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**1.11** If $V$ is a velocity, $\ell$ a length, and $\nu$ a fluid property (the kinematic viscosity) having dimensions of $L^2T^{-1}$, which of the following combinations are dimensionless: **(a)** $V\ell\nu$, **(b)** $V\ell/\nu$, **(c)** $V^2\nu$, **(d)** $V/\ell\nu$?

**1.12** If $V$ is a velocity, determine the dimensions of $Z$, $\alpha$, and $G$, which appear in the dimensionally homogeneous equation

$$V = Z(\alpha - 1) + G$$

**1.13** The volume rate of flow, $Q$, through a pipe containing a slowly moving liquid is given by the equation

$$Q = \frac{\pi R^4 \Delta p}{8\mu\ell}$$

where $R$ is the pipe radius, $\Delta p$ the pressure drop along the pipe, $\mu$ a fluid property called viscosity $(FL^{-2}T)$, and $\ell$ the length of pipe. What are the dimensions of the constant $\pi/8$? Would you classify this equation as a general homogeneous equation? Explain.

**1.14** According to information found in an old hydraulics book, the energy loss per unit weight of fluid flowing through a nozzle connected to a hose can be estimated by the formula

$$h = (0.04 \text{ to } 0.09)(D/d)^4 V^2/2g$$

where $h$ is the energy loss per unit weight, $D$ the hose diameter, $d$ the nozzle tip diameter, $V$ the fluid velocity in the hose, and $g$ the acceleration of gravity. Do you think this equation is valid in any system of units? Explain.

**1.15** The pressure difference, $\Delta p$, across a partial blockage in an artery (called a *stenosis*) is approximated by the equation

$$\Delta p = K_v \frac{\mu V}{D} + K_u \left(\frac{A_0}{A_1} - 1\right)^2 \rho V^2$$

where $V$ is the blood velocity, $\mu$ the blood viscosity $(FL^{-2}T)$, $\rho$ the blood density $(ML^{-3})$, $D$ the artery diameter, $A_0$ the area of the unobstructed artery, and $A_1$ the area of the stenosis. Determine the dimensions of the constants $K_v$ and $K_u$. Would this equation be valid in any system of units?

**1.16** Assume that the speed of sound, $c$, in a fluid depends on an elastic modulus, $E_v$, with dimensions $FL^{-2}$, and the fluid density, $\rho$, in the form $c = (E_v)^a(\rho)^b$. If this is to be a dimensionally homogeneous equation, what are the values for $a$ and $b$? Is your result consistent with the standard formula for the speed of sound? (See Eq. 1.19.)

**1.17** A formula to estimate the volume rate of flow, $Q$, flowing over a dam of length, $B$, is given by the equation

$$Q = 1.70\, BH^{3/2}$$

where $H$ is the depth of the water above the top of the dam (called the head). This formula gives $Q$ in m$^3$/s when $B$ and $H$ are in meter. Is the constant, 1.70, dimensionless? Would this equation be valid if units other than meter and seconds were used?

**1.18** The force, $P$, that is exerted on a spherical particle moving slowly through a liquid is given by the equation

$$P = 3\pi\mu D V$$

where $\mu$ is a fluid property (viscosity) having dimensions of $FL^{-2}T$, $D$ is the particle diameter, and $V$ is the particle velocity. What are the dimensions of the constant, $3\pi$? Would you classify this equation as a general homogeneous equation?

**†1.19** Cite an example of a restricted homogeneous equation contained in a technical article found in an engineering journal in your field of interest. Define all terms in the equation, explain why it is a restricted equation, and provide a complete journal citation (title, date, etc.).

**1.20** Water flows from a large drainage pipe at a rate of 4500 L/min. What is this volume rate of flow in m$^3$/s?

**1.21** Dimensionless combinations of quantities (commonly called dimensionless parameters) play an important role in fluid mechanics. Make up five possible dimensionless parameters by using combinations of some of the quantities listed in Table 1.1.

**1.22** WILEY GO An important dimensionless parameter in certain types of fluid flow problems is the *Froude number* defined as $V/\sqrt{g\ell}$, where $V$ is a velocity, $g$ the acceleration of gravity, and $\ell$ a length. Determine the value of the Froude number for $V = 3$ m/s, $g = 9.81$ m/s$^2$, and $\ell = 0.6$ m. Recalculate the Froude number using SI units for $V$, $g$, and $\ell$. Explain the significance of the results of these calculations.

## Section 1.4 Measures of Fluid Mass and Weight

**1.23** Obtain a photograph/image of a situation in which the density or specific weight of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

**1.24** A tank contains 500 kg of a liquid whose specific gravity is 2. Determine the volume of the liquid in the tank.

**1.25** Clouds can weigh thousands of pounds due to their liquid water content. Often this content is measured in grams per cubic meter (g/m$^3$). Assume that a cumulus cloud occupies a volume of one cubic kilometer, and its liquid water content is 0.2 g/m$^3$. **(a)** What is the volume of this cloud in cubic kilometers? **(b)** How much does the water in the cloud weigh in newtons?

**1.26** A tank of oil has a mass of 365 kg. **(a)** Determine its weight in newtons at the Earth's surface. **(b)** What would be its mass (in kg) and its weight (in newtons) if located on the moon's surface where the gravitational attraction is approximately one-sixth that at the Earth's surface?

**1.27** A certain object weighs 300 N at the Earth's surface. Determine the mass of the object (in kilograms) and its weight (in newtons) when located on a planet with an acceleration of gravity equal to 1.92 m/s$^2$.

**1.28** The density of a certain type of jet fuel is 775 kg/m$^3$. Determine its specific gravity and specific weight.

**1.29** A *hydrometer* is used to measure the specific gravity of liquids. (See **Video V2.8**.) For a certain liquid, a hydrometer reading indicates a specific gravity of 1.15. What is the liquid's density and specific weight? Express your answer in SI units.

