Visualizing the Nucleation Stage of Water Freezing

https://vimeo.com/147550019

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1. Introduction

The intent of this video was to show the freezing of a super-cooled liquid as it comes into contact with a nucleation center, specifically using purified bottled water. When water has been super-cooled and is very pure and still, the molecules are unable to crystallize due to the lack of nucleation centers, and thus cannot freeze. This transformation is homogeneous meaning that the nucleation is spontaneous, as observed in the video, and will only occur with purified water. To replicate this phenomena, purified water (not tap water) must be used along with a nucleation agent, in this case an ice cube (water quality of the ice cube will have negligible impact on the phenomena observed). Purified water is ideal for several reasons; water from tap contains minerals and various impurities that will allow for nucleation centers whereas purified water removes these impurities through distillation or reverse osmosis. Any impurities or slight disturbances can activate the nucleation of the water allowing the water to freeze prior to the intended time when observing the phenomena is desired. In order to super-cool the water, it must be placed in a freezer for a period between two and a half hours to two hours and forty five minutes. This allows the temperature of the water to drop below the freezing point without actually forming solid water. Any abrupt movement will activate the flash freezing reaction inside the bottle. During the making of the video, three bottles at a time were placed in various areas inside a standard household freezer and two of them flash froze in reaction to people walking around the house and the freezer door opening. The third bottle had to be handled very delicately and the cap had to be gently unscrewed. Once the lid was removed, the water could be poured over ice to initiate the nucleation and form the "slush" like consistency observed in the video. The inspiration and logistics to produce this phenomena came from Grant "The King of Random" Thompson's youtube video cited in source 5.

2. Methods and Discussion

To achieve the phenomena captured in the video, the purified bottled water used was the generic King Soopers brand that was purified through reverse osmosis. Three of these bottles of water were placed inside a standard household freezer for exactly two hours and thirty two minutes. The single water bottle used in the video was the only bottle that was not accidentally flash frozen, and was poured over the ice cube sitting at the bottom of the martini glass. It is important to note that the water did not flash freeze while it was being poured from the bottle but only when it came into direct contact with the ice cube or the "slushified" water. This was due to the nature of the flow of the water prior to contact with the ice and when it came into contact with the ice. As the water was being poured from the bottle, the flow was laminar and not pressurized. As it came into contact with the ice, the flow became turbulent at the nucleation site and created small pockets of pressurized areas. Ice crystals were able to form in these pressurized areas due to an increase in the strong hydrogen bonds and Van der Walls forces occurring in these regions. The ice cube in the video was created using kitchen tap water and frozen in a household ice cube tray. The martini glass was also found at the same residence but both can be purchased from Target or Walmart. The black backdrop was a sheet purchased from Target that was pinned to the wall and laid across the table that the phenomena was produced on. The source of lighting was from two 60 watt bulbs attached to the ceiling 51 inches above the surface of the martini glass. Images one and two shown below, offer a visual representation of this setup.

