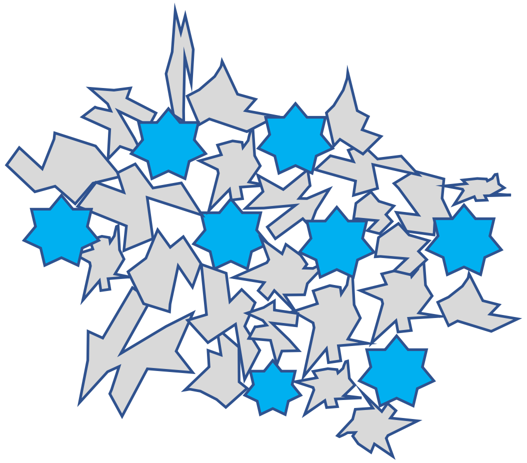
Separation of Ice from Regolith by vibration

The Shackleton crater on the South Pole of the moon where NASA wants to look for water ice is 12 miles across and the rim is a few hundred feet high. It would not make sense to try to remove tons of the regolith and ice mixture from the bottom of the crater (where the ice is) to process in the sun. Instead, it would be better to have robots that could do at least some of the separation and increase the percentage of ice in the mixture so that we don't have to transport tons and tons of regolith. NASA is hoping the ice and regolith are mixed loosely and somewhat evenly together. Because ice and regolith have very different densities, it may be possible to use vibration to lift one to the top and let the other go to the bottom of a container. Even concentrating the ice by 10 to 20% could save a huge amount of time, effort and money.

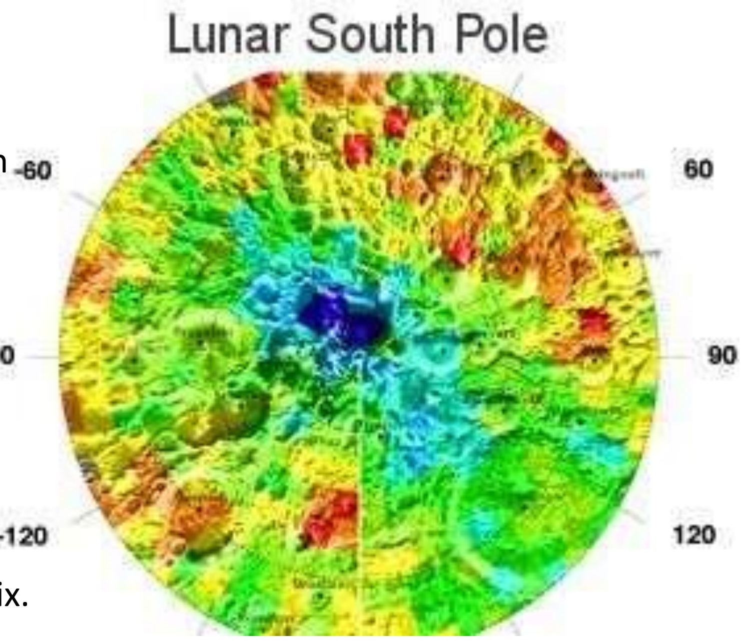
Ice particles in regolith



Requirements

Imagine you are part of the team developing the robot tasked with doing the first separation of ice from the regolith. It drives back and forth (kind of like mowing the lawn) gathering up a mixture of ice and regolith and spitting out the regolith in the crater (with less ice in it) is a separate job. **Your job is to demonstrate the portion of the robot that does the separation and show where the ice is kept for return to the habitat where the ice can be used.**

- **Design, build and test** a demonstration for how loose ice crystals might be separated from loose regolith using vibration.
    - Use ABS (density of 1.0 g/cm^3) shavings to simulate the lower density ice from the higher density regolith (density of 1.5 g/cm^3)
    - Variable speed vibrator
        - Off center mass on motor or Speaker style (check with your physics teacher)
    - Cookie sheet and/or Lasagna pan (a place to start but your container design can be any shape)
    - We don't expect your sample to be perfectly clean but increases the concentration of the ice in the regolith significantly.
    - Can be either a batch process or a continuous process.
    - How clean of "ice" particles can you provide?
- Lunar crater regolith simulant **(YOU WILL NEED TO USE A DUST MASK)**
    - 5 gallon bucket for mixing
        - 3 gallons of cement mix?---these dust particles are very small
        - 4 cups of low density plastic shavings— (ABS, EVA, COC, LDPE or PP) the closer to density of ice, the closer your demonstration will be to reality
            - use 80 grit sandpaper and make plastic dust from a solid plastic
            - You may use any color you like. It may be helpful for it to contrast the color of your cement mix.
        - 2 cups of different size gravel



