Fluids

Advanced Placement Physics B
Mr. DiBucci

AP Physics B

Summary of assigned problems from the study guide for Fluids

Mr. DiBucci

Section:	*Assigned Problems*
11.1:	*1,2,3,6*
11.2:	*10,13,14,16,19*
11.3 & 11.4:	*20,23,25,27,32*
11.5:	*33,34,36,38,39*
11.6 :	*40,42,46,47,48,50*
11.8:	*53-57*
11.9 & 11.10:	*59,62,64,65,66,67,69*

Read Chapter 10, sections 10.1 up to and including 10.9

Substance	Mass Density ρ (kg/m^3)
Solids	
Aluminum	2 700
Brass	8 470
Concrete	2 200
Copper	8 890
Diamond	3 520
Gold	19 300
Ice	917
Iron (steel)	7 860
Lead	11 300
Quartz	2 660
Silver	10 500
Wood (yellow pine)	550
Liquids	
Blood (whole, 37 °C)	1 060
Ethyl alcohol	806
Mercury	13 600
Oil (hydraulic)	800
Water (4 °C)	1.000×10^3
Gases	
Air	1.29
Carbon dioxide	1.98
Helium	0.179
Hydrogen	0.0899
Nitrogen	1.25
Oxygen	1.43

[a] Unless otherwise noted, densities are given at 0 °C and 1 atm pressure.

Name ______________________________________ per.____ date _______
Hydrostatic fluids DiBucci
AP Physics

1. The Body of a man whose weight is about 690 N contains about 5.2E -3 M^3 of blood.(5.5 qt.). Find the blood's weight and (b) express it as a percentage of the body weight. (54N, 7.8%)

2. Calculate the absolute pressure on a swimmer at a depth of 5.5m below the surface of a swimming pool.(1.55E+5 Pa)

3. Assume the blood flowing in the arteries can be treated as a static fluid for approximation purposes. Estimate the amount by which the blood pressure in the anterior tibial artery at the foot exceeds the blood pressure in the aorta at the heart when the body is reclining horizontally and standing. Assume the height difference is 1.35 m (1.4E4 Pa)

4. In a hydraulic car lift, the input piston has a radius of r1=0.0120m and a negligible weight. The output plunger has a radius of r2=0.150m. The combined weight of the car and the plunger is 20,500N. The lift uses hydraulic oil that has a density of 8.00E+2 kg/m^3. What input force is needed to lift the car and output plunger when the input piston and output plunger are at the same height.(131N).

b) When the output plunger is 1.10 m ***below*** the input plunger(127N)

5. A solid square, pinewood (550 kg/m^3) raft measures 4.0 m on a side and is 0.30 m thick.

a) Determine whether the raft floats in the water, and (b) if so, how much the raft is beneath the surface.(yes, 0.17 m)

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Name__________________________________ per. ___ date ____

Archimedes' Principle **DiBucci**

1. An ice cube floats in a glass of water. What fraction of the cube lies above the water level? (8.3%)

2. A person in a boat floating in a small pond throws an anchor overboard. Does the level of the pond rise, fall or stay the same?

3. Steel is much denser than water. How, then, do ships made of steel float?

4. A piece of Aluminum is suspended from a string and then completely immersed in a container of water. The mass of the aluminum is 1.0 kg, and its density is 2.7 E +3 kg/m^3. Calculate the tension on the string before and after the string is immersed. (Hint: draw a free body diagram for each situation.) (9.8N, 6.2N)

Quick facts about Archimedes . . .

Born	About 287 BC in Syracuse, Sicily. At the time Syracuse was an independent Greek city-state with a 500-year history.
Died	212 or 211 BC in Syracuse when it was being sacked by a Roman army. He was killed by a Roman soldier who did not know who he was.
Education	Probably studied in Alexandria, Egypt, under the followers of Euclid.
Family	His father was an astronomer named Phidias and he was probably related to Hieron II, the king of Syracuse. It is not known whether he was married or had any children.
Inventions	Many war machines used in the defense of Syracuse, compound pulley systems, planetarium, water screw (possibly), water organ (possibly), burning mirrors (very unlikely).
Fields of Science Initiated	Hydrostatics, static mechanics, pycnometry (the measurement of the volume or density of an object). He is called the "father of integral calculus" and also the "father of mathematical physics".
Major Writings	On plane equilibriums, Quadrature of the parabola, On the sphere and cylinder, On spirals, On conoids and spheroids, On floating bodies, Measurement of a circle, The Sandreckoner, On the method of mechanical problems.
Place in History	Generally regarded as the greatest mathematician and scientist of antiquity and one of the three greatest mathematicians of all time (together with Isaac Newton (English 1643-1727) and Carl Friedrich Gauss (German 1777-1855)).

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EXAMPLE 10.1

A tank is filled with water to a depth of 1.5 m. What is the pressure at the bottom of the tank due to the water alone?

(15 kPa)

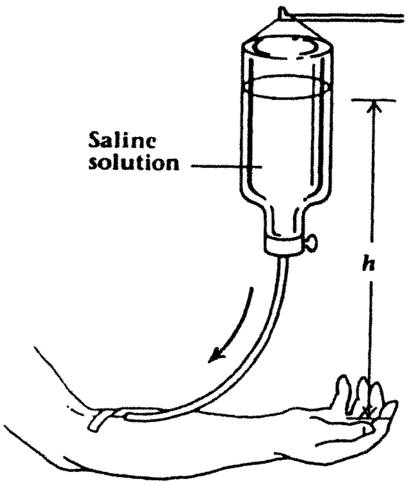


Figure **10.5** Example 10.2: A fluid is fed into a patient's arm from a suspended container. The pressure of the fluid must exceed the pressure in the arm.

EXAMPLE 10.2

A nurse administers medication in a saline solution to a patient by infusion into a vein in the patient's arm (Fig. 10.5). The density of the solution is 1.0×10^3 kg/m^3, and the gauge pressure inside the vein is 2.4×10^3 Pa. How high above the insertion point must the container be hung so that there is sufficient pressure to force the fluid into the patient? (24 cm)

EXAMPLE 10.3

You can make a simple hydraulic lift by fitting a piston attached to a handle into a 3-cm-diameter cylinder, which is connected to a larger cylinder of 24-cm diameter (Fig. 10.7). If a 50-kg (110-lb) woman puts all her weight on the handle of the smaller piston, how much weight can be lifted by the larger one?

3.14×10^4 N ≈ 7000 lb ≈ 3.5 tons

EXAMPLE 10.4

A scuba diver searches for treasure at a depth of 20.0 m below the surface of the sea. At what pressure must the scuba (self-contained underwater breathing apparatus) device deliver air to the diver? 3.03 kPa ≈ 3 ATM

EXAMPLE 10.5

Icebergs are made of fresh-water ice, which has a density ρ_i of 0.92×10^3 kg/m^3 at 0°C. Ocean water, largely because of the dissolved salt, has a density ρ_w of about 1.03×10^3 kg/m^3. What fraction of an iceberg lies below the surface? (0.89)

EXAMPLE 10.7

A horizontal pipe of 25-cm^2 cross section carries water at a velocity of 3.0 m/s. The pipe feeds into a smaller pipe with a cross section of only 15 cm^2. What is the velocity of water in the smaller pipe? (5 m/s)

EXAMPLE 10.8

Determine the pressure change that occurs on going from the larger-diameter pipe to the smaller pipe for the conditions of Example 10.7; that is, take $A_1 = 25$ cm^2, $A_2 = 15$ cm^2, and $v_2 = 5.0$ m/s. $\Delta P = -8.0 \times 10^3$

Derivation of Bernoulli's Equation
AP Physics B

Mr. DiBucci

$$mgh_1 + \frac{1}{2}mv_1^2 + W_o = mgh_2 + \frac{1}{2}mv_2^2$$

$$mgh_1 + \frac{1}{2}mv_1^2 + (F_1X_1 - F_2X_2) = mgh_2 + \frac{1}{2}mv_2^2$$

$$mgh_1 + \frac{1}{2}mv_1^2 + (P_1A_1X_1 - P_2A_2X_2) = mgh_2 + \frac{1}{2}mv_2^2$$

$$mgh_1 + \frac{1}{2}mv_1^2 + (P_1 - P_2)V = mgh_2 + \frac{1}{2}mv_2^2$$

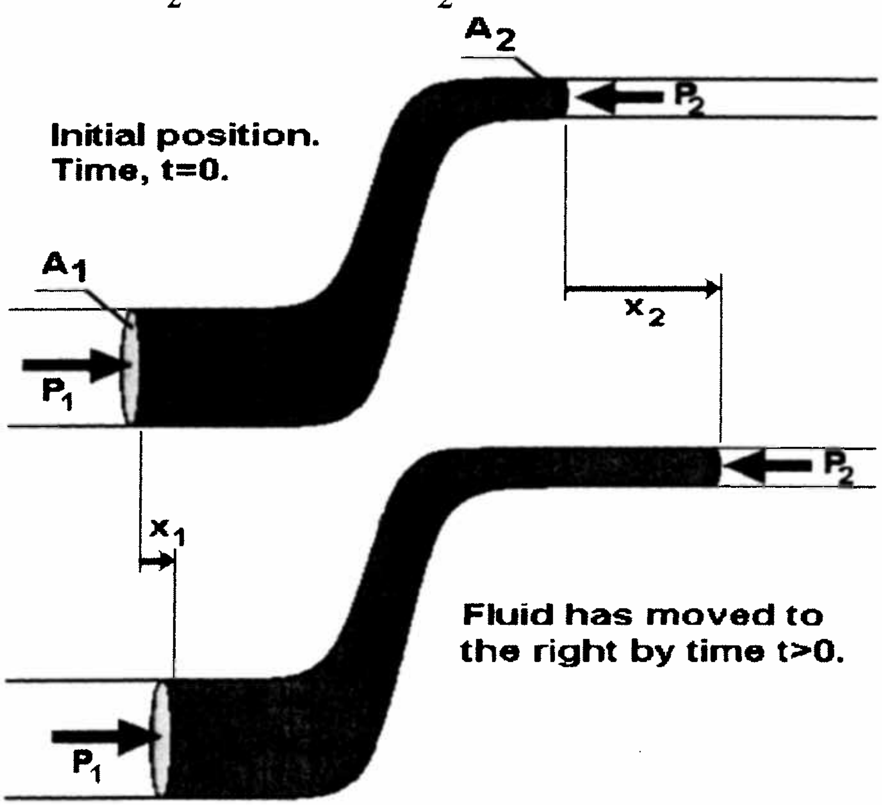
$$\rho Vgh_1 + \frac{1}{2}\rho Vv_1^2 + (P_1 - P_2)V = \rho Vgh_2 + \frac{1}{2}\rho Vv_2^2$$

$$\rho gh_1 + \frac{1}{2}\rho v_1^2 + (P_1 - P_2) = \rho gh_2 + \frac{1}{2}\rho v_2^2$$

$$P_1 + \rho gh_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho gh_2 + \frac{1}{2}\rho v_2^2$$

or

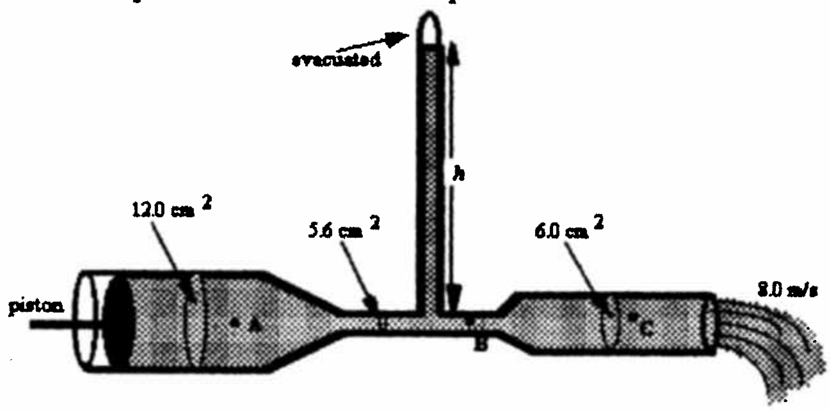
$$P_1 + \rho gy_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho gy_2 + \frac{1}{2}\rho v_2^2$$



Name ____ per. ___ Date _______
Bernoulli's Principle and Applications DiBucci

Use the following diagram and information to answer questions 1-4

A glass tube has several different cross-sectional areas with the values indicated in the figure. A piston at the left end of the tube exerts pressure so that the water within the tube flows from the right end with a speed of 8.0 m/s. Three points within the tube are labeled **A**, **B**, and **C**.



Notes: The drawing is not drawn to scale. Atmospheric pressure is 1.01×10^5 N/m^2; and the density of water is 1000 kg/m^3.

1. What is the speed is water flowing past the point labeled **A**?

2. What is the total pressure at point **A**?

3. What is the total pressure at point **B**?

4. Determine the height ***h*** of water in the manometer with the evacuated upper end.

Solutions to Bernoulli's Principle — DiBucci

$P_0 = 1.013\times10^5\,Pa$

1) $A_A v_A = A_c v_c$

$$v_A = \frac{A_c}{A_A} v_c = \left(\frac{6}{12}\right)(8\,m/s) = \boxed{4\,m/s}$$

2) $P_A + \frac{1}{2}\rho v_A^2 = P_c + \frac{1}{2}\rho v_c^2$

$$P_A = P_c + \frac{1}{2}\rho v_c^2 - \frac{1}{2}\rho v_A^2 \quad [P_c = P_0]$$

$$P_A = P_0 + \frac{1}{2}\rho(v_c^2 - v_A^2)$$

$$= (1.013\times10^5\,Pa) + \frac{1}{2}(1000)(8^2 - 4^2)$$

$$\boxed{= 1.25\times10^5\,Pa}$$

3) $A_B v_B = A_c v_c$

$$v_B = \frac{A_c}{A_B} v_c = \left(\frac{6}{5.6}\right) 8\,m/s = \boxed{8.57\,m/s}$$

$$P_B + \frac{1}{2}\rho v_B^2 = P_c + \frac{1}{2}\rho v_c^2$$

$$P_B = P_c + \frac{1}{2}\rho v_c^2 - \frac{1}{2}\rho v_B^2$$

$$P_B = P_0 + \frac{1}{2}\rho(v_c^2 - v_B^2) = 1.013\times10^5\,Pa + \frac{1}{2}(1000)(8^2 - 8.57^2)$$

$$\boxed{P_B = 9.66\times10^4\,Pa}$$

4) $\rho g h = P_B$

$$h = \frac{P_B}{\rho g} = \frac{9.66\times10^4\,Pa}{(1000)(9.8)} = \boxed{9.85\,m}$$

Fluids

PREVIEW

In this chapter you will be introduced to the properties of fluids. You will learn to describe the inertial properties and the weight of a fluid in terms of its mass density and weight density. Also you will describe the forces acting on a fluid and exerted by a fluid in terms of pressure.

