CHAPTER 1

1.1 An object has a mass of 46 kg and weighs 450 N on a spring scale. Determine the acceleration due to gravity at this location.

$$m = 46 \text{ kg, } W = 450 \text{ N, } g = \frac{W}{m} = \frac{450}{46} = \boxed{9.78 \text{ m/s}^2}$$

1.2 Use the Appendix tables to find the conversion factor between gallons per minute (gpm) to cubic feet per second (cfs or ft^3/s).

$$\frac{\text{gallons}}{\text{minute}} \bullet \frac{3.785411784 \times 10^{-3}}{2.8316846592 \times 10^{-2}} \bullet \frac{1 \text{ minute}}{60 \text{ s}}$$

$$\boxed{\text{gpm} \bullet 2.228 \times 10^{-3} = \text{ft}^3/\text{s}}$$

1.3 What is the weight in N of 1 ft^3 of kerosene?

$\cancel{V} = 1$ ft^3; kerosene Appendix Table A-5, $\rho = 0.823(1.94)$ slug/ft^3;
$W = mg = \rho \cancel{V} g = 0.823(1.94)(1)(32.2) = 5.14$ lbf; $W = 5.14(4.448)$ or
$\boxed{W = 22.9 \text{ N}}$

1.4 What is the conversion factor between BTU/hr and horsepower? Use the conversion factors from Appendix Table A.2 to determine the answer.

$$\frac{\text{BTU}}{\text{hr}} \cdot \frac{1 \text{ hr}}{3600 \text{ s}} \cdot \frac{1054}{745.7} = \boxed{3.926 \times 10^{-4} \frac{\text{HP}}{(\text{BTU/hr})}}$$

1.5 Water has a density of 1 000 kg/m^3. What is its density in lbm/ft^3, slug/ft^3, and g/cm^3?

$\rho = 1\,000$ kg/m^3 (SI); $\rho = \dfrac{1\,000}{16.01} = \boxed{62.5 \text{ lbm/ft}^3}$

$\rho = \dfrac{1\,000}{16.01(32.2)} = \boxed{1.94 \text{ slug/ft}^3}$ $\rho = \dfrac{1\,000}{1\,000} = \boxed{1 \text{ g/cm}^3}$

1.6 The density of Ocean Breeze Shampoo was determined by weighing an object of known volume in air, and again by weighing it while submerged in the liquid. If the object was a 4 cm diameter sphere made of aluminum (specific gravity = 2.7), what is the expected weight of the object while submerged in the shampoo?

$D = 4$ cm $\cancel{V} = \dfrac{\pi D^3}{6} = \dfrac{\pi(0.04)^3}{6} = 3.35 \times 10^{-5}$ m^3

$s = 2.7$ for the al $\rho_{liq} = 1\,121$ kg/m^3 from the example

$(s\rho_w)_{object} = 2.7(1\,000) = 2\,700$ kg/m^3

$$\rho_{Liq} = (s\rho_w)_{object} - \frac{W_2}{\forall g}$$

Rearranging, $\frac{W_2}{\forall g} = (s\rho_w)_{object} - \rho_{Liq}$

and $W_2 = \forall g\,[(s\rho_w)_{object} - \rho_{Liq}]$

Substituting,

$$W_2 = 3.35 \times 10^{-5}(9.81)(2\,700 - 1\,121)$$

$$\boxed{W_2 = 0.519 \text{ N}}$$

1.7 The density of Golden Apple Shampoo is to be determined by weighing an object of known volume in air, and again by weighing it while submerged in the liquid. A stainless steel cylinder of diameter 1 inch and length 2 inches is submerged in the shampoo. The measured weight while submerged is 0.39 lbf. What is the density of the shampoo?

$\forall_{cul} = \pi R^2 L = \pi(0.0417)^2(0.1667) = 9.09 \times 10^{-4}$ ft^3
By definition, the specific gravity of the cylinder is

$$s = \frac{\rho}{\rho_w}$$

With the density of water as 1.94 slug/ft^3, the density of the steel is

$$\rho_{cyl} = s\,\rho_w = 8(1.94) = 15.52 \text{ slug/ft}^3$$

The weight of the cylinder in air is calculated to be

$$W_1 = (\rho\forall)_{cyl}g = (15.52)(9.09 \times 10^{-4})(32.2)$$

$$W_1 = 0.45 \text{ lbf}$$

The weight of the cylinder while submerged was measured as $W_2 = 0.39$ lbf. The buoyant force is the difference between these two weights:

$$B = W_1 - W_2 = 0.45 - 0.39 = 0.06 \text{ lbf}$$

The specific weight of the liquid is:

$$SW = \rho g = \frac{B}{\forall} = \frac{0.06}{9.09 \times 10^{-4}} = 71 \text{ lbf/ft}^3$$

The density is finally determined as:

$$\rho = \frac{71}{32.2}$$

$$\underline{\rho_{liq} = 2.20 \text{ slug/ft}^3}$$

1.8 The density of Strawberry Breeze Shampoo is to be determined by weighing an object of known volume in air, and again by weighing it while submerged in the liquid. The object is a 4 cm diameter sphere made of brass (density = 8.4 g/cm^3), and the weight while submerged is 2.36 N. What is the density of the shampoo?

$\forall_{cul} = \pi D/6 = \pi(0.04)^3/6 = 3.351 \times 10^{-5}$ m^3
By definition, the specific gravity of the cylinder is

$$s = \frac{\rho}{\rho_w}$$

With the density of water as 1 000 kg/m^3, the density of the steel is

$$\rho_{cyl} = s\,\rho_w = 8.4(1\,000 \text{ kg/m}^3) = 8\,400 \text{ kg/m}^3$$

The weight of the cylinder in air is calculated to be

$$W_1 = (\rho\forall)_{cyl}g = (8\,400 \text{ kg/m}^3)(3.351 \times 10^{-5} \text{ m}^3)(9.81 \text{ m/s}^2)$$

$$W_1 = 2.76 \text{ N}$$

The weight of the cylinder while submerged was measured as $W_2 = 2.36$ N. The buoyant force is the difference between these two weights:

$$B = W_1 - W_2 = 2.76 \text{ N} - 2.36 \text{ N} = 0.4 \text{ N}$$

The specific weight of the liquid is:

$$SW = \rho g = \frac{B}{\forall} = \frac{0.4 \text{ N}}{3.351 \times 10^{-5} \text{ m}^3} = 12\,968 \text{ N/m}^3$$

The density is finally determined as:

$$\rho = \frac{12\,968 \text{ N/m}^3}{9.81 \text{ m/s}^2}$$

$$\underline{\rho_{liq} = 1\,220 \text{ kg/m}^3}$$

1.9 It is commonly known that there are 16 ounces in one pound. However, Appendix Table A.2 lists the ounce as a unit of volume for liquids. A 1/2 lbf glass weighs 1 lbf when filled with 8 ounces of liquid. Determine the liquid density and the specific weight in SI units.

Liquid weighs 1 - 1/2 = 1/2 lbf; $\rho g = \dfrac{0.5 \text{ lbf}}{8 \text{ ounces}}$; using conversions,

$$\rho g = \frac{0.5 \text{ lbf}}{8 \text{ oz}} \cdot \frac{4.448}{2.957 \times 10^{-5}} = \boxed{9.4 \times 10^3 \text{ N/m}^3 = SW}$$

$$\rho = \frac{9\,400}{9.81} = \boxed{958 \text{ kg/m}^3 = \rho} \qquad \rho = \frac{958}{515.379} = \boxed{1.86 \text{ slug/ft}^3 = \rho}$$

$$\rho g = 1.86(32.2) = \boxed{59.9 \text{ lbf/ft}^3 = SW}$$

1.10 What is the mass in kg of 5 ft^3 of acetone?
$\forall = 5$ ft^3, acetone Appendix Table A-5, $\rho = 0.787(1.94 \text{ slug/ft}^3)$;
$m = \rho\forall = 0.787(1.94)(5) = 7.63$ slug; $m = 7.63(14.59)$ or
$\boxed{m = 111 \text{ kg}}$

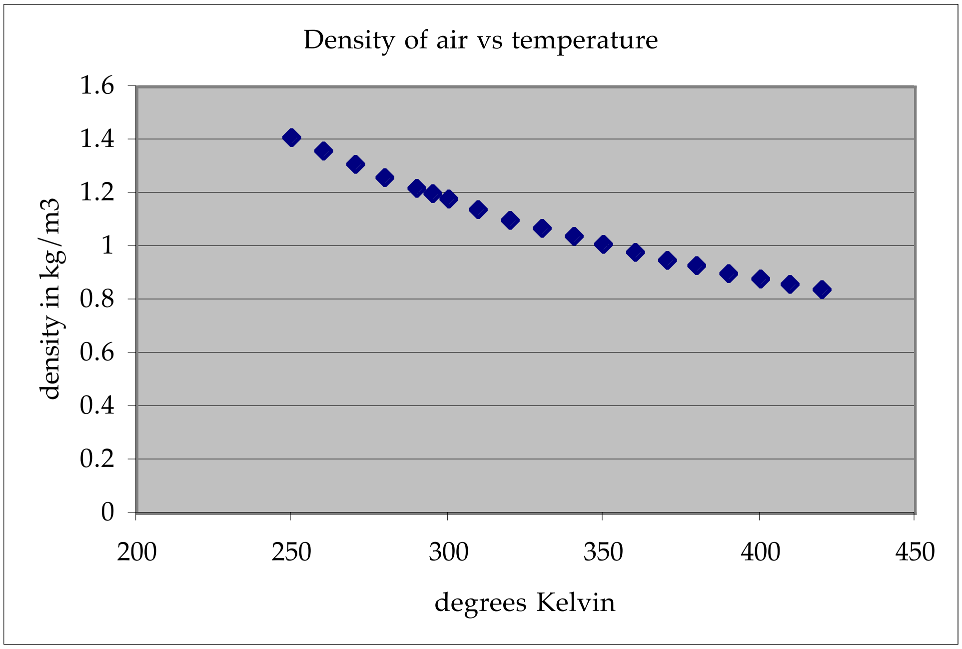
1.11 What is the density of ethylene glycol lbm/ft^3? What is the mass of 1 ft^3 of ethylene glycol in slugs?

