Pearson New International Edition

Conceptual Physics Fundamentals

Paul G. Hewitt
First Edition

ALWAYS LEARNING

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11. ● Belly-flop Bernie dives from atop a tall flagpole into a swimming pool below. His potential energy at the top is 10,000 J and at the water surface it is zero.
a. Show that when his potential energy reduces to 1000 J, his kinetic energy will be 9000 J.
b. Compared with the height of the flagpole, how far above water level will Bernie be when his kinetic energy is 9000 J?
12. ● This question is similar to some on driver's-license exams: A car moving at 50 km/h skids 15 m with locked brakes. Show that with locked brakes at 150 km/h the car will skid 135 m.
13. ● A lever is used to lift a heavy load. When a 50-N force pushes one end of the lever down 1.2 m, the load rises 0.2 m. Show that the weight of the load is 300 N.
14. ● In raising a 5000-N piano with a pulley system, the workers note that, for every 2 m of rope pulled down, the piano rises 0.2 m. Ideally, show that the force required to lift the piano is 500 N.
15. ■ If we multiply both sides of the equation for Newton's second law, $F_{net} = ma$, by d, we get $F_{net}d = mad$. In this chapter we learn that Fd equals work, and we learned that the distance traveled by an object starting from rest and undergoing constant acceleration a is $d = \frac{1}{2}at^2$. Show that when this equation for distance is substituted for d on the right side of the equation above, the result is $F_{net}d$ (work) $= \frac{1}{2}mv^2$ (kinetic energy).
16. ■ A braking force is needed to bring a car of mass m moving at speed v to rest in time t.
a. Show that the braking force is mv/t.
b. The mass of the car is 1200 kg and its initial speed is 25 m/s. Show that the braking force needed to stop it in 12 s is 2500 N.
17. ■ A block of mass m moving at a speed v is stopped by a constant force F.
a. Show that the time required to stop the block is mv/F.
b. If the mass of the block is 20.0 kg, its initial speed is 3.0 m/s, and the stopping force is 15.0 N, show that the time to stop the block is 4.0 s.
18. ■ A goofy parrot of mass m drops vertically onto a skateboard of mass M that rolls horizontally at a speed v. The parrot grabs it tightly and moves with the skateboard.
a. Show that the speed of the skateboard with the parrot is $\frac{M}{M + m}v$.
b. If the parrot's mass is 2.0 kg, the mass of the skateboard is 8.0 kg, and the initial speed of the skateboard was 4.0 m/s, show that the final speed is 3.2 m/s.
19. ◆ An astronaut of mass M floating next to his spacecraft in deep space becomes untethered. To return to the craft, he throws a hammer of mass m at speed v away from the craft.
a. Show that the astronaut will recoil back toward the spacecraft at a speed $\frac{mv}{M}$.
b. If the astronaut's mass is 110 kg and the mass of the hammer is 15 kg, and the hammer is tossed at 4.5 m/s, show that the recoil speed of the astronaut is 0.6 m/s.
20. ◆ A lump of putty of mass m_1 and velocity v_1 catches up with and bumps into a slower lump of putty of mass m_2 and velocity v_2 heading in the same direction. They share a common velocity after they stick together.
a. Show that this common velocity is $\frac{m_1v_1 + m_2v_2}{m_1 + m_2}$.
b. If the mass of the first lump of putty is 2.2 kg with an initial speed of 3.2 m/s, and the second lump of putty is 2.8 kg with an initial speed of 1.2 m/s, show that the final speed of the combined lumps is 2.1 m/s.
21. ◆ An oil tanker of mass M travels a distance x at constant speed in time t.
a. Show that the momentum of the tanker is Mx/t.
b. Show that the KE of the oil tanker is $\frac{Mx^2}{2t^2}$.
c. If the mass of the oil tanker is 9.0×10^7 kg and it sails 250 km in 8.0 hours at a constant speed, show that its KE is 3.4×10^9 J. (Useful information: 1 km = 1000 m and 1 hour = 3600 s.)
22. ◆ Hank bats a baseball that weighs w and leaves the bat with a speed v.
a. Show that the baseball's momentum is wv/g.
b. Show that the baseball's KE is $\frac{wv^2}{2g}$.
c. If the weight of the baseball is 1.5 N and it leaves the bat with a speed of 38 m/s, show that its KE is 110 J.
23. ◆ When an average force F is exerted over a certain distance on a shopping cart of mass m, its kinetic energy increases by $\frac{1}{2}mv^2$.
a. Show that the distance over which the force acts is $\frac{mv^2}{2F}$.
b. If twice the force is exerted over twice the distance, how does the resulting increase in kinetic energy compare with the original increase in kinetic energy?
24. ◆ Manuel drops a water balloon of mass m from rest atop the roof of a building of unknown height. The balloon takes time t to hit the ground below.
a. Show that if air resistance is negligible, its kinetic energy just before it hits is $\frac{1}{2}mg^2t^2$.
b. If the water balloon has a mass of 1.2 kg and the dropping time from rest is 2.0 s, show that its kinetic energy when it hits the ground is 230 J.
c. Why can't the force of impact be found with the information given?
25. ◆ A block of ice of mass m is at rest atop an inclined plane of vertical height h. It then slides down the incline, reaching the floor below at speed v.
a. If friction can be ignored, show that the speed of the ice when it reaches the floor is $\sqrt{2gh}$.
b. If the block's mass is 27 kg and it slides down an incline of vertical height 1.5 m, show that its speed at the bottom is 5.4 m/s.
26. ◆ A motor of peak power P raises an elevator of mass m.
a. Show that the maximum speed at which the motor can raise the elevator is P/mg.
b. The elevator has a mass 900 kg and is powered by a 100-kW motor. Show that the maximum speed at which the elevator can be raised is 11 m/s.