Pascal's principle reveals how pressures applied to fluids are transmitted to other portions of the fluid. Archimedes' principle describes how and why objects float in fluids. Using these principles, you will be able to understand such things as how hydraulic jacks work and how submarines can sometimes float on and other times dive below the surface of the ocean.

In this chapter you will also learn about flowing fluids including the equation of continuity, Bernoulli's equation, and viscous flow. Numerous applications are discussed, such as fluid flow through pipes, streamline air flow around an airplane wing, what makes a spinning baseball curve, and many others.

QUICK REFERENCE

Important Terms

Fluid
A material which has the ability to flow. Usually fluids are liquids and gases.

Mass density
The mass of a volume of a substance divided by the volume.

Specify gravity
Is the mass density of the material compared to the mass density of water at 4 °C.

Pressure on a surface
The perpendicular component of the force acting on the surface divided by the area of the surface.

Absolute pressure
The amount by which a pressure exceeds the pressure of a true vacuum.

Gauge pressure
The amount by which a pressure exceeds atmospheric pressure.

Buoyant force
The net force exerted by a fluid on an object which is partially or wholly immersed in the fluid. The direction of the buoyant force is up.

Steady fluid flow
Movement in which the velocity of the fluid particles at any point in the fluid is constant with time. Every particle that passes through a particular point in the fluid has the same velocity.

Incompressible fluid
One in which the density of the liquid remains constant as the pressure changes.

Viscous fluid
A fluid that does not flow readily (like honey) due to the viscosity of the fluid.

Ideal fluid
An incompressible, nonviscous fluid.

Streamline
Lines representing the trajectory of the fluid particles in a steadily flowing fluid.

Mass flow rate
The mass of fluid which flows past a given point per unit time. Units are (kg/s).

Equation of continuity
The mass of fluid that enters one end of a pipe must leave at the other end. In other words, the mass flow rate must remain constant between any two positions along a tube of flowing fluid.

Equations

The **mass density** of a substance

$$\rho = \frac{m}{V} \tag{11.1}$$

The **specific gravity** of a substance

$$\text{Specific gravity} = \frac{\text{Density of substance}}{1.000 \times 10^3 \text{ kg/m}^3} \tag{11.2}$$

The **pressure** exerted by a force acting perpendicular to a surface of area A

$$P = \frac{F}{A} \tag{11.3}$$

The **pressure within a fluid** at a depth, h, when an external pressure, P_1, is applied to the fluid

$$P_2 = P_1 + \rho g h \tag{11.4}$$

The force transmitted by a fluid from one piston to another piston

$$F_2 = F_1 \left(\frac{A_2}{A_1} \right) \tag{11.5}$$

The **equation of continuity** is:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \tag{11.8}$$

For an **incompressible fluid**:

$$A_1 v_1 = A_2 v_2 \tag{11.9}$$

Bernoulli's equation is:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2 \tag{11.11}$$

The force needed to move a layer of **viscous fluid** is:

$$F = \frac{\eta A v}{y} \tag{11.13}$$

Poiseuille's law can be written as:

$$Q = \frac{\pi R^4 (P_2 - P_1)}{8 \eta L} \tag{11.14}$$

Principles

Pascal's principle - any change in the pressure applied to a completely enclosed fluid is transmitted undiminished to all parts of the fluid and the walls of the container.

Archimedes' principle - a fluid will exert an upward buoyant force on an object wholly or partially immersed in it equal to the weight of the fluid displaced by the object.

Important Numbers

Mass density of water at 4 °C	1.00×10^3 kg/m^3 or 1.00 g/cm^3
Mass density of air at 0 °C	1.29 kg/m^3
Atmospheric pressure at sea level	1.013×10^5 Pa or 14.70 lb/in^2.

DISCUSSION OF SELECTED SECTIONS

11.1 Mass Density

Example 1
What is the volume of 1.00 kg of air?

Equation (11.1) gives the volume of air

$$V = \frac{m}{\rho} = \frac{1.00\ \text{kg}}{1.29\ \text{kg/m}^3} = 0.775\ \text{m}^3$$

This is roughly one cubic yard.

Example 2
An object weighs 450 N and has a volume of 0.083 m^3. Use the density data in Table 11.1, to determine the material from which the object is made.

Equation (11.1) gives the density of the material to be

$$\rho = \frac{M}{V} = \frac{\frac{450\ \text{N}}{9.8\ \text{m/s}^2}}{0.083\ \text{m}^3} = 550\ \text{kg/m}^3$$

Comparing this density with the values in Table 11.1 reveals that the object is made of PINE.

11.2 Pressure

Example 3
What is the downward force on the top of your head due to atmospheric pressure. Assume that the top of your head is a flat circle with a diameter of 7.00 inches.

$$F = P_{atm}A = (14.70\ \text{lb/in}^2)\pi(3.50\ \text{in})^2 = 566\ \text{lb}.$$

11.3 Pressure and Depth in a Static Fluid

A static fluid generates a pressure within itself due to its own weight. This pressure varies with the depth below the surface of the fluid of the point in question.

Example 4
What is the pressure due to the sea water at a depth of 500.0 m below the surface of the ocean? The density of sea water is 1025 kg/m^3.

The pressure due to the weight of the sea water is

$$P_2 - P_1 = \rho g h = (1025\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(500.0\ \text{m}) = 5.02 \times 10^6\ \text{Pa}$$

This is about 730 lb/in^2!

Example 5
A small boy stands with his finger plugging a hole in a dike. The hole has a diameter of 12 mm and is located 3.4 m below the surface level of the water behind the dike. How much force must the boy exert to hold back the water?

The pressure acting on the boy's finger due to the water is $\rho g h$. The force exerted by the water on the boy, hence the force exerted by the boy is then

$$F = \rho g h A$$
$$F = (1.00 \times 10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(3.4\ \text{m})\pi(6.0 \times 10^{-3}\ \text{m})^2 = 3.8\ \text{N}$$

11.4 Pressure Gauges

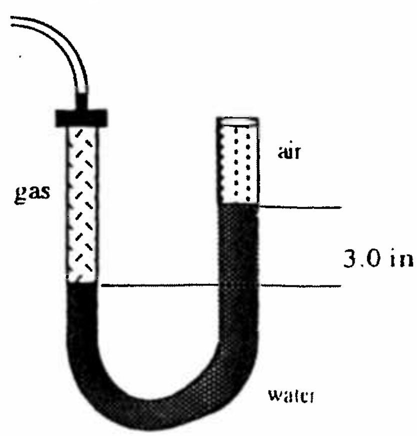
Example 6
A gas orifice in a furnace is designed to work with a gauge pressure of 3.0 in of water as measured by an open tube manometer. What is this pressure in lb/in^2? Water has a weight density of 62.4 lb/ft^3.

The gauge pressure of the gas is the absolute gas pressure in the left arm of the tube, P_2, minus the atmospheric pressure in the right arm of tube.

$$\text{gauge pressure} = P_2 - P_{atm} = \rho g h$$

$$\text{gauge pressure} = (62.4\ \text{lb/ft}^3)(0.25\ \text{ft}) = 15.6\ \text{lb/ft}^2$$

$$\text{gauge pressure} = (15.6\ \text{lb/ft}^2)(1\ \text{ft}^2/144\ \text{in}^2) = 0.11\ \text{lb/in}^2$$



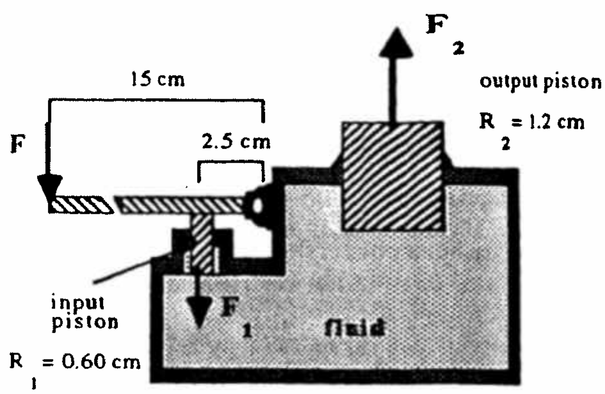
11.5 Pascal's Principle

Pascal's principle lies at the heart of many useful devices such as hydraulic jacks, hydraulic brake systems, etc. In any situation where a force is transmitted by a fluid, Pascal's principle is involved.

Example 7
The handle of a hydraulic jack is 15 cm long and is pivoted 2.5 cm from the input piston which has a radius of 0.60 cm. The output piston has a radius of 1.2 cm. What weight could be lifted by the jack if the person pushing on the handle is to exert no more than 110 N of force?

The weight that can be lifted is equal of the magnitude of the force exerted by the output piston. The output force is related to the input force by

$$F_2 = F_1\left(\frac{A_2}{A_1}\right) = F_1\left(\frac{R_2}{R_1}\right)^2$$



We need the force, F_1, on the input piston. Taking torques on the handle about an axis through the pivot gives

$$F(15\text{ cm}) - F_1'(2.5\text{ cm}) = 0$$

$$F_1' = 6.0\ F = 660\text{ N.}$$

The force on the input piston due to the handle is equal in magnitude to the force on the handle exerted by the input piston , F_1'.
The force exerted by the output piston is then

$$F_2 = (660\text{ N})\left(\frac{1.2\text{ cm}}{0.60\text{ cm}}\right)^2 = 2600\text{ N}$$

11.6 Archimedes' Principle

The buoyant force on an object in a fluid is equal to the weight of the fluid displaced by the object. The net upward force on the object is then

$$F = B - W = \rho_f g V_f - \rho_o g V_o.$$

If the object floats, then the net force on it is zero and

$$\rho_o = \rho_f\left(\frac{V_f}{V_o}\right)$$

If the object floats partially submerged, then it displaces less than it own volume of fluid. This implies that the density of the object is less than the density of the fluid. However, if the object floats submerged in the fluid, then it displaces exactly its own volume of fluid and the densities of the object and fluid must be equal.

In the case where the object sinks, it displaces its own volume of fluid and the net force is directed downward and is negative. Now the density of the object must be greater than the density of the fluid.

Example 8
Archie is playing with a small boat in the bathtub. The boat has a mass of $M = 0.22$ kg and a volume of $V = 0.0011\ m^3$. Archie has several lead weights each with a mass of $m = 0.028$ kg. How many lead weights could Archie place in the boat before it sinks?

In order for the boat to float just submerged, its density must be equal to the density of the water. The average density of the boat with N lead weights in it is (M + Nm)/V, so

$$N = \frac{\rho_w V - M}{m} = \frac{(1.00 \times 10^3\ kg/m^3)(0.0011\ m^3) - 0.22\ kg}{0.028\ kg} = 31$$

He can place 31 lead weights in the boat before it sinks. The thirty-second weight will sink the boat.

Example 9
An empty barge 25 m long and 4.0 m wide floats with the waterline at the 1.0 m mark. That is, 1.0 m of its hull is submerged. Gravel is added to the barge until it floats with the waterline at the 3.5 m mark. What is the weight of the gravel? Assume that the barge is a rectangular solid.

Since the empty barge is floating, its weight must be equal to the buoyant force exerted by the water.

$$W_E = \rho_w g V_E = \rho_w g A h_E$$

A similar expression must hold for the loaded barge.

$$W_E + W_L = \rho_w g A h_L$$

The weight of the load of gravel is then

$$W_L = \rho_w g A(h_L - h_E)$$
$$W_L = (1.00 \times 10^3\ kg/m^3)(9.80\ m/s^2)(25\ m \times 4.0\ m)(3.5\ m - 1.0\ m)$$
$$W_L = 2.5 \times 10^6\ N$$

Example 10
An 80.0 kg person weighs 30.0 N when weighed in water. If body fat has a density close to that of water and the lean portion of the body has an average density of $1.060 \times 10^3\ kg/m^3$, what is the person's percentage of body fat?

The percentage of body fat is the mass of fat divided by the total mass of the person. Also, the mass of fat, $\rho_f V_f$, and lean, $\rho_L V_L$, must add to give 80.0 kg. So

$$\rho_L V_L + \rho_f V_f = 80.0\ kg$$

$$1.060\ V_L + V_f = 8.00 \times 10^{-2} \qquad (1)$$

Archimedes' principle applied to the person weighed in water gives

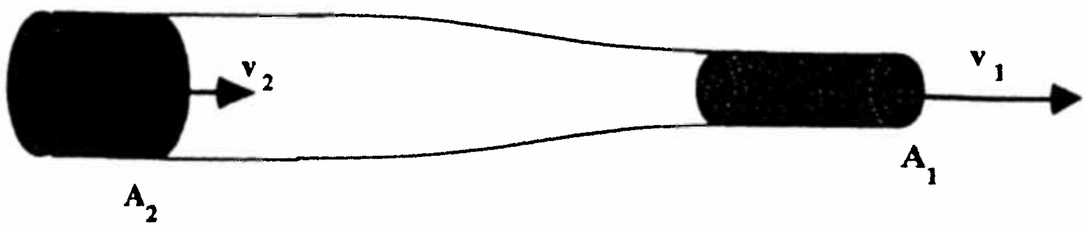
$$\rho_w g V_L + \rho_w g V_f = (80.0\ kg)g - 30.0\ N$$

$$V_L + V_f = 7.69 \times 10^{-2} \qquad (2)$$

Solving (2) for V_L, substituting into (1) and rearranging yields $V_f = 0.025\ m^3$. The mass of fat in the person is then $(1.00 \times 10^3\ kg/m^3)(0.025\ m^3) = 25$ kg. This represents 25/80.0 = 0.31 or 31 % of the person's weight.

11.8 The Equation of Continuity

In the figure below, a mass of fluid flows along a tube. The fluid has a density ρ, and travels with a velocity v_2, through a segment of the tube whose cross-sectional area is A_2. The tube then tapers off to cross-sectional area A_1, and the fluid, whose density is now ρ, now travels with velocity v_1.



At position 1 we have: Mass Flow Rate $= \rho_1 A_1 v_1$ (11.7b)

At position 2 we have: Mass Flow Rate $= \rho_2 A_2 v_2$ (11.7a)

The **equation of continuity** states that the mass flow rate must remain constant, that is,

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \quad (11.8)$$

If the fluid is incompressible, i.e., $\rho_1 = \rho_2$, equation (11.8) can be written as

$$A_1 v_1 = A_2 v_2 \quad (11.9)$$

where Q = Av is the **volume flow rate**. Note: Units are $Q = m^3/s$, $\rho = kg/m^3$, $A = m^2$, $v = m/s$.

Example 11
Water is flowing through a 3.0 mm diameter pipe at a speed of 5.0 m/s. The pipe has a constriction of 1.5 mm diameter. What is the velocity of the water through the constriction?

