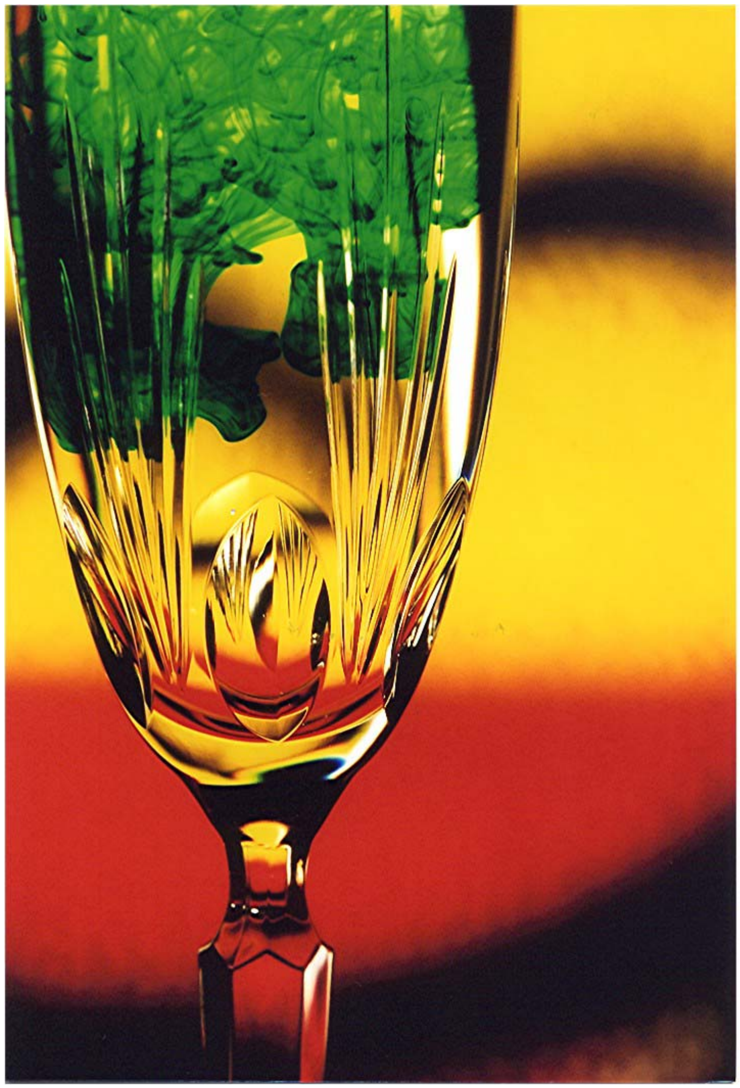
Mike B. Demmons
"Let It Flow"



Flow Visualization
MCEN 4228/5228
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“Let It Flow”

Elliott Erwitt once said, “photography is an art of observation. It's about finding something interesting in an ordinary place... I've found it has little to do with the things you see and everything to do with the way you see them.” [1] Most have drank from a wine glass. Most have used food coloring. And all have enjoyed a simple glass of tap water. None of these common day items are particularly interesting independently. However, by combing a wine glass, food coloring and tap water, with the addition of creative lighting, a photographer can create “something interesting in an ordinary place.” Upon closer inspection of the three item combination, a layman observer can enjoy the aesthetic appeal of fluid interaction. At the same time, an academic can appreciate the complexity of fluid interactions. This is the purpose of the “Get Wet” assignment. It is to bring the enjoyment and appreciation of fluid interaction and flow visualization to the layman and academic alike.

