<u>**Get Wet: Rain**</u>

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The underlying idea of this project was to capture a beautiful and artistic image of some physically meaningful fluid flow. I was immediately drawn to the concept of droplet formations and different physical situations in which they occur. Though droplet formation often comes about from a liquid-solid interface, I was more concerned with the flow of liquid droplets through an interstitial fluid such as air. Initially, I attempted to drip water from a glass and capture still images of spherical droplets suspended in a black background. However, it was quite difficult to attain a clear image depicting droplet formation. The following weekend, I went to visit family in Los Angeles, CA for my birthday (January 17th). It was quite gloomy and rainy that weekend, which gave me the idea to try to capture an image of a droplet of rain. I began taking photographs of falling raindrops from inside the house looking through a clean window. Once the appropriate field of view and focus settings were determined, I was able to obtain a gorgeous image of droplets of rain falling through a beam of sunlight with a dark grey background.

As mentioned previously, this photograph was taken of natural phenomena. Therefore, the apparatus consisted of falling rain with a grey cloud shield in the background and a light source out of the field of view. However, it would not be too difficult to mimic the ambient conditions of this picture. In order to recreate this image, set up a series of droppers about five feet above the focal point and one foot in front. Each dropper should be set to release a given amount of water at a specified time. The background of the image should be a dark grey sheet of velvet, and a light source that mimics natural sunlight should be placed on the left side of the apparatus. When the droppers release the water, the camera should be set to take snap shots as the droplets are falling. By following these steps, a person could recreate a similar picture of falling droplets.

As shown in the final image, the droplets of rain falling are quite spherical. This is undoubtedly due to the size of these droplets. Near cloud level, larger droplets (radius > 4.5 mm) will accumulate and fall towards the ground [1]. As the droplet flows through air, a pressure difference occurs over the drop causing a deformation. Eventually, the surface tension over the droplet is less than the force of the air deforming the droplet, and the droplet bursts into smaller droplets. This type of forced division among larger drops will continue as they approach the ground. Therefore, it much more common to find droplets of 1-2 mm diameter at ground level. According to a geological survey from Georgia Water Science Center, droplets appear spherical at ground level when the radius is less than 1 mm [1]. This information strongly agrees with the phenomena observed, as the droplets in the picture are about 1-2 mm in diameter. Because the sizes of the raindrops are known, it is possible to estimate the terminal velocity of the droplets in the image. The figure shown below shows the results of a study conducted by James E. McDonald from the University of Arizona.

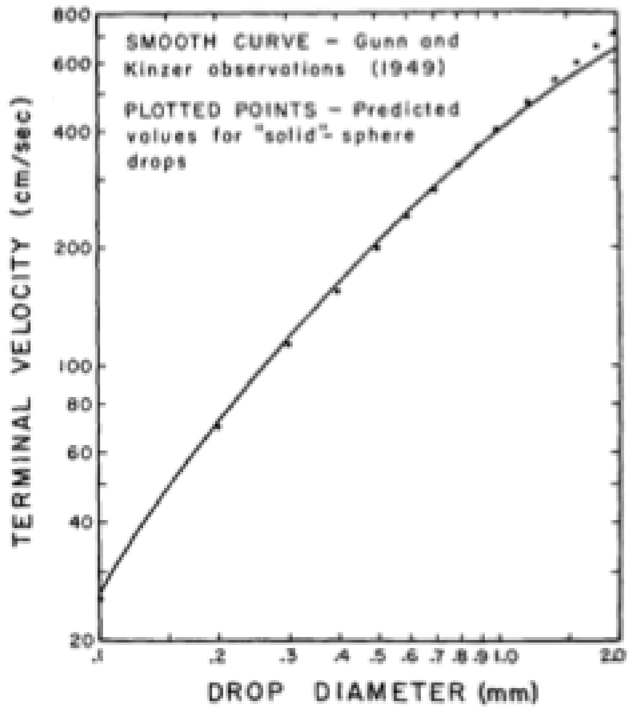

Figure 2: Terminal velocity as a function of drop diameter [2].

From this figure, it can be determined that the velocities of the drops in the image range from 4-6 m/s. Because the droplet diameters and velocities have been approximated, it is possible to calculate the Reynold's number of a droplet in the photograph. The Reynold's number (Re) in this case indicates the ratio of the inertial forces of the raindrop to the viscous forces of air. This dimensionless quantity can be calculated in the following manner.

$$\mathrm{Re} = \frac{uD}{\nu} = \frac{(6\, {}^{m}\!/_{s})(2\cdot 10^{-3}\, m)}{(1.488\cdot 10^{-5}\, {}^{m^2}\!/_{s})} = 806$$

In this calculation of Re for a falling drop, I assumed the drop was 2 mm in diameter and traveling at 6 m/s. The value ν is the kinematic viscosity of air at 1 atm and 20 C [3]. For a sphere (raindrop) flowing through a fluid (air), the laminar regime is classified as Re < 0.1. We can see that the flows of the raindrops are in the turbulent regime based on the extremely high Reynolds number. This would make sense if one were to think about the physical path of a raindrop. Seldom will a raindrop travel down a constant streamline from the clouds to the ground as in the laminar flow of a sphere in a viscous fluid.

The main focus of the image was on the individual droplets of water falling; however, light interaction with the droplets played a large role in the picture. The background is very dark because a large grey sheet of clouds spanned the field of view of the image. Out of the view of the camera, a small opening in the cloud shield allowed a beam of light to pass through into the field of view. Because water has a greater index of refraction than air, light was refracted as it passed through the droplets. The image shows light being refracted at an angle, which indicates the position of the light source and the angle of light entering the field of view. Not only does the droplet refract light due to its physical properties, it also acts as a lens due to its spherical properties. The bright spots on the droplets in the image show the increased focus of light as it exits the medium. Therefore, light was refracted and focused as it passed through the droplets of water.

Raindrops are very small (~1 mm) and require an extremely tight field of view. The digital camera I was using was a Canon SD780IS; however, the photo-processing program I used did not store the camera specifications. The width of the image was 2,048 pixels and the height of the image was 1,536 pixels. In order to achieve a well-resolved image, the physical field of view was about 7cm by 5 cm and the raindrops were approximately one foot from the lens. Using such a narrow field of view allowed me to capture an appropriate number of well-focused raindrops.

The aperture, shutter speed, and ISO settings can be extracted via Photoshop. The photo-processing program I used was called iPhoto. I mainly tried to lower the scattering of light throughout the picture to enhance the edges of the droplets. Also, I chose to make the final photo a shade of blue to enhance the refraction of light.

There are several phenomena revealed in this photograph. First, a clear interface between the droplets and the surrounding air shows the spherical nature of the drops. Also, the light refracting through the droplets helps define the beautiful spheres. The only part of the image that I dislike is the intense light near the top. It was very difficult to remove the scattering of light through the image due to this bright spot. However, I fulfilled the intent of the project, as well as my desire to capture a unique type of fluid flow. To further develop this idea, it would be interesting to take the same image with a jet of air flowing upwards. This would increase the pressure exerted on each droplet by the air, causing deformation in the particles. The resulting image should look similar, but the droplets would no longer be spherical.

References:

1.) United States Geological Survey: Georgia Water Science Center. http://ga.water.usgs.gov/

2.) McDonald, James E. "A Note on the Aerodynamic Effects of Internal Circulations in Small Raindrops." Journal of Meteorology. Volume 17. November 5, 1959

3.) de Nevers, Noel. Fluid Mechanics for Chemical Engineers. 3rd Edition. McGraw-Hill 1997