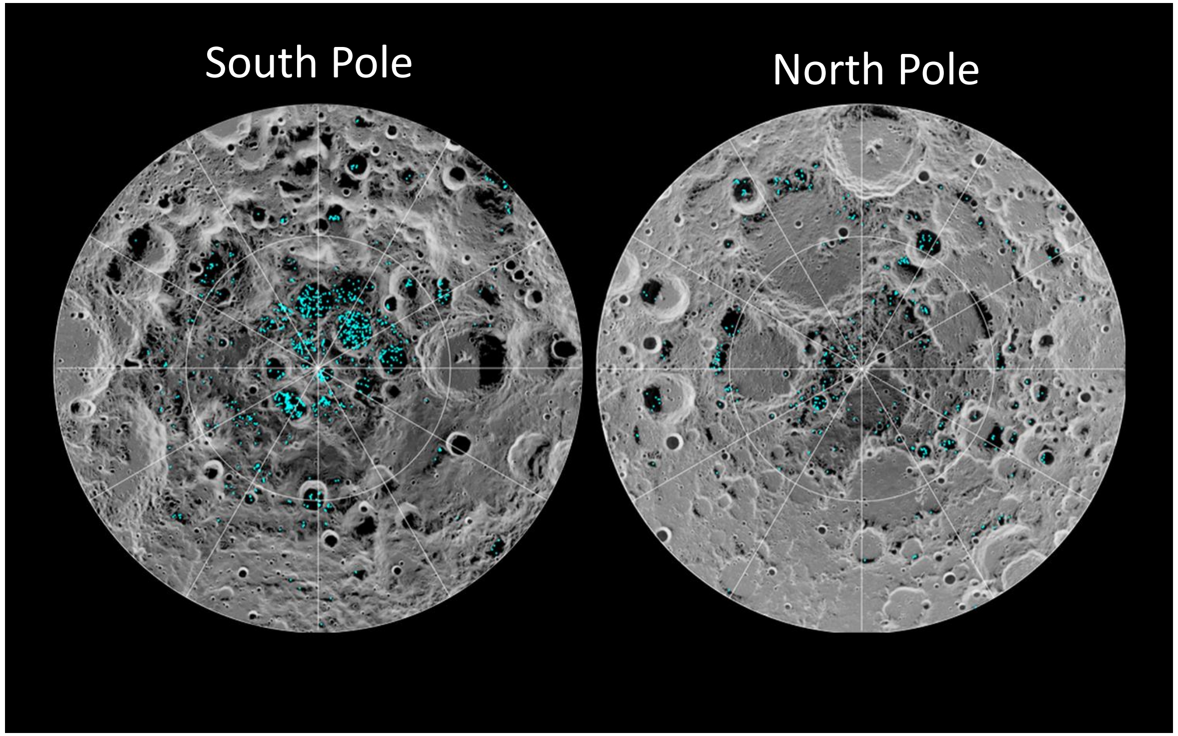
Where does the Lunar ice come from?

This is theory- because it is not completely known and we don't have enough data

- The suggested method that ice accumulates onto the surface of the moon is that comets pass through the inner solar system and release water vapor as they are heated by the sun. The vapor cools and turns to small ice crystals that are eventually captured by other planets and the moon's gravity and fall to the surface. If the crystals fall in a sunny area (most of the moon) the crystals evaporate and continue through their journey through the solar system. If they land in craters on the north or south pole where the sunlight never shines (due to the high ridges of the craters and the low angle of the sun) the small ice crystals remain solid. Because the moon is constantly being hit by meteors (mostly small), the regolith tossed up by the meteors eventually falls and mixes to cover the ice crystals. In theory, the ice crystals would be mixed fairly evenly with regolith but the exact mixture ratio is unknown.
- Water on the moon is exciting because it could make it much easier for people to live on the moon if we don't have to bring water with us for drinking and eating—water is fairly heavy and would cost a significant amount money to ship there. It is also possible to use solar power to chemically separate the water into hydrogen and oxygen using electrolysis. The hydrogen and oxygen could then be used to power rockets. With less gravity than earth, the rockets would need much less fuel to get off the moon.
- Lunar regolith is composed of very small shards of broken rock from the meteor impacts. Without water and wind to move the particles around, they remain sharp and jagged instead of rounded like sand. This also makes it so the particles can interlock instead of roll past each other the way sand does. Regolith is not very compressible—astronauts had a hard time drilling core samples because the regolith is compacted from a billions of years of settling and doesn't allow for drilled sediments from the drilling to be pushed to the sides and back up to the surface. Imagine if you had a bucket of dry concrete and tapped the side for a long time, the little particles would settle downward into little, tight spaces and the air would go to the top of the bucket.

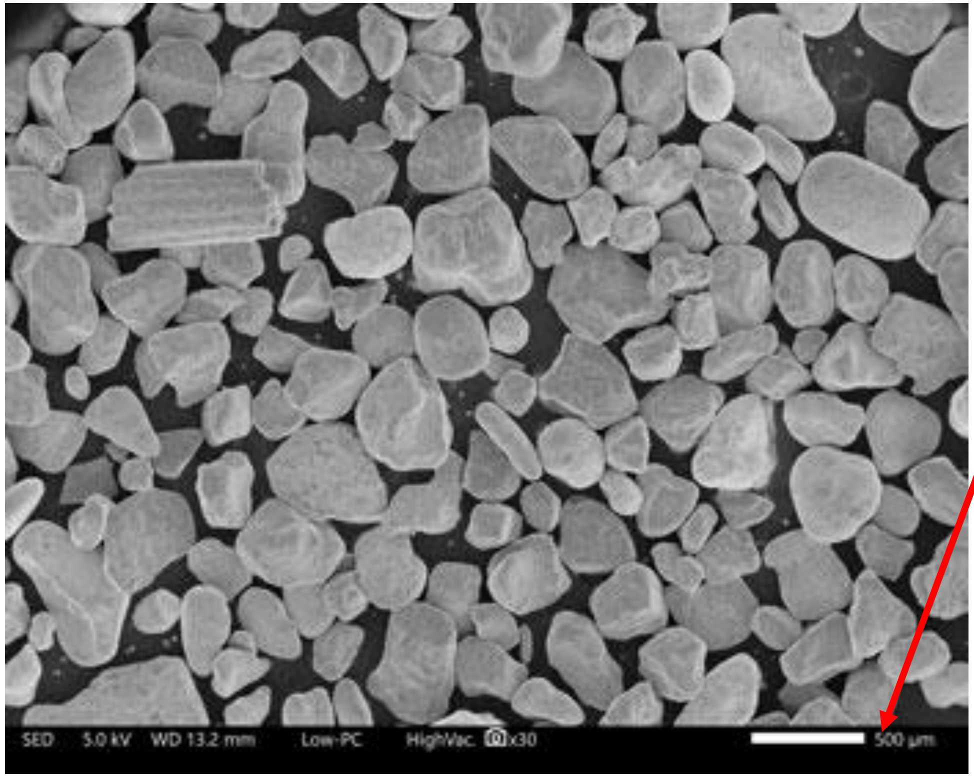
What else may be in the regolith?