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Fluid Mechanics

The forces due to atmospheric pressure are nicely shown by Swedish father-and-son physics professors, P.O. and Johan Zetterberg, who pull on a classroom model of the Magdeburg hemispheres.

Liquids and gases have the ability to flow; hence, they are called *fluids.* Because they are both fluids we find that they obey similar mechanical laws. How is it that iron boats don't sink in water or that helium balloons don't sink from the sky? Why is it impossible to breathe through a snorkel when you're under more than a meter of water? Why do your ears pop when riding an elevator? How do hydrofoils and airplanes attain lift? To discuss fluids, it is important to introduce two concepts—*density* and *pressure*.

1 Density

An important property of materials, whether in the solid, liquid, or gaseous phases is the measure of compactness: **density**. We think of density as the "lightness" or "heaviness" of materials of the same size. It is a measure of how much mass occupies a given space; it is the amount of matter per unit volume:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Or in shorthand notation,

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

where ρ (rho) is the symbol for density, m is mass, and V is volume.

The densities of a few materials are listed in Table 1. Mass is measured in grams or kilograms, and volume in cubic centimeters (cm^3) or cubic

TABLE 1

Densities of Some Materials

Material	Grams per Cubic Centimeter (g/cm³)	Kilograms per Cubic Meter (kg/m³)
Liquids		
Mercury	13.6	13,600
Glycerin	1.26	1,260
Seawater	1.03	1,025
Water at 4°C	1.00	1,000
Benzene	0.90	899
Ethyl alcohol	0.81	806
Solids		
Iridium	22.6	22,650
Osmium	22.6	22,610
Platinum	21.1	21,090
Gold	19.3	19,300
Uranium	19.0	19,050
Lead	11.3	11,340
Silver	10.5	10,490
Copper	8.9	8,920
Brass	8.6	8,600
Iron	7.8	7,874
Tin	7.3	7,310
Aluminum	2.7	2,700
Ice	0.92	919
Gases (atmospheric pressure at sea level)		
Dry air		
0°C	0.00129	1.29
10°C	0.00125	1.25
20°C	0.00121	1.21
30°C	0.00116	1.16
Helium	0.000178	0.178
Hydrogen	0.000090	0.090
Oxygen	0.00143	1.43

meters (m^3).* A gram of any material has the same mass as 1 cubic centimeter of water at a temperature of 4°C. So water has a density of 1 gram per cubic centimeter. Mercury's density is 13.6 grams per cubic centimeter, which means that it has 13.6 times as much mass as an equal volume of water. Iridium, a hard, brittle, silvery-white metal in the platinum family, is the densest substance on Earth.

A quantity known as weight density, commonly used when discussing liquid pressure, is expressed by the amount of weight of a body per unit volume:**

FIGURE 1

When the volume of a loaf of bread is reduced, its density increases.

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

The metals lithium, sodium, and potassium (not listed in Table 1) are all less dense than water and will float in water.

STOP AND CHECK YOURSELF

1. Which has the greater density—1 kg of water or 10 kg of water?
2. Which has the greater density—5 kg of lead or 10 kg of aluminum?
3. Which has the greater density—an entire candy bar or half a candy bar?

CHECK YOUR ANSWERS

1. The density of any amount of water is the same: 1 g/cm³ or, equivalently, 1000 kg/m³, which means that the mass of water that would exactly fill a thimble of volume 1 cubic centimeter would be 1 gram; or the mass of water that would fill a 1-cubic-meter tank would be 1000 kg. One kg of water would fill a tank only a thousandth as large, 1 liter, whereas 10 kg would fill a 10-liter tank. Nevertheless, the important concept is that the ratio of mass/volume is the same for *any* amount of water.
2. Density is a *ratio* of weight or mass per volume, and this ratio is greater for any amount of lead than for any amount of aluminum—see Table 1.
3. Both the half and the entire candy bar have the same density.

