Springtime in Colorado

Water Droplets on Columbine Leaves Demonstrate the Lotus Effect

Project 3: Group Phi

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Intent

After browsing the galleries of images from this course, I decided that there is a lack of images that involve natural elements, such as plants. This fact in addition to the beautiful green spring vegetation inspired my partner, Austin Ruppert, and I to incorporate flow visualization and lush green plants. We researched a phenomenon observed on certain species of plant leaves known as the lotus effect, which causes the leaf surface to become superhydrophobic, meaning that water droplets do not wet the leaf surface, but instead are suspended and slip off with ease. We discovered that Colorado's state flower, the columbine, exhibits the lotus effect, so we decided to use the columbine in our images. My intent was to create an image that demonstrated the physics of the lotus effect but also incorporated a refreshing feel with the water and green leaves.

Description of Apparatus

We traveled to McGuckin Hardware to take photographs of their columbine flowers. We arranged the leaves and flowers in different orientations and then applied small droplets of water to the leaves. More details on this method are described below. Once a desired quantity and size of water droplets were on the leaves, we took several images of the leaves and flowers.

Fluid Flow Visualization Technique

We experimented with two techniques for applying the water droplets to the plants. At first we tried dripping water onto the leaves from a water bottle, but the large drops disturbed the leaves and shook off the droplets. We then used a small spray bottle to mist the leaves with small droplets. This was a very successful method of placing several droplets onto the leaves for our photographs. The water droplets in my image are approximately 4-6 mm in diameter. We had to be careful not to touch the leaves because the oils from our fingers would ruin the superhydrophobic properties of the leaf surface.

Photographic Techniques

All photographs were taken using an Olympus FE-370 8.0 megapixel digital camera. This camera has a focal length range of 6.3-31.5mm and an aperture range of 1:3.5-5.6. All photographs utilized the camera's "indoor" setting in conjunction with the "super macro" setting with the flash disabled. Table 1 lists detailed information about the final photograph.

Table 1: Details of photograph

Photograph Date	Apr 25, 2009
Field of View	2 x 1.5 inches
Distance from Lens Object	0.75 inches
Lens Focal Length	7.7mm
Original Image Size	3264 x 2448 pixels
Final Image Size	3264 x 1945 pixels
Shutter Speed	1/80 sec
Aperture	f/4
ISO Setting	100

The camera was held in hand for all photographs. Image processing was performed using the Paint.NET image editing software. I wanted to preserve the natural aspects of the image, so the only alteration I made to the image was cropping. I cropped some of the top and bottom from the image where the focus was poor. The original image can be found in the Appendix.

Fluid Mechanics and Physics Demonstrated

The Lotus Effect and Surface Tension

Water is a polar molecule, which means that water molecules are attracted to each other. This causes water droplets to bead up on a surface. A water molecule inside the water drop is being pulled in every direction equally by the surrounding molecules, resulting in no net force on the molecule. However a molecule at the surface of the drop experiences a net force back into the drop because the air does not pull on the molecule. This net inward force at the drop surface is called surface tension, which is why water drops are round instead of flat [Zenner et al. 2008].

As mentioned previously, the superhydrophobicity demonstrated by the columbine leaves is a phenomenon known as the lotus effect, because it was first observed and understood in the leaves of the lotus. The surface structure of the leaf is responsible for the water shedding properties. Figure 1 is a scanning electron micrograph (SEM) of the surface of a lotus leaf. We can see that the surface is covered with micron-scale bumps and that each bump is covered with nano-scale wax rods. The surface of the columbine leaf would have a similar surface structure. Normally water droplets will stick to the surface that they are in contact with, but there is enough surface tension due to the small contact points with the nano-scale wax rods that the water drop cannot fit between them. Thus, the bumps and nano-scale wax rods suspend the water droplets above the leaf surface [Koch et al. 2009, Zenner et al. 2008]. Because the nano-scale wax rods suspending the water drop create such small contact points, the drop is essentially surrounded entirely by air. This creates surface tension on all sides of the drop, forcing it to bead up into a more spherical shape and reduce its contact with the leaf surface, which results in the superhydrophobic properties.

