Abigail King

Chemistry

Mr. Johanson

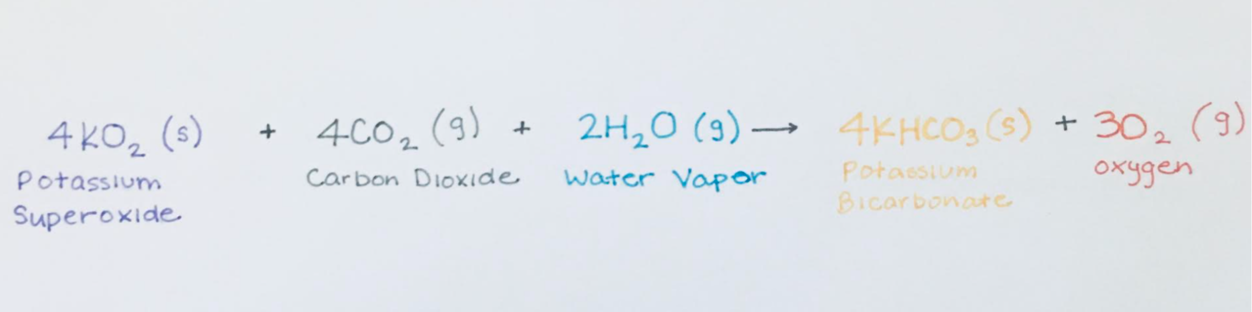
October 29, 2023

Carbon Dioxide Spacecraft Removal

On earth, we breathe a combination of different gases. The troposphere, the closest layer of the atmosphere, is made of 78% nitrogen, 21% oxygen, 0.96% various other gases and finally 0.04% carbon dioxide. This level of carbon dioxide is perfectly safe for our respiratory system. On Earth, the maintenance of this percentage is provided by plants transforming the carbon dioxide we exhale into oxygen through photosynthesis. However, what are astronauts supposed to do? There aren't any plants on a spacecraft. After a long enough time, the astronauts' exhalations would fill the cabin with carbon dioxide. Once the carbon dioxide levels reach above 8% the air in the spacecraft would be fatal to the respiratory system and the astronauts would die. Thankfully, a brilliant system has been developed to prevent this by using chemistry.

The primary technique implemented by the International Space Station (ISS) uses molecular sieves, called a "carbon dioxide removal assembly" (CDRA), to absorb the carbon dioxide (CO_2). The CDRA combines potassium superoxide and water vapor with the carbon dioxide from human exhalations. This absorbs the carbon dioxide and in its place, potassium bicarbonate and oxygen is formed (See image 1).