FIGURE 1:

Figure 1 illustrates the interaction between two fluids of different viscosity. The interaction may be described by the Rayleigh-Taylor instability phenomena. The phenomena occurs when a “light fluid is accelerated into a heavy fluid, and is a fundamental fluid-mixing mechanism. Any perturbation along the interface between the two fluids will grow. The width of the mixing layer at a given time is reduced by the development of turbulence. The growth rate of the instability and the rate of mixing between the two fluids depends on the effective viscosity of the two fluids.” [2] Additionally, the Rayleigh-Taylor instability phenomena occurs when a “heavy fluid (food coloring dye) is placed above

a light one (tap water) in a gravitational field. The interface becomes increasingly distorted and small wavelength disturbances degenerate finally into a turbulent mixing process.” [3]

Calculations were conducted using water as the main fluid medium. Values were obtained via online resources.[4] Relevant values for water are summarized in *Figure 2*.

FIGURE 2:

Input Values		
Fluid:	Water	
Temperature:	20	(degrees C)
Digits:	4	

Calculate

Results		
Density: ρ	9.978E+2	(kg/m^3)
Dynamic Viscosity: μ	9.772E-4	(kg/m.s)
Kinematic Viscosity: ν	9.794E-7	(m^2/s)
Specific Heat: c_p	4.076E+3	(J/kg.K)
Conductivity: k	0.6047	(W/m.K)
Prandtl number:	6.587	
Thermal Diffusivity: α	1.487E-7	(m^2/s)
Thermal Expansion Coefficient: β	3.411E-3	(1/K)

Using the values from *Figure 2*, the Reynolds Number was estimated using *Equation 1*:

$$Re = \frac{\rho v_s L}{\mu}$$ (*Equation 1*)

- v_s - mean fluid velocity = 0.1 m/s
- L - characteristic length (equal to diameter 2r if a cross-section is circular) = 10 cm
- μ - (absolute) dynamic fluid viscosity
- ρ - fluid density

The Reynolds Number estimated as **10,210**, which puts the interaction within the threshold of **turbulent flow**.

Finally, the Grashof Number was estimated using *Equation 2*:

$$Gr = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$$ (*Equation 2*)

- g - acceleration due to gravity
- β - volumetric thermal expansion coefficient
- T_s - source temperature = 20 deg C
- T_∞ - quiescent temperature = 25 deg C
- L - characteristic length = 10 cm
- ν - kinematic viscosity

The Grashof Number estimated as **14.5×10^9**. This value puts the flow in a **turbulent regime**. This estimated value further supports a turbulent Reynolds Number

