Team Project 2 – Condensation Droplets on a Cold Soda Can
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Background:
This photograph was taken as the second team project assignment for the Flow Visualization course offered at the University of Colorado, Boulder campus. The intent of this image was to capture condensation that had formed on the outside of a cold Squirt beverage can. This picture was taken with a Sony Cybershot point and shoot camera. The can was in a very humid climate creating more condensation and a more visible effect.

Experimental Setup:
The setup of this experiment for this photograph was very simple. It included a cold can of soda, a table and a bright white wall. All lighting was natural and coming from a window behind the location of the camera (see Figure 1).

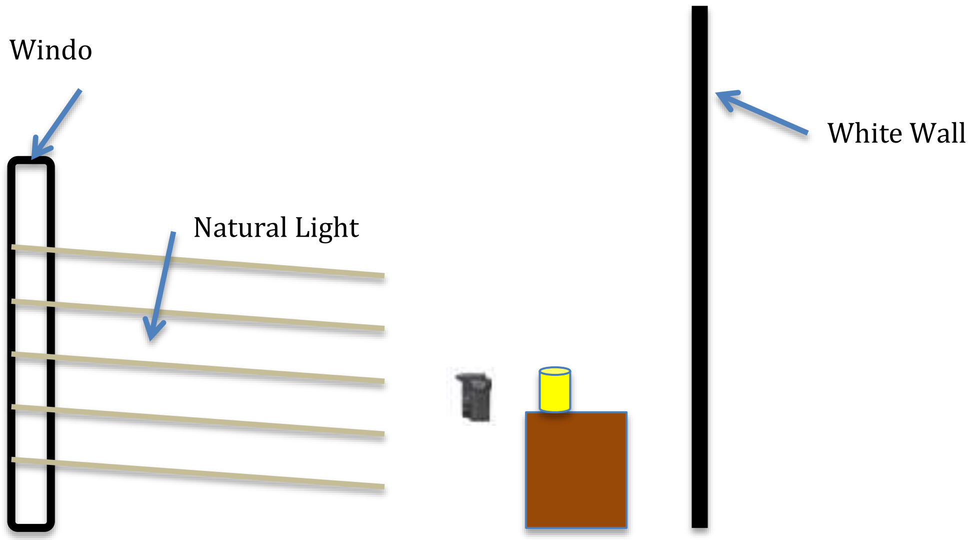

Figure 1 - Experimental Setup

I tried to capture as much of the condensation phenomenon as possible within the field of view of the camera. The camera was held 6 inches from the can when the picture was taken. The macro setting was used with natural lighting and the following camera settings:

- F-number – 4.4
- Shutter Speed – 1/20
- Focal Length – 10.12

The photograph was taken in Cancun, Mexico where the relative humidity was 70% and the temperature in the room was 74 degrees Fahrenheit. The estimated temperature of the can was 40 degrees Fahrenheit. Due to the amount of moisture in the air the can became covered in condensation within 10 minutes. The field of view of the photograph is about 2 inches in the horizontal direction and 4 inches in the vertical direction.
The original photograph was 3240 x 4320 pixels and the can and edge of picture did not run parallel to each other. I used Adobe Photoshop to edit this photograph by cropping the image to emphasize the condensation along the edge that was in the best focus. I also changed the contrast colors to my satisfaction. The final photograph ended up a size of 1980 × 3412 pixels.

Results – Explanation of the Phenomenon:
The phenomenon that is highlighted in this photograph is the accumulation of condensed water molecules on the outside of a cold aluminum can. The moisture in the air is cooled

when it comes in contact with the surface of the aluminum can. In this scenario the pressure and boundary temperatures are assumed to remain constant therefore the only way that the water vapor within the air will condense is if the temperature of the can is below the phase change temperature. This temperature called the Wet Bulb Temperature (dew point) can be approximately calculated using a psychometric chart (Figure 2[i]).

