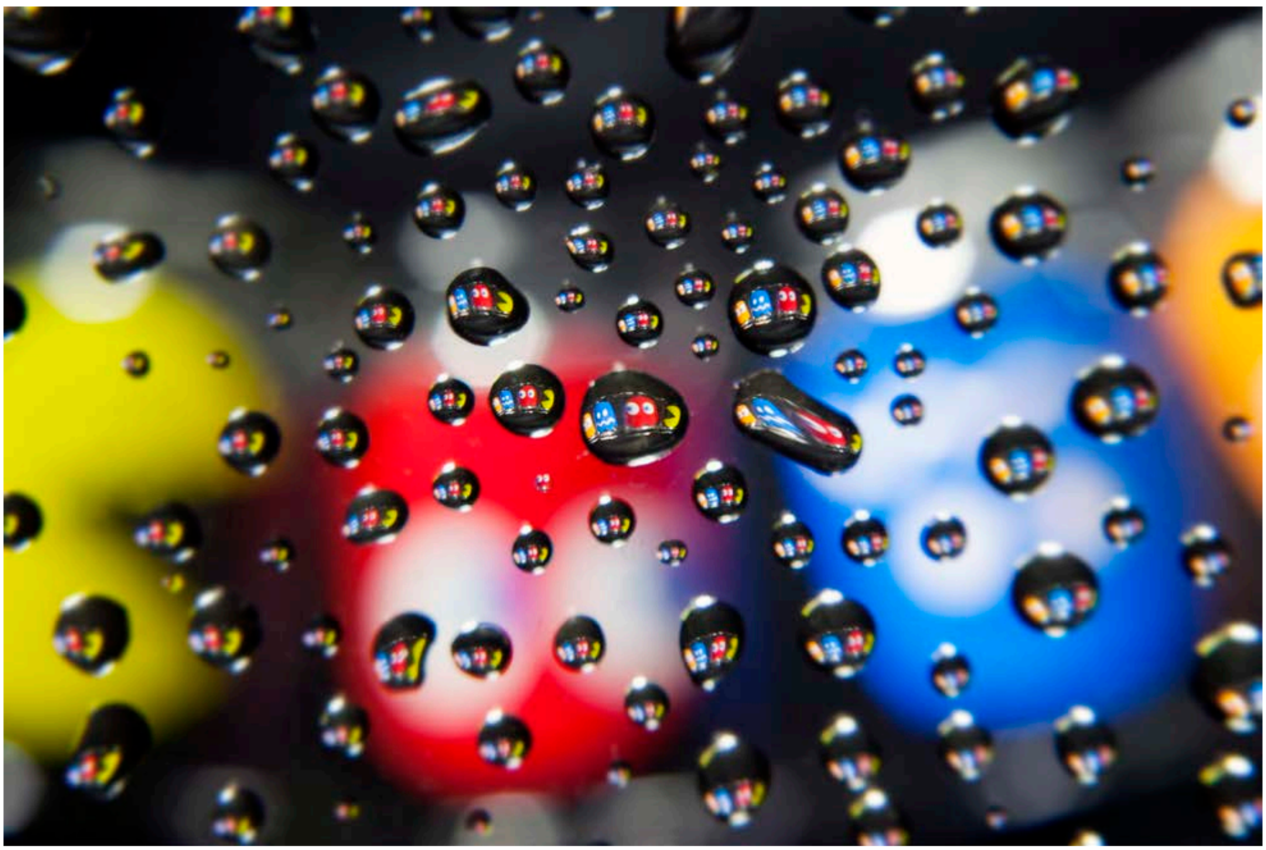
# Get Wet Project

# Where's Pinky?



MCEN 5151: Flow Visualization

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## Introduction

The purpose of the get wet project is to introduce students in the class with basic experience capturing flow visualizations. After significant thought on how to “get wet” with my first photography assignment in my engineering education, I decided to attempt to use water as a lens. I had seen an image quite a while ago that used a similar technique to create a repeating image. I really enjoyed the composition with multiple colors and focal points. My goal was to create a similar image. While this may seem to be a simple idea, creating the final image came with great challenges. One of the most difficult challenges was to figure out how to create a proper convex lens to converge the light within the water droplet.