**1.30** The specific weight of a certain liquid is 1366 kg/m$^3$. Determine its density and specific gravity.

**1.31** An open, rigid-walled, cylindrical tank contains 0.1 m$^3$ of water at 4 °C. Over a 24-hour period of time the water temperature varies from 4 to 32 °C. Make use of the data in Appendix B to determine how much the volume of water will change. For a

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tank diameter of 0.6 m, would the corresponding change in water depth be very noticeable? Explain.

†**1.32** Estimate the number of kilogram of mercury it would take to fill your bathtub. List all assumptions and show all calculations.

**1.33** A mountain climber's oxygen tank contains 4.45 N of oxygen when he begins his trip at sea level where the acceleration of gravity is 9.81 m/s$^2$. What is the weight of the oxygen in the tank when he reaches the top of Mt. Everest where the acceleration of gravity is 9.78 m/s$^2$? Assume that no oxygen has been removed from the tank; it will be used on the descent portion of the climb.

**1.34** WILEY GO The information on a can of pop indicates that the can contains 355 mL. The mass of a full can of pop is 0.369 kg, while an empty can weighs 0.153 N. Determine the specific weight, density, and specific gravity of the pop and compare your results with the corresponding values for water at 20 °C. Express your results in SI units.

***1.35** WILEY The variation in the density of water, $\rho$, with temperature, $T$, in the range 20 °C $\le T \le$ 50 °C, is given in the following table.

| Density (kg/m$^3$) | 998.2 | 997.1 | 995.7 | 994.1 | 992.2 | 990.2 | 988.1 |
|---|---|---|---|---|---|---|---|
| Temperature (°C) | 20 | 25 | 30 | 35 | 40 | 45 | 50 |

Use these data to determine an empirical equation of the form $\rho = c_1 + c_2T + c_3T^2$, which can be used to predict the density over the range indicated. Compare the predicted values with the data given. What is the density of water at 42.1 °C?

**1.36** WILEY If 1 cup of cream having a density of 1005 kg/m$^3$ is turned into 3 cups of whipped cream, determine the specific gravity and specific weight of the whipped cream.

**1.37** A liquid when poured into a graduated cylinder is found to weigh 8 N when occupying a volume of 500 ml (milliliters). Determine its specific weight, density, and specific gravity.

†**1.38** The presence of raindrops in the air during a heavy rainstorm increases the average density of the air–water mixture. Estimate by what percent the average air–water density is greater than that of just still air. State all assumptions and show calculations.

## Section 1.5 Ideal Gas Law

**1.39** Determine the mass of air in a 2 m$^3$ tank if the air is at room temperature, 20 °C, and the absolute pressure within the tank is 200 kPa (abs).

**1.40** WILEY Nitrogen is compressed to a density of 4 kg/m$^3$ under an absolute pressure of 400 kPa. Determine the temperature in degrees Celsius.

**1.41** WILEY The temperature and pressure at the surface of Mars during a Martian spring day were determined to be −50 °C and 900 Pa, respectively. **(a)** Determine the density of the Martian atmosphere for these conditions if the gas constant for the Martian atmosphere is assumed to be equivalent to that of carbon dioxide. **(b)** Compare the answer from part (a) with the density of the Earth's atmosphere during a spring day when the temperature is 18 °C and the pressure 101.6 kPa (abs).

**1.42** WILEY A closed tank having a volume of 0.06 m$^3$ is filled with 1.3 N of a gas. A pressure gage attached to the tank reads 83 kPa when the gas temperature is 27 °C. There is some question as to whether the gas in the tank is oxygen or helium. Which do you think it is? Explain how you arrived at your answer.

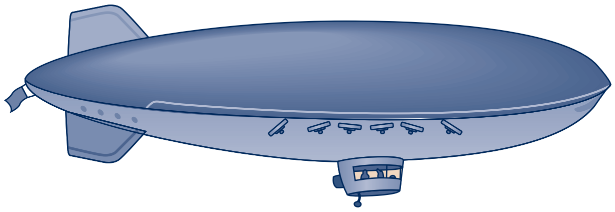
**1.43** A tire having a volume of 0.081 m$^3$ contains air at a gage pressure of 180 kPa and a temperature of 21 °C. Determine the density of the air and the weight of the air contained in the tire.

**1.44** WILEY A compressed air tank contains 5 kg of air at a temperature of 80 °C. A gage on the tank reads 300 kPa. Determine the volume of the tank.

**1.45** WILEY A rigid tank contains air at a pressure of 620 kPa and a temperature of 15 °C. By how much will the pressure increase as the temperature is increased to 43 °C?

**1.46** The density of oxygen contained in a tank is 2.0 kg/m$^3$ when the temperature is 25 °C. Determine the gage pressure of the gas if the atmospheric pressure is 97 kPa.

**1.47** The helium-filled blimp shown in Fig. P1.47 is used at various athletic events. Determine the number of newtons of helium within it if its volume is 1926 m$^3$ and the temperature and pressure are 27 °C and 98 kPa, respectively.



■ **Figure P1.47**

***1.48** Develop a computer program for calculating the density of an ideal gas when the gas pressure in pascals (abs), the temperature in degrees Celsius, and the gas constant in J/kg · K are specified. Plot the density of helium as a function of temperature from 0 °C to 200 °C and pressures of 50, 100, 150, and 200 kPa (abs).

## Section 1.6 Viscosity (also see Lab Problems 1.1LP and 1.2LP)

**1.49** Obtain a photograph/image of a situation in which the viscosity of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

**1.50** For flowing water, what is the magnitude of the velocity gradient needed to produce a shear stress of 1.0 N/m$^2$?

