Get Wet Image: Water Droplets Flowing Down a Buddha Board

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Introduction

A Buddha Board (or Zen Board) allows for a clear view of capillary action and surface tension of a droplet flowing down the board. Buddha Boards are white, but they turn black where they come in contact with water. They return to white when the water evaporates. Because the paper turns black, not the liquid, the interaction between the liquid and the paper can be clearly seen. Additionally, the paper turns a very saturated black color, allowing for a clear and stylized image.

Visualization and Photographic Technique

While the exact materials used are a trade secret, Buddha Boards are built using three elements: a white paper, black paper and plastic backing. It looks like a canvas (as shown in Figure 1), and was created as an art tool for calligraphy and painting. The white paper becomes transparent when wet and the black paper beneath shows through. The plastic backing is used to retain moisture long enough for users to create their drawings. The water will evaporate after a few minutes, and the white paper becomes opaque once again.

Figure 1: Buddha Board[1]

The Buddha Board allowed a clear view of the interactions of the fluid with the paper, but it also presented some challenges. The photo was taken indoors and most artificial lighting created a glare on the water that prevented the fluid from appearing transparent. Natural sunlight was used to light the board because it was more diffuse and reduced glare. The camera used was an Olympus PEN E-PM2 micro four-thirds camera with the standard kit zoom lens with a focal length between 14mm and 42mm. A diagram of the method used to shoot the image is shown below in Figure 2. The board is 12” by 9.5” in size and all three streaks are contained in a width of about 2” and height of 3” in the image. The final image was 3065 x 4602 pixels (approximately 14 Mpx), which is three decades of scales in the shortest dimension. This should be enough to be well resolved on a computer screen. However, the image may appear grainier as a large print because its resolution is around the standard for 100% size, that is, 300 x 300 pixels per inch.

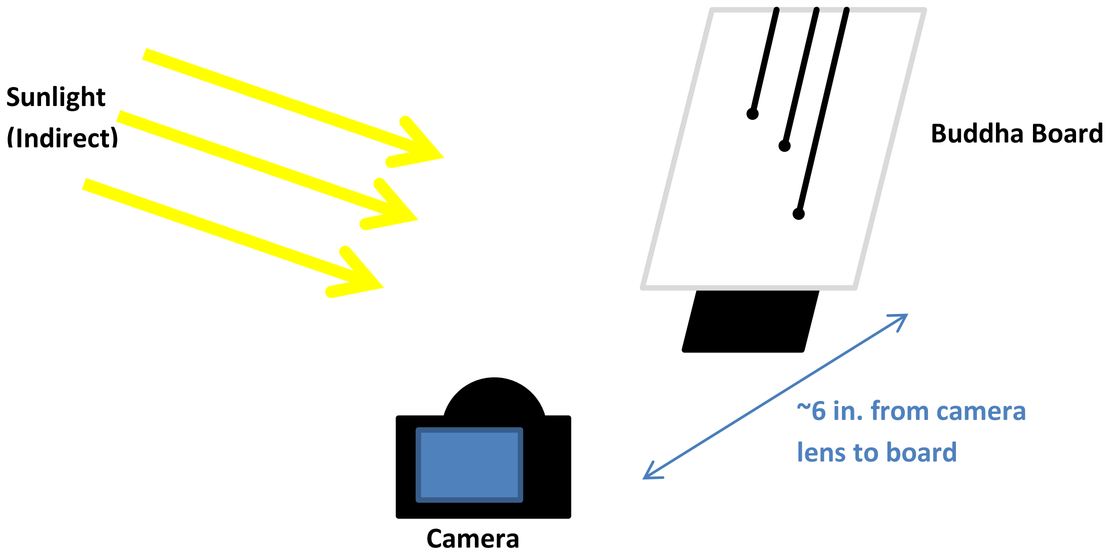

Figure 2: Sketch of Apparatus

The fast shutter speed required to capture the droplet in motion caused the image to be underexposed. The image was shot in S mode, but the exact shutter speed, ISO, and aperture was not recorded. To mitigate the darkness of the image, the ISO was increased to approximately 1800; diffusion caused the image to be blurry at higher ISOs. The image was later enhanced using curves and unsharp mask in Gimp 2.8 to lighten it and bring out the contrast. It was cropped such that the highest droplet (the one in focus) was in line with the upper left intersection of the grid overlay used in Gimp to assist with the rule of thirds.