- We expect there are some gases in the regolith in very small quantities. Mostly we should expect some hydrogen and helium because they are the majority of the solar wind coming off the sun and some of them probably get trapped in the regolith for a short period of time. There are probably others including helium 3 and some others at much smaller quantities. These other gasses and materials are in such small quantities that it won't be worth worrying about them at this time—maybe on a future project.
- The reason helium balloons rise on earth is because the helium has less mass than the other gasses like nitrogen and oxygen. The helium is buoyed up by the more massive gasses moving underneath the less massive helium. On the moon, there aren't any gasses to make an atmosphere so a helium balloon on the moon won't float, it will just sit on the ground.



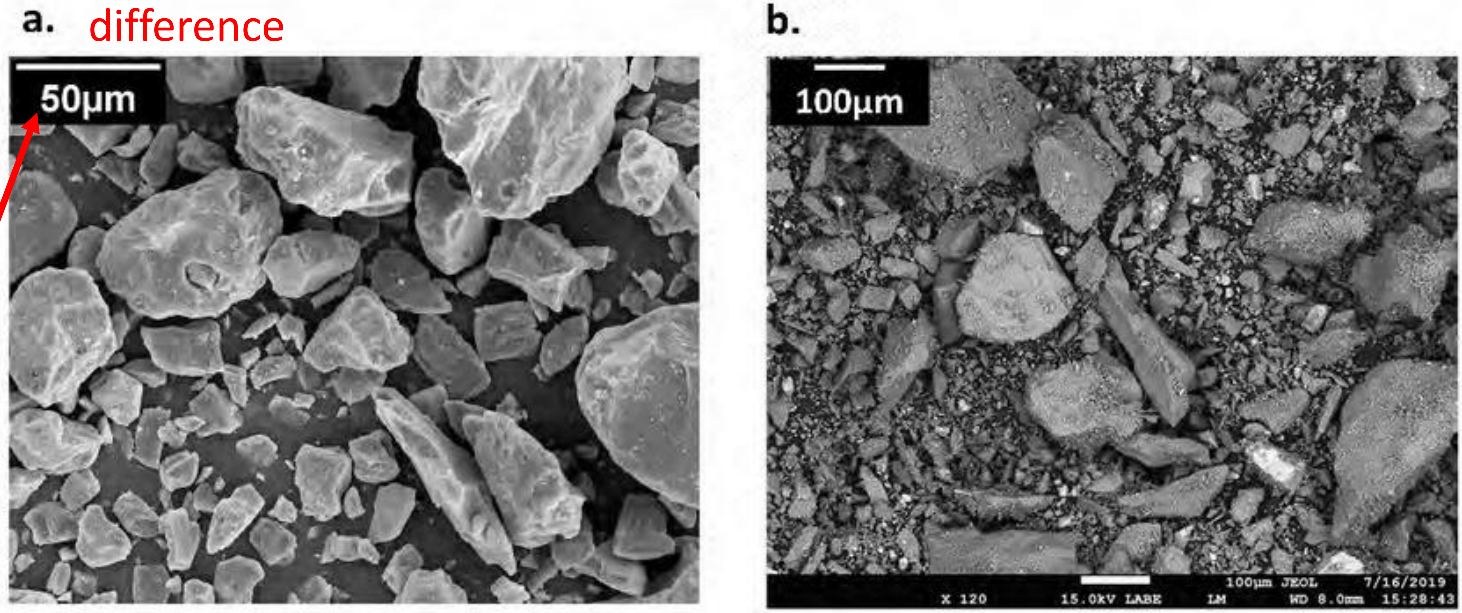
Blue areas are where Ice has been measured to exist by satellite instruments. Ice is able to remain in the permanently shadowed areas since it stays cold (-400 F) there.

Differences in Granules



Beach sand (much bigger and rounded than regolith particles)