We assume the flow is incompressible, so equation (11.9) is valid. Noting that $A = \pi r^2$ where r is the radius of the pipe and r = d/2 we can write

$$A_1 v_1 = (\pi r_1^2) v_1 = A_2 v_2 = (\pi r_2^2) v_2,$$ and solving for v_2 yields,

$$v_2 = v_1 \left(\frac{r_1}{r_2}\right)^2 = (5.0\ m/s)\left(\frac{1.5 \times 10^{-3}\ m}{7.5 \times 10^{-4}\ m}\right)^2 = 20\ m/s.$$

Example 12
Oil is flowing with a speed of 4.00 ft/s through a 2.00-ft diameter pipeline. How many gallons of oil flow through the pipeline in one day? (1 gal = 0.134 ft^3)

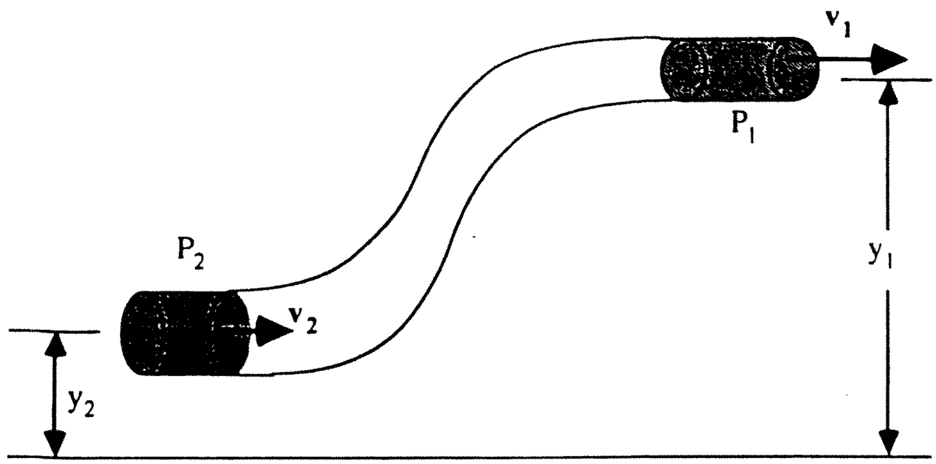
The volume flow rate is: $Q = Av = \pi r^2 v = \pi\ (1.00\ ft)^2\ (4.00\ ft/s) = 12.6\ ft^3/s.$
Converting units gives:

$$Q = \left(12.6 \frac{ft^3}{s}\right)\left(\frac{1\ gal}{0.134\ ft^3}\right)\left(\frac{3600\ s}{1\ h}\right)\left(\frac{24\ h}{1\ day}\right) = 8.12 \times 10^6\ gal/day$$

11.9 Bernoulli's Equation

For any two points (1 and 2) in the steady, irrotational flow of an incompressible, nonviscous fluid, the pressure P, the fluid speed v, and the elevation y, are related by

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2 \qquad (11.11)$$



Example 13
In the diagram above, let the difference in pressure be $\Delta P = P_2 - P_1 = 5.0 \times 10^4$ Pa, take $\Delta y = y_1 - y_2 = 2.0$ m, and let $v_2 = 4.0$ m/s. What is the speed v_1 of water flowing through this pipe? (For water, $\rho = 1.0 \times 10^3$ kg/m^3)

Using equation (11.11) we have,

$$\frac{1}{2}\rho v_1^2 = (P_2 - P_1) + \rho g(y_2 - y_1) + \frac{1}{2}\rho v_2^2, \text{ and solving for } v_1$$

$$v_1 = \sqrt{\frac{2\Delta P}{\rho} - 2g\Delta y + v_2^2} = \sqrt{\frac{2(5.0 \times 10^4 \text{ Pa})}{1.0 \times 10^3 \text{ kg/m}^3} - 2(9.8 \text{ m/s}^2)(2.0 \text{ m}) + (4.0 \text{ m/s})^2}$$

$$= 8.8 \text{ m/s.}$$

11.10 Applications of Bernoulli's Equation

For a fluid moving through a horizontal pipe ($y_1 = y_2$), equation (11.11) becomes

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 \qquad (11.12)$$

Example 14
Water is flowing at a speed of 0.500 m/s through a 4.00-cm diameter hose. The hose is horizontal. (a) What is the mass flow rate of the water? (b) At what speed does the water pass through a nozzle whose effective diameter is 0.600 cm? (c) What must be the absolute pressure of the water entering the hose if the pressure at the nozzle is atmospheric pressure?

(a) Using equation (11.7) the mass flow rate is,

$$MFR = \rho A v = (1.00 \times 10^3 \text{ kg/m}^3)\pi(2.00 \times 10^{-2} \text{ m})^2(0.500 \text{ m/s}) = 0.628 \text{ kg/s}.$$

(b) Since the water is incompressible, use equation (11.9), $A_1v_1 = A_2v_2$, and therefore,

$$v_1 = v_2 (A_2/A_1) = v_2 (r_2/r_1)^2 = (0.500 \text{ m/s})[(2.00 \text{ cm})/(0.300 \text{ cm})]^2 = 22.2 \text{ m/s}.$$

(c) Using equation (11.12) we can write,

$$P_2 = P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2)$$

$$= (1.01 \times 10^5 \text{ Pa}) + \frac{1}{2}(1.00 \times 10^3 \text{ kg/m}^3)[(22.2 \text{ m/s})^2 - (0.500 \text{ m/s})^2]$$

$$= 3.47 \times 10^5 \text{ Pa}.$$

11.11 Viscous Flow

In all real fluids, the different fluid layers do NOT all have the same velocity. The fluid at the center of a pipe moves fastest while the fluid near the walls of the pipe moves slowest. In fact, the fluid directly in contact with the wall does not move at all because it is held tightly by intermolecular forces. Such forces give rise to the **viscosity** of the fluid. Examples of fluids that are highly viscous are honey or tar. Fluids such as water, and especially oil, have low viscosities.

The tangential force F required to move a fluid layer at a constant speed v, when the layer has an area A and is located a perpendicular distance y from an immobile surface, is given by

$$F = \frac{\eta A v}{y} \qquad (11.13)$$

Where η is known as the **coefficient of viscosity** or simply the viscosity. The SI unit for viscosity is the poise (P) where 1 P = 0.1 Pa s.

In many cases of interest, it is necessary to know the volume flow rate in a viscous fluid. Consider two points (1 and 2) separated by a distance L in a pipe of constant radius R. If the pressure difference between these two points is $P_2 - P_1$, and η is the viscosity of the fluid in the pipe, the volume flow rate Q is given by **Poiseuille's law**, which is

$$Q = \frac{\pi R^4 (P_2 - P_1)}{8\eta L} \qquad (11.14)$$

Example 15

Glycerin flows through a tube of 1.0 cm radius. If the ends of the pipe are 5.0 m apart and a pressure difference of 3.0×10^4 Pa is maintained between the ends, find the volume flow rate.

Using equation (11.14), and the value of η for glycerin found in the table we have

$$Q = \frac{\pi R^4 (P_2 - P_1)}{8\eta L} = \frac{\pi(0.010 \text{ m})^4(3.0 \times 10^4 \text{ Pa})}{8(1.5 \text{ Pa s})(5.0 \text{ m})} = 1.6 \times 10^{-5} \text{ m}^3/\text{s}.$$

PRACTICE PROBLEMS

1. The tires of a 1600 kg automobile are inflated to a pressure of 25 lb/in^2. Assuming that each tire supports 1/4 the weight of the car, calculate the area of contact between a tire and the road.

2. A research diving vessel is shaped like a sphere of radius 3.5 m. If the inside of the vessel is maintained at atmospheric pressure, what is the net force trying to crush the vessel when it is at a depth of 1500 m below the surface of the ocean?

3. What is the weight of the water in a waterbed which is 2.4 m long, 1.8 m wide and 0.23 m deep?

4. A 80.0 kg person weighs 40.0 N in fresh water and finds it difficult to stay afloat. In the Great Salt Lake the density of the water is increased due to dissolved salts and the person finds that he can float just submerged with no effort at all. What is the density of the water in the Great Salt Lake?

5. A "U" tube of volume, V, and uniform cross-section is initially filled with water. Then 1/2 V of mercury is poured into one arm of the tube and pushes the water through the tube. How much water spills out of the other arm of the tube?

6. Water is being siphoned from a fish tank. The procedure begins with filling a hose of diameter 1.0 cm with water and then placing one end of the hose in the tank and the other end 1.0 m below the surface of the water, but outside the tank. A net force then acts to push the water from the tank through the tube. Where does this force originate? What is its magnitude?

7. A garden hose having an internal diameter of 2.0 cm is connected to a lawn sprinkler that consists of an enclosure with 36 holes, each 0.10 cm in diameter. If the water in the hose has a speed of 0.75 m s, at what speed does it leave the sprinkler holes?

8. A venturi meter has a cross section of 40.0 cm^2 at its entry and exit ports and a cross section of 25.0 cm^2 in its constricted region. Water enters at 3.5 m/s. (a) What is the speed of the water through the constricted region? (b) What is the difference in pressure between the two regions?

9. Water is moving with a speed of 8.0 m/s through a pipe of 4.0 cm diameter. The water gradually descends 15 m as the pipe diameter increases to 6.0 cm. (a) What is the speed of flow at the lower level? (b) If the pressure at the upper level is 2.0×10^5 Pa, what is the pressure at the lower level?

10. A stream of water (initially horizontal) flows from a small hole in the side of a tank. The stream is 2.5 m from the side of the tank after falling 0.70 m. How far below the surface of the water in the tank is the hole?

11. A straight horizontal pipe with a diameter of 1.0 cm and a length of 50.0 m carries oil with a density of $\rho = 930$ kg/m^3 and a viscosity of 0.12 Pa s. The discharge rate is 0.80 kg/s at atmospheric pressure. Find the gauge pressure at the pipe input.

12. During a heavy rain, a 3.0 m x 4.6 m family room is flooded to a depth of 15 cm. To remove the water ($\eta = 1.00 \times 10^{-3}$ Pa-s), a pump is used that does the job in two hours. The water flows through a horizontal pipe of radius 0.64 cm and length 6.7 m. What gauge pressure does the pump produce?

HELPFUL SUGGESTIONS

1. Keep in mind that the pressure generated by a force acting on a surface area depends ONLY on the component of force perpendicular to the surface. The component of the force parallel to the surface produces no pressure. Also, a pressure acting on a surface area produces only a force perpendicular to the surface.

2. Pressures cited in everyday life are almost always gauge pressures. That is, the pressure above atmospheric pressure that would be measured by a pressure gauge exposed to the atmosphere. An example is the pressure in your car's tires, say, 28.0 lb/in^2. This is a gauge pressure. The corresponding absolute pressure is
$28.0\ \text{lb/in}^2 + 14.7\ \text{lb/in}^2 = 42.7\ \text{lb/in}^2$.

3. To find the pressure due to the weight of a fluid, one only has to find the vertical distance from the surface of the fluid to the point in question, that is, the depth. The pressure is the same at all points within the fluid that are at the same depth. This depth is so important in finding pressures due to fluid weight that engineers give it a special name, the "pressure head". It is the large pressure head of a tall water tower that is responsible for providing the pressure in a city's water system.

4. Bernoulli's equation is only valid under a strict set of assumptions. The equation is valid only for an incompressible, nonviscous, steady flow of fluid with no turbulence.

5. Be careful to be consistent with units when applying the continuity equation or Bernoulli's equation. SI units should be used as a rule; so that liters (or gallons) should be converted to m^3,pressure in atmospheres should be converted to Pa (N/m^2), and so on. Do not mix units.

6. If a pipe is an open pipe, and exposed to the atmosphere, the pressure at that point is 1 atm = 1.0×10^5 Pa.

7. Bernoulli's equation relates the conditions of pressure, velocity, and height at two different points in the fluid. When choosing these points in applying the equation, be sure that there are no obstructions between the two points. That is, the two points must lie along the same streamline.

EVERYDAY PHYSICS

1. The next time you put air in your tires, pay particular attention to the "contact patch" of a tire as you add air. Can you explain what you see?

2. You can estimate the volume of a helium filled balloon by attaching small fishing weights to the string of the balloon until the balloon neither rises or sinks and then applying Archimedes' principle.

3. Take a glass jar filled to the brim with water and place an oversized lid on it. Turn the jar and lid upside down while holding the lid. Remove your hand from the lid. What happens? Why? It is best to do this experiment over a sink!

4. Airplane wings are an excellent example of Bernoulli's effect. The bottom side of the wing is relatively flat, while the top side is curved. The air must travel a greater distance over the top of the wing and hence, moves faster over the top side. According to equation (11.12), the higher velocity means a lower pressure on the top side. Thus, the greater pressure on the bottom of the wing produces a net force which "lifts" the airplane.

5. The curving of a thrown baseball can be explained in a way similar to that in #4. The spin of the ball produces pressure differences which displace the ball on a curved path.

6. Another illustration of Bernoulli's effect is to take a strip of paper, hold one end between your lips and blow across the top. As long as you blow, the strip will remain in an essentially horizontal position. When you stop, the paper relaxes and dangles below your chin. Explain.

CHAPTER QUIZ

1. The inside of a spaceship is maintained at 75 % of atmospheric pressure while the outside is a perfect vacuum. What is the total force on a 1.0 m X 1.0 m hatch in the wall of the spacecraft?
   a. 5.1×10^4 N   b. 2.5×10^4 N   c. 3.8×10^4 N   d. 7.6×10^4 N

2. An object floats in water half submerged. What is the density of the object?
   a. 500 kg/m^3 b. 2000 kg/m^3 c. 750 kg/m^3 d. It is impossible to know.

3. A diver descends to a depth of 25 m in fresh water. What is total pressure on the diver?
   a. 2.5×10^5 N/m^2 b. 3.5×10^5 N/m^2 c. 1.5×10^5 N/m^2 d. 2.5×10^4 N/m^2

4. A diver descends in the ocean to a depth of 50 m. How does the buoyant force on the diver change as he descends?
   a. It increases linearly with the depth.
   b. It decreases linearly with the depth.
   c. It increases quadratically with the depth.
   d. It doesn't change.

5. A helium filled balloon with a total mass of 580 kg rises with an acceleration of 0.50 m/s^2. What is the volume of the balloon? The density of air is 1.29 kg/m^3.
   a. 4900 m^3 b. 6500 m^3 c. 5400 m^3 d. 470 m^3

6. A hydraulic lift has an input piston with a diameter of 1.0 cm and an output piston with a diameter of 25 cm. How much force acts on the input piston if the output piston supports a 1500 kg car?
   a. 6.0 N   b. 59 N   c. 0.24 N   d. 2.4 N

7. The radius of a pipe carrying water increases by a factor of two. As a result, the speed of the water in the pipe
   a. increases by a factor of two.
   b. decreases by a factor of two.
   c. increases by a factor of four.
   d. decreases by a factor of four.

