Team Image 2:

Water Drops on Penny

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Purpose:

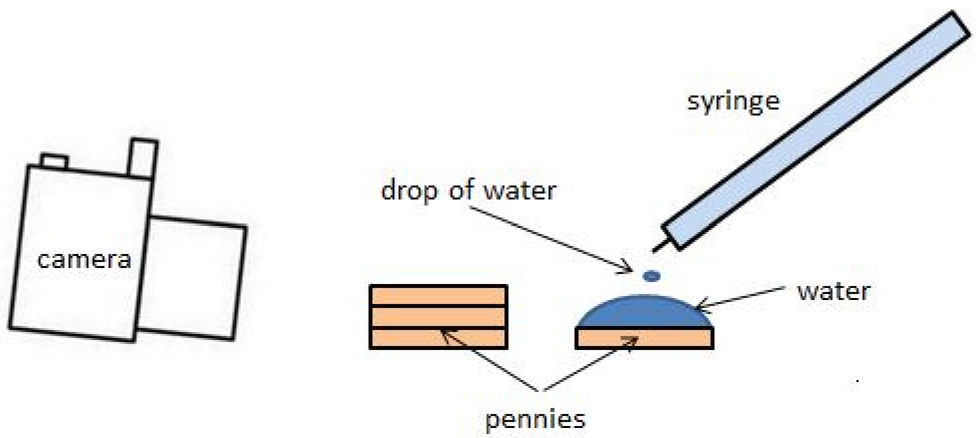
The purpose of this image is to capture the physics of a fluid with a high surface tension. For this image, the fluid is water, and a penny was used to provide a round surface on which the water would build up as it attracts to itself. To give a better understanding of the scale and effect of surface tension, there is a stack of three pennies next to the original penny.

Apparatus:

The equipment used for this setup included four pennies and a plastic syringe filled with water.

I placed a penny on a white surface and started adding drops of water until they built up so much that they almost overflowed over the side of the penny. I noticed that I was able to get about 24 drops of water on the penny before it spilled over (with the particular syringe I was using). I also stacked three pennies on top of each other vertically and placed them close to the original penny to give the viewer an idea of how high the water on the first penny builds up.

The camera was held about 6 inches pennies. Once I managed to keep about 21 drops on the penny, I would take a few images, then add another drop, then take a few more images, until the water spilled over. The following is a visual representation of my set up:



Flow Phenomena Observed:

There are two main reasons for the water to build up on a penny the way it shows in my image on the front cover of this report. First, water has a high surface tension, and second, a penny is hydrophobic. These two concepts will be discussed as the basis of the analysis. First, I will consider surface tension.

Surface tension is a phenomenon in which the surface of a liquid, where the liquid is in contact with gas, acts like a thin elastic sheet.[1] Note that this term is usually used to refer to the surface of a liquid that is in contact with a gas (such as air); the surface between two liquids is often referred to as "interface tension." Surface tension in water is caused by hydrogen bonding.

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[1] http://physics.about.com/od/physicsexperiments/a/surfacetension.htm

Water molecules (H_20) consist of one oxygen and two hydrogen atoms. The oxygen atom is held together with the hydrogen atoms because they share electrons in a manner that creates a covalent bond. The oxygen atom holds on the hydrogen atom electrons tightly, creating a partial negative charge for the oxygen atom and a partial positive charge for the hydrogen atoms. These opposite forces cause the water molecules to stick to one another. Similarly, the hydrogen atoms tend to line themselves up with oxygen atoms of neighboring water molecules. The tendency of water molecules to stick together due to the partial positive and negative charges is called hydrogen bonding.[2] It is because of hydrogen bonding that water has a high surface tension.

Within water, the positive and negative charges balance each other among neighboring molecules, similar to a tug-of-war game with equal sides, so no net force is created between the molecules. However, the water molecules on the surface of the liquid that is in contact with air have no neighboring water molecules above them to bond with. This results in a net force pulling them inward. Hence, the surface tension of water holds the water molecules together as if there were a layer of skin on its surface. The following image gives a visual representation of this effect:

