Surface Tension Determination through Capillary Rise and Laser Diffraction Patterns

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Various methods for determining surface tension have been described in this *Journal*, such as capillary rise, vibrating jet, and drop-weight methods (*1–3*). A consequence of the tendency of a liquid toward the smallest possible surface area is "capillary rise". Surface tension creates a meniscus whose concave side is at atmospheric pressure while the convex side is less. Therefore, during a capillary rise event, the liquid in the tube rises until a height is achieved where the pressure difference equals ρgh. This method produces eq 1

$$\rho g h = \frac{2\gamma}{r} \tag{1}$$

which relates the density of the solvent (ρ), the gravitational constant (g), the capillary rise height (h), the surface tension (γ), and the radius of the capillary tube (r). There are several straightforward methods to determine the radius of the capillary tubing. One method uses a solvent of known density and surface tension; another uses a microscope to determine the radius of the tubing.

Our experiment uses general-purpose capillary tubing whose diameter is not precisely known.[1] A laser beam is passed through the tubing to create a diffraction pattern, and measurements on the diffraction pattern are used to calculate the radius of the capillary tubing. Students have used this method to determine the surface tension of various solvents with a relative error that is typically less than 7%.

Synopsis of Experimental Procedure

In this experiment students first measure reproducible capillary rise heights for several solvents (using a length of the tubing) and then determine the radius of the capillary tubing. Figure 1 illustrates the experimental setup used to determine the radius of the capillary tubing. The purpose of the gimbaled mirror shown in Figure 1 is to control the position of the laser beam. A short piece of capillary tubing is placed on one arm of a clamp (Fig. 2) over which black electrical tape has been stretched to provide a surface to support the capillary and hold it in place. The clamp is then placed in the laser beam path between the gimbaled mirror and the screen. By adjusting the screw clamp for the two-pronged arm (Fig. 2), one can finely adjust the height of the capillary opening to match the height of the laser beam. To create the required circular diffraction pattern, the laser must be aligned through the capillary tubing with a minimum of internal reflection. The capillary position is adjusted until a circular diffraction pattern similar to that shown in Figure 3 is observed. The diffraction pattern consists of a central bright circular region surrounded by a series of alternating dark and bright fringes.

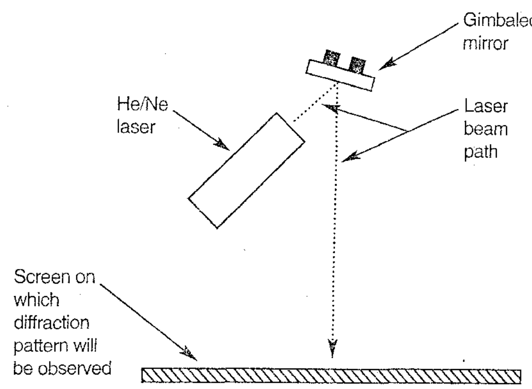

Figure 1. The gimbaled mirror is rotated until the laser beam strikes a screen that is approximately 100 cm away.

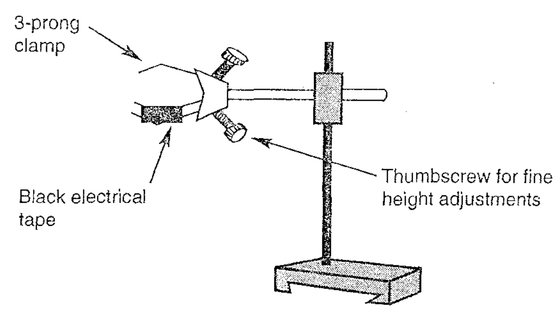

Figure 2. A piece of black electrical tape is stretched across the two-prong arm of a 3-prong clamp. The capillary tube is not shown on the electrical tape.

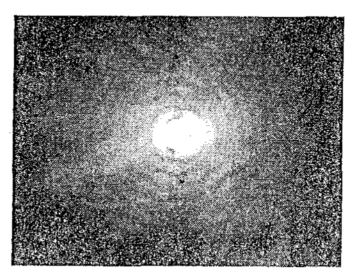

Figure 3. The laser diffraction pattern created by passing a He/Ne laser through a short capillary consists of central bright region surrounded by alternating dark and bright fringes.

After the circular diffraction pattern is obtained on the screen, distances X and Y shown in Figure 4 are measured. The angle θ described in Figure 4 is determined using eq 2.

$$\theta = \tan^{-1}\frac{Y}{X} \qquad (2)$$

The first minimum for the diffraction pattern (θ) is related to the diameter D of the capillary tubing through eq 3, where λ is the wavelength of the laser (*4*).

$$\sin\theta = 1.22\frac{\lambda}{D} \qquad (3)$$

A discussion of diffraction patterns may be found in any college physics text (*5*). Typical results are shown in Table 1.

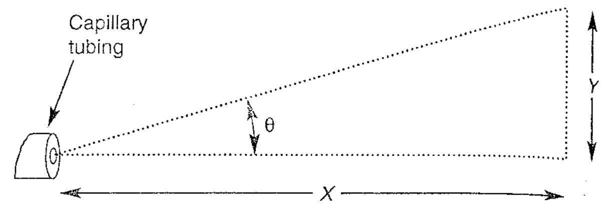

Figure 4. The angle θ must be found by measuring the distances X and Y. X is the distance between the aperture and the interference pattern and Y is the distance from the center of the interference pattern to the center of the first dark fringe.

Table 1. Typical Student Results

Solvent	Experimental Surface Tension/(g s^{-2})	Relative Error from Lit Values (%) (*6, 7*)
Water	73.3	1
p-Xylene	27.9	2
Ethanol	21.4	6
Isopropanol	20.2	7

Summary

This experiment reinforces concepts such as surface tension and capillary rise. It has students apply an equation that describes a circular diffraction pattern to obtain the radius of capillary tubing. The tubing is inexpensive and its radius is not well characterized, which makes it ideal for this experiment. The experiment is well suited for the undergraduate physical chemistry laboratory. Student results typically have a relative error that is less than 7%.

WSupplemental Material

The theoretical background related to this experiment and detailed instructions for students are available in this issue of *JCE Online*.

Note

1. CENCO: 1-800-262-3626; catalog number 14106-01.

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