8. Water flows downward through a pipe of constant diameter. If the water falls through a height of 10.0 m, what is the change in pressure between the two heights? (The density of water is 1.0×10^3 kg/m^3.)
   a. 9.8 Pa   b. 980 Pa   c. 9800 Pa   d. 98 000 Pa

9. Blood flows through a blood vessel at 0.10 m/s. The vessel has a cross-sectional area of 1.0×10^{-4} m^2. The volume flow rate of the blood is
   a. 1.0×10^{-5} kg/s   b. 1.0×10^{-5} m^3/s c. 1.0×10^{-3} m^3/s d. 1.0×10^{-2} m^3/s

10. Water flows with a volume flow rate of 2.5 m^3/s. What is the approximate speed of the water where the pipe diameter is 0.5 m?
    a. 2.5 m/s   b. 5.0 m/s   c. 13 m/s   d. 25 m/s

11. A tank holds water which empties out through a hole located 10.0 meters below the surface of the water. How fast is the water moving when it leaves the tank?
    a. 10 m/s   b. 14 m/s   c. 25 m/s   d. 98 m/s

12. The Sears tower is 512 m high. What must be the minimum water pressure in a pipe at ground level in order to get water up to a restaurant on the top floor?
    a. 1.0×10^5 Pa   b. 5.0×10^5 Pa   c. 6.0×10^5 Pa   d. 5.0×10^6 Pa

SOLUTIONS AND ANSWERS

Practice Problems

1. Each tire pushes against the ground with a force F = PA which is equal and opposite to the force exerted by the ground on the tire. The total force exerted by the ground on the tire is then 4F which must equal the weight of the car, 4F = 4PA = mg. Solving for A gives A = 1/4 mg/P. Now

$$P = (25 \text{lb/in}^2/14.7 \text{ lb/in}^2)(1.01 \times 10^5 \text{ Pa}) = 1.7 \times 10^5 \text{ Pa},$$

so that,

$$A = (1/4)(1600 \text{ kg})(9.8 \text{ m/s}^2)/(1.7 \times 10^5 \text{ Pa}) = \mathbf{0.023 \text{ m}^2}.$$

2. The net pressure on the vessel is

$$P = \rho gh = (1025 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(1500 \text{ m}) = 1.5 \times 10^7 \text{ Pa}.$$

The net force on the spherical surface of the vessel is then

$$F = PA = P(4\pi R^2) = (1.5 \times 10^7 \text{ Pa})(4\pi)(3.5 \text{ m})^2 = \mathbf{2.3 \times 10^9 \text{ N}}.$$

3. The weight of the water is

$$W = mg = \rho gV = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(2.4 \text{ m})(1.8 \text{ m})(0.23 \text{ m}) = \mathbf{9\,700 \text{ N}}.$$

4. In fresh water $mg - \rho_w gV = 40.0$ N. In the salt water $mg - \rho_s gV = 0$. The first equation gives the volume of the person to be

$$V = [(80.0 \text{ kg})(9.8 \text{ m/s}^2) - 40.0 \text{ N}]/[(1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)] = 0.076 \text{ m}^3.$$

The second equation then gives the density of the salt water to be

$$\rho_s = m/V = (80.0 \text{ kg})/(0.076 \text{ m}^3) = \mathbf{1050 \text{ kg/m}^3}.$$

5. Let h_w and h_m be the heights of the water column and mercury columns, respectively, measured from the mercury-water interface. If the column is not to move, the weight of the mercury above the interface must equal the weight of the water above the interface.

$$\rho_w g h_w A = \rho_m g h_m A.$$

The length of the column of water lost is $L_w = L - h_w$ where L is the total length of the tube. Additionally, $2h_w - h_m = 1/2$ L. Elimination of h_w and h_m from the above equations results in

$$L_w = L - 1/2\, L\, \{\rho_m/\rho_w\}/\{2\rho_m/\rho_w - 1\} = L - (1/2\, L)\, \{13.6\}/\{27.2 - 1\} = 0.74\, L.$$

Hence, the volume of water lost is $V_w = \mathbf{0.74\ V}$.

6. The force originates from the weight of the water in the portion of the siphoning tube that lies below the surface of the water in the tank. If h is the height of the water level in the tank above the end of the tube, then the net pressure at the end of the tube is

$$p = p_{atm} + \rho gh - p_{atm} = \rho gh.$$

This pressure generates a force,

$$F = pA = \rho ghA = (1000\ kg/m^3)(9.8\ m/s^2)(1.0\ m)(3.14)(0.05 \times 10^{-2}\ m)^2 = \mathbf{7.7 \times 10^{-3}\ N}$$

to push the water from the tube.

---

7. Use $A_1 v_1 = A_2 v_2$, where

$$A_2 = \pi r_2^2 = \pi(1.0 \times 10^{-2}\ m)^2 = 3.14 \times 10^{-4}\ m^2,\ v_2 = 0.75\ m/s,$$
$$A_1 = 36(\pi r_1^2) = 36\pi(5.0 \times 10^{-4}\ m)^2 = 2.83 \times 10^{-5}\ m^2.$$

Solving for v_1 we obtain,

$$v_1 = v_2(A_2/A_1) = (0.75\ m/s)(3.14 \times 10^{-4}\ m^2)/(2.83 \times 10^{-5}\ m^2) = \mathbf{8.3\ m/s}.$$

---

8. (a) Equation (11.9), $A_1 v_1 = A_2 v_2$ so that

$$v_1 = v_2(A_2/A_1) = (3.5\ m/s)(40\ cm^2/25\ cm^2) = \mathbf{5.6\ m/s}.$$

(b) Equation (11.12),

$$P_1 + (1/2)\rho v_1^2 = P_2 + (1/2)\rho v_2^2,$$

solving for the change in pressure,

$$\Delta P = (P_2 - P_1) = (1/2)\rho(v_1^2 - v_2^2) = (1/2)(1.0 \times 10^3\ kg/m^3)[(5.6\ m/s)^2 - (3.5\ m/s)^2] = \mathbf{9600\ N/m^2}.$$

---

9. (a) Equation (11.9),

$$v_1 = v_1(A_2/A_1) = (8.0\ m/s)(4.0\ cm/6.0\ cm)^2 = \mathbf{3.6\ m/s}.$$

(b) Solving equation (11.11) for P_1 yields, $P_1 = P_2 + (1/2)\rho(v_2^2 - v_1^2) + \rho gh$, substituting,

$$P_1 = 2.0 \times 10^5\ Pa + (1/2)(1.0 \times 10^3\ kg/m^3)[(8.0\ m/s)^2 - (3.6\ m/s)^2]$$
$$+ (1.0 \times 10^3\ kg/m^3)(9.8\ m/s^2)(15\ m) = \mathbf{3.7 \times 10^5\ Pa}.$$

---

10. Find the speed of the water as it leaves the hole. Using $v_{0y} = 0$ we can write

$$t^2 = 2y/a = 2(0.7\ m)/(9.8\ m/s^2)$$

$$t = 0.38\ s.$$

Using $a_x = 0$ gives $x = v_{0x}t$ so that

$$v_{0x} = x/t = (2.5\ m)/(0.38\ s) = 6.6\ m/s.$$

Using the result $v = \sqrt{2gh}$, we obtain

$$h = v^2/2g = (6.6\ m/s)^2/2(9.8\ m/s^2) = \mathbf{2.2\ m}.$$

---

11. The flow rate is

$$Q = (0.80\ kg/s)/(930\ kg/m^3) = 8.6 \times 10^{-4}\ m^3/s.$$

Now use equation (11.14) and solve for ΔP,

$$\Delta P = P_2 - P_1 = 8\eta LQ/\pi R^4 = 8(0.12\ Pa\ s)(50.0\ m)(8.6 \times 10^{-4}\ m^3/s)/\pi(5.0 \times 10^{-3}\ m)^4 = \mathbf{2.1 \times 10^7\ Pa}.$$

---

12. Find the volume flow rate,

$$Q = V/t = (3.0\ m \times 4.6\ m \times 0.15\ m)/(2\ h) = (2.07\ m^3)/(7200\ s) = 2.9 \times 10^{-4}\ m^3/s.$$

Using equation (11.14), we can solve for the gauge pressure, $P_g = P_2 - P_1$, i.e.,

$$P_g = 8\eta LQ/\pi R^4 = 8(1.00 \times 10^{-3}\ Pa\ s)(6.7\ m)(2.9 \times 10^{-4}\ m^3/s)/\pi(0.64 \times 10^{-2}\ m)^4 = \mathbf{2.9 \times 10^3\ Pa}.$$

Quiz answers

1. d	4. d	7. d	10. c
2. a	5. d	8. d	11. b
3. b	6. d	9. b	12. d

MCAT REVIEW PROBLEMS

Bernoulli's law and the continuity equation can help us understand some aspects of the circulatory system. According to Bernoulli's law,

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2,$$

where p refers to the pressure, v refers to the speed, and h refers to the height of the fluid. The subscripts "1" and "2" refer to the fluid at two different points in the system.

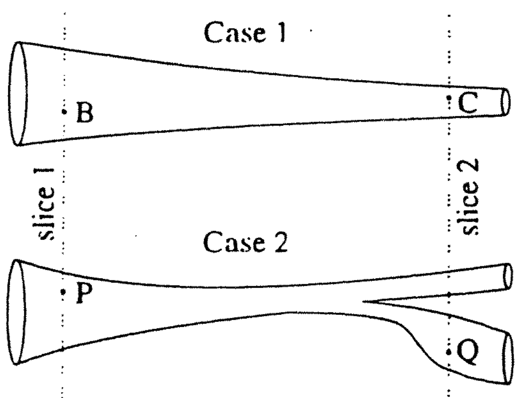
According to the continuity equation, if a piece of the "pipeline" gets thicker, gets thinner, or branches, the volume of fluid per second passing two imaginary cross-sectional "slices" must be the same. For instance, in both cases drawn in figure 1, the volume of fluid per second passing slice 1 must equal the volume of fluid per second passing slice 2.

In case 1, the pipeline doesn't branch. In such cases, for essentially incompressible fluids, the continuity equation can be written

$$A_1 v_1 = A_2 v_2,$$

where A denotes the cross-sectional area of the "pipe."

FIGURE 1



1. Consider case 1. The blood at point B flows at 10 m/s. The blood at point C flows at a speed:

   A. greater than 10 m/s **B.** equal to 10 m/s
   C. less than 10 m/s **D.** Impossible to determine from the information provided

2. Consider case 2. The blood at point P flows at speed 10 m/s. The blood at point Q flows at a speed:

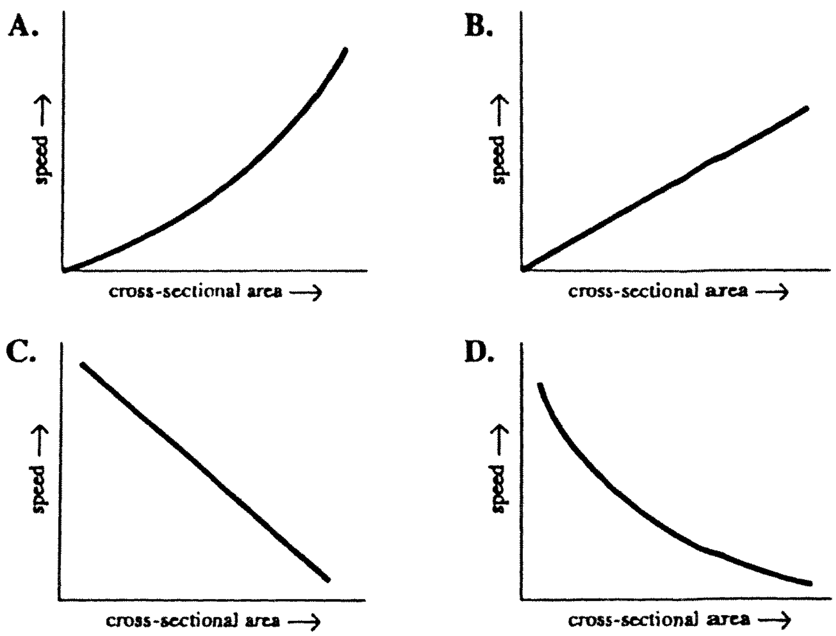
   A. greater than 10 m/s. **B.** equal to 10 m/s.
   C. less than 10 m/s. **D.** Impossible to determine from the information provided

3. Assume that points B and C are at the same height. Let p_B and p_C denote the pressure at points B and C, respectively. Which of the following is true?

A. $p_B > p_C$ B. $p_B = p_C$
C. $p_B < p_C$ D. We cannot determine the relationship between p_B and p_C.

---

4. Suppose a blood vessel gets thinner, but doesn't "branch." Case 1 is an example. Which of the following graphs best shows the relationship between the cross-sectional area of the blood vessel and the speed of the blood flowing through it?



ANSWERS TO MCAT REVIEW PROBLEMS

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1. **A.** The continuity equation tells us that $A_B v_B = A_C v_C$. And the blood vessel is thinner at point C. In other words, A_C is less than A_B. Therefore, v_C must be *greater* than v_B, to ensure that the two sides of the continuity equation are in fact equal.

---

2. **D.** Because the blood vessel "branches," the equation $A_1 v_1 = A_2 v_2$ doesn't apply. We can't set $A_P v_P$ equal to $A_Q v_Q$. Therefore, without more information, we can't relate v_P to v_Q.

---

3. **A.** As found in question 1, v_B is less than v_C. Since those two points share the same height, Bernoulli's law implies that p_B must be greater than p_C. Otherwise, the right-hand side of

$$p_B + \frac{1}{2}\rho v_B^2 + \rho g h_B = p_C + \frac{1}{2}\rho v_C^2 + \rho g h_C$$

would be bigger than the left-hand side.

---

4. **D.** According to the continuity equation for unbranched pipelines, $A_1 v_1 = A_2 v_2 = A_3 v_3$, and so on. In other words,

$$A v = \text{constant}.$$

By playing around with this formula, or by rewriting it as $v = \frac{\text{constant}}{A}$, you can confirm that v is inversely proportional to A. For instance, doubling the cross-sectional area cuts the velocity in half. Tripling A cuts v in third. Quadrupling A cuts v in fourth.

Graph C does *not* express this relationship. It shows v decreasing *linearly* with A. The following two tables demonstrate the difference between an inverse proportionality and a linear decrease. Make sure you develop an intuitive feel for this distinction.

TABLE 1: INVERSE PROPORTIONALITY
$(v = \frac{1}{A})$

A (mm^2)	v (m/s)
1	1.00
2	0.50
3	0.33
4	0.25

Section 11.1 Mass Density

1. **ssm** The ice on a lake is 0.010 m thick. The lake is circular, with a radius of 480 m. Find the mass of the ice.

2. Neutron stars consist only of neutrons and have unbelievably high densities. A typical mass and radius for a neutron star might be 2.7×10^{28} kg and 1.2×10^{3} m. (a) Find the density of such a star. (b) If a dime ($V = 2.0 \times 10^{-7}$ m^3) were made from this material, how much would it weigh (in pounds)?

3. A pirate in a movie is carrying a chest (0.30 m × 0.30 m × 0.20 m) that is supposed to be filled with gold. To see how ridiculous this is, determine the weight (in newtons) of the gold. To judge how large this weight is, remember that 1 N = 0.225 lb.

4. One end of a wire is attached to a ceiling, and a solid brass ball is tied to the lower end. The tension in the wire is 120 N. What is the radius of the brass ball?

