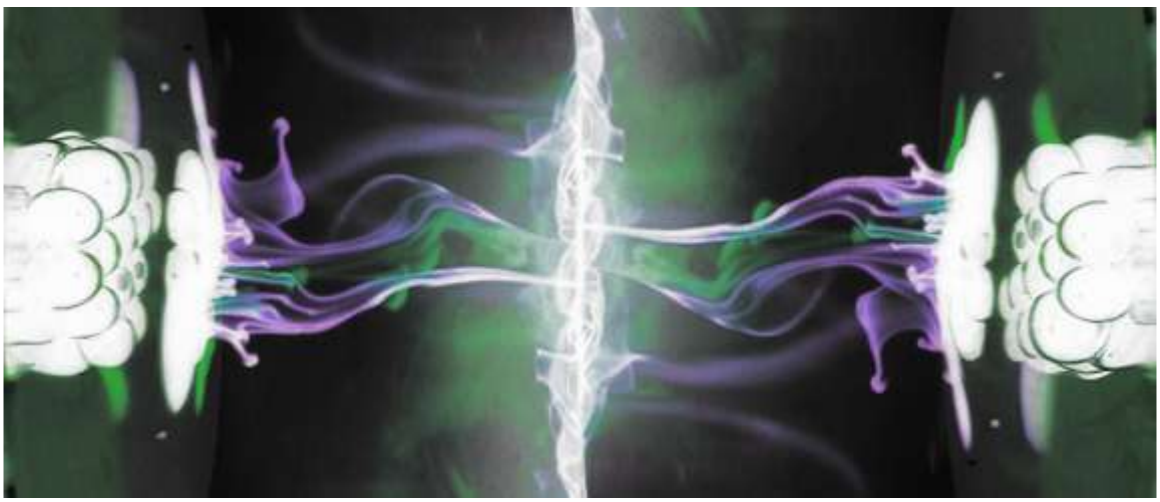
# Dyed Feet

Anthony Johnson

Get Wet Report



# Image description:

Dye falling in water is widely used to demonstrate the fluid dynamics of the Rayleigh Taylor Instability. Though functional in its own right, the artistic effect of the dye cascading through the water is one that captivates the audience and exhibits the relationship between the science of fluid dynamics' with the art of natural photography. For this assignment, the idea was not to simply photograph this interaction between the dye and water, but to manipulate the process in which the Rayleigh-Taylor instability is presented to the audience to provide a clarity and artistic approach that has not been attempted before. In addition to the Rayleigh-Taylor Instability, other fluid characteristics such as fluid density and surface tension were displayed. The overall objective to gain insight into the photography of fluid dynamic phenomenon and the art of capturing the fluids principles in an artistic and revealing manner was accomplished.

# Method for capturing Phenomenon:

This flow visualization of the Rayleigh-Taylor instability came by way of experimentation of not only the proper method to photograph the phenomenon but in which way the photograph should be taken to display the fluid flow and incorporated additional fluid dynamic principles such as surface tension. This was done by taking a small, 8 ounce drinking glass and filling it initially with 6 ounces of room temperature water. Approximately 1 tablespoon of vegetable oil was slowly and gently placed in the same drink glass to ensure no bubbles or mixing occurred. This formed a disk of oil that floated on the surface of the water. The mixture was then left to sit for a few minutes to ensure everything came to proper equilibrium. A light was then placed above the apparatus to achieve the desired lighting given the ambient lighting of the room was inadequate. In addition to the flashlight, the flash on the camera was diffused using a piece of white tissue paper to accentuate the highlights of the dye spheres. Three droplets of green, yellow, blue and red food dye were dropped in evenly spaced locations on the oil disk. They were evenly spaced to ensure they were not mixed from the force of one droplet hitting another. Finally, the droplets were allowed to congregate in the center of the oil disk and slowly permeate through the oil. Once they began to contact the water they dispersed and the instability was then photographed in a series of consecutive images. The total photographic apparatus can be seen in figure 1 below.