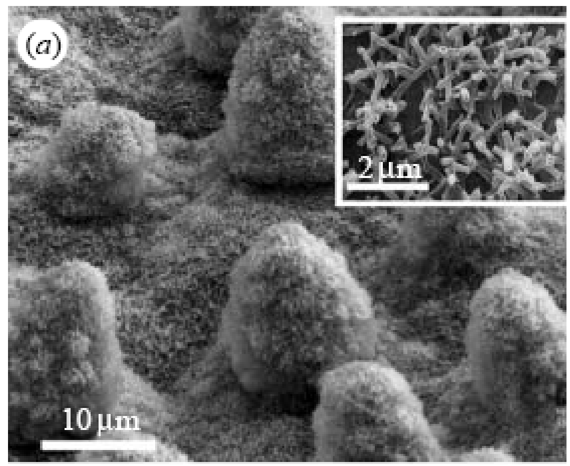

Figure 1: SEM of the surface of a lotus leaf. The micron-scale bumps and nano-scale wax rods are responsible for the lotus effect [Koch et al. 2009].

Contact Angle

The contact angle between a drop and the surface is a widely used parameter to characterize the wettability of a surface. A high contact angle describes a surface on which water droplets will form spherical shapes. The actual contact area between the drop and the surface is very small. A low contact angle describes a wettable surface on which water drops will spread out and flatten. Based on this definition, superhydrophobic surfaces such as the columbine leaf should exhibit a high contact angle. Figure 2 shows four classes of contact angle and examples of plants that demonstrate each class.

