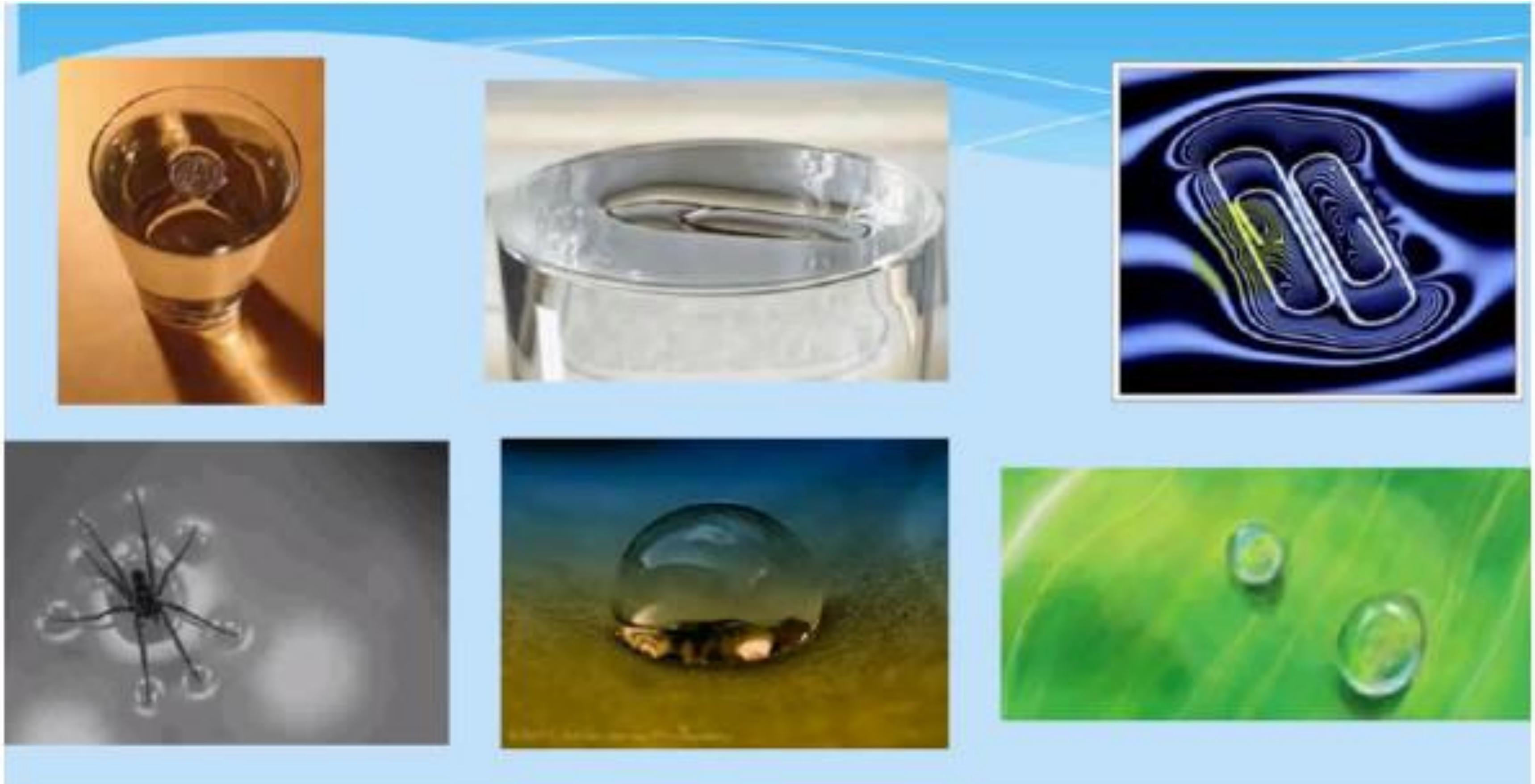
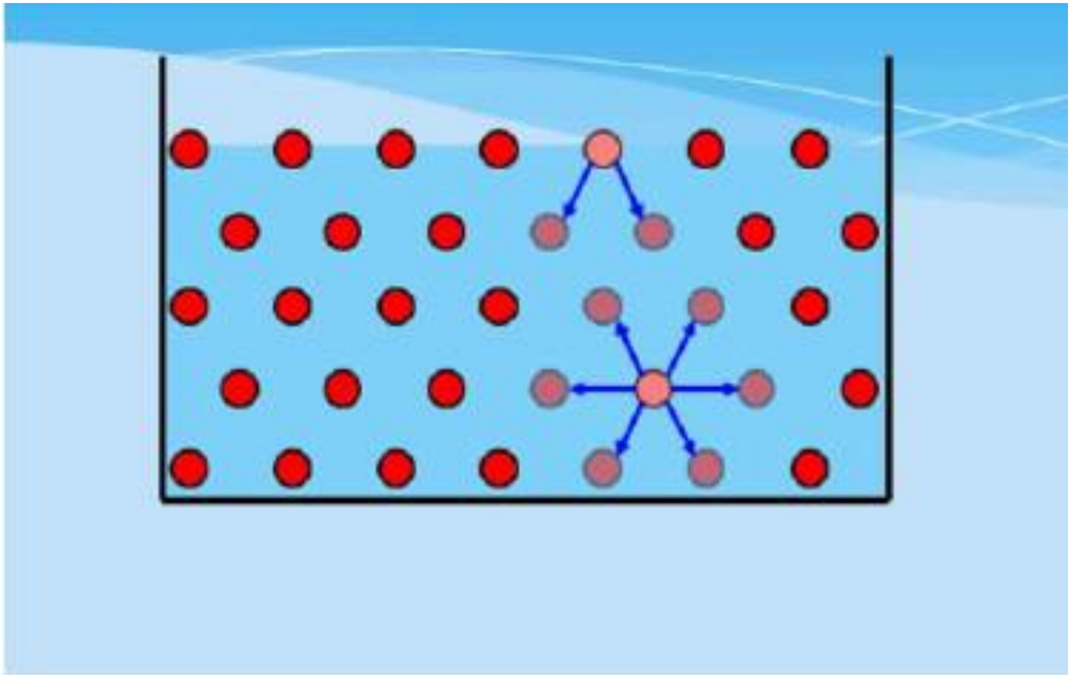