## The Physics behind the Image

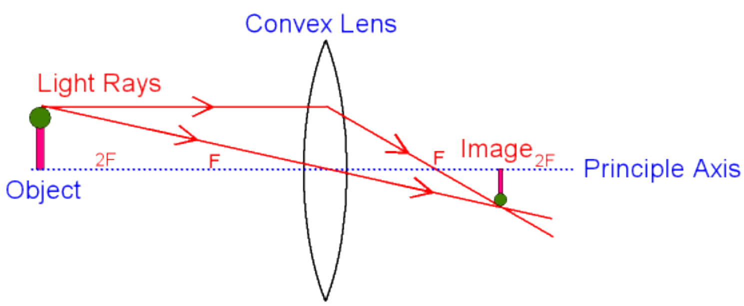


Figure 1-Ray Diagram for a convex lens (France, 2014)

In order to create convex lenses with the individual water droplets; I first had to create a hydrophobic surface. I originally chose to use a plexiglass sheet to put the droplets due to the relatively low cost and decent availability. Unfortunately, plexiglass is slightly hydrophilic due to hydroxyl groups at the end of the polymer chains creating polarized end groups. (O'Brien, Hermann, & Shepherd, 1972). These endgroups allow for a lower energy state than maintaining surface tension with other water molecules. Due to the hydrophilic nature of the plexiglass, the water spread out on the surface. With the water spreading out over the surface, I did not get the correct refraction through the water droplets necessary to focus on an image within the droplets. With the liquid flat on the acrylic surface due to polar molecules attracting the water and gravity acting on the water; these forces created a plano-concave lens. While, in theory, this would work to focus the light, the hydrophilic nature of the plate forces the water into a near flat orientation that neither converges nor diverges the light similar to a piece of flat glass. (Sunex Incorporated, 2014). As seen in Figure 1, a convex lens allows light traveling from an originating image to be refocused on the opposite side of the lens albeit inverted. The main analysis performed on the setup consists of a ray tracing performed for the setup as seen in Figure 3. In order to create this ray-tracing diagram, I used Snell’s Law (equation