**1.51** Make use of the data in Appendix B to determine the dynamic viscosity of glycerin at 29 °C.

**1.52** Make use of the data in Appendix B to determine the dynamic viscosity of mercury at 24 °C.

**1.53** WILEY One type of *capillary-tube viscometer* is shown in **Video V1.5** and in Fig. P1.53. For this device the liquid to be tested is drawn into the tube to a level above the top etched line. The time is then obtained for the liquid to drain to the bottom etched line. The kinematic viscosity, $\nu$, in m$^2$/s is then obtained from the equation $\nu = KR^4t$ where $K$ is a constant, $R$ is the radius of the capillary

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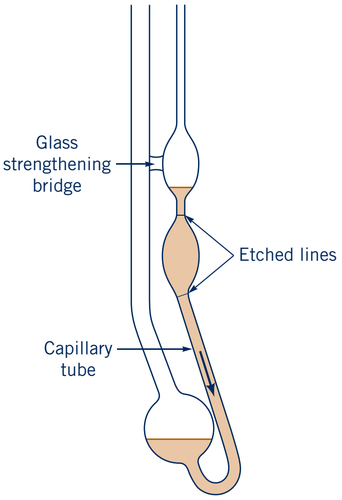
tube in mm, and $t$ is the drain time in seconds. When glycerin at 20 °C is used as a calibration fluid in a particular viscometer, the drain time is 1430 s. When a liquid having a density of 970 kg/m$^3$ is tested in the same viscometer the drain time is 900 s. What is the dynamic viscosity of this liquid?




■ **Figure P1.53**

**1.54** The viscosity of a soft drink was determined by using a capillary tube viscometer similar to that shown in Fig. P1.53 and **Video V1.5**. For this device the kinematic viscosity, $\nu$, is directly proportional to the time, $t$, that it takes for a given amount of liquid to flow through a small capillary tube. That is, $\nu = Kt$. The following data were obtained from regular pop and diet pop. The corresponding measured specific gravities are also given. Based on these data, by what percent is the absolute viscosity, $\mu$, of regular pop greater than that of diet pop?

| | Regular pop | Diet pop |
|---|---|---|
| $t$(s) | 377.8 | 300.3 |
| $SG$ | 1.044 | 1.003 |

**1.55** Determine the ratio of the dynamic viscosity of water to air at a temperature of 60 °C. Compare this value with the corresponding ratio of kinematic viscosities. Assume the air is at standard atmospheric pressure.

**1.56** The kinematic viscosity and specific gravity of a liquid are $3.5 \times 10^{-4}$ m$^2$/s and 0.79, respectively. What is the dynamic viscosity of the liquid in SI units?

**1.57** A liquid has a specific weight of 945 kg/m$^3$ and a dynamic viscosity of 131.67 N.s/m$^2$. Determine its kinematic viscosity.

**1.58** The kinematic viscosity of oxygen at 20 °C and a pressure of 150 kPa (abs) is 0.104 stokes. Determine the dynamic viscosity of oxygen at this temperature and pressure.

***1.59** Fluids for which the shearing stress, $\tau$, is not linearly related to the rate of shearing strain, $\dot{\gamma}$, are designated as non-Newtonian fluids. Such fluids are commonplace and can exhibit unusual behavior, as shown in **Video V1.6**. Some experimental data obtained for a particular non-Newtonian fluid at 27 °C are shown below.

| $\tau$(kPa) | 0 | 0.1 | 0.37 | 0.89 | 1.5 |
|---|---|---|---|---|---|
| $\dot{\gamma}$ (s$^{-1}$) | 0 | 50 | 100 | 150 | 200 |

Plot these data and fit a second-order polynomial to the data using a suitable graphing program. What is the apparent viscosity of this fluid when the rate of shearing strain is 70 s$^{-1}$? Is this apparent viscosity larger or smaller than that for water at the same temperature?

**1.60** Water flows near a flat surface and some measurements of the water velocity, $u$, parallel to the surface, at different heights, $y$, above the surface are obtained. At the surface $y = 0$. After an analysis of the data, the lab technician reports that the velocity distribution in the range $0 < y < 0.1$ m is given by the equation

$$u = 0.81 + 9.2y + 4.1 \times 10^3 y^3$$

with $u$ in m/s when $y$ is in m. (**a**) Do you think that this equation would be valid in any system of units? Explain. (**b**) Do you think this equation is correct? Explain. You may want to look at **Video 1.4** to help you arrive at your answer.

**1.61** Calculate the Reynolds numbers for the flow of water and for air through a 4 mm diameter tube, if the mean velocity is 3 m/s and the temperature is 30 °C in both cases (see Example 1.4). Assume the air is at standard atmospheric pressure.

**1.62** SAE 30 oil at 15 °C flows through a 5 cm diameter pipe with a mean velocity of 1.5 m/s. Determine the value of the Reynolds number (see Example 1.4).

**1.63** For air at standard atmospheric pressure the values of the constants that appear in the Sutherland equation (Eq. 1.10) are $C = 1.458 \times 10^{-6}$ kg/(m · s · K$^{1/2}$) and $S = 110.4$ K. Use these values to predict the viscosity of air at 10 °C and 90 °C and compare with values given in Table B.4 in Appendix B.

***1.64** Use the values of viscosity of air given in Table B.4 at temperatures of 0, 20, 40, 60, 80, and 100 °C to determine the constants $C$ and $S$ which appear in the Sutherland equation (Eq. 1.10). Compare your results with the values given in Problem 1.68. (*Hint:* Rewrite the equation in the form

$$\frac{T^{3/2}}{\mu} = \left(\frac{1}{C}\right) T + \frac{S}{C}$$

and plot $T^{3/2}/\mu$ versus $T$. From the slope and intercept of this curve, $C$ and $S$ can be obtained.)