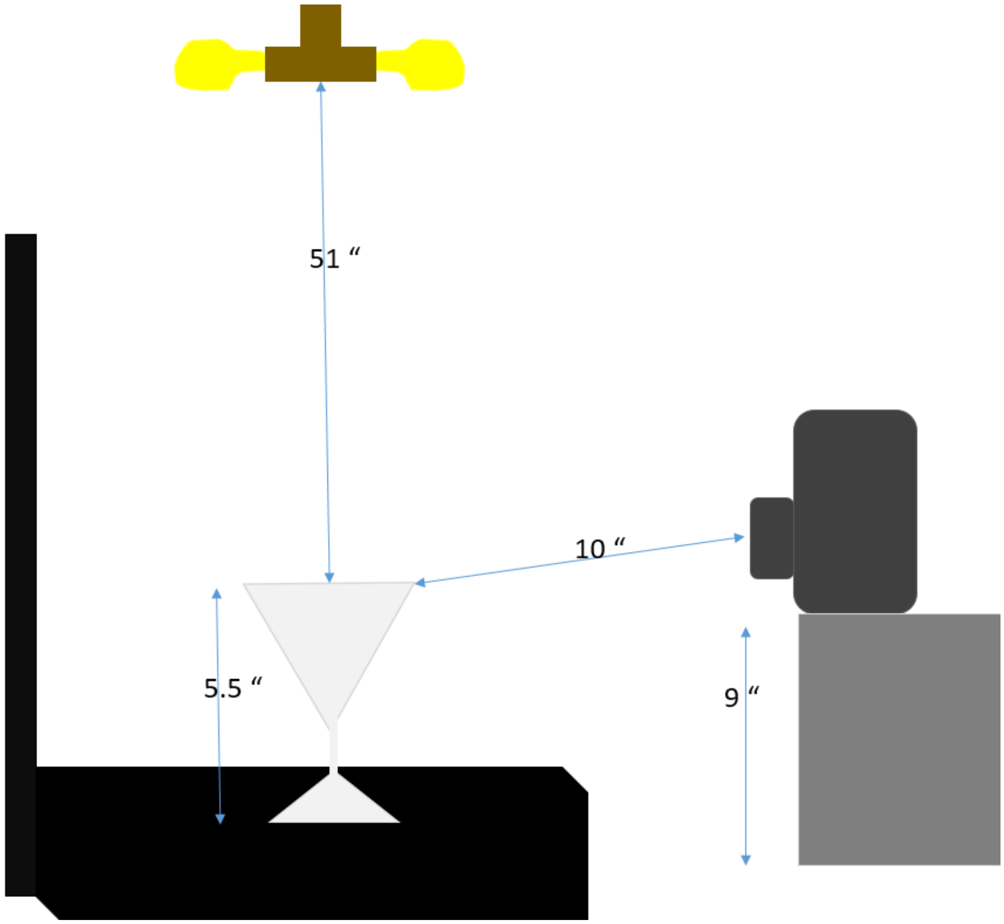

Figure 1: Schematic of setup

Figure 2: Image of actual setup

The camera was approximately ten inches from the rim of the glass and placed on a nine inch platform. The martini glass used was five and a half inches tall and four and a quarter inches in diameter. The water-ice formations reached up to six inches in height before slumping over or falling to the table. The water was poured from a height of seven inches above the rim of the martini glass.

An important observation seen in the video is that not all the water appears to freeze, which is seen as the water travels down the stem of the glass. Several factors can be attributed to this observation. First off, the temperature of the glass and surrounding air was approximately 67 degrees Fahrenheit, so environmental factors will cause the “slush” to melt much like snow would when brought indoors and placed in a glass at room temperature. Another factor contributing to this phenomena would be that the water being poured from the bottle must come into direct contact with the ice or “slush” in order to create this nucleation reaction. The water in direct contact with the glass melts almost immediately and pools at the bottom and all other water coming into contact with it will result in the same liquid state rather than flash freezing since this water is no longer at the super-cooled level where nucleation can occur. So why is it that the water will flash freeze with itself while still in the bottle when activated by a rapid stimulus as it did in the other two bottles? The answer to this question involves environmental factors and pressure. The water is isolated and pressurized inside the bottle and adding additional pressure or a sudden force will create a chain reaction within the water molecules much like they do when they come into contact with the ice cube. The water can be observed to spider web throughout the bottle, freezing all the molecules as they come into contact with the frozen web. The nucleated water reacts with the unfrozen water in the exact same way the ice cube does in the video. The nucleated water is now completely frozen and is essentially an ice cube in direct contact with the surrounding water molecules which initiates the nucleation within the rest of the water. Because the water in the bottle is all at the same threshold of nucleation, this chain reaction can occur in the isolated environment of the water bottle as well as with the water that comes into direct contact with the ice cube in the video. Below is a graph illustrating this threshold of nucleation and offering a visual representation of the phase changes the water goes through.

