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Flow Visualization
Group Project 1
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The flow seen in this photo occurred by accident while our group was trying to visualize the Saffman-Taylor instability using the Hele-Shaw cell. We attempted this using vegetable oil and colored Isopropyl alcohol, but it was a complete failure as far as photographing the Saffman-Taylor instability goes. The glass cover slid off of the surface of oil and alcohol, destroying our intended photo opportunity but creating this interesting pattern at the edge of the pool of alcohol. It grabbed my attention because the droplets looked so small and delicate, but when I stepped back from them I saw that there was some sort of order in how they were forming and lining up, so I decided to photograph what was happening.

As mentioned above, this experiment began with the Hele-Shaw setup shown in Figure 1, but after the experiment failed the setup for what was *actually* photographed is seen in Figure 2. This flow is entirely driven by surface tension through the interactions of the three fluids present (oil, alcohol, and air) and by the contact angle of the alcohol on the oil substrate. When the top plate was present the alcohol was pressed between the glass and the oil into a very thin layer. When the plate was removed the alcohol's surface tension began to turn the thin layer into beads. Surface tension can also be considered *surface energy* (rubbing alcohol's is 21.7 dyn/cm) and because of this the thin layer of alcohol is trying to arrange itself into the smallest surface area (minimum surface energy) possible.

You can see in the image that the larger droplets are forming in regions where the initial layer of alcohol is thicker and the smaller droplets are forming in the regions where the alcohol layer is thinner. These droplets form because of the surface energy reasons listed above, but they are forming in the *patterns* that you see here because of contact angles and the effect of gravity on the contact angle. At the boundary of the initial thin layer of alcohol, there is a receding contact angle between the alcohol and the oil beneath it. As the alcohol layer receded it leaves small droplets behind at regular intervals. The reason that the droplets are larger in the thicker regions is because gravity and the weight of the upper levels of the layer changes the contact angle at the bottom causing it to recede slower and allowing larger droplets to form. The thinner regions do not have this effect and thus recede faster and do not allow large droplets to form. Scientifically the contact angle can be described using the Young Equation:

$$0 = \gamma_{\text{oil-air}} - \gamma_{\text{oil-alcohol}} - \gamma_{\text{alcohol-air}} \, \mathrm{COS}\theta$$

Where θ is the contact angle and γ is the interfacial energy between the two substances in subscripts.

Soon after these droplets are formed they are still neatly arranged in the rows that the recession left them in, but they quickly begin to move and slide in relation to one another on the surface of the oil. They do this because there is very little wetting between the alcohol and the oil and the coefficient of friction between the two is very low. At the far left of the photo we can see where many of these droplets have formed sort of a ‘river’ of individual droplets (they are ‘flowing’ very slowly in this direction because the plate that the oil and alcohol were resting on was at a *very* slight incline in this direction). There is no wetting at all between the individual droplets so they keep their original size and we see many varying sizes of droplets in this ‘river’ coming in from the different regions of film thickness.

This photograph was taken in direct bright sunlight at approximately 3:00 in the afternoon. It was taken at approximately a 60 degree angle to perpendicular from the surface in order to minimize reflections from the sun, camera and photographer. The camera used was a Canon Digital Rebel XT (8.2 Megapixel) at a distance of 1 ft using a lens focal length of 55 mm and an aperture of F/16. The ISO speed used was 200.
The size of the flow shown is approximately 5 inches across and the small droplets in the ‘river’ region (the dark prominent line through the center of the photograph) are moving at approximately 2 in/min. With the shutter speed set at 1/500 sec we have a time resolution for the flow of 67 µin. Spatial resolution is 14.47 x 10^-4 in. Image post-processing was done in Photoshop. The red and green components of the photo were inverted in order to give the color scheme. Also the darker levels were adjusted slightly to center in order to make the colors a little more vibrant.

I really like the macro-scale organization that you can see in this photograph and the fact that it is made up of so many tiny spherical components gives it a unique feel. The color scheme is also very pleasing to the eye with the yellow fading from the corner to pink and then to blue. It was a hard decision for me whether or not to submit the original, as-is photograph or the color-inverted one seen here. Both were incredible in my opinion. The original had a little more of a 3-D feel but it was the added interest of the yellows and blues in this one that swayed my decision. I especially like the way that this photograph just came together by accident. Some of my best photographs that I have ever taken have been just an accident that turned out to be quite beautiful. I would like to try to repeat more visualization of surface tension effects with a similar setup. I would use different colors so that there are more color schemes available with Photoshop manipulation. I feel this technique could produce many more beautiful and interesting photographs.