Group Project 1

Group Gamma
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This is the first project for Team Gamma. For this project, the team explored the reaction of dry ice sublimating. To perform this, the ice was placed in hot water, and the resulting gas and water vapor were photographed. The intent of this image was to get the group working together in an academic environment, and capture the beauty and physics of the gas and liquid interaction. The group chose dry ice based on the many different possibilities for discovering fluid flows.

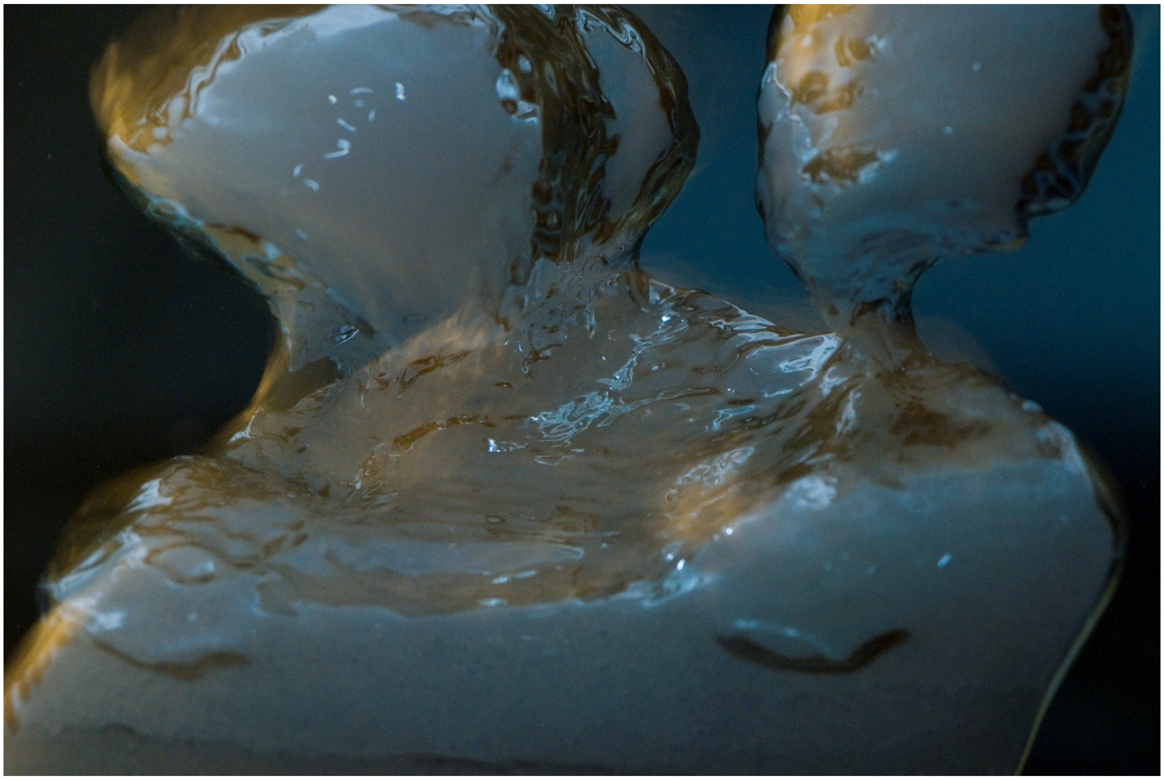

Figure 1. Carbon dioxide bubble.

Dry ice is frozen carbon dioxide. A block of dry ice has a surface temperature of -109.3 degrees Fahrenheit (-78.5 degrees C). Figure-2 shows the phase diagram of carbon dioxide [1]. As it indicates at normal pressures like 1 ATM, carbon dioxide moves straight between the gas and solid phases when the solid sublimates. In our experiments, dry ice shows its very nice feature of sublimation -- as it breaks down, it turns directly into carbon dioxide gas to form bubbles in warm water rather than forming a liquid. The bubbles contain condensed water vapor which creates a fog-like effect surrounded by a translucent bubble film.

