MARS JARS: How students can build inexpensive, mini Mars environments for science and engineering projects.

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Background: What is a Mars Jar?

We have prepared our own very small, Martian test tubes and flasks which possess many of the conditions of Mars' surface (up to the first three of five conditions listed below) and at a cost well below $100**. We did several experiments of interest to us, namely: lightening on Mars in a jar (12-13 year olds) and what might happen to ice cream on Mars (an 8 year old).

Student, amateur, and professional researchers alike need Mars-like conditions in which to test their ideas and to help answer their questions. It has been proposed that vacuum stations like those used in industry and university labs could be employed to produce Mars-like conditions to test student ideas for whole classrooms of children.[1] It is our goal to find simpler and lower cost ways to help researchers set up their own small test stations where they can test out their ideas. The test stands need only meet those characteristics of Mars which are pertinent for testing the ideas.

1. INTRODUCTION

The surface characteristics of Mars include:

1. A low-pressure atmosphere composed mostly of carbon dioxide.
2. A moderately low surface temperature.
3. Rock and/or fine powder in many places of particular compositions. We also note that others have address how to achieve this characteristic. Hawaiian Basaltic lavas chemically resemble "Mars-type" powders and rocks.
4. Less sunlight than earth but more UV in the 300 nm range.
5. Low surface gravity.

The focus of this paper is to describe how the first two characteristics can be produced relatively quickly and easily, by using two cryogenics: dry ice and liquid nitrogen (LN). Specifically, liquid nitrogen and dry ice are required to produce low-pressure Mars-like atmospheres. And dry ice alone is required to produce most of the low temperatures found on Mars. This is done without the use of compressed gas cylinders, vacuum pumps, control valves, and/or vacuum gauges. We aim to describe this in sufficient detail for the reader to understand the procedure and be able to adapt it for her needs, but we encourage students to view the presentation at Prof. Allred's BYU website for clarifying photos and notes. Seeing what we have done may help the researcher avoid some frustrations and pit falls by showing the answer some questions which we haven't anticipated as being a problem and may omit in this brief account.

2. OUR APPROACH

2.1 Constant Temperature Baths

A very cold, constant-temperature bath (CTB) is important in preparing a low-pressure Martian atmosphere and they can be helpful in maintaining a constant low-temperature environment for Mars ambient studies. Researchers sometimes use an ice bath (a mixture of ice and water) to keep a flask at a constant temperature of 0 C (273 K). The melting ice absorbs heat and a well-stirred bath will stay at 0 C until all of the ice melts. Are there materials, like ice and water, which melt at lower temperatures and could be employed for this project to produce well-defined low temperature environments? The answer is yes.

It is important to identify the temperature ranges required. To produce a Martian atmosphere at less than one-hundredth of an earth atmosphere (0.01 Bar = 10 milliBar) materials which freeze at about -123^0 C (150 K) are required. The average surface temperature of Mars is about 220 K. In section 2.3, we suggest an antifreeze and water mixture which could be used to keep a flask at about -53 C. Specifically, this is a eutectic ethylene glycol-water mixture.

These low-temperature baths work similar to an ice-water bath. Except that we have to freeze our CTB material ourselves, whereas you can buy crushed ice. We have to have a very cold refrigerant to freeze the lower temperature CTB materials. For example, to produce a146 K CTB material, LN is poured onto n-propanol and the mixture is stirred. (Dry ice sublimes about –80 C. It isn't sufficiently cold to produce the mostly frozen slushes of 1-propanol, petroleum ether, etc.) As more LN is added the liquid chills and finally begins to freeze. In the case of n-propanol, this marked by the thickness of the mixture increasing dramatically until it is like Jell-O. Big crystals as might be observed when water freezes don't form in this case, but they can with other materials. We stop adding LN when the mixture is mostly frozen. The reason we don't keep adding the cryogenic after the material is frozen is that it only acts as a CTB material as long as it is melting. Pure water can be entirely frozen to ice and then the ice chilled to even lower temperature in a cold refrigerator. It won't produce a constant temperature bath until it is warmed up to its melting temperature or enough water is added so liquid water is present. Similarly the CTB described here will only work if there is some liquid present.

We got our CTB set up in insulated containers a few minutes before we began preparing the carbon dioxide atmosphere of Mars in our Mars jars.

Cryogenics: Summary of their uses:

Liquid nitrogen in needed to freeze the liquid to be used to make the South Pole bath. Dry ice sublimes about –80 C. It isn't sufficiently cold to produce the mostly frozen slushes of 1-propanol, petroleum ether, etc. However, dry ice in needed to create the Martian atmosphere and can be used to set the flask to a Martian temperature. Incidentally pure liquid nitrogen is too cold to be used to set the mars temperature. It boils at –196 C at atmospheric pressure. At this temperature the partial pressure of CO_2 is about 10^{-4} mBar, considerably below Mar's pressure.