$\boxed{\rho = 1.1(62.4) = 68.64 \text{ lbm/ft}^3}$ $\qquad \cancel{V} = 1 \text{ ft}^3; \qquad W = 68.6 \text{ lbf}$

$$W = mg; \qquad m = \frac{W}{g} = \frac{68.6}{32.2}$$

$\boxed{m = 1.94 \text{ slug}}$

1.12 Graph the density of air as a function of temperature.

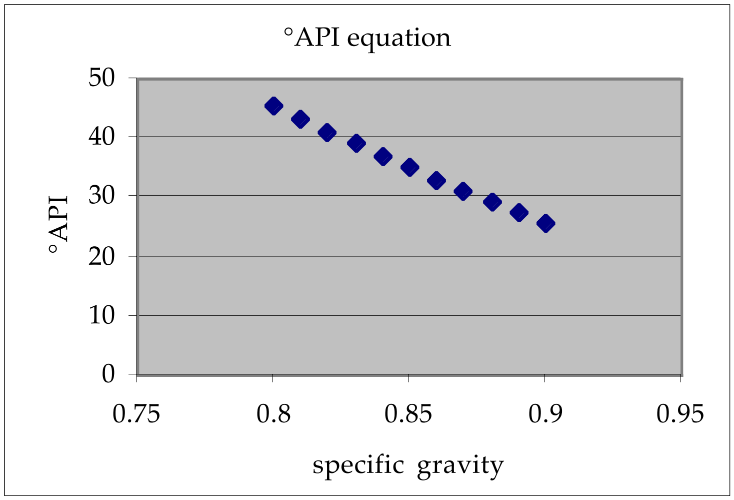


1.13 In the petroleum industry, the specific gravity of a substance (usually an oil) is expressed in terms of degrees API; or °API (American Petroleum Institute). The specific gravity and the °API are related by

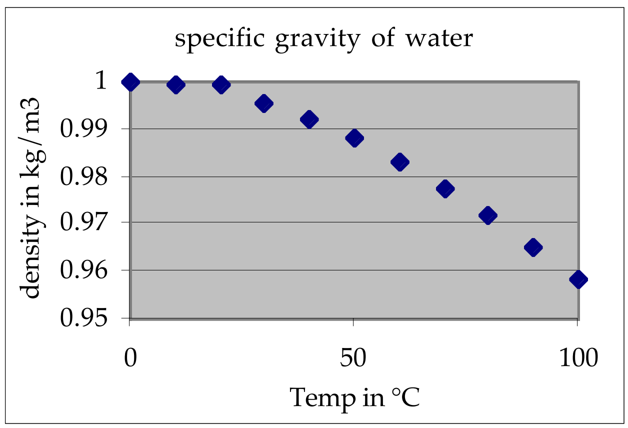
$$°\text{API} = \frac{141.5}{\text{specific gravity}} - 131.5$$

Graph °API (vertical axis) versus specific gravity ranging from 0.8 to 0.9 (typical for many oils).

$$°\text{API} = \frac{141.5}{\text{specific gravity}} - 131.5$$



1.14 Prepare a plot of specific gravity of water as a function of temperature. Let temperature vary in 10° increments.



1.15 In Example 1.4b, what is the minimum mass required to move the upper plate if the fluid has an initial yield stress of 4 N/m^2?

minimum shear required is τ_o; movement impending when $\tau = \tau_o$

$$\tau_o = 4 \text{ N/m}^2 = \frac{\text{force}}{\text{area}} = \frac{mg}{A};$$

$$\text{so } m = \frac{A\tau_o}{g} = \frac{0.5 \text{ m}^2 \, (4 \text{ N/m}^2)}{9.81 \text{ m/s}^2} = 0.204 \text{ N·s}^2\text{/m} = 0.204 \text{ kg}$$

$\boxed{\text{so for movement to begin } m > 0.204 \text{ kg}}$

1.16 If the mass in example 1.4b is 0.045 kg, and the fluid is castor oil, determine the plate velocity.

$$\frac{F}{A} = \mu \frac{\Delta V}{\Delta y}; \; F = 0.045 \text{ kg}(9.81 \text{ m/s}^2) = 0.441 \text{ N}$$

$\Delta y = 0.01$ m; castor oil, $\mu = 650 \times 10^{-3}$ N·s/m^2; $A = 0.75$ m^2

$$\Delta V = \frac{0.441(0.01)}{0.75(650 \times 10^{-3})} = 0.0091 \times 10^{-3} \text{ m/s}$$

so $\boxed{V = 9.1 \text{ mm/s}}$

1.17 Referring to Figure 1.7, assume that the fluid in the space is castor oil. What weight is required to move the plate at 5 cm/s?

$$\tau = \mu \frac{\Delta V}{\Delta y}; \tau = \frac{W}{A} = \frac{W}{0.5 \text{ m}^2}$$

Table A-5 for castor oil, $\mu = 650 \times 10^{-3}$ N·s/m²

$\Delta V = 0.05$ m/s; By substitution, $\frac{W}{0.5} = 650 \times 10^{-3} \frac{0.05}{0.005}$

$\boxed{W = 3.25 \text{ N}}$

1.18 A weightless plate is moving upward in a space as shown in Figure P1.20. The plate has a constant velocity of 2.5 mm/s, and kerosene is placed on both sides. The contact area for either side is 2.5 m². The plate is equidistant from the outer boundaries with Δy = 1.2 cm. Find the force F.

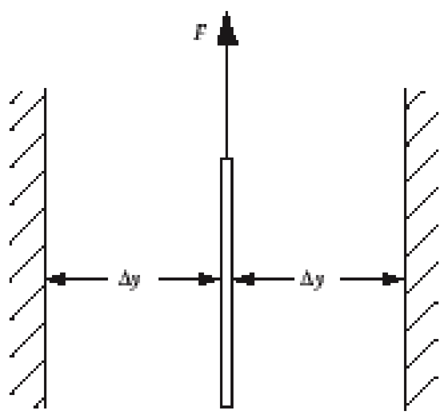


FIGURE P1.18

$$\frac{F}{A} = \mu \frac{\Delta V}{\Delta y}; A = 2 \text{ sides} \cdot \frac{2.5 \text{ m}^2}{\text{side}} = 5 \text{ m}^2; \Delta V = 0.002\,5 \text{ m/s}; \Delta y = 0.012 \text{ m}$$

Table A-5 $\mu = 1.64 \times 10^{-3}$ N·s/m²

so $F = \frac{5(1.64 \times 10^{-3})(0.002\,5)}{0.012}$ or

$\boxed{F = 1.708 \times 10^{-3} \text{ N}}$

1.19 What is the kinematic viscosity of the Ocean Breeze Shampoo in Example 1.6? Express the results in m²/s and in centistokes (cs).

$$\nu = \frac{\mu}{\rho} = \frac{9.11}{1\,121} = \boxed{8.13 \times 10^{-3} \text{ m}^2/\text{s} = 8\,130 \text{ cs}}$$

1.20 Referring to Figure P1.20, the plate is being pulled upward in a space filled with chloroform. The plate velocity is 12 in./s and $\Delta y = 0.05$ in. The force is 2 lbf. Determine the area of contact of each side of the plate.

$$\frac{F}{A} = \mu \frac{\Delta V}{\Delta y}\ ; F = 2 \text{ lbf};\ \mu = 1.11 \times 10^{-5} \text{ lbf·s/ft}^2\ ; \Delta V = 12 \text{ in./s} = 1 \text{ ft/s}$$

$$\Delta y = (0.05/12) \text{ ft};\ 2A = \frac{F\Delta y}{\mu \Delta V} = \frac{2(0.05/12)}{1.11 \times 10^{-5}\,(1)} = 750 \text{ ft}^2$$

$$\boxed{A = 375 \text{ ft}^2}$$

1.21 The total space between stationary boundaries is 1 cm. Ethylene glycol is placed on the left side and propylene glycol on the right. When the infinite plate that separates the liquids is pulled upward, it finds an equilibrium position. Determine the lateral location of the plate if it has a thickness of 1 mm.

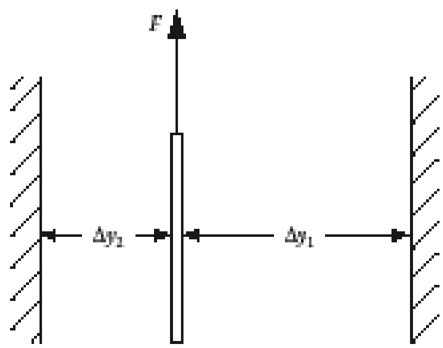


FIGURE P1.21

τ is the same on both sides. Given $\Delta y_1 + \Delta y_2 = 1 - 0.1$ or
$\Delta y_1 + \Delta y_2 = 0.9 \text{ cm} = 0.009 \text{ m}$

$$\tau = \mu_1 \frac{\Delta V}{\Delta y_1} = \mu_2 \frac{\Delta V}{\Delta y_2} \quad \text{so} \quad \frac{\mu_1}{\Delta y_1} = \frac{\mu_2}{\Delta y_2} \quad \text{From Table A-5, we get}$$

$$\frac{\mu_1}{\mu_2} = \frac{16.2}{42} = \frac{\Delta y_1}{\Delta y_2} \quad \text{or} \quad \frac{0.009 \text{ m} - \Delta y_2}{\Delta y_2} = 0.386 \qquad 1.386\Delta y_2 = 0.009$$

Solving,

$\boxed{\Delta y_2 = 0.006\,5 \text{ m} = 0.65 \text{ cm}}$ $\qquad \Delta y_1 = 0.9 - 0.65$ or

$\boxed{\Delta y_1 = 0.35 \text{ cm}}$

1.22 A falling sphere viscometer is used to measure the viscosity of shampoo whose density is 1 008 kg/m^3. A sphere of diameter 0.792 cm is dropped into the shampoo, and measurements indicate that the sphere travels 0.183 m in 7.35 seconds. The density of the sphere is 7 940 kg/m^3. Calculate the absolute and kinematic viscosity of the shampoo.

