

Air Over a Heated Surface
By Spencer Aguilar



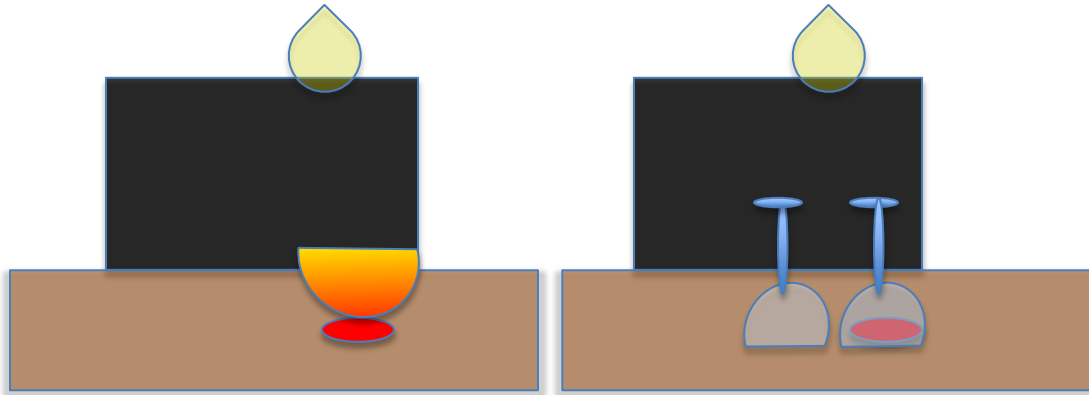
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Context:

The purpose of this experiment was to observe the flow of a fluid that demonstrates a physical phenomenon and visualize it in a clear, artistic way. My friends suggested I capture images of their smoke tricks but, although they're very talented, that would be artificial phenomenon. Still, I stuck with smoke as a visualizer since it was a convenient medium and decided to try to juxtapose hot, rising smoke with cool, standing smoke. I toyed around with the setup for a while before I settled on using two upturned wine glasses to contain the smoke and using thermal conduction to warm the surface of the table beneath one glass. Finally, I resorted to video instead of still images because it seemed more educationally useful to see the continuous movement and especially the evolution of convection cells. The final video is a composition of two takes with differing temperatures, shot at 30fps and shown at 60fps so sped up twice as much.

Approach:

At first I tried placing an extinguished cigarette butt alongside a carefully blown layer of smoke but it was near impossible to orient them without disturbing either the horizontal layer or the vertically rising trail. I grabbed two wine glasses, polished them as best I could, and decided to blow smoke under one and let it settle and then place the cigarette butt under the other. This was by far an easier way to protect the smoke from unwanted air disturbance, but the overall effect was still underwhelming. I wanted a way to generate enough heat that convection cells would be visible, but I would need more heat and smoke than a cigarette butt. At the time I was preparing some macaroni and cheese on the stove and briefly debated incorporating the stovetop. I poured the pasta in a bowl and as the warmth spread to the bowl and then my hands I realized I could just use thermal conduction via the warm bowl to heat the table first and then place the glass over that surface. So I let the bowl sit for a few minutes on a marked spot on the wooden table and then I placed one glass over it and the other glass to the left.



I transferred the smoke to the glasses by inhaling it from a burning cigarette and holding the smoke in my mouth and then slightly tipping the glass and exhaling beneath it. The moment I finished exhaling the smoke into the second glass I started recording. The smoke in the glass on the left quickly fell and settled. The smoke over the heated surface also fell initially, but immediately began to slowly rise as it was heated via convection. In the first twenty seconds of video, so 40 seconds, the shape of the smoke resembles a cone. Over the next five seconds it becomes sort of top heavy and some faint convection cells form on the left side. At the thirty-second mark, a minute in, a clear updraft forms in the center and strong convection cells can be seen on the left and right. In fact, although it is difficult to see, the convection cells seem to encompass the updraft on all sides so that the pattern of the smoke flow is reminiscent of a water fountain. I was very pleased with the first result so I attempted the experiment again, but this time I reheated the bowl of pasta in the microwave till it was too hot to handle. I repeated my steps and like before the smoke at room temperature stayed mostly motionless at the bottom. The smoke over the heated surface though was incredibly volatile; it never even had a chance to initially settle and immediately formed one enormous convection cell within the glass which lost most of its form and fury as the temperature stabilized throughout the glass over the course of a minute. I repeated the process again afterwards, without reheating the bowl, and the smoke again formed one convection cell, just a little slower moving. It's pretty unfortunate I didn't think to have a thermometer on

hand, because I would have liked to try to find a spot between these two patterns or perhaps see it transition.

Physical Phenomenon: Smoke is denser than air, but since it is usually produced from an exothermic reaction we tend to see it travel up. As a kid I used to think smoke naturally rose. But if we give it a chance to cool down to the surrounding air temperature it will sink to the ground. If you look carefully though in the first trial, you will see the smoke in the left glass actually forms a very thin and delicate cell along the surface of the glass on the right side. I believe that the heat in the table probably spread out further than I expected. As the air becomes less dense it rises up, which forces the air above it to move off to the side. On a large gradient scale this produces weather effects. In the little wine glass though this produces predictable cell physics. The curvature of the glass was ideal for forming that single cell within the sphere, but I bet you could create some interesting designs with multiple centralized heating spots. One thing I wish I could have done differently would be the transfer of the smoke. Holding it in my mouth obviously introduces temperature, humidity, and other factors and then blowing it into the glass creates disturbance. My experiment is basically just a rough sketch of what these phenomenon look like, but I would need better tools to capture finer details with better control.

Visualization and Photography:

I used a Canon Vixia HF100 camcorder to record the video. It was shot at 1440x1080 at PF30 and then sped up to 60fps because I thought it was easier to see the flow at the higher speed and it made the video length shorter. It was shot in color but I color corrected to grey scale because I thought the colors were a distraction and the main focus was on the smoke. Though the smoke was clearly visible in grey scale I bumped up the contrast and the gain to highlight it even more. Also, I placed a black piece of construction paper behind the glasses to provide better contrast as well. The scene was lit overhead with a compact fluorescent bulb, which somehow illuminated the inside of the glasses more than the surrounding

table surface. Also, there was less reflective glare when lit from above than when lit from the side.

Conclusion:

Although I would have liked to first introduce the smoke and then the heat to observe the convection without any air disturbance, I was pretty satisfied with what I came up with. The smoke works wonderful for visualization and I think I used the black background and color correction to its advantage. The titles and labels I use in the video, though minimal, do a reasonable job of explaining the setup. If only I had actually temperatures instead of warm and hot!