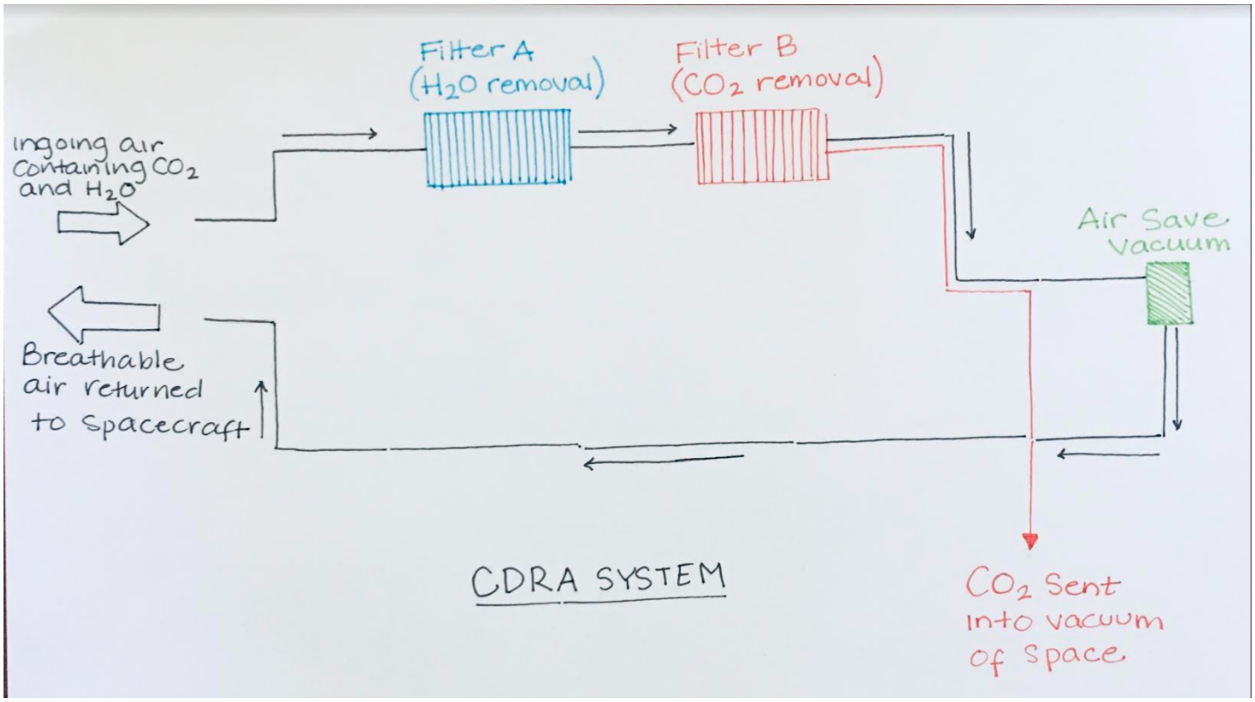
Image1



$$4KO_2\,(s) + 4CO_2\,(g) + 2H_2O\,(g) \longrightarrow 4KHCO_3\,(s) + 3O_2\,(g)$$

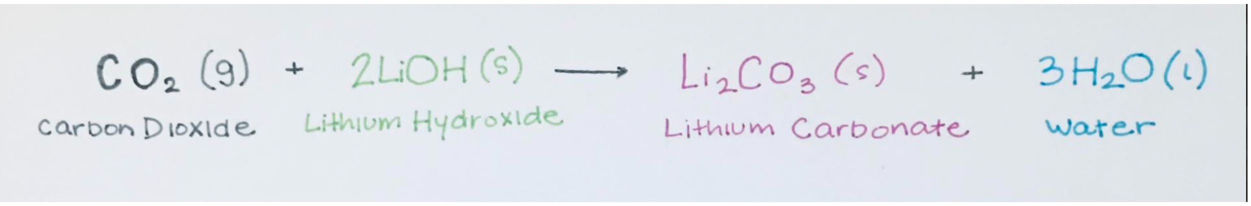
The sieves are made of silicon dioxide and aluminum dioxide crystals. These crystals form screens which allow water vapor and carbon dioxide to pass through. Through one screen (Filter A), water is trapped and removed from the air. The remaining air particles then go through a second screen (Filter B), removing the carbon dioxide. The carbon dioxide is sent into space while the air is saved and sent to the end of the process, where it comes out as breathable air, free of any harmful carbon dioxide and is released into the spacecraft (See image 2).

Image 2



Used as a backup plan to the CDRA, canisters filled with powdered lithium hydroxide (LiOH) are utilized. When carbon dioxide (CO_2) passes through the canisters, it is mixed with lithium hydroxide (LiOH). These two compounds form lithium carbonate (Li_2CO_3) and water (H_2O) (See image 3). This method was also used during the Apollo 11 mission (see image 4).