Practically this is how the "freezing" is done to make "south pole" slurry. Pour the liquid to be frozen into a mixing container. Pour LN (BP= -196^o C) on top of the liquid and stir the liquids together. Use a spoon, being careful to minimize splashing. Add more LN until the liquid is mostly frozen. There should be some liquid left. However, there should be no LN.

2.2 The first characteristic: A low-pressure atmosphere composed mostly of carbon dioxide.

Three steps are required here. First, select a vessel which can be pumped to low pressure without implosion. Second, prepare a Martian atmosphere of the right composition and third, decrease the pressure of this atmosphere to that of Mars.

The first step: selecting an appropriate vessel and way to seal it.

We used beakers without spouts and black rubber stoppers. Figure 1. The largest beaker we used was about 500 ml. Filter flasks and test tubes could also be used. We will term the vessel used for the Mars environment a flask but, of course, other vessels could be used.

At sea level the earth's atmosphere puts pressure on all side of an object of 100,000 pascal (10^5 Pa= 1 Bar =750 torr= ~14.7 lb/sq in). If all of the air is taken out of a container there is no longer pressure on the inside opposing the air pressure inside. Unless the container is made to withstand this pressure it can collapse. In some science classes to show the effect of unbalanced pressure, a vacuum pump is connect to the opening to an empty metal solvent or fuel cans. The pump is switched on. As the air is exhausted from the can it immediately and noisily implodes. The large metal sides of the can collapse inward. Its shape and strength work against it. Such cans are not made for high-pressure differences, neither are most food bottles. However, chemistry wares like filter flasks, glass desiccators and many test tubes are made to withstand them and for many decades glass "bell jars" ~1 m high by > 0.6 m in diameter have been used with great success for vacuum pumping stations.

If the researcher is uncertain as to the suitability of a glass container, she can test it inside a closed hood. The flask could also be "taped" for some of its early trials to minimize the possibility of injury should the flask rupture.

We employed standard chemistry rubber stoppers to seal our flasks. We cut holes to bring in the services we needed for the experiments we were doing. In every case there was a hole for the ¼ inch copper tubing used to cryogenically pump the flask. The closed end of this tube is termed the South Pole. See Fig. 2. See below.

Second Step: preparing a Martian atmosphere of the right composition

Mars' atmosphere is 95% CO_2. There is almost no oxygen in it. Almost all of the rest of the gas is inert N_2 (3%) and Ar (2%). We can approximate Mars' atmosphere by producing an atmosphere which is as close to pure CO_2 as practical. This will be a satisfactory approximation for most purposes, since the inert gases and even nitrogen, in most cases, will not enter into reactions. We can use dry ice to produce such an atmosphere and liquid nitrogen to produce the partial vacuum if we are careful.

We remove earth air from our test station by displacement. We place small pieces of dry ice in the bottom of the flask. We also push the open end of the U-shaped copper tube shaped through the stopper which will seal the Mars jar. The other end will be placed into our cryogenically frozen, now melting, slush. We also pushed, some tiny CO_2 chunks down the copper tubing, and then shaking them to get them against the sealed end. We then hold the sealed end of the tube down and wait one to two minutes for the dry ice in both places to vaporize enough to displace the air in the copper tube and the experimental flask. Figure 3.

This works because CO_2 has a molecular mass of 44, whereas air has am average mass of about 29. Regarding these as ideal gases, carbon dioxide is about 50% denser than air. As the dry ice turns to a gas, its vapors fill the beaker from the bottom up. Soon they fill the flask and spill out. There may be some mixing of CO_2 with the air in the flask as it is evolved so it is good to place enough of the dry ice for it completely fill the flask 2-3 times. At this point, it can be considered an atmosphere of pure CO_2. However, it will be at the pressure of the laboratory on earth. And the dry ice continues to sublime. If the stopper were placed on the beaker without the south pole being chilled pressure would build up and pop the stopper off.

temp	Kelvin	1/t	pressure	log pres
-134.3	138.85	7.202017	1	0
-127	146.15	6.842285	3.5	0.544068
-123	150.15	6.660007	6	0.778151
-119.5	153.65	6.508298	10	1
-108.6	164.55	6.07718	40	1.60206
-100.2	172.95	5.782018	100	2
-85.7	187.45	5.334756	400	2.60206
-78.2	194.95	5.12952	760	2.880814

