1.2 Pressure in Fluid Systems

Objectives

- Describe the four states of matter.
- Define density and pressure.
- Explain why pressure in a fluid depends on depth in the fluid.
- Explain why an object submerged in a fluid experiences a buoyant force.
- Predict whether an object will sink or float in a given fluid.
- Explain how a force can be multiplied in a hydraulic lift.
- Explain where atmospheric pressure comes from.
- Describe how a barometer measures atmospheric pressure.
- Explain the difference between absolute and gage pressure.

INTERNET connection

To find out more about pressure in fluid systems, follow the links at **www.learningincontext.com.**

Refer to Appendix F for a career link to this concept.

States of Matter

All matter is made of atoms and molecules. Water, for example, is made of molecules that each have two hydrogen atoms and one oxygen atom. A molecule of water is represented by the shorthand H_2O. Matter can exist in four states: solid, liquid, gas, and plasma. Atomic and molecular motion is different in each state.

For example, water is a solid (ice) at temperatures below 0°C (32°F). In a **solid**, molecules are constantly moving, but they do not move around in the solid—they vibrate about fixed positions.

If you add heat to ice, the rate of molecular vibration increases and the temperature increases. Water becomes a liquid when the temperature rises above 0°C. In a **liquid**, the molecules are no longer confined to fixed positions. The molecules continue to vibrate, but they can now easily slide over one another and move about throughout the liquid. This is why the shape of a liquid is not fixed—it takes the shape of its container.

If you continue to add heat to liquid water, the molecules vibrate even more rapidly and the temperature continues to increase. Water becomes a **gas** (water vapor or steam) when the temperature rises above 100°C. In the gaseous state, the molecules move freely about the container. When a molecule in the gas hits another molecule or the side of the container, it bounces like a billiard ball hitting another billiard ball or a wall. The shape of a gas also takes the shape of its container.

If you add enough heat to water vapor, the molecules separate into individual hydrogen and oxygen atoms. Continued heating (to temperatures over 2000°C) causes electrons to separate from atoms. An atom with missing electrons is called an *ion*. A gas containing free electrons and ions is called a **plasma**. The gas inside an operating fluorescent light is a plasma. Plasmas are not commonly part of our everyday lives on Earth, but they are the most common state of matter in the universe. The stars, including our sun, and most intergalactic matter are in the plasma state.

Fluids

Both liquids and gases are fluids. A **fluid** is a material that can flow, has no definite shape of its own, and conforms to the shape of its container.

Fluid systems use liquids or gases to operate mechanical devices or to circulate fluids. The fluid used by the system is called the working fluid. A **hydraulic system** uses a liquid as the working fluid. A **pneumatic system** uses a gas as the working fluid.

A city's water distribution system is a complex hydraulic system made up of elevated water tanks, underground pipes, water meters, and valves. A ventilating system for a building is a pneumatic system. It uses fans to force air through a building's ductwork in order to control temperature and humidity in the building. In the water distribution system, the elevation of the water tank creates pressure that moves water through the pipes. In the ventilating system, the fan creates pressure that moves air through the ducts. Pressure is the prime mover in a fluid system.

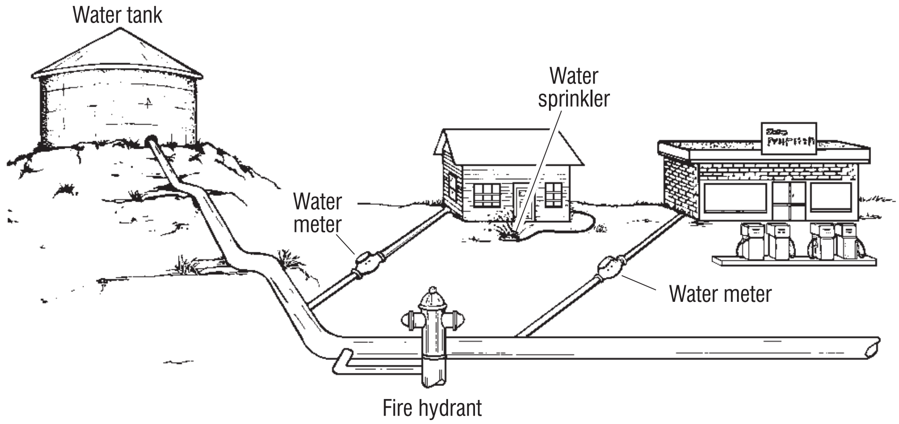


Figure 1.18
A city water distribution system depends on pressure to move water.

Density and Pressure

Have you ever wondered why oil floats on water? Or why a balloon filled with helium or hot air rises? The answer is found in a property of materials called *density*. Density describes how much mass is contained in a given space. The **density** of a material is the amount of matter per unit volume. Density is represented by the Greek letter ρ (*rho*). Density is defined as the mass m of a substance divided by the volume V of the substance.

$$\boxed{\begin{aligned} \text{Density} &= \frac{\text{mass}}{\text{volume}} \\ \rho &= \frac{m}{V} \end{aligned}}$$

In SI units, mass is measured in kilograms (kg) and volume is measured in cubic meters (m^3). Thus, density is expressed in kg/m^3. Mass is also commonly measured in grams (g) and volume in cubic centimeters (cm^3). In these metric units, density is expressed in g/cm^3. The mass of 1 cm^3 of water (at 4°C) is exactly 1 g. Therefore, the density of water is exactly 1 g/cm^3. Can you show why 1 g/cm^3 = 1000 kg/m^3?

