

Get Wet – Droplet Evolution

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9/18/2026

MCEN 5151: Flow Visualization



Abstract:

In this image, a drop of water is imaged in a single exposure using a repeating flash. This image was taken for the Get Wet assignment of the Flow Visualization course taught at CU Boulder. The image was intended to track the evolution of a single water droplet as it formed and fell, “freezing” moments in time as it fell using a repeating flash. To make the visualization, an eyedropper filled with water was used to create individual drops. The camera was set to a 1/6 second exposure, with a repeating flash set to fire 5 times at 50 Hz. When the drop was about to fall, the shutter release was triggered and the camera captured the image, with each flash illuminating a different moment in the drop’s evolution.

Flow Apparatus and Characteristics:

To create the drops in the flow, an eyedropper filled with water was used. The eyedropper had an outlet hole with a diameter of about 3mm and a body diameter of about 7.3mm. The body diameter tapered to the outlet hole diameter over about 13mm.



Figure 1: The dropper used for the experiment, with a ruler in cm scale below the dropper.

To capture the images, the setup shown below in Figure 2 was used.

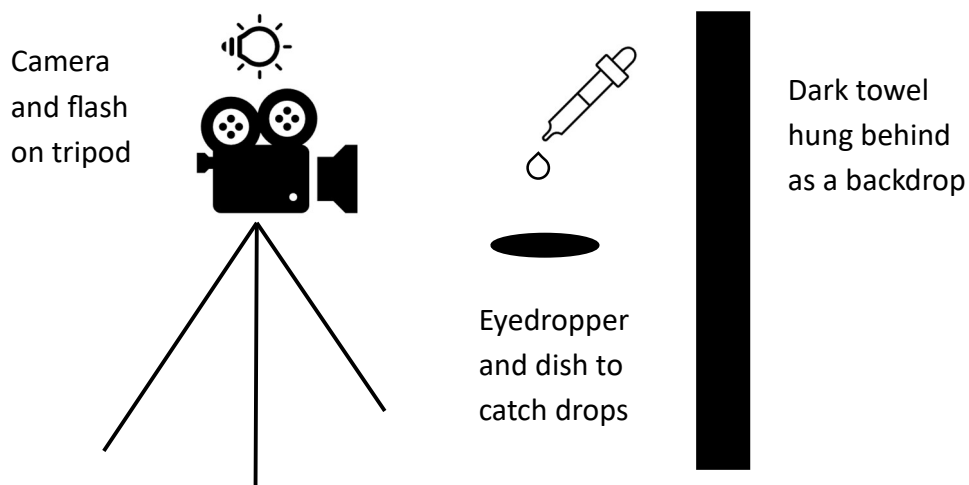


Figure 2: Schematic of the imaging setup. The dropper was held about 40 cm from the camera’s sensor plane.

When a drop was ready to be released, the bulb was slowly squeezed until the drop fell from the end. During this action, the drop slowly increased in size until it was heavy enough to counteract its adhesion to the glass of the eyedropper. At this point, it forms a small cylinder of water which quickly undergoes a “pinching off” process due to the Rayleigh-Plateau instability. As the drop falls, it is then accelerated by gravity and forms into a sphere. The spherical shape seen in the final drop is caused by a push for the droplet to reduce its surface free energy, as spheres have the lowest surface area-to-volume ratio. The gravitational acceleration can be seen in the increasing space between each image of the drop. Because the interval between the first and last flash was 1/10 of a second, and the acceleration of gravity is constant at 9.81 m/s^2 , the drop traveled a total of 4.9 cm over the duration of the image.

The Rayleigh-Plateau instability is the tendency for water jets or streams to break up into individual droplets. It is driven by the surface tension of the liquid making it unstable to perturbations from the fluid motion within the stream [1]. The most relevant dimensionless number for the Rayleigh-Plateau instability is the Ohnesorge number (Oh), which “compares viscous forces to inertial and surface tension forces,” [1]. It is defined by:

$$Oh = \frac{\eta}{\sqrt{\rho R_0 \gamma}} \quad (\text{Eqn. 1})$$

Where η is the dynamic viscosity, ρ is the density of the fluid, R_0 is the characteristic length, and γ is the fluid’s surface tension. In the high Oh regime, viscosity is more important to the flow, while in the low Oh regime surface tension forces dominate. The relevant values associated with the flow in this project are shown in Table 1 below.

