply the mass of an object divided by its volume: Density = Mass/Volume. It has units of gm/cm^3, or kg/m^3. The densities of various substances are listed in Table 1. Note that we have two densities listed here, one for the solid phase and one for the liquid phase.

Table 1: The Densities of Various Substances

Substance	**Density as a Solid** (g/cm^3)	**Density as a Liquid** (g/cm^3)
Water	0.92	1.0
Carbon Dioxide	1.6	1.1
Nitrogen	1.03	0.80
Iron	7.9	6.9
Silver	10.5	9.3
Gold	19.3	17.3

11. Compared to the other substances listed in Table 1, water is unusual. Why do we say that? What does this actually mean? [Hint: what happens when you put the solid phase of a substance on top of its liquid phase?] (**4 points**)

Experiment #3: Let's confirm your answer to question #11. Using the beaker with water in it that your TA gave you, drop an ice cube into the water.

12. What happens? (**2 points**)

Now we are going to drop the piece of dry ice into the beaker (this is going to be a bit more exciting!). Before doing so, look at Table 1, what do you think is going to happen? Carefully drop the chunk of dry ice from the Ziploc bag into the beaker.

13. What happened? (**2 points**)

There are few other substances that behave like water. This behavior is what helps determine how various objects in the outer solar system are structured.

1.7 Europa, Enceladus, Titan and Pluto

Now we are going to use the knowledge we have just acquired and apply it to four bodies in the outer solar system: Europa, Enceladus, Titan and Pluto. Europa is one of the four big moons of Jupiter, while Enceladus and Titan are moons of Saturn. Pluto is the infamous "dwarf planet" discovered by Clyde Tombaugh, a former faculty member at NMSU (note that astronomers still argue about whether Pluto should be called a planet, but that discussion is for some other time and place).

Exercise #1: Understanding Europa

In the binder that you were given as part of this lab, we have some images of Europa. Of the four "Galilean satellites" of Jupiter (discovered by Galileo in 1610), Europa is the smallest and least massive. It is similar in size to the Earth's moon (a radius of 1,560 km vs. 1,738 km), but its density, 3 gm/cm^3, is lower than that of our moon, 3.3 gm/cm^3, so it is quite a bit less massive. Europa orbits Jupiter between Io and Ganymede. All three of these moons are locked in an orbital resonance, that causes tidal heating. This creates an internal heat source that supports a sub-surface ocean for Europa (and possibly Ganymede), and hundreds of volcanoes on Io.

Image #1 shows a wide view of Europa. In this wide view there is not very much surface detail. We can see what looks like a crater towards the bottom right. Otherwise there just seem to be some brownish regions, and some dark, linear streaks.

14. The average surface temperature of Europa is -160°C. If there is water on its surface, what phase will the water be in? (**1 point**)

Image #2 shows a close-up view of Europa, giving us a better view of the streaks, some other brown spots, and some white bumps, appearing to be a bit higher than the local area. Europa has the smoothest surface in the solar system, with most of the highest features having elevations of $\sim$ 10 meters. Remember, we said its radius was 1,560 km; 10 meters is 0.01 km, so its surface is essentially smooth to 1 part in 156,000. A billiard ball is smooth to 1 part in 57,150. If you could shrink Europa down to the size of a billiard ball, it would be smoother!

Why so smooth? The surface of Europa is almost pure water ice. If you have seen the surface of a frozen pond or lake, you know that such a surface can be very smooth. Astronomers believe that the pull of gravity from Jupiter, and the moons Io and Ganymede, is tugging on Europa, causing it to stretch and contract. This stretching heats the inside of Europa, melting the ice, and turning it into water. The surface of Europa is cold, so a thin (10, 20, or 100 km thick?) layer of ice forms on top the ocean.