Third step: achieving Martian Pressure ~~The approach we describe doesn't use the standard approach which requires vacuum pumps and gauges. We use cryogenic (very cold) materials instead.~~ Mars has a very interesting atmosphere, it is mostly is CO_2 and CO_2 is readily condensable under conditions which can be found sometimes on present-day Mars. Condensable means that it goes from being a gas (very, low density) to a solid (which has much higher density) at temperatures similar to those typical of very cold locations on Mars, such as at the poles in winter. Because of this volume change when the CO_2 condenses, it leaves behind a partial vacuum. In fact, at Mars' south pole (and to a lesser extent at its north pole) the CO_2 in the atmosphere condenses in the winter. The atmospheric pressure all over Mars drops during the South Pole winter as the largest component of the atmosphere begins condensing there.

The advantage of this for us is that low pressure can be obtained in a Mars jar by partially condensing its CO_2 atmosphere by placing the closed end of the U-shaped, copper tube in a low temperature environment of the correct temperature to condense CO_2 down to .005-.008 Bar. 1 Bar is earth's nominal pressure near sea level.

Researchers can use liquid nitrogen and dry ice to produce, in standard test tubes or flasks, the partial vacuum that exists at the pressure of the surface of Mars in the same way low pressure is maintained on Mars. To prepare the system's south pole, we prepare a copper tube sealed tightly at one end and open at the other. The open end penetrates the stopper at the top of the flask or test tube. It is left open so that the mostly CO_2 atmosphere in the Mars jar can freely move up towards the sealed end. The sealed end will be put into a liquid/ solid mixture of slushy materials, like n-propanol, which melt in the –122 to –128 C range. It can be deduced that this is the likely average temperature at Mars' south pole during part of the winter. We bend the copper tube into an upside down U shape, one end through the stopper and the other end, the sealed end ready to immerse into the cryogenically frozen, now melting, slush which condenses excess CO_2.

We call the sealed end of the copper tube the experiment's South Pole, because we see that when it is refrigerated to the correct temperature it will function like Mars' south pole, condensing excess CO_2 atmosphere from atmospheric pressure the lab where the experiment is done down to the pressure level that is observed on the planet Mars. In table 1 we show the temperature in each case for which dry ice (solid CO_2) is in equilibrium with different pressures of CO_2. That is, the table gives the vapor pressure of dry ice at different temperatures. The data is drawn from the CRC Handbook.[2] We can see that dry ice at a temperature of ~-123 to –128 CO_2 will have a partial pressure of 4 to 6 milliBar.

How do we get a refrigerator that is that cold and that precise? If we wanted to get 0^o C, we could use an ice bath. - Ice can be very cold but it cannot be over 0^o C. As it is warmed up, it will start to melt at zero Celsius. Then the temperature of the ice + water does not increase. It stays at zero C until all the ice is melted, as long as the ice bath is stirred to keep it well mixed.

However, we want –123 to -127 ^{o} C. What can we use? What can we freeze which melts at about - 125 ^{o} C?

	Melting point (^oC)	MP K	Press. mBar	Press. torr
Methanol	-93.9	179.25	249.72524	187.294
Ethanol	-117.3	155.85	17.222935	12.9172
Isopropyl alcohol	-85.8	187.35	539.35995	404.52
Acetone	-94.6	178.55	232.88306	174.662
1-propanol	-127	146.15	4.4224161	3.31681
Gasoline	-56	217.15	5590.7183	4193.04
N-pentane	-130	143.15	2.7979884	2.09849
Hexane	-95.3	177.85	217.05743	162.793
Toluene	-95	178.15	223.71886	167.789
Diethyl ether	-116.3	156.85	19.625717	14.7193
LN2 (Boiling P)	-196.15	77	1.337E-08	1E-08
	Mars is 5 to 8 mBar			

Table 2:

In table 2, we show the melting point of some common liquids which can be obtained in most chemical stock rooms.

The melting points of 1-propanol and n-pentane are closest to the correct temperature to establish Martian pressure. We have experience using 1-propanol, also called, normal propyl alcohol. We used n-propanol because its melting temperature. We found that it mostly gels when it is frozen with LN2. This formation of a thick gel may make it more difficult to stir the bath well and so have the entire bath at the same pressure. Prof. Bevan Ott (Emeritus BYU) suggests mixing some hex and getting the right temperature thusly. He states that it should be crystalline and thus could make a better "ice bath" than the alcohol does.

