Answer to Essential Question 9.6: A>B>C. Point A, being the lowest of the three points, has the highest pressure. Point C, being the highest of the three points, has the lowest pressure.

9-7 Atmospheric Pressure

At sea level on Earth, standard atmospheric pressure is 101.3 kPa, or about 1.0×10^5 Pa, a substantial value. Atmospheric pressure is associated with the air molecules above sea level. Air is not very dense, but the atmosphere extends upward a long way so the cumulative effect is large. The reason we, and most things, don't collapse under atmospheric pressure is that in almost all situations there is pressure on both sides of an interface, so the forces balance. If you can create a pressure difference, however, you can get some interesting things to happen. This is how suction cups work, for instance – by removing air from one side the air pressure on the outside of the suction cup gives rise to a force that keeps the suction cup attached to a surface. It's also fairly easy to use atmospheric pressure to crush a soda can (see end-of-chapter Exercise 6).

In many situations what matters is the **gauge pressure**, which is the difference between the total pressure and atmospheric pressure. The total pressure is generally referred to as the **absolute pressure**. For instance, the absolute pressure at the surface of a lake near sea level is 1 atmosphere (1 atm), so the gauge pressure there would be 0. The gauge pressure 10 meters below the surface of a lake is about 1 atmosphere (1 atm), taking the density of water to be 1000 kg/m^3, because:

$$\rho\, g\, h \approx 1000 \frac{\text{kg}}{\text{m}^3} \times 10 \frac{\text{m}}{\text{s}^2} \times 10 \text{ m} = 1 \times 10^5 \frac{\text{kg m}}{\text{s}^2} \frac{1}{\text{m}^2} = 1 \times 10^5 \frac{\text{N}}{\text{m}^2} = 1 \times 10^5 \text{ Pa} .$$

The absolute pressure 10 m below the surface is about 2 atm. This is particularly relevant for divers, who must keep in mind that every 10 m of depth in water is associated with an additional 1 atmosphere worth of pressure.

EXAMPLE 9.7 – Under pressure

A plastic box is in the shape of a cube measuring 20 cm on each side. The box is completely filled with water and remains at rest on a flat surface. The box is open to the atmosphere at the top. Assume atmospheric pressure is 1.0×10^5 Pa and use g = 10 m/s^2.

(a) What is the gauge pressure at the bottom of the box?
(b) What is the absolute pressure at the bottom of the box?
(c) What is the force associated with this absolute pressure?
(d) What is the force associated with the absolute pressure acting on the inside surface of one side of the box?
(e) What is the net force associated with pressure acting on one side of the box?
(f) What is the net force acting on one side of the box?

SOLUTION

As usual let's begin with a diagram of the situation, shown in Figure 9.21.

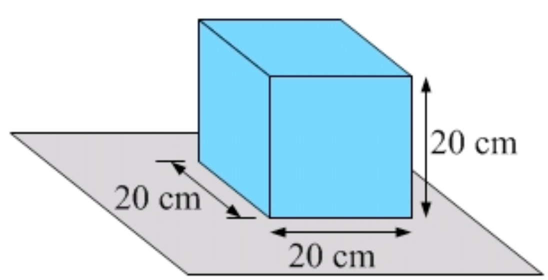

Figure 9.21: A box in the shape of a cube that is open at the top and filled with water.

(a) Because the pressure at the top surface is atmospheric pressure, the gauge pressure at the bottom is simply the pressure difference between the top of the box and the bottom. Applying Equation 9.7, regarding the pressure difference between two points in a static fluid, we get the gauge pressure at the bottom:

$$\Delta P = \rho\, g\, h = 1000 \frac{\text{kg}}{\text{m}^3} \times 10 \frac{\text{m}}{\text{s}^2} \times 0.20 \text{ m} = 2000 \text{ Pa} .$$

(b) The absolute pressure at the bottom is the gauge pressure plus atmospheric pressure. This gives: $P_{bottom} = P_{atm} + P_{gauge} = 1.0 \times 10^5 \text{ Pa} + 2000 \text{ Pa} = 1.02 \times 10^5 \text{ Pa}$. Stating this to three significant figures would violate the rules about significant figures when adding, so we should really round this off to $1.0 \times 10^5 \text{ Pa}$.

(c) To find the force from the pressure we use Equation 9.6, re-arranged to read $\text{Force} = \text{Pressure} \times \text{Area}$. This gives a force of $F_{bottom} = \left(1.0 \times 10^5 \text{ Pa}\right)\left(0.2 \text{ m}\right)^2 = 4000 \text{ N}$, directed down at the bottom of the box.

(d) Finding the force associated with the side of the box is a little harder than finding it at the bottom, because the pressure increases with depth in the fluid. In other words, the pressure is different at points on the side that are at different depths. Because the pressure increases linearly with depth, however, we can take the average pressure to be the pressure halfway down the side of the box. The gauge pressure at a point inside the box that is halfway down the side is:

$$P_{gauge} = \rho g h = 1000 \frac{\text{kg}}{\text{m}^3} \times 10 \frac{\text{m}}{\text{s}^2} \times 0.1 \text{ m} = 1000 \text{ Pa.}$$

To find the force associated with the pressure we use absolute pressure, so we get: $F_{side} = \left(P_{atm} + P_{gauge}\right) \times \text{Area} = \left(1.0 \times 10^5 \text{ Pa} + 1000 \text{ Pa}\right) \times \left(0.2 \text{ m}\right)^2 = 4040 \text{ N}$, which we should round off to 4000 N directed out from the center of the box.

(e) In part (d) we were concerned with the fluid pressure applying an outward force on one side of the box. Now we need to account for the air outside the box exerting an inward force on the same side of the box. This force is simply atmospheric pressure multiplied by the area, and is thus 4000 N directed inward. The net force associated with pressure is thus the combination of the 4040 N force directed out and the 4000 N force directed in, and is thus 40 N directed out. The same result can be obtained from $F_{pressure} = P_{gauge} \times \text{Area}$.

(f) Because the box and all its sides remain at rest, the net force on any one side must be zero, so this 40 N outward force associated with the gauge pressure of the water must be balanced by forces applied to one side by the rest of the box.

Related End-of-Chapter Exercises: 27, 28.

Essential Question 9.7: In Example 9.7, we accounted for the change in water pressure with depth, but we did not account for the increase in air pressure with depth, which could affect our calculation of the inward force exerted by the air on a side of the box. Explain why we can neglect this change in air pressure.