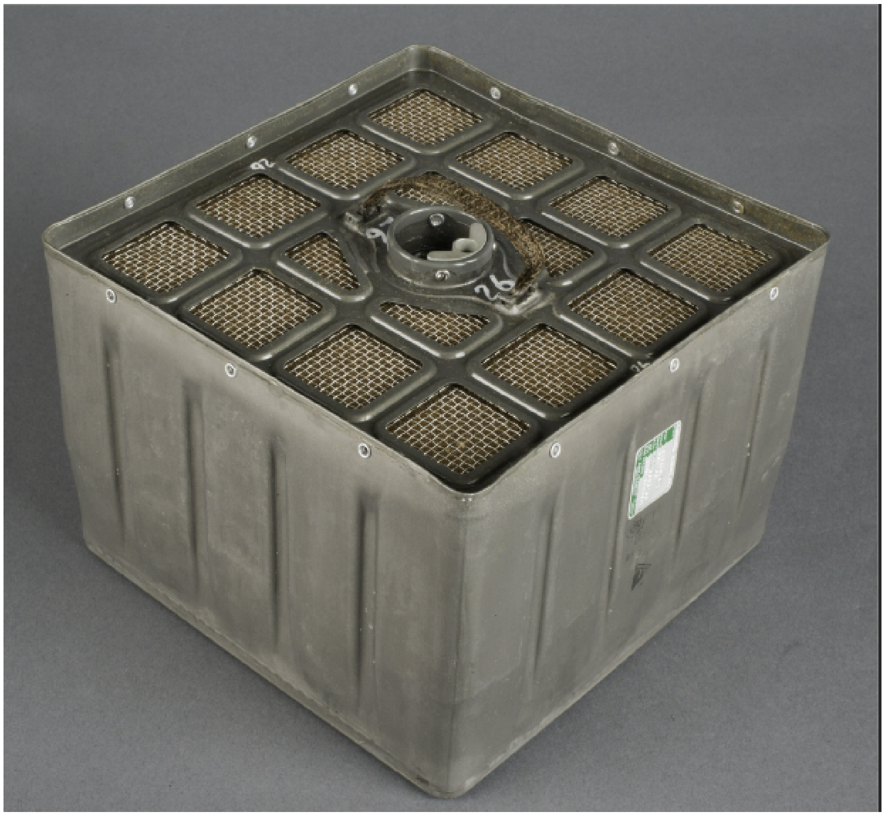
Image 3



$$CO_2\,(g) + 2LiOH\,(s) \longrightarrow Li_2CO_3\,(s) + 3H_2O\,(l)$$

Carbon Dioxide   Lithium Hydroxide   Lithium Carbonate   Water

Image 4: The lithium hydroxide air canister used on Apollo 11



The International Space Station puts into use both the CDRA system and lithium hydroxide canisters today to keep all those aboard safe, allowing them to continue their research in space. Both systems are just two fascinating examples of how chemistry can be utilized and put to practical use—even in space!

Jessica Nottoli

November 3, 2023

Mr. Johanson

Chemistry

Spacecraft CO_2 Removal

Question: How is carbon dioxide gas - which is exhaled by astronauts - eliminated from a spacecraft? How do you prevent it from building up and poisoning the astronauts?

Just imagine for a moment that you are an astronaut on his way to fulfill a longtime dream; to land and walk on the moon. You're over halfway there and everything's going great until an oxygen tank suddenly explodes! You and your fellow spacemen have to move into the lunar module and out of the command module because of the lack of oxygen. But the room is filling up with Carbon Dioxide and the air is being overwhelmed with fatal amounts of it. Luckily, you have a square CO_2 absorber canister. Unluckily, you have a round shaped filtration system that could not possibly fit a square object. Connecting the two would take some adapting, but how were you even able to do anything to dispose of the dangerous CO_2 collecting right in your spacecraft? The answer lies in the chemistry of the engineering and chemical reactions of the filters.

There are two ways for carbon dioxide gas to be eliminated from a spacecraft. The first would be by Lithium Hydroxide (LiOH) canisters. This is the more common system on spacecraft and was in use during the Apollo 13 incident. This carbon dioxide removing structure works when air filled with CO_2 is filtered through the canister and combines with the Lithium Hydroxide (LiOH) powder inside and creates Lithium Carbonate (Li_2CO_3) and water (H_2O). After this chemical reaction has been completed, the canister is thrown out and replaced with a new LiOH canister. During the infamous Apollo 13 mission, where the astronauts had to live in the lunar module while the spacecraft made its orbit back to Earth, the astronauts had to use square Lithium Hydroxide canisters while the lunar module could only use round shaped canisters. Because of the shape difference, the LiOH canisters could not be replaced and the engineers at Mission Control had to create a makeshift system fashioned out of duct tape, plastic bags, and anything else that was on board the spacecraft for the men to use. They were finally able to literally stick a square into a circle with the new system and the astronauts escaped death by a Carbon Dioxide overdose.

Chemical Equation: $CO_2 + 2LiOH \longrightarrow Li_2CO_3 + 3H_2O$

The above equation uses a displacement reaction which kicks out the Hydrogen in the Lithium Hydroxide to be replaced with the Carbon Dioxide.