In English units, mass is measured in slugs and volume is measured in cubic feet (ft^3). Density is expressed in $slugs/ft^3$.

The densities of some other liquids and solids are shown in Table 1.4.

Table 1.4 Densities of Several Solids and Liquids

	g/cm^3	kg/m^3
Solids		
Gold	19.3	19,300
Lead	11.3	11,300
Silver	10.5	10,500
Copper	8.9	8,900
Steel	7.8	7,800
Aluminum	2.7	2,700
Ice	0.9	900
Oak Wood	0.8	800
Balsa Wood	0.3	300
Liquids		
Mercury	13.6	13,000
Water	1.0	1,000
Oil	0.9	900
Alcohol	0.8	800

Density is sometimes written as a comparison of an object's weight to its volume. This ratio is called **weight density**. We use ρ_w to represent weight density.

$$\text{Weight density} = \frac{\text{weight}}{\text{volume}}$$

$$\rho_w = \frac{\text{weight}}{V}$$

The SI units of weight density are N/m^3. The English units are lb/ft^3. In English units, water has a weight density of 62.4 lb/ft^3.

Example 1.6 Density of a Fluid

A volume of 500 cm^3 of a certain fluid has a mass of 550 g. What is the density of the fluid?

Solution :

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

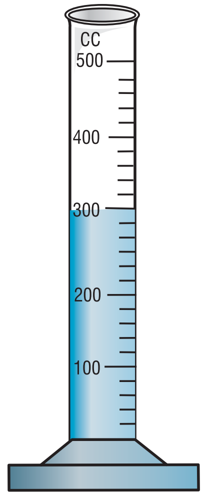
$$= \frac{550\ \text{g}}{500\ \text{cm}^3}$$

$$= 1.1\ \text{g/cm}^3$$

The density of the fluid is 1.1 g/cm^3.

Example 1.7 Calculating Mass from Density and Volume

The graduated cylinder at the right contains alcohol. Find the mass of alcohol in the cylinder.



Solution: From Table 1.4, the density of alcohol is $0.8\ g/cm^3$. The graduated cylinder contains $300\ cm^3$ of alcohol. Use the equation for density, and solve for the mass.

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

$$m = \rho V$$

$$= (0.8\ g/cm^3)(300\ cm^3)$$

$$= 240\ g$$

There are 240 g of alcohol in the cylinder.

When a fluid is contained in a vessel, the molecules that make up the fluid bounce against the walls of the vessel and exert a force. Since the fluid takes the shape of the vessel, the force is spread over the surface of the vessel. A force applied over a surface is *pressure*. **Pressure** P is defined as the force F divided by the area A on which it acts.

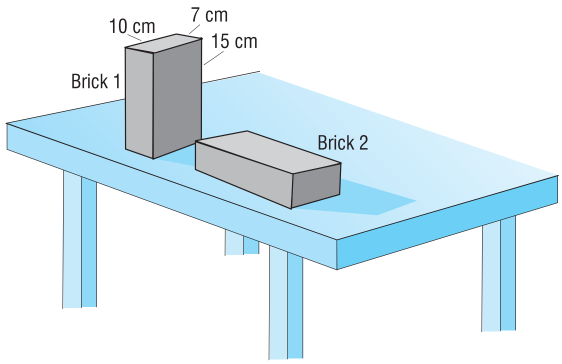
$$\boxed{\begin{aligned} \text{Pressure} &= \frac{\text{force}}{\text{area}} \\ P &= \frac{F}{A} \end{aligned}}$$

In SI units, force is measured in newtons (N) and area is measured in square meters (m^2). Thus, pressure is expressed in N/m^2. This unit is called a **pascal** (Pa), and $1\ N/m^2 = 1\ Pa$. One pascal is a very small quantity, so the kilopascal (kPa) is more commonly used. One kPa equals 1000 Pa.

In English units, force is measured in pounds (lb) and area is measured in square feet (ft^2). Thus, pressure is expressed in lb/ft^2. Another common unit of pressure is lb/in^2, often abbreviated psi.

Example 1.8 Comparisons of Forces and Pressures

Two identical bricks, each weighing 32 N, are placed on a table—one on its end and one on its side.



(a) Which brick exerts the greater force on the table?

(b) Calculate the pressure exerted by each brick on the table.

Solution: (a) The bricks have the same weight, and therefore both exert the same force on the table. This force equals 32 N, directed downward.

(b) In brick 1, the force is distributed over an area A_1:

$$A_1 = (10\ \text{cm})\ (7\ \text{cm}) = 70\ \text{cm}^2$$

Convert to square meters.

$$A_1 = 70\ \text{cm}^2 \bullet \frac{1\ \text{m}^2}{10^4\ \text{cm}^2} = 7 \times 10^{-3}\ \text{m}^2$$

In brick 2, the force is distributed over an area A_2:

$$A_2 = (15\ \text{cm})(10\ \text{cm}) = 150\ \text{cm}^2$$

Convert to square meters.

$$A_2 = 150\ \text{cm}^2 \bullet \frac{1\ \text{m}^2}{10^4\ \text{cm}^2} = 1.5 \times 10^{-2}\ \text{m}^2$$

Calculate the pressure exerted by each brick:

$$P_1 = \frac{F}{A_1} = \frac{32\ \text{N}}{7 \times 10^{-3}\ \text{m}^2} \qquad P_2 = \frac{F}{A_2} = \frac{32\ \text{N}}{1.5 \times 10^{-2}\ \text{m}^2}$$

$$P_1 = 4570\ \text{Pa} \qquad P_2 = 2130\ \text{Pa}$$

$$= 4.57\ \text{kPA} \qquad = 2.13\ \text{kPa}$$

The upright brick 1 exerts the greater pressure on the table because its force is distributed over a smaller area.