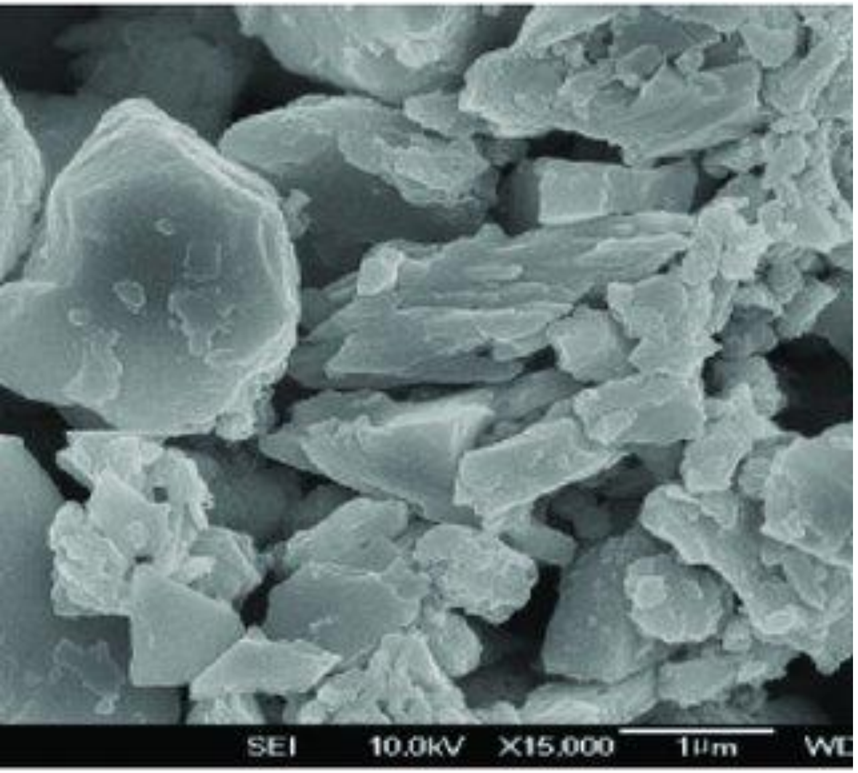
Notice the size difference



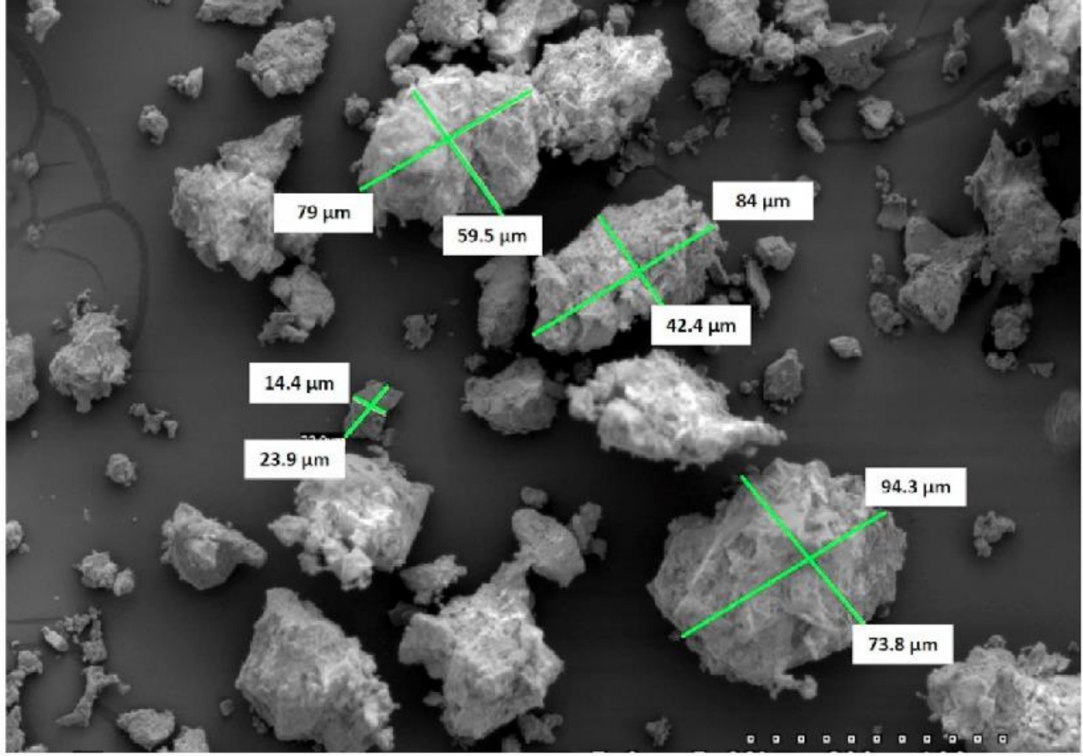
Lunar Regolith (much finer particles and more jagged)

Because sand on Earth is tumbled by wind, water, landslides and even by animals, the grains are abraded by each other and knock off the smaller and sharper edges, making them rounded. These rounded edges allow the particles to roll or slide past each other. Pushing a shovel into the sand is easy since the particles will move out of the way of the blade. The sand will also fall of the shovel more easily because of the rounded particles.

Lunar Regolith is basaltic or anorthosite rock (like from a volcano)that has been broken apart by meteorites. Some of them are just broken and thrown, others are melted and thrown and broken. Since there isn't any wind, rain, water, animals to break off the sharp edges, lunar regolith is sharper. These sharp edges allows them to link together instead of rolling past each other. This changes how tools, like shovels and stakes interact with the soil. Shovel blades will go in easily initially but the particles linking together to prevent the blade from getting very deep. These edges are also what cause damage to cloth and rubbery components of the space suits.



Dry cement particulate



Regolith simulant __ 100 µm __ MAG: 300x

Dry cement is closer to lunar regolith than sand because it is limestone that has been pounded into pieces and then heated to drive out the water from the chemical bonds but the type of rock (limestone) breaks in a different fashion than the basaltic rock. However, if you compare pushing a spike into a bucket of sand to pushing the spike into a bucket of dry cement that has been compacted with tapping, you should feel a significant difference. If you don't vibrate the cement, it will be loose with air pockets and won't act the same to your spike being driven in.

The regolith on the moon is well compacted. Without air on the moon, there are fewer pockets of empty space in the regolith. Whenever there is a moon quake or something hits the moon, the little vibration helps settle the dirt more. This has been happening for billions of years.

