MARS: ROAD TO THE RED PLANET

Mars is the fourth planet from the Sun at an average distance of about 140 million miles (225 million km). Mars is known as the Red Planet because iron minerals in the Martian soil oxidize, causing the soil and atmosphere to look red. Mars' surface cannot support life; however current missions are determining Mars' future potential for life.

The first Mars missions were called flybys – Mariner 4 performed the first successful flyby of the planet Mars in 1965, taking the first photos of another planet from space. Several missions (from orbiters to rovers) have visited the planet Mars since 1965. The most recent being NASA's Mars InSight lander which landed on the Red Planet on November 26, 2018. InSight is on a two-year mission to understand the processes that shaped the rocky planets, including Earth and the Moon.

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In 2020, NASA's Mars 2020 mission will launch MOXIE, an "oxygen processing plant" that might support future human expeditions to Mars. MOXIE – which stands for Mars Oxygen In-Situ Resource Utilization Experiment – is a 1% scale model that will produce ~22 grams/hr of O_2 from the CO_2-rich Martian atmosphere (Figure 1). MOXIE will record the purity and efficiency of the O_2 production rate before it is vented into an O_2 storage tank. If this proves successful, NASA engineers will consider designing a full-scale model which would be capable of producing oxygen on a larger scale, mainly for life-sustaining activities for humans. In addition, the CO produced by MOXIE may be utilized directly as fuel or converted to methane for use as propellant.

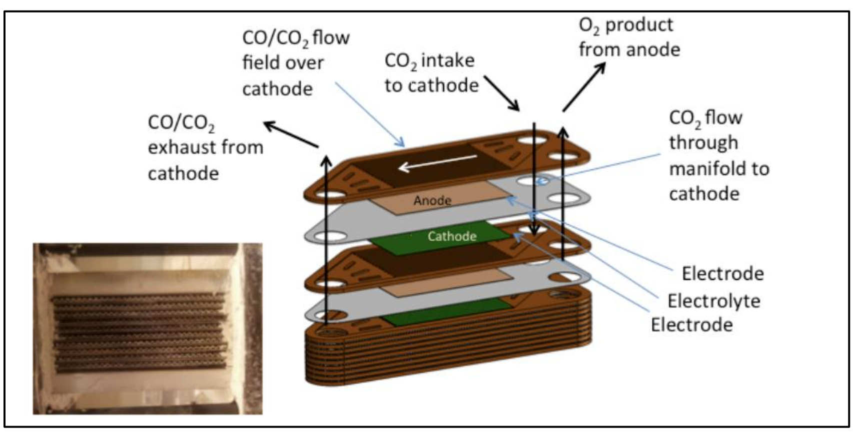
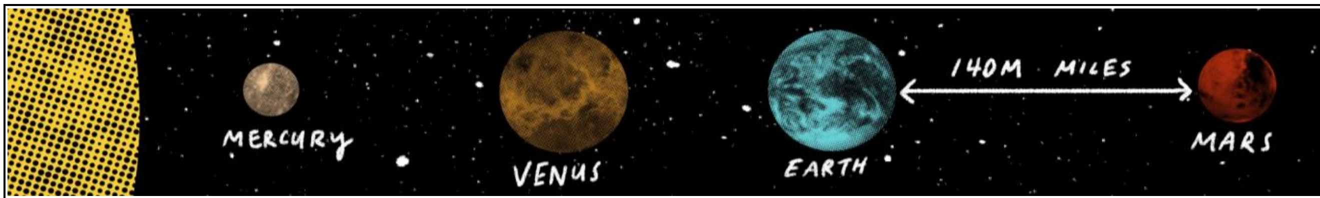


Figure 1. Conversion of CO_2 to O_2.

MOXIE will intake Mars' atmosphere, then it will electrochemically split the carbon dioxide molecules into dioxygen (O_2) and carbon monoxide (CO) via a SOXE stack. CO is vented back out into the Mars atmosphere along with other exhaust products (non-condensables). "MOXIE uses a solid oxide electrolysis (SOXE) stack for converting CO_2 to O_2. When CO_2 flows over the catalyzed cathode it is electrolyzed according to the reaction $CO_2 + 2e^- \Rightarrow CO + O^{2-}$. The CO is exhausted, while the oxygen ion is electrochemically driven through the solid oxide electrolyte to the anode, where it is oxidized ($O^{2-} \Rightarrow O + 2e^-$). The O atoms combine to produce the gaseous O_2" (Hecht et al).



The launch date is still a few years away, but preparations are underway. The JFK Tank and Manufacturing Co., for example, have designed an O_2 storage tank prototype to accompany MOXIE in the Mars 2020 mission. According to the JKF Tank and Manufacturing Co., the storage tank prototype is designed to “meet a wide range of requirements…”

STUDENT INSTRUCTIONS

MOXIE has already passed the preliminary design review and is now scheduled for critical design review. You are a chemical engineer working for NASA and your job is to monitor and analyze data from processes and identify ways to optimize performance. Upon receiving the prototype tank at your facility, you read “rupture pressure of 78 atm” on the tank. Knowing that Mars follows a highly elliptical orbit, and thus temperatures vary significantly as the planet travels around the Sun, you take it upon yourself to validate JFK Tank and Manufacturing Co.’s statement “designed to meet a wide range of requirements...” and review the behaviour of gases.

