Why are clouds white?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

Clouds are made from air (transparent) and droplets of water (also transparent.) So clouds are made of things which are clear. Why can't we see through them? Why are clouds white, and not clear?

We let students ponder this question by having them consider a related question: Can you make a colorful cloud with colored water?

Necessary materials:

Activity 1

- Clear container of water
- One ultrasonic mister (provided)
- Paper towels
- Food coloring

The ultrasonic mister is the crucial piece for this experiment. It's necessary to break the water up into droplets to create the "cloud" above the water.

If your cloud isn't appearing, make sure there is the right amount of water above the little metal speaker. Too little water means it won't work; too much means that the cloud that forms will be thinner than it should be.

Theory

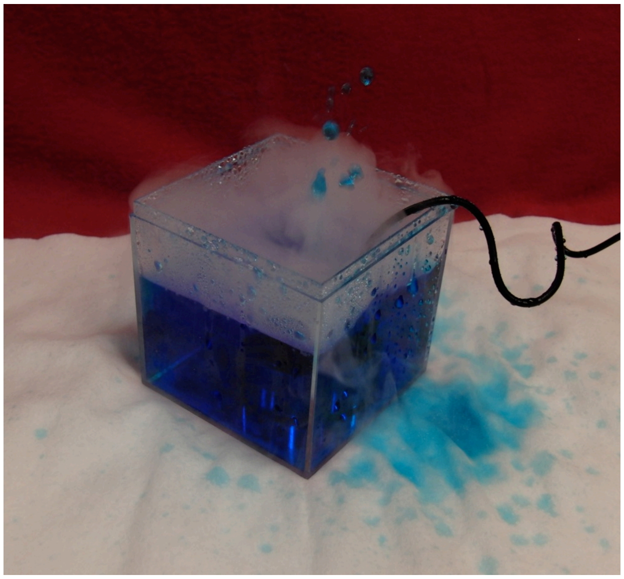
Isaac Newton performed a classic series of experiments over 300 years ago to demonstrate that the white light from the sun is composed of all the colors of the rainbow. Light is a wave (an electromagnetic wave) and these colors are each characterized by their **wavelengths**. The wavelengths of light are quite small. Red light has a wavelength of 0.0000007 meters, just 0.7 microns. One micron is 1 millionth of a meter, so that's pretty small—and that's the longest wavelength your eyes can see. Blue light has a wavelength of about 0.4 microns.

How can clouds be white when they are made of millions of tiny cloud droplets—which are clear?

Clouds are composed of millions of tiny water droplets (**cloud droplets**) or ice crystals. The average size of cloud droplets is about 10 microns. This is pretty tiny, but these cloud droplets are much bigger than the wavelengths of visible light. Since a cloud droplet is much bigger than any wavelength of light, all the different colors of light behave the same when they hit a droplet—they **scatter**. Scattering means that light is redirected in random directions. All of the colors are scattered equally, so the light is diffuse and made up of all colors...and the net result–clouds appear white!

Doing the Experiment - Activity 1

This is a demonstration activity to do with the whole class, centered around a discussion.



The larger water droplets splatter the blue color on the paper towel, but the cloud remains white!

Pose the question to your students: Why are clouds white? Gather their ideas and then explain that you have an activity that will help them ponder the answer to this question.

Put down a white paper towel on your table and then put a clear container with water in it.

Submerge the ultrasonic mister in the water and plug it in. As students observe the white cloud forming, explain: *A cloud is made up of small droplets of water in air. Air is clear and so is water.* Then ask: *So why does the cloud appear white?*

Now, ask the class: Could we make a cloud that is another color using food coloring?

Collect predictions and then have a student add food coloring to the container.

In a very short time, students should see a white cloud appearing over the colorful water. If droplets of water escape from the container however, they may leave little food coloring spots behind!

Have a discussion with your class about what they think is happening and why.

Doing the Experiment - Activity 2

This is a quick activity that students can easily try for themselves.

Have students put on the safety goggles.

Have them place a clear ice cube on the black felt square. Fold the material over the ice cube so it is covered.

Carefully crush the felt covered ice cube with the hammer and then open up the material. The smashed ice pieces should look white!

Review that this is another case of scattering and that the ice looks white because all the wavelengths of light are scattered equally.

Necessary materials:

Activity 2

- Clear ice cubes
- Black felt squares
- Safety goggles
- Hammers

If you use clear ice cubes, the results will be more dramatic for your students. We boil water, let it cool, and then freeze it in ice cube trays to get the clearest cubes.

Doing the Experiment - Activity 3

This is a great activity to pose a mystery to your students. It is also a great demonstration that helps explain why some clouds look gray or dark.

