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Making Clouds: Aerosol-Cloud Interactions in a Beaker

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From: The PUMAS Collection http://pumas.nasa.gov

Materials:
600-1000 mL beaker or glass jar
zip-lock bag of ice
source of warm but not boiling water (directly from sink or heated using hot plate)
matches or small piece of cardboard/paper and lighter
laser pointer

Background:

Have you ever noticed that cloudy days feel cooler than sunny days, but that cloudy nights feel warmer than clear nights? The reason has to do with how clouds absorb and reflect energy. During the day, some of the incoming sunlight bounces off of the top of the clouds and back into space. Normally this sunlight energy would have been absorbed by us and also by the Earth's surface, thereby increasing our energy and making us feel warmer. However, on a cloudy day, less sunlight reaches the surface where we are, less energy is absorbed, and we feel cooler. At night the situation is reversed because the sun is no longer a source of energy, but the Earth is. On a clear night, the Earth's energy is radiated out to space as heat and is lost. But on a cloudy night, the clouds absorb some of this outward-radiated heat energy, trapping it at the surface and we feel warmer[1].

This simple example explains how clouds can affect us at the local level, but scientists throughout the world are currently studying how clouds may have a substantial cooling effect on the entire globe. Again, this is because clouds reflect some of the sun's energy back to space, which would otherwise be absorbed by the surface. Scientists currently think that pollution emitted by humans may have changed global cloudiness, which has

[1] It is important to note that the Earth's surface is always emitting heat energy into space even during the day. However, because the incoming solar energy has a bigger effect on daytime surface temperatures than the outgoing heat energy, the net effect is surface cooling when clouds are present. At night, the solar energy effect is not present, so the surface temperature is controlled entirely by the outgoing heat energy.

slightly cooled the Earth. Meanwhile, humans have emitted greenhouse gases, which have warmed the Earth. By knowing how humans have influenced clouds, scientists can better predict how the climate will change in the future. To understand how people may have affected cloudiness, it is useful to look at how clouds form in the first place.

Clouds consist of tiny water droplets suspended in air, which form when humid air is cooled enough that some of the water vapor becomes a liquid. This is sometimes explained by saying that "the cool air cannot hold as much water as warmer air", but such a statement is not correct. In truth, the air does not "hold" the water, but rather, the water gas molecules exist alongside the other air gas molecules. When the mixture of the two gases is cooled, some of the water vapor molecules condense into liquid droplets but all of the air molecules remain as a gas. Sometimes we hear the amount of water vapor referred to as the *relative humidity* (RH), which is typically expressed as a percent. Relative humidity is defined as *the actual concentration of water vapor divided by the maximum amount of water vapor that can exist at a given temperature*. The maximum amount of water vapor is determined from thermodynamics. Scientists sometimes express the actual water vapor concentration as the partial pressure of water vapor (P_{H2O}) and the maximum water vapor concentration (at a certain temperature) as the saturation vapor pressure of water (P_{H2O}^{sat}). Thus, RH is described as

$$RH = P_{H2O} \big/ P_{H2O}^{sat}$$

When the RH is very low, we say that it feels dry outside. When the RH is high, we say that it feels humid. When the RH exceeds 100%, the actual amount of water vapor exceeds the thermodynamically-stable amount, and some of the water vapor wants to condense to form liquid cloud droplets. But, it turns out that cloud formation is not quite that simple. Even though the water vapor has exceeded its maximum amount and wants to form a liquid droplet, this is a difficult process because many water vapor molecules need to collect and stick together, forming a completely new surface[2]. Things would be a lot easier if there were already some bigger particles floating around that the water molecules could stick to, because no completely new surface would have to be formed. As luck would have it, there are usually plenty of particles floating around in the atmosphere, which come from natural sources such as wind-blown dust and sea spray, wildfire smoke, and plant emissions, as well as from human activities (e.g., operating cars and factories). We can now see how humans might affect global cloudiness and climate – if we emit more particles into the atmosphere, they might nucleate more cloud droplets, which could then reflect more sunlight back into space.

Not all particles are able to act as *cloud condensation nuclei* and form these droplets. Scientists studying these particles measure their size and also their chemistry, which requires some high-tech tools – these are microscopic particles after all, about the size of bacteria and viruses! One way of detecting particles is by passing them through a laser and measuring how many times they scatter the laser light and in what way. This approach is kind of neat because it is the ability of particles and cloud droplets to scatter

[2] The process is somewhat complicated and the interested reader is referred to: http://en.wikipedia.org/wiki/Nucleation and http://en.wikipedia.org/wiki/Cloud_condensation_nuclei

light that makes them so important in the first place.[3] The following activity illustrates this using a laser pointer.

Activity (See Figure A for Photographs):

1) Fill the bottom of the beaker with about an inch of warm-to-hot water from the sink. The water should feel warm-to-hot but not be steaming, as this would cause a lot of water to condense on the sides of the beaker.

2) Fill a zip-lock sandwich bag with ice and place it on top of the beaker.

3) Explain to the students that the warm water is a source of both water vapor and heat. The ice represents the top of the atmosphere, which is cooler than the surface. As the water vapor rises toward the ice at the top of the beaker, it cools and the water vapor will condense onto any particles present to form droplets.

4) Shine the laser pointer through the beaker. Although some light is reflected by the glass (less if the glass is clean), the air inside (having relatively few particles) does not scatter the laser light very much, if at all. There are few particles, and few if any cloud droplets.

5) Remove the bag of ice and place a lit match (or lighted piece of cardboard) inside the beaker and blow out the flame. After a second or two, drop the match into the water and replace the bag of ice. Now, there should be lots of particles from the match smoke!

6) Shine the laser pointer through the beaker again and note that over a short time (20-30 seconds) more and more light is scattered as water vapor condenses onto the smoke particles to form a cloud.

