COSMOS Cluster 3
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Cloud in a Bottle

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References: *Atmospheric Chemistry and Physics*
J.H. Seinfeld and S.N. Pandis, 1997
Clouds in a Glass of Beer: Simple Experiments in Atmospheric Physics
C.F. Bohren, 1987

Objectives:

As part of this demonstration, the student will be able to

1. Show how a bottle without particles is very challenging environment for growing clouds
2. Supply CCN to a bottle and create a cloud by changing pressure
3. Understand the roles of heterogeneous nucleation on CCN and changes in pressure as they apply to clouds in the real atmosphere
4. Begin to form ideas about the sizes of particles and their effects on light scattering in the atmosphere
5. Begin to bring in experiences with previous demos and prior COSMOS cluster 3 concepts towards a better understanding of the climate system

Key terms:

- cloud condensation nuclei (CCN)
- heterogeneous and homogeneous nucleation
- thermodynamics
- light scattering

Introduction:

We demonstrated on the first day of COSMOS how we could make clouds in root beer out of salt and supersaturated CO_2. Try to remember the analogy between these clouds and real ones in the atmosphere. Recall: clouds in the atmosphere form when water that is in the vapor phase condenses into liquid drops. It is physically possible to form cloud drops from an atmosphere of pure water vapor, but this requires very special conditions that do not readily occur in the Earth's environment (upwards of 500% relative humidity!!!). Instead, a process known as 'heterogeneous nucleation' is required to form liquid drops on preexisting particles. Literally, this means generating ('-geneous') a 'nucleus' out of different ('hetero-') substances. It is this small nucleus that condenses more and more water onto it until it becomes large enough to be a cloud drop, or eventually rain or snow. You have hopefully convinced yourself of these steps by now. Today, we will demonstrate how a cloud in the sky forms, by making one in a jar.

We already know that cloud condensation nuclei (CCN) are required to make drop nucleation more efficient. Without some sort of particle for water vapor to condense onto, we would likely have very few clouds on Earth. But if all it took to make clouds was the presences of water vapor and CCN, clouds would be much more abundant.

Recall the satellite demo of visible images versus the water vapor images. Were they the same, i.e. did every visible cloud correspond with a water vapor feature? Why or why not?
What might this tell you about the distribution of CCN?
Do you think anything else might play a role in the cloud patterns differing from water vapor patterns?

Another factor to consider is how temperature and pressure affect phase changes of water between liquid and vapor (what we call 'thermodynamics'). Water condenses easier at lower temperatures, and evaporates at higher ones.

Think to yourself about this statement – can you think of any instances where you have seen water condense onto something cold? Or have you seen water evaporate from something being heated?

Temperature must play a role in how the water vapor in the atmosphere is making clouds. We have also learned how air exerts a force on its surroundings in a property called pressure. At the surface, it literally pushes down on us from the weight of all air sitting above. The ideal gas law (try to remember this from chemistry of physics class) tells us that pressure is proportional to temperature. Therefore, as the pressure of a volume of air goes up, so must its temperature. Likewise, if you lower the pressure, the temperature should also drop.

It may not be clear yet, but try to be thinking ahead – how could we apply this to an air parcel containing water vapor and CCN?

We also know that pressure decreases as an air parcel rises from the surface in the atmosphere, simply because there is less air above pushing down the higher it rises upward.

When confronting new ideas, it is often good to apply simple mental experiments on simple processes you experience first hand. What would happen to a balloon if it were put in an environment with less pressure inside than outside? What would happen it the pressure was higher inside than outside?

Use the analogy of a balloon extended to a parcel of air, and you should be able to convince yourself that a rising parcel expands and cools, and a sinking parcel contracts and warms. This is because pressure changes with altitude.

Now you can apply all these ideas at once. Join what you know about thermodynamics, CCN and air pressure to guess the best situation for a cloud to form.

You should eventually realize that a rising parcel expands, which makes it cool in temperature, which allows for easier condensation on CCN to make clouds. I n reverse, a sinking parcel will contract, warm, and evaporate away clouds. We obviously cannot raise or lower a parcel enough in the classroom to make a cloud, *but can you think of a way to simulate this process with what we have here?*

Experiment:

Each group of 4-6 students should have:

- 1 bottle with about filled with about 2 inches of water
- 1 book of matches
- 1 rubber stopper with metal attachment
- 1 pump to attach to metal tube
- 1 laser pointer (DO NOT SHINE AT EACH OTHERS EYES PLEASE!)

The first step is to convince you that homogeneous nucleation is too difficult to regularly achieve. Simply put the stopper and pump on the bottle with the water inside, and pump until a cloud forms. Also try pumping until there is a lot of pressure in the bottle. Then remove the cap to quickly decrease the pressure in the bottle.

With all good science, detailed observations are key. Write down anything and everything you see. Are you seeing any clouds yet?

This was a trick! It is highly unlikely we can generate enough of a pressure change with these pumps to make a cloud without CCN. *Recall what condition we need to make clouds without CCN? Is such a high relative humidity possible in a demo like this?*

We will now add CCN (in the form of smoke particles) to the bottle. Let somebody else in your group do this step – group efforts are more efficient at lab work. Drop one to two lit matches into the water, so you see enough smoke in the bottle. BE CAREFUL NOT TO BURN ANYTHING ELSE. Try to seal the jug as soon as you can after dropping the matches. Now try to pump the bottle. As soon as there is enough pressure, uncap the bottle and observe what happens. Observe how when the clouds form.

Is it when the pump is adding pressure to the bottle? Is it when the pressure the plug is removed and the pressure is released? What does this mean about the temperature inside? What does this simulate about a rising or falling parcel?

If a cloud lasts long enough, we can see how light interacts with it. Another person in the group should now shine the laser light about 3 inches from their hand pointed at their palm. Not to worry, these lasers are too weak to hurt your hand. *Do you see a whole beam along the path, or just the spot on your hand? What does this tell you about what is in between your hand and the pen? With what you know about optics, can you infer a size of what ever is in between?*

Now shine the pen through the jug (BE CAREFUL NOT TO SHINE IN EACH OTHERS EYES!). Make sure you share the pointer and pass it around for all to try. First had experience is the key to accepting science. If a cloud is present, you should notice a big difference than the quick experiment on your hand. *What does this tell you about what is inside the bottle? What size particle would create this effect? What approximate wavelength of light is this laser? How* *do you know? With what you know about optics, what phenomenon is taking place?*

Afterthoughts:

The clouds we see on a daily basis in the sky are a complicated mix of CCN, large-scale water vapor patterns and micro-scale thermodynamics. We have tried to simulate these effects in a bottle. The concepts we feel are worth taking away are:

- The role of CCN on cloud formation
- The role of rising and descending air parcels and the changes in pressure and temperature that come with them
- The interaction of light with cloud particles

Consider what you have learned in this lab in a global context

- How might raising temperatures from anthropogenic climate change affect cloud formation?
- How might changes in CCN and air pollution change affect cloud formation?
- How might the changes in cloud formation affect the interaction of solar radiation on the global energy budget? Consider albedo and the climate models we have used in this class already.
- Can you think of a way to use these principles to mitigate global warming?