1. Assemble your mystery blocks before class begins. Take two rectangles of the paraffin wax and sandwich a piece of aluminum foil between them. The aluminum foil should be slightly smaller than the rectangles of wax. Melt the wax together by using the trigger lighter..
2. When your class arrives, tell them that you have a mystery for them to solve. Using a bright desk lamp, overhead light, or sunlight, hold the wax block horizontally so the top layer is very white, but the bottom layer is gray. Now dazzle your students by flipping the block over, so now the gray block has turned white and the white block has turned gray!
3. Ask them what they think could be happening. (The paraffin scatters light just like the cloud droplets. When light enters the wax block, the different wavelengths are scattered equally in random directions and the block appears white. But the aluminum foil blocks most of the light from reaching the lower block. The lower block still scatters all colors of light equally, and so it doesn't have a color, but because it scatters less light than the top block it appears gray. The gray and the white are really the same color—that is, no color at all—but they differ in intensity.)
4. Ask your students: Why do clouds sometimes appear white and sometimes gray? (All clouds are the same color, no color at all. When we see light scattered off the front of a cloud, it sends a lot of light our way; the cloud appears white. But if the sun is behind a thick cloud, not much light makes it to the bottom, so the cloud appears gray.)

Necessary materials:

- Paraffin Wax rectangles
- Aluminum foil
- Heat source such as a long lighter for candles or barbeque grills
- Heat source such as a long lighter for candles or barbeque grills

The wax we use is used for canning and candle making. You can find it at a grocery or hardware store.

Your students will be stunned when you flip this wax block over!

Summing Up

Clouds appear white because of scattering. The droplets in clouds are big compared to the wavelength of light, so all wavelengths scatter the same. It's a different story for the scattering of light from molecules of air in the atmosphere. These are much tinier than the wavelength of light, so blue light scatters much more than red. So the sky is blue and sunsets are red.

But clouds are white; they have no color at all, even if the water making them up has color. Clouds can appear white or gray. In fact, the same cloud can appear white to one person and gray to another. This has to do with where you are with respect to the cloud. People flying in an airplane may pass over a cloud that looks quite bright as it scatters the abundant sunlight from above, but an observer on the ground may see the same cloud as gray, because little sunlight penetrates to the lowest level.

For more information:

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

Why do raindrops sometimes land gently and sometimes land with a splat?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

You've certainly been out during a gentle shower, in which small drops drift like mist, gently landing on your skin. You've also been out in rain showers with big, fat drops that land at high speeds, with a serious splat.

Why the difference?

In this activity, students will observe that raindrops fall at very different rates depending on their size. In this case, size does matter!

Necessary materials:

- 1 clear square sided plastic bottle with lid (We've sometimes used empty Fiji water bottles.)
- Mineral oil
- Water
- Food coloring
- Paper towels
- Epoxy or hot glue (optional)
- Tape (optional)

This activity takes patience and a lot of careful observation. If you just have one raindrop bottle for your class, you may want to set this up at a science station and have individual students or small groups rotate through.

Theory

We teach our students that all objects fall at the same speed, but this is only true if you can ignore air resistance. For big things falling at slow speeds, air resistance is a small force. If you jump off a diving board, air resistance has a negligible effect on your fall.

Modeling the fall of raindrops with oil and water.

This isn't the case for small objects. Air resistance is a big factor. A mouse can fall from any height and land unharmed—it's small enough that air resistance slows its fall.

For raindrops, the situation is even more extreme. Very small drops will fall imperceptibly slowly. Larger drops will fall faster, so small droplets will drift slowly downward. Big, fat drops fall at high speeds, and hit with a splat. In the real world, the speed that things fall at does depend on size. It's not that Galileo was wrong; it's just that he didn't consider air resistance, and for small objects air resistance is quite crucial.

Doing the Experiment

If you have not done so, you will need to prepare your raindrop bottle. Choose your favorite color of food coloring and add a couple of drops to water in a measuring cup. Pour a small amount of water into a clear square-sided plastic bottle–perhaps 10% of the volume of your bottle, or experiment with how much water to add. If you are using a recycled Fiji bottle, we usually fill water up to the lowest ridge at the bottom of the bottle. Now fill the remainder of the bottle with mineral oil. Fill to the top until it looks like it might spill over. Screw on the cap and have paper towels ready for any oil spills! We recommend coating the lid in epoxy or sealing it with hot glue and then wrapping it with tape, so your classroom stays oil free.

Ask your students the question, "Why do raindrops fall gently sometimes and land with a splat other times?" Jot down their ideas and then have them work with the bottle. They should start by gently tipping the bottle back and forth a few times and then observing. After they done this, have them give the bottle a more vigorous shake and observe again.

Things to look for:

- What shape are the droplets when they are tiny?
- What shape do they take when they are larger?
- Why do you think they change shape?
- Which ones fall slowly?
- Which ones fall faster?
- Why do you think this is so?
- What happens when a big droplet falls?
- What happens if two droplets collide?

Summing Up

Although not a perfect comparison, the raindrop bottle activity lets students observe in slow motion the behavior of falling droplets, and explore concepts such as drag and terminal velocity.

