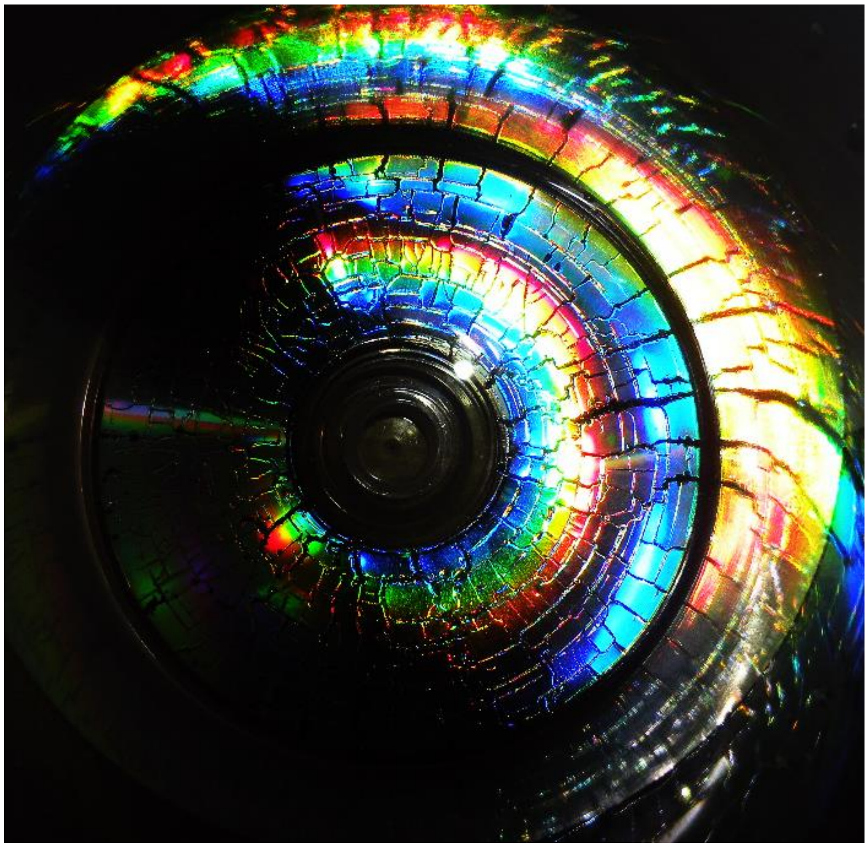
Light reflected from a CD in a Vortex of Water



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Professor Jean Hertzberg

INTRODUCTION AND PURPOSE

This photograph and paper was created for the initial "Get Wet" assignment in the Flow Visualization course at CU Boulder. The instructions for this assignment were to simply capture an image of any flow that displays physical phenomenon. I decided to interpret physical phenomenon related to the changing index of refraction in different materials. In order to display this effect, I decided to use a CD to reflect the light in a rainbow manner.

FLOW GENERATION

The apparatus used to capture this image consisted of several components: a microwaved CD, CD case, tap water, a sheet black construction paper, a sheet white paper, a flashlight, and the camera. Figure 1 displays the arrangement of the components to capture the image. The water was swirled in a circular fashion to create a small spinning vortex. The flashlight was then held at an angle to reflect off the white sheet of paper to avoid getting the large white spot reflection in the shot. I rotated the flashlight around to get the best rainbow reflection. The camera and flashlight were held approximately 6 inches above the surface of the water, with the angle from the flashlight being approximately 60 degrees. The fluid used to create the flow was slightly swirling tap water in a cylindrical container.

