4-3 Pressure

Vocabulary **Pressure:** The force per unit area.

$$\textbf{pressure} = \frac{\textbf{force}}{\textbf{area}} \quad \text{or} \quad P = \frac{F}{A}$$

The SI unit for pressure is the **pascal,** which equals one **newton per square meter ($P = N/m^2$).**

It is very easy to confuse pressure with force. While force is a push or a pull, pressure is a push or pull on a certain area. For a given force, the pressure due to that force is inversely proportional to the area on which the force is exerted. Therefore, if the area of contact is small, the amount of pressure between two surfaces is much greater than if the force were exerted over a larger area.

For example, place a pencil between the palms of your hands with the pointed end pushing against one palm and the eraser end against the other. As you squeeze your hands together, you will feel a much more unpleasant sensation at the pencil tip than at the eraser! The eraser has a larger area, so the force is spread out more evenly over the nerve endings of your hand.

Solved Examples

Example 9: Brooke comes home from school and puts her books down on the kitchen table while she goes to grab a snack. The books have a combined weight of 25 N and the area of contact is 0.19 m by 0.24 m. What pressure do the books apply on the table?

Solution: First, find the area of the surface that is pressing down on the table.

$$\text{area} = \text{length} \times \text{width} = 0.19\ \text{m} \times 0.24\ \text{m} = 0.046\ \text{m}^2$$

Given: $F = 25\ \text{N}$
$A = 0.046\ \text{m}^2$

Unknown: $P = ?$
Original equation: $P = \dfrac{F}{A}$

Solve: $P = \dfrac{F}{A} = \dfrac{25\ \text{N}}{0.046\ \text{m}^2} = \mathbf{540\ N/m^2}$

Example 10: A full coffee mug has a mass of 0.60 kg and an empty mug has a mass of 0.30 kg. a) Which mug, the full one or the empty one, applies a greater pressure on the table? b) If the full mug applies a pressure of 1200. N/m^2, what is the area inside a circular ring of coffee left on the table by the bottom of the mug? c) What is the radius of the ring of coffee?

a. The full mug applies more pressure because a larger force is spread over the given area.

b. The force exerted by the full mug is its weight.

$$w = mg = (0.60\ \text{kg})(10.0\ \text{m/s}^2) = 6.0\ \text{N}$$

Given: $F = 6.0\ \text{N}$
$P = 1200.\ \text{N/m}^2$

Unknown: $A = ?$
Original equation: $P = \dfrac{F}{A}$

Solve: $A = \dfrac{F}{P} = \dfrac{6.0\ \text{N}}{1200.\ \text{N/m}^2} = \mathbf{0.0050\ m^2}$

c. To find the radius, use the equation for the area of a circle.

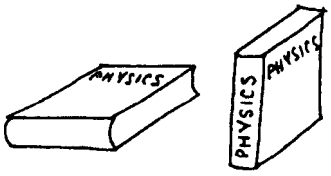
Given: $A = 0.0050\ \text{m}^2$
$\pi = 3.14$

Unknown: $r = ?$
Original equation: $A = \pi r^2$

Solve: $r = \sqrt{\dfrac{A}{\pi}} = \sqrt{\dfrac{0.0050\ \text{m}^2}{3.14}} = \mathbf{0.040\ m}$

Practice Exercises

Exercise 12: a) Which exerts a greater force on a table, a 1.70-kg physics book lying flat on the table, or a 1.70-kg physics book standing on end on the table? b) Which applies a greater pressure? c) If each book measures 0.260 m $\times$ 0.210 m $\times$ 0.040 m, calculate the pressure applied in each of these two drawings.



Answer: **a.** _____

Answer: **b.** _____

Answer: **c.** _____

Exercise 13: Miss Culp, a high school English teacher, marches next to Miss Vance, a physics teacher, in the graduation procession across the football field. Each woman has a mass of 60.0 kg, but Miss Culp is wearing spike heels that have an area of 0.40 cm^2 while Miss Vance wears wide heels with an area of 6.0 cm^2. a) Calculate how much pressure each woman will apply on the ground. b) What could Miss Culp do, while she walks, to help her sink less into the ground?

Answer: **a.** _____

Answer: **b.** _____

Exercise 14: Morgan has a mass of 85 kg and is on top of a bed in such a position that she can apply a pressure of 9530 N/m^2 on the mattress. Would you calculate that Morgan is standing, sitting, or lying on the bed?

Answer: _____

Exercise 15: Caleb is filling up water balloons for the Physics Olympics balloon toss competition. Caleb sets a 0.50-kg spherical water balloon on the kitchen table and notices that the bottom of the balloon flattens until the pressure on the bottom is reduced to 630 N/m^2. a) What is the area of the flat spot on the bottom of the balloon? b) What is the radius of the flat spot?

Answer: **a.** _____

Answer: **b.** _____

Additional Exercises

A-1: What is the minimal force a mother must exert to lift her 5.0-kg baby out of its crib?

A-2: On the moon, the gravity is 1/6 that of Earth. While on the moon, Buzz Aldrin carried on his back a support system that would weigh over 1760 N on Earth. a) What did the backpack weigh on the moon? b) What was its mass on the moon?

A-3: A common malady in runners who run on too hard a surface is shin splints. If a runner's 7.0-kg leg hits the pavement so that it comes to rest with an acceleration of $-200.0\ m/s^2$ on each hit, how much force must the runner's leg withstand on each step?

A-4: In the district soccer championship finals, Elizabeth kicks a 0.600-kg soccer ball with a force of 80.0 N. How much does she accelerate the soccer ball from rest in the process?