**1.65** The viscosity of a fluid plays a very important role in determining how a fluid flows. (See **Video V1.3**.) The value of the viscosity depends not only on the specific fluid but also on the fluid temperature. Some experiments show that when a liquid, under the action of a constant driving pressure, is forced with a low velocity, $V$, through a small horizontal tube, the velocity is given by the equation $V = K/\mu$. In this equation $K$ is a constant for a given tube and pressure, and $\mu$ is the dynamic viscosity. For a particular liquid of interest, the viscosity is given by Andrade's equation (Eq. 1.11) with $D = 0.000023$ N.s/m$^2$ and $B = 2222$ K. By what percentage will the velocity increase as the liquid temperature is increased from 4 °C to 37 °C? Assume all other factors remain constant.

***1.66** Use the value of the viscosity of water given in Table B.2 at temperatures of 0, 20, 40, 60, 80, and 100 °C to determine the constants $D$ and $B$ which appear in Andrade's equation (Eq. 1.11). Calculate the value of the viscosity at 50 °C and compare with the value given in Table B.2. (*Hint:* Rewrite the equation in the form

$$\ln \mu = (B)\frac{1}{T} + \ln D$$

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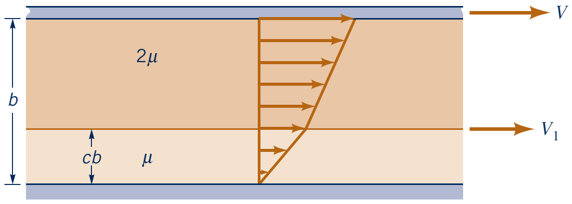
and plot ln $\mu$ versus $1/T$. From the slope and intercept of this curve, $B$ and $D$ can be obtained. If a nonlinear curve-fitting program is available, the constants can be obtained directly from Eq. 1.11 without rewriting the equation.)

**1.67** For a certain liquid $\mu = 0.0034$ N.s/m$^2$ at 4 °C and $\mu = 0.009$ N.s/m$^2$ at 66 °C. Make use of these data to determine the constants $D$ and $B$ which appear in Andrade's equation (Eq. 1.11). What would be the viscosity at 27 °C?

**1.68** For a parallel plate arrangement of the type shown in Fig. 1.5 it is found that when the distance between plates is 2 mm, a shearing stress of 150 Pa develops at the upper plate when it is pulled at a velocity of 1 m/s. Determine the viscosity of the fluid between the plates. Express your answer in SI units.

**1.69** Two flat plates are oriented parallel above a fixed lower plate as shown in Fig. P1.69. The top plate, located a distance $b$ above the fixed plate, is pulled along with speed $V$. The other thin plate is located a distance $cb$, where $0 < c < 1$, above the fixed plate. This plate moves with speed $V_1$, which is determined by the viscous shear forces imposed on it by the fluids on its top and bottom. The fluid on the top is twice as viscous as that on the bottom. Plot the ratio $V_1/V$ as a function of $c$ for $0 < c < 1$.

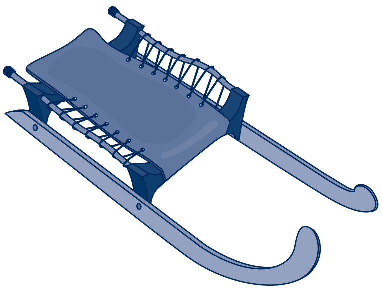



■ **Figure P1.69**

**1.70** There are many fluids that exhibit non-Newtonian behavior (see, for example, **Video V1.6**). For a given fluid the distinction between Newtonian and non-Newtonian behavior is usually based on measurements of shear stress and rate of shearing strain. Assume that the viscosity of blood is to be determined by measurements of shear stress, $\tau$, and rate of shearing strain, $du/dy$, obtained from a small blood sample tested in a suitable viscometer. Based on the data given below, determine if the blood is a Newtonian or non-Newtonian fluid. Explain how you arrived at your answer.

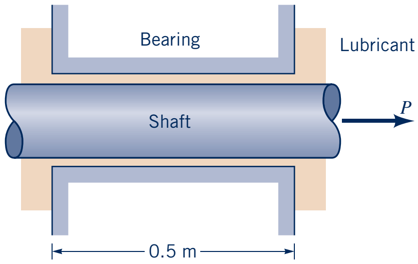
| $\tau$ (N/m$^2$) | 0.04 | 0.06 | 0.12 | 0.18 | 0.30 | 0.52 | 1.12 | 2.10 |
|---|---|---|---|---|---|---|---|---|
| $du/dy$ (s$^{-1}$) | 2.25 | 4.50 | 11.25 | 22.5 | 45.0 | 90.0 | 225 | 450 |

**1.71** The sled shown in Fig. P1.71 slides along on a thin horizontal layer of water between the ice and the runners. The horizontal force that the water puts on the runners is equal to 5.3 N when the sled's speed is 15 m/s. The total area of both runners in contact with the water is 0.007 m$^2$, and the viscosity of the water is $168 \times 10^{-5}$ N.s/m$^2$. Determine the thickness of the water layer under the runners. Assume a linear velocity distribution in the water layer.