In Example 1.8, force had both magnitude and direction, because force is a vector. But pressure has magnitude only. We treat pressure as a scalar.

Pressure Increases with Depth

Have you ever dived into a swimming pool and swum to the bottom? You can feel the water exerting pressure against your eardrums. This pressure is caused by the weight of the water above you. As you swim deeper, the weight of water above you increases, and the pressure increases.

You can calculate the pressure at any depth in a liquid using the weight density. Consider a column of liquid, as shown in Figure 1.19. The column has a cross-sectional area A, and height h (also equal to the depth). The volume of the column is Ah.

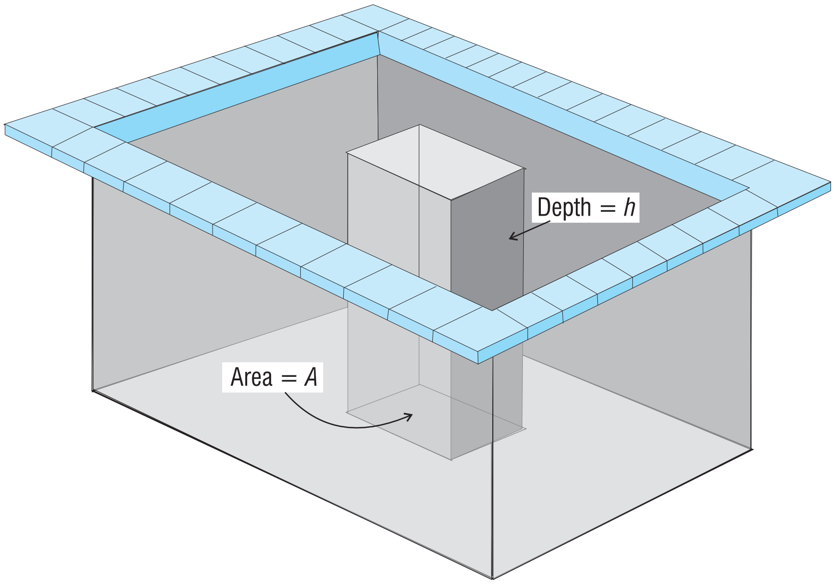


Figure 1.19
A column of water with cross-sectional area A and height h has volume Ah.

The weight density of the liquid is given by the formula

$$\text{Weight density} = \frac{\text{weight}}{\text{volume}}$$

Therefore, the weight of the liquid in the column is given by

$$\text{Weight} = \text{weight density} \times \text{volume}$$

Now write an equation for the pressure at the bottom of the column:

$$\text{Pressure} = \frac{\text{force}}{\text{area}} = \frac{\text{weight}}{A} = \frac{\text{weight density} \times \text{volume}}{A}$$

Since volume $= Ah$,

$$\text{Pressure} = \frac{\text{weight density} \times Ah}{A} = \text{weight density} \times h$$

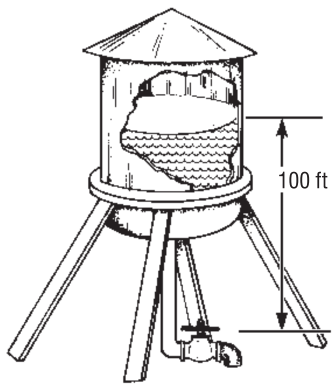
You have derived the relationship between the pressure P and depth h in a fluid of weight density ρ_w:

$$\boxed{\begin{array}{l} \text{Pressure} = \text{weight density} \times \text{fluid depth} \\ P = \rho_w \times h \end{array}}$$

Example 1.9 Water Pressure Calculation

The height of the water in a storage tank is 100 ft above a valve. Find the pressure at the valve in lb/ft^2 and lb/in^2.

The weight density of water is 62.4 lb/ft^3.



Solution: $P = \rho_w \times h$

$= (62.4 \text{ lb/ft}^3)(100 \text{ ft})$

$= 6240 \text{ lb/ft}^2$

To express pressure in lb/in^2, use the relation 1 ft^2 = 144 in^2.

$$P = 6240 \frac{\text{lb}}{\text{ft}^2} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 43.3 \text{ lb/in}^2$$

The units lb/in^2 are abbreviated psi. The pressure at the valve is 6240 lb/ft^2 or 43.3 psi.

Buoyancy and Archimedes' Principle

If you have ever lifted a heavy object under water, you know it appears to weigh less as long as it is submerged. As soon as the object is raised above the surface of the water, it appears to gain weight. This is because, as long as the object is totally or partially submerged, the water exerts an upward force on the object. This upward force is called the **buoyant force**. It is caused by the pressure increasing with depth.

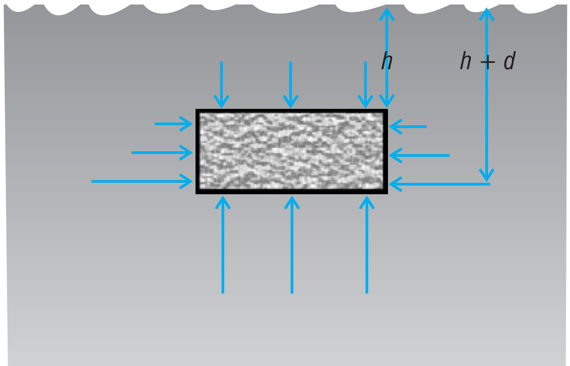


Figure 1.20
A brick is immersed in water. The top surface of the brick is at depth h. The bottom surface is at depth $h + d$, where d is the length of the edge of the brick.