5. **ssm** Accomplished silver workers in India can pound silver into incredibly thin sheets, as thin as 3.00×10^{-7} m (about one hundredth of the thickness of this sheet of paper). Find the area of such a sheet that can be formed from 1.00 kg of silver.

*6. A full can of soda has a mass of 0.416 kg. It contains 3.54×10^{-4} m^3 of liquid. Assuming that the soda has the same density as water, find the volume of aluminum used to make the can.

*7. A gold prospector finds a solid rock that is composed solely of quartz and gold. The rock has a mass of 12.0 kg and a volume of 4.00×10^{-3} m^3. What mass of gold is contained in the rock?

*8. Planners of an experiment are evaluating the design of a helium-filled (0 °C, 1 atm pressure) sphere of radius R. Ultrathin silver foil of thickness T is used to make the sphere, and the designers claim that the mass of helium in the sphere equals the mass of silver used. Assuming that T is much less than R, calculate the ratio T/R for such a sphere.

9. **ssm www An antifreeze solution is made by mixing ethylene glycol ($\rho = 1116$ kg/m^3) with water. Suppose the specific gravity of such a solution is 1.0730. Assuming that the total volume of the solution is the sum of its parts, determine the volume percentage of ethylene glycol in the solution.

Section 11.2 Pressure

10. An airtight box has a removable lid of area 1.3×10^{-2} m^2 and negligible weight. The box is taken up a mountain where the air pressure outside the box is 0.85×10^{5} Pa. The inside of the box is completely evacuated. What is the magnitude of the force required to pull the lid off the box?

11. A rectangular table measures 0.80 m by 1.2 m. What is the magnitude and direction of the force that one atmosphere of pressure applies to the (a) top and (b) bottom surfaces of the table?

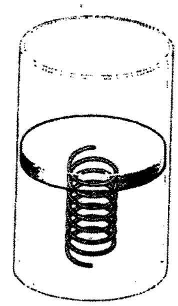
12. The circular top of a can of soda has a radius of 0.0320 m. The pull-tab has an area of 3.80×10^{-4} m^2. The absolute pressure of the carbon dioxide in the can is 1.40×10^{5} Pa. Find the force that this gas generates (a) on the top of the can (including the pull-tab) and (b) on the pull-tab itself.

13. **ssm** High-heeled shoes can cause tremendous pressure to be applied to a floor. Suppose the radius of a heel is 6.00×10^{-3} m. At times during a normal walking motion, nearly the entire body weight acts perpendicular to the surface of such a heel. Find the pressure that is applied to the floor under the heel because of the weight of a 50.0-kg woman.

14. A storm approaches and the air pressure outside your apartment suddenly drops to 0.960×10^{5} Pa from 1.013×10^{5} Pa. Before the pressure inside your apartment has had time to change, what is the magnitude of the net force exerted on a window that measures 2.0 m × 3.1 m?

15. A brick weighs 17.8 N and is resting on the ground. Its dimensions are 0.203 m × 0.0890 m × 0.0570 m. A number of the bricks are then stacked on top of this one. What is the smallest number of whole bricks (including the one on the ground) that could be used, so that their weight creates a pressure of at least one atmosphere on the ground beneath the first brick? *(Hint: First decide which face of the brick is in contact with the ground.)*

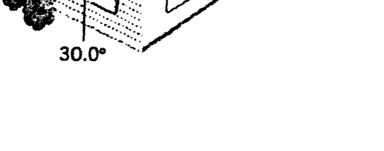
*16. A cylinder is fitted with a piston, beneath which is a spring, as in the drawing. The cylinder is open at the top. Friction is absent. The spring constant of the spring is 3600 N/m. The piston has a negligible mass and a radius of 0.025 m. (a) When air beneath the piston is completely pumped out, how much does the atmospheric pressure cause the spring to compress? (b) How much work does the atmospheric pressure do in compressing the spring?



*17. **ssm** A cylinder (with circular ends) and a hemisphere are solid throughout and made from the same material. They are resting on the ground, the cylinder on one of its ends and the hemisphere on its flat side. The weight of each causes the same pressure to act on the ground. The cylinder is 0.500 m high. What is the radius of the hemisphere?

*18. A 58-kg skier is going down a 35° slope. The area of each ski in contact with the snow is 0.13 m^2. Determine the pressure that each ski exerts on the snow.

**19. A house has a roof (colored gray) with the dimensions shown in the drawing. Determine the magnitude and direction of the net force that the atmosphere applies to the roof, when the outside pressure rises suddenly by 10.0 mm of mercury before the pressure in the attic can adjust.



MASS Density

1) 6.6×10^{6} kg
2) 3.7×10^{18} kg/m^3
1.6×10^{12} lb
3) 3400 N
4) 7.0×10^{-2} m
5) 317 m^2
6) 2.3×10^{-5} m^3
7) 1.57 kg
8) 5.68×10^{-6}
9) 63%
10) 1.1×10^{3} N
11) 9.7×10^{4} N ↓, ↑
12) 4.5×10^{2} N
53.2 N
13) 4.33×10^{6} Pa
14) 3.3×10^{4} N
15) 29 Bricks
16) 0.055 m
5.4 J
17) 0.750 m
18) 1.8×10^{3} Pa
19) 1.41×10^{5} N ↓
20) 1.3×10^{5} Pa

Section 11.3 Pressure and Depth in a Static Fluid, Section 11.4 Pressure Gauges

20. The deep end of a swimming pool has a depth of 3.00 m. The atmospheric pressure above the pool is 1.01×10^5 Pa. What is the pressure at the bottom of the pool?

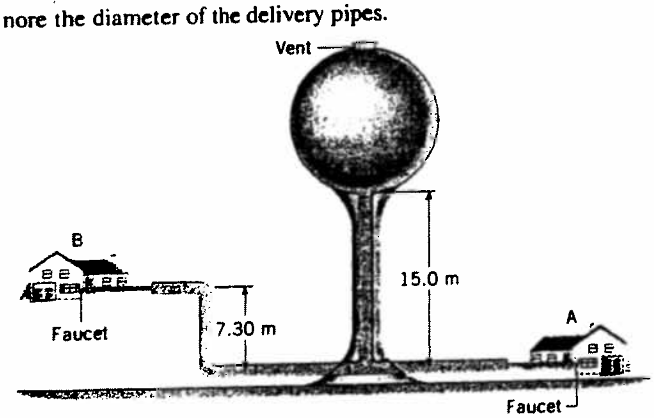
21. **ssm** Some researchers believe that the dinosaur Barosaurus held its head erect on a long neck, much as a giraffe does. If so, fossil remains indicate that its heart would have been about 12 m below its brain. Assume that the blood has the density of water, and calculate the amount by which the blood pressure in the heart would have exceeded that in the brain. Size estimates for the single heart needed to withstand such a pressure range up to two tons. Alternatively, Barosaurus may have had a number of smaller hearts.

22. Suppose you are drinking a can of soda ($\rho = 1.0 \times 10^3$ kg/m^3) using a straw. When you suck on the straw the gauge pressure inside your mouth and lungs is 1200 Pa. How high is the soda drawn up into the straw?

23. The Mariana trench is located in the Pacific Ocean at a depth of about 11 000 m below the surface of the water. The density of seawater is 1025 kg/m^3. (a) If an underwater vehicle were to explore such a depth, what force would the water exert on the vehicle's observation window (radius = 0.10 m)? (b) For comparison, determine the weight of a jetliner whose mass is 1.2×10^5 kg.

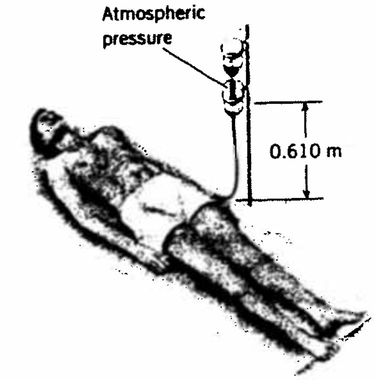
24. Review Conceptual Example 6 as an aid in understanding this problem. Consider the pump on the right-hand side of Figure 11.12, which acts to reduce the air pressure in the pipe. The air pressure outside the pipe is one atmosphere. Find the maximum depth from which this pump can extract water from the well.

25. **ssm** A water tower is a familiar sight in many towns. The purpose of such a tower is to provide storage capacity and to provide sufficient pressure in the pipes that deliver the water to customers. The drawing shows a spherical reservoir that contains 5.25×10^5 kg of water when full. The reservoir is vented to the atmosphere at the top. For a full reservoir, find the gauge pressure that the water has at the faucet in (a) house A and (b) house B. Ignore the diameter of the delivery pipes.



26. As background for this problem, review Conceptual Example 6. A submersible pump is put under the water at the bottom of a well and is used to push water up through a pipe. What minimum output gauge pressure must the pump generate to make the water reach the nozzle at ground level, 71 m above the pump?

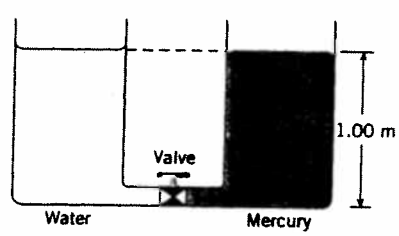
27. The drawing shows an intravenous feeding. With the distance shown, nutrient solution ($\rho = 1030$ kg/m^3) can just barely enter the blood in the vein. What is the gauge pressure of the venous blood? Express your answer in millimeters of mercury.



*28. A mercury barometer reads 747.0 mm on the roof of a building and 760.0 mm on the ground. Assuming a constant value of 1.29 kg/m^3 for the density of air, determine the height of the building.

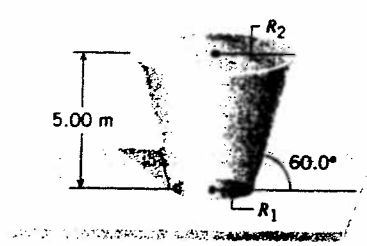
*29. **ssm www** Mercury is poured into a tall glass. Ethyl alcohol is then poured on top of the mercury until the height of the ethyl alcohol itself is 110 cm. The two fluids do not mix, and the air pressure at the top of the ethyl alcohol is one atmosphere. What is the absolute pressure at a point that is 7.10 cm below the ethyl alcohol–mercury interface?

*30. Two identical containers are open at the top and are connected at the bottom via a tube of negligible volume and a valve which is closed. Both containers are filled initially to the same height of 1.00 m, one with water, the other with mercury, as the drawing indicates. The valve is then opened. Water and mercury are immiscible. Determine the fluid level in the left container when equilibrium is reestablished.



*31. The vertical face of a reservoir dam is 120 m wide and 11 m high. Find the total force that the water in a completely full reservoir exerts on this vertical face. (*Hint: The pressure varies linearly with depth, so you must use an average pressure.*)

**32. As the drawing illustrates, a pond has the shape of an inverted cone with the tip sliced off and has a depth of 5.00 m. The atmospheric pressure above the pond is 1.01×10^5 Pa. The circular top surface (radius = R_2) and circular bottom surface (radius = R_1) of the pond are both parallel to the ground. The magnitude of the force acting on the top surface is the same as the magnitude of the force acting on the bottom surface. Obtain (a) R_2 and (b) R_1.



Pressure + Depth in a Static Fluid

20) 1.3×10^5 Pa
21) 1.2×10^5 Pa
22) 0.12 m
23) 3.5×10^6 N
1.2×10^6 N
24) 10.3 m
25) 2.45×10^5 Pa
1.73×10^5 Pa
26) 7.0×10^5 Pa
27) 46.2 mmHg
28) 137 m
29) 1.19×10^5 Pa
30) 1.46 m
31) 7.1×10^7 N
32) 16.1 m
13.2 m

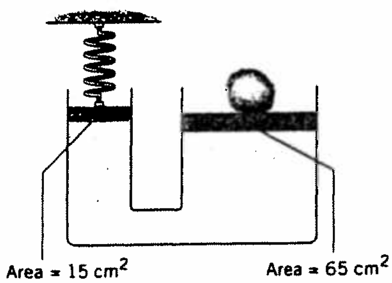
Section 11.5 Pascal's Principle

33. **ssm** The atmospheric pressure above a swimming pool changes from 755 to 765 mm of mercury. The bottom of the pool is a 12 m × 24 m rectangle. By how much does the force on the bottom of the pool increase?

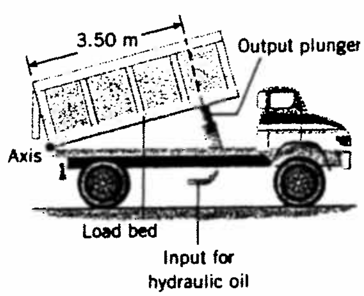
34. In the process of changing a flat tire, a motorist uses a hydraulic jack. She begins by applying a force of $F_1 = 7.0$ N to the input piston. As a result, the output plunger applies a force of $F_2 = 420$ N to the car. The height difference between the input piston and the output plunger can be neglected. What is the ratio A_2/A_1 of the plunger and piston areas?

35. In the hydraulic press used in a trash compactor, the radii of the input piston and the output plunger are 6.4×10^{-3} m and 5.1×10^{-2} m, respectively. If the height difference between the input piston and the output plunger can be neglected, what force is applied to the trash when the input force is 330 N?

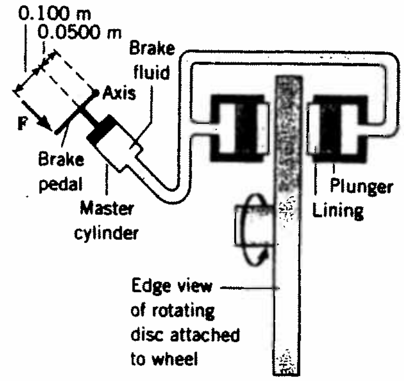
36. The drawing shows a hydraulic chamber in which a spring (spring constant = 1600 N/m) is attached to the input piston, and a rock of mass 40.0 kg rests on the output plunger. The piston and plunger are at the same height, and each has a negligible mass. By how much is the spring compressed from its unstrained position?



***37.** **ssm** A dump truck uses a hydraulic cylinder, as the drawing illustrates. When activated by the operator, a pump injects hydraulic oil into the cylinder at an absolute pressure of 3.54×10^6 Pa and drives the output plunger, which has a radius of 0.150 m. Assuming the plunger remains perpendicular to the floor of the load bed, find the torque that the plunger creates about the axis identified in the drawing.

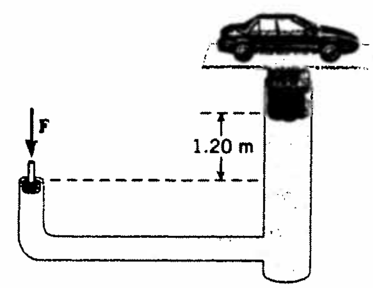


***38.** The drawing shows a hydraulic system used with disc brakes. The force **F** is applied perpendicularly to the brake pedal.