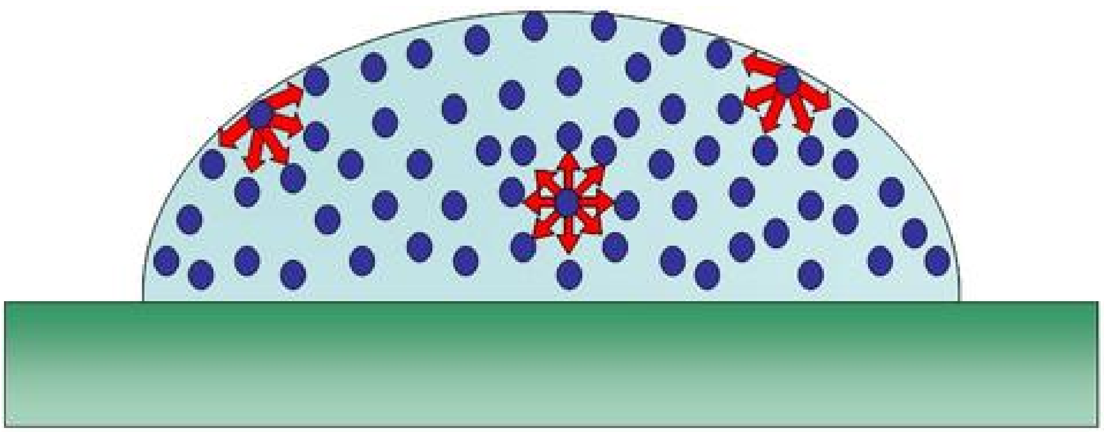

Image taken from http://physicaplus.org.il/zope/home/en/1185176174/water_elect_en

Surface tension is a quantity measured in units of energy per unit area (force per length). It expresses the amount of energy needed to enlarge the surface of the liquid by surface unit. Hence, drops form in the shape of a sphere because the sphere has the lowest surface area per given volume.[3] This is why the water builds up in a spherical shape on the penny.

The other significant factor that allows the water to accumulate the way it does in my image is the fact that the penny is made of copper, which is a hydrophobic material.[4] A hydrophobic material lacks an affinity for water,[5] or is simply is "water-fearing," and tends to repel from water. A penny is also generally quite greasy as it has been handled by many human hands, which increases its hydrophobicity.

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[2] http://www.sciencebuddies.org/science-fair-projects/project_ideas/Chem_p021.shtml
[3] http://physicaplus.org.il/zope/home/en/1185176174/water_elect_en
[4] George Valette, "Hydrophilicity of metal surfaces: Silver, gold and copper electrodes," *Journal of Electroanalytical Chemistry*, (1982)
[5] http://www.biology-online.org/dictionary/Hydrophobic

One measurement that can be calculated as a result of surface tension is the contact angle. The contact angle, θ, is the angle created between the outer surface of the liquid and the surface on which it lies.[6] This value can be calculated based on the following formula:

$$\gamma_{LG} cos\theta = \gamma_{SG} - \gamma_{SL} \qquad \text{eq. (1)}$$

Where γ_{LG} is the surface tension between the liquid and the air, γ_{SG} is the surface tension between the surface and the air, and γ_{SL} is the surface tension between the liquid and the solid surface. Below is a visual of how the above variables relate to each other:

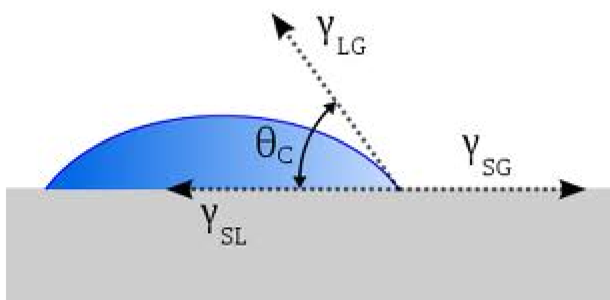

Image taken from: http://en.wikipedia.org/wiki/Contact_angle

Once the values of the three surface tensions are known, the contact angle of water on copper can be estimated. The only value I was able to obtain is the surface tension of water at 25 degrees C, which is 0.072 N/m.[7] Note that this is a valid value because the drops that were produced by the plastic dropper were on average about 0.19 in in diameter[8]. As we are left with one equation and three unknowns, I must rely on another method for measuring the contact angle. In fact, there are a few different methods of calculating contact angles such as optical tensiometry, in which very sensitive and accurate devices are used to optically detect the drop shape and surface and fits the drop shape to recorded images using equation (1) above.[9] I do not have access to such a device, so I will rely on my image.