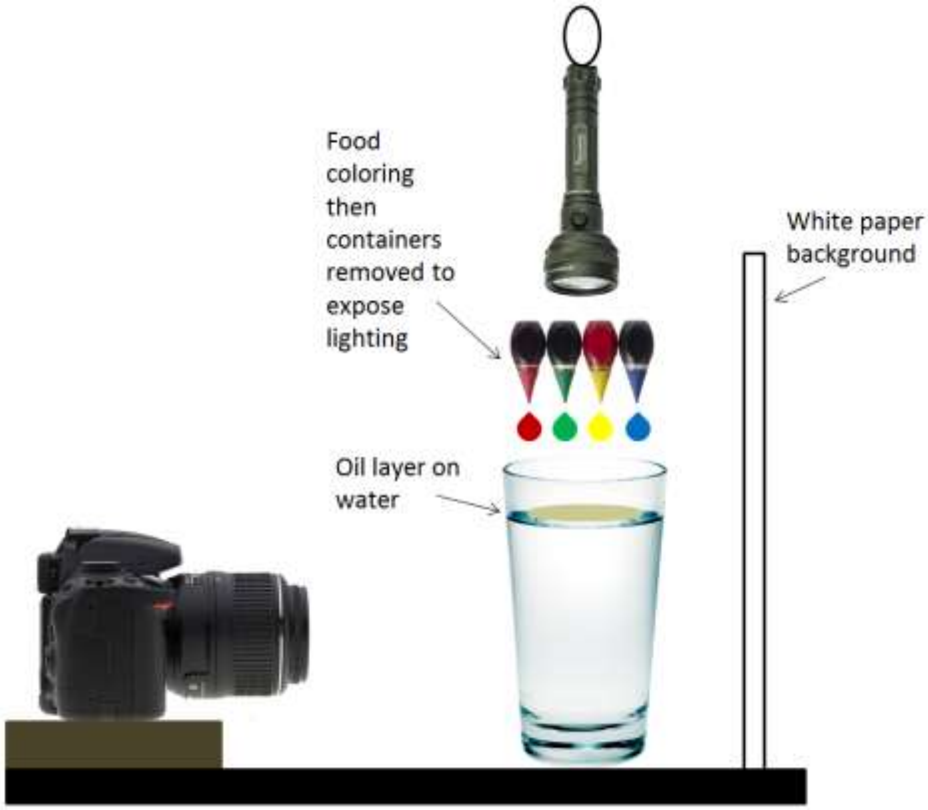



Figure 1: Photographic apparatus

## Fluid dynamics and phenomenon:

The primary fluid dynamics presented in this image is that of the Rayleigh-Taylor instability. In the image, this instability is represented in the area just below the oil in which the dye hits the water and disperses downward. This instability occurs due to the fact that the dye has a higher density then the surrounding water (water @ 20 ˚C = 998.2 $Kg/m^3$, food coloring @ 20 ˚C (polypropylene glycol 60% mix) = 1040 $Kg/m^3$) [1-2]. Once the dye permeates through the oil and makes contact with the water, this change in densities combined with gravitation force, drive the dye to the bottom of the container housing the water. This downward driving force disrupts the spherical shape of the dye droplet and rapidly results in the dye being perturbed and unstable. The Instability from this driving force causes the release of potential energy, which inevitably deforms the dye droplet causing the formation of Rayleigh-Taylor fingers[4] as seen in the cover image. The formation of these fingers increases as the dye travels further into the water until the variance in potential energy between the dye and water have reached equilibrium. This can be seen at the center of the cover image in which the colors appears to completely mix forming a nearly complete white cloud of dye and water combination. To clearly define the fluid flow characteristics present, the Reynolds number can be calculate. This Reynolds number indicates whether the fluid is considered laminar or turbulent which in turn provides insight into whether there are viscous (laminar) or inertial (turbulent) forces primarily acting on the fluid. The Reynolds number calculation is seen below.

$$Re = \frac{\rho V L}{\mu}$$

- μ = water viscosity @ 20 ˚C = 1.002 $x10^{-3}$ N $s/m^2$
- ρ = water density @ 20 ˚C = 998.2 $Kg/m^3$
- L = characteristic length = .1016 m (4 in)
- V = mean velocity ~ .02 m/s

This results in a Reynolds number of 2024 which is much less than the critical value of $5x10^5$ where laminar flow translates into unstable turbulence. This indicates that the flow is laminar and demonstrates that the chaotic nature of the dye falling in the water and the randomness of the Rayleigh-Taylor fingers is due primarily to the forces and physics described by the Rayleigh-Taylor instability.