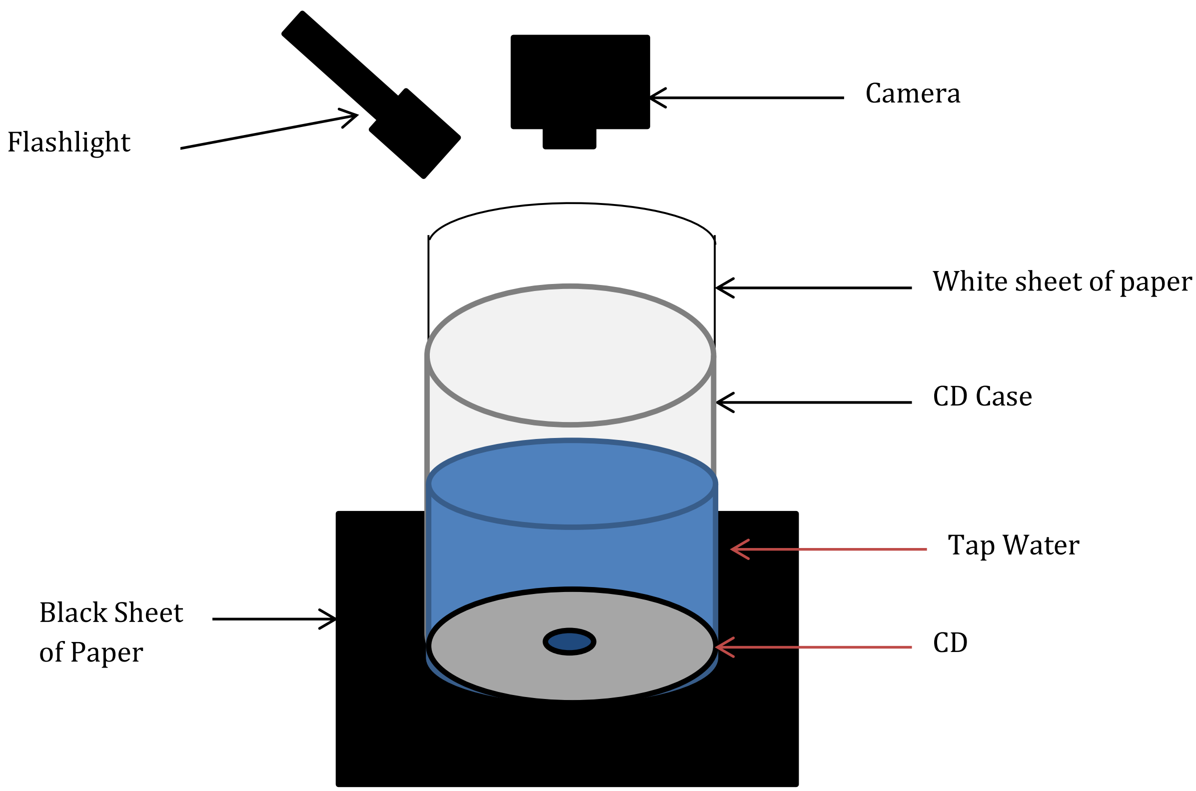


Figure 1: Schematic of Setup

FLUID PHYSICS

To create the rainbow display seen in the photo, a point light source must be used. The flashlight I used had a wide and narrow function, I noticed that the rainbow colors were more intense with the focused light ray. To avoid getting a large white reflection spot in the image, the flashlight light was aimed toward the area of white paper above the water line (out of sight in the image). The paper is an opaque object, so all of the light is reflected back at varying angles (as can be seen in Figure 2). Some of the light bounces back up everywhere, but most of it is reflected down toward the water, and an angle opposite the incident angle. When the light hits the surface of the water, most of the light is refracted through the medium, but a percentage of the light is reflected back upwards. This is why slight reflections of the surface of the water can be seen in the original image (seen in Figure 3). Water has a different index of refraction than air so the light that is not reflected upwards is refracted down through the water, this follows Snell's law, seen below in Equation 1. The amount of bending in light depends on the change of density in the medium.

$$\frac{\eta_1}{\eta_2} = \frac{sin\theta_2}{\sin\theta_1} \qquad \text{Equation 1}$$