Ethanol also merits attention for ice baths. The melting temperatures of absolute (100%) ethanol and laboratory ethanol (5% water) are almost in the ideal range. These may be more available to some researchers and may be adequate for many purposes. It should be noted that at the slurry temperatures ethanol provides, the pressure of these Mars jars will be about double Mars standard. For (5% water) ethanol the pressure will be about three times Mars standard. For some studies this difference could be minor enough to be inconsequential. For others, this difference could be expected to have large consequences that ethanol should not be used to make the ice bath. Such a case could be if the presence, or absence, of liquid water was deemed to be important for the studies. Mars atmospheric pressure is just above the triple point of water but the air is very dry. Sublimation of ice is thought to be the rule on Mars and melting the exception, though it could happen in the rare areas where nearly all the CO_2 was replaced with water vapor. Doubling the pressure in a Mars jar could lead to false conclusions if the presence or absence of liquid water were an issue in studying present-day Mars.

We used ¼ inch copper tubing for the South Pole. We used a combination of Swagelock fittings to seal the one end of the tubing. A store with air conditioning and/or plumbing supplies can probably be used to find parts and instructions for this purpose.

2.3. Summarizing the prior work to performing an experiment in carbon dioxide at Mars pressure.

The flask has been obtained.

A stopper found, drilled and the South Pole copper tube pressed through the stopper.

The experiment to be tested is placed in the flask

The cryogenically frozen liquid has been prepared. And is in its insulated container awaiting the system's south pole.

The atmosphere in the flask and in the copper tubing has been replaced by CO_2 and there is still some dry ice in the flask.

It is now time to place the stopper with the bent tubing on to of the flask. Then immediately place the S pole end in the cryogenically frozen liquid. This will keep the stopper from popping off as more dry ice sublimes. Now that the system as a very cold pole, instead of the pressure building up in the flask, the pressure should now plunge to Mars levels.

Now you have inside a flask or test tube Mars atmospheric conditions.

3. OBTAINING MARS TEMPERATURE FOR THE FLASK.

For some experiments it is enough to have a low-pressure carbon dioxide atmosphere, but for others it is as, or more, important that the temperature of the experiment match that of Mars.

The average temperature on Mars is about 220 K (~ -55 C). This is very cold for earth but just right for Mars. After all, it is about 50% further from the sun. Therefore, it should receive about 40% as much light as earth averaged over large times. On earth, the temperature can vary by well over 100 K depending on location, where it is day or night, winter or summer. The temperature on Mars varies over a much larger range. Therefore, a researcher can "pick an ambient" over a large range of temperatures for his experiment. However, she may wish to base it on Mars average.

Table 1 shows some materials which would be frozen

Here we suggest a 50:50 ethylene glycol-water mixture. Amount REF? Ethylene glycol is the predominant ingredient in automotive antifreeze. This mixture has the advantages of being low cost and nonflammable. On the back of many antifreeze containers is a table which gives the volume of antifreeze to volume of water required to "protect the engine". The solution thus prepared will not freeze until that temperature is reached. Once that temperature is reached the mixture begins to freeze. And the temperature then continues to decline, though more slowly, until the eutectic temperature and composition is reached at this point the temperature stops declining as the remaining liquid freezes. In the lab we did this with dry ice. We used the eutectic composition ( ) so that the slush that we made acted like a pure substance and melted at one temperature ().

Calibrating thermometers. AND TCs: I have more to write here. WEB SITES?

4. TWO STUDENT EXPERIMENTS.

What we have just described is how to make the basic chamber and set up its atmosphere. Each experiment will be different. We will describe two experiments which we conducted that were of interest to members of our team.

1. Lightening in a jar. This was a project which evolved out of a question of Thomas Riddle and in a discussion between Riddle, Paul and David Allred. Thomas Riddle, a middle school student at the time, wondered if it would be possible to show lightening in a bottle. The question evolved into determining if lightening would be any different in a low-pressure environment like Mars. It is well known that as pressure decreases the electric field strength required to produce a high electric field breakdown decreases.

We prepared two vacuum compatible electrodes by epoxying two wires into plastic sleeve about 7 cm long. Two more holes were cut in the rubber stopper to accommodate the two wires.

We deemed that the essential part of the experiment was doing it at the pressure and the atmospheric composition of Mars so that was what we did. We didn't worry about cooling the flask to Mars temperatures.

How did the nature of sparks change at low-pressure? We observed that the sparks with struck may have continued to a larger gap distance than at laboratory pressure, but this wasn't conclusive.

2. Ice cream on Mars. Third graders have different questions about Mars. John Allred's question in 2001 was how does ice cream change if it were on Mars. Here the issue was obtaining the surface temperature and approximate pressure of Mars. An insulated Styrofoam box of the type used to ship heat sensitive chemicals in was used to hold the beaker.
We observed that the ice cream became much harder at –55 C. It could be used as a building material. A number of 3rd graders were very interested in testing the ice cream when it was removed from it Martian ambient. 3rd graders' questions and interests are not the same as adults.