A-5: Barker is unloading 20-kg bottles of water from this delivery truck when one of the bottles tips over and slides down the truck ramp that is inclined at an angle of 30° to the ground. What amount of force moves the bottle down the ramp?

A-6: Sarah, whose mass is 40.0 kg, is on her way to school after a winter storm when she accidentally slips on a patch of ice whose coefficient of sliding friction is 0.060. What force of friction will eventually bring Sarah to a stop?

A-7: In her physics lab, Molly puts a 1.0-kg mass on a 2.0-kg block of wood. She pulls the combination across another wooden board with a constant speed to determine the coefficient of sliding friction between the two surfaces. If Molly must pull with a force of 6.0 N, what coefficient of sliding friction does she calculate for wood on wood?

A-8: A 1250-kg slippery hippo slides down a mud-covered hill inclined at an angle of 18.0° to the horizontal. a) If the coefficient of sliding friction between the hippo and the mud is 0.0900, what force of friction impedes the hippo's motion down the hill? b) If the hill were steeper, how would this affect the coefficient of sliding friction?

A-9: What force must you exert on a ball point pen in order to apply a pressure of 0.067 N/mm^2 on a piece of paper, if the ball of the pen has a surface area of 1.2 mm^2 touching the paper?

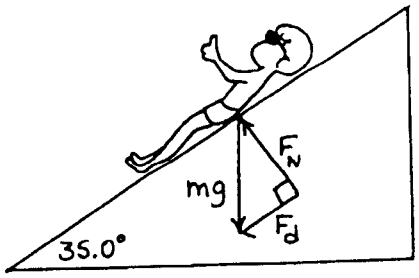
A-10: Asad cuts his knee in a fall while chasing a soccer ball. If a 6-N force is exerted on Asad's knee during the fall, applying a pressure of 1000 N/m^2 on an area of his skin, what is the area of the cut that results from the impact?

A-11: In the TV show, *The Addams Family,* Uncle Fester found it quite comfortable to sleep on a bed of nails. Though this doesn't sound like the most pleasant way to take a nap, it is not too painful if many nails are placed fairly close together. a) If Uncle Fester has a mass of 53 kg and his body covers 700 nails, each with a surface area of 1.00 mm^2, what is the pressure exerted on his body? b) What would be the pressure if Uncle Fester napped on a bed made of only 1 nail?

Challenge Exercises for Further Study

Example 11: Linc, the 65.0-kg lifeguard, slides down a water slide that is inclined at an angle of 35.0° to the horizontal, into the community swimming pool. If the coefficient of friction of the slide is 0.050, what is Linc's rate of acceleration as he slides down?

Solution: Start by constructing a triangle showing all the forces acting on the lifeguard. Then find the normal force acting on Linc when he is inclined at an angle to the horizontal. Because the normal force always acts perpendicular to the surface on which the object sits, find this force with the use of trigonometry.



$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{F_N}{mg}$$

$$F_N = mg\cos\theta = (65.0\text{ kg})(10.0\text{ m/s}^2)\cos 35.0^\circ = 532\text{ N}$$

Now use this normal force to find the force of friction.

Given: $F_N = 532$ N, $\mu = 0.050$ *Unknown:* $F_f = ?$ *Original equation:* $F_f = \mu F_N$

Solve: $F_f = \mu F_N = (0.050)(532\text{ N}) = 27\text{ N}$

Next, return to the original triangle to find the downward component of the weight, which pulls Linc down the slide.

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{F_d}{mg}$$

$$F_d = mg\sin\theta = (65.0\text{ kg})(10.0\text{ m/s}^2)\sin 35.0^\circ = 373\text{ N}$$

The exercise asks for Linc's acceleration at the bottom of the slide. Because friction opposes Linc's motion, subtract its effect from F_d. The net force acting on Linc is

$$F_{net} = F_d - F_f = 373\text{ N} - 27\text{ N} = 346\text{ N}$$

Now solve for the rate of acceleration.

Given: $F = 346$ N, $m = 65.0$ kg *Unknown:* $a = ?$ *Original equation:* $F = ma$

Solve: $a = \dfrac{F}{m} = \dfrac{346\text{ N}}{65.0\text{ kg}} = \mathbf{5.32\ m/s^2}$

B-1: The circus is moving on to the next town and the last animal to board is a stubborn 1500-kg elephant who refuses to budge. Noah pulls the elephant at a constant speed up the 10° incline with a force of 10,000 N. What is the coefficient of sliding friction between the elephant and the loading platform?

B-2: Madison, whose mass is 35.0 kg, climbs the ladder on the slide in her back yard, and slides to the ground at an angle of 30.0° to the horizontal. If the coefficient of sliding friction is 0.15, what is Madison's acceleration down the slide? Ignore the initial effects of starting friction.

B-3: A chunk of rock of mass 50.0 kg slides down the side of a volcano that slopes up at an angle of 30.0° to the horizontal. If the rock accelerates at a rate of 3.0 m/s^2, what is the coefficient of sliding friction between the rock and the side of the volcano?

B-4 While waterskiing behind her father's boat, Cheryl is pulled at a constant speed with a force of 164 N by a rope that makes an angle of 10.0° with the horizontal. If Cheryl has a mass of 65.0 kg, what is the coefficient of sliding friction between Cheryl and the water?

B-5: Keelut, an Inuit, is pulling a 62.0-kg sled through the snow on his way home from ice fishing. On the back of the sled is his 50.0-kg sack of fishing tackle. The coefficient of sliding friction between the sled and the snow is 0.0700 and the coefficient of sliding friction between the sled and the sack is 0.100. While pulling, the fishing rod sticking out of his sack catches on a tree branch, but Keelut doesn't notice and keeps walking. What force does he need to exert to keep the sled moving with a constant speed while the sack is pulled back across it?