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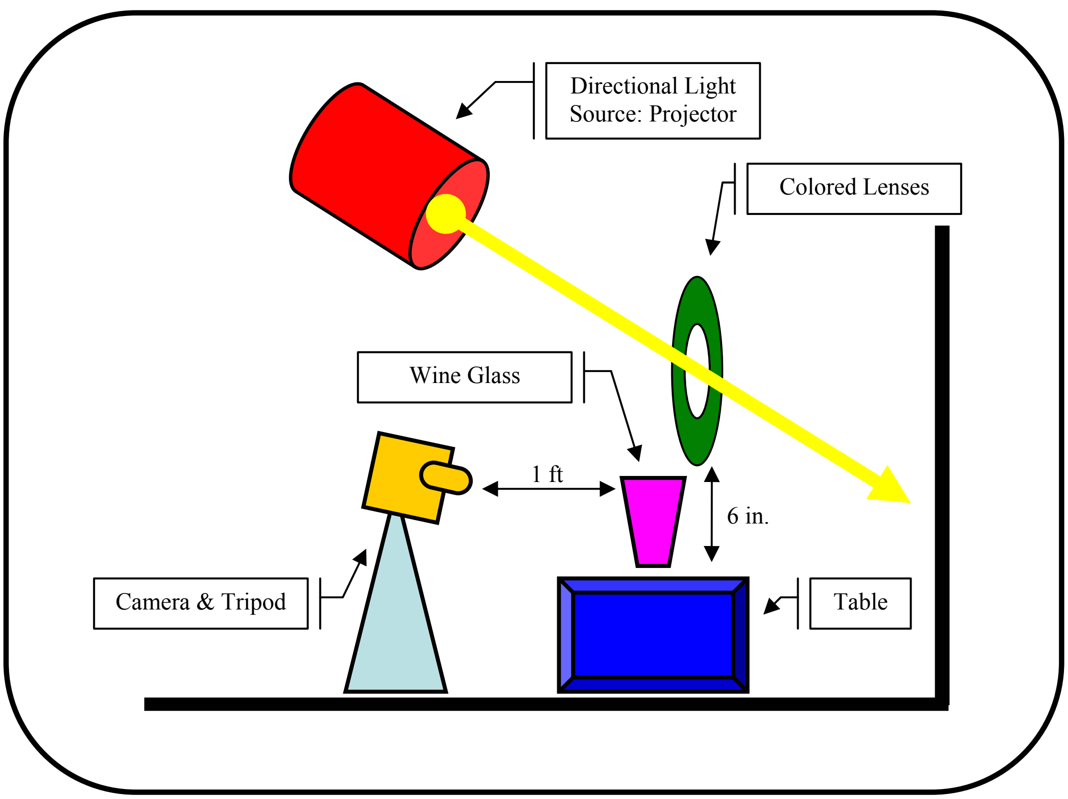
The photographic shoot was performed in a darkened room with no lighting other than what was provided by the directional light source of the slide projector. With limited lighting, long shutter speeds were required and the lens aperture needed to be large. A large lens aperture led to a shallow depth of field. A shallow depth of field was desirable in order to blur background context. A blurred background led to less visual distraction of intended subject. More importantly, in order to compensate for extended shutter speeds and reduce blurring of image, a tripod was used with a shutter release remote. The apparatus set-up may be noted by *Figure 3*.

FIGURE 3:



Once apparatus was set-up and lighting was at desired illumination, wine glass was placed on central table and filled with simple tap water. At this point, undiluted food coloring was placed into water one drop at a time. Time between pictures varied in 1-5 second intervals from onset of food coloring insertion. Multiple pictures were taken in order to capture the "perfect" image.

IMAGE SUMMARY:

- Field of View: ≈ 4 inches
- Distance from Object to Lens: ≈ 1 foot
- Lens Focal Length: 50 mm (macro setting)
- Type of Camera: Canon Elan 7E - 35 mm print film
- Exposure Specifications:
  - Shutter Speed: 1/40 second
  - Aperture (f-stop): 5.6
- Film Type & Speed: Kodak Gold – 200 Speed
- Digital Manipulation: None

The image (*Figure 1*) reveals intricate fluid dynamics present during the Rayleigh-Taylor instability phenomena. The phenomenon is presented in a manner that is visually appealing and, at the same time, scientifically compelling. The supple motion of a denser and more viscous fluid "falling" through a less dense and less viscous fluid is complex and beautiful, all at the same time. Adding to the phenomena is an artistic sense of bold lighting with saturated colors that draw the viewer into the physics of the Rayleigh-Taylor phenomena. In my opinion, in order for science to be interesting and appealing, it must be tempered with imaginative and artistic visuals. Hence, this photograph has accomplished the goal of appealing to the layman and academic alike. The photograph has created "something interesting in an ordinary place." It has taken the science outside of the laboratory and made it engaging for many.

REFERENCES:

[1] http://en.thinkexist.com/quotation/to_me-photography_is_an_art_of_observation-it-s/205742.html. Accessed: February 6, 2006.

[2] http://www.globalsecurity.org/wmd/intro/rayleigh-taylor-instability.htm. Accessed: February 6, 2006.

[3] Andrews, M.J., Spalding, D.B., 1990. *A simple experiment to investigate two-dimensional mixing by Rayleigh-Taylor instability*. Phys. Fluids A 2 (6), 922-927.

[4] http://www.mhtl.uwaterloo.ca/old/onlinetools/airprop/airprop.html. Accessed: February 7, 2006.