The Growth of a Cloud Droplet

A series of hands-on experiments from the Little Shop of Physics at Colorado State University

Overview

Clouds are made of tiny droplets of water. As clouds form, Water vapor from the atmosphere condenses around small bits of dust and dirt in the air, forming infinitesimal droplets. As time goes on, these drops grow in size, until they become massive enough to fall to the ground as rain.

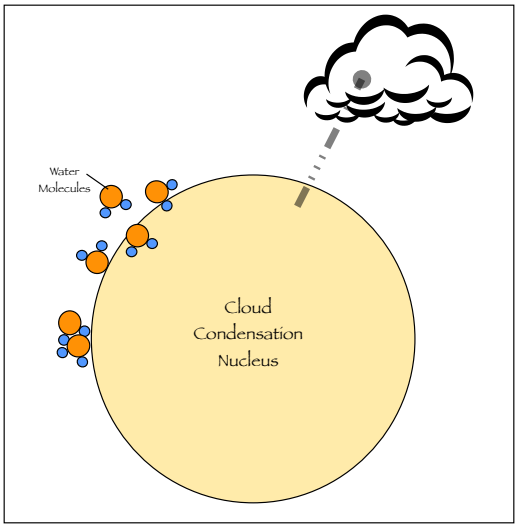
Necessary materials:

Activity 1

- Laser pointer (1 per group)
- Helping Hands
- Two Liter Bottle
- Tire Valves fit into caps
- Air freshener (Glade Powder Fresh works well.)
- Bike Pump

Theory

Water vapor can condense to form liquid water if the air is cooled, because cooler air can hold less water vapor. Air cools as it rises due to **adiabatic cooling**. (Adiabatic, pronounced "a-dE-&-'ba-tik" means that there is no transfer of heat between an air parcel and its surroundings.) When a parcel of air rises, it expands; the expansion requires energy, which comes from the thermal energy of the air, so the air cools. As we noted, cold air holds less water, so when the air rises, as it cools, the water vapor will "want" to condense out of the air—it will want to form droplets. The air can become **supersaturated**, with a relative humidity greater than 100%., but the droplets don't form yet... they need help. Liquid water has surface tension. This means that making a droplet requires energy to create this surface tension. The water molecules can get around this energy barrier by condensing on a surface. In the summer, when a cold glass of ice water meets warm, moist air, water droplets form on the outside of the glass.



Molecules of water vapor are helped to form a droplet of liquid water by a condensation nucleus.

In the atmosphere, **condensation nuclei** provide the surfaces on which water vapor can condense. Dust particles will allow water vapor to form a droplet as in the above diagram; alternatively , soluble materials such as salt will dissolve in the condensing water vapor, facilitating droplet formation in a slightly different manner. Without cloud condensation nuclei, the relative humidity must be several hundred percent in order for water vapor molecules to condense freely. Condensation nuclei in the atmosphere range from dust, to volcanic ash, to pollution. With these nuclei, the water vapor in the air can condense to create a cloud made of billions of tiny droplets of liquid water.

Doing the Experiment - Activity 1 - Making Clouds

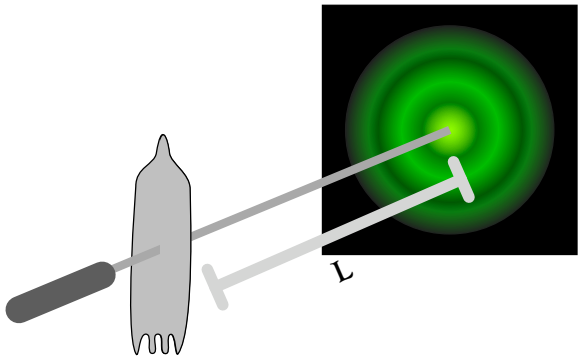
***SAFETY NOTES* :**

- **The bottles will easily hold more pressure than the pump can provide as long as they are intact. If a bottle has any defect, replace it.**
- **When you pump the bottles up, they won't explode, but the caps can fly off at high speed if they are released. You should fasten the caps in place to eliminate this possibility. Folks open soda bottles all the time with no ill effects. But these bottle caps have valves in them so a bit of caution is warranted.**

1. Add a small amount of water to both bottles.
2. Spray (just one squirt!) the air freshener into one bottle. Swirl the water around the bottle so all the air freshener has a chance to mix in.
3. Pump up the bottles to a fixed pressure; 30 psi/2 bars is plenty. The air in the bottles will warm as you do this.
4. Let the bottles cool to room temperature.
5. Let the air out of the valve slowly, using the sticks, and observe.

Doing the Experiment - Measuring Droplet Size

Now that you know what to look for, aim your laser through a bottle which is at pressure. As you slowly let the air out of the bottle, watch for a pattern of light and dark rings around the laser's dot. As the droplets grow, you should see the pattern change size. If you stop releasing air, the pattern should hold steady, giving you a change to make some measurements of ring size.



As you release the air, the pressure will decrease, cooling the bottle. As the bottle cools, the water will condense around the droplets. If you were to pump more air back into the bottle, you can actually cause the droplets to shrink!

Measure the radius of one or more dark rings and the distance from the slide to the wall.

The size of the dark rings depends on the size of the cells and the wavelength of light. You can show that destructive interference (the dark circles) happens as the following angles from the center of the pattern:

$$d\sin(\theta) = n\lambda$$

In this equation, L is the distance from the wall to the blood slide, d is the diameter of a red blood cell, r is the radius of a dark ring, and λ=532 nm is the wavelength of the laser light.

For double slits or diffraction gratings, n is an integer. For the interference of waves from multiple circular obstructions, the values aren't integers:

***n* values for dark circles**	***n* values for light circles**
1.22	0

***n* values for dark circles**	***n* values for light circles**
2.23	1.64
3.24	2.68
4.24	3.69

The angles are small, so we can approximate:

$$\sin(\theta) \approx r_n / L$$

This gives a final formula that we can use to determine the size of the cell:

$$d = \frac{n\lambda L}{r_n}$$

Multiple measurements give different values that can be averaged to give a more accurate value with an error estimate.