■ **Figure P1.71**

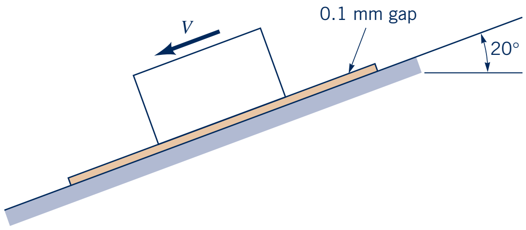
**1.72** A 25 mm diameter shaft is pulled through a cylindrical bearing as shown in Fig. P1.72. The lubricant that fills the 0.3 mm gap between the shaft and bearing is an oil having a kinematic viscosity of $8.0 \times 10^{-4}$ m$^2$/s and a specific gravity of 0.91. Determine the force $P$ required to pull the shaft at a velocity of 3 m/s. Assume the velocity distribution in the gap is linear.




■ **Figure P1.72**

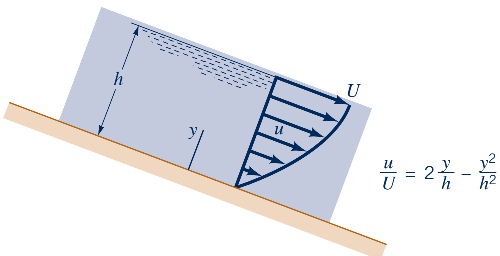
**1.73** A piston having a diameter of 13.92 cm and a length of 24.13 cm slides downward with a velocity $V$ through a vertical pipe. The downward motion is resisted by an oil film between the piston and the pipe wall. The film thickness is 0.005 cm, and the cylinder weighs 0.23 kg. Estimate $V$ if the oil viscosity is 0.766 N.s/m$^2$. Assume the velocity distribution in the gap is linear.

**1.74** A 10 kg block slides down a smooth inclined surface as shown in Fig. P1.74. Determine the terminal velocity of the block if the 0.1 mm gap between the block and the surface contains SAE 30 oil at 15 °C. Assume the velocity distribution in the gap is linear, and the area of the block in contact with the oil is 0.1 m$^2$.




■ **Figure P1.74**

**1.75** A layer of water flows down an inclined fixed surface with the velocity profile shown in Fig. P1.75. Determine the magnitude and direction of the shearing stress that the water exerts on the fixed surface for $U = 2$ m/s and $h = 0.1$ m.




■ **Figure P1.75**

**1.76** A thin layer of glycerin flows down an inclined, wide plate with the velocity distribution shown in Fig. P1.76. For $h =$ 0.75 cm and $\alpha = 20°$, determine the surface velocity, $U$. Note that for equilibrium, the component of weight acting parallel to the plate surface must be balanced by the shearing force developed along the plate surface. In your analysis assume a unit plate width.

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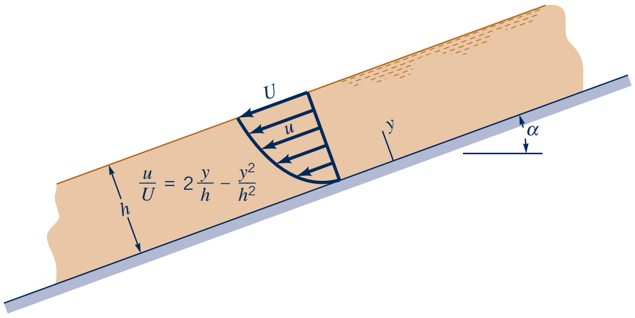



■ **Figure P1.76**

***1.77** Standard air flows past a flat surface, and velocity measurements near the surface indicate the following distribution:

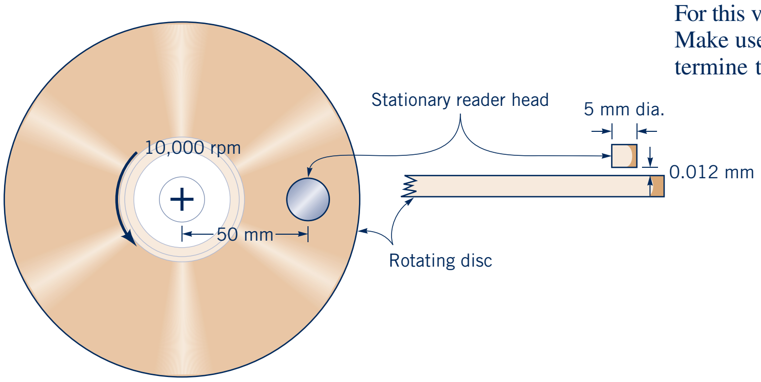
| $y$ (m) | $1.5\times10^{-3}$ | $3\times10^{-3}$ | $6\times10^{-3}$ | $12\times10^{-3}$ | $18\times10^{-3}$ | $24\times10^{-3}$ |
|---|---|---|---|---|---|---|
| $u$ (m/s) | 0.23 | 0.46 | 0.92 | 1.94 | 3.11 | 4.39 |

The coordinate $y$ is measured normal to the surface and $u$ is the velocity parallel to the surface. **(a)** Assume the velocity distribution is of the form

$$u = C_1 y + C_2 y^3$$

and use a standard curve-fitting technique to determine the constants $C_1$ and $C_2$. **(b)** Make use of the results of part (a) to determine the magnitude of the shearing stress at the wall ($y = 0$) and at $y = 0.05$ ft.

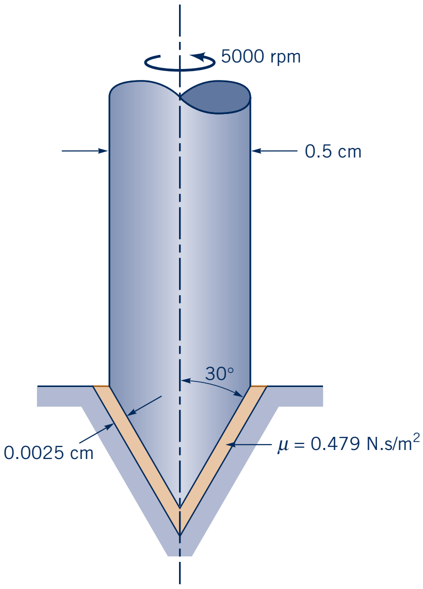
**1.78** A new computer drive is proposed to have a disc, as shown in Fig. P1.78. The disc is to rotate at 10,000 rpm, and the reader head is to be positioned 0.012 mm above the surface of the disc. Estimate the shearing force on the reader head as a result of the air between the disc and the head.