Suppose that a brick is immersed in water, as shown in Figure 1.20. Let d represent the length of a vertical side of the brick. If the top face is at depth h, the bottom face is at depth $(h + d)$. Water pressure exerts forces all along the surfaces of the brick. Since the bottom face of the brick is at a lower depth than the top, the pressure P_{bottom} exerted on the bottom face is greater than the pressure P_{top} exerted on the top face. If ρ_w represents the weight density of the water, the pressures are:

$$P_{top} = \rho_w \times h \qquad\qquad P_{bottom} = \rho_w \times (h + d)$$

The pressures that act along the sides are at the same depth, and cancel each other out. The area A of the bottom face equals the area of the top face. Therefore, the force F_{bottom} acting on the bottom face is greater than the force F_{top} acting on the top face.

$$\begin{aligned} F_{top} &= P_{top} \times A \\ &= \rho_w \times h \times A \\ &= \rho_w Ah \end{aligned} \qquad\qquad \begin{aligned} F_{bottom} &= P_{bottom} \times A \\ &= \rho_w \times (h + d) \times A \\ &= \rho_w A(h + d) \end{aligned}$$

Thus, there is a net force acting on the brick upward. This is the buoyant force $F_{buoyant}$.

$$\begin{aligned} F_{buoyant} &= F_{bottom} - F_{top} \\ &= \rho_w A(h + d) - \rho_w Ah \\ &= \rho_w Ah + \rho_w Ad - \rho_w Ah \\ &= \rho_w Ad \end{aligned}$$

The product Ad is the volume of the brick V_{brick}. Weight density times volume equals weight. Therefore, the buoyant force equals the weight of water displaced by the volume of the brick:

$$F_{buoyant} = \rho_w \times V_{brick} = \text{weight of water displaced}$$

The buoyant force is the upward force on the brick exerted by the water. If the weight of the brick is greater than the buoyant force, the brick will sink.

If the weight of the brick is less than the buoyant force, the brick will rise to the surface and float. If the weight exactly equals the buoyant force, the brick will stay at the submerged level without moving up or down.

When it is submerged, the brick displaces a *volume* of water equal to the *volume* of the brick. The buoyant force equals the *weight* of this displaced water. This relationship was first discovered by the ancient Greek scientist Archimedes in 212 B.C. **Archimedes' principle** states that:

> *An object immersed in a fluid has an upward force exerted on it equal to the weight of the fluid displaced by the object.*

Notice that the buoyant force does not depend on the weight of the object, but only on the weight of fluid displaced by the object.

When an object such as a block of wood floats in water, the block floats with just enough volume in the water so that the weight of the displaced water equals the weight of the block. If a brick is placed on the block of wood, the block floats lower and displaces more water. The weight of displaced water increases and the buoyant force increases, to balance the increased weight of the block and brick.

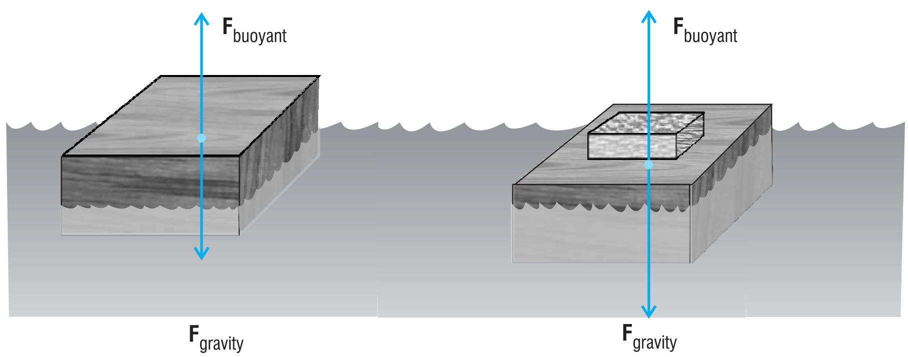


Figure 1.21

You can use densities with a simple rule to predict whether an object will sink or float when placed in a fluid:

1. If the object has a greater density than the fluid, it will sink.
2. If the object has a lower density than the fluid, it will float.

Can you use Archimedes' principle to explain the rule?

A submarine controls its density by changing its mass and weight while keeping its volume constant. To dive, a submarine takes water into its ballast tanks, thus increasing the weight of the submarine. When its density exceeds the density of water, the submarine sinks. To ascend, the submarine removes water from its ballast tanks and replaces it with air. When its density is lower than that of water, the submarine rises.

Use Table 1.4 on page 30 to answer this question: "Will a block of lead float or sink in mercury?"

Pascal's Principle

Figure 1.22 shows a simple fluid system that uses pressure to multiply force. A liquid is confined to two connecting chambers, each fitted with a movable piston.