The brake pedal rotates about the axis shown in the drawing and causes a force to be applied perpendicularly to the input piston (radius = 9.50×10^{-3} m) in the master cylinder. The resulting pressure is transmitted by the brake fluid to the output plungers (radii = 1.90×10^{-2} m), which are covered with the brake linings. The linings are pressed against both sides of a disc attached to the rotating wheel. Suppose that the magnitude of **F** is 9.00 N. Assume that the input piston and the output plungers are at the same vertical level and find the force applied to each side of the revolving disc.

***39.** Prepare for this problem by reviewing Example 7. The hydraulic oil in a car lift has a density of 8.00×10^2 kg/m³. The weight of the input piston is negligible. The radii of the input piston and output plunger are 8.00×10^{-3} m and 0.140 m, respectively. What input force **F** is needed to support the 22 300-N combined weight of a car and the output plunger, when the bottom surfaces of the piston and plunger are at (a) the same level and (b) the levels shown in the drawing?



Pascal's Principle

33) 3.8×10^5 N
34) 60
35) 2.1×10^4 N
36) 5.7×10^{-2} m
37) 8.50×10^5 N·m
38) 108 N
39) 72.8 N
40) 2.5×10^2 N

Section 11.6 Archimedes' Principle

40. A bodybuilder is holding a 29-kg steel barbell above her head. How much force would she have to exert if the barbell were lifted underwater?

41. ssm What is the radius of a hydrogen-filled balloon that would carry a load of 5750 N (in addition to the weight of the hydrogen) when the density of air is 1.29 kg/m^3?

42. A solid object floats on ethyl alcohol, with 68.2% of the object's volume submerged. Using Table 11.1, identify the substance from which the object is made.

43. What is the total mass of swimmers that the raft in Example 8 can carry and float with its top surface at water level?

44. An 80.0-kg person is wearing a life jacket and floating in water. The life jacket has a volume of 3.0×10^{-2} m^3 and is completely submerged under the water. The volume of the person's body that is underwater is 6.2×10^{-2} m^3. What is the density of the life jacket?

45. ssm www A person can change the volume of his body by taking air into his lungs. The amount of change can be determined by weighing the person under water. Suppose that under water a person weighs 20.0 N with partially full lungs and 40.0 N with empty lungs. Find the change in body volume.

***46.** What is the smallest number of whole logs (ρ = 725 kg/m^3, radius = 0.0800 m, length = 3.00 m) that can be used to build a raft that will carry four people, each of whom has a mass of 80.0 kg?

***47.** A spring has a spring constant of 578 N/m. When used to suspend an object in air, the spring stretches by 0.0640 m. When used to suspend the same object in water, the spring stretches by 0.0520 m. (a) What buoyant force acts on the object? (b) What is the volume of the part of the object that is underwater?

***48.** To verify her suspicion that a rock specimen is hollow, a geologist weighs the specimen in air and in water. She finds that the specimen weighs twice as much in air as it does in water. The solid part of the specimen has a density of 5.0×10^3 kg/m^3. What fraction of the specimen's apparent volume is solid?

***49. ssm** A 1967 Kennedy half-dollar has a mass of 1.150×10^{-2} kg. The coin is a mixture of silver and copper, and in water weighs 0.1011 N. Determine the mass of silver in the coin.

****50.** One kilogram of glass ($\rho = 2.60 \times 10^3$ kg/m^3) is shaped into a hollow spherical shell that just barely floats in water. What are the inner and outer radii of the shell? Do not assume the shell is thin.

****51.** A lighter-than-air balloon and its load of passengers and ballast are floating stationary above the earth. Ballast is weight (of negligible volume) that can be dropped overboard to make the balloon rise. The radius of this balloon is 6.25 m. Assuming a constant value of 1.29 kg/m^3 for the density of air, determine how much weight must be dropped overboard to make the balloon rise 105 m in 15.0 s.

****52.** A spring is attached to the bottom of an empty swimming pool, with the axis of the spring oriented vertically. An 8.00-kg block of wood (ρ = 840 kg/m^3) is fixed to the top of the spring and compresses it. Then the pool is filled with water, completely covering the block. The spring is now observed to be stretched twice as much as it had been compressed. Determine the percentage of the block's total volume that is hollow. Ignore any air in the hollow space.

ARCHIMEDES Principle

40) 2.5×10^2 N
41) 4.89 m
42) yellow pine
43) 2.2×10^3 kg
44) 4×10^2 kg/m^3
45) 2.04×10^{-3} m^3
46) 20 logs
47) 6.9 N, 7×10^{-4} m^3
48) 0.40
49) 6.3×10^{-3} kg
50) 6.2×10^{-2} m
51) 1120 N
52) 60.3%

Section 11.8 The Equation of Continuity

53. **ssm** Water flows with a volume flow rate of $1.50\ m^3/s$ in a pipe. Find the water speed where the pipe radius is 0.500 m.

54. Oil is flowing with a speed of 1.22 m/s through a pipeline with a radius of 0.305 m. How many gallons of oil ($1\ gal = 3.79 \times 10^{-3}\ m^3$) flow in one day?

55. Suppose that blood flows through the aorta with a speed of 0.35 m/s. The cross-sectional area of the aorta is $2.0 \times 10^{-4}\ m^2$. (a) Find the volume flow rate of the blood. (b) The aorta branches into tens of thousands of capillaries whose total cross-sectional area is about $0.28\ m^2$. What is the average blood speed through them?

56. Water flows straight down from an open faucet. The radius of the faucet is 0.75 cm and the speed of the water as it leaves is 0.85 m/s. At a distance of 0.10 m below the faucet, the speed of the water is 1.6 m/s. (a) What is the radius of the water stream at this point? (b) How long would it take to fill a bucket whose volume is $2.0 \times 10^{-2}\ m^3$?

*57. **ssm** A water line with an internal radius of 6.5×10^{-3} m is connected to a shower head that has 12 holes. The speed of the water in the line is 1.2 m/s. (a) What is the volume flow rate in the line? (b) At what speed does the water leave one of the holes (effective hole radius $= 4.6 \times 10^{-4}$ m) in the head?

*58. In an adjustable nozzle for a garden hose, a cylindrical plug is aligned along the axis of the hose and can be inserted into the hose opening. The purpose of the plug is to change the speed of the water leaving the hose. The speed of the water passing around the plug is to be three times greater than the speed of the water before it encounters the plug. Find the ratio of the plug radius to the inside hose radius.

EQUATION OF CONTINUITY

53.) 1.91 m/s

54.) 8.12×10^6 gal

55.) $7 \times 10^{-5}\ m^3/s$

2.5×10^{-4} m/s

56) 0.55 cm

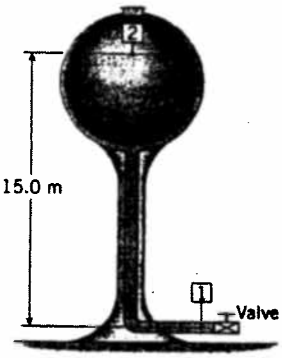
1.3×10^2 s

57) $1.6 \times 10^{-4}\ m^3/s$

58) 0.816

the speed of the water at the point where the water leaves the pipe feeding the fountain? At that point, the pressure is atmospheric pressure. (b) The effective cross-sectional area of the pipe is 5.00×10^{-4} m^2. How many gallons per minute are being used by the fountain? (1 gal = 3.79×10^{-3} m^3)

64. The water tower in the drawing is drained by a pipe that extends to the ground. The flow is nonviscous. (a) What is the absolute pressure at point 1 if the valve is *closed*, assuming that the top surface of the water at point 2 is at atmospheric pressure. (b) What is the absolute pressure at point 1 when the valve is opened and the water is flowing? Assume that the water speed at point 2 is negligible. (c) Assuming the effective cross-sectional area of the valve opening is 2.00×10^{-2} m^2, find the volume flow rate at point 1.



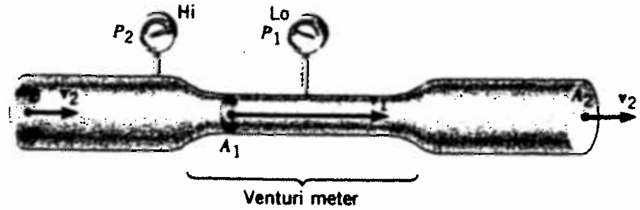
65. **ssm** An airplane wing is designed so that the speed of the air across the top of the wing is 251 m/s when the speed of the air below the wing is 225 m/s. The density of the air is 1.29 kg/m^3. What is the lifting force on a wing of area 24.0 m^2?

***66.** A cylindrical water tunnel runs through a dam. The entrance to the tunnel has a radius of 1.30 m and is located at a depth of 22.0 m below the surface of the water. The other end of the tunnel has a radius of 0.840 m, is 46.0 m below the water's surface, and is open to the air. (a) What is the speed of the water when it exits the tunnel? (b) Determine the absolute pressure of the water just after it enters the tunnel.

***67.** The construction of a flat rectangular roof (4.0 m × 5.5 m) allows it to withstand a maximum net outward force of 21 000 N. The density of the air is 1.29 kg/m^3. At what wind speed will this roof blow outward?

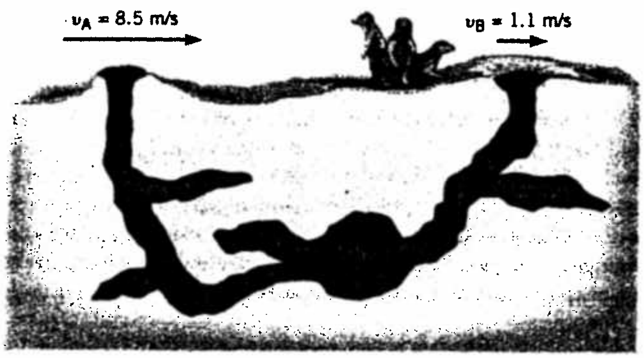
***68.** Water is running out of a faucet, falling straight down, with an initial speed of 0.50 m/s. At what distance below the faucet is the radius of the stream reduced to one-half its value at the faucet?

***69.** **ssm** A Venturi meter is a device for measuring the speed of a fluid within a pipe. The drawing shows a gas flowing at speed v_2 through a horizontal section of pipe whose cross-sectional area is



Section 11.9 Bernoulli's Equation, Section 11.10 Applications of Bernoulli's Equation

59. Prairie dogs are burrowing rodents. They do not suffocate in their burrows, because the effect of air speed on pressure creates sufficient air circulation. The animals maintain a difference in the shapes of two entrances to the burrow, and because of this difference, the air (ρ = 1.29 kg/m^3) blows past the openings at different speeds, as the drawing indicates. Assuming that the openings are at the same vertical level, find the difference in air pressure between the openings and indicate which way the air circulates.



60. Review Conceptual Example 13 before attempting this problem. The truck in that example is traveling at 27 m/s. The density of air is 1.29 kg/m^3. By how much does the pressure inside the cargo area beneath the tarpaulin exceed the outside pressure?

61. **ssm** Review Conceptual Example 13 as an aid in understanding this problem. Suppose that a 15-m/s wind is blowing across the roof of your house. The density of air is 1.29 kg/m^3. (a) Determine the reduction in pressure (below atmospheric pressure of stationary air) that accompanies this wind. (b) Explain why some roofs are "blown outward" during high winds.

62. Water is circulating through a closed pipe system in a two-floor apartment. On the first floor, the gauge pressure of the water is 9.7×10^4 Pa and its speed is 2.1 m/s. On the second floor, which is 4.0 m higher, the speed of the water is 3.7 m/s. The water speeds are different on the two floors, because the pipe diameters are different. (a) What is the gauge pressure of the water on the second floor? (b) When the water stops flowing, the gauge pressure of the water on the first floor becomes 1.1×10^5 Pa. What is the gauge pressure on the second floor?

63. A fountain sends a stream of water 5.00 m into the air. (a) Neglecting air resistance and any viscous effects, what must be

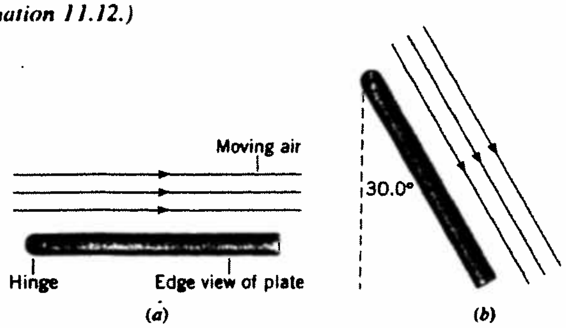
A_2 = 0.0700 m^2. The gas has a density of ρ = 1.30 kg/m^3. The Venturi meter has a cross-sectional area of A_1 = 0.0500 m^2 and has been substituted for a section of the larger pipe. The pressure difference between the two sections is $P_2 - P_1$ = 120 Pa. Find (a) the speed v_2 of the gas in the larger original pipe and (b) the volume flow rate Q of the gas.

*70. In a very large closed tank, the absolute pressure of the air above the water is 6.01 × 10^5 Pa. The water leaves the bottom of the tank through a nozzle that is directed straight upward. The opening of the nozzle is 4.00 m below the surface of the water. (a) Find the speed at which the water leaves the nozzle. (b) Ignoring air resistance and viscous effects, determine the height to which the water rises.

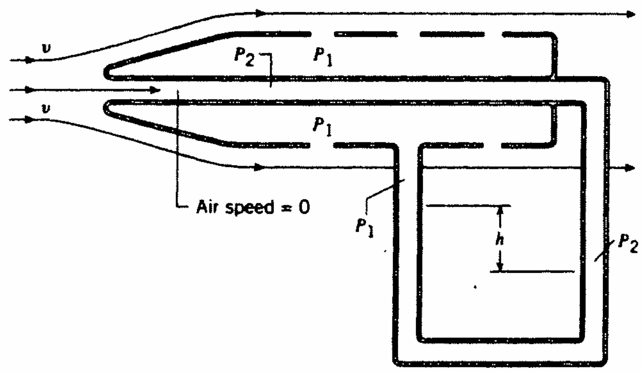
*71. A pump and its horizontal intake pipe are located 12 m beneath the surface of a reservoir. The speed of the water in the intake pipe causes the pressure there to decrease, in accord with Bernoulli's principle. Assuming nonviscous flow, what is the maximum speed with which water can flow through the intake pipe?

*72. Two circular holes, one larger than the other, are cut in the side of a large water tank whose top is open to the atmosphere. The center of one of these holes is located twice as far beneath the surface of the water as the other. The volume flow rate of the water coming out of the holes is the same. (a) Decide which hole is located nearest the surface of the water. (b) Calculate the ratio of the radius of the larger hole to the radius of the smaller hole.