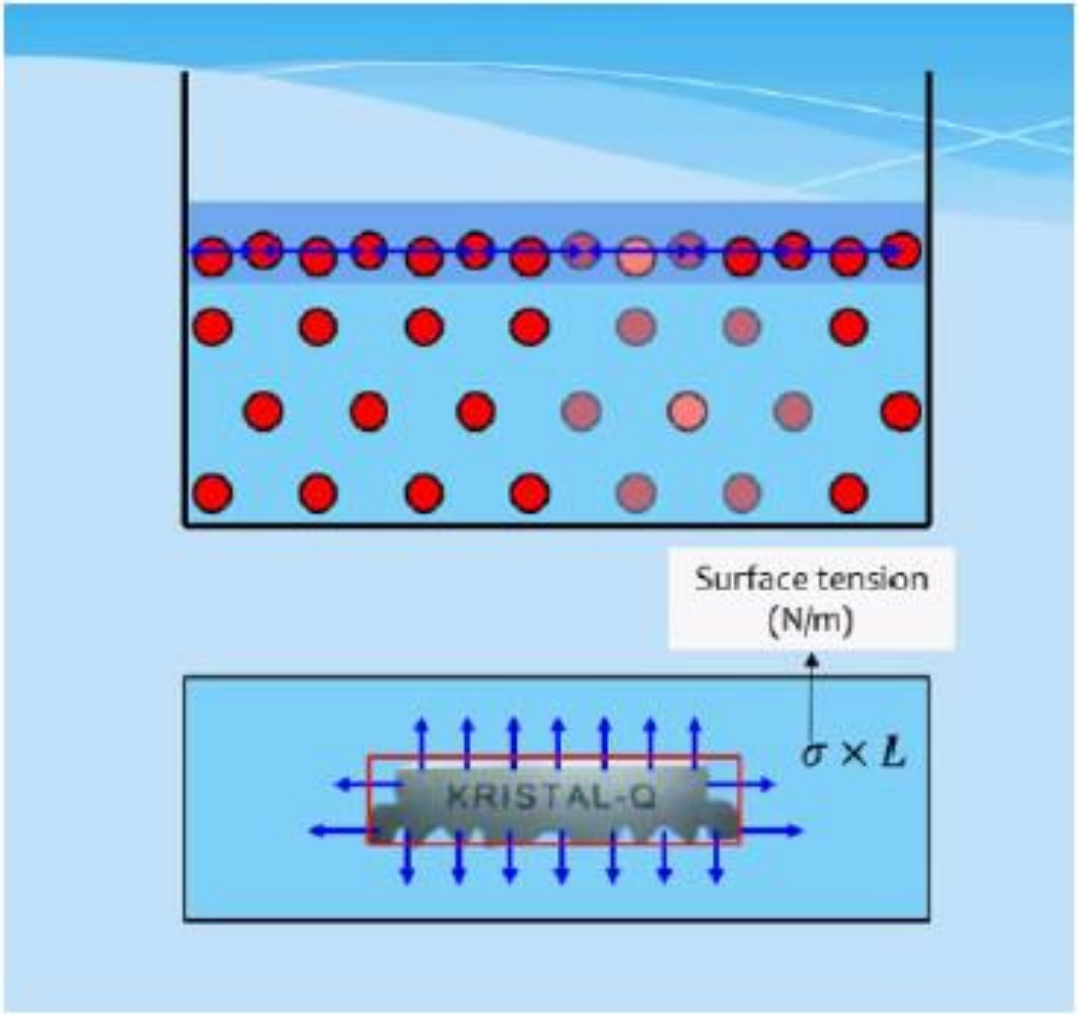
Surface Tension