5. DISCUSSION.

We have shown how dry ice and liquid nitrogen can be used to realize the first two characteristics of the surface of Mars listed above. and how slushes prepare other low freezing point materials they freeze cryogenic temperatures and we have given some examples of how.

5.1 Limitations:

What we have done is probably adequate for initial test and beginning researchers. The idea of using cryogenics to reduce pressure is well know. Cryogenic pumping, whether for rough vacuum using sorption pumps or high vacuum using helium refrigerator cryopumps, is a good way to achieve low pressures in vacuum systems used by professionals. These systems also have gauges to show when certain pressures are achieved and whether or not there are leaks. None of the systems we describe above have vacuum gauges. Indeed finding accurate low cost very low pressure gauges is an unsolved problem. It may endure.

In addition student researchers would be benefited by our doing further research in addressing issues such as: seeing how fast the low pressure we calculate from standard tables is achieved, whether it is what we compute and if the procedures outlined above accomplish all that the concepts described here suggest, also, to what extent leaks are a problem and the best ways to remedy them. We have access to a 10 torr full-scale capacitance manometer and other measurement equipment. We intend to perform additional test to answer these question and to report in 2003's meeting.

5.2 Meeting other characteristics of Mars in Mars Jars

We would now like to discuss reliably producing one or more of the other three characteristics of Mars.

The third can be accomplished by obtaining rocks and/or fine powders from one of several sources. Hawaiian Basaltic lavas chemically resemble "Mars-type" powders and rocks. We also note that others have address how to achieve this characteristic.

The fourth characteristic, less sunlight than earth but more UV in the 300 nm range, can be divided in two. First, UV isn't important. In the simplest case some researchers, as a first order approximation, need introduce in to the flask flux which equals the integrated power/ area which as Mars receives from the sum. The exact spectral power density is treated as a correction to the total flux and as such is neglected. An example of this is Gan and co-workers work on the potential transitory existence of liquid water in the sunlight zone on Mars's surface. (REF) ADD MY NOTE To GAN.

Just power alone is easier.

The intensity of light at the surface of Mars's atmosphere is about 40% of earth's. The solar constant at earth is 1.35 KW/m2 so mars would have about 540 W/m2. A 100 W light bulb radiating in all directions (4π steradians- units of solid angle) would have an intensity of about 540 W/m2 at about 12 cm. That is about 5 inches. But only 90% of the light makes it through a pain of glass so you would have to have the light bulb closer, 11.5 cm for flat glass. If the glass is curved then even less will make it in and you will have to have the source still closer.

You should not forget that if you have the apparatus in a warm room. It will heat the apparatus by convection, conduction and IR radiation. It may be possible to use mirrors to correct for some of this. What is it you want to do?

On the one hand, there is a second case where UV is important. If chemical systems, especially those which include organic chemicals and the potential of life, are under consideration, producing a spectrum which matches that on the surface of Mars after it penetrates the walls of the flask may be important. The most important thing in this case will be knowing the flux in different bands even if the flux does not match that from the laboratory sources. It then may be possible to compute dosages and see which bands are important. This area needs quite a bit more research before it is possible to describe sufficiently robust techniques for nonprofessional use. We have done some study on solar flux at Mars' surface and will address it more completely later.

The fifth characteristic, Martian gravity for periods of time longer than seconds, is beyond what any single researcher can achieve. It can be obtained only in a low gravity environment, specifically, Mars, the Moon, or in a spacecraft in free fall with a rotating chamber inside. At the present, only the last approach, near-earth orbit, is at all possible (REF) and it is very expensive. We encourage researchers to concentrate at the present on one, or more, of the first four characteristics.

6. SUMMARY.

Children have different questions about Mars than many adults.

We suggest that the Mars Jars approach might be scaleable to a room sized Mars bottle for equipment and shakedowns and tests. We note that less than 100 Km north of the MDRS in Utah are a number of CO_2 wells, including several "cold" geysers. The natural gas extracted in this region also has a considerable quantity of CO_2 in it which is extracted by local gas companies. Perhaps, this gas could be employed to produce an inexpensive, but useful Mars Environment Test Station near where it is extracted.

ACKNOWLEDGEMENTS

We also acknowledge gratefully the financial contributions of V. Dean and Alice J. Allred and Marathon Oil Company (US Steel) of gifts to Brigham Young University for physics research.