15. Water covers much of the Earth's surface, but water ice covers the entire surface of Europa. Why? (**4 points**)

The other thing to notice in the wide view of Europa is that there are almost no impact craters: There are only seven craters on Europa that have diameters of 20 km or more. In contrast Callisto, the fourth of the Galilean satellites, has hundreds!

16. Something is erasing the impact craters on Europa. Can you think of a reason why there are no big impact craters on the surface of Europa? [Hint: Think of the process: a high speed impactor crashes into a thin layer of ice that covers a body of water. What happens?](**4 points**)

Finally, for Europa, is Image #3: there are water vapor plumes that erupt from the surface of this moon! Presumably they come from one (or more) of the cracks. *This proves that there is a source of liquid water below Europa's icy surface.* We will see much more dynamic versions of these plumes on our next object, Enceladus.

Exercise #2: Investigating Enceladus

Enceladus is the sixth largest moon of Saturn with a radius of 500 km. It has a low density of only 1.6 gm/cm^3. Given its low density we can infer that water must make up much of the mass of Enceladus. Enceladus is the "shiniest" large object in the solar system in that it reflects about 80% of the incoming light. This, and its great distance from the Sun (1.4

billion km), means its surface is very cold: -200 °C, and any water or carbon dioxide will be frozen solid.

Image #4 is a wide view of Enceladus. The upper-right portion of Enceladus appears to be covered with craters. At the bottom are some blueish stripes, or cracks. On the left edge is a very, very smooth region devoid of any surface features.

17. Compare the surface of Enceladus to that of Europa. How are they different, and how are they similar? (**4 points**)

Image #5 is a distant picture of Enceladus taken by the Cassini spacecraft. Note the jets of material coming out of the bottom of the moon. Image #6 is a closer view of those jets, or "geysers." It is now clear that this material is shooting out of the blue stripes seen in Image #4 (note that we have to see the jets of material illuminated by the sunlight against the blackness of space, as they are faint in comparison to the moon itself).

18. We now know that most of the material in these jets is water vapor, various kinds of ice crystals, hydrogen gas, and a bit of salt (sodium chloride = table salt!). What does this tell you about what is beneath the icy surface of Enceladus? (**4 points**)

In Image #7, we take a long look at Enceladus (the tiny black dot near the bright white spot) and find that it has created its own ring around Saturn! This is the so-called "E-ring," and is made up of material ejected from the inside of Enceladus. Just like Europa, Enceladus is in a orbital resonance with a nearby moon (Dione), and the tidal heating causes some portion of the interior of Enceladus to melt, creating a sub-surface lake, or ocean, from which the geysers emanate. This ejected material then goes into orbit around Saturn, forming a ring.

Exercise #3: Exploring Titan

Titan is the largest moon of Saturn, and the second largest moon in the solar system. It has a radius of 2,575 km, making it larger in size than the planet Mercury (radius of 2,432 km). But Titan only has a density of 1.9 gm/cm^3, compared to Mercury's 5.5 gm/cm^3. Mercury is much more massive. Titan is surrounded by a very dense atmosphere, with a surface pressure of 1.45 bar. Titan has a more massive atmosphere than that of the Earth! This atmosphere is 97% nitrogen (N_2), and 2.7% methane (CH_4). Methane is a very intense "greenhouse gas," and thus the surface temperature of Titan is warmer than it would be without its atmosphere: $-180°$C (= 93 K).

With an atmosphere dominated by nitrogen and methane, we now have to examine the triple point diagrams for these substances to fully understand Titan. In Fig. 6, we plot the (simplified) phase diagrams for water, methane and nitrogen. Note that unlike the previous diagrams, pressure is now on the x-axis, and temperature on the y-axis (and the temperature scale is in Kelvin. Remember, 0 K = $-273°$C). Also note that 10^0 bar = 1 bar, 10^2 bar = 100 bar, 10^{-2} bar = 0.01 bar, etc.