One of the mentors brought a bucket of lunar regolith simulant and a spike with a hammer. The spike was driven into the regolith. The first and second blow drove the spike a few inches but the 3rd blow to the spike stopped it dead. Because the regolith particles are jagged, they don't roll past each other when pushed. Instead they link to each other and make it difficult to drive the spike. Sand particles on Earth are rounded so they will roll past each other when jostled.

Vibration options:

An electric hand sander might be held against a bucket and used to vibrate with one frequency.

Is there a value to use a spinning motor with an off-set weight or a speaker to make the vibrations?

Which one is more tunable?

What frequencies work the best?

Do different frequencies work better on different sizes of particles?

What happens to the rocks that have a similar density as the sand?

How do you release the material you don’t want but keep the ice particles you do want?

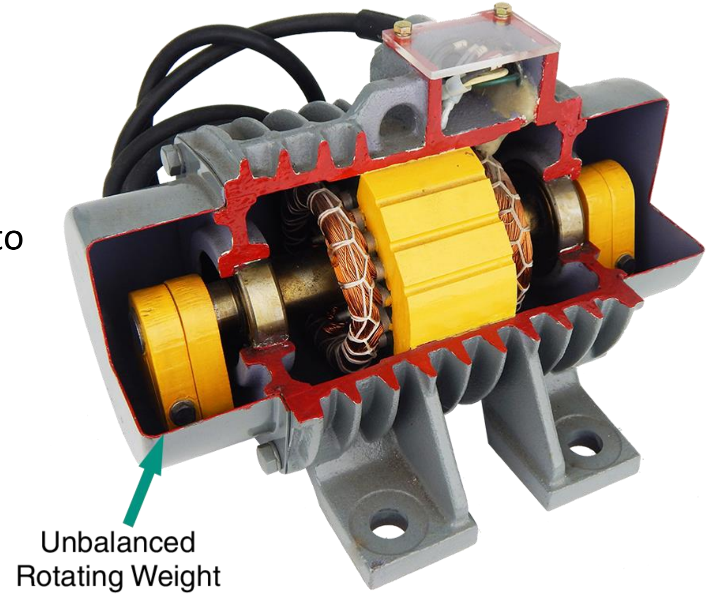
How big of a pan of sand and plastic particles do you need to vibrate compared to the size of vibrator needed?

Could there be specific regions of your vibrational box that ice crystals may show up?

How long does it take to get results?

The more we vibrate the regolith, the more heat we put into the regolith and risk sublimating the ice.

Is there another way to vibrate only the material?



Separating ice from lunar regolith using vibration

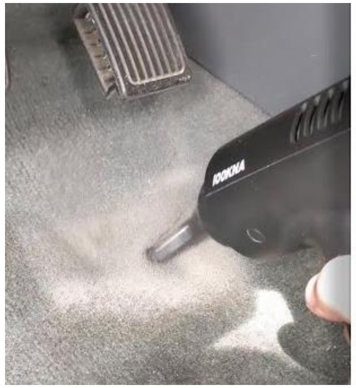
NASA does not expect to see visible ice sitting on the surface of the craters on the moon. The ice is expected to be small crystals mixed with the granules of the regolith. The temperatures are very cold, -400 degrees F. It is unknown whether the ice will act as a binder to the regolith or if the granules will remain as separate loose granules. It's possible that it could be clumpy or all hard pack but at these low temperatures, it seems they would just remain as loose granules.

- Separate with density
  - Density of the regolith (around 1.5 g/cm^3) is higher than density of ice (.91 g/cm^3). Shake or vibrate the mixture in some fashion so the densities separate.
  - Which goes to the top, Ice or regolith? Where do the larger rocks go?
  - Scrape off the top layer?
    - How much shaking (duration, frequency) is needed to separate?
    - How much of the top layer should be scraped?
    - How thick of a regolith/ice mixture is needed to get a good separation?
    - Can this be done in a continuous process or must it be done as a batch process?

- Other method?
  - It may be possible to separate the regolith from the ice crystals using static electricity but it would be very difficult to know the properties of either the ice or regolith at -400F without testing.
  - Paramagnetic and diamagnetic differences between ice and regolith may also valuable properties for aiding in separation since we are using plastic as a simulant it won't be the same effects.
  - I don't pretend to think we have identified all the ways this could be done. There may also be a reason to do many methods. Expand the possibilities with your own research.

vibrator

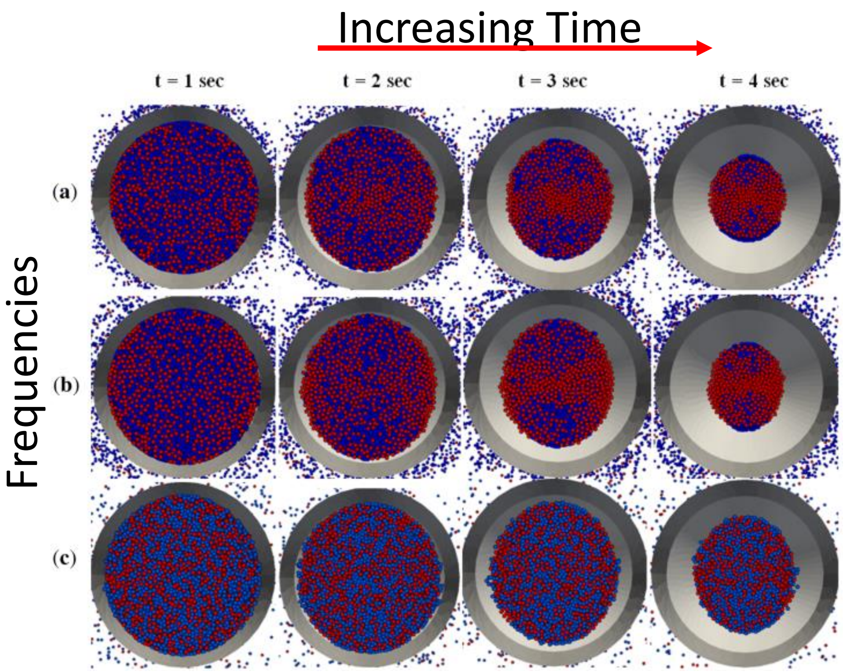
Vibrations make a sieve work fast but unfortunately, we expect the ice and regolith to have similar particle size.