POINTS OF DISCUSSION/QUESTIONS

1. The 1.98-L storage tank has a listed capacity of 215 g of O_2. Use the ideal gas law to calculate the pressure of the storage tank at 20 °C (the peak daytime temperature on Mars). Is the O_2 tank safe against sudden rupture at capacity?

2. The calculation in question 1 was made assuming ideal gas behaviour. For 1 mole of an ideal gas, PV/RT=1. However, under some conditions gas behaviour deviates from ideal. Consider the following diagrams:

Figure 2

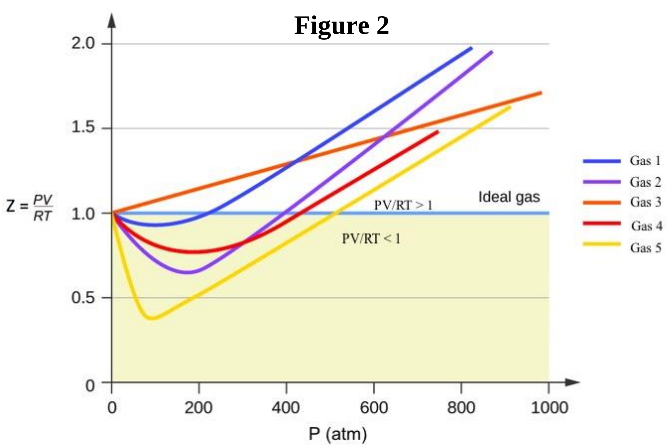
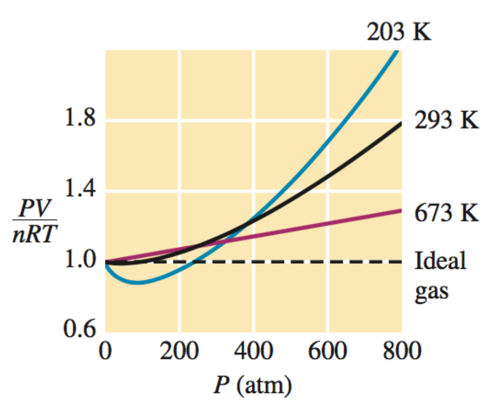
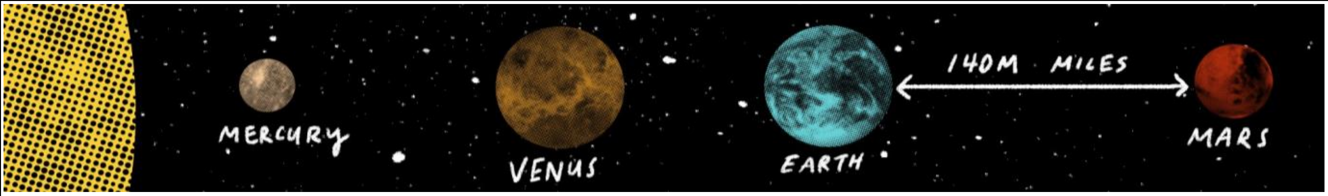


Figure 3



What is Z? What is the most important conclusion to be drawn from these plots? *(Hint: PV/RT > 1 and PV/RT < 1)*



3. Real gases do not always behave ideally. The van der Waals equation, $\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$, modifies the assumptions of the kinetic molecular theory to fit the behaviour of real gases. Why is a term added to P and why is a term subtracted from V to correct for non-ideal gas behaviour?

4. Using the van der Waals equation, re-calculate the pressure of question 1 and compare the results. Is the O_2 tank safe against sudden rupture?

5. Substitute CO_2 for O_2. Which gas, CO_2 or O_2, shows the greater departure from ideal gas behaviour? Explain.

6. Mars has a thin atmosphere which consists of approximately 95.5% carbon dioxide, 2.7% nitrogen, 1.6% argon, and traces of free oxygen, krypton and xenon. Predict which of these gases shows the strongest intermolecular attractions. Explain. Predict which gas shows the smallest correction for the molecular volume. Explain.

7. How might the world be different if all gases behaved ideally?

References

[1] Image 1. Retrieved on Jan 19, 2019 from https://cdn-images-1.medium.com/max/2000/1*EzpbBZ_Y1BgN9Um40NLzzA.jpeg

[2] Hecht, M. H.; Rapp, D. R.; Hoffman, J. A., The Mars Oxygen ISRU Experiment (MOXIE). NASA. Retrieved from https://ssed.gsfc.nasa.gov/IPM/PDF/1134.pdf

[3] Figure 2. Retrieved on Jan 19, 2019 from https://archive.cnx.org/resources/a17c4638ba4b4a2579119474155e02 aeaab19181/CNX_Chem_09_06_ZvsPgraph.jpg

[4] Figure 3. Retrieved from Zumdahl, S. S.; DeCoste, D. J., *Chemical Principles*, 8th ed. Brooks Cole: Boston, **2016**, p 159.