Temperature-Driven Convection

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Warm air aloft is stable. This explains the lack of strong winds in a warm front and how nighttime radiative cooling can lead to motionless air that can trap smog. The stability of stratospheric air can be attributed to the fact that it is heated from above as ultraviolet radiation strikes the ozone layer. On the other hand, fluid heated from below is unstable and can lead to Bernard convection cells. This explains the generally turbulent nature of the troposphere, which receives a significant fraction of its heat directly from the Earth's warmer surface. The instability of cold fluid aloft explains the violent nature of a cold front, as well as the motion of Earth's magma, which is driven by radioactive heating deep within the Earth's mantle.[1] This paper describes how both effects can be demonstrated using four standard beakers, ice, and a bit of food coloring.

For our quick and simple demonstration,[2–5] we have used beaker sizes ranging from 400 to 600 ml. A table or surface that permits a bit of spilling is also required. Tape white paper to the backs of the beakers to better see the difference between the stable fluid cooled from below and the unstable fluid cooled from above. To prevent the spills from ruining the paper, cover the entire surface with tape. Fill two beakers with water and two with ice and then water. Fill all beakers to the brim, using plenty of ice in the iced beakers.

Fill an eyedropper with food coloring (blue is best) and gently insert it into a beaker of water. Then slowly squeeze some food coloring onto the bottom of the beaker. Almost all of the food coloring should be inserted at the bottom. A small "ribbon" of color will often form as you remove the dropper. This small amount serves a purpose—it will be a tracer that permits estimates of fluid velocity. Repeat with the other

Fig. 1. Stacking the beakers.

Fig. 2. Experiment complete (after 20 minutes).

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beaker of water, trying to keep the two beakers as identical as possible. (You may wish to use two eyedroppers.)

Almost all chemistry beakers can be stacked on top of each other, although in a given set, some are more stackable than others. If all four beakers are filled to capacity, water will spill as they are stacked. This is necessary to prevent the formation of an air bubble under the bottom of the upper beaker, which would interfere with the heat transfer.

Stack the beakers in pairs as follows: place a water/ice beaker on top of a water/food coloring beaker, and place a water/food coloring beaker on top of a water/ice beaker (see Fig. 1). With ice on top, the water with food coloring will become unstable and the food coloring will show the motion of the water. With ice on the bottom, the water with food coloring will remain stable.

Within one to two minutes, it should be apparent that the fluid cooled from above is in motion. There may be some initial motion in the fluid cooled from below, but it will soon become negligible. In our test, this fluid was almost completely motionless throughout the experiment. Within three minutes, the unstable cell will show noticeable mixing of contents (the water begins to turn blue). After about 20 minutes, the unstable cell will be almost completely mixed (see Fig. 2).

While it is possible to let students do this as a class activity, some students will be distracted by concerns about food coloring, and others will have difficulty inserting the food coloring at the bottom of the beakers. Unless you take care to verify that all pairs of beakers can be easily stacked as described above, expect at least one spill.

We videotaped the procedure. It is possible to see the motion of the food coloring "tracer" in the recording. We also calculated the velocity of the tracers by referring to the volume markers on the beaker. The maximum velocity noted was 3 mm/s.

References

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