The viscosity is found with the equations derived previously:

$$\mu = \frac{\rho g D^2}{18V}\left(\frac{\rho_s}{\rho} - 1\right)$$

where

$\rho = 1\,008 \text{ kg/m}^3$
$\rho_s = 7\,940 \text{ kg/m}^3$
$D = 0.007\,92 \text{ m}$
$g = 9.81 \text{ m/s}^2$
$V = 18.3 \text{ cm}/7.35 \text{ s} = 2.49 \text{ cm/s} = 0.024\,9 \text{ m/s}$

Substituting,

$$\mu = \frac{(1\,008 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0.007\,92 \text{ m})^2}{18(0.024\,9 \text{ m/s})}\left(\frac{7\,940}{1\,008} - 1\right)$$

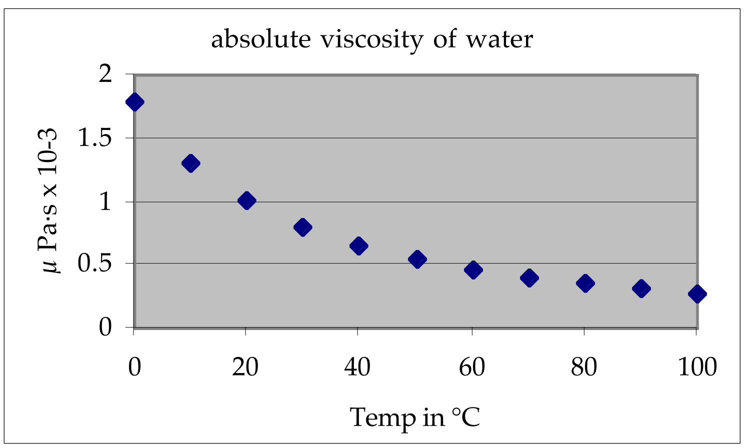
$$\underline{\mu = 9.52 \text{ N·s/m}^2 = 9.52 \text{ Pa·s}}$$

As a check on the validity of using the equation for the drag force, we calculate:

$$\frac{\rho V D}{\mu} = \frac{1\,008(0.024\,9)(0.007\,92)}{9.52} = 0.02$$

which is less than 1.

1.23 Graph the absolute viscosity of water as a function of temperature.



1.24 Figure P1.24 illustrates an infinite plate being pulled upward in a space filled with ethyl alcohol on the right and an unknown fluid on the left. The plate is not equidistant from the boundaries; in fact, $\Delta y_1 = 2\Delta y_2$. Determine the viscosity of the unknown fluid.

The shear applied to both fluids is the same. Thus on the left,

$\tau = \mu_1 \dfrac{\Delta V}{\Delta y_1}$ and on the right, $\tau = \mu_2 \dfrac{\Delta V}{\Delta y_2}$; so $\dfrac{\mu_1}{\Delta y_1} = \dfrac{\mu_2}{\Delta y_2}$

From Table A-5, $\mu_1 = 1.095 \times 10^{-3}$ N·s/m^2

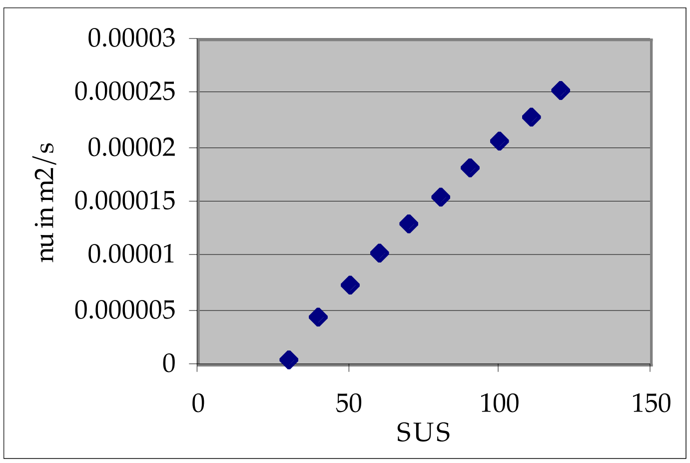
Also, $\Delta y_1 = 2\Delta y_2$; With $\mu_2 = \mu_1 \dfrac{\Delta y_2}{\Delta y_1} = 1.095 \times 10^{-3} \cdot (1/2)$ or

$\boxed{\mu_2 = 0.548 \times 10^{-3}\ \mathrm{N{\cdot}s/m^2}}$

1.25 A Saybolt viscometer is used in the petroleum industry to measure viscosity of lubricating oils. The test oil is placed in a cup surrounded by a constant temperature bath. At time zero (a stopwatch is started), test oil is allowed to flow out of the bottom of the cup, through an orifice. The oil leaves in the form of a stream and is collected in a calibrated beaker. When 60 ml of oil flows through the orifice, the elapsed time is recorded. The time required for 60 ml of oil to flow through the orifice is thus experimentally determined. The viscosity of the oil is expressed in terms of the elapsed time; e.g., one would say that the oil has "a viscosity of 100 Saybolt Universal Seconds." This is abbreviated as "100 SUS." The equation to convert SUS to units of m^2/s is given by

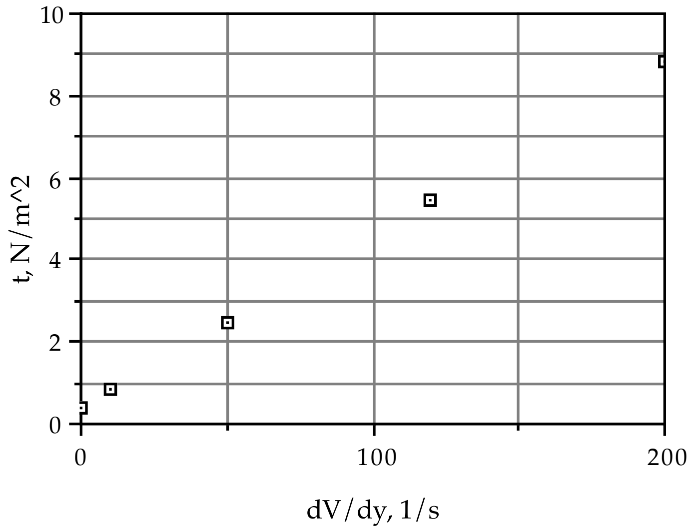
$$\nu\ (\mathrm{m^2/s}) = 0.224 \times 10^{-6}\ (\mathrm{SUS}) - \frac{185 \times 10^{-6}}{\mathrm{SUS}}$$

Graph this equation as ν on the vertical axis vs SUS. Allow SUS to vary from 30 to 120 SUS in increments of 10 SUS. (The equation is valid over only this range.)



1.26 What type of fluid is described by the following shear stress-strain rate data?

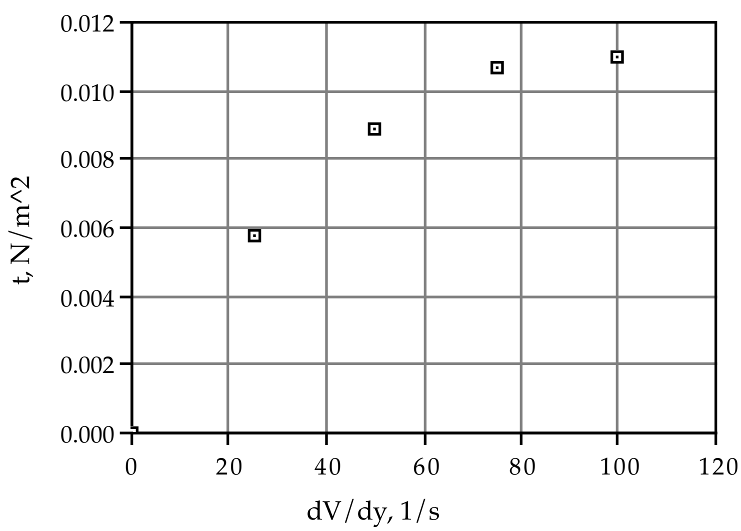
τ (N/m^2)	0.4	0.82	2.50	5.44	8.80
dV/dy (rad/s)	0	10	50	120	200



Bingham Plastic

1.27 What type of fluid is described by the following shear stress-strain rate data?

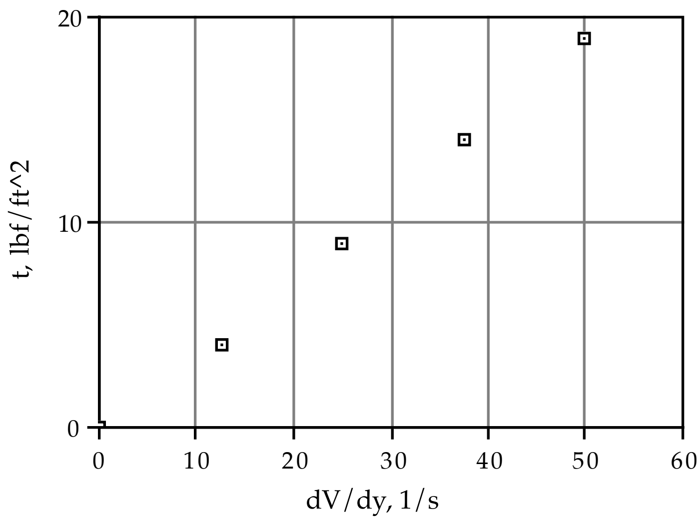
τ (N/m^2)	0	0.005 8	0.008 9	0.010 7	0.011
dV/dy (rad/s)	0	25	50	75	100