■ **Figure P1.78**

**1.79** The space between two 15 cm long concentric cylinders is filled with glycerin (viscosity $= 407 \times 10^{-3}$ N.s/m$^2$). The inner cylinder has a radius of 7.6 cm and the gap width between cylinders is 0.25 cm. Determine the torque and the power required to rotate the inner cylinder at 180 rev/min. The outer cylinder is fixed. Assume the velocity distribution in the gap to be linear.

**1.80** A pivot bearing used on the shaft of an electrical instrument is shown in Fig. P1.80. An oil with a viscosity of $\mu =$ 0.479 N.s/m$^2$ fills the 0.0025 cm gap between the rotating shaft and the stationary base. Determine the frictional torque on the shaft when it rotates at 5000 rpm.

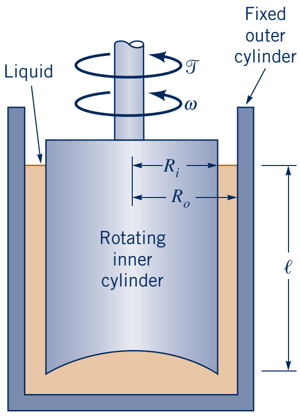



■ **Figure P1.80**

**1.81** The viscosity of liquids can be measured through the use of a *rotating cylinder viscometer* of the type illustrated in Fig. P1.81. In this device the outer cylinder is fixed and the inner cylinder is rotated with an angular velocity, $\omega$. The torque $\mathcal{T}$ required to develop $\omega$ is measured and the viscosity is calculated from these two measurements. **(a)** Develop an equation relating $\mu$, $\omega$, $\mathcal{T}$, $\ell$, $R_o$, and $R_i$. Neglect end effects and assume the velocity distribution in the gap is linear. **(b)** The following torque-angular velocity data were obtained with a rotating cylinder viscometer of the type discussed in part (a).

| Torque (N.m) | 17.8 | 35.3 | 53.6 | 71.5 | 87.9 | 106.5 |
|---|---|---|---|---|---|---|
| Angular velocity (rad/s) | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 |

For this viscometer $R_o = 6.35$ cm, $R_i = 6.22$ cm, and $\ell = 12.7$ cm. Make use of these data and a standard curve-fitting program to determine the viscosity of the liquid contained in the viscometer.




■ **Figure P1.81**

**1.82** One type of rotating cylinder viscometer, called a *Stormer* viscometer, uses a falling weight, $\mathcal{W}$, to cause the cylinder to rotate with an angular velocity, $\omega$, as illustrated in Fig. P1.82. For this device the viscosity, $\mu$, of the liquid is related to $\mathcal{W}$ and $\omega$ through the equation $\mathcal{W} = K\mu\omega$, where $K$ is a constant that depends only on the geometry (including the liquid depth) of the

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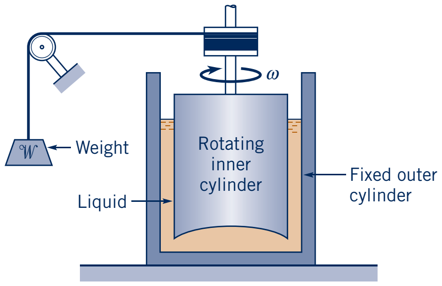
viscometer. The value of $K$ is usually determined by using a calibration liquid (a liquid of known viscosity).

**(a)** Some data for a particular Stormer viscometer, obtained using glycerin at 20 °C as a calibration liquid, are given below. Plot values of the weight as ordinates and values of the angular velocity as abscissae. Draw the best curve through the plotted points and determine $K$ for the viscometer.

| $\mathcal{W}$(kg) | 0.1 | 0.3 | 0.5 | 0.7 | 1 |
|---|---|---|---|---|---|
| $\omega$ (rev/s) | 0.53 | 1.59 | 2.79 | 3.83 | 5.49 |

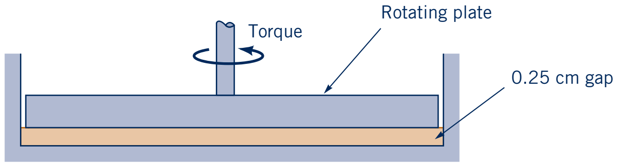
**(b)** A liquid of unknown viscosity is placed in the same viscometer used in part (a), and the data given below are obtained. Determine the viscosity of this liquid.

| $\mathcal{W}$(kg) | 0.02 | 0.05 | 0.1 | 0.15 | 0.2 |
|---|---|---|---|---|---|
| $\omega$ (rev/s) | 0.72 | 1.89 | 3.73 | 5.44 | 7.42 |




■ **Figure P1.82**

**1.83** A 30 cm diameter circular plate is placed over a fixed bottom plate with a 0.25 cm gap between the two plates filled with glycerin as shown in Fig. P1.83. Determine the torque required to rotate the circular plate slowly at 2 rpm. Assume that the velocity distribution in the gap is linear and that the shear stress on the edge of the rotating plate is negligible.




■ **Figure P1.83**

**†1.84** Vehicle shock absorbers damp out oscillations caused by road roughness. Describe how a temperature change may affect the operation of a shock absorber.