Zooming in on my image, I can use a protractor to measure the contact angle between the water and the penny, which turns out to be just about 90 degrees. The acceptable contact angle of water on a penny is about 89 degrees.[10] Thus, my measurement is quite accurate. I can measure the percent error using the following equation:

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[6] http://physicaplus.org.il/zope/home/en/1185176174/water_elect_en

[7] S. L. Manzello, J. C. Yang, "An experimental study of a water droplet impinging on a liquid surface," *Experiments in Fluids* 32, (2002): 588

[8] Richard C. Tolman, "The Effect of Droplet Size on Surface Tension," *The Journal of Chemical Physics 17-3,* 1949, 337

[9] http://www.attension.com/contact-angle?_kk=measure%20contact%20angle&_kt=8aec43de-d800-4d3c-8402-7cbba5e92fdc&gclid=CN7ZvrHA6q8CFQdeTAod-R8v2Q

[10] http://www.csu.edu/chemistryandphysics/csuphysvan/participantactivities/Kondratko.FengertHS.ContactAngleIFTWetting.pdf

$$\%error = \frac{|E - A|}{A} \times 100$$

Where A represents the actual value (theoretical) and E represents the experimental value (measured). So for calculating the percent error of the contact angle between water and a penny, we have:

$$\%error = \frac{|E - A|}{A} \times 100 = \frac{|89 - 90|}{90} \times 100 \rightarrow \%error = 1.11\%$$

This low percentage of error means that my measurement based on my image is very accurate.

Possible Sources of Error:

As my percentage error was very small, there are few sources of error associated with this lab. If I were able to use equation (1), then I could have measured a very precise value for my contact angle, which would have most likely had a bit of error due to the fact that a penny is not a smooth surface. Actually, the difficult part in determining the contact angle is that there is a small outlining lip on a penny that makes it difficult to measure the exact contact angle when the image is zoomed in. Also, I may not have placed the ideal number of drops of water on the penny for the optimal measurement.

Imaging Techniques:

For this image, I used very simple photographing techniques. The lighting was supplied by two 32-Watt fluorescent ceiling lights in my kitchen. The images were taken with a Canon EOS Digital Rebel XT. I took this photo on the manual program setting. The shutter speed was 1/60 s and the ISO was 400. Although this combination helped me get a good image that was in focus with a lot of light, I am not sure why I did not use a lower shutter speed and lower ISO, as the image was a still image. The focal length and aperture for the image were 54 mm and f/5.6, respectively. The original photo was 1728 pixels wide and 1152 pixels high. After cropping, the final image was 1305 x 726 pixels.

For the final image, I made some simple manipulations using Photoshop. The first thing I did was crop the image to keep only the white surface I intended to keep for the image. I was trying to get an image that was relatively horizontal to the pennies, but the lens of the camera made it difficult to do so. Thus, I placed the pennies at the edge of the surface of my portable dishwasher on my kitchen counter and took the image from a lower angle such that more than just the top surface of the dishwasher was included. After that, I used Photoshop to auto-tone the image, increase the vibrance by 75, the saturation to 50, and the brightness and contrast by 10 each in order to add more life to the image and really bring out the colors of the pennies and make the background more interesting. I decided to keep the glare on the water to make it more evident that it's water. The following is the original image before any Photoshop manipulations:

Analysis and Conclusions:

As mentioned earlier, this image reveals the surface tension of water as a result of water droplets accumulating over a penny. I believe the image communicates this phenomenon very clearly. Overall, I am satisfied with the image, but there are a few things I wish I had thought of before taking the photo. First of all, although this is a clear, focused image, I think it may have turned out better had I used a lower ISO and lower shutter speed. After all, this is a still image, and the goal is to use as low an ISO as possible. I could have simply lowered the ISO to get a better quality image and increased the exposure time (decreased the shutter speed) to allow ample light for the photo.

I wonder if this phenomenon will be better demonstrated with any mediums other than a penny. I also wonder what other liquids might have an even more dramatic surface tension effect than water. I had a lot of fun with this image, especially in guessing how many drops of water would fit on the penny before it spilled over. It's amazing to see that the water just keeps building up for at least a few drops beyond what I would imaging. However, it also would get tempting at times to continue to pour "just one more drop" and then have the water spill over and have to start over again! It's fascinating to see that the water builds up to a vertical height of two pennies, which can easily be seen from the direct side-by-side comparison of the stack of pennies in the image. This project definitely gave me a more tangible understanding of the effects of surface tension, and overall, I am very pleased with my simple, yet creative image.