* A cubic meter is a sizable volume and contains a million cubic centimeters, so there are a million grams of water in a cubic meter (or, equivalently, a thousand kilograms of water in a cubic meter). Hence, $1\ g/cm^3 = 1000\ kg/m^3$.

** Weight density is common to United States Customary System (USCS) units in which one cubic foot of freshwater (nearly 7.5 gallons) weighs 62.4 pounds. So freshwater has a weight density of $62.4\ lb/ft^3$. Saltwater is slightly denser, $64\ lb/ft^3$.

2 Pressure

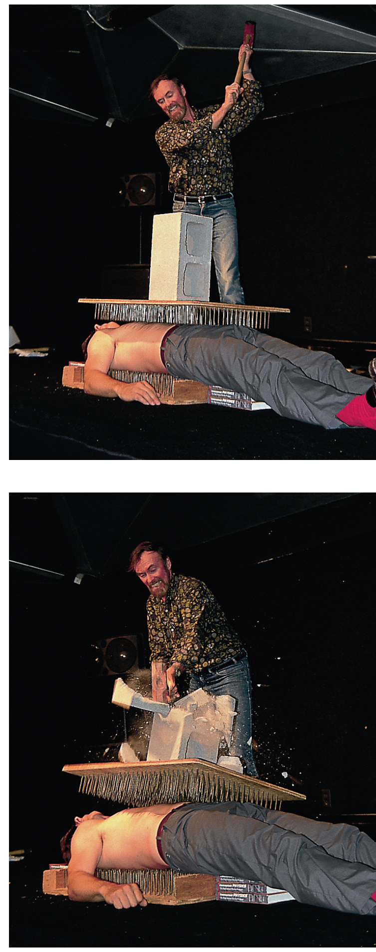
Place a book on a bathroom scale and, whether you place it on its back, on its side, or balanced on a corner, it still exerts the same force. The weight reading is the same. Now balance the book on the palm of your hand and you sense a difference—the *pressure* of the book depends on the area over which the force is distributed (Figure 2). You'll see a distinction between force and pressure. **Pressure** is defined as the force exerted over a unit of area, such as a square meter or square foot:*

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

A dramatic illustration of pressure is shown in Figure 3 The author applies appreciable force when he breaks the cement block with a sledgehammer. Yet his teaching buddy, who is sandwiched between two beds of sharp nails, is unharmed. This is because the force is distributed over more than 200 nails making contact with his body. The combined surface area of the nails results in a tolerable pressure that does not puncture the skin. Again, force and pressure are different from each other.

FIGURE 3

The author applies a force to physics teacher Pablo Robinson, who is bravely sandwiched between beds of sharp nails. The driving force per nail is not enough to puncture the skin. From an inertia point of view, is Pablo safer if the block is massive? From the point of view of energy, is he in danger if the block doesn't break?



STOP AND CHECK YOURSELF

Does a bathroom scale measure weight, pressure, or both?

CHECK YOUR ANSWER

A bathroom scale measures weight, the force that compresses an internal spring or equivalent. The weight reading is the same whether you stand on one or both feet (although the pressure on the scale is twice as much when standing on one foot).

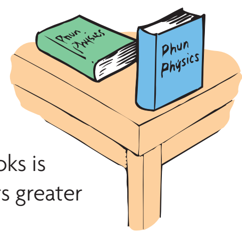


FIGURE 2

Although the weight of both books is the same, the upright book exerts greater pressure against the table.

* Pressure may be measured in any unit of force divided by any unit of area. The standard international (SI) unit of pressure, the newton per square meter, is called the *pascal* (Pa), after the seventeenth-century theologian and scientist Blaise Pascal. A pressure of 1 Pa is very small and approximately equals the pressure exerted by a dollar bill resting flat on a table. Physics types prefer kilopascals (1 kPa = 1000 Pa).

3 Pressure in a Liquid

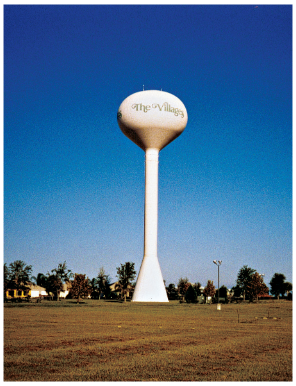
When you swim under water, you can feel the water pressure acting against your eardrums: the deeper you swim, the greater the pressure. What causes this pressure? It is simply the weight of the fluids directly above you—water plus air—pushing against you. As you swim deeper, there is more water above you. Therefore, there's more pressure. If you swim twice as deep, there is twice the weight of water above you, so the water's contribution to the pressure you feel is doubled. Added to the water pressure is the pressure of the atmosphere, which is equivalent to an extra 10.3-meter depth of water. Because atmospheric pressure at Earth's surface is nearly constant, pressure differences you feel under water depend only on changes in depth.