For More Information

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What is a "convection cell"?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

In Activity 1, a demonstration, students can observe a number of small convection cells, which will help them visualize the large scale structures that contain much of the motion in the atmosphere and oceans, from rising plumes of air that lead to thunderstorms to the motion of air masses on a much larger scale that leads to the earth's climate zones.

Necessary materials:

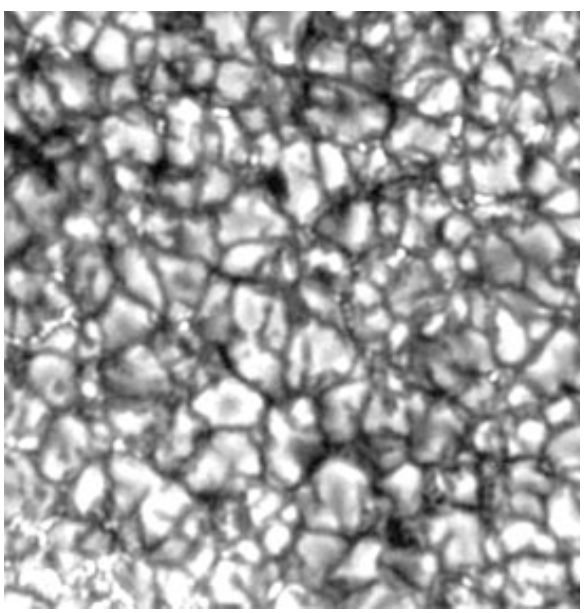
Activity 1

- One hot plate
- One round metal fry pan or cake pan
- Silicon oil
- Aluminum powder
- Rubber spatula

The aluminum powder and silicon oil are crucial to this demo. We obtained ours from the chemistry supply stockroom at CSU.

Theory

The earth isn't heated evenly. At the equator, the sun hits the earth straight on. At the poles, sunlight shines at an angle and is spread out over a large area. So there is much more heating at the equator than at the poles, as you know. This differential heating leads to motion of the air over large scales; this process ultimately drives the earth's weather and leads to the earth's climate zones.



Convection cells happen on the surface of the sun too.

At a smaller scale, there is differential heating as well. Sunlight warms the atmosphere when it strikes the earth, warming the atmosphere from the bottom. This warm air "wants" to rise, and it will, but if air is rising, air must be falling somewhere else. And this leads to a convection cell: Warm air rises, and cold air sinks. The rising warm air cools, and falls; the cold air warms at the surface and rises—leading to a cycle of convection that drives the vertical motion of the air.

Doing Experiment 1

IMPORTANT SAFETY NOTE: The hot plate, pan, and oil can become very hot. Please warn students to be careful around these two items when observing the demo.

- Turn the hot plate to its lowest setting.
- Mix the aluminum powder into the silicon oil and pour it in the pan.
- Place the pan on the warm hot plate.

- Have students observe the magic of the convection cells!
- The aluminum filings allow you to see the motion of the fluid. They filings line up with the flow. When the flow is moving up or down, you see the filings end on. They appear dark. If the flow is sideways, you see the sides of the filings, and they appear silvery. So you see dark spots where the oil is rising or falling, and silver areas where the fluid is moving sideways.

Doing Experiment 2

This experiment is a modification of the activity, *Do cities affect the weather?* You will be making a cloud in the bottle, then will create convection and will view it with the laser.

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 with no ill effects. But these bottle caps have valves in them so a bit of caution is warranted.***
- ***When you use the laser, please exercise caution that the light doesn't shine in anyone's eyes.***

1. Add a small amount of water to the bottle.
2. Light a match, shake it out, and drop it in to the bottle.
3. Pump up the bottle to a fixed pressure; 30 psi/2 bars is plenty. The air in the bottles will warm as you do this. Students can easily feel where the energy comes from for this increase in thermal energy!
4. Let the bottle cool to room temperature.
5. Let the air out of the valve of the bottle using the lollipop stick, and observe. As the cloud forms, hold the top of the bottle to steady it, as a volunteer presses one of his/her hands on one side of the bottle.
6. You should start to see the cloud rising as it warms (where the volunteer's hand has warmed the bottle) and then dropping down as it cools. You can use the laser to visualize this motion.
7. Discuss what is happening with your class.

Necessary materials

Activity 2

- One 2-liter bottle
- Pressure cap
- Matches
- Water
- Lollipop stick to release pressure
- Green laser fitted with a small piece of rubber tubing to hold small glass rod
- Bike pump with pressure gauge

The most important element is the tire valve, purchased at an auto parts store. It fits inside a 2 liter bottle cap, and allows you to pressurize the bottle.

The laser, tubing and rod are to make a laser "slice" that lets you observe the motion of cloud droplets due to convection.

We purchased rubber tubing and thin pyrex rods from a chemistry stockroom. We punched two small holes in the tubing to hold the pyrex rod, and slipped the tube over the end of the laser.

Summing Up

The atmosphere is all about the movement of energy. These demonstrations are a way to have students observe a method that the atmosphere uses to transport energy from one area to another.

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