Deep muscle massagers getting dirt out of car mats.

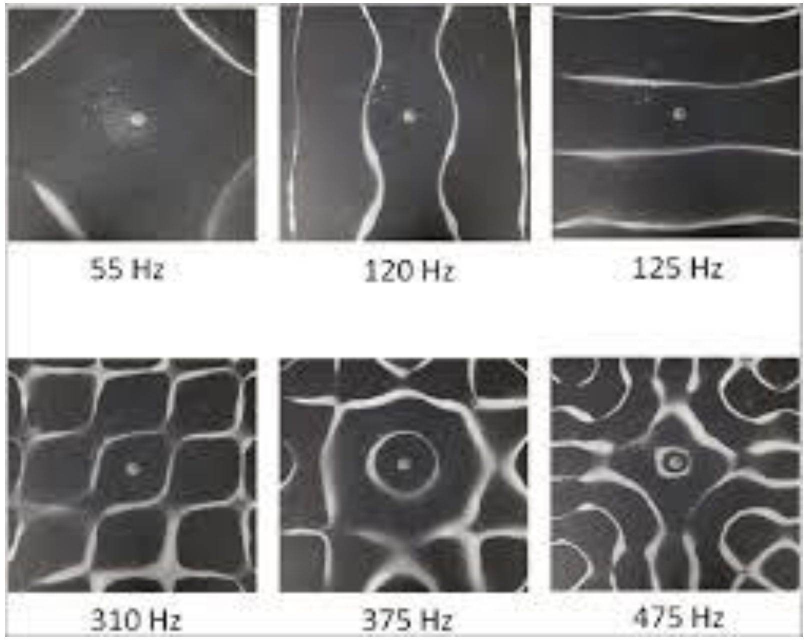
Factors that may affect the separation of ice from lunar regolith

- Vibration frequency
- Amplitude of the vibration frequency (loud vs quiet)
- Shape of the container holding ice and regolith—circular, rectangular, triangular, conical, ½ sphere, like a trough, ………
- Thickness (depth in a pan) of the sample of regolith and ice mixture
- Particle sizes
- Looseness of the sample (how clumpy is the sample)
- 1/6th gravity on the moon will also be an important factor and may decrease the power you need—how will you account for it.



These are 3 cone shaped chambers vibrated at different frequencies and some particles are allowed to leave the container. Lighter particles bounce higher. Could this be done in a continuous process or does it need to be done as a batch?

Using vibration to Separate seeds in farming
https://www.youtube.com/watch?v=uKAMpz--3IE



Patterns of sand on flat plates attached to speakers. Could different frequencies be used to separate the ice from the regolith into a region(s) of higher concentrations where the ice could be removed. Ask your physics teacher if they can demonstrate this. It changes the patterns by using different shaped plates.

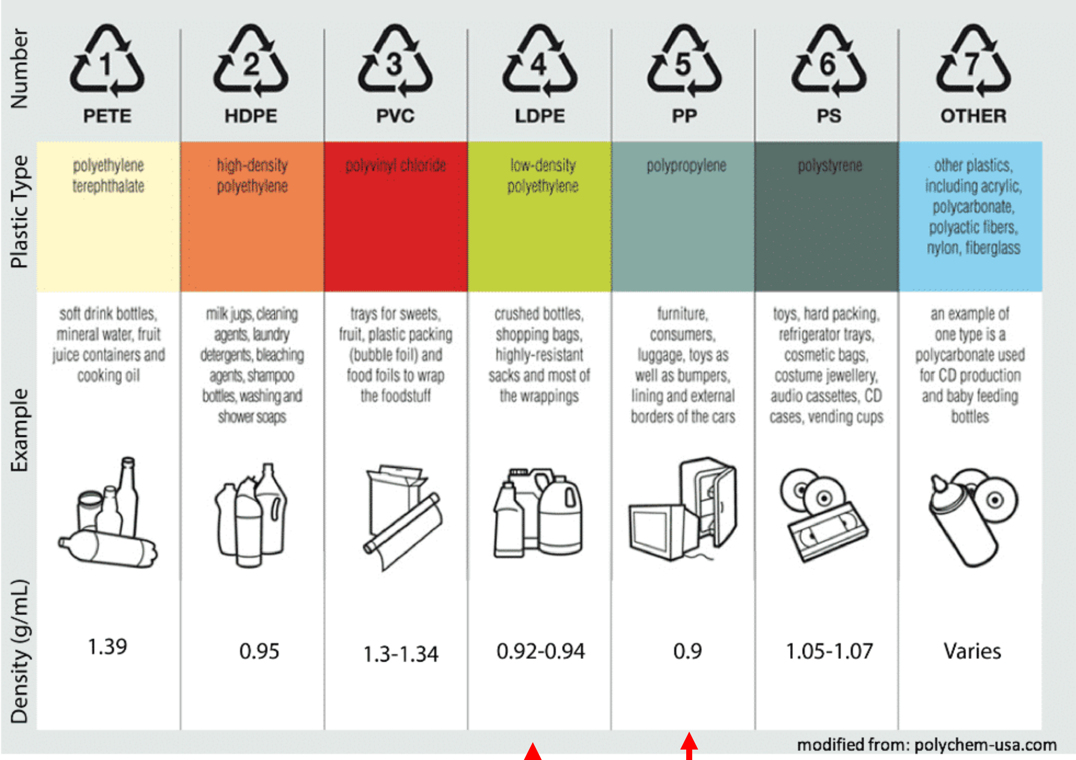
Using speakers to concentrate particles on a plate.
https://www.youtube.com/watch?v=wvJAgrUBF4w

