Chapter 14 Fluids

Mass Density
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Archimedes' Principle

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The Equation of Continuity

DEFINITION OF MASS DENSITY

The mass density ρ is the mass m of a substance divided by its volume V:

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

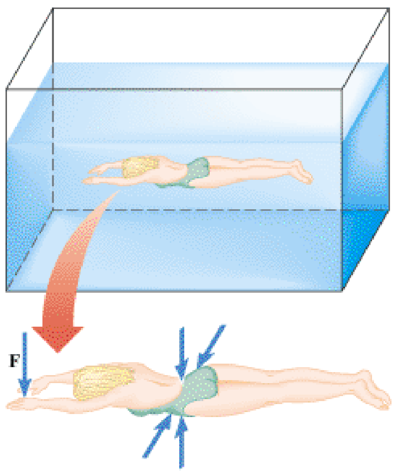
SI Unit of Mass Density: kg/m^3

Table 11.1 Mass Densities[a] of Common Substances

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
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.

Pressure



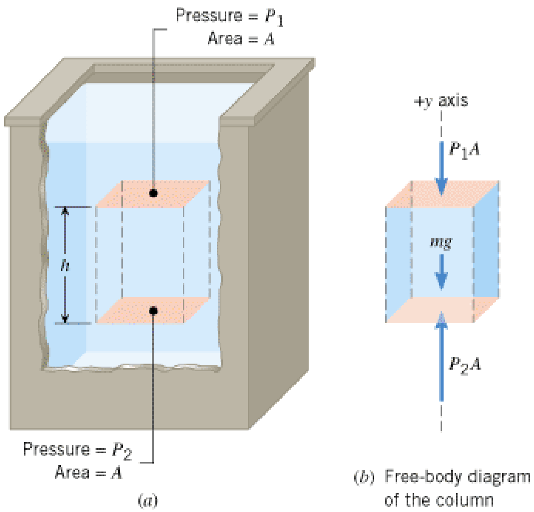
Water applies a force perpendicular to each surface within the water, including the walls and bottom of the swimming pool, and all parts of the swimmer's body.

The pressure *P* exerted by a fluid is defined as the magnitude *F* of the force acting perpendicular to a surface divided by the area *A* over which the force acts:

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

The SI unit for pressure is a newton/meter^2 (N/m^2), a combination that is referred to as a pascal (Pa).

Pressure in a Static Fluid

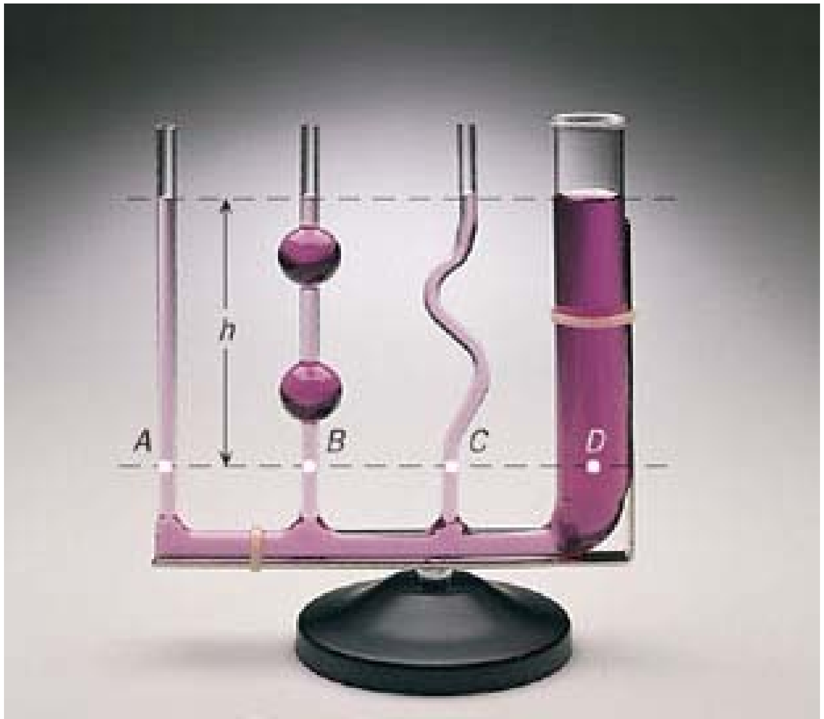


Since the column is in equilibrium, the sum of the vertical forces equal to zero:

$$\Sigma F_y = P_2A - P_1A - mg = 0 \quad \text{or} \quad P_2A = P_1A + mg$$

The mass m is related to the density ρ and the volume V of the column by $m = \rho V = \rho Ah$.