**1.85** Some measurements on a blood sample at 37 °C indicate a shearing stress of 0.52 N/m$^2$ for a corresponding rate of shearing strain of 200 s$^{-1}$. Determine the apparent viscosity of the blood and compare it with the viscosity of water at the same temperature.

## Section 1.7 Compressibility of Fluids

**1.86** Obtain a photograph/image of a situation in which the compressibility of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

**1.87** A sound wave is observed to travel through a liquid with a speed of 1500 m/s. The specific gravity of the liquid is 1.5. Determine the bulk modulus for this fluid.

**1.88** A rigid-walled cubical container is completely filled with water at 4 °C and sealed. The water is then heated to 38 °C. Determine the pressure that develops in the container when the water reaches this higher temperature. Assume that the volume of the container remains constant and the value of the bulk modulus of the water remains constant and equal to 2.1 GPa.

**1.89** In a test to determine the bulk modulus of a liquid it was found that as the absolute pressure was changed from 103 to 21 MPa the volume decreased from 167.8 to 166.13 cm$^3$. Determine the bulk modulus for this liquid.

**1.90** Estimate the increase in pressure (in kPa) required to decrease a unit volume of mercury by 0.1%.

**1.91** A 1 m$^3$ volume of water is contained in a rigid container. Estimate the change in the volume of the water when a piston applies a pressure of 35 MPa.

**1.92** Determine the speed of sound at 20 °C in **(a)** air, **(b)** helium, and **(c)** natural gas (methane). Express your answer in m/s.

**1.93** Calculate the speed of sound in m/s for **(a)** gasoline, **(b)** mercury, and **(c)** seawater.

**1.94** Air is enclosed by a rigid cylinder containing a piston. A pressure gage attached to the cylinder indicates an initial reading of 172 kPa. Determine the reading on the gage when the piston has compressed the air to one-third its original volume. Assume the compression process to be isothermal and the local atmospheric pressure to be 101.3 kPa.

**1.95** Repeat Problem 1.94 if the compression process takes place without friction and without heat transfer (isentropic process).

**1.96** Carbon dioxide at 30 °C and 300 kPa absolute pressure expands isothermally to an absolute pressure of 165 kPa. Determine the final density of the gas.

**1.97** Oxygen at 30 °C and 300 kPa absolute pressure expands isothermally to an absolute pressure of 120 kPa. Determine the final density of the gas.

**1.98** Natural gas at 21 °C and standard atmospheric pressure of 101.3 kPa (abs) is compressed isentropically to a new absolute pressure of 483 kPa. Determine the final density and temperature of the gas.

**1.99** Compare the isentropic bulk modulus of air at 101 kPa (abs) with that of water at the same pressure.

***1.100** Develop a computer program for calculating the final gage pressure of gas when the initial gage pressure, initial and final volumes, atmospheric pressure, and the type of process (isothermal or isentropic) are specified. Check your program against the results obtained for Problem 1.94.

**1.101** Often the assumption is made that the flow of a certain fluid can be considered as incompressible flow if the density of the fluid changes by less than 2%. If air is flowing through a tube such that the air pressure at one section is 62 kPa and at a downstream section it is 59 kPa at the same temperature, do you think that this flow could be considered an incompressible flow? Support your answer with the necessary calculations. Assume standard atmospheric pressure.

**1.102** An important dimensionless parameter concerned with very high-speed flow is the *Mach number*, defined as $V/c$, where $V$ is the speed of the object such as an airplane or projectile, and $c$ is the speed of sound in the fluid surrounding the object. For a projectile traveling at 1290 km/h through air at 10 °C

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and standard atmospheric pressure, what is the value of the Mach number?

**1.103** Jet airliners typically fly at altitudes between approximately 0 to 12200 m. Make use of the data in Appendix C to show on a graph how the speed of sound varies over this range.

**1.104** (See Fluids in the News article titled **"This water jet is a blast,"** Section 1.7.1.) By what percent is the volume of water decreased if its pressure is increased to an equivalent to 304 MPa?

## Section 1.8 Vapor Pressure

**1.105** During a mountain climbing trip it is observed that the water used to cook a meal boils at 90 °C rather than the standard 100 °C at sea level. At what altitude are the climbers preparing their meal? (See Tables B.2 and C.2 for data needed to solve this problem.)

**1.106** When a fluid flows through a sharp bend, low pressures may develop in localized regions of the bend. Estimate the minimum absolute pressure (in kPa) that can develop without causing cavitation if the fluid is water at 70 °C.

**1.107** A partially filled closed tank contains ethyl alcohol at 20 °C. If the air above the alcohol is evacuated, what is the minimum absolute pressure that develops in the evacuated space?

**1.108** Estimate the minimum absolute pressure (in pascals) that can be developed at the inlet of a pump to avoid cavitation if the fluid is carbon tetrachloride at 20 °C.

**1.109** When water at 70 °C flows through a converging section of pipe, the pressure decreases in the direction of flow. Estimate the minimum absolute pressure that can develop without causing cavitation. Express your answer in SI units.

**1.110** At what atmospheric pressure will water boil at 35 °C? Express your answer in SI units.

## Section 1.9 Surface Tension

**1.111** Obtain a photograph/image of a situation in which the surface tension of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

**1.112** 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 (see **Video V1.10**). The contact angle between the liquid and the tube is zero, and the specific weight of the liquid is $1.2 \times 10^4$ N/m$^3$. Determine the value of the surface tension for this liquid.

**1.113** An open 2 mm diameter tube is inserted into a pan of ethyl alcohol, and a similar 4 mm diameter tube is inserted into a pan of water. In which tube will the height of the rise of the fluid column due to capillary action be the greatest? Assume the angle of contact is the same for both tubes.