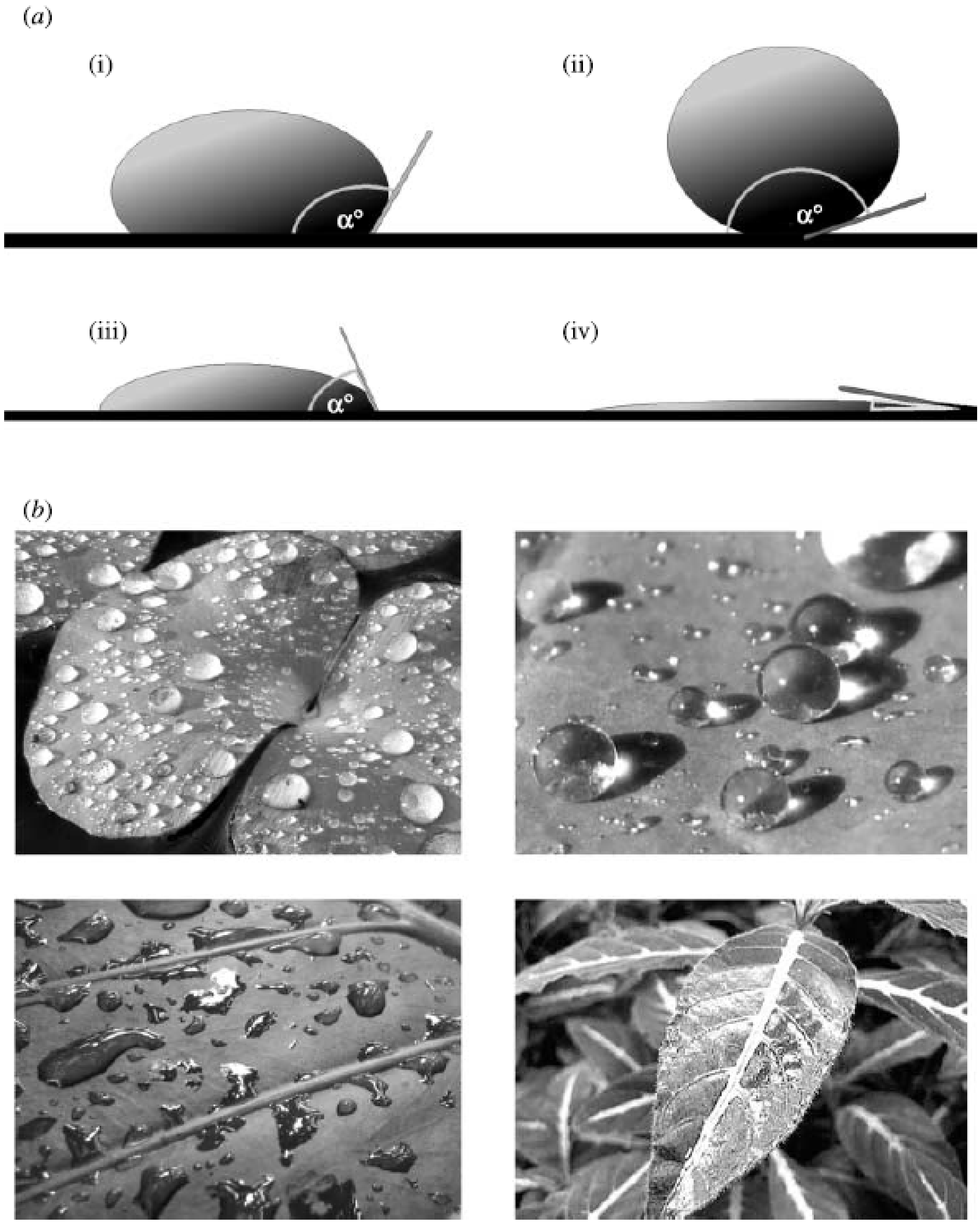

Figure 2: Four classes of surface wettability. Images a(i)–a(iv) show their characteristic static contact angles (CA) and images b(i)–b(iv) show representative leaves of each CA and wettability class. (i) An example of a hydrophobic leaf is Regnellidium diphyllum. (ii) An example of a superhydrophobic leaf is Brassica oleracea. (iii) An example of a hydrophilic leaf is Alocasia odora and (iv) is an example of the superhydrophilic leaf of Ruellia devosiana. (a) (i) CA 90–150°, (ii) CA>150°, (iii) CA>10°<90°, (iv) CA<10° [Koch et al. 2009].

Figure 3 is an image I took of a water droplet on a columbine leaf. I used a side view to estimate the observed contact angle. Based on Figure 3, I estimated that the angle β is approximately 30 degrees. Thus, the contact angle α for the columbine leaf is equal to 180-β, or approximately 150 degrees. According to Figure 2, superhydrophobic surfaces are characterized by a contact angle greater than 150 degrees. The observed contact angle between the droplet and the columbine leaf surface is right at this limit, which verifies that the columbine demonstrates the lotus effect. A full size version of Figure 3 is in the Appendix for a more detailed view of the water droplet used to estimate the contact angle.

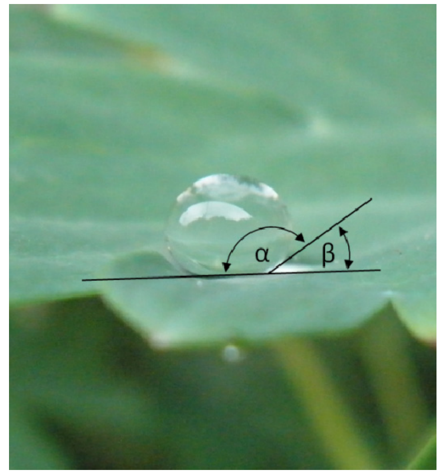

Figure 3: Side view of drop used to estimate the contact angle α.

Image Discussion

I am very pleased with my final image. I think it is beautiful and also sparks interest in the observer. I like the soft texture of the image created by the leaf surface and the smooth water droplets. The best aspect of the image in my opinion is that it consists of natural greenery and has a simple elemental feel to it. When I look at the image I can almost smell the air after a rainstorm and hear the raindrops falling on the leaves. I enjoy the fact that it appeals not only to sight, but to other senses as well. I think that my image will develop a similar reaction in the observer, providing a refreshing connection to nature that my other flow visualization images might not.

Acknowledgements

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References

Koch K, Barthlott W. "Superhydrophobic and superhydrophilic plant surfaces: an inspiration for biomimetic materials." Philosophical Transactions of the Royal Society A: **367** (2009): 1487–1509

Zenner GM, Duncan K. "Lotus Leaf Effect." Nanoscale Informal Science Education Network: (2008)

Appendix

Original Photograph

Full size version of Figure 3, used to estimate contact angle