Densities of plastics

Material	Density g/cm3	
Water	1.00	
Ice	.91	This difference is why ice floats on water
Sea water	1.03	
Regolith	1.5	
sand	1.6 to 1.7	
ABS plastic	1.05	
PLA plastic	1.24	
TPU plastic	1.66	
COC plastic	1.0	
EVA plastic	.914 to .980	

Science of vibration of different particles?

Do not use foam of the plastics as they will have a much lower density.



Looking at several different types of plastics and their densities, it looks like there are a few plastics with a density close to ice and may be a good stand-ins for the kind of tests we are looking for. A more rigid plastic may move through the regolith more like ice than a more rubbery plastic. It would be good to verify that the plastic you buy really is the density you are looking for. Just calculate the density before you start making your powdered plastic.

Temperature effects to consider

- Temperatures on the moon range between 250 F in the sun to -250 F in the shade. Except in the bottom of craters that haven't seen sunlight where it is expected to be -400 F.
- What happens to different materials at -400F
  - Batteries—if a battery freezes, the chemistry freezes—little or no electricity
  - Cloth, rubbery materials of a space suit—some things lose elasticity and break into shards like glass.
- Some things may be harder (many but not all metals) and others may be more brittle
- Things that flex and return to shape at warmer temperatures may crack or stay deformed at lower temperatures.
  - The dark craters of the moon are colder than Liquid nitrogen but these videos should give you some idea of what we are up against.
  - https://www.google.com/search?sca_esv=75ce3f1a0c12c434&rlz=1C1GCEA_enUS1104US1104&q=things+in+liquid+nitrogen&tbm=vid&source=lnms&sa=X&ved=2ahUKEwjwh9mx5pyGAxVbHTQ
  - https://www.google.com/search?q=things+in+liquid+nitrogen&rlz=1C1GCEA_enUS1104US1104&oq=things+in+liquid+nitrogen&gs_lcrp=EgZjaHJvbWUyBggAEEUYOdIBCTE3MDU2ajBqNKgCALACAQ
  - There are lots of liquid nitrogen videos on Youtube.
- Cody's Lab
- https://www.google.com/search?q=do+any+metals+get+brittle+in+liquid+nitrogen&sca_esv=75ce3f1a0c12c434&rlz=1C1GCEA_enUS1104US1104&biw=1536&bih=730&tbm=vid&ei
- https://www.youtube.com/watch?v=V1WwZpqve8s&rco=1
- Action lab
- https://www.google.com/search?q=do+any+metals+get+brittle+in+liquid+nitrogen&sca_esv=75ce3f1a0c12c434&rlz=1C1GCEA_enUS1104US1104&biw=1536&bih=730&tbm=vid&ei=AZBLZruQHPbCkPIPqaGS-AM&oq=do+any+metals+get+brittle+in+&gs_lp=Eg1nd3Mtd2l6LXZpZGVvIh1kbyBhbnkgbWV0YWxzIGdldCBicml0dGxlIGluICoCCAAyBRAhGKABMgUQIRigATIFECEYqwIyBRAhGKsCMgUQIRirAjIFECEYnwVIvlVQAFjhPHAAeACQAQCYAcMBoAHJG6oBBDEuMji4AQPIAQD4AQGYAh2gAqUcwgILEAAYgAQYkQIYigXCAg4QABiABBixAxiDARiKBcICCxAAGIAEGLEDGIMBwgIFEAAYgATCAggQABiABBixA8ICERAAGIAEGJECGLEDGIMBGIoFwgIOEAAYgAQYkQIYsQMYigXCAgoQABiABBhDGIoFwgILEAAYgAQYsQMYigXCAgsQABiABBiGAxiKBcICCBAAGIAEGKIEwgIIEAAYogQYiQXCAgYQABgWGB6YAwCSBwQwLjI5oAfNsQE&sclient=gws-wiz-video#fpstate=ive&vld=cid:893ca706,vid:5G7IwrT1ZNs,st:0

Reasons for NOT using heat

Heating the materials to separate with sublimation, liquid water or steam:

This makes sense on Earth where the temperatures are much warmer and we have an atmosphere. Evaporating the water out and then condensing it would be easy. However, NASA is expecting the temperatures in the forever shaded craters to be around -400F. Getting the ice up to melting point or steam temperatures would be require a lot of heat and energy—impractical.

Because the moon has no atmosphere, the ice is most likely to sublimate not evaporate when it receives heat.

