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This image was produced as an assignment for a flow visualization class taken at the University of Colorado. The specific assignment was meant to preliminarily exhibit fluid flow behavior while increasing student confidence in capturing meaningful and artistic expressions of the physics behind the behavior of fluids. The particular image taken documents food coloring in milk, and specifically displays the effects of very old blue food coloring in initially dispersing violently and secondly clotting to make a 'vein' like appearance. The original intention of the set up was to use baking soda, vinegar, food coloring and a syringe, in the hopes of capturing the beautiful colored bubbles that can be produced.

The flow apparatus used in the image was principally the basic forces of surface tension and hydrogen bonding. Hydrogen Bonding is the result of hydrogen being covalently bonded to another electronegative atom or molecule. Some common electronegative atoms include nitrogen, oxygen, and fluorine but can be any atom that tends to have an lack of electrons. In this image, hydrogen bonding caused the blue food coloring (C37H34N2Na209S3) to rapidly expand when exposed to the surface of the milk, and then later caused the clotting or 'veiny' appearance that is present in the image. The reason for the extended time required for the color to clot is most easily explained the polarity of the atoms being able to line up after being allowed sufficient time to align. Interestingly the main clotting or 'veins' appeared in the center of the blue coloring protrusions as you can see in the sketch below. The total required time was approximately 4.5 minutes from the time of blue food coloring being added. Upon the blue food coloring being added the food coloring traveled a distance of approximately two inches in all directions from the point of impact and elapsed a time of less than a second. The fluids present in the container were then left alone and after about two and a half minutes small 'veins' or clotting became visible to the human eye. The fluids were then left to sit for several more minutes in which the clotting became more intense. It was at this point (~4.5 minutes) that the specific image was taken. The specific rate at which the blue food coloring diffused is relatable by Fick's Law of diffusion which states:

$$J = -D\frac{\partial \phi}{\partial x}$$

Fick's first law relates the diffusive flux to the concentration field, by postulating that the flux goes from regions of high concentration to regions of low concentration, with a magnitude that is proportional to the concentration gradient (spatial derivative). In one (spatial) dimension, this is the equation stated above.

$$\frac{\partial \phi}{\partial t} = D\,\frac{\partial^2 \phi}{\partial x^2}$$

Fick's second Law predicts how diffusion causes the concentration gradient to change with time.

In this photograph, whole milk was poured into a bowl. Then general Kroger brand food coloring of colors yellow, green, and red were added to the milk in drops around the center of the circle. Next old blue food coloring of the same Kroger brand was used to drop droplets of the food coloring into the very center of the bowl where the blue dye would rapidly diffuse along the surface and also mix with the other colors in it's path outwards. The lighting was supplied through the use of a 200 watt industrial light and also through the use of a Speedlite 430EXII that was bounced off of the ceiling located above the apparatus..

In this photograph, the field of view is approximately 5 inches across and the image was approximately a foot from the lens. The specific lens used is a 100mm macro lens present on the Cannon 5D MarkII. The camera is of course a digital camera and the aperture was f4, Shutter Speed was $1/125^{th}$ of a second and ISO settings were 250. The image was further processed using Adobe Lightroom 2 in order to increase the contrast, crop the image to its final size, increased the exposure slightly, and gave the image a slightly warmer feeling light.

This image reveals the chemistry that is occurring in fluid interaction on an atomic level. It is interesting to think of all of the interactions that occur that are far beyond the capabilities of human sight, and yet we get to observe the macroscopic effects of what is occurring billions of times on such a small scale. I not only like the clotting and quick dissemination that was due to the covalent bonding and electronegative atoms in a atomic level, but also the various colors that were the macroscopic result of the dyes mixing at an atomic level. One of the theories that I have for why the blue food coloring acted so differently than the other food coloring dyes is perhaps due to a transformation of it's chemical makeup that happened over time. Perhaps when allowed to sit the solution separated into a different compound that was much more electronegative than the original solution? Also being new to photography, I would like to know what sort of lighting would cause the image to have a better look and warmth in the future. If I was goint o develop the idea further from a science perspective, I would probably start by seeing if I could capture similar dissemination and clotting with other chemicals. Once the exact culprit chemicals were known, then I feel the image could be further exaggerated by using more intense dissemination and clotting and perhaps using a video medium instead of a single photograph. The effect was pretty interesting to observe in real time.