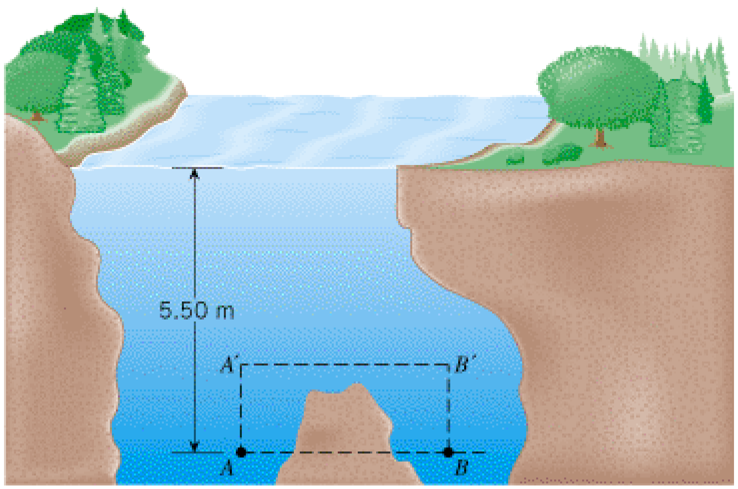
$$P_2 = P_1 + \rho gh$$



The pressure difference between two points in the fluid only depends on the vertical height between the two points, not the horizontal distance within the fluid

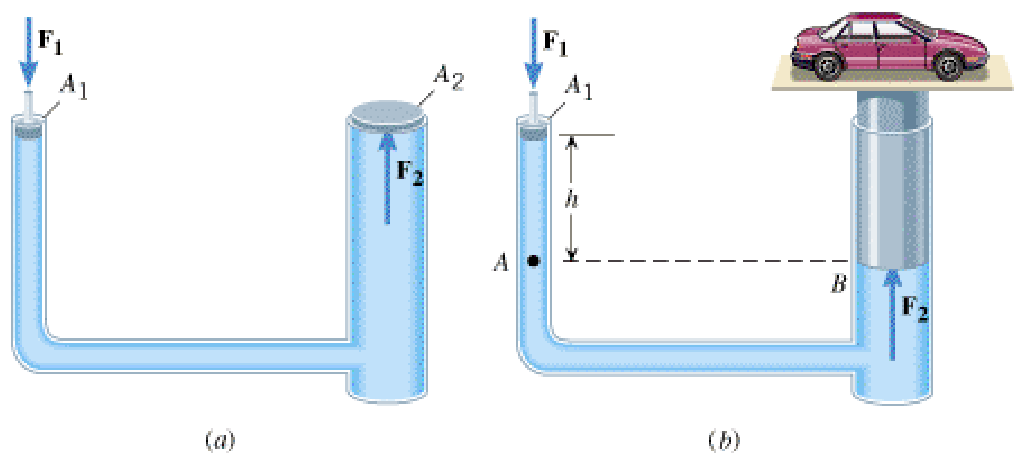
Example 4 The Swimming Hole

Figure 11.8 shows the cross section of a swimming hole. Points *A* and *B* are both located at a distance of $h = 5.50$ m below the surface of the water. Find the pressure at each of these two points.