Orphaned text which may be used:

What this means is, that as 95% of the atmosphere is CO_2 and CO_2 can be changed from gas (low density) to solid (which has much higher density) at temperatures similar to those typical of very cold locations on Mars, such as at the poles, low pressure can be obtained in a Mars jar by condensing the atmosphere by placing the closed end of the copper tube in a low temperature environment of the correct temperature. When the CO_2 condenses, it leaves behind a partial vacuum. In fact, at Mars' South Pole (and to a lesser extent at its North Pole) a portion of the CO_2 in the atmosphere condenses in the winter. The atmospheric pressure all over Mars drops during the South Pole winter as the largest component of the atmosphere begins condensing there.

Researchers can use liquid nitrogen and dry ice to produce, in standard test tubes or flasks, the partial vacuum that exists at the pressure of the surface of Mars in the same way low pressure is maintained on Mars. (We will term the vessel used for the Mars environment a flask but, of course, other vessels could be used.)

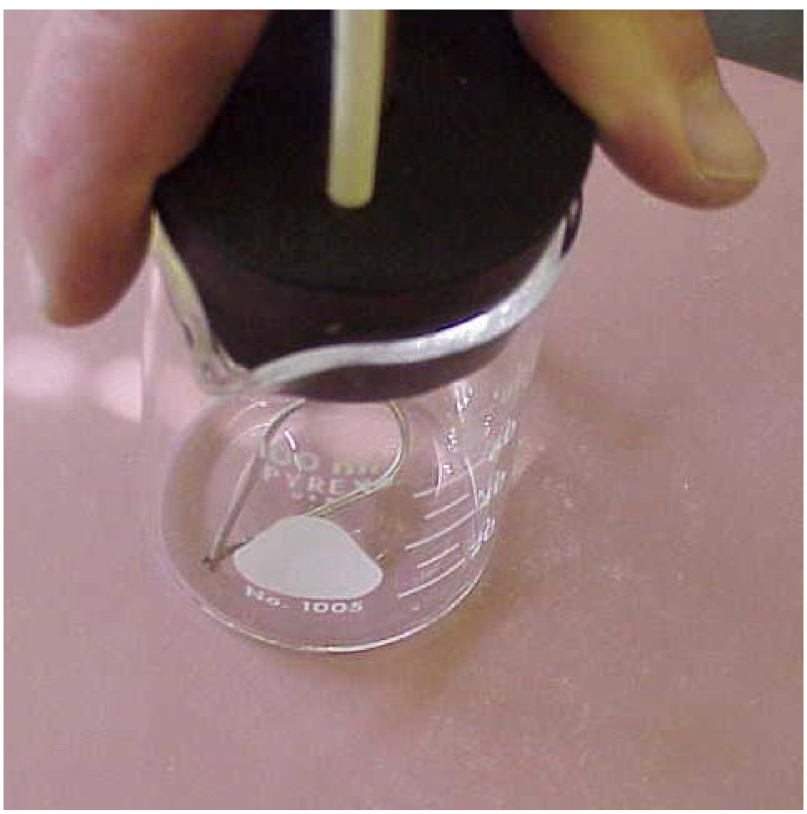

Figure 1. A stopper on a Mars Jar. This configuration will not work since the lip of the beaker prevents a seal from forming. The white tube on the stopper is an electrical feed through produced by running wire through a hollow plastic tube. The tube does not fit tight on the wire. 5 minute epoxy is used to fill the top end of the tube to seal the wire and the tube. The tube runs through a drilled stopper.

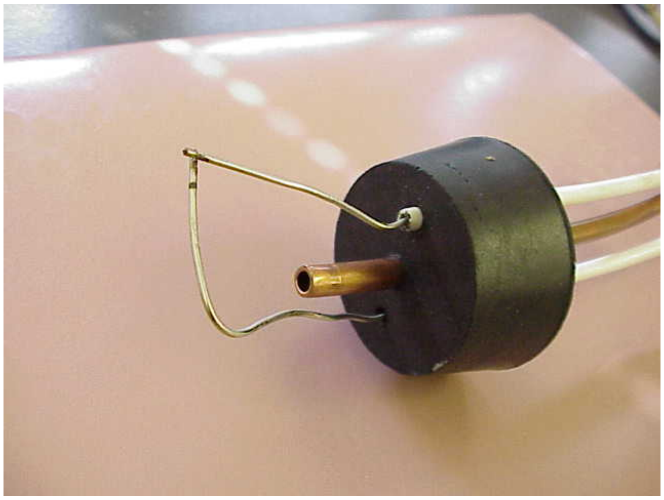

Figure 2. A better view of the rubber stopper for the Mars Jar used for electrical discharges