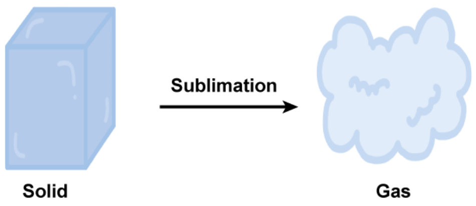
We would need to have a **sealed container** to hold the vapor.

Having a sealed container in a dusty environment is difficult at best. With all the lunar dust able to get onto seals and prevent any gasses from leaving the container would be difficult even for the first sample taken let alone keeping it sealed for weeks or months worth of opening and closing the container would be very complicated if possible at all.

Converting electricity to heat with coils is one of the quickest ways to drain a battery.

- Heat the regolith to allow the ice to **sublimate** and capture the vapor. Requires that you have a pressure vessel for capture of the vapor and the regolith/ice mixture can be drawn into and out of easily.
    - Heat with electric coils?
        - How thermally conductive is the regolith? Will heat pass through the regolith easily and warm up the ice or will it act more as an insulator?

          Current studies of regolith show that it is a pretty good thermal insulator.
        - Electric heat requires a lot of power (shorter life of battery) any heat that radiates down toward the ground may cause sublimation in the regolith below the rover and we could be losing more ice than we are collecting.
    - Heat with microwaves (not very practical for high school students)
        - Does the regolith absorb or reflect any of the microwaves?
        - not as inefficient as electric coils but still uses a significant amount of power
    - Heat with infrared laser? (not very practical for high school students)
        - Will heat the top surface material but probably won't go very deep into the regolith
    - Can this be done in a continuous process or must it be done as a batch process?



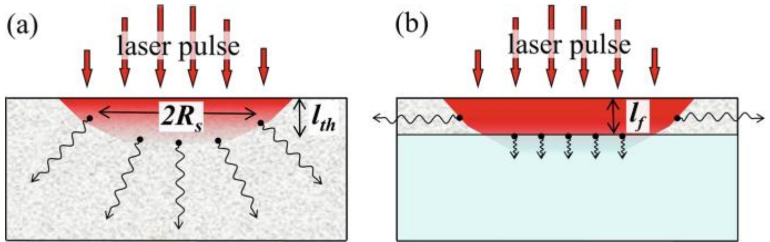
Sublimation

Conversion of a substance from the solid to the gaseous state without its becoming liquid.

This is what is happening with dry ice.

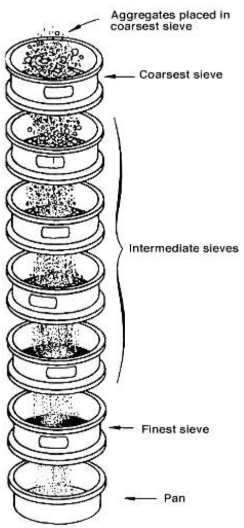
Water will go from a solid to gas when in a partial or full vacuum. You may notice this in your freezer when an ice cube sits in the airflow in your freezer for a long time. The ice gets smaller without a puddle forming.

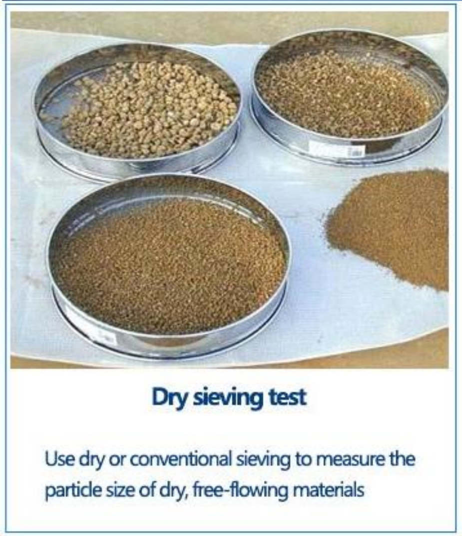
Dry ice (carbon dioxide) sublimating

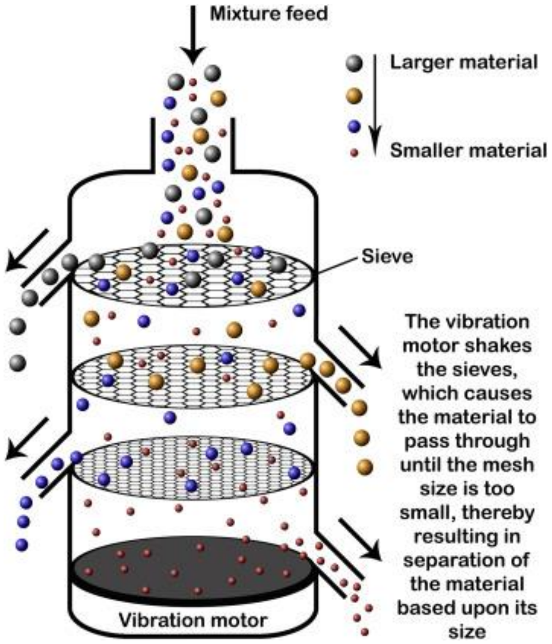


Separation by size?

- Would it be possible to separate the ice from the regolith with a sieve?
- We don’t <u>know </u>what the ice particle size would be, but it is suspected that the ice crystals could be **similar to the particles size** of the regolith. (not impossible but until we get samples back, we won’t know)







Winnowing?

- Although it is tempting to use a puff of air to blow the lower density ice from the higher density regolith, that would require having a tank of air that would empty after a short time and would need refilling. It is much better to limit the number of consumable to as few as possible so the robot can operate for longer periods of time.