The other way CO_2 gas can be eliminated from a spacecraft is through SCUBA. This newer equipment absorbs the Carbon Dioxide through molecular sieves, a material with very small holes of uniform size. The SCUBA rebreathers can use Lithium Hydroxide canisters but others use a Potassium Superoxide (KO_2) reaction. When the Potassium Superoxide fuses with the Carbon Dioxide (CO_2) and water vapor (H_2O), the CO_2 and the Hydrogen from water link to the Potassium Superoxide creating Potassium Bicarbonate ($KHCO_3$) and Oxygen gas (O_2). So this system cannot only cleanse the air of Carbon Dioxide but can also produce new oxygen to be breathed. In this system the CDRA, Carbon Dioxide Removal Assembly, uses molecular sieve tech to remove the Carbon Dioxide from the spacecraft. Molecular sieves are made of synthetic zeolite materials, crystals of Silicon Dioxide (SiO_2) and Aluminum Dioxide (Al_2O_3). The openings in the zeolite material allows some molecules to pass through and it traps others in its sieves. One zeolite absorbs water and separately absorbs Carbon Dioxide. The air that passes afterwards comes out dry and free from CO_2. While the Lithium Hydroxide canisters above had to be replaced with new canisters regularly, the CDRA's zeolites could be reinvigorated by electrical heating elements. During the refreshing, the Carbon Dioxide gets kicked out into space and the water is recycled into the system. The CDRA keeps both systems of filtering out the Carbon Dioxide and rejuvenating the network on at the same time to continue the flow of clean air.

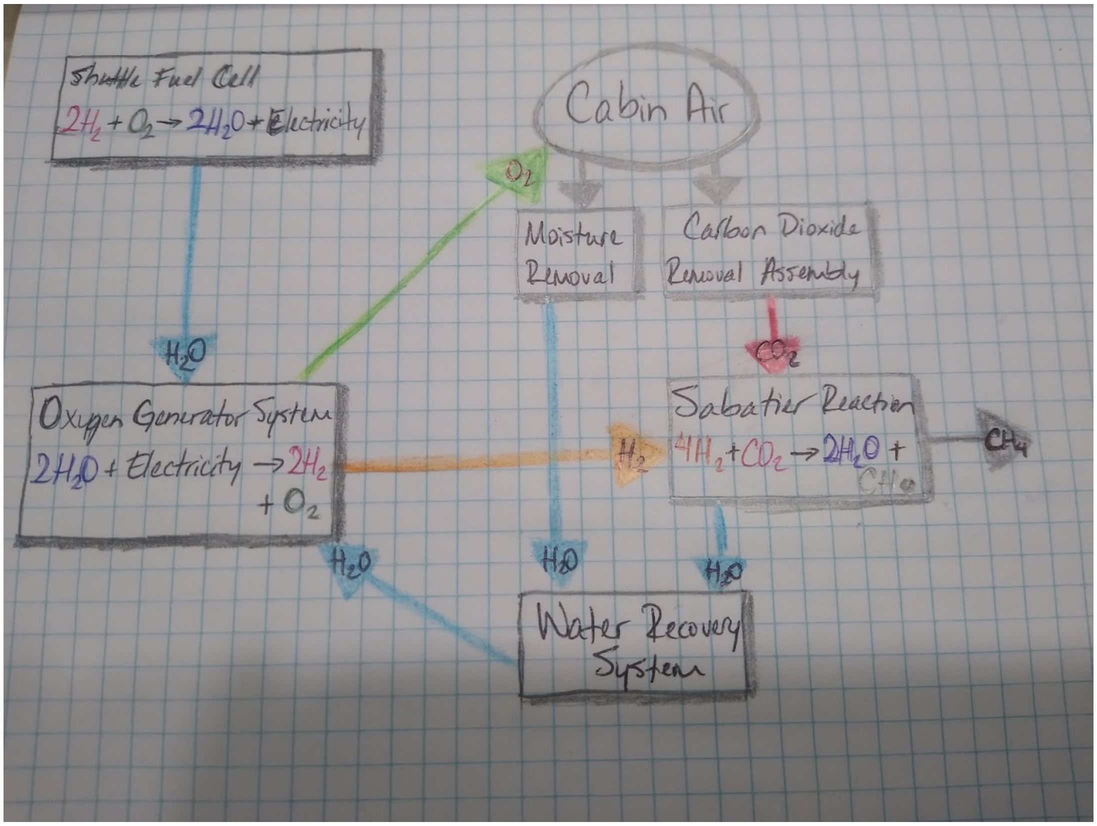
Chemical Equation: $4KO_2 + 4CO_2 + 2H_2O \longrightarrow 4KHCO_3 + 3O_2$