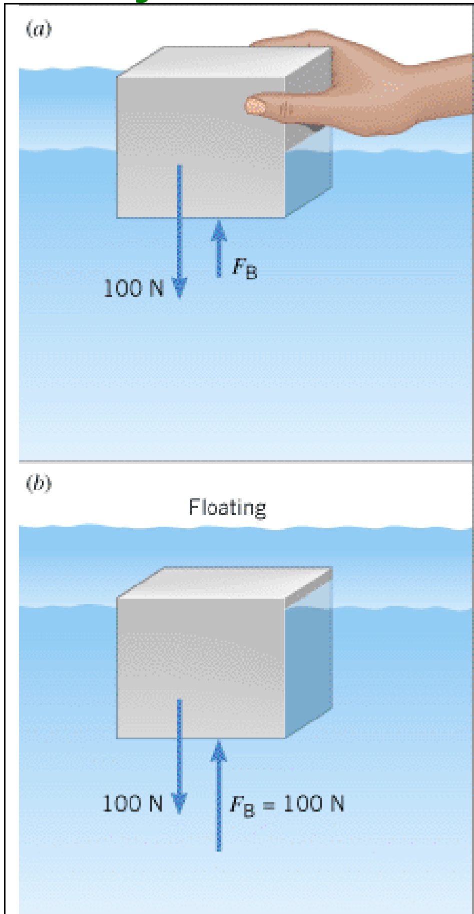


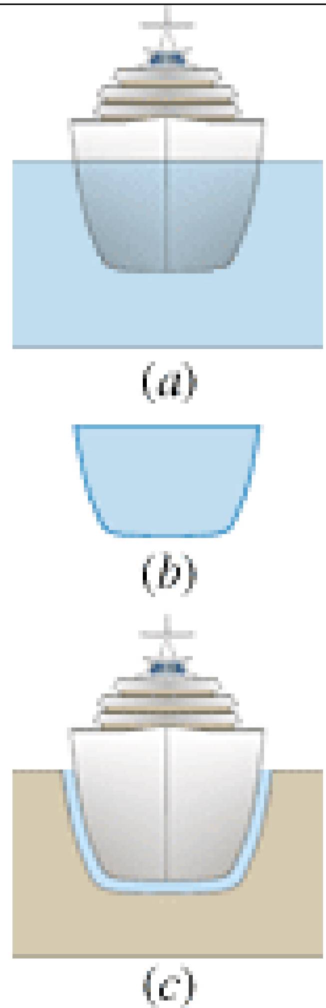
PASCAL'S PRINCIPLE

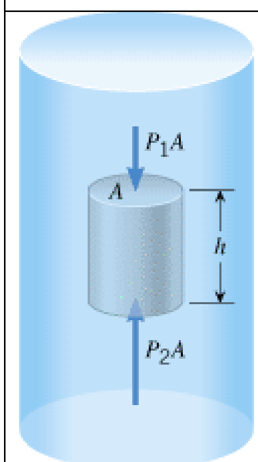
Any change in the pressure applied to a completely enclosed fluid is transmitted undiminished to all parts of the fluid and the enclosing walls.



Buoyant force



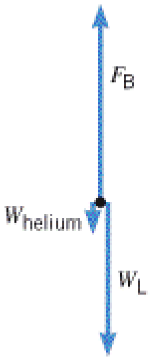


ARCHIMEDES' PRINCIPLE	
Any fluid applies a buoyant force to an object that is partially or completely immersed in it; the magnitude of the buoyant force equals the weight of the fluid that the object displaces: $$\underbrace{F_B}_{\text{Magnitude of buoyant force}} = \underbrace{W_{fluid}}_{\text{Weight of displaced fluid}}$$	
	The liquid applies to the cylinder a net upward force, or buoyant force, whose magnitude F_B is $$F_B = P_2A - P_1A = (P_2 - P_1)A = \rho ghA$$

Example 10 **A Goodyear Airship**

Normally, a Goodyear airship, such as that in Figure, contains about 5.40×10^3 m^3 of helium (He) whose density is 0.179 kg/m^3. Find the weight of the load W_L that the airship can carry in equilibrium at an altitude where the density of air is 1.20 kg/m^3.

(*b*)



(*b*) Free-body diagram of the airship

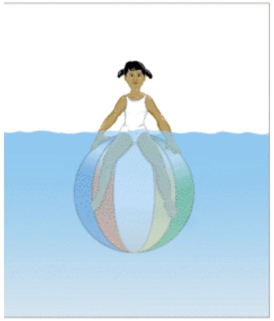
Check Your Understanding 2

A glass is filled to the brim with water and has an ice cube floating in it. When the ice cube melts, what happens?

	a.	Water spills out of the glass.
	b.	The water level in the glass drops.
	c.	The water level in the glass does not change.