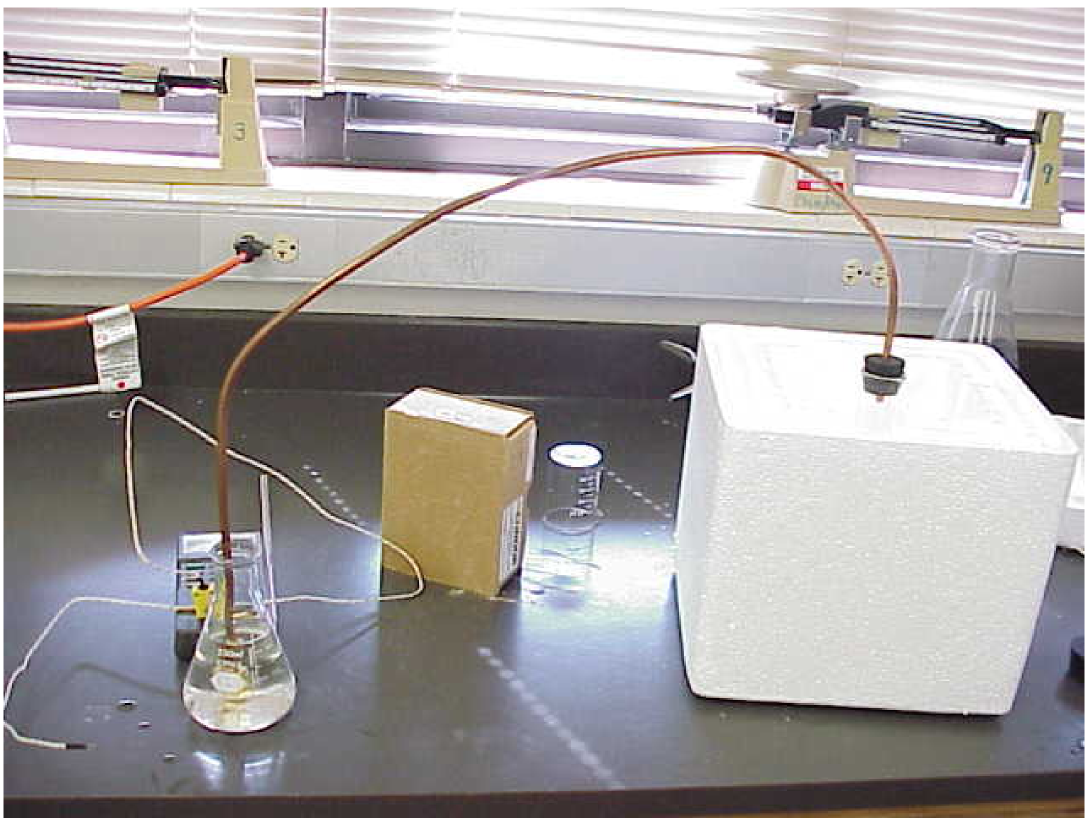

Figure 3. The copper tuber is bent in an invert U shape. On the right it is attached to the Mars Jar with a rubber stopper on the left the sealed end is inserted into the flask which will have the -125º C melting liquid/solid slurry. That end is termed the South Pole and pumps CO_2 gas from the Mars Jar when it is chilled with the slurry. The Mars Jar is in an insulated box so that it can be chilled to the temperature the researcher plans. In operation the -125º C flask will also be insulated.

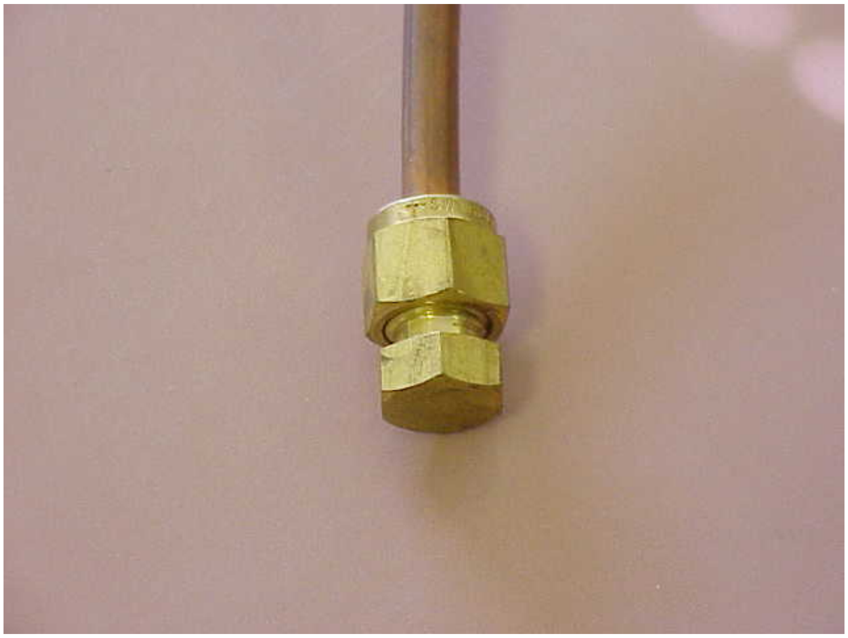

Figure 3. Close-up of a Mars Jar South Pole.