*73. **ssm** A uniform rectangular plate is hanging vertically downward from a hinge that passes along its left edge. By blowing air at 11.0 m/s *over the top of the plate only*, it is possible to keep the plate in a horizontal position, as illustrated in part *a* of the drawing. To what value should the air speed be reduced so that the plate is kept at a 30.0° angle with respect to the vertical, as in part *b* of the drawing? *(Hint: Apply Bernoulli's equation in the form of Equation 11.12.)*



*74. The air speed of a plane can be measured with a Pitot-static tube, an example of which is illustrated in the drawing. The Pitot-static tube consists of two concentric tubes: The inner one is the static tube, and the outer one with holes in it is the Pitot tube. The difference in air pressure between the two is measured by the U-tube manometer in the drawing. The air speed inside the static tube is zero, because the closed tube presents an immovable obstacle to the flow of air. In contrast, the air rushing past the holes in the Pitot tube has a high speed. (a) By applying Bernoulli's equation, show that the speed of the air is $v = \sqrt{2(P_2 - P_1)/\rho}$, where $P_2 - P_1$ is the difference in pressure and ρ is the air density at the altitude of the plane. (b) By expressing $P_2 - P_1$ in terms of the height h and density ρ_0 of the fluid in the U-tube, show that the air speed can be expressed as $v = \sqrt{2gh\rho_0/\rho}$.



Section 11.11 Viscous Flow

75. A pressure difference of 1.1 × 10^3 Pa is needed to drive water (η = 1.0 × 10^{-3} Pa · s) through a pipe whose radius is 6.4 × 10^{-3} m. The volume flow rate of the water is 3.2 × 10^{-4} m^3/s. What is the length of the pipe?

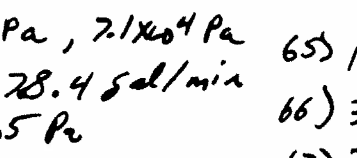
76. A blood vessel is 0.10 m in length and has a radius of 1.5 × 10^{-3} m. Blood (η = 4 × 10^{-3} Pa · s) flows at a rate of 1.0 × 10^{-7} m^3/s. Determine the difference in pressure that must be maintained between the two ends of the vessel.

77. **ssm www** A 1.3-m length of horizontal pipe has a radius of 6.4 × 10^{-3} m. Water flows with a volume flow rate of 9.0 × 10^{-3} m^3/s out of the right end of the pipe and into the air. What is the pressure in the flowing water at the left end of the pipe if the water behaves as (a) an ideal fluid and (b) a viscous fluid (η = 1.00 × 10^{-3} Pa · s)?

78. A cylindrical air duct in an air conditioning system has a length of 5.5 m and a radius of 7.2 × 10^{-2} m. A fan forces air (η = 1.8 × 10^{-5} Pa · s) through the duct, such that the air in a room (volume = 280 m^3) is replenished every ten minutes. Determine the difference in pressure between the ends of the air duct.

79. During a heavy rain, a 3.0-m × 4.6-m family room is flooded to a depth of 0.15 m. To remove the water (η = 1.00 × 10^{-3} Pa · s), a pump is used that does the job in two hours. The water flows out into the yard through a horizontal pipe of radius 6.4 × 10^{-3} m and length 6.7 m. What gauge pressure does the pump produce?

*80. Water (η = 1.00 × 10^{-3} Pa · s) is flowing through a horizontal pipe with a volume flow rate of 0.014 m^3/s. As the drawing



72) upper hole must have larger area, 1.19
73) 7.7 m/s

69) 14 m/s, 0.98 m^3/s
70) 32.8 m/s, 54.9 m

Bernoulli's Equation
59) ΔP = 46 Pa enters A exits B
60) 4.7 x 10^2 Pa
61) 150 Pa
62) 5.3 x 10^4 Pa, 7.1 x 10^4 Pa
63) 9.9 m/s, 28.4 gal/min
64) 2.48 x 10^5 Pa
P_1 = 1.01 x 10^5 Pa
[illegible]
65) 1.92 x 10^5 N
66) 30.0 m/s, 2.38 x 10^5 Pa
67) 38 m/s
68) 0.19 m

Chapter 10: Fluids

MULTIPLE CHOICE

1. A plastic block of dimensions 2.00 cm X 3.00 cm X 4.00 cm has a mass of 30.0 g. What is its density?

   a) 0.80 g/cm^3
   b) 1.20 g/cm^3
   c) 1.25 g/cm^3
   d) 1.60 g/cm^3

   Answer: c Difficulty: 1

2. Substance A has a density of 3.0 g/cm^3 and substance B has a density of 4.0 g/cm^3. In order to obtain equal masses of these two substances, the ratio of the volume of A to the volume of B will be equal to

   a) 1:3
   b) 4:3
   c) 3:4
   d) 1:4

   Answer: b Difficulty: 1

3. A liquid has a specific gravity of 0.357. What is its density?

   a) 357 kg/m^3
   b) 643 kg/m^3
   c) 1000 kg/m^3
   d) 3570 kg/m^3

   Answer: a Difficulty: 1

4. A brick weighs 50.0 N, and measures 30.0 cm X 10.0 cm X 4.00 cm. What is the maximum pressure it can exert on a horizontal surface?

   a) 1.25 Pa
   b) 12.5 Pa
   c) 1.25 kPa
   d) 12.5 kPa

   Answer: d Difficulty: 1

5. A person weighing 900 N is standing on snowshoes. Each snowshoe has area 2500 cm^2. What is the pressure on the snow?

   a) 0.18 N/m^2
   b) 0.36 N/m^2
   c) 1800 N/m^2
   d) 3600 N/m^2

   Answer: c Difficulty: 2

6. What is the absolute pressure at a location 15.0 m below the surface of sea? (The density of seawater is 1.03×10^3 kg/m^3.)

a) 1.01×10^5 N/m^2
b) 1.51×10^5 N/m^2
c) 2.48×10^5 N/m^2
d) 2.52×10^5 N/m^2

Answer: d Difficulty: 1

7. How much pressure must a submarine withstand at a depth of 120.0 m?

a) 123.0 N/m^2
b) 1205 N/m^2
c) 123.0 kPa
d) 1205 kPa

Answer: d Difficulty: 1

8. What is the gauge pressure if the absolute pressure is 300 kPa?

a) 97 kPa
b) 101 kPa
c) 199 kPa
d) 300 kPa

Answer: c Difficulty: 1

9. Which of the following is not a unit of pressure?

a) atmosphere
b) N/m
c) Pascal
d) mm of mercury

Answer: b Difficulty: 1

10. What is the difference between the pressures inside and outside a tire called?

a) absolute pressure
b) atmospheric pressure
c) gauge pressure
d) N/m^2

Answer: c Difficulty: 1

11. You are originally 1.0 m beneath the surface of a pool. If you dive to 2.0 m beneath the surface, what happens to the absolute pressure on you?

    a) It quadruples.
    b) It more than doubles.
    c) It doubles.
    d) It less than doubles.

    Answer: d Difficulty: 2

12. When atmospheric pressure changes, what happens to the absolute pressure at the bottom of a pool?

    a) It does not change.
    b) It increases by a lesser amnount.
    c) It increases by the same amount.
    d) It increases by a greater amount.

    Answer: c Difficulty: 2

13. You are originally 1.0 m beneath the surface of a pool. If you dive to 3.0 m, what happens to the additional pressure (in excess of atmospheric pressure) on you?

    a) Increases by a factor of nine.
    b) More than triples.
    c) Triples.
    d) Less than triples.

    Answer: c Difficulty: 1

14. What is the gauge pressure at a location 15.0 m below the surface of sea? (The density of seawater is $1.03X10^3$ kg/m^3.)

    a) $1.01X10^5$ N/m^2
    b) $1.51X10^5$ N/m^2
    c) $1.47X10^5$ N/m^2
    d) $2.52X10^5$ N/m^2

    Answer: b Difficulty: 1

15. Consider three drinking glasses. All three have the same area base, and all three are filled to the same depth with water. Glass A is cylindrical. Glass B is wider at the top than at the bottom, and so holds more water than A. Glass C is narrower at the top than at the bottom, and so holds less water than A. Which glass has the greatest liquid pressure at the bottom?

a) Glass A.
b) Glass B.
c) Glass C.
d) All three have equal pressure.

Answer: d Difficulty: 2

16. A circular window of 30 cm diameter in a submarine can withstand a maximum force of $5.20X10^5$ N. What is the maximum depth in a lake to which the submarine can go without damaging the window?

a) 680 m
b) 750 m
c) 1200 m
d) 1327 m

Answer: b Difficulty: 2

17. A 13,000 N vehicle is to be lifted by a 25 cm hydraulic piston. What force needs to be applied to a 5.0 cm diameter piston to accomplish this?

a) 260 N
b) 520 N
c) 2600 N
d) 5200 N

Answer: b Difficulty: 2

18. In a hydraulic garage lift, the small piston has a radius of 5.0 cm and the large piston has a radius of 15 cm. What force must be applied on the small piston in order to lift a car weighing 20,000 N on the large piston?

a) $6.7X10^3$ N
b) $5.0X10^3$ N
c) $2.9X10^3$ N
d) $2.2X10^3$ N

Answer: d Difficulty: 2

19. A 500 N weight sits on the small piston of a hydraulic machine. The small piston has area 2.0 cm^2. If the large piston has area 40 cm^2, how much weight can the large piston support?

a) 25 N
b) 500 N
c) 10000 N
d) 40000 N

Answer: c Difficulty: 1

20. A cylindrical rod of length 12 cm and diameter 2.0 cm will just barely float in water. What is its mass?

a) 38 g
b) 75 g
c) 150 g
d) 300 g

Answer: a Difficulty: 1

21. A block of metal weighs 45 N in air and 25 N in water. What is the buoyant force of the water?

a) 20 N
b) 25 N
c) 45 N
d) 70 N

Answer: a Difficulty: 1

22. An object has a volume of 4.0 m^3 and weighs 40,000 N. What will its weight be in water?

a) 40,000 N
b) 39,200 N
c) 9,800 N
d) 800 N

Answer: d Difficulty: 1

23. A 1.0 m^3 object floats in water with 20% of it above the waterline. What does the object weigh out of the water?

a) 1,960 N
b) 7,840 N
c) 9,800 N
d) 11,800 N

Answer: b Difficulty: 2

24. As a rock sinks deeper and deeper into water of constant density, what happens to the buoyant force on it?

a) It increases.
b) It remains constant.
c) It decreases.
d) It may increase or decrease, depending on the shape of the rock.

Answer: b Difficulty: 2

25. 50 cm^3 of wood is floating on water, and 50 cm^3 of iron is totally submerged. Which has the greater buoyant force on it?

a) The wood.
b) The iron.
c) Both have the same buoyant force.
d) Cannot be determined without knowing their densities.

Answer: b Difficulty: 2

26. Salt water has greater density than fresh water. A boat floats in both fresh water and in salt water. Where is the buoyant force greater on the boat?

a) Salt water.
b) Fresh water.
c) Buoyant force is the same in both.
d) Impossible to determine from the information given.

Answer: c Difficulty: 2

27. A piece of wood is floating in a bathtub. A second piece of wood sits on top of the first piece, and does not touch the water. If the top piece is taken off and placed in the water, what happens to the water level in the tub?

a) It goes up.
b) It goes down.
c) It does not change.
d) Cannot be determined from the information given.

Answer: c Difficulty: 3

28. Salt water is more dense than fresh water. A ship floats in both fresh water and salt water. Compared to the fresh water, the volume of water displaced in the salt water is

a) more.
b) less.
c) the same.
d) Cannot be determined from the information given.

Answer: b Difficulty: 2

29. A piece of iron rests on top of a piece of wood floating in a bathtub. If the iron is removed from the wood, what happens to the water level in the tub?

a) It goes up.
b) It goes down.
c) It does not change.
d) Impossible to determine from the information given.

Answer: b Difficulty: 2

30. A steel ball sinks in water but floats in a pool of mercury. Where is the buoyant force on the ball greater?

a) Floating on the mercury.
b) Submerged in the water.
c) It is the same in both cases.
d) Cannot be determined from the information given.

Answer: a Difficulty: 2

31. An object floats with half its volume beneath the surface of the water. The weight of the displaced water is 2000 N. What is the weight of the object?

a) 1000 N
b) 2000 N
c) 4000 N
d) Cannot be determined from the information given.

Answer: b Difficulty: 2

32. A solid object floats in water with three-fourths of its volume beneath the surface. What is the object's density?

a) 1333 kg/m^3
b) 1000 kg/m^3
c) 750 kg/m^3
d) 250 kg/m^3

Answer: c Difficulty: 2

33. A 200 N object floats with three-fourths of its volume beneath the surface of the water. What is the buoyant force on the object?

a) 50 N
b) 150 N
c) 200 N
d) 267 N

Answer: c Difficulty: 2

34. A 4.00-kg cylinder of solid iron is supported by a string while submerged in water. What is the tension in the string? (The specific gravity of iron is 7.86.)

a) 2.50 N
b) 19.6 N
c) 23.7 N
d) 34.2 N

Answer: d Difficulty: 2

35. If the density of gold is 19.3×10^3 kg/m^3, what buoyant force does a 0.60-kg gold crown experience when it is immersed in water?

a) 3.0×10^{-5} N
b) 3.0×10^{-4} N
c) 3.0×10^{-2} N
d) 0.30 N

Answer: d Difficulty: 2

36. A 10 kg piece of aluminum sits at the bottom of a lake, right next to a 10 kg piece of lead. Which has the greater buoyant force on it?

a) The aluminum.
b) The lead.
c) Both have the same buoyant force.
d) Cannot be determined without knowing their volumes.

Answer: a Difficulty: 2

37. A crane lifts a steel submarine (density = 7.8×10^3 kg/m^3) of mass 20,000 kg. What is the tension in the lifting cable (1) when the submarine is submerged, and (2) when it is entirely out of the water?

a) (1) 2.0×10^5 N (2) 1.7×10^5 N
b) (1) 1.7×10^5 N (2) 2.0×10^5 N
c) (1) 2.6×10^3 N (2) 2.0×10^5 N
d) (1) 2.0×10^5 N (2) 2.6×10^3 N

Answer: b Difficulty: 2

38. A rectangular box measures 5.0 m long, 1.0 m wide, and 0.50 m high. How many kilograms of mass can be loaded onto the box before it sinks in a lake?

a) 0.5×10^3 kg
b) 1.5×10^3 kg
c) 2.5×10^3 kg
d) 3.5×10^3 kg

Answer: c Difficulty: 1

39. A polar bear of mass 200 kg stands on an ice floe 100 cm thick. What is the minimum area of the floe that will just support the bear in saltwater of specific gravity 1.03? The specific gravity of ice is 0.98.

a) 1.0 m^2
b) 2.0 m^2
c) 3.0 m^2
d) 4.0 m^2

Answer: d Difficulty: 3

40. A sunken steel ship has a mass of 500,000 kg. It is filled with water. In order to lift the ship, air bags are to be inflated inside the hull. What volume of air is needed? The specific gravity of steel is 7.8.

a) 225 m^3
b) 436 m^3
c) 1266 m^3
d) 2778 m^3

Answer: b Difficulty: 2

41. A container of water is placed on a scale, and the scale reads 120 g. Now a 20-g piece of copper (specific gravity = 8.9) is suspended from a thread and lowered into the water, not touching the bottom of the container. What will the scale now read?

a) 120 g
b) 122 g
c) 138 g
d) 140 g

Answer: b Difficulty: 3

42. An object weighs 7.84 N when it is in air and 6.86 N when it is immersed in water. What is the specific gravity of the object?

a) 6.0
b) 7.0
c) 8.0
d) 9.0

Answer: c Difficulty: 2

43. An ideal fluid flows at 12 m/s in a horizontal pipe. If the pipe widens to twice its original radius, what is the flow speed in the wider section?

a) 12 m/s
b) 6.0 m/s
c) 4.0 m/s
d) 3.0 m/s

Answer: d Difficulty: 1

44. An ideal fluid flows at 12 m/s in a horizontal pipe. If the pipe narrows to half its original radius, what is the flow speed in the narrower section?

a) 12 m/s
b) 24 m/s
c) 36 m/s
d) 48 m/s

Answer: d Difficulty: 1

45. Which one of the following is associated with the law of conservation of energy in fluids?

a) Archimedes' principle
b) Bernoulli's principle
c) Pascal's principle
d) equation of continuity

Answer: b Difficulty: 2

46. When you blow some air above a paper strip, the paper rises. This is because

a) the air above the paper moves faster and the pressure is higher.
b) The air above the paper moves faster and the pressure is lower.
c) The air above the paper moves slower and the pressure is higher.
d) The air above the paper moves slower and the pressure is lower.