Figure 2 - Measurement of Contact Angle of Water droplet on hydrophobic surface

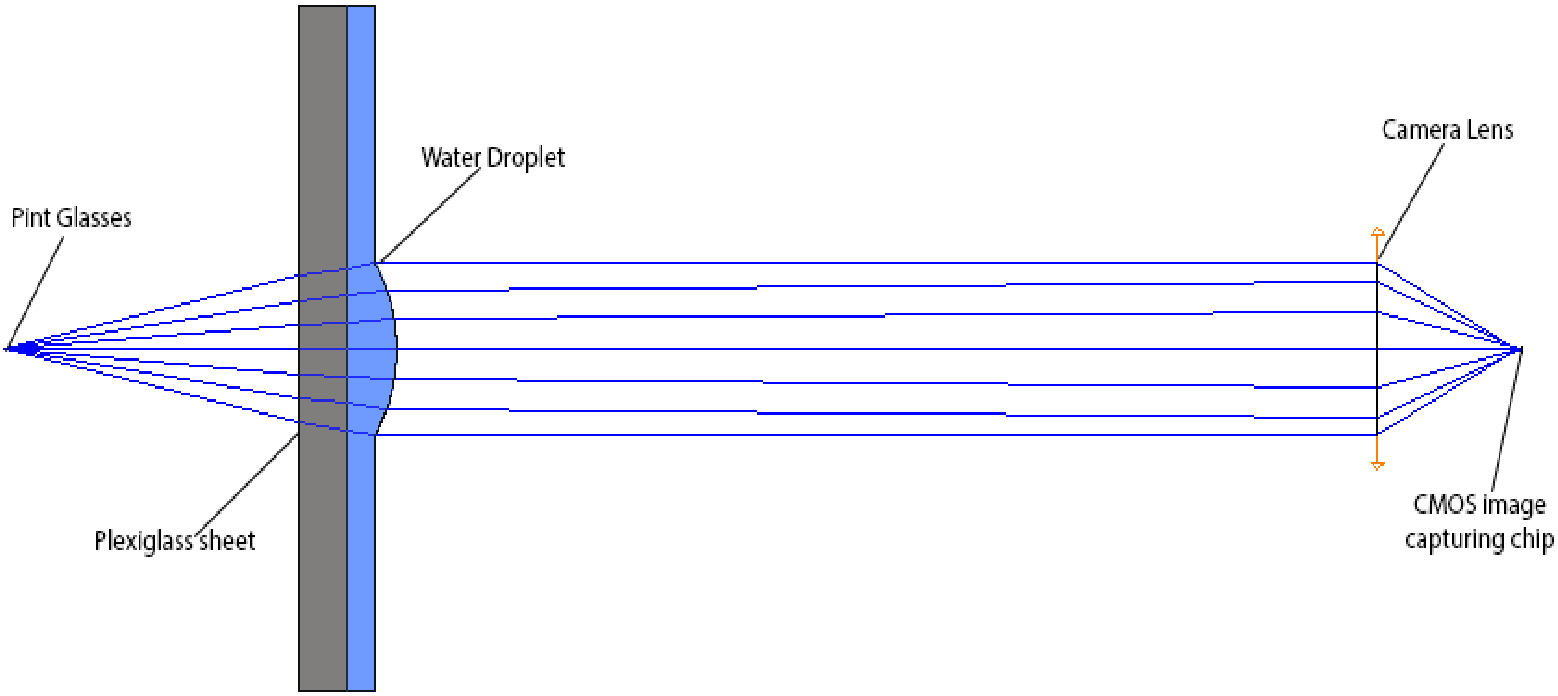


**Figure 3 - Ray Tracing for Photo Setup**

below).

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

Snell's Law describes the magnitude of light ray deviation when the beam transfers mediums. The angle at which the light rays deviate is related to the incident angle as well as the indexes of refraction for the two materials. The incident angle is measured from a normal axis to the surface interface. If one looks closely at Figure 3, one can see the beam deviation within the material interfaces. It should be noted that the graphic was created with a single point but could easily be expanded similar to a ray tracing seen in Figure 1. The ray tracing shows how a plano-convex lens will focus light rays from divergent into parallel rays. In combination with the camera lens, an image can be created.

Another interesting analysis that could be performed would be to determine the solid surface energy created by the hydrophobic wax. In order to determine this energy value, one would first have to experimentally determine contact angles for a few different fluids similar to what is done in Figure 2. The water used to take the image had a contact angle of approximately 155 degrees (measured using Photoshop measurement tool). With a few more liquids, I could determine their contact angles as well. With the experimental contact angles determined, One can quickly combine with well known liquid-vapor interfacial tensions energy values for the individual liquids to determine a critical surface tension or $\Upsilon_c$ (Hoffman, 2005). The critical surface tension is an interpolated, empirical approximation of the surface tension of the surface (Hoffman, 2005). This value is found by determining the point where a fluids contact angle is zero. With just a few more specialty liquids, I could easily determine the surface energy for the Tech Wax using this method. After determining the surface energy, one could easily determine the characteristics using Young-Dupre Equation (below) for any other liquid that could be put on the surface (Hoffman, 2005).

$$\gamma_{sv} = \gamma_{ls} + \gamma_{lv} cos\theta$$

This equation describes the force balance for a droplet at equilibrium using the contact angle and the interface tensions between: surface to vapor ($\gamma_{sv}$), liquid to surface ($\gamma_{ls}$), liquid to vapor ($\gamma_{lv}$) (Hoffman, 2005). From the experiment we now know the liquid to surface interface tension and thus can determine the surface to vapor interface tension. As a whole, this method is an excellent way to get a better understanding of how the Tech Wax would behaves for a variety of fluids.

Figure 4 - Water droplets on hydrophobic waxed acrylic

## Creating the Proper Setup

The setup used to create this image can be seen below in Figure 5. I used eight pint glasses to hold an acrylic sheet approximately sixteen inches above the floor. The reason for this was to allow for a larger subject area to be focused upon. Initially I tested my setup with just plain acrylic sheet with water droplets on top. I quickly found, as stated above, that the material was hydrophilic. This did not allow for focusing of images within the water droplets. In order to create convex lenses on the plate, I initially tried using vegetable oil to create a more hydrophobic surface. The oil help to some extent but did not create a high enough contact angle with the acrylic. After further research and thought, I realized that I had Meguiar's NXT Generation® Tech Wax® 2.0, a synthetic car wax that claims to have extreme hydrophobic properties. After applying the wax to the acrylic, I took quite a few test shots to make sure that the water droplets were behaving as expected for a hydrophobic surface. A sample image showing the hydrophobic nature of the car wax can be seen in Figure 4. After establishing the correct setup for the liquid droplets, I began trying to experiment with color additives within the individual droplets. I tried many different methods for changing the color including food coloring, watercolors, and acrylic paint. I quickly found that all of these methods clouded the water to the point where the droplets were either blurred or totally