Surface Tension






Surface tension
(N/m)
σ × L
KRISTAL-Q

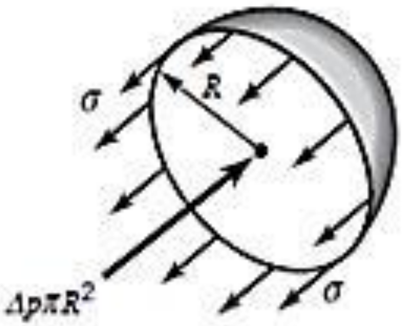


FIGURE 1.9 Forces acting on one-half of a liquid drop.

The pressure inside a drop of fluid can be calculated using the free-body diagram in Fig. 1.9. If the spherical drop is cut in half (as shown), the force developed around the edge due to surface tension is $2\pi R\sigma$. This force must be balanced by the pressure difference, Δp, between the internal pressure, p_i, and the external pressure, p_e, acting over the circular area, πR^2. Thus,

$$2\pi R\sigma = \Delta p \, \pi R^2$$

or

$$\Delta p = p_i - p_e = \frac{2\sigma}{R} \qquad (1.21)$$

1.95 Small droplets of carbon tetrachloride at 68 °F are formed with a spray nozzle. If the average diameter of the droplets is 200 μm what is the difference in pressure between the inside and outside of the droplets?

$$p = \frac{2\sigma}{R}$$ (Eq.

Since $\sigma = 2.69 \times 10^{-2} \frac{N}{m}$ at $68°F (=20°C)$,

$$p = \frac{2\left(2.69 \times 10^{-2} \frac{N}{m}\right)}{100 \times 10^{-6}\, m} = \underline{\underline{538\ Pa}}$$

1.96 A 12-mm diameter jet of water discharges vertically into the atmosphere. Due to surface tension the pressure inside the jet will be slightly higher than the surrounding atmospheric pressure. Determine this difference in pressure.

For equilibrium (see figure),

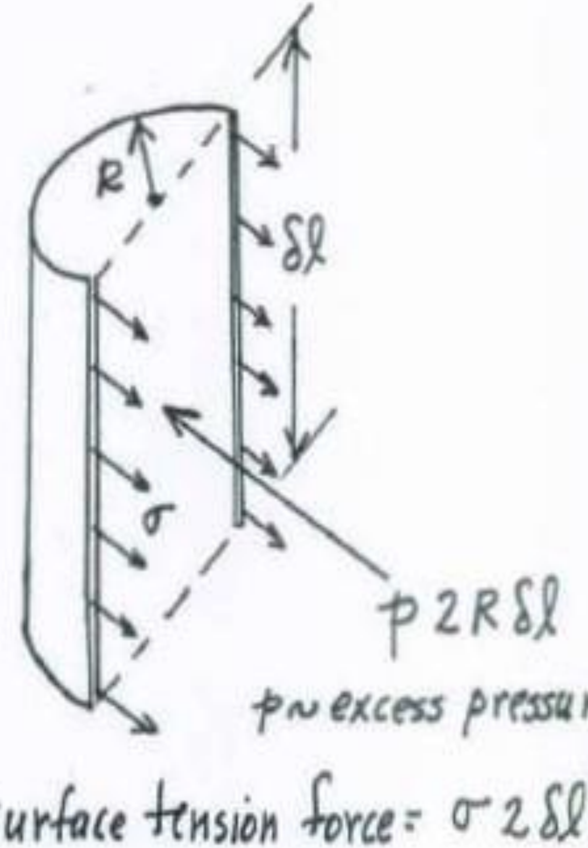
$$p(2R\delta\ell) = \sigma(2\delta\ell)$$