Answer: b Difficulty: 1

47. Water flows at 12 m/s in a horizontal pipe with a pressure of 3.0×10^4 N/m^2. If the pipe widens to twice its original radius, what is the pressure in the wider section?

a) 3.0×10^4 N/m^2
b) 4.9×10^4 N/m^2
c) 7.4×10^4 N/m^2
d) 9.8×10^4 N/m^2

Answer: d Difficulty: 2

48. A hole of radius 1.0 mm occurs in the bottom of a water storage tank that holds water at a depth of 15 m. At what rate will water flow out of the hole?

a) $5.4X10^{-4}$ m^3/s
b) $5.4X10^{-5}$ m^3/s
c) $5.4X10^{-6}$ m^3/s
d) $5.4X10^{-7}$ m^3/s

Answer: b Difficulty: 3

49. Water flows through a horizontal pipe of cross-sectional area 10.0 cm^2 at a pressure of 0.250 atm. The flow rate is $1.00X10^{-3}$ m^3/s. At a valve, the effective cross-sectional area of the pipe is reduced to 5.00 cm^2. What is the pressure at the valve?

a) 0.112 atm
b) 0.157 atm
c) 0.200 atm
d) 0.235 atm

Answer: d Difficulty: 3

50. Suppose that the build-up of fatty tissue on the wall of an artery decreased the radius by 10%. By how much would the pressure provided by the heart have to be increased to maintain a constant blood flow?

a) 48%
b) 52%
c) 46%
d) 54%

Answer: b Difficulty: 2

51. SAE No. 10 oil has a viscosity of 0.20 Pa-s. How long would it take to pour 4.0 L of oil through a funnel with a neck 15 cm long and 2.0 cm in diameter? Assume the surface of the oil is kept 6 cm above the top of the neck, and neglect any drag effects due to the upper part of the funnel.

a) 46 s
b) 52 s
c) 84 s
d) 105 s

Answer: b Difficulty: 3

52. When a small spherical rock of radius r falls through water, it experiences a drag force arv, where "v" is its velocity and "a" is a constant proportional to the viscosity of water. From this, one can deduce that if a rock of diameter 2.0 mm falls with terminal velocity, "v", then a rock of diameter 4.0 mm will fall with terminal velocity

a) v
b) 1.4v
c) 2.0v
d) 4.0v

Answer: d Difficulty: 3

53. Two styrofoam balls, of radii R and 2R, are released simultaneously from a tall tower. Which will reach the ground first?

a) Both will reach the ground simultaneously.
b) The larger one
c) The smaller one
d) The result will depend on the atmospheric pressure.

Answer: b Difficulty: 2

54. Which has the greatest effect on the flow of fluid through a narrow pipe? That is, if you made a 10% change in each of the quantities below, which would cause the greatest change in the flow rate?

a) The fluid viscosity
b) The pressure difference
c) The length of the pipe
d) The radius of the pipe

Answer: d Difficulty: 2

55. As the speed of a moving fluid increases, the pressure in the fluid

a) increases.
b) remains constant.
c) decreases.
d) may increase or decrease, depending on the viscosity.

Answer: c Difficulty: 1

56. Two horizontal pipes are the same length, but pipe B has twice the diameter of pipe A. Water undergoes viscous flow in both pipes, subject to the same pressure difference across the lengths of the pipes. If the flow rate in pipe A is Q, what is the flow rate in pipe B?

a) 2Q
b) 4Q
c) 8Q
d) 16Q

Answer: d Difficulty: 2

57. Two horizontal pipes have the same diameter, but pipe B is twice as long as pipe A. Water undergoes viscous flow in both pipes, subject to the same pressure difference across the lengths of the pipes. If the flow rate in pipe B is Q, what is the flow rate in pipe A?

a) Q
b) 2Q
c) 4Q
d) 8Q

Answer: b Difficulty: 2

58. A sky diver falls through the air at terminal velocity. The force of air resistance on him is

a) half his weight.
b) equal to his weight.
c) twice his weight.
d) Cannot be determined from the information given.

Answer: b Difficulty: 1

59. Water flows through a pipe. The diameter of the pipe at point B is larger than at point A. Where is the speed of the water greater?

a) Point A
b) Point B
c) Same at both A and B
d) Cannot be determined from the information given.

Answer: a Difficulty: 1

60. Water flows through a pipe. The diameter of the pipe at point B is larger than at point A. Where is the water pressure greatest?

a) Point A
b) Point B
c) Same at both A and B
d) Cannot be determined from the information given.

Answer: b Difficulty: 2

61. How much pressure does it take for a pump to supply a drinking fountain with 300 kPa, if the fountain is 30.0 m above the pump?

a) 294 kPa
b) 300 kPa
c) 594 kPa
d) 675 kPa

Answer: c Difficulty: 2

62. Liquid flows through a pipe of diameter 5.0 cm at 1.0 m/s. Find the flow rate.

a) $2.0X10^{-3}$ m^3/s
b) $7.9X10^{-3}$ m^3/s
c) 20 m^3/s
d) 79 m^3/s

Answer: a Difficulty: 2

63. Liquid flows through a 4.0 cm diameter pipe at 1.0 m/s. There is a 2.0 cm diameter restriction in the line. What is the velocity in this restriction?

a) 0.25 m/s
b) 0.50 m/s
c) 2.0 m/s
d) 4.0 m/s

Answer: d Difficulty: 2

64. The surface tension of water is 0.073 N/m. How high will water rise in a capillary tube of diameter 1.2 mm?

a) 1.2 cm
b) 1.5 cm
c) 2.2 cm
d) 2.5 cm

Answer: d Difficulty: 2

65. When a tube of diameter d is placed in water, the water rises to a height h. If the diameter were half as great, how high would the water rise?

a) h/2
b) h
c) 2h
d) 4h

Answer: c Difficulty: 1

Name____ per. __ Date _____
Fluids Review DiBucci

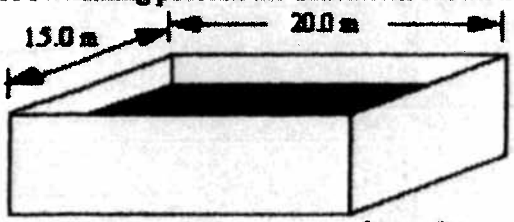
Directions: Place the solutions to the following problems on **a separate sheet of paper**. Attach it to this cover sheet, and submit it.
Incomplete and/or illegible solutions will receive no credit.

1. What mass of water (at 4.0 °C) can be contained in a rectangular box whose dimensions are 10.0 cm by 5.00 cm by 1.00 cm? The density of water at 4.0 °C is 1.000×10^3 kg/m^3.

2. The density of iron is 7860 kg/m^3. What is the mass of an iron sphere whose diameter is 0.50 m?

Use the following to answer question 3:

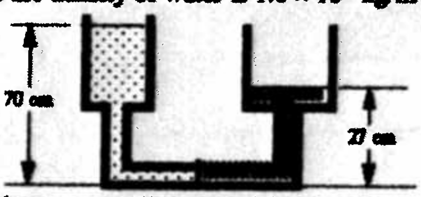
A swimming pool has the dimensions shown in the drawing. It is filled with water to a uniform depth of 8.00 m.



The density of water = 1.00×10^3 kg/m^3.

3. What is the total pressure exerted on the bottom of the swimming pool?

4. A column of water 70.0 cm high supports a column of an unknown liquid as suggested in the figure (not drawn to scale). Assume that both liquids are at rest and that the density of water is 1.0×10^3 kg/m^3.



Determine the density of the unknown liquid.

5. The largest barometer ever built was an oil-filled barometer constructed in Leicester, England in 1991. The oil had a height of 12.2 m. Assuming a pressure of 1.013×10^5 Pa, what was the density of the oil used in the barometer?

6. The density of ice is 0.92 g/cm^3; and the density of seawater is 1.03 g/cm^3. A large iceberg floats in Arctic waters. What fraction of the volume of the iceberg is exposed?

7. A small sculpture made of brass (ρ_{brass} = 8470 kg/m^3) is believed to have a secret central cavity. The weight of the sculpture in air is 15.76 N. When it is submerged in water, the weight is 13.86 N. What is the volume of the secret cavity?

8. Ann uses a hose to water her garden. The water enters the hose through a faucet with a 6.0-cm diameter. The speed of the water at the faucet is 5 m/s. If the faucet and the nozzle are at the same height, and the water leaves the nozzle with a speed of 20 m/s, what is the diameter of the nozzle?

1. 50.0 g
2. 514 kg
3. 1.80×10^5 Pa
4. 2.6×10^3 kg/m^3
5. 847 kg/m^3
6. 11 %
7. 4×10^{-6} m^3
8. 3.0 cm

Measuring Blood Pressure

Almost any time you get a medical checkup, someone measures your blood pressure. The procedure is one of the most common in medicine: Someone wraps a cuff around your arm, inflates the cuff until it's tight, then listens through a stethoscope held to your arm while letting the cuff slowly deflate. What is happening during this procedure? The person is measuring the pressure in a fluid, your blood.

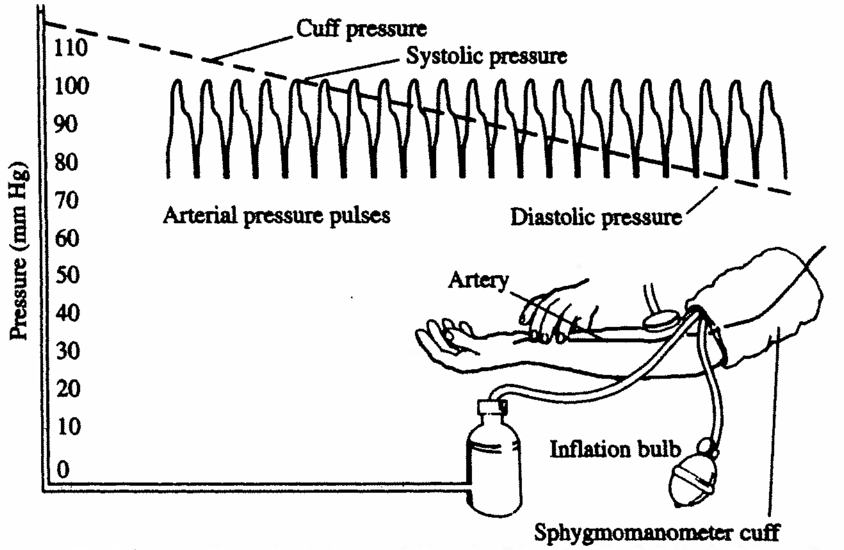


Figure B10.1 Measuring blood pressure with a sphygmomanometer. Identifiable sounds occur in the arm when the cuff pressure falls below the systolic and diastolic pressures.

The heart is a large muscle, responsible for pumping oxygen-supplying blood to all parts of the body. The blood returns from the body through the veins to the right side of the heart, which pumps the blood to the lungs. The lungs remove carbon dioxide from the blood and add oxygen. The left side of the heart receives the oxygenated blood from the lungs and pumps it throughout the body by way of the arteries. The blood flows from the arteries to the veins through capillary beds.

Two pressures in the heart's action are of particular medical interest: the *systolic* pressure, when the heart is contracted, and the *diastolic* pressure, when the heart is relaxed between beats. Normal heart action causes arterial blood pressure to oscillate between these two values. Abnormally high or low arterial blood pressure can sometimes indicate physical and mental conditions of varying degrees of seriousness.

The most direct way of measuring blood pressure is to insert a fluid-filled tube into the artery and connect it to a pressure gauge. Though this is sometimes done, it is neither comfortable nor convenient. The commonly used indirect method involves a device called a sphygmomanometer. A nonelastic cuff that has an inflatable bag within it is placed around the upper arm, roughly at the same vertical level as the heart. The cuff is connected directly to some pressure gauge, such as a manometer (Fig. B10.1). When the cuff is inflated, the tissue in the arm is compressed; if sufficient pressure is applied, the flow of arterial blood in the arm stops. If the cuff is long enough and if it is applied snugly, the pressure in the tissues in the arm is the same as the pressure in the inflated part of the cuff, and is also the same as the pressure in the artery. In effect, Pascal's principle holds for the system composed of cuff, arm, and artery.

After the blood flow has been cut off, the pressure in the cuff is reduced by releasing some of the air. The falling pressure corresponds to the dashed line in Fig. B10.1. At some point the maximum arterial pressure slightly exceeds the pressure in the surrounding tissue and cuff, allowing the blood to resume flowing. The acceleration of the blood through the arteries gives rise to a characteristic sound, which can be identified by means of a stethoscope. When this sound occurs, the manometer indicates the maximum, or systolic, pressure. As the pressure in the cuff falls further, a second change in the sound is heard, characteristic of the drop below diastolic pressure. The readings shown in Fig. B10.1 correspond to the two pressures and are reported as "110 over 80," which is a typical value of the pressures for a healthy person.

The measurements made by this technique may vary because of the need to fit the cuff properly and to reliably estimate the point at which the sound changes. The condition of the manometer, the size of the arm, and the rate at which the cuff is inflated and deflated can also have an effect. Figure B10.2 compares pressures measured directly in the artery and pressures measured indirectly by a sphygmomanometer.

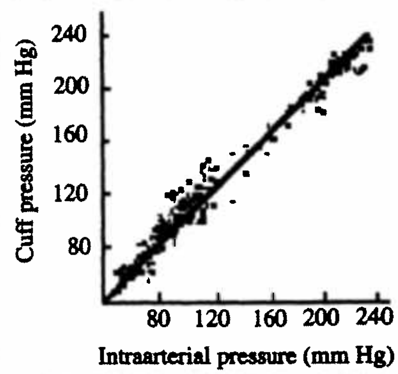


Figure B10.2 Comparison of blood pressure measurements by sphygmomanometry with direct measurements of arterial pressure.