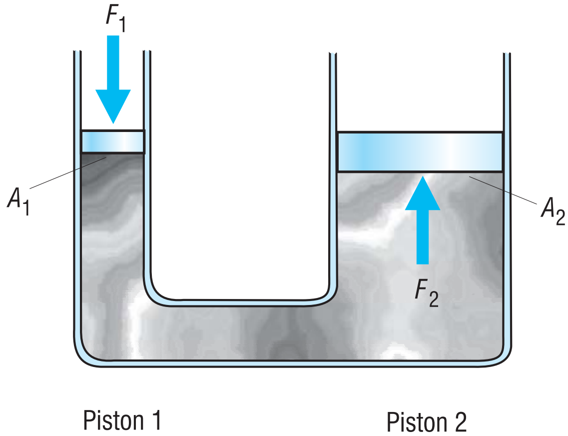


Figure 1.22
The force exerted on piston 1 increases the pressure in the liquid. This pressure is transmitted throughout the liquid and results in a multiplied force on piston 2.

If a force is applied to one of the pistons, the pressure in that chamber increases. The pressure throughout the fluid increases by the same amount. This was discovered in the 1600s by the French physicist and mathematician Blaise Pascal. The rule is now called **Pascal's principle**:

> *A change in pressure at any point in a confined fluid is transmitted undiminished throughout the fluid.*

According to Pascal's principle, if a force F_1 is applied to piston 1 and the pressure is increased, exactly the same pressure increase is felt under piston 2. This pressure causes a force F_2 to be exerted on piston 2. Let A_1 and A_2 represent the areas of the pistons. Since pressure = force/area,

$$P_1 = P_2 \quad \text{or} \quad \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

As an example, suppose F_1 represents a weight of 10 N. What weight can be lifted by piston 2 if $A_1 = 0.1\ \text{m}^2$ and $A_2 = 1\ \text{m}^2$? Solve the proportion for F_2.

$$\begin{aligned} F_2 &= A_2 \frac{F_1}{A_1} \\ &= 1\ \text{m}^2 \times \frac{10\ \text{N}}{0.1\ \text{m}^2} \\ &= 100\ \text{N} \end{aligned}$$

A weight of 100 N can be lifted by a weight of 10 N. The force applied to the small piston is multiplied so that a large weight can be lifted. This is the basis of operation of hydraulic lifts.

Example 1.10 Hydraulic Lift

In a hydraulic lift, compressed air exerts pressure on the hydraulic fluid (oil) in a reservoir. The hydraulic fluid transmits the pressure to a cylinder, and this pressure pushes a piston, which raises the lift.

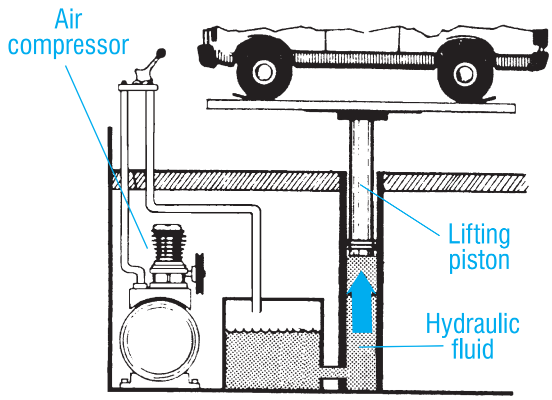


Figure 1.23
A hydraulic lift

If the compressor delivers air at a pressure of 30 psi, and the radius of the cylinder and piston is 6 in., what weight can be lifted?

Solution: The weight that can be lifted is the force F applied to the piston by the hydraulic fluid.

$$P = \frac{F}{A} \quad \text{or} \quad F = PA$$

The cylinder and piston have a circular cross section. So the area A of the piston is

$$\begin{aligned} A &= \pi r^2 \\ &= \pi(6\,\text{in})^2 = 113\ \text{in}^2 \\ F &= 30\frac{\text{lb}}{\text{in}^2} \times 113\ \text{in}^2 = 3390\ \text{lb} \end{aligned}$$

The lift can raise a weight of 3390 pounds.

Atmospheric Pressure

On Earth, we live at the bottom of a thick blanket of air. Like the water in a swimming pool, the air in the atmosphere is held to Earth by gravity. Air also has weight, and, just as water pressure is caused by the weight of water above an area, atmospheric pressure is caused by the weight of air above an area. At sea level, a column of air extending up through the atmosphere, with a cross-sectional area of 1 m^2, encloses about 10,000 kg of air. This mass has a weight of about 1×10^5 N. Thus, atmospheric pressure is about

$$\frac{1 \times 10^5 \text{ N}}{1 \text{ m}^2} = 10^5 \text{ Pa, or 100 kPa at sea level.}$$

Atmospheric pressure decreases with altitude. The change in pressure is what causes your ears to pop when you ride in a car on a mountain highway or in an airplane. For example, at 5.6-km altitude the pressure is about half the value at sea level. At 10-km altitude, atmospheric pressure is about 30 kPa. There are also variations in the pressure of the atmosphere at any given location, due to changing weather. Meteorologists monitor atmospheric pressure constantly in their attempts to predict weather.

A **barometer** is an instrument used for measuring atmospheric pressure. One type is the mercury barometer. In this instrument, a glass tube is filled with mercury and inverted into a bowl of mercury with the open end of the tube below the level of mercury in the bowl. Some of the mercury in the tube drains into the bowl, but no air is allowed to enter the tube. An empty space is created above the mercury in the tube. This empty space is called a *vacuum*.

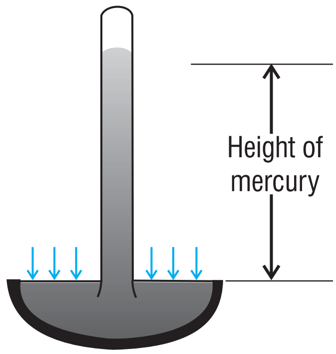


Figure 1.24
A simple barometer

The atmosphere exerts pressure on the top surface of the mercury in the bowl. This pressure is transmitted to the mercury at the base of the tube (Pascal's principle). This pressure also equals the pressure at the base of the tube caused by the weight of the mercury column in the tube. Therefore, the mercury in the tube must extend to the exact height required to produce a pressure equal to that of the air outside. This height is sometimes used as a unit for atmospheric pressure.