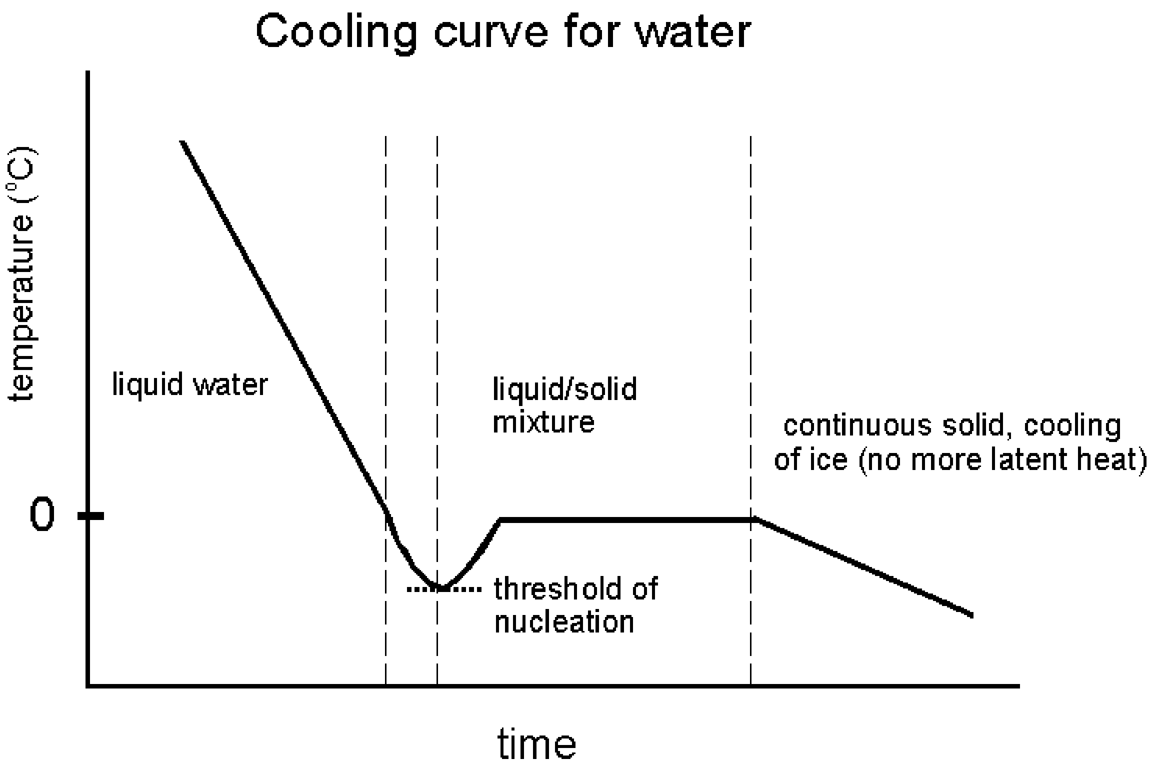

Figure 3: Graph of the cooling curve for water

3. Visualization Technique

The visualization technique used was intended to bring out the detail in the nucleation of the water as well as provide contrast that would allow both the phenomena and the water to be seen in perfect detail. The lighting used was intended to illuminate the formation of the ice crystals in the martini glass as well as highlight the flow of the water as it exited the bottle. This source of lighting was bright enough and concentrated enough to produce the desired visualization effect. The water reflected that light in a way that helped bring out the detail of the flow without creating any distracting reflections.

4. Photographic Technique

The video recording technique was intended to decrease motion blur and focus on the detail of the nucleation as well as accentuate the contrast of the water and ice formations. Thus, to achieve this, the camera settings of the Cannon EOS REBEL T3i were adjusted to be at 60 frames per second, auto exposure, movie recording size of 1280 x 720 pixels, auto lighting optimizer, focal length of 25mm, and manual focus. This allowed the camera to continuously adjust to flow of the water and formation of the ice. The size of the field of view in the video was five inches wide by twelve inches high.

The video editing was performed in Windows Movie Maker 6.0 with the intent to make minor adjustments to the original video in order to enhance the understanding of the phenomena. These adjustments were to rotate the video 90 degrees so that it was facing upright, and to slow down the speed of the video to half speed in order to allow a better understanding of the phenomena occurring. When the video played at the original frame rate, the state change and motion were occurring too fast for a clear visualization of the nucleation and much of the detail was going unnoticed with the high playback rate. All other video elements, such as lighting, color, and vibrancy remained the same as the original video. A final addition was added to the movie in order to put a crowning finish on the movie. That was to include an original score composed by Daniel Morrison specifically made for this video. The original video for obvious reasons, could not be included in this report but an image extracted from the original video can be seen below in figure four.

Figure 4: Image taken from original video

Conclusion

This video does an amazing job of revealing the behavior of water at the critical threshold of nucleation from start to finish. It demonstrates the transition of the flow of water into the ice-slush formations in a way that accurately demonstrates the phenomena occurring. The minimal post processing additions help clearly reveal the detail of this transformation without losing the integrity of the phenomena being observed. A recommendation for further development of this phenomena would be to shoot video from multiple angles (overhead, side, and up-close) in order to fully demonstrate the phenomena at multiple approaches. Additionally, this phenomena can be demonstrated in many other ways. A few examples would be that the ice cube could be introduced to the water by placing it on the surface of a glass filled with the water and see the nucleation as it spreads across the surface and down through the rest of the glass, as well as videoing the bottle when it is agitated and seeing the nucleation effect within as it spreads throughout the bottle. Any of these options would demonstrate the phenomena and provide creative ways of demonstrating the flow and properties of the phenomena.

The link to the final video is: https://vimeo.com/147550019

5. References

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