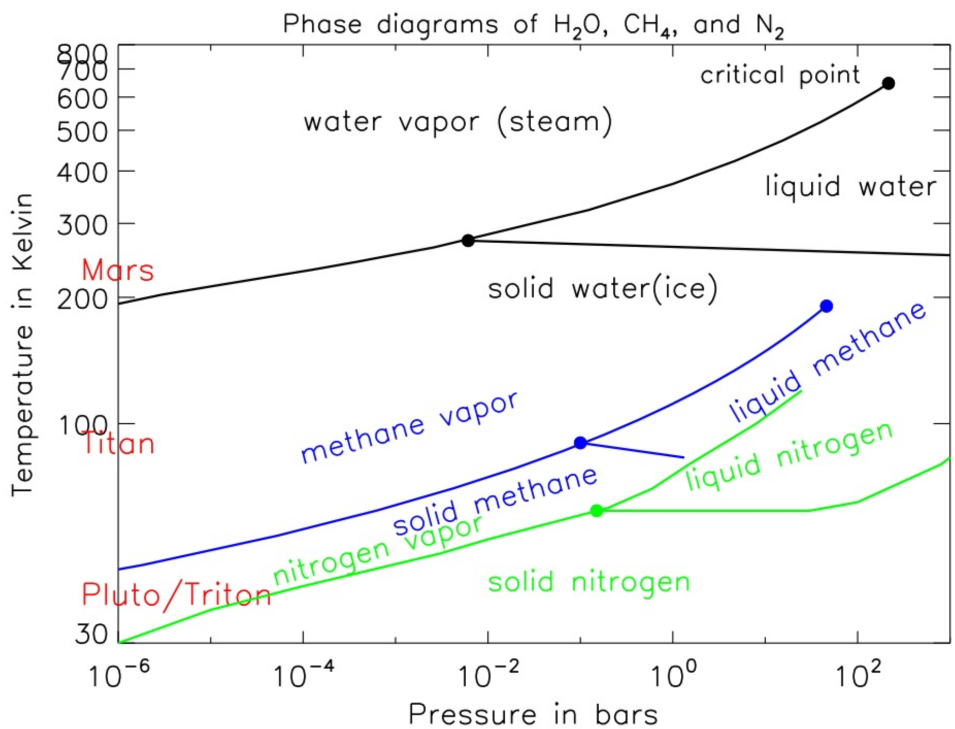

Figure 6: The triple point/phase diagrams for water (top, black), methane (middle, blue), and nitrogen (bottom, green). The x-axis has pressure labeled in an unusual way, but just note that 10^0 bar = 1 bar, and 10^2 bar = 100 bar, etc.

19. Given that the surface pressure is 1.4 bar, and the temperature 93K, in what phases do we expect to see water, methane, and nitrogen? (**4 points**)

20. This is a surprising result, isn't it? We now have at least one substance that should be a liquid on the surface of Titan. What do you think this might mean if we could take some images of the surface of Titan? (**2 points**)

In Image #8 we show a wide view of Titan. Boring, eh? Titan's atmosphere is very hazy and cloudy, and we cannot see anything in visible light. Fortunately, as Cassini entered the Saturnian system it dropped a little probe named Huygens into Titan's atmosphere. As Huygens floated down to the surface it took pictures, one of which is shown in Image #9.

21. What surface feature is shown in Image #9, and what do you think forms, or creates, this feature? (**4 points**)

If Titan has rivers, what else might it have? Because astronomers already knew Titan was cloudy, they equipped the Cassini probe with a radar system to map the surface of Titan (radar waves can see through clouds, a similar system was sent to Venus). Image #10 is one of these radar maps of a slice of Titan's surface: there are lakes of methane on Titan! The conditions on Titan are just right to have a "hydrological cycle" based on methane. This means that high in the atmosphere methane *condenses* from gaseous vapor into liquid droplets, these grow and fall as rain, the rain forms rivers and lakes, there is *vaporization* (evaporation) from the lakes producing gaseous methane, and the cycle is completed.