At sea level, the average atmospheric pressure is 101.3 kPa. This equals a height of 760 mm of mercury, and this pressure is called **one atmosphere**. Other units commonly used to measure atmospheric pressure are shown in Table 1.5.

Table 1.5 Units of Atmospheric Pressure

1 atmosphere	= 101.3 kPa
	= 760 mm of mercury
	= 14.7 psi
	= 2117 lb/ft^2

Absolute and Gage Pressure

When working with fluid systems, pressure measurements often are reported either as *absolute* pressure or as *gage* pressure. It's important to know the difference. For example, if you check the pressure of the air in a tire with a gage, it might read 30 psi. But what does this reading mean?

Absolute pressure is the total pressure measured above zero pressure (a perfect vacuum.) **Gage pressure** is the pressure measured above atmospheric pressure. Gage pressure is a measure of how much greater the air pressure inside the tire is than the air pressure outside the tire. Gage pressure is generally measured with a gage, hence the name. Absolute, atmospheric, and gage pressures are related in a simple equation:

$$\text{Absolute pressure} = \text{gage pressure} + \text{atmospheric pressure}$$

Suppose a tire gage measures air pressure in a tire as 30 psi. If the atmospheric pressure equals 14.7 psi, the absolute pressure in the tire is:

$$\begin{aligned}\text{Absolute pressure} &= 30 \text{ psi} + 14.7 \text{ psi}\\ &= 44.7 \text{ psi}\end{aligned}$$

The air inside the tire pushes out with a pressure of 44.7 psi. The atmosphere (air on the outside) pushes in with a pressure of 14.7 psi. The difference—30 psi—is the gage pressure. That's what the gage measures.

The tire gage is a useful pressure-measuring device. Its operation is quite simple.

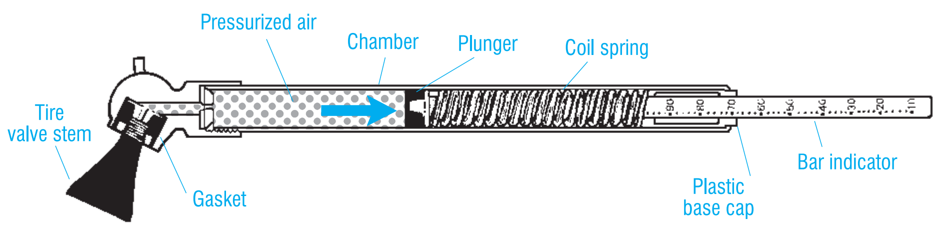


Figure 1.25
A tire pressure gage measures gage pressure.

The tire gage is made of a movable bar indicator and coiled spring housed in a cylindrical tube. When the gage is placed over the valve stem of a tire, the gage chamber and tire become sealed. The pressurized air from the tire flows into the gage chamber. This forces the coil spring to compress. As the spring compresses, it pushes the calibrated bar indicator out of the cylinder housing. When the force of the compressed spring equals the force caused by the pressure within the gage chamber, the forces are balanced. The exposed calibrated bar indicates the gage pressure—the pressure within the tire.

Pressure Is a Prime Mover

All fluid systems have two things in common. First, each system contains a fluid—either a liquid or a gas—that moves through a system of connecting pipes and devices. Second, a pressure difference in the system creates a net force, which causes fluids to move or perform some special function—like pushing a piston or opening and closing a valve. In this sense, pressure is a **prime mover** in fluid systems. Forces are still responsible for moving fluids through the system, but we can usually bypass the vector forces and deal with only the scalar pressures.

Equilibrium in Fluid Systems

Liquid or gas moves in a fluid system when pressure differences exist between different points in the system. If there's no pressure difference, there's no movement. For example, Figure 1.26 shows two tanks connected by a pipe that contains a closed gate valve. The pressure at the bottom of the tanks is different. That's because the water level in tank 2 is higher than in tank 1. Pressure P_2, at the bottom of tank 2, is higher than P_1, the pressure at the bottom of tank 1. The pressure on the left side of the valve is P_1 and the pressure on the right side is P_2. Since P_2 is greater than P_1, there is a pressure difference across the valve. As long as the valve is closed the tanks are isolated. But when the valve is opened, the pressure difference means the system is not in equilibrium. What happens when the valve is opened?

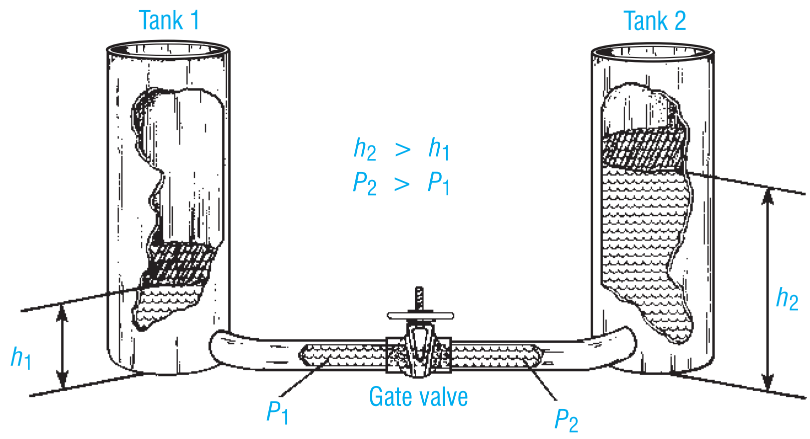


Figure 1.26
Unbalanced pressures across valve

Since P_2 is greater than P_1, there will be a force per unit area on the right side of the valve greater than the force per unit area on the left side of the valve. Water then will be pushed through the valve from tank 2 to tank 1. Water will flow until the levels in the two tanks are equal. When this happens, the pressures at the bottoms of the tanks will be equal and there is no longer a pressure difference in the system. Then, the system will be in equilibrium. This situation is shown in Figure 1.27.