As of October 2010, the Sabatier system was added. This arrangement takes the Carbon Dioxide removed by the CDRA system and fuses it with the Hydrogen gas left from the Environmental Control and Life Support System (ECLSS) water system and this shapes liquid water (H_2O) and Methane gas (CH_4). The Methane gas is released into space.

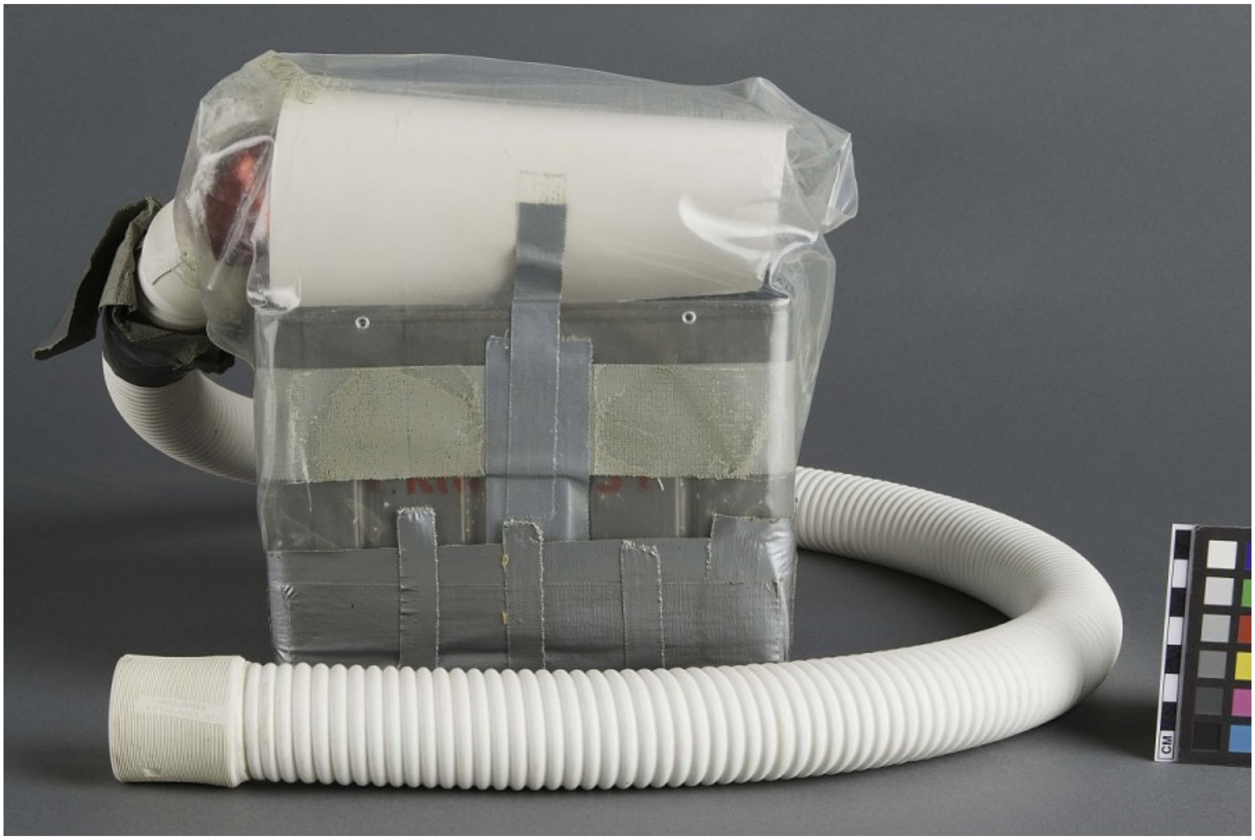
Chemical Equation: $CO_2 + H_2 \longrightarrow H_2O + CH_4$

After these explanations of chemical reactions and creative, man made systems, one can see the true genius that went into these spacecrafts to make sure the astronauts could receive clean and non toxic air. Soon, scientists hope to be able to sustain naturally living plants in space-craft and -stations in order that we may someday be able to produce oxygen and remove carbon dioxide even without these ingenious inventions.