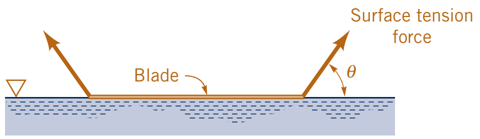
**1.114** Small droplets of carbon tetrachloride at 20 °C are formed with a spray nozzle. If the average diameter of the droplets is 200 $\mu$m, what is the difference in pressure between the inside and outside of the droplets?

**1.115** 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.

**1.116** Estimate the excess pressure inside a raindrop having a diameter of 3 mm.

**1.117** What is the difference between the pressure inside a soap bubble and atmospheric pressure for a 7.5 cm diameter bubble? Assume the surface tension of the soap film to be 70% of that of water at 21 °C.

**1.118** 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 $\theta$ relative to the water surface as shown in Fig. P1.118. **(a)** The mass of the double-edge blade is $0.64 \times 10^{-3}$ kg, and the total length of its sides is 206 mm. Determine the value of $\theta$ required to maintain equilibrium between the blade weight and the resultant surface tension force. **(b)** The mass of the single-edge blade is $2.61 \times 10^{-3}$ kg, and the total length of its sides is 154 mm. Explain why this blade sinks. Support your answer with the necessary calculations.




■ **Figure P1.118**

**1.119** To measure the water depth in a large open tank with opaque walls, an open vertical glass tube is attached to the side of the tank. The height of the water column in the tube is then used as a measure of the depth of water in the tank. (**a**) For a true water depth in the tank of 1 m, make use of Eq. 1.21 (with $\theta \simeq 0°$) to determine the percent error due to capillarity as the diameter of the glass tube is changed. Assume a water temperature of 27 °C. Show your results on a graph of percent error versus tube diameter, $D$, in the range 0.25 cm $< D <$ 2.5 cm. (**b**) If you want the error to be less than 1%, what is the smallest tube diameter allowed?

**1.120** Under the right conditions, it is possible, due to surface tension, to have metal objects float on water. (See **Video V1.9**.) Consider placing a short length of a small diameter steel ($\gamma$ = 77 kN/m$^3$) rod on a surface of water. What is the maximum diameter that the rod can have before it will sink? Assume that the surface tension forces act vertically upward. *Note:* A standard paper clip has a diameter of 0.09 cm. Partially unfold a paper clip and see if you can get it to float on water. Do the results of this experiment support your analysis?

**1.121** An open, clean glass tube, having a diameter of 3 mm, is inserted vertically into a dish of mercury at 20 °C (see **Video V1.10**). How far will the column of mercury in the tube be depressed?

**1.122** An open, clean glass tube ($\theta$ = 0°) is inserted vertically into a pan of water (see **Video V1.10**). What tube diameter is needed if the water level in the tube is to rise one tube diameter (due to surface tension)?

**1.123** Determine the height that water at 15 °C will rise due to capillary action in a clean, 0.6 cm diameter tube (see **Video V1.10**). What will be the height if the diameter is reduced to 0.03 cm?

**1.124** Two vertical, parallel, clean glass plates are spaced a distance of 2 mm apart. If the plates are placed in water, how high will the water rise between the plates due to capillary action?

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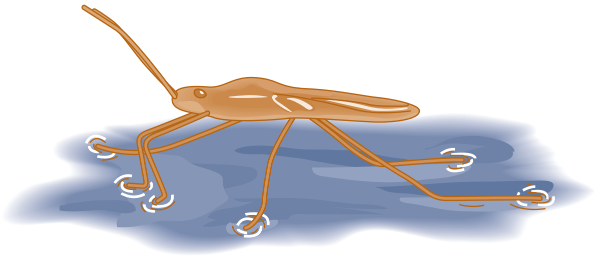
**1.125** (See Fluids in the News article titled **"Walking on water,"** Section 1.9.) **(a)** The water strider bug shown in Fig. P1.125 is supported on the surface of a pond by surface tension acting along the interface between the water and the bug's legs. Determine the minimum length of this interface 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 P1.125**

## ■ Lab Problems

**1.1LP** This problem involves the use of a Stormer viscometer to determine whether a fluid is a Newtonian or a non-Newtonian fluid. To proceed with this problem, go to Appendix H, which is located in *WileyPLUS* or on the book's website, www.wiley.com/college/munson.

**1.2LP** This problem involves the use of a capillary tube viscometer to determine the kinematic viscosity of water as a function of temperature. To proceed with this problem, go to Appendix H, which is located in *WileyPLUS* or on the book's website, www.wiley.com/college/munson.

## ■ Lifelong Learning Problems

**1.1 LL** Although there are numerous non-Newtonian fluids that occur naturally (quicksand and blood among them), with the advent of modern chemistry and chemical processing, many new manufactured non-Newtonian fluids are now available for a variety of novel applications. Obtain information about the discovery and use of newly developed non-Newtonian fluids. Summarize your findings in a brief report.

**1.2 LL** For years, lubricating oils and greases obtained by refining crude oil have been used to lubricate moving parts in a wide variety of machines, motors, and engines. With the increasing cost of crude oil and the potential for the reduced availability of it, the need for non-petroleum-based lubricants has increased considerably. Obtain information about non-petroleum-based lubricants. Summarize your findings in a brief report.

**1.3 LL** It is predicted that nanotechnology and the use of nano sized objects will allow many processes, procedures, and products that, as of now, are difficult for us to comprehend. Among new nanotechnology areas is that of nano scale fluid mechanics. Fluid behavior at the nano scale can be entirely different than that for the usual everyday flows with which we are familiar. Obtain information about various aspects of nano fluid mechanics. Summarize your findings in a brief report.

## ■ FE Exam Problems

Sample FE (Fundamentals of Engineering) exam question for fluid mechanics are provided in *WileyPLUS* or on the book's website, www.wiley.com/college/munson.

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