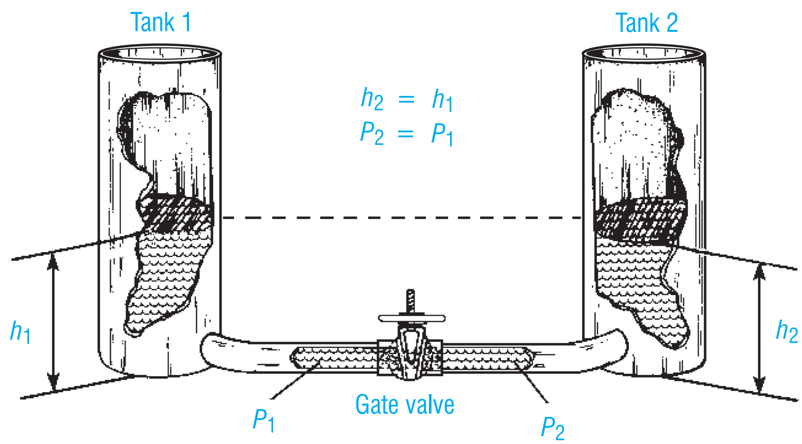


Figure 1.27
Balanced pressures across valve

Now consider Figure 1.28. Here, there are two tanks filled to the same level. Tank 2 has a larger diameter than tank 1, so it contains much more water. But since pressure on the bottom of the tank depends on only height of water contained, the pressure on the bottom of tank 1 and tank 2 is the same. Pressure at any point in a fluid doesn't depend on the shape of the container or the amount of water it contains—just on the height of the water column above the point. What happens when the gate valve in Figure 1.28 is opened?

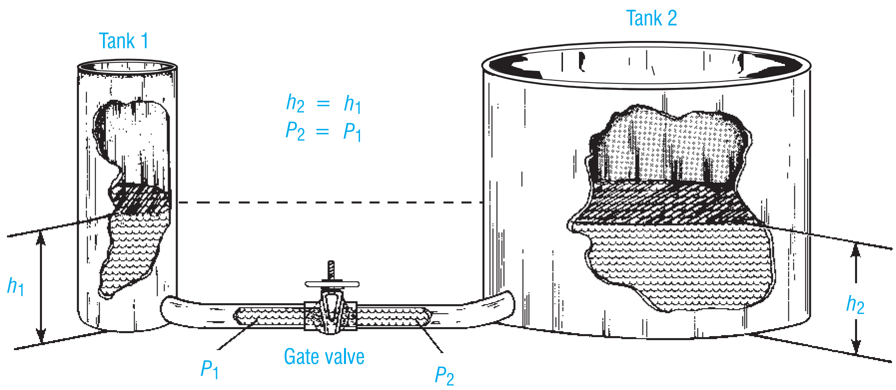


Figure 1.28
Pressure at bottom does not depend on size or shape of tank.

Summary

- Matter can exist in four states: solid, liquid, gas, and plasma. Liquids and gases are called fluids.
- The density of a substance is its mass per unit volume. The density of water is 1 g/cm^3.
- Weight density is weight per unit volume.
- Pressure is force divided by the area over which the force acts. We treat pressure as a scalar. In SI units, pressure is measured in pascals, where 1 Pa = 1 N/m^2.
- Pressure increases with depth in a fluid. For a given fluid, the pressure does not depend on the size or shape of the container.
- When an object is submerged in a fluid, an upward force is exerted on the object caused by the pressure difference between the top and the bottom of the object. This force is called a buoyant force.
- The buoyant force exerted on a submerged object equals the weight of the fluid displaced by the object.
- A pressure applied to a confined fluid is transmitted throughout the fluid.
- Atmospheric pressure is caused by the weight of the air above a given area. Atmospheric pressure can be measured with a barometer.
- Absolute pressure is the sum of the gage pressure and atmospheric pressure.

Exercises

1. The four states of matter are __________ , __________ , __________ , and __________ .
2. Water can be made to change state from solid (ice), to liquid, to gas (steam) by ____________________ .
3. The density of a substance describes how much __________ of the substance is in a unit of volume.
4. Pressure is defined as ________________ divided by ________________ .
5. Fluid systems that use air or some other gas for the fluid are called __________ systems. Fluid systems that use water, oil, or other liquid are called __________ systems.

For Exercises 6–8, you may need to use the fact that 1 kg weighs 9.80 newtons.