7) Remove the bag of ice and watch the cloud evaporate into the room.

Additional Resources:

Jacob, Daniel J. Introduction to Atmospheric Chemistry, Princeton UP, 1999. Available for free online at: http://acmg.seas.harvard.edu/people/faculty/djj/book/index.html

The Cloud Appreciation Society (http://cloudappreciationsociety.org/) and their excellent book entitled *The Cloudspotter's Guide*, by Gavin Pretor-Pinney, Perigee Trade, 2007.

http://en.wikipedia.org/wiki/Relative_humidity

http://en.wikipedia.org/wiki/Cloud

http://en.wikipedia.org/wiki/Cloud_condensation_nuclei

http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/cloud-in-a-bottle/

[3] Interestingly, physicists also use cloud chambers to detect the trajectories of subatomic particles. As the particles move through the chamber they nucleate tiny droplets, which form trails of mist, which allow scientists to observe them: http://en.wikipedia.org/wiki/Cloud_chamber

http://www.stevespanglerscience.com/experiment/00000030

"Volcanic Clouds and the Atmosphere", The PUMAS Collection http://pumas.nasa.gov

Resources for Educators Teaching Atmospheric Sciences http://eo.ucar.edu/educators/

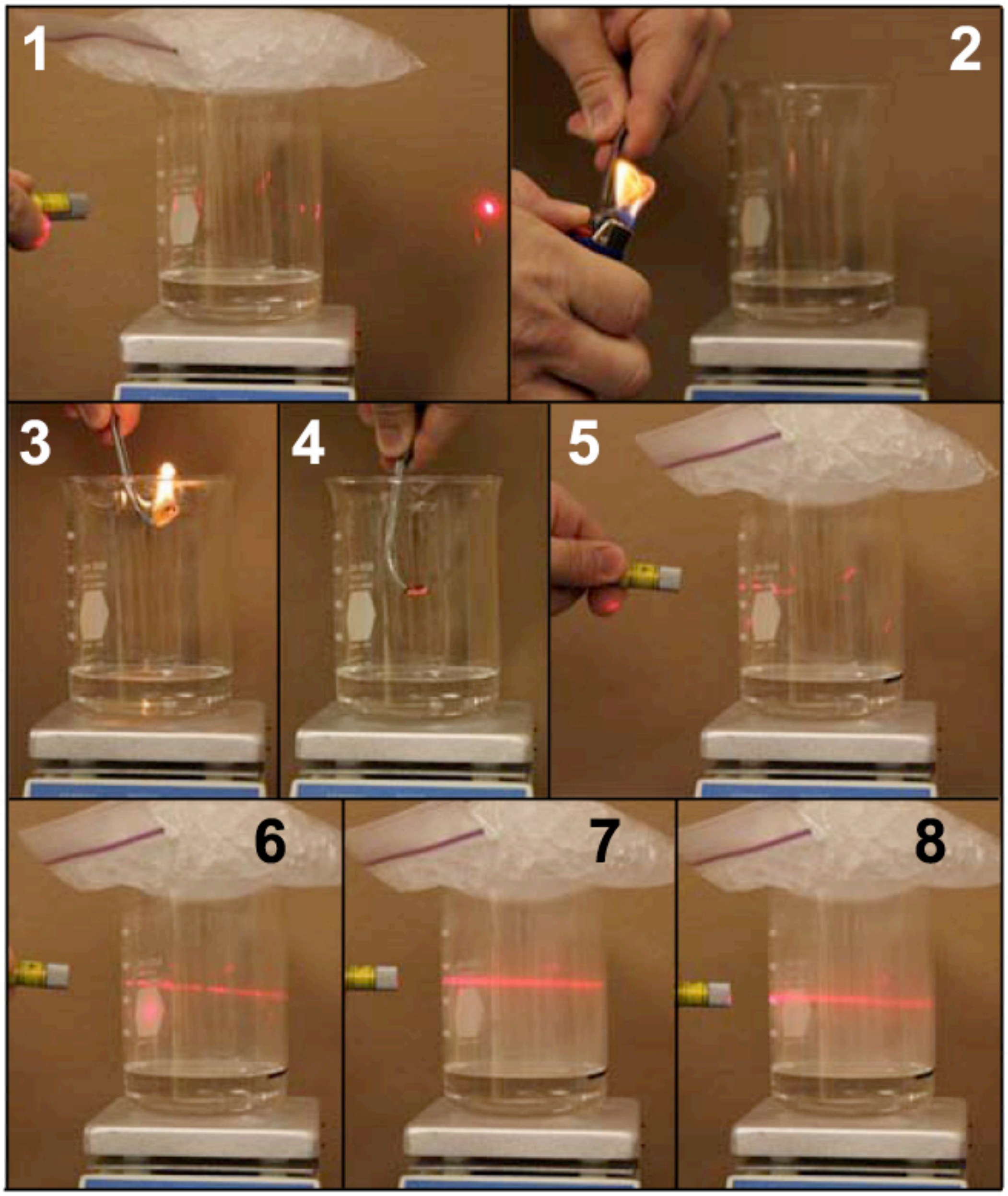

Figure A: Photographs showing the sequential progression (1 to 8) of the activity over approximately 2-3 minutes. As shown in Image 1, initially only light is reflected by the beaker glass and most of the laser light hits the opposite wall. A piece of cardboard is held with tweezers and lit with a lighter in Image 2, and lowered into the beaker in Image 3. The flame is blown out in Image 4 and the cardboard piece can be dropped into the water to extinguish it. Then, the ice bag is quickly replaced and the laser pointer is directed at the beaker continuously

throughout Images 5-8. Laser light still hits the opposite wall (not shown), but now some of the light is reflected by the cloud droplets within the beaker.