Description of Flow

The flow used in the image included three laminar drops flowing down the Buddha Board paper. The most interesting fluids phenomena captured in the image are capillary action and surface tension. Capillary action comes into play when the water travels laterally across the paper, rather than solely straight down due to gravity as would be expected. Capillary action, or capillarity, is the tendency of fluids to rise or to be depressed in tubes of small diameter[2]. The spaces between the fibers in the paper cause the capillarity in this case. The stream on the right of the image clearly demonstrates capillarity with its horizontal expansion. The force that causes capillarity is adhesion, the force of attraction between two unlike surfaces. The diagram below shows the adhesive forces causing water to rise into a capillary.

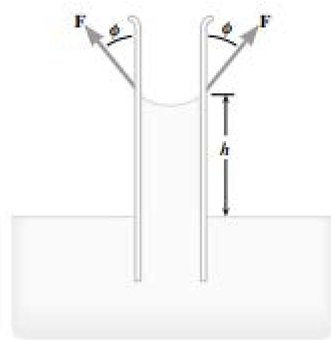

Figure 3: Adhesive forces causing capillarity[3]

Another mode of flow observed in this photo is surface tension. This is best seen at the leading edge of the droplet, where surface tension is holding the drop in a spherical shape. Surface tension is caused by cohesive forces, which are forces between like particles. For particles on the outside of a liquid, there is a near net force towards the center, as shown in the figure below, that causes the surface tension.

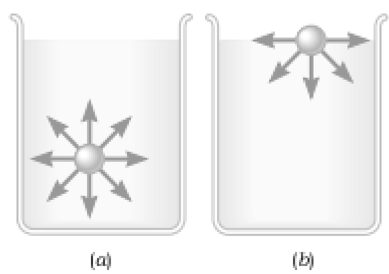

Figure 4: Surface tension[3] (the droplet in (b) is experiencing surface tension, while (a) is not)

This is particularly interesting for this photo in the context of wettability of the paper. The contact angle of the droplet (see the diagram below) affects the wettability of the paper, with larger angles creating less wettability than smaller angles. The contact angle is changed by the surface tension – greater surface tensions create larger contact angles. The wettability of the paper can be gauged by the saturation of the black color. It is evident that there is a large contact angle beneath the leading edge of the droplet because the white color can be seen beneath it, indicating that the wettability of the paper there is low.

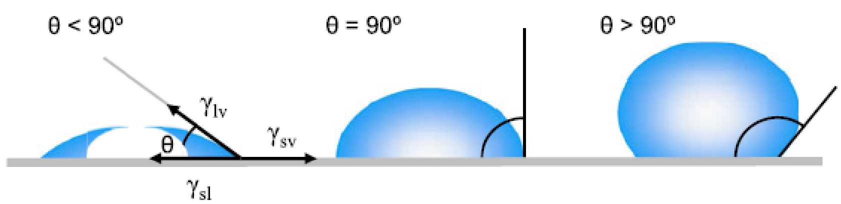

Figure 5: Contact angles on droplets[4]

The Reynold's number of the top left droplet was approximated using the following equation for flow over a flat plate.

$$Re = \frac{VL}{v}$$

where V is the velocity, L is the length that the droplet traveled, and *v* represents the kinematic viscosity of air. Because all except one side of the droplet was flowing through air (the other side was in contact with the board), it was assumed that the droplet was flowing through air. To compensate for the one side in contact with the board, the velocity recorded was smaller, decreasing the Reynold's number. The velocity was measured as 0.102 m/s and L as 0.02 m. The kinematic viscosity of air at standard conditions is $1.49 \cdot 10^{-5}$ m^2/s. The Reynold's number found with these values was 136. This low Reynold's number indicates laminar flow, which matches the laminar appearance of the droplet visually.

Discussion and Reflection

The image successfully fulfilled the intent of photographing several different aspects of the interaction between water and paper, including capillarity and wettability. The resolution was fine enough to be able to clearly see where the paper was wet in black and where it was not (in white.) If this experiment were to be done again, it would be better to use a diffuse white light that is brighter than sunlight to allow the image to be better lit.

References

[1] "Buddha Board." *Www.naefspiele.ch*. Naef Spiele AG, n.d. Web. 10 Feb. 2014.

[2] "Capillary Action." *HowStuffWorks*. HowStuffWorks.com, 24 Aug. 2009. Web. 11 Feb. 2014.

[3] "Surface Tension." *Physics 5B Home Page*. N.p., n.d. Web. 11 Feb. 2014.

[4] Bracco, Gianangelo, and Bodil Holst. *Surface Science Techniques*. Berlin: Springer, 2013. Print.