Pseudoplastic

1.28 What type of fluid is has the following shear stress-strain rate relationship?

τ (lbf/ft^2)	0	4	9	14	19
dV/dy (rad/s)	0	12.5	25.0	37.5	50.0

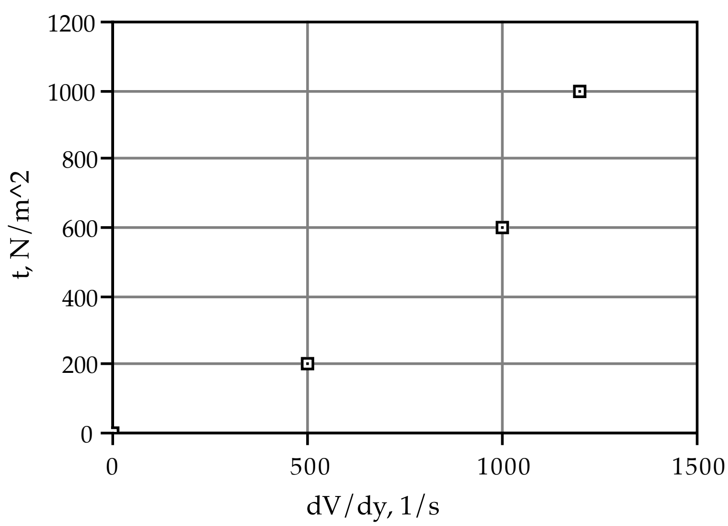


$\boxed{\text{Newtonian}}$ (close enough)

1.29 Actual tests on vaseline yielded the following data:

τ (N/m^2)	0	200	600	1 000
dV/dy (1/s)	0	500	1 000	1 200

Graph the data and determine the fluid type.



$\boxed{\text{Dilatant}}$

1.30 Figure P1.32 shows a shaft 4 in. in diameter moving through a well oiled sleeve that is 12 in. long. The force required to move the shaft is 25 lbf, and the shaft velocity is 5 in./s. The oil filled clearance between the shaft and sleeve is 0.005 in. Calculate the viscosity of the lubricating oil (a Newtonian fluid).

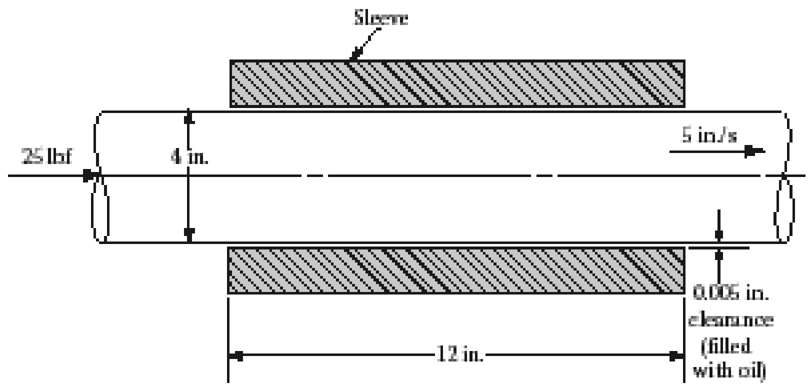


FIGURE P1.30

Assume oil is Newtonian so $\tau = \mu \dfrac{dV}{dy}$; sleeve is stationary, shaft velocity is $V = 5$ in./s $= 0.417$ ft/s; $\tau = \dfrac{F}{A}$; A = area of contact. Surface area of shaft does not equal surface of sleeve, so take an average. For shaft, $A = \pi DL = \pi(4/12)(12/12) = 1.047$ ft^2 ; for the sleeve,

$A = \pi(4.01/12)(12/12) = 1.05$ ft^2 ; use $A = \dfrac{1.05 + 1.047}{2} = 1.048$ ft^2

$\tau = \dfrac{25}{1.048} = 23.8$ lbf/ft^2 ; $\dfrac{dV}{dy} = \dfrac{\Delta V}{\Delta y} = \dfrac{5/12 - 0}{0.005/12} = 1000$

$\mu = \dfrac{\tau}{dV/dy} = \dfrac{23.8}{1000}$ or $\boxed{\mu = 23.8 \times 10^{-3} \text{ lbf}\cdot\text{s/ft}^2}$

1.31 Mayonnaise is tested in the laboratory to obtain its rheological diagram. Two data points are:
1. $\tau = 4.63 \times 10^{-2}$ lbf/ft^2 $\quad dV/dy = 25$ rad/s
2. $\tau = 6.52 \times 10^{-2}$ lbf/ft^2 $\quad dV/dy = 50$ rad/s

Determine the consistency index and the flow behavior index. Calculate the strain rate if the shear stress is increased to 7×10^{-2} lbf/ft^2.

Mayo pseudoplastic $\qquad \tau = K\left(\dfrac{dV}{dy}\right)^n$; substituting,

$4.63 \times 10^{-2} = K(25)^n$ and $6.52 \times 10^{-2} = K(50)^n$; dividing gives

$\dfrac{4.63}{6.52} = \left(\dfrac{25}{50}\right)^n$; which becomes $0.71 = (0.5)^n$; $\ln(0.71) = n \ln(0.5)$;

$\boxed{n = 0.494}$

$4.63 \times 10^{-2} = K(25)^{0.494}$; $K = \dfrac{4.63 \times 10^{-2}}{4.91}$

$\boxed{K = 9.44 \times 10^{-3}}$

Check with second equation: $9.44 \times 10^{-3} (50)^{0.494} = 6.52 \times 10^{-2}$ which is OK.
$\tau = 9.44 \times 10^{-3} (dV/dy)^{0.494}$; when $\tau = 7 \times 10^{-2}$,

$$7 \times 10^{-2} = 9.44 \times 10^{-3} \left(\frac{dV}{dy}\right)^{0.494}; \qquad \frac{dV}{dy} = (7.42)^{1/0.494} \text{ or}$$

$$\boxed{\frac{dV}{dy} = 57.7 \text{ rad/s}}$$

1.32 Two data points on a rheological diagram of a certain grease are:
1. $dV/dy = 20$ rad/s $\qquad \tau = 8.72 \times 10^{-3}$ N/m^2
2. $dV/dy = 40$ rad/s $\qquad \tau = 2.10 \times 10^{-3}$ N/m^2

Determine the consistency index and the flow behavior index. Calculate the strain rate if the shear stress is increased to 3×10^{-2} N/m^2.

$$\tau = K\left(\frac{dV}{dy}\right)^n; \quad 8.72 \times 10^{-3} = K(20)^n \quad \text{and } 2.10 \times 10^{-2} = K(40)^n \text{ ; dividing,}$$

$$\frac{8.72 \times 10^{-3}}{2.10 \times 10^{-2}} = \left(\frac{20}{40}\right)^n; \qquad 0.415 = (0.5)^n ; \qquad \ln(0.415) = n \ln(0.5)$$

$\boxed{n = 1.27}$

$8.27 \times 10^{-3} = K(20)^{1.27}$; $\qquad \boxed{K = 1.95 \times 10^{-4}}$

Check $\qquad 1.95 \times 10^{-4} (40)^{1.27} = 2.1 \times 10^{-2} \qquad$ OK

$$\tau = 1.95 \times 10^{-4} \left(\frac{dV}{dy}\right)^{1.27}; \qquad \tau = 3 \times 10^{-2}$$

$$\frac{dV}{dy} = \left(\frac{3 \times 10^{-2}}{1.95 \times 10^{-4}}\right)^{1/1.27}$$

$$\boxed{\frac{dV}{dy} = 53.1 \text{ rad/s}}$$

1.33 A highly viscous slow-drying paint has a viscosity μ_0 of 0.04 lbf·s/ft^2. At a shear stress of 2.7 lbf/ft^2, the strain rate is 70 rad/s. Calculate its initial yield stress.

$$\mu_o = 0.04 \text{ lbf·s/ft}^2 \text{ ;} \quad \tau = 2.7 \text{ lbf/ft}^2 \text{ ;} \qquad \frac{dV}{dy} = 70 \text{ rad/s}$$

$$\tau = \tau_o + \mu_o \frac{dV}{dy}; \qquad 2.7 = \tau_o + 0.04(70); \ \tau_o = 2.7 - 0.04(70)$$

$\boxed{\tau_o = 0.1 \text{ lbf/ft}^2}$

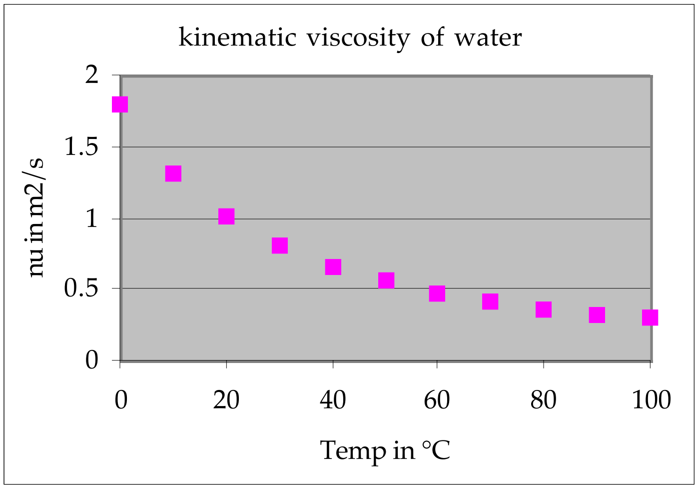
1.34 A fluid with a viscosity of 8 centipoise has a density of 59 lbm/ft^3. What is its kinematic viscosity in the CGS system?