Water and air have a slightly different index of refraction, creating an angle change in the refracted light. The angle of refraction in the water can be calculated to be:

$$\eta_{air} = 1.00029, \qquad \eta_{water} = 1.3$$

$$\theta_{water} = \sin^{-1}\left(\frac{(sin\theta_{air})(\eta_{air})}{\eta_{water}}\right) = \sin^{-1}\left(\frac{(\sin(60))(1.00029)}{1.3}\right) = 41.79\ degrees$$

The beam of light then travels through the column of water at a 41 degree angle, until it collides with the first plastic portion of the CD. The plastic has a similar index of refraction to air, so the angle reverts back to approximately 60 degrees, Equation 1 can be repeated for the water to plastic interface. At each interface with the plastic from the CD (2 layers), some light is reflected upward, and some continues through to the aluminum film on the CD. The aluminum film contains small little grooves where the information is stored.

When a CD is microwaved, parts of the thin aluminum film are melted along the grooves radially outward, creating an interesting pattern on the face of the CD. The melted parts of the aluminum film will not reflect light.

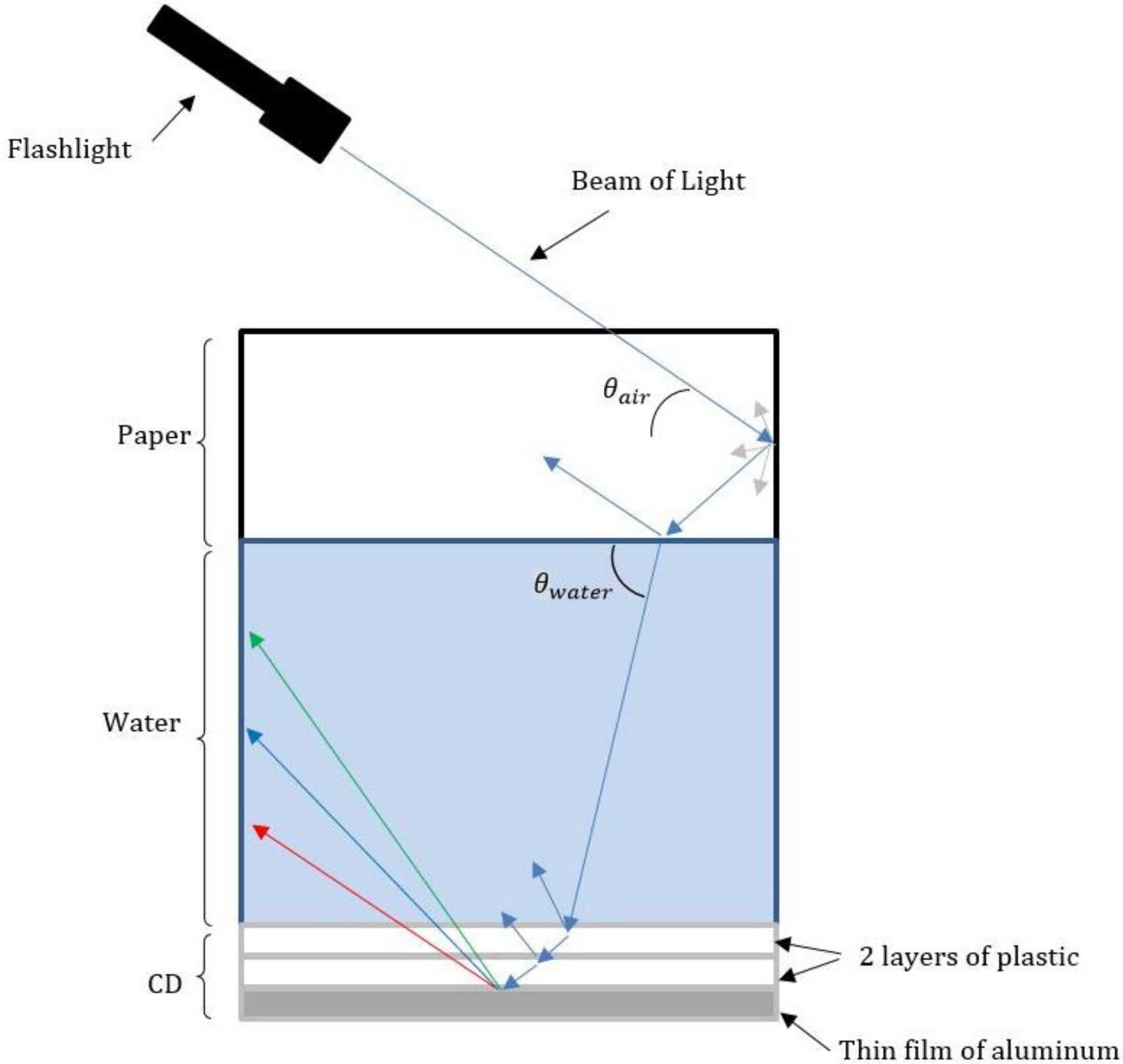
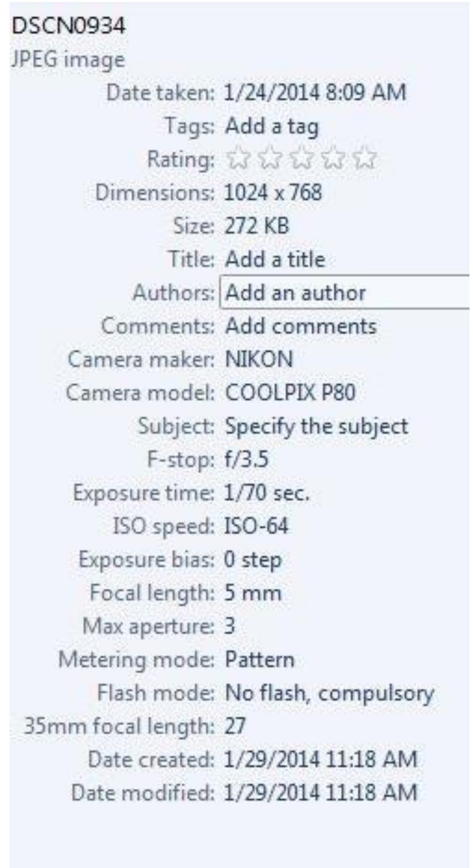