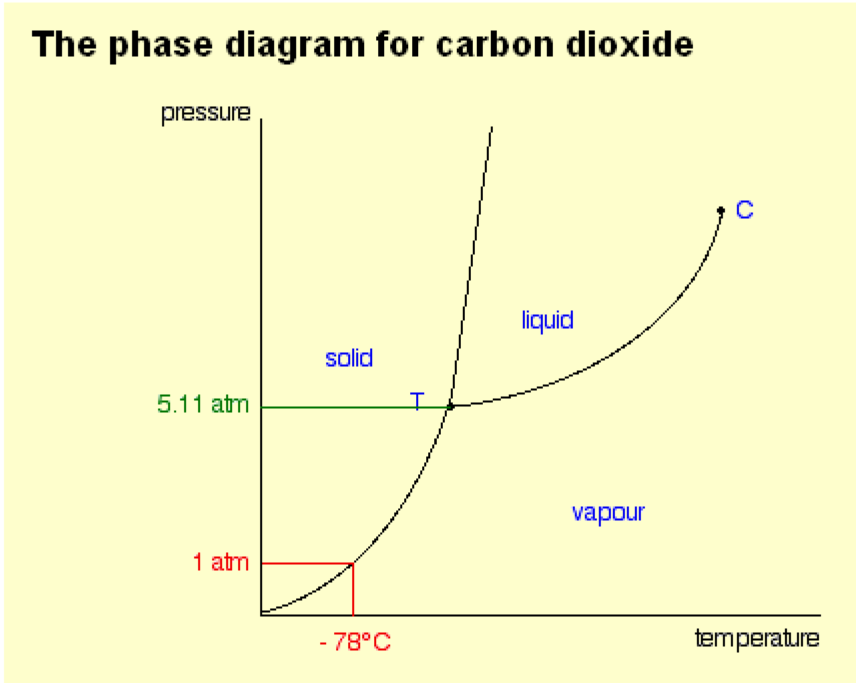

Figure 1: Phase diagram for carbon dioxide.

The bubbling fluidic phenomena in our experiments can be seen as bulk boiling [2]. It is characterized by the fact that both the liquid and vapor phase are saturated. The system can be simulated and approximated in a fractional analysis on a flowing two phase system (Kline,1965) [3]. For bubbly/slug flow, the important force are given by,

$$\{\text{Net buoyancy force at a bubble}\} = \frac{1}{6}\pi D_b^3(\rho_l - \rho_g)\frac{g}{g_c} \qquad \text{(eq-1)}$$

$$\{\text{Inertia force on a bubble}\} = \frac{\rho_l}{g_c}u_t^2\left(\frac{1}{4}\pi D_b^2\right) \qquad \text{(eq-2)}$$

$$\{\text{Surface tension force on a bubble}\} = \pi D_b \sigma \qquad \text{(eq-3)}$$

$$\{\text{Viscous force on a bubble}\} = 3\pi U t \upsilon_l D_b \rho_l \qquad \text{(eq-4)}$$

Assuming that ratio between inertia force to the buoyancy force and the ratio of the inertia force to the surface tension force are constants as $\frac{Eq-2}{Eq-1} = k_1$; $\frac{Eq-2}{Eq-3} = k_2$.

The terminal rise velocity can be solved as

$$u_t = \sqrt{k_1 k_2}\left[\frac{(\rho_l - \rho_g)\sigma g g_c}{\rho_l^2}\right]^{1/4} \qquad \text{(eq-5)}$$

Surface force between carbon dioxide gas vapor and water can be found in table 1[4] in different temperatures.

TABLE I. Stabilized density ρ_1 and corresponding bubble radius R_1 for CO_2 and Xe gas bubbles in various liquids with surface tension σ.

Liquid	Gas vapor	Temperature (°C)	σ (dyn/cm^2)	ρ_1 (g/cm^3)	$R_1 \times 10^6$ (cm)
H_2O	CO_2	20	72.75	0.2040	2.306
Ga	CO_2	30	358	0.2223	10.22
H_2O	CO_2	40	69.56	0.2457	1.780
K	CO_2	62	411	. . .	. . .
H_2O	Xe	20	72.75	0.5487	2.604

It should be noted that due to hydrostatic pressure forces, the bubbles will increase in size as they gain height in the water. This will cause the bubbles to 'break' as they rise, due to the imbalance of forces on the bubble.

To capture this image, a 10 gallon fish tank was used to provide a clear interface to photograph the gas sublimation and ensuing bubbles. The camera was set on a horizontal plane with the ice, and photos were taken of the top half of the ice and the water above it. A series of light sources were used, in order to experiment with different lighting techniques. The best combination proved to be an incandescent lamp paired with a strobe. With the camera rotated to the vertical frame position, the light from the strobe was bounced using a piece of translucent plastic. The sizes of dry ice chunks used were no more than 2 inches in diameter, and the bubbles formed not much larger.

The camera used was a Nikon D200 digital SLR, with a 60mm f/2.8 Micro Nikkor lens. The distance to the dry ice was approximately 6 inches at the most, and the distance across the wide axis of the frame was approximately 3.5 inches. The shutter speed was 1/60th of a second, with an aperture of f/18. To freeze the motion, the strobe was set to 1/64th of a second. The size of the picture was 3872 pixels wide by 2592 pixels tall, in the unedited state. The ISO sensitivity was 400. The picture was actually underexposed under these conditions, but was rendered in a very aesthetically pleasing fashion.

This image reveals the complex interface between the carbon dioxide gas and the water. The physical system also happens to be beautiful. The added effect of underexposing the picture brings out the highlights of the strobe, and gives the bubble an unreal, seemingly artificial texture. In the future, the team will attempt to improve their images by allowing more creativity during the photo shoot. The team would like to take our experience with dry ice and explore it further, since dry ice supplies so many options for fluid interactions.

[Reference]
[1] Carbon dioxide phase diagram
http://www.chemguide.co.uk/physical/phaseeqia/phasediags.html
[2] R.T. Lahey. Jr. & F. J. Moody, The Thermal-Hydraulics of A Boiling Water Nuclear Reactor, 2nd ED, American Nuclear Society (1993)
[3] Kline, S. J., Similitude and Approximation Theory, McGraw-Hill Book Company, New York (1965)
[4] R.A. Wentzell, van der Waals Stablization in Bubbles, Phys. Rev. Lett. 56, 732 (1986)