$\mu = 8 \text{ cp} \cdot 1 \times 10^{-3} = 8 \times 10^{-3} \text{ N·s/m}^2$; $\rho = 59 \text{ lbm/ft}^3 \cdot 16.01 = 945 \text{ kg/m}^3$

$$\nu = \frac{\mu}{\rho} = \frac{8 \times 10^{-3}}{945} = 8.47 \times 10^{-6} \text{ m}^2/\text{s} \cdot (100^2 \text{ cm}^2/\text{m}^2)$$

$$\boxed{\nu = 8.47 \times 10^{-2} \text{ cm}^2/\text{s}}$$

1.35 Graph the kinematic viscosity of water as a function of temperature.



1.36 Determine the pressure inside a water droplet of diameter 500 μm in a partially evacuated chamber where p = 70 kN/m^2.

$$p_i - p_o = \frac{2\sigma}{R}; \quad p_o = 70\,000 \text{ N/m}^2 ; R = 250 \times 10^{-6} \text{ m}; \sigma = 72 \times 10^{-3} \text{ N/m, so}$$

$$p_i = 70\,000 + \frac{2(72 \times 10^{-3})}{250 \times 10^{-6}} = \boxed{70\,576 \text{ N/m}^2}$$

1.37 Calculate the pressure inside a 2 mm diameter drop of acetone exposed to atmospheric pressure (101.3 kN/m^2).

$$p_i - p_o = \frac{2\sigma}{R}; \quad p_o = 101\,300 \text{ N/m}^2 ; R = 0.001 \text{ m}; \sigma = 23.1 \times 10^{-3} \text{ N/m, so}$$

$$p_i = 101\,300 + \frac{2(23.1 \times 10^{-3})}{0.001} = \boxed{101\,346 \text{ N/m}^2}$$

1.38 Calculate the pressure inside a 1/16 in. diameter drop of chloroform in contact with air at a pressure of 14.7 lbf/in^2.

$$p_i - p_o = \frac{2\sigma}{R}; \; D = 1/16 \text{ in.} = 0.0052 \text{ ft}; R = 0.0026 \text{ ft}$$

$p_o = 14.7(144) = 2117 \text{ lbf/ft}^2$; $\sigma = 27.14 \times 10^{-3}$ N/m (Table A-5); converting,

$$\sigma = \frac{27.14 \times 10^{-3}}{4.448}(0.3048) = 1.86 \times 10^{-3} \text{ lbf/ft so}$$

$$p_i = 2117 + \frac{2(1.86 \times 10^{-3})}{0.0026} \quad \text{or} \quad \boxed{p_i = 2118 \text{ lbf/ft}^2}$$

1.39 A drop of benzene is 1 mm in diameter and is in contact with air at a pressure of 100 kN/m^2. (a) Calculate its internal pressure. (b) If the pressure difference (inside minus outside) for the benzene droplet is the same as that for a mercury droplet, what is the diameter of the mercury droplet?

Benzene $\sigma = 28.2 \times 10^{-3}$ N/m (Table A-9); D = 1 mm;

R = 0.5 mm = 0.000 5 m; $p_o = 100\,000$ N/m^2 ; $p_i - p_o = \dfrac{2\sigma}{R}$;

$p_i = 100\,000 + \dfrac{2(28.2 \times 10^{-3})}{0.000\,5}$; solving,

a) $\boxed{p_i = 1.001 \times 10^5 \text{ N/m}^2}$ (benzene)

b) $p_i - p_o = 113 \text{ N/m}^2 = \dfrac{2\sigma}{R}$ for Hg; $R = \dfrac{2\sigma}{113}$; $\sigma = 484 \times 10^{-3}$ N/m (from Appendix Table A-5 or A-9); $R = \dfrac{2(0.484)}{113}$ or

b) $\boxed{R = 0.008\,6 \text{ m} = 8.6 \text{ mm}}$

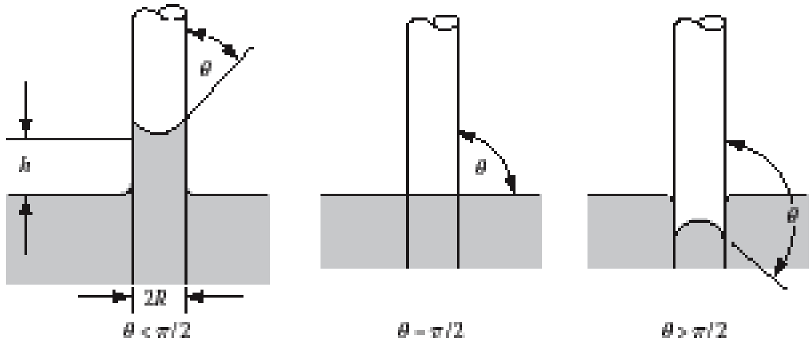
1.40 If a small diameter tube is immersed slightly in a liquid, the rise of a column of liquid inside is due to surface tension. This phenomenon is referred to as capillary action, examples of which are illustrated in Figure P1.43. The weight of the liquid column in the tube equals the product of force due to the pressure difference across the gas-liquid interface and the tube area. These are also equal to the peripheral force around the tube circumference due to surface tension. Thus we write

$$\rho g h(\pi R^2) = \sigma 2\pi R \cos\theta$$

The capillary rise can be solved for in terms of surface tension as

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

As shown in Figure P1.43, three cases can exist, depending on the value of the angle θ. When θ equals π/2, there is no rise in the tube. The angle θ is usually taken as 0° for water and 140° for mercury, if the tube is made of glass. (a) Determine the height h that water at room temperature would rise in a 4 mm diameter tube. (b) Determine the height h that mercury at room temperature would rise in a 4 mm diameter tube.



$h = \dfrac{2\sigma}{\rho R g}\cos\theta$; $\rho = 1\,000$ kg/m^3, R = 0.002 m, $\theta = 0°$

H_2O at room temperature, Table A-5; $\sigma = 71.97 \times 10^{-3}$ N/m

$h = \dfrac{2(71.97 \times 10^{-3})}{1\,000(0.002)(9.81)}$; solving,

a) $\boxed{h = 0.007\,337 \text{ m} = 7.34 \text{ mm}}$

Table A-5 for Hg, $\sigma = 484 \times 10^{-3}$ N/m; $\rho = 13.6(1\,000)$

$h = \dfrac{2(484 \times 10^{-3})\cos 140°}{13.6(1\,000)(9.81)(0.002)}$; and

b) $\boxed{h = -\,2.8 \times 10^{-3} \text{ m} = -\,2.8 \text{ mm}}$

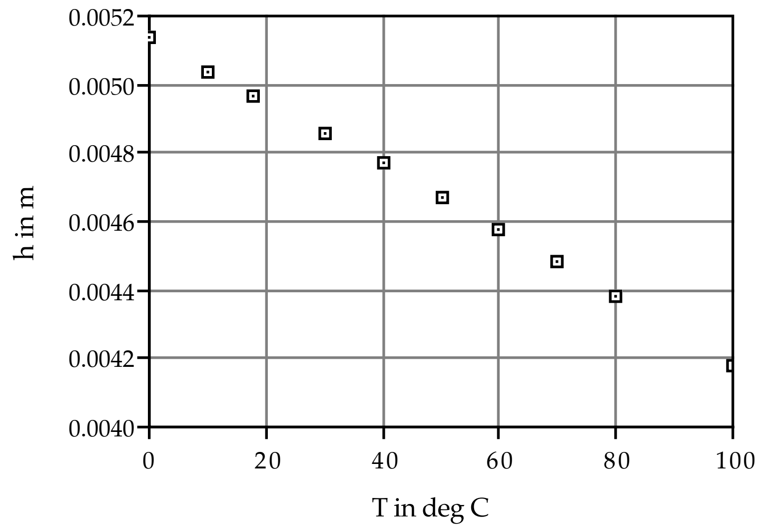
1.41 Following are surface tension data for water given as a function of temperature. If a 6 mm diameter tube is inserted into a sample at each temperature, the capillary rise as explained in Problem 1.40 would vary according to

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

Determine h for each temperature and plot h versus T.

$h = \dfrac{2\sigma}{\rho R g}$; R = 0.003 m; $h = \dfrac{2\sigma}{\rho R g} = \dfrac{2\sigma}{\rho(0.003)(9.81)} = 67.96\,\dfrac{\sigma}{\rho}$

T, °C	σ, N/m	Table A-4 ρ, kg/m^3	h, m
0	75.6×10^{-3}	0.9999(1 000)	0.00514
10	74.2	0.9997	0.00504
18	73.1	0.9986	0.00497
30	71.2	0.9957	0.00486
40	69.6	0.9922	0.00477
50	67.9	0.9881	0.00467
60	66.2	0.9832	0.00458
70	64.4	0.9778	0.00448
80	62.6	0.9718	0.00438
100	58.9	0.9584	0.00418



1.42 A capillary tube that is 0.2 in. in diameter has its end submerged in mercury. The capillary depression (see Problem 1.40) is 0.052 in. Calculate the surface tension of the mercury.