The Physics Place
Dam Keeps Water in Place
Water Keeps Dam in Place

If you were submerged in a liquid denser than water, the pressure would be correspondingly

FIGURE 4

This water tower does more than store water. The depth of water above ground level insures substantial and reliable water pressure to the many homes it serves.



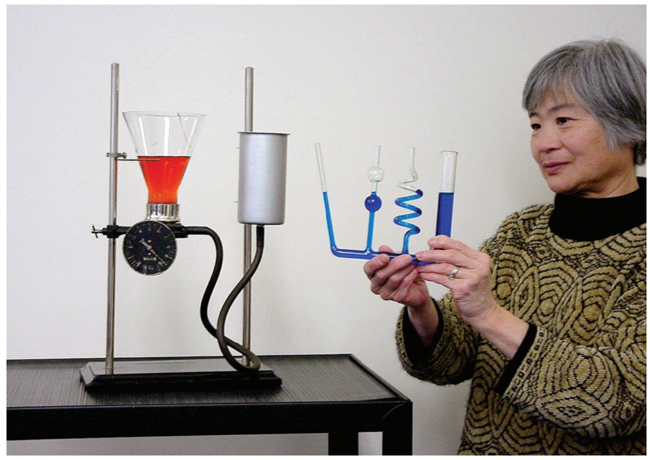


FIGURE 5

Tsing Bardin shows her class that liquid pressure is the same for any given depth below the surface, regardless of the shape of the containing vessel.

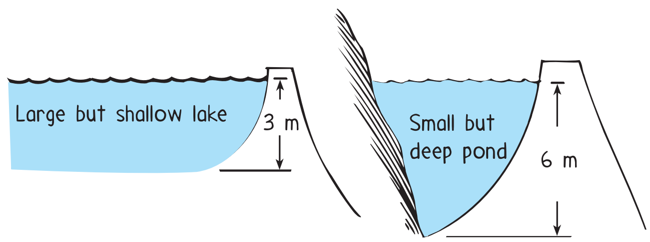


FIGURE 6

The average water pressure acting against the dam depends on the average depth of the water and not on the volume of water held back. The large shallow lake exerts only one-half the average pressure that the small deep pond exerts.

greater. The pressure due to a liquid is precisely equal to the product of weight density and depth:*

$$\text{Liquid pressure} = \text{weight density} \times \text{depth}$$

It is important to note that pressure does not depend on the volume of liquid. You feel the same pressure a meter deep in a small pool as you do a meter deep in the middle of the ocean. This is illustrated by the connecting vases shown in Figure 5. If the pressure at the bottom of a large vase were greater than the pressure at the bottom of a neighboring narrower vase, the greater pressure would force water sideways and then up the narrower vase to a higher level. We find, however, that this doesn't happen. Pressure depends on depth, not volume.

When measuring blood pressure, notice that you measure it in your upper arm—level with your heart.

Water seeks its own level. This can be demonstrated by filling a garden hose with water and holding the two ends upright. The water levels will be equal whether the ends are held close together or far apart. Pressure is depth dependent, not volume dependent. So we see there is an explanation for why water seeks its own level.

In addition to being depth dependent, liquid pressure is exerted equally in all directions. For example, if we are submerged in water, it makes no difference which way we tilt our heads—our ears feel the same amount of water pressure. Because a liquid can flow, the pressure isn't only downward. We know pressure acts upward when we try to push a beach ball beneath the water's surface. The bottom of a boat is certainly pushed upward by water pressure. And we know water pressure acts sideways when we see water spurting sideways from a leak in an upright can. Pressure in a liquid at any point is exerted in equal amounts in all directions.

When liquid presses against a surface, there is a net force directed perpendicular to the surface

* This is derived from the definitions of pressure and density. Consider an area at the bottom of a vessel that contains liquid. The weight of the column of liquid directly above this area produces pressure. From the definition *weight density = weight/volume*, we can express this weight of liquid as *weight = weight density × volume*, where the volume of the column is simply the area multiplied by the depth. Then we get

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

$$= \frac{\text{weight density} \times (\cancel{\text{area}} \times \text{depth})}{\cancel{\text{area}}}$$

$$= \text{weight density} \times \text{depth}.$$

For the total pressure we should add to this equation the pressure due to the atmosphere on the surface of the liquid.