Sketches and Diagrams:



The makeshift adaptor for the CO_2 filtering created during the Apollo 13 emergency



Citations:

- How is carbon dioxide eliminated aboard a spacecraft? | HowStuffWorks
- The Greatest Space Hack Ever | Popular Science (popsci.com)
- **Oxford Languages** for definitions, synonyms, etc.

Jingyi (Judy) Zhu

Mr. Johanson

Chemistry

4 November 2023

Spacecraft CO_2 Removal Assignment

Have you ever wondered how carbon dioxide gas is eliminated from the spacecraft, thus preventing it from poisoning the astronauts? In fact, the entire process of eliminating carbon dioxide gas from the spacecraft is primarily done through either the Carbon Dioxide Removal Assembly (CDRA), or the Vozdukh, which is the Russian counterpart for the CDRA. Lithium hydroxide canisters are also used as a backup to absorb carbon dioxide.

The CDRA has two beds, one adsorbs the CO_2 from the cabin air (see figure 1, Bed 2), while the other desorbs the accumulated CO_2 into the space vacuum (see figure 1, Bed 1). First, the air from the cabin flows into Bed 1. Because zeolite (see figures 2 & 3), a sponge-like material that locks in a CO_2 molecule, reacts best with atmospheric CO_2, the incoming air with CO_2 and H_2O must be desiccated in the Bed 1A (see figure 1). This also causes the desiccant bed to slowly fill up with water. Afterwards, the remaining CO_2 is moved through the blower into Bed 2B, the CO_2 adsorbent bed (see figure 1). This is where the reaction with zeolite takes place. The cleansed air then flows out through the desiccant bed (Bed 2A), which was previously saturated with water, and absorbs the moisture, returning it to the space cabin. Bed 1B, the CO_2 adsorbent bed in Bed 1 (see figure 1), is isolated from the rest of the space cabin. It is heated with the space vacuum, which causes carbon dioxide to be released into space. When Bed 2B becomes saturated with carbon dioxide, the two beds alternate roles: "Bed 1 adsorbs and Bed 2 desorbs to space" (Matty, *Overview of Carbon Dioxide Control Issues During International Space Station*).

The Vozdukh, the Russian counterpart of CDRA, works mostly the same way, except that it has three beds instead of two, and uses an amine-based adsorbent instead of zeolite.

In addition to using the CDRA or the Vozdukh, lithium hydroxide (LiOH) canisters are used as a backup to absorb carbon dioxide (see figures 4, 5, and 6). This material reacts with carbon dioxide to form lithium carbonate and water ($2LiOH+CO_2 \rightarrow Li_2CO_3+H_2O$). However, because the lithium carbonate cannot be changed back to lithium hydroxide, the reaction is permanent, which is why the lithium hydroxide canisters have a limited life.