$h = \dfrac{2\sigma}{\rho R g}\cos\theta$; $\theta = 140°$ for Hg; Table A-5 for Hg, $\rho = 13.6(1.94\ \text{slug/ft}^3)$

$D = 0.2$ in. $= 0.0166$ ft; $R = 0.00833$ ft; $h = -\ 0.052$ in. $= -\ 0.0043$ ft

$$\sigma = \frac{\rho R h g}{2\cos\theta} = \frac{13.6(1.94)(0.00833)(-\ 0.0043)(32.2)}{2\cos 140°}$$

$\boxed{\sigma = 0.0198\ \text{lbf/ft}}$

1.43 Determine the height h that ethyl alcohol at room temperature would rise in a 5 mm diameter tube. The contact angle is 0°. (See Problem 1.40.)

$\theta = 0°$; $R = 0.002\,5$ m, ethyl alcohol, Table A-5; $\sigma = 22.33 \times 10^{-3}$ N/m;

$$\rho = 787\ \text{kg/m}^3\ ;\ h = \frac{2\sigma}{\rho R g} = \frac{2(22.33 \times 10^{-3})}{787(0.002\,5)(9.81)}$$

$\boxed{h = 2.31\ \text{mm}}$

1.44 The surface tension of benzene is measured with a capillary tube whose inside diameter is 4 mm. The contact angle is 0°. What is the expected height h that the benzene will rise in the tube? (See Problem 1.40.)

$\theta = 0°$; $R = 0.002$ m, benzene, Table A-5; $\sigma = 28.18 \times 10^{-3}$ N/m;

$$\rho = 876\ \text{kg/m}^3\ ;\ h = \frac{2\sigma}{\rho R g} = \frac{2(28.18 \times 10^{-3})}{876(0.002)(9.81)}$$

$\boxed{h = 3.28\ \text{mm}}$

1.45 Determine the height h that carbon tetrachloride at room temperature would rise in a 3 mm diameter tube given that the contact angle is 0°. (See Problem 1.43.)

$\theta = 0°$; R = 0.001 5 m, carbon tet, Table A-5; $\sigma = 26.3 \times 10^{-3}$ N/m;

$$\rho = 1\,590 \text{ kg/m}^3 \text{ ; } h = \frac{2\sigma}{\rho R g} = \frac{2(26.3 \times 10^{-3})}{1\,590(0.001\,5)(9.81)}$$

$\boxed{h = 2.25 \text{ mm}}$

1.46 The surface tension of glycerin at room temperature is measured with a capillary tube. If the inside diameter of the tube is 2.5 mm and the contact angle is 0°, what is the expected rise of glycerin in the tube? (See Problem 1.43.)

$\theta = 0°$; R = 0.001 25 m, glycerin, Table A-5; $\sigma = 63.0 \times 10^{-3}$ N/m;

$$\rho = 1\,263 \text{ kg/m}^3 \text{ ; } h = \frac{2\sigma}{\rho R g} = \frac{2(63.0 \times 10^{-3})}{1\,263(0.001\,25)(9.81)}$$

$\boxed{h = 8.14 \text{ mm}}$

1.47 Determine the height h that octane at room temperature would rise in a 2 mm diameter tube given that the contact angle is 0°. (See Problem 1.43.)

$\theta = 0°$; R = 0.001 m, octane, Table A-5; $\sigma = 21.14 \times 10^{-3}$ N/m;

$$\rho = 701 \text{ kg/m}^3 \text{ ; } h = \frac{2\sigma}{\rho R g} = \frac{2(21.14 \times 10^{-3})}{701(0.001)(9.81)}$$

$\boxed{h = 6.15 \text{ mm}}$

1.48 When glass tubes are used with mercury, instrumentation guides recommend tubes with a minimum bore of 10 mm to avoid capillary error. Estimate the height mercury rises in a tube of this diameter. (See Problem 1.43.)

$\theta = 140°$; R = 0.005 m, Hg, Table A-5; $\sigma = 484 \times 10^{-3}$ N/m;

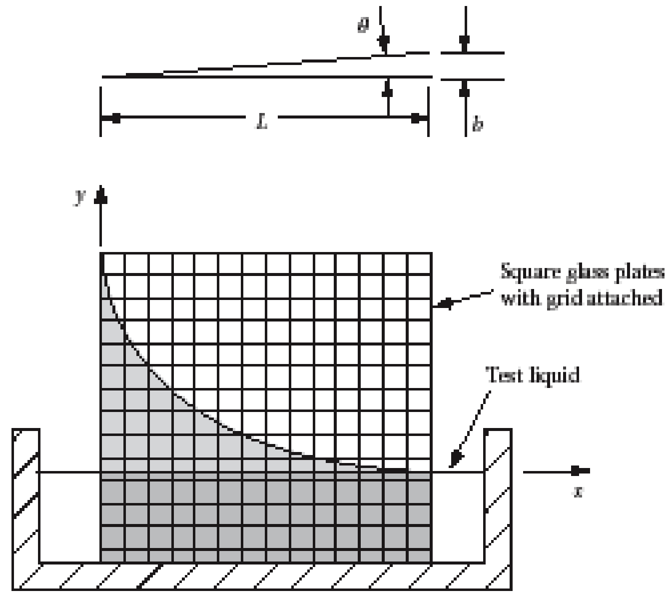
$$\rho = 13\,600 \text{ kg/m}^3 \text{ ; } h = \frac{2\sigma}{\rho R g} \cos\theta = \frac{2(484 \times 10^{-3})}{13\,600(0.005)(9.81)} \cos 140°$$

$\boxed{h = -\ 1.11 \text{ mm}}$

1.49 An interesting variation of the capillary tube method of measuring surface tension is the hyperbola method. With the hyperbola method, two glass plates which have a small angle between them are positioned vertically as shown in Figure P1.45. The glass plates (5 in. x 5 in.) are separated by a small wedge at one end and held together by two binder clips at the other end. A transparency of graph paper is attached to one of the plates. If the plates are partially submerged, liquid rises between them and, when viewed from the side, the liquid surface forms a hyperbola. An *x-y* coordinate system is imposed on the graph paper. The *x* axis is the free surface of the liquid in the reservoir and the *y* axis is at the touching edges of the plates. Readings of *x-y* pairs of various points on the hyperbola are taken and can be used to calculate surface tension with

$$\sigma = \frac{xy\theta}{2}\rho g = (\text{geometry factors}) \cdot \rho g$$

Suppose that the fluid used in the hyperbola method is water and that the angle θ is 1°. Determine the equation of the hyperbola and sketch its shape. Is there any similarity between the above equation and that derived for the capillary



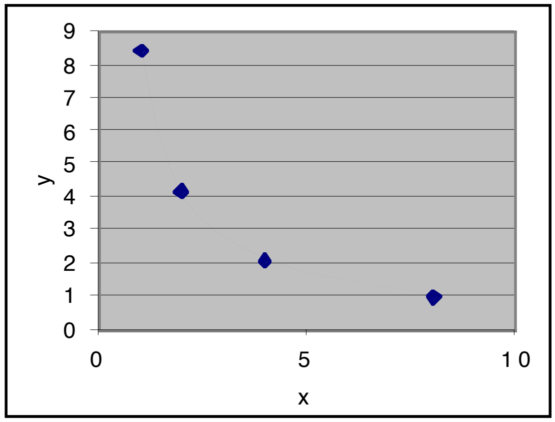
tube?

$\sigma = \frac{xy\theta}{2}\rho g$; $\sigma = 71.97 \times 10^{-3}$ N/m; $\rho = 1\,000$ kg/m^3 ; $\theta = 1° \cdot 2\pi/360$

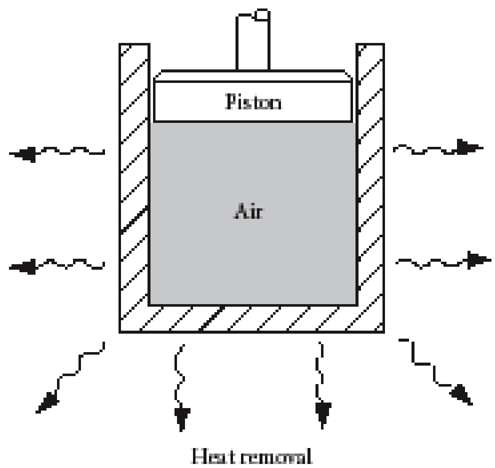
$\theta = 0.017\,45$ rad; substituting,

$71.97 \times 10^{-3} = xy\left(\frac{0.017\,45}{2}\right)(1\,000)(9.81)$; $xy = 8.048 \times 10^{-4}$ m^2

x	y
1	8.408
2	4.2
4	2.1
8	1.05



1.50 Figure P1.53 depicts 0.1 slugs of air in a piston-cylinder arrangement. Heat is removed from the air so that the air temperature is reduced by 25°F. Assuming a frictionless, movable piston, determine the amount of heat removed.



m = 0.1 slug; $\Delta T = 25°F$; Table A-6 for air, $c_p = 7.72$ BTU/slug·°R

$\tilde{Q} = mc_p\Delta T = 0.1(7.72)(25)$

$\boxed{\tilde{Q} = 19.3 \text{ BTU}}$

1.51 The vessel in Figure P1.53 contains 1 kg of carbon dioxide. The gas is cooled so that its temperature is decreased by 25°C. Determine the amount of heat removed per unit mass of carbon dioxide. Assume a frictionless, movable piston.

CO_2 Appendix Table A-6 $c_p = 876$ J/(kg·K); m = 1 kg; $\Delta T = 25°C$

$\tilde{Q} = mc_p\Delta T = 1(876)(25) = 2.19 \times 10^4$ J;

$\tilde{Q}/m = 2.19 \times 10^4/1 = \boxed{2.19 \times 10^4 \text{ J/kg}}$

1.52 A rigid vessel contains 8 kg of argon heated by 50 kJ of energy. Determine the temperature change of the gas.

Argon $\tilde{Q} = mc_v\Delta T$; Table A-6, $c_p = 523$ J/(kg·K); $c_p/c_v = 1.67$; so we calculate

$c_v = 313$ J/(kg·K); $\tilde{Q} = 8\text{ kg}(313\text{ J/(kg·K)})(\Delta T) = 50\ 000$ J; solving,

$\boxed{\Delta T = 20.0 \text{ K increase in temperature}}$

1.53 Carbon dioxide gas is inside of a constant volume container. Initially, the carbon dioxide is at 101.3 kN/m^2 and 25°C. The container is heated until the gas reaches 50°C. What is the change in the internal energy of the gas.