so that

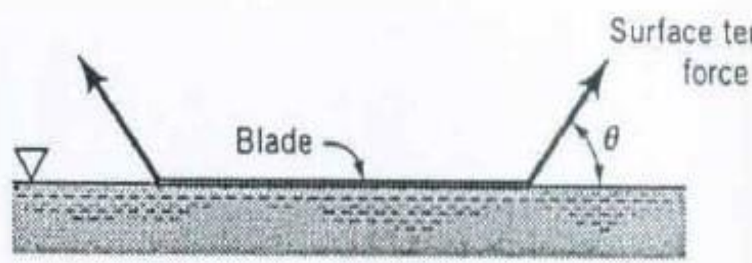
$$p = \frac{\sigma}{R}$$

$$= \frac{7.34 \times 10^{-2}\ \frac{N}{m}}{\frac{12}{2} \times 10^{-3}\ m}$$

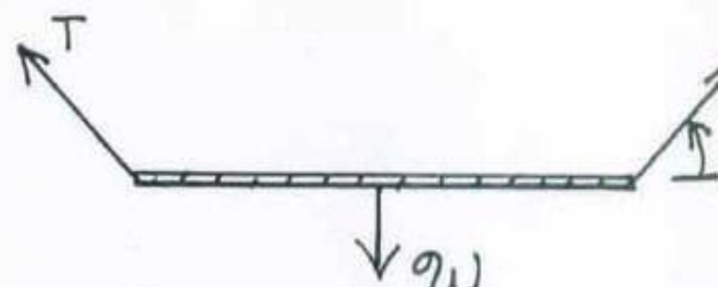
$$= \underline{\underline{12.2\ Pa}}$$



1.97 As shown in **Video V1.9**, surface tension forces can be strong enough to allow a double-edge steel razor blade to "float" on water, but a single-edge blade will sink. Assume that the surface tension forces act at an angle θ relative to the water surface as shown in Fig. P1.97. (a) The mass of the double-edge blade is 0.64×10^{-3} kg, and the total length of its sides is 206 mm. Determine the value of θ required to maintain equilibrium between the blade weight and the resultant surface tension force. (b) The mass of the single-edge blade is 2.61×10^{-3} kg, and the total length of its sides is 154 mm. Explain why this blade sinks. Support your answer with the necessary calculations.



■ FIGURE P1.97



(a) $\sum F_{vertical} = 0$

$$w = T \sin\theta$$

(a) $\Sigma F_{vertical} = 0$

$$\mathcal{W} = T \sin\theta$$

where $\mathcal{W} = m_{blade} \times g$ and $T = \sigma \times$ length of sides.

$$\therefore \left(0.64 \times 10^{-3}\,kg\right)\left(9.81\,m/s^2\right) = \left(7.34 \times 10^{-2}\,\frac{N}{m}\right)\left(0.206\,m\right)\sin\theta$$

$$\sin\theta = 0.415$$

$$\underline{\underline{\theta = 24.5^\circ}}$$

(b) For single-edge blade

$$\mathcal{W} = m_{blade} \times g = \left(2.61 \times 10^{-3}\,kg\right)\left(9.81\,m/s^2\right)$$
$$= 0.0256\,N$$

and $T \sin\theta = \left(\sigma \times \text{length of blade}\right)\sin\theta$

$$= \left(7.34 \times 10^{-2}\,N/m\right)\left(0.154\,m\right)\sin\theta$$
$$= 0.0113\,\sin\theta$$

In order for blade to "float" $\mathcal{W} < T\sin\theta$.
Since maximum value for $\sin\theta$ is 1, it follows that $\mathcal{W} > T\sin\theta$ and single-edge blade will sink.