In addition to the Rayleigh-Taylor instability, this image demonstrates the effects that surface tension plays on fluid and fluid flows. On the surface of the image (both left and right sides of the image) you see spheres of dye floating on the layer of oil above the water. Intuitively, it would be assumed that when placing droplets of various colored dyes on the oil, they would congregate in the center of the oil and mix into one large droplet, yet this is not the case. This is due, primarily to surface tension in which the cohesive forces between the molecules of both the dye and the oil are stronger then the force of gravity and weight of the physical droplet and therefore the surface tension cannot be overcome and the droplets remain separate while floating on the oil[3]. As they permeate through the oil layer due to the force of gravity, they continue to remain in individual spherical droplets because of not only the surface tension but also the fact that the cohesion force of the molecules within the droplet applies a force inward to the center of the sphere, which reduces the wall tension and results in the spherical shape[3]. This spherical shape has a higher surface area, which increases the strength of the surface tension of the dye droplet[3].

## Photographic technique:

The photographic technique used to make this image was limited due to the use of a Kodak Easyshare Z981 which is in essence a point and shoot camera. The camera saves its pictures in a digital format with a pixel quality of 14.1 megapixels. Though the camera has the option to adjust the exposure time and ISO the two cannot be adjusted at the same time. The selection was made to use a faster exposure time in an effort to obtain a clear image of the Rayleigh-Taylor fingers and dye spheres. The ISO setting was at 400, which seemed to be appropriate for the photograph and additional lighting. The exposure time selected was 1/1200 s, which, after a few trials proved to provide the highest quality image in terms of clarity and blur with minimal loss of detail. The camera was placed six inches away from the glass with the liquids in order to allow the automatic focus to properly lock onto the contents of the glass. The original image has a frame size of roughly 2.5 inches wide by 4 inches tall.

The post processing of the image was done using the Adobe Photoshop software in which the image was rotated and mirrored. The contrast, saturation and colors were then adjusted. Finally a black and white color swap image was placed in a layer above the color-adjusted image. This layer was given a 50 percent transparency which allowed the colors of the dye Rayleigh-Taylor fingers to remain in color while giving the other aspects including the dye spheres and un-dyed water to remain in inverse black and white. This provided an aesthetic appeal and made the dyes behavior and mixing to be in color and therefore emphasized.

## Conclusions:

Overall I feel this image does a great job at capturing the desired fluid dynamics. The image turned out as clear as possible considering the post processing and I feel it displays not only the intricate physics involved, but it is an image that at first glance does not say "I am a picture of fluids" instead it takes the viewer a few instances to realize what they are looking at outside of the photographic beauty and artistic approach. This image fulfills all of my intentions and portrays one of the most beautiful fluid phenomenon. One of my favorite aspects of the image is the spheres of dye in the oil. They reflect off the light in a wonderful way and give a dimension to the image that is not present in dye simply dropped into water. One of the things I dislike about the image is that there was no red dye hitting the surface, which limited the coloration possible in post processing. If I were to attempt this photo again, I would try to speed up the dropping of the dye to have all four colors contacting the water at roughly the same time. This would give the image a broader range of color and beauty. Overall I really enjoyed getting my "feet wet" and how physics is often assumed to be boring, yet it is a beautiful thing and when the right photographic techniques are utilized, it can compete with the best gallery photographs while providing a depth and deeper understanding that is not commonly seen in the world of art.

## Bibliography:

[1] "Water - Density and Specific Weight." *Engineering ToolBox*. Web. 19 Feb. 2012. <http://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html>.

[2]"Technical Data – Polypropylene Glycol: Density of Aqueous Propylene Glycol Solutions." *Lyondell Chemical Company*, Web. 19 Feb. 2012. <http://www.lyondellbasell.com/techlit/techlit/2510.pdf>

[3] Nave, R. "Surface Tension." Web. 19 Feb. 2012. <http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html>.

[4] Cook, A.W., Youngs, D. "Rayleigh-Taylor Instability and Mixing" Scholarpedia, Web. 19 Feb. 2012. <http://www.scholarpedia.org/article/Rayleigh-Taylor_instability_and_mixing>