CO_2 Appendix Table A-6 $c_p = 876$ J/(kg·K); $\gamma = 1.30$;

$c_v = \dfrac{876}{1.3} = 674$ J/(kg·K); $\Delta u = c_v\Delta T = 674(50 - 25)$

$\boxed{\Delta u = 1.68 \times 10^4 \text{ J/kg}}$

1.54 One kg of gas is in a piston cylinder arrangement. It is desired to raise the temperature of the gas by 25°C. When heat is added, the piston is free to move due to a frictionless seal. If the gas is helium, will more heat be required than if it were hydrogen? Calculate the heat required in both cases and also calculate the change in enthalpy for each gas.

$m = 1$ kg; $\Delta T = 25$°C
Table A-6
He $c_p = 5\ 188$ J/(kg·K)
H_2 $c_p = 14\ 310$ J/(kg·K)

$\tilde{Q} = mc_p\Delta T = 1(5\ 188)(25)$

$\boxed{\tilde{Q} = 1.3 \times 10^5 \text{ J for He}}$

$\tilde{Q} = mc_p\Delta T = 1(14\ 310)(25)$

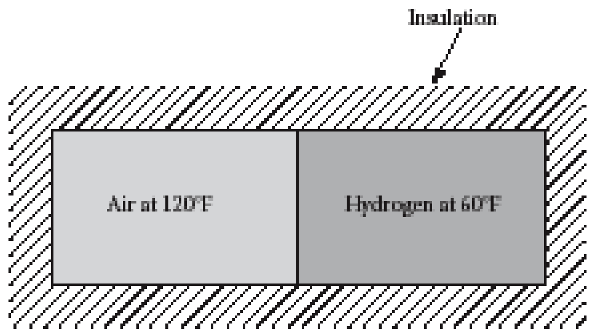
$\boxed{\tilde{Q} = 3.6 \times 10^5 \text{ J for } H_2}$

$\Delta h = \dfrac{\tilde{Q}}{m} = \dfrac{1.3 \times 10^5}{1}$; $\boxed{\Delta h = 1.3 \times 10^5 \text{ J/kg for He}}$

$\Delta h = \dfrac{\tilde{Q}}{m} = \dfrac{3.6 \times 10^5}{1}$; $\boxed{\Delta h = 3.6 \times 10^5 \text{ J/kg for } H_2}$

$\boxed{\text{Hydrogen requires more energy}}$

1.55 Figure P1.58 shows two constant volume containers that are equal in size and they are in contact with one another. The air and its container are at 120°F while the hydrogen and its container are at 60°F. The containers are well insulated except where they touch. Heat is transferred from the air to the hydrogen and both fluids and container eventually reach the same final temperature. The mass of air is twice that of the hydrogen. Calculate the final temperature.



Air loses $\tilde{Q} = mc_v(120 - T_f)$

H_2 gains $\tilde{Q} = mc_v(T_f - 60)$

$m_{air} = 2m_{H2}$; Table A-6 gives

air $c_p = 7.72$ BTU/slug·°R; $c_p/c_v = 1.4$

H_2 $c_p = 110$ BTU/slug·°R; $c_p/c_v = 1.405$

$$c_{vair} = \frac{7.72}{1.4} = 5.51; \; c_{vH2} = \frac{110}{1.405} = 78.3$$

$\tilde{Q}$ are equal so; $\quad mc_v(120 - T_f)\,|_{air} = mc_v(T_f - 60)\,|_{H2}$

substituting, $2m_{H2}(5.51)(120 - T_f) = m_{H2}(78.3)(T_f - 60)$;

$1322 - 11.02T_f = 78.3T_f - 4698; \; 6020 = 89.32T_f$

$\boxed{T = 67.4°F}$

1.56 What change in pressure is required to decrease the volume of benzene by 1%?

Benzene Appendix Table A-5 $\quad a = 1\,298$ m/s; $\rho = 876$ kg/m^3

$a = (k/\rho)^{1/2} \quad k = \rho a^2 = 876(1\,298)^2 = 1.48 \times 10^9$ N/m^2

$$-\frac{\Delta \mathcal{V}}{\mathcal{V}} = 0.01; \; k = -\mathcal{V}\left(\frac{\partial p}{\partial V}\right)_T = -\mathcal{V}\frac{\Delta p}{\Delta \mathcal{V}} \; ; \quad \Delta p = k\left(-\frac{\Delta \mathcal{V}}{\mathcal{V}}\right)$$

$\Delta p = -1.48 \times 10^9\,(-0.01) = \boxed{1.48 \times 10^7 \text{ N/m}^2}$

1.57 The volume of glycerin changes by 2% under the action of a change in pressure. What is the change in pressure required to do this?

Glycerin Appendix Table A-5 $\quad a = 1\,909$ m/s; $\rho = 1\,263$ kg/m^3

$a = (k/\rho)^{1/2} \quad k = \rho a^2 = 1\,263(1\,909)^2 = 4.6 \times 10^9$ N/m^2

$$-\frac{\Delta \cancel{V}}{\cancel{V}} = 0.02;\ k = -\cancel{V}\left(\frac{\partial p}{\partial V}\right)_T = -\cancel{V}\,\frac{\Delta p}{\Delta \cancel{V}}\ ; \quad \Delta p = k\left(-\frac{\Delta \cancel{V}}{\cancel{V}}\right)$$

$\Delta p = -4.6 \times 10^9\,(-0.02) = \boxed{9.21 \times 10^7 \text{ N/m}^2}$

1.58 The pressure exerted on a liquid increases from 500 to 1 000 kPa. The volume decreases by 1%. Determine the bulk modulus of the liquid.

$$k = -\cancel{V}\left(\frac{\partial p}{\partial \cancel{V}}\right)_T = -\cancel{V}\,\frac{\Delta p}{\Delta \cancel{V}} = -\frac{\cancel{V}}{\Delta \cancel{V}}\,\Delta p;\ \Delta p = \text{ 1 000 kPa - 500 kPa or}$$

$$\Delta p = 500 \text{ kN/m}^2\ ;\ -\frac{\cancel{V}}{\Delta \cancel{V}} = \frac{1}{0.01}\ ;\text{ so } k = \frac{1}{0.01}\,(500\,000)$$

$\boxed{k = 50 \times 10^6 \text{ N/m}^2}$

1.59 Determine the coefficient of compressibility for the liquid of Problem 1.61.

$$\beta = \frac{1}{k} = \frac{1}{50 \times 10^6} = \boxed{2 \times 10^{-8} \text{ m}^2/\text{N} = \beta}$$

1.60 Water at 45°F has a bulk modulus of about 300,000 lbf/in^2. Determine the pressure rise required to decrease its volume by 1%.

$$H_2O \quad k = 300\,000 \text{ lbf/in}^2\ ;\ -\frac{\Delta \cancel{V}}{\cancel{V}} = 0.01;\ k = -\cancel{V}\left(\frac{\partial p}{\partial \cancel{V}}\right)_T = -\cancel{V}\,\frac{\Delta p}{\Delta \cancel{V}}\ ;\text{ so}$$

$$\Delta p = -k\,\frac{\Delta \cancel{V}}{\cancel{V}} = 300\,000(0.01)$$

$\boxed{\Delta p = 3000 \text{ psi increase}}$

1.61 Water at 20°C has a bulk modulus of 21.8 x 10^8 N/m^2. Determine the pressure change required to decrease its volume by 1%.

$$H_2O \quad k = 21.8 \times 10^8 \text{ N/m}^2\ ;\ -\frac{\Delta \cancel{V}}{\cancel{V}} = 0.01;\ k = -\cancel{V}\left(\frac{\partial p}{\partial \cancel{V}}\right)_T = -\cancel{V}\,\frac{\Delta p}{\Delta \cancel{V}}\ ;\text{ so}$$

$$\Delta p = -k\,\frac{\Delta \cancel{V}}{\cancel{V}} = 21.8 \times 10^8\,(0.01)$$

$\boxed{\Delta p = 2.18 \times 10^7 \text{ N/m}^2 \text{ increase}}$

1.62 What is the bulk modulus of a liquid whose volume decreases by 0.5% for a pressure increase of 1000 lbf/in^2? For a density of 1.8 slug/ft^3, what is the sonic velocity in the liquid?

$\Delta p = 500$ psi; $-\frac{\Delta \cancel{V}}{\cancel{V}} = 0.005$; $k = -\cancel{V}\left(\frac{\partial p}{\partial \cancel{V}}\right)_T = -\cancel{V}\frac{\Delta p}{\Delta \cancel{V}}$; $k = \frac{500}{0.005}$

$\boxed{k = 100{,}000 \text{ psi}}$ $\quad a = \sqrt{k/\rho} = \sqrt{100{,}000(144)/1.8}$ or

$\boxed{a = 2830 \text{ ft/s}}$

1.63 What is the bulk modulus of a liquid whose volume decreases by 0.5% for a pressure increase of 60 kN/m^2?

$-\frac{\Delta \cancel{V}}{\cancel{V}} = 0.005$; $\Delta p = 60$ kPa; $k = -\cancel{V}\left(\frac{\partial p}{\partial \cancel{V}}\right)_T = -\cancel{V}\frac{\Delta p}{\Delta \cancel{V}} = \frac{60}{0.005}$

$\boxed{k = 1\,200 \text{ kPa} = 1.2 \text{ MPa}}$

1.64 Carbon dioxide gas inside of a constant volume container is initially at 101.3 kN/m^2 and 25°C. The container is heated until the gas reaches 50°C. Calculate the final pressure of the gas.