Table 1: Ohnesorge number values for this experiment

Variable	Value
η	$0.0009737 \frac{\text{N} \cdot \text{s}}{\text{m}^2}$
ρ	$997.96 \frac{\text{kg}}{\text{m}^3}$
R_0	0.003 m
γ	$0.0644 \frac{\text{N}}{\text{m}}$

Values for η , ρ , and γ were assumed to be at 70°F and were found using [2][3][4], respectively. R_0 was assumed to be the dropper’s outlet diameter of 3mm. Plugging these values into Equation 1 gives:

$$Oh = \frac{\left(0.0009737 \frac{\text{N} \cdot \text{s}}{\text{m}^2}\right)}{\sqrt{\left(997.96 \frac{\text{kg}}{\text{m}^3}\right) (0.003 \text{ m}) \left(0.0644 \frac{\text{N}}{\text{m}}\right)}} = \frac{\left(0.0009739 \frac{\text{kg}}{\text{m} \cdot \text{s}}\right)}{\sqrt{0.1928 \frac{\text{kg}^2 \cdot \text{m}^2}{\text{m}^4 \cdot \text{s}^2}}} = 0.0022$$

This small value of 0.0022 for Oh means that this drop is in the regime where surface and inertial forces dominate. Because the flow is in the low Oh limit, the characteristic breakup time of the stream can be found by $t_{breakup} = 2.91 * \sqrt{\frac{\rho R_0^3}{\gamma}}$ [5]. This means if there was a continuous stream coming from the dropper, it would take ~ 0.06 seconds for the stream to break up into individual droplets. However, because the dropper was slowly actuated to only release drops one at a time, this effect was not observed in this experiment.

Visualization Technique:

This flow is visualized using a marked boundary technique. By keeping the drops in focus and the only thing that could reflect the flash in the frame, their shapes were highlighted as they fell. The room was kept fairly dark, only lit dimly by the light from a window, and the exposure was balanced such that anything not hit by flash wouldn't be exposed in the image. This also allowed the drop to travel between flashes without creating a streaking effect due to the long exposure time. The in-camera flash was used, as it was programmable enough to allow for the image to be realized. A dark grey towel was placed in the background to remove distractions and increase the uniformity of the image.

Imaging Technique:

The camera, lens, and exposure specifications are shown in the table below.

Table 1: Camera and image specifications

Camera model	Nikon D7500
Lens model	AF-S NIKKOR 24-70mm 1:2.8G ED
Focal length (as shot)	52 mm
Aperture	f5
Shutter speed	1/6
ISO	125
Image resolution (as shot)	5568 x 3712 pixels
Image resolution (final)	1249 x 3170 pixels
# of flashes	5
Flash repetition rate	50 Hz
Field of view	25.6° horizontal, 17.1° vertical

These settings allowed for the only exposure to occur when the flash was fired: any movement which occurred outside of the flash durations did not get imaged. This prevented

streaking and excess motion blur in the image. The shutter speed was set to allow for all five flashes to occur during the exposure.

The image was minimally edited to enhance the conveyance of the physics occurring. The image was cropped to draw attention to the water stream and eyedropper tip. The highlights and shadows were adjusted in Darktable using curves to try and minimize the appearance of the dark shadow behind the flow caused by the dropper. The unedited image is shown below in Figure 3, along with the final image for comparison.



Figure 3: The original, unedited image (left) and the final image (right).

Conclusion:

This image reveals a number of interesting physics phenomena, including the “pinching off” of a droplet caused by the Rayleigh-Plateau instability, acceleration due to gravity, and the behavior of droplets to form spheres to minimize their surface energy. The author’s favorite part of the image is the droplet just before leaving the dropper, which shows the pinching off and formation of the droplet extremely clearly. If the image were to be recreated, having a separate stand for the dropper would be very beneficial, instead of trying to hold it steady by hand. Using a buret would further improve the consistency of the drops, allowing the photographer to focus more on timing and adjusting exposure settings. Additionally, using fluids other than water could be very interesting, to try and compare the drops and determine the effects of surface tension, viscosity, and other forces on drop formation. Using external flashes and bouncing the light off of different surfaces could also give a more even lighting gradient, or one could try shooting into an empty space to give a black background, instead of the light gray captured here.

References:

- (1) Barker, B.; Bell, J. B.; Garcia, A. L. Fluctuating Hydrodynamics and the Rayleigh–Plateau Instability. *Proceedings of the National Academy of Sciences* **2023**, *120* (30). <https://doi.org/10.1073/pnas.2306088120>.
- (2) Engineering ToolBox. *Water - Dynamic and Kinematic Viscosity*. Engineeringtoolbox.com. https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html (accessed 2026-09-17).
- (3) The Engineering ToolBox. *Water - Density, Specific Weight and Thermal Expansion Coefficient*. The Engineering Toolbox. https://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html (accessed 2026-09-17).
- (4) The Engineering ToolBox. *Surface Tension*. www.engineeringtoolbox.com. https://www.engineeringtoolbox.com/surface-tension-d_962.html (accessed 2026-09-17).
- (5) Bush, J. W. M. *18.357 Interfacial Phenomena, Lecture 11*. MIT OpenCourseWare. https://ocw.mit.edu/courses/18-357-interfacial-phenomena-fall-2010/resources/mit18_357f10_lecture11/ (accessed 2026-09-17).