Exercise #4: Inspecting Pluto

When Pluto was discovered in 1930 by Clyde Tombaugh, astronomers thought they had finally found the most distant planet in our solar system. Pluto is indeed very far away, with an average distance of 5.9 billion kilometers (39.5 AU). But we now know that there are other objects beyond Pluto that are just as big, and thus to avoid having to add extra planets to the solar system every few years, a new classification was devised: the "dwarf planet." This did not make everyone happy (especially at NMSU), but officially, Pluto has been reclassified as a dwarf planet.

Pluto is so far away that the Sun provides little heat, and it is very cold: 44 K = −229°C. Pluto has a radius of 1,188 km, smaller than the Earth's moon (1,738 km). Pluto has a density of 1.9 gm/cm^3, similar to that of Titan. Therefore it must be made of similar materials. We do not have time today to perform a deep investigation of Pluto, but the take home portion of this lab will have two questions about Pluto, so be sure to read those before you leave lab today.

Until the New Horizons spacecraft went by Pluto in 2015, we knew very little about this interesting object. Before we look at the surface of Pluto, we want you to look at what was actually one of the last pictures taken by New Horizons, Image #11. Here, Pluto is blocking the direct view of the Sun, and we see that it has an atmosphere!

22. Given that Pluto probably has water, CO_2, methane and nitrogen on its surface, use the triple point diagrams above to predict which of these substances is the *most likely one* to be in a gaseous phase at the temperature of Pluto. (**2 points**)

23. Given the substance you have chosen, what must the pressure be in this atmosphere? (**2 points**)

The surface pressure measured from New Horizons data for Pluto is 10^{-5} bar. This should now make sense to you, and demonstrates how useful triple point diagrams are. Now for the surface of Pluto. In Image #12 we present a wide view of Pluto. Note that Pluto has flat, smooth regions, highlands, shallow impact craters, and darker regions. Pluto is both quite a bit different, and at the same time somewhat similar, to the other objects we've looked at today.

In Image #13 we show a close up of some mountains that appear to have *nitrogen* glaciers flowing from them with embedded chunks of water ice that form "hill chains," and "hill clusters." We return to this image in the take home portion.

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1.8 Take Home Exercise (35 points total)

Answer the following questions in the space provided:

1. What is a triple point diagram? What are the two quantities on the axes of the plot? What does this diagram tell you, and how do you use it? (**5 points**)

2. In this week's lab, we encountered three objects that were very smooth, or had very smooth regions on their surfaces (Europa, Enceladus, and Pluto). As you have learned in class, the solar system is a violent place, with meteors crashing into the planets and moons all of the time (more so long ago). How can Enceladus or Pluto have such smooth regions on their surfaces? [Hint: Words you might use in your explanation are "activity," "resurfacing," "convection," or "recycling." Do some research!] (**10 points**)

3. In discussing the last image of Pluto in this week's lab, it mentioned nitrogen glaciers (!)

that seemed to have water ice "hills" embedded in them. The suggestion is that huge blocks of water ice are being carried by these solid nitrogen ice glaciers. Describe how this is possible. Use the data in Table 1 to support your answer. (**10 points**)

4. In the Introduction we mentioned that if we are going to find life elsewhere in our solar system, we need to locate liquid water. Given what you know now, where would you go to search for life in our solar system? How would you go about doing this? (**10 points**)

1.9 Possible Quiz Questions

1. What is a triple point diagram?
2. What does 1 bar, a unit of pressure, actually mean?
3. List the three phases, or states, of ordinary substances.
4. What is a Kelvin?

1.10 Extra Credit (ask your TA for permission before attempting, 5 points)

In several of the triple point diagrams in this week's lab there was a point labeled the "critical point." What is the critical point? See if you can identify two more elements/substances that behave like water (i.e., their solid forms are less dense than their liquid forms).