1.103 (See Fluids in the News article titled "Walking on water," Section 1.9.) (a) The water strider bug shown in Fig. P1.103 is supported on the surface of a pond by surface tension acting along the interface between the water and the bug's legs. Determine the minimum length of this interface needed to support the bug. Assume the bug weighs 10^{-4} N and the surface tension force acts vertically upwards. (b) Repeat part (a) if surface tension were to support a person weighing 750 N.

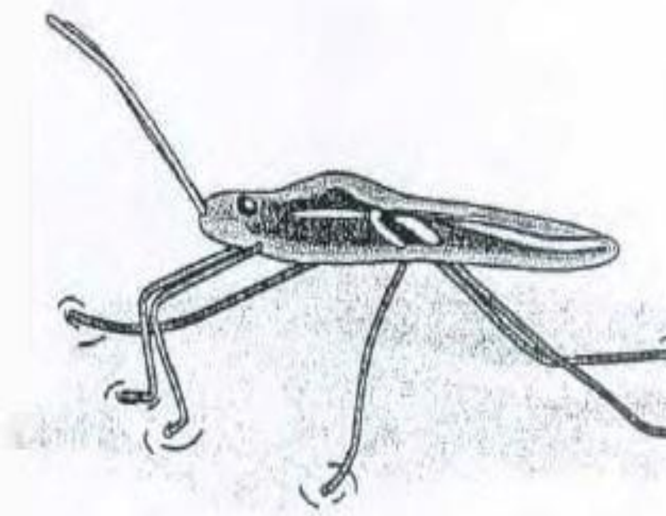
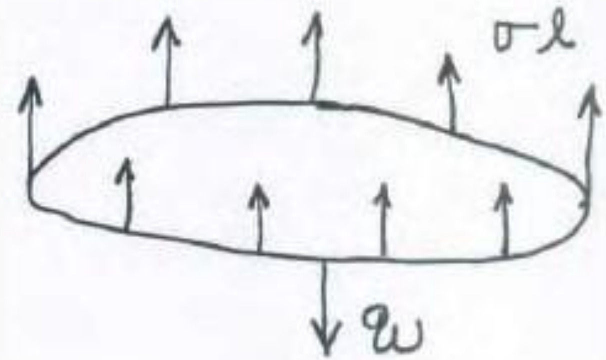


FIGURE P1.103

For equilibrium,

$$\mathcal{W} = \sigma \ell$$



$\mathcal{W} \sim$ weight
$\sigma \sim$ surface tension
$\ell \sim$ length of interface

(a) $$\ell = \frac{\mathcal{W}}{\sigma} = \frac{10^{-4}\ N}{7.34 \times 10^{-2}\ \frac{N}{m}}$$

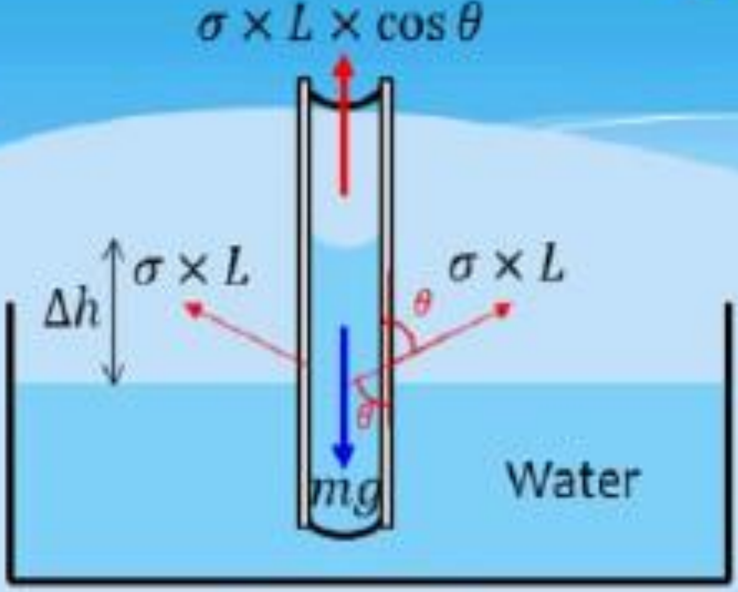
$$= 1.36 \times 10^{-3}\ m$$

$$= (1.36 \times 10^{-3}\ m)\left(10^{3}\ \frac{mm}{m}\right) = \underline{\underline{1.36\ mm}}$$