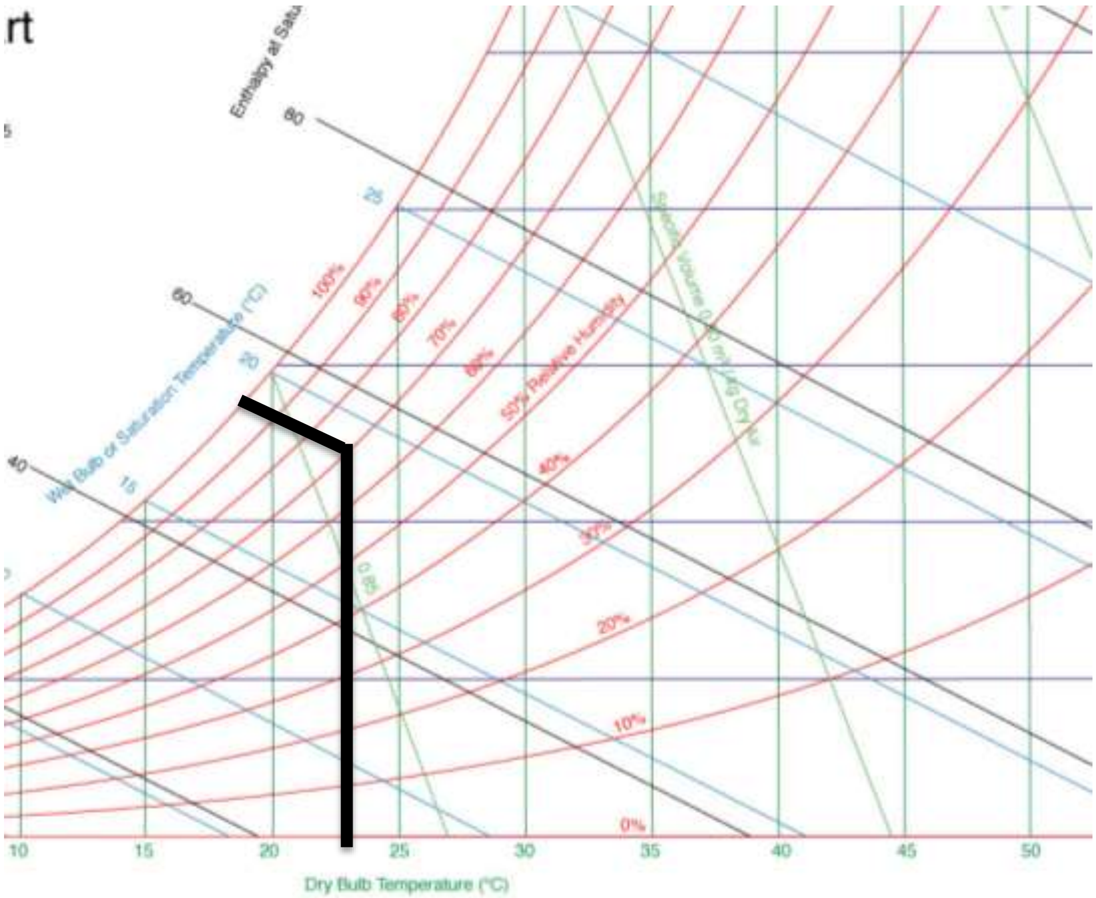

Figure 2 - Portion of the psychometric chart at sea-level. Black line indicates the path to determine the Wet Bulb Temperature.

Using the ambient temperature of the air as the dry bulb temperature of 74°F/23°C (temperature on the thermostat), and travelling vertically until intersecting the relative humidity at the time (70%) and then following the trajectory of the wet bulb temperature lines it can be estimated that the dew point of the water vapor in the air was approximately 66°F/19°C. The temperature of the can is below the dew point temperature of the water vapor causing enough cooling to condense the water out of the air and produce small water droplets on the surface of the can. Once the water is out of the air it is taken over by the main physical and chemical phenomena that occur within condensation droplets. These phenomena include adsorption, adhesion, cohesion and surface tension.

Adsorption is the binding of molecules and/or particles to a surface (not to be confused with absorption which is the filling of a porous surface with molecules). Adsorption occurs when an adsorbent (in this case condensed water vapor) is introduced to a stable surface (aluminum can) that is dis-similar in molecular composition and remains on the surface without being absorbed. The amount of adsorption that can occur can be generalized using an adsorption isotherm. This plot with respect to pressure shows the amount of adsorbent that can accumulate at a given temperature. There are various models that predict this plot. *Physics and Chemistry of Interfaces* (H.J Butt, K. Graf, M. Kappl) describes the differences and situations when each is most accurate.[ii]

The next step in creating the depicted phenomenon is dispersive adhesion. Weak Van der Wall forces form between the water molecules and the surface molecules creating slight positive and negative ions. Adhesion is a molecular attraction that occurs between two different substances with its strength being dependent on the two interacting substances. K. Kendall's *Adhesion: Molecules and Mechanics* outlines the mechanics and chemistry behind these forces that determine the strength of bond.[iii] As more water is condensed out of the humid air the water molecules begin to form larger droplets. In order to form these droplets cohesion must provide a strong force. Cohesion is the intermolecular attraction between the same molecules and can provide very strong forces. In this case cohesive forces cause the droplets to increase in size as more condensate is formed. Cohesion also triggers a physical phenomenon that describes how each of the water droplets maintains a smoothly curved boundary – surface tension. Surface tension is a result of cohesion at the boundary where there are two different molecules. The molecules within the liquid have an attractive force in all directions around them. The surface molecules exhibit the same magnitude of force but have to apply more of that force to the neighboring molecules causing the liquid "film".[iv] Figure 3 shows this molecular attraction.

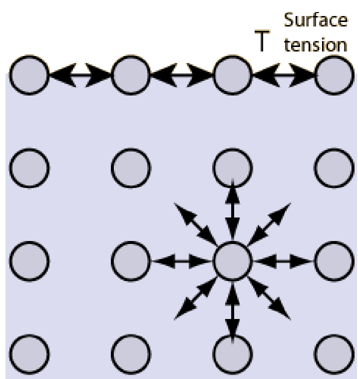

Figure 3 - Cohesion and Surface Tension

Once a critical mass is reached the mass of the water droplet causes a downward force greater than that of the Van der Wall forces and the droplet begins to move.

Discussion, Conclusion and Future Work:
Although the picture itself doesn't have the necessary depth of field to capture all of the droplets in focus, the phenomenon is clearly depicted. Near the top right portion of the photograph the water droplets cause a slight lensing effect, bending the light and adding color. This observation although not intended also shows an interesting phenomenon that is around us all the time. Future work for this experiment could be to take pictures of different cold surface materials and attempt to correlate them with the theoretical models

for adsorption. It may be possible to determine which surfaces create the largest contact areas and hold the most condensate. It may also be possible to determine what type of surface holds the greatest amount (by mass or volume) of condensate for certain applications like distillation or moisture retention.

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[i] Ogawa, Arthur. The Psychometric Chart. http://www.av8n.com/physics/axes.htm (Accessed 4/01/2011)

[ii] H.J Butt, K. Graf, M. Kappl. *Physics and Chemistry of Interfaces.* (2003) Wiley and Sons. Berlin, Germany. (Pg 179-190)

[iii] K. Kendall. *Adhesion: Molecules and Mechanics.* Science. 25 March 1994: **263** (5154), 1720-1725.

[iv] R. Nave. Hyperphysics, Georgia State University. (2010). http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html (Accessed 4/01/2011)