6. A steel block has a volume of 1.74×10^{-4} m^3 and a mass of 1.357 kg.
   (a) What is the density of steel?
   (b) What is the weight density of steel?
7. A gallon of water sample occupies a volume of 3.785×10^{-3} m^3. The mass of the water sample is 3.785 kg.
   (a) What is the density of water in kg/m^3?
   (b) What is the weight, in newtons, of one gallon of water?
   (c) What is the weight, in pounds, of one gallon of water?
   (d) Ricardo dives to the bottom of a swimming pool. He is 7 feet below the surface of the pool. How much more pressure does Ricardo feel at the bottom of the pool than at the surface?
8. Karen dives to a depth of 21 meters in fresh water, with a scuba rig. How much does the pressure increase, in kPa, during the dive?
9. When you sit or stand, is your blood pressure higher in your arms or your legs? Explain your answer.
10. Use Table 1.4 to explain why ice floats in water.
11. When a submarine is under water, how does its volume compare with the volume of water displaced?
12. When a submarine is under water, does the buoyant force depend on the weight of the submarine? Explain your answer.

13. An egg will not float in fresh water, but, if you dissolve enough salt in the water, the egg will float.

    (a) Which has the higher density, the egg or the fresh water?

    (b) Which has the higher density, the egg or the salt water?

    (c) Which has the higher density, the fresh water or the salt water?

14. Divers often use helium and oxygen as a breathing mixture for very deep dives. A storage tank containing a mixture of 80% helium and 20% oxygen has an inside volume of 37.85 liters. (1 liter = 1000 cm^3) The gas mixture has a mass of 2.163 kilograms.

    (a) What is the density, in kg/m^3, of the gas mixture in the tank?

    (b) The volume of the whole tank is 40.59 liters. What is the buoyant force, in newtons, when the tank is submerged in fresh water?

    (c) The weight of the tank and gas mixture is 231 N. What are the magnitude and direction of the net force acting on the tank when it is submerged in fresh water?

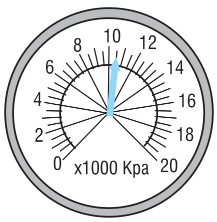
15. The gage pressure of the gas mixture in the tank of Exercise 14 is 13,700 kPa.

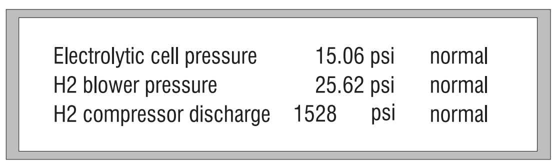
    (a) If the atmospheric pressure is 101 kPa, what is the absolute pressure of the gas in the tank before the tank is lowered into the water?

    (b) The tank is lowered to a depth of 120 m in fresh water. At this depth, what is the pressure exerted on the tank by the water?

    (c) At a depth of 120 m, what is the total pressure exerted on the outside wall of the tank?

16. A petrochemical manufacturing plant uses a 1000-horsepower compressor to compress hydrogen gas to a gage pressure around 1550 psi. The operations computer displays the hydrogen pressure as 1528 psi. At the same time the mechanical gage on the output of the compressor reads 10,500 kPa. Are the two pressure readings substantially in agreement? Explain your answer.



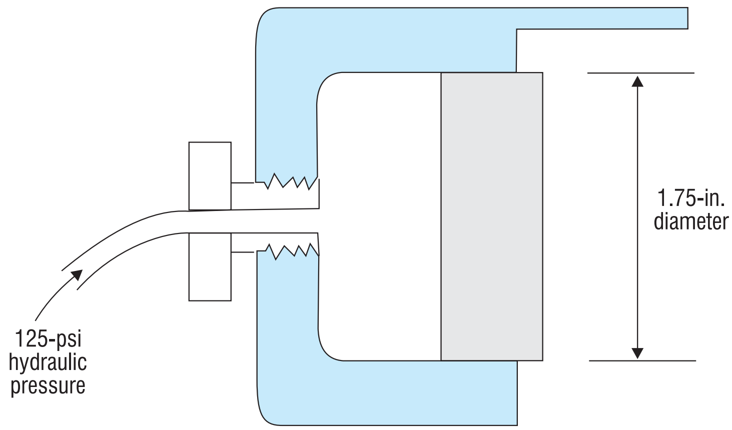


17. A nuclear submarine is running at a depth of 230 meters. The seawater at its location has a density of 1040 kg/m^3.

   (a) What is the pressure exerted by the seawater on the outside of the submarine?

   (b) What is the force exerted on a circular periscope well door that has a diameter of 60 cm?

18. The pressure in an automotive brake line is 125 psi. This line is connected to a piston, with a diameter of 1.75 in., in the brake caliper. How much force, in pounds, will the piston apply to the brake pad?



19. The density of substances is often described by stating the ratio of the density of the substance to the density of water. This ratio is called the **specific gravity** of the substance. For example, the density of alcohol is 800 kg/m^3 and the density of water is 1000 kg/m^3. The specific gravity of alcohol is

$$sg = \frac{\rho_{alcohol}}{\rho_{water}} = \frac{800 \text{ kg/m}^3}{1000 \text{ kg/m}^3} = 0.800 \qquad \text{Specific gravity has no units.}$$

Andrew is preparing a Cessna 206 airplane for a trip that will require an overnight stop in Bettles, Alaska. The temperature in Bettles is forecast to fall to –17°F. At this temperature the specific gravity of the electrolyte in the plane's battery must be above 1.22 to prevent freezing. To determine the specific gravity, Andrew removes an 8.5-cm^3 sample of the electrolyte. The sample has a mass of 10.51 grams.

   (a) What is the density of the electrolyte?

   (b) What is the specific gravity of the electrolyte?

   (c) Will the electrolyte freeze if the temperature falls to –17°F? Explain your answer.