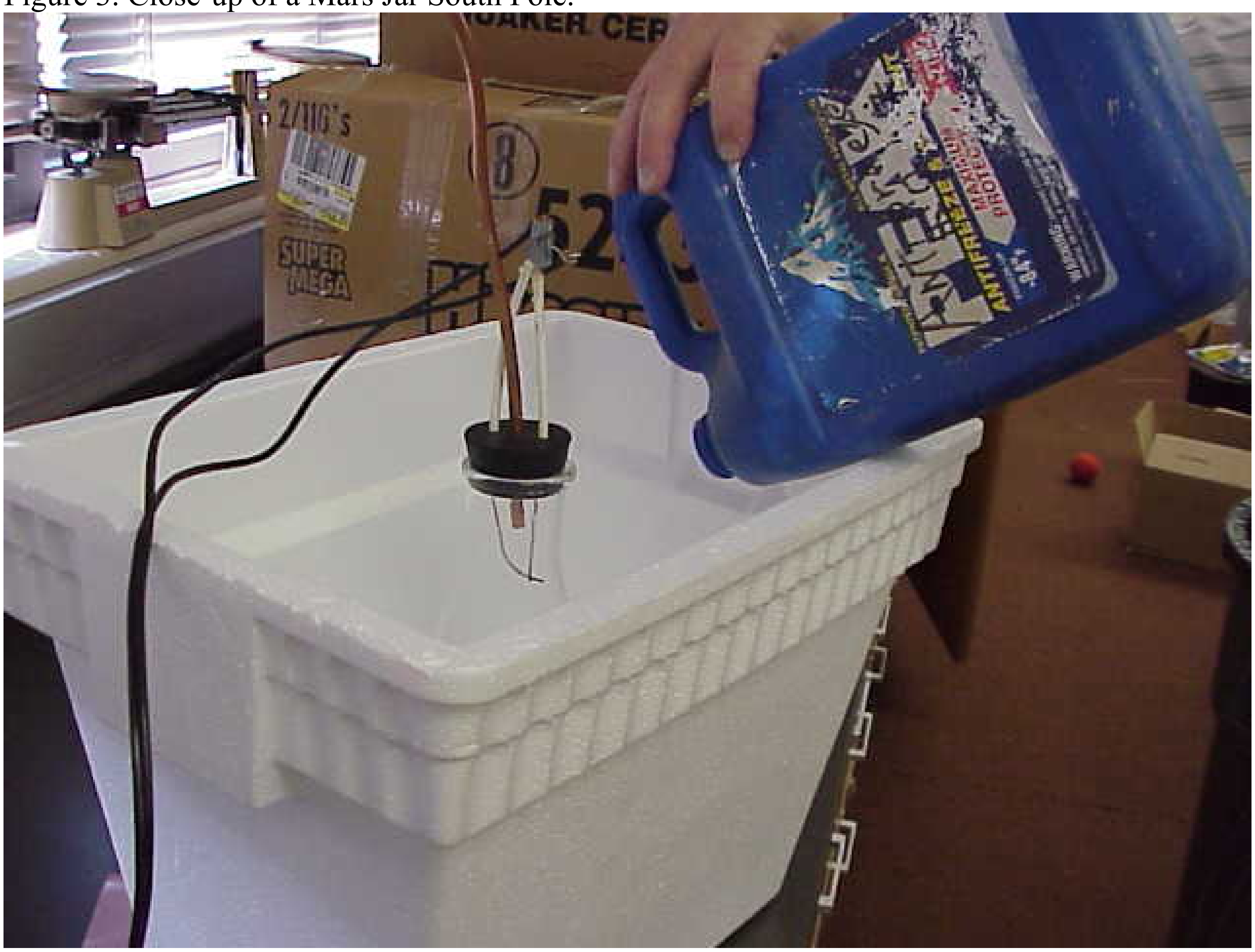

Figure 4. Adding a chilled ethylene antifreeze-water mixture to the insulated box can chill the Mars Jar to a temperature typical of Mars and maintain it at those temperatures for long periods of time.

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