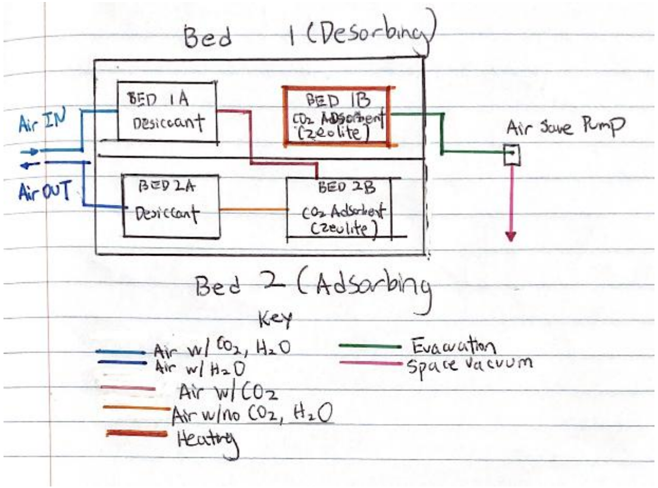


Figure 1: How the CDRA Works

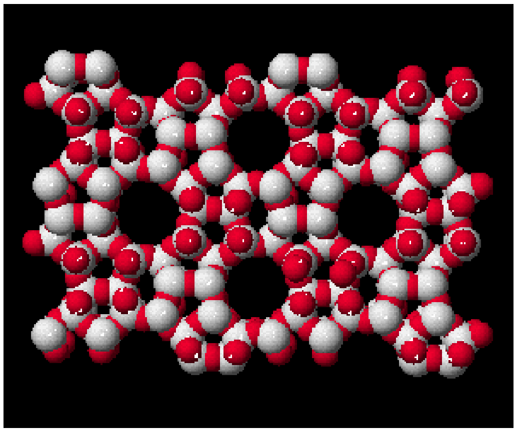


Figure 2: Zeolite Molecule

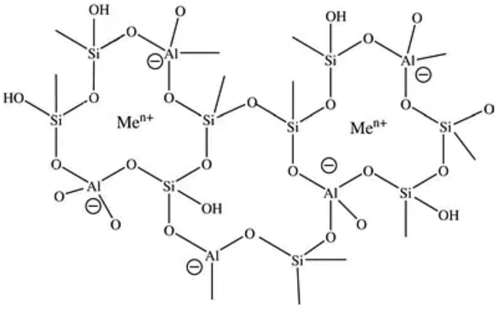


Figure 3: Zeolite Structure

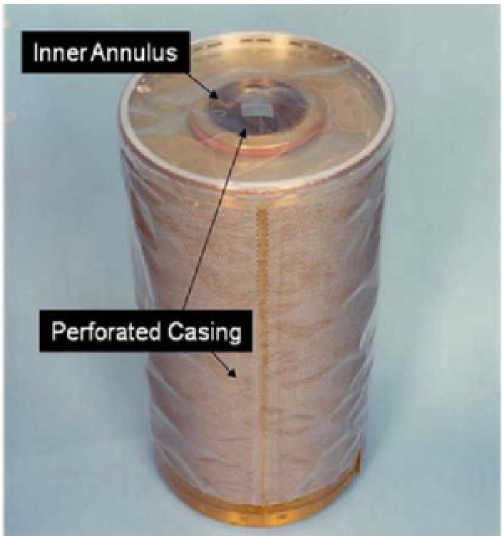


Figure 4: Lithium Hydroxide Canister

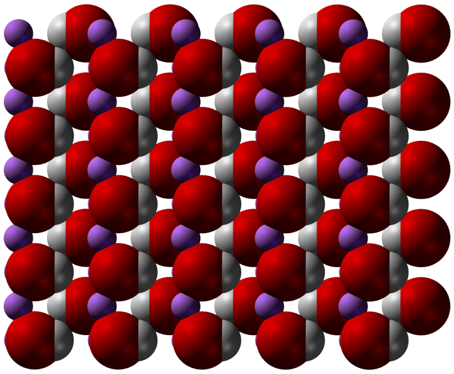


Figure 5: Lithium Hydroxide Molecule

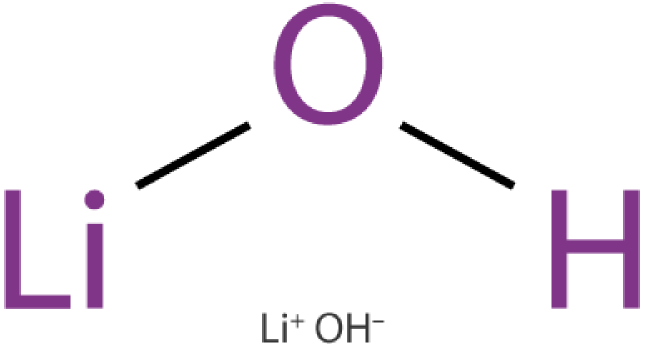


Figure 6: Lithium Hydroxide Structure

Work Cited:

Matty, Christopher M. "Overview of Carbon Dioxide Control Issues during International Space ..." *Overview of Carbon Dioxide Control Issues During International Space Station/Space Shuttle Joint Docked Operations*, ntrs.nasa.gov/api/citations/20100021976/downloads/20100021976.pdf. Accessed 28 Oct. 2023.