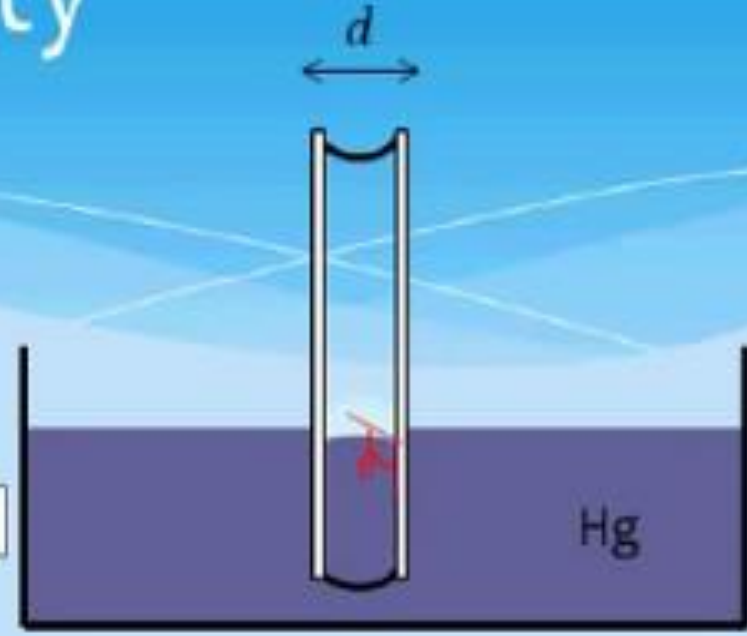
(b) $$\ell = \frac{750\ N}{7.34 \times 10^{-2}\ \frac{N}{m}} = \underline{\underline{1.02 \times 10^{4}\ m}} \ (6.34\ mi\ !!)$$

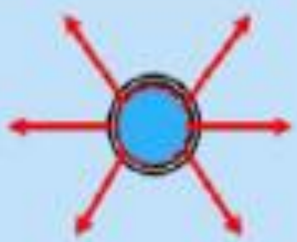
Capillary tube

Capillarity



θ = contact angle





$$\sigma \times \pi d \times \cos\theta = \sigma L \cos\theta = mg = \rho V g = \rho\left(\frac{\pi}{4} d^2 \Delta h\right) g$$

$$\Delta h = \frac{4\sigma \cos\theta}{\rho g d}$$

1.101 An open, clean glass tube ($\theta = 0°$) is inserted vertically into a pan of water. What tube diameter is needed if the water level in the tube is to rise one tube diameter (due to surface tension)?

$$h = \frac{2\sigma \cos\theta}{\gamma R}$$

For $h = 2R$ and $\theta = 0°$

$$2R = \frac{2\sigma(1)}{\gamma R}$$

and

$$R^2 = \frac{\sigma}{\gamma} = \frac{5.03 \times 10^{-3} \ \frac{lb}{ft}}{62.4 \ \frac{lb}{ft^3}}$$

$$R = 8.98 \times 10^{-3} \ ft$$

$$\text{diameter} = 2R = \underline{1.80 \times 10^{-2} \ ft}$$

1.100 An open, clean glass tube, having a diameter of 3 mm, is inserted vertically into a dish of mercury at 20 °C. How far will the column of mercury in the tube be depressed?

$$h = \frac{2\sigma \cos\theta}{\gamma R} \qquad \text{(Eq. 1.22)}$$

For $\theta = 130°$,

$$h = \frac{2\left(4.66 \times 10^{-1}\ \frac{N}{m}\right)\cos 130°}{\left(133 \times 10^{3}\ \frac{N}{m^3}\right)(0.0015\ m)} = -3.00 \times 10^{-3}\ m$$

Thus, column will be depressed 3.00 mm

1.94 When a 2-mm-diameter tube is inserted into a liquid in an open tank, the liquid is observed to rise 10 mm above the free surface of the liquid. the contact angle between the liquid and the tube is zero, and the specific weight of the liquid is $1.2 \times 10^4 \text{ N/m}^3$. Determine the value of the surface tension for this liquid.

$$h = \frac{2\sigma \cos\theta}{\gamma R}, \quad \text{where } \theta = 0$$

Thus,

$$\sigma = \frac{\gamma h R}{2 \cos\theta} = \frac{\left(1.2 \times 10^4 \frac{N}{m^3}\right)(10 \times 10^{-3} m)(2 \times 10^{-3} m/2)}{2 \cos 0}$$

$$= \underline{\underline{0.060 \frac{N}{m}}}$$