Figure 2: Depiction of light traveling through flow setup

When light hits the aluminum all of it is reflected upward (except the melted parts), through the plastic and water. The grooves on the aluminum film are so close to the wavelength of light that they disrupt the angle of reflection of the light, essentially splitting the light into colors. This causes some of the wavelengths of light to cancel out, and the rest to add together, creating an intense rainbow spectrum. A depiction of this effect can be seen in Figure 2. The rainbow light beams reflect from the aluminum and then reflect again off of the side of the water container and eventually into your eye. The reflection of the side of the container can be seen in the final image, where the reflection occurs again and the lines from the melted aluminum can also be seen reflected.

PHOTOGRAPHIC TECHNIQUE

The camera used to capture this shot was a Nikon CoolPix P80 held directly over the apparatus setup, see diagram in Figure 1. As can be seen in the data in Figure 3, a fairly large aperture was used f/3.5, giving the image a greater depth of field. This allowed for the tunnel effect of the reflection up the sides of the water column in the image. The light source from the flashlight created an intensely bright spot, so I was able to use a fast shutter speed of 1/70th of a second, in order to prevent motion blur in the image.


DSCN0934
JPEG image

Date taken:	1/24/2014 8:09 AM
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Rating:	☆☆☆☆☆
Dimensions:	1024 x 768
Size:	272 KB
Title:	Add a title
Authors:	Add an author
Comments:	Add comments
Camera maker:	NIKON
Camera model:	COOLPIX P80
Subject:	Specify the subject