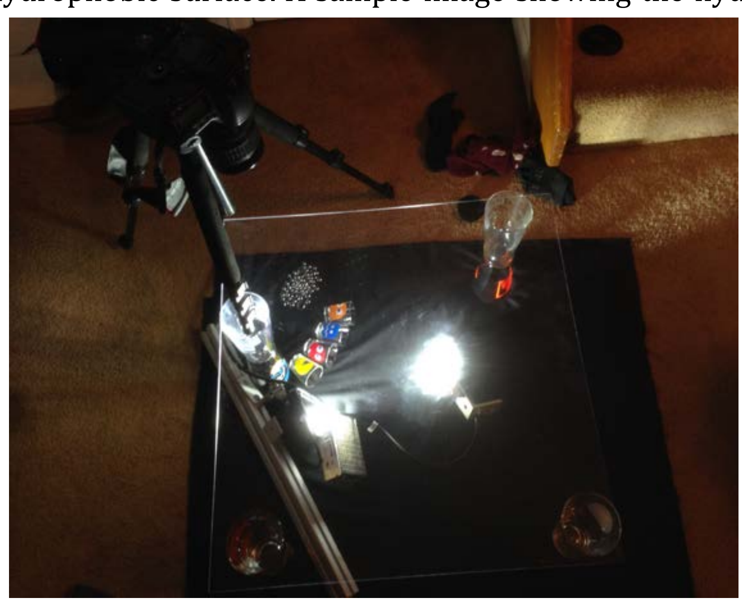

Figure 5 - Photo Capturing Setup

opaque. I was not happy with this method for adding colors to the image and quickly abandoned coloring the droplets. Instead, I decided to use a colorful medium as the background.

I eventually settled on using four shot glasses depicting Inky, Blinky, Clyde and Pacman from the classic arcade game. In order to light the subject correctly, I used two LED light boxes that were put on either side of the glasses. Finally a dropper was used to manually put the droplets into a small region as seen in Figure 5. To ensure a sharp contrast to the bright colors of the glasses, I used a simple black cloth to great a dark backdrop. After such a widespread and varied experimentation process, I became satisfied with the images that were being produced with this setup.