Example 18 **The Buoyant Force**

A father (weight $W = 830$ N) and his daughter (weight $W = 340$ N) are spending the day at the lake. They are each sitting on a beach ball that is just submerged beneath the water (see Figure). Ignoring the weight of the air within the balls and the parts of their legs that are underwater, find the radius of each ball.



Fluids in Motion

- **The *steady flow*** the velocity of the fluid particles at any point is constant as time passes. The steady flow is often called ***streamline flow.***
- The **incompressible fluid** is that the density of a liquid remains almost constant as the pressure changes
- A **nonviscous fluid** flows in a manner with no dissipation of energy.

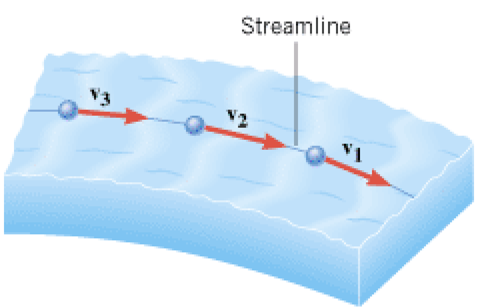
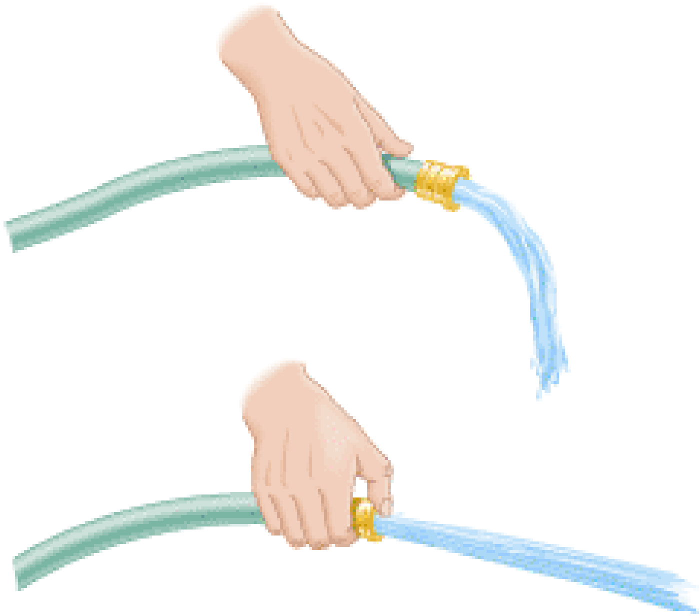
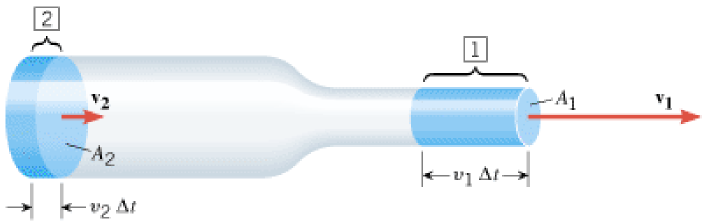


Figure 11.25 At any point along a streamline, the velocity vector of the fluid particle at that point is tangent to the streamline.



The ***mass flow rate*: *is*** the mass of fluid per second that flows through a tube.



EQUATION OF CONTINUITY

The mass flow rate (ρAv) has the same value at every position along a tube that has a single entry and a single exit point for fluid flow. For two positions along such a tube

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

where

	ρ = fluid density (kg/m^3)
	A = cross-sectional area of tube (m^2)
	v = fluid speed (m^2)

SI Unit of Mass Flow Rate: kg/s

For an incompressible fluid, $\rho_1 = \rho_2$, ***Incompressible fluid*** $A_1 v_1 = A_2 v_2$

Example 11 A Garden Hose

A garden hose has an unobstructed opening with a cross-sectional area of 2.85×10^{-4} m^2, from which water fills a bucket in 30.0 s. The volume of the bucket is 8.00×10^{-3} m^3 (about two gallons). Find the speed of the water that leaves the hose through (a) the unobstructed opening and (b) an obstructed opening with half as much area.

Check Your Understanding 3

Water flows from left to right through the five sections (A, B, C, D, E) of the pipe shown in the drawing. In which section(s) does the water speed increase, decrease, and remain constant? Treat the water as an incompressible fluid.