$p_1 = 101.3$ kN/m^2, $T_1 = 25°C$, $T_2 = 50°C$, $m_1 = m_2$, $\cancel{V}_1 = \cancel{V}_2$; ideal gas law

$\rho_1 = \frac{p_1}{RT_1}$; $\rho_2 = \frac{p_2}{RT_2}$; so $\frac{p_1}{T_1} = \frac{p_2}{T_2}$; $p_2 = p_1\frac{T_2}{T_1} = 101.3\frac{50+273}{25+273}$ or

$\boxed{p_2 = 109.8 \text{ kN/m}^2}$

1.65 What is the density of air at 30°C and 300 kN/m^2?

Ideal gas law $\quad \rho = p/RT$; $\quad$ Table A-6, $\quad R = 286.8$ J/(kg·K)

$T = 30 + 273 = 303$ K; $\quad \rho = \frac{300\,000}{286.8(303)}$ or

$\boxed{\rho = 3.45 \text{ kg/m}^3}$ $\quad SW = \rho g = 3.45(9.81)$; $\boxed{SW = 33.9 \text{ N/m}^3}$

$s = \frac{33.9}{1\,000}$; $\quad \boxed{s = 33.9 \times 10^{-3}}$

1.66 What volume of air would have the same weight of 1 ft^3 of carbon dioxide if both are at room temperature and atmospheric pressure?

For CO_2 from Table A-6, $\rho = 0.00354$ slug/ft^3; for air, $\rho = 0.0023$ slug/ft^3;

$\frac{m}{\cancel{V}} = \frac{p}{RT}$ for CO_2 and for air; 1 ft^3 of CO_2 has a mass of:

$\frac{m}{\cancel{V}} = 0.00354$; $m = 0.00354$ slug; so for the air,

$\frac{0.00354}{\cancel{V}_{air}} = 0.0023$; $\quad \boxed{\cancel{V}_{air} = 1.54 \text{ ft}^3}$

1.67 With the ideal gas law, derive an expression that is useful for relating pressures and volumes at the beginning and end of a process that occurs at constant temperature and constant mass.

Ideal gas law $\rho = p/RT$; beginning $\rho_1 = m_1/\cancel{V}_1 = p_1/RT_1$
end $\rho_2 = m_2/\cancel{V}_2 = p_2/RT_2$; $Rm_1T_1 = p_1\cancel{V}_1$ and $Rm_2T_2 = p_2\cancel{V}_2$
constant temperature and constant mass, so
$p_1\cancel{V}_1 = p_2\cancel{V}_2$; which gives

$$\boxed{\frac{p_1}{p_2} = \frac{\cancel{V}_2}{\cancel{V}_1}}$$

1.68 Use the ideal gas law to derive an expression that is useful for relating temperatures and volumes at the beginning and end of a process that occurs at constant pressure and constant mass.

Ideal gas law $\rho = p/RT$; beginning $\rho_1 = m_1/\cancel{V}_1 = p_1/RT_1$
end $\rho_2 = m_2/\cancel{V}_2 = p_2/RT_2$; $Rm_1T_1 = p_1\cancel{V}_1$ and $Rm_2T_2 = p_2\cancel{V}_2$
constant pressure and mass, so

$$\boxed{\frac{T_2}{T_1} = \frac{\cancel{V}_2}{\cancel{V}_1}}$$

1.69 Beginning with the universal gas constant as $\bar{R} = 49{,}709$ ft·lbf/(slugmol·°R). Use the conversion factor table to determine its value in SI units.

$$49{,}709\,\frac{\text{ft}\cdot\text{lbf}}{\text{slugmol}\cdot°\text{R}} \times 4.448\,\frac{\text{N}}{\text{lbf}} \times 0.3048\,\frac{\text{m}}{\text{ft}} \times \underbrace{\frac{1\text{slugmol}}{14.59\text{ mol}}}_{\text{mass}} \times \underbrace{\frac{9°\text{R}}{5\text{ K}}}_{\text{temp}}$$

conversions

$$\boxed{\bar{R} = 8\,314\,\frac{\text{N}\cdot\text{m}}{\text{mol}\cdot\text{K}}}$$

1.70 A piston-cylinder arrangement contains 0.07 slugs of air. Heat is removed from the air until the air temperature has been reduced by 15°F. For a frictionless piston, determine the change in volume experienced by the air if the pressure remains constant at 2500 lbf/ft^2.

At beginning or end of process, $\rho = \dfrac{p}{RT} = \dfrac{m}{\cancel{V}}$; so

$\cancel{V}_1 = \dfrac{m_1RT_1}{p_1}$; $\cancel{V}_2 = \dfrac{m_2RT_2}{p_2}$; $m_1 = m_2 = 0.07$ slug;
$R = 1710$ ft·lbf/slug·°R from Table A-6; $p_1 = p_2 = 2500$ lbf/ft^2

$\cancel{V}_1 - \cancel{V}_2 = \dfrac{mR}{p}(T_1 - T_2) = \dfrac{0.07(1710)}{2500}(15)$; or

$$\boxed{\cancel{V}_1 - \cancel{V}_2 = 0.72\text{ ft}^3}$$

1.71 Carbon dioxide gas exists in a chamber whose volume is 5 ft^3. The temperature of the gas is uniform at 40°C and the pressure is 3 atm. What is the mass of carbon dioxide contained?

CO_2 from Table A-6, R = 189 J/(kg·K); $\rho = \frac{p}{RT} = \frac{m}{\cancel{V}}$;

$m = \frac{p\cancel{V}}{RT}$; $p = 3 \text{ atm} \cdot 101\,300 \frac{N/m^2}{atm} = 303\,900 \text{ N/m}^2$

$T = 40°C + 273 = 313$ K; $\cancel{V} = 5 \text{ ft}^3 \cdot (0.3048 \text{ m/ft})^3 = 0.142 \text{ m}^3$

$m = \frac{303\,900(0.142)}{189(313)} = \boxed{0.73 \text{ kg of } CO_2}$

1.72 A rigid vessel containing 8 kg of argon is heated until its temperature increases by 20°C. Determine the final pressure of the argon if its initial temperature is 28°C and its pressure is 150 kN/m².

Argon; at beginning or end, $\rho = \frac{p}{RT} = \frac{m}{\cancel{V}}$; so $\rho = \frac{p_1}{RT_1}$ and $\rho = \frac{p_2}{RT_2}$

Mass and volume both constant, $\rho_1 = \rho_2$; and $\frac{p_1}{T_1} = \frac{p_2}{T_2}$;

$T_2 = T_1 + 20.0$ K; $T_1 = 28°C$; $T_2 = 48°C$; $p_1 = 150 \text{ kN/m}^2$

$p_2 = p_1 \frac{T_2}{T_1} = 150 \frac{48 + 273}{28 + 273}$; $\boxed{p_2 = 160 \text{ kN/m}^2}$

1.73 A certain gas a molecular mass of 40. It is under a pressure of 2.5 atm and a temperature of 25°C. Determine its density and pressure in g/cm³.

$MW = 40$; $p = 2.5 \text{ atm} \cdot 101\,300 \frac{N/m^2}{atm} = 253\,250 \text{ N/m}^2$; $T = 25°C$;

Converting, $p = \frac{253\,250}{1 \times 10^{-1}} = \boxed{2.53 \times 10^6 \text{ dyne/cm}^2}$

$T = 273 + 25 = 298$; $R = \frac{\bar{R}}{MW} = \frac{8\,312 \text{ N·m/(mol·K)}}{40 \text{ kg/mol}}$;

$R = 207.8$ N·m/(kg·K); $\rho = \frac{p}{RT} = \frac{253\,250}{107.8(298)} = 4.089 \text{ kg/m}^3$;

converting,

$\rho = \frac{4.089}{1 \times 10^3}$; $\boxed{\rho = 4.089 \times 10^{-3} \text{ g/cm}^3}$

1.74 Appendix Table A.3 gives properties of air at atmospheric pressure and for various temperatures. Atmospheric pressure is 101.3 kN/m². With this information, verify values of density in the table corresponding to any 4 temperatures of your choosing.

$\rho = \frac{p}{RT}$; $p = 101\,300 \text{ N/m}^2$; $R = 286.8$ J/(kg·K) from Table A-6; so

$\rho = \frac{0.353 \times 10^3}{T} \text{ kg/m}^3$

T	ρ (from above eq)	ρ from App Table
250	1.413	1.413
300	1.177	1.177
350	1.009	1.008
400	0.883	0.882

1.75 A gas mixture has a density of 0.01 kg/m³ when a pressure of 4 atm is exerted on it. Determine its molecular mass if its temperature is 40°C.

$$\rho = 0.01 \text{ kg/m}^3 = \frac{p}{RT}\,;\ R = \frac{8\,312 \text{ N·m/(mol·K)}}{\text{Mol Mass}}\,;$$

$$p = 4 \text{ atm} \cdot 101\,300 \frac{\text{N/m}^2}{\text{atm}} = 405\,200 \text{ N/m}^2\,;\ T = 40°\text{C} + 273 = 313 \text{ K}$$

$$R = \frac{p}{\rho T}\,; \qquad \frac{8\,312}{\text{Mol Mass}} = \frac{405\,200}{0.01(313)} = 1.29 \times 10^5 \text{ ; so}$$

$$\text{Mol Mass} = \frac{1.29 \times 10^5}{8\,312}\,; \qquad \boxed{\text{Mol Mass} = 15.5}$$