**Capturing the Image**

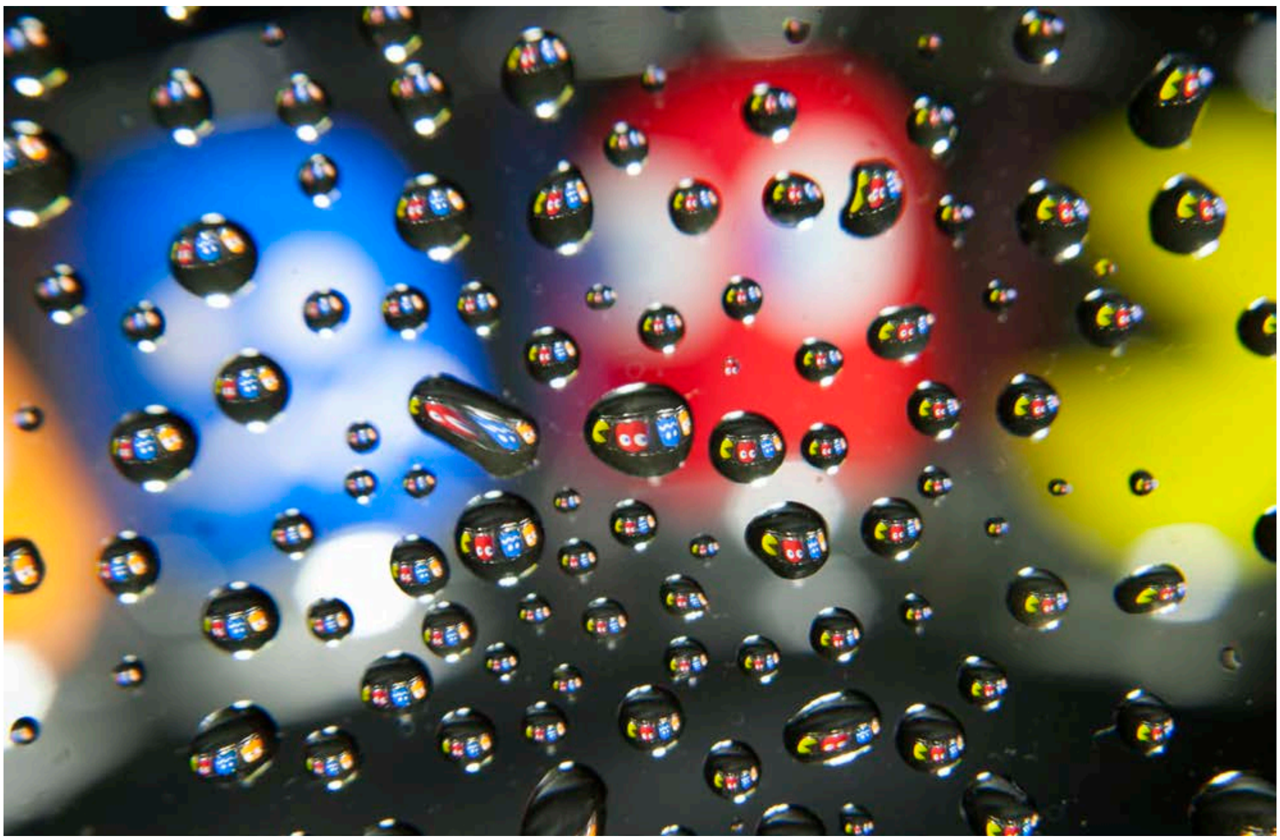

Figure 6-Raw Image Capture

To properly capture the image seen on page 1, I took hundreds of exposures to ensure proper focus, lighting, contrast, warmth, and depth of field. The camera used was a Canon EOS 10D. This camera takes images with a 3072x2048 pixel resolution. This corresponds to 6.3 megapixels In order to create such a good close up image with the 28mm-135mm lens I have available, I used a 2X macro screw-on attachment to allow for a narrower field of view. One variable that I spend a fair bit of time experimenting with was the f-stop. I could not decide on whether or not I wanted the actual subject in focus with the droplets or not. Ultimately I decided on an f-stop of 8 for a relatively narrow depth of field. Other settings for my image include a focal length of 135mm, an exposure time of 1/13 second, and an ISO setting of 100. The end of the camera lens was approximately 1 foot away (the maximum distance for focusing with macro shots with the standard lens) from the water droplets. Overall I was extremely happy with the raw shot that was produced; this image can be seen in Figure 6.

**Post Processing**

In order to finalize the captured image, I used Adobe Photoshop to clean up and polish the raw photo. Using the raw image file, I increased the contrast and coolness of the image. From there I used the spot healing tool to soften some of the imperfections within the image caused by fibers left from the microfiber polishing towel used for the wax. Finally, I realized that I wanted to narrow my focal point of my image further to draw people's eyes to the central point of the image. To do this I created a copy of the background image. Next I applied a Gaussian blur of 7 pixels on this layer. Finally, A large soft-edge brush approximately 250 pixels in diameter was used to "paint" the center of the image eliminating the blur in the center and fading outward from the circle. In total, the post processing used was to enhance the image without distracting or taking away from the original image. I believe that my changes definitely improved the overall image.

**The Image**

Overall, I am extremely satisfied with the quality of the final image. I think that it perfectly illustrates the power of many optical properties that are often taken for granted including Snell's law, refraction, and surface tension. All of these properties have been used to create a unique image that immediately captures the eye. I feel that the post processing that was performed helps to draw the viewer in even further with the gentle focus in the middle. One question that I was unable to answer was whether or not colored drops would be possible. I was unable to find a method for pigmenting the droplets well enough to maintain clarity. I would love to further experiment with color droplets to further create an interesting image. One thing that I would love to further improve would be the focus of the image. While it is quite good in my image, I know with a better macro lens, a better cleaning method for the plexiglass, and more pure water, I could get an even crisper image. To further develop this image, I would love to expand the subject that I used. I think it may be interesting to angle the plate to change the shape of the droplet slightly to show refraction through the water in a different way. One final thing that I would love to try is having a moving stream of water. Ideally the stream would uniform or at least consistent. Changing exposure times with a moving stream may possibly create quite an interesting effect. In conclusion, I am quite content with the final product for my project and after receiving feedback, it seems the majority of the class enjoyed the image as well.

## Works Cited

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