F-stop:	f/3.5
Exposure time:	1/70 sec.
ISO speed:	ISO-64
Exposure bias:	0 step
Focal length:	5 mm
Max aperture:	3
Metering mode:	Pattern
Flash mode:	No flash, compulsory
35mm focal length:	27
Date created:	1/29/2014 11:18 AM
Date modified:	1/29/2014 11:18 AM

Figure 3: Photo data

IMAGE POST PROCESSING

In the final stages of this image creation, I did minimal edits using Adobe Photoshop. Using the Curves function, I essentially made the blacks blacker in the image, I wanted to remove the unsightly background (desk, tape pieces and white paper), and so the image was also cropped slightly. I also slightly increased the contrast of the image in order to make the rainbow more intense, and to remove the “shine” from the image.

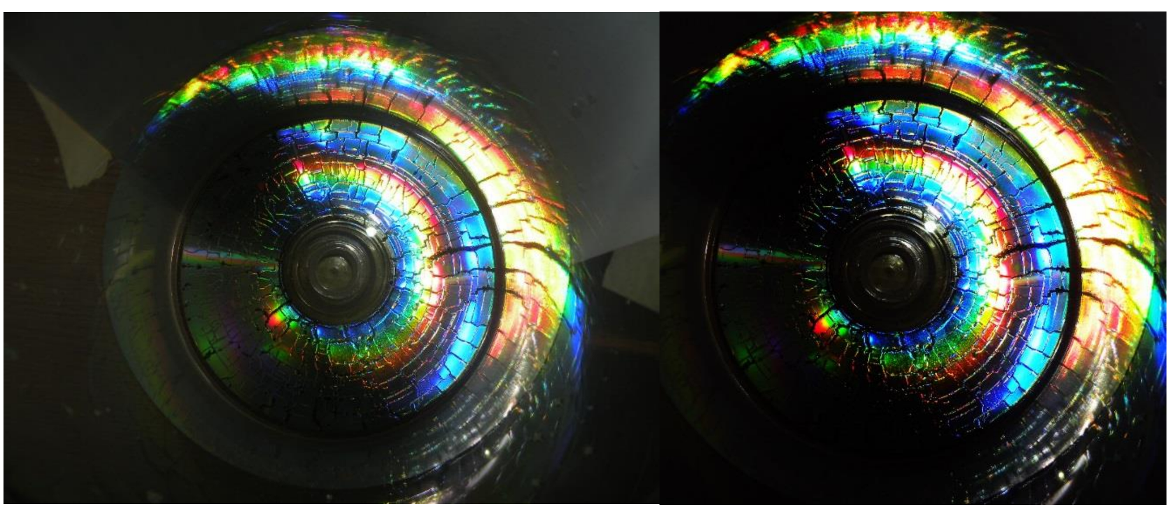
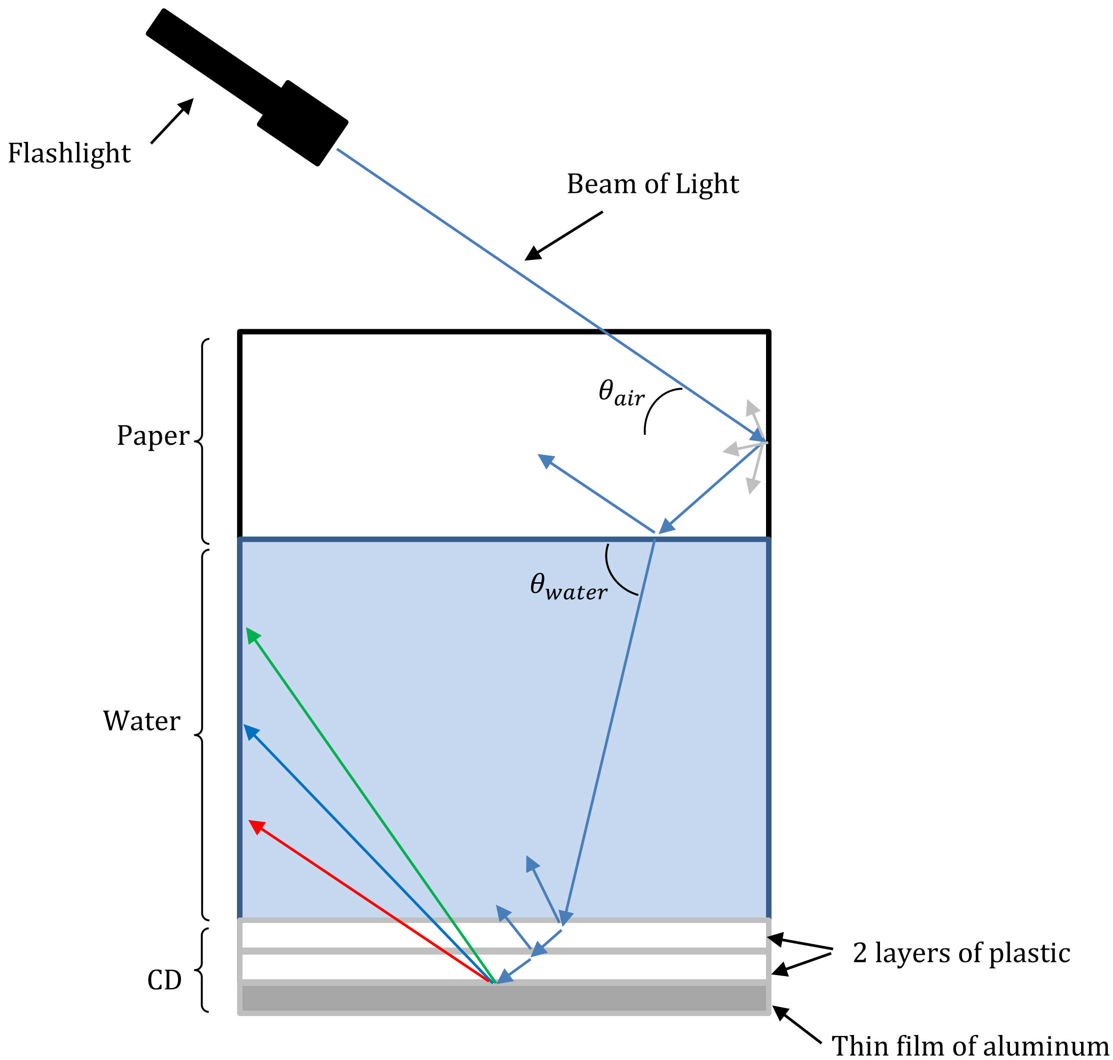


Figure 4: Left: Original image, Right: Final image

REFERENCES

1. Ansell, Dave. "The Naked Scientists." *Colours in CDs*. University of Cambridge, 7 Dec. 2008. Web. 10 Feb. 2014. http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/colours-in-cds/
2. Tanmay. "Rainbow Colors on My CD." *Wownder*. Blogger, 20 Sept. 2011. Web. 10 Feb. 2014. http://wownder.windforwings.com/2011/09/rainbow-colors-on-my-cd.html .
3. Pryor, Kimberley. "The Art in Science." *Microwaving CDs*. The Art in Science, 8 Nov. 2010. Web. 10 Feb. 2014. http://theartinscience.blogspot.com/2010/11/microwaving-cdsdont-try-this-at-home.html
4. "Why do CDs reflect rainbow colors?" 01 April 2000. HowStuffWorks.com. <http://electronics.howstuffworks.com/question52.htm> 10 February 2014.


Flashlight
Beam of Light
θ_{air}
Paper
θ_{water}
Water
CD
2 layers of plastic
Thin film of aluminum