Chapter 1

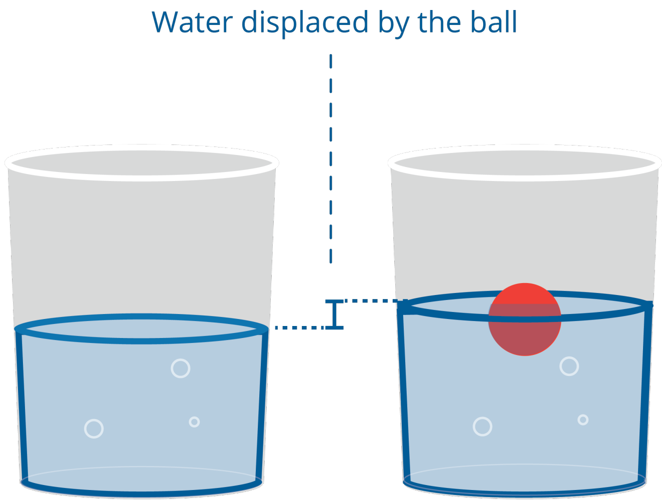
Buoyancy

The word buoyancy probably brings to mind images of floating in water. Before we dive in, let's zoom out for a moment and consider that the study of buoyancy is about much more than just boats and water. You might be thinking: I want to be a computer programmer, why do I need to know about buoyancy? This topic is much bigger than it might seem at first glance. Buoyancy concerns how all liquids and gasses interact with gravity. The concept of buoyancy is connected to fundamental concepts about how things work in the universe. The *buoyant force*, as it's known in engineering, is an important concept that has wide ranging applications. A big part of engineering is moving stuff around, and understanding buoyancy helps us solve problems where we need to move things in and through fluids. Even if you don't have plans to build a robotic submarine, these are super useful ideas to be familiar with. We'll start exploring the topic with familiar scenarios around boats and water.

When you put a boat into water, it will sink into the water until the mass of the water it displaces is equal to the mass of the boat. We think of this in terms of forces. Gravity pulls the mass of the boat down. The *buoyant force* pushes the boat up. A boat dropped into the water will bob up and down a bit before reaching an *equilibrium* where the two forces are equal.

The buoyant force pushes things up – against the force of gravity. The force is equal to the weight of the fluid being replaced. So, for example, a cubic meter of freshwater has a mass of about 1000kg. If you submerge anything with a volume of one meter in freshwater on earth, the buoyant force will be about 9800 newtons.

For some things, like a block of styrofoam, this buoyant force will be sufficient to carry it to the surface. Once it reaches the surface, it will continue to rise (displacing less water) until the mass of the water it displaces is equal to its mass. And then we say "It floats!"



For some things, like a block of lead, the buoyant force is not sufficient to lift it to the surface, and thus we say "It sinks!"

This is why a helium balloon floats through the air. The air that it displaces weighs more than the balloon and the helium itself. (It is easy to forget that air has a mass, but it does.)

Exercise 1 Buoyancy

You have an aluminum box that has a heavy base, so it will always float upright. The box and its contents weigh 10 kg. Its base is 0.3 m x 0.4 m. It is 1m tall.

When you drop it into freshwater ($1000 \mathrm{kg}/\mathrm{m}^3$), how far will it sink before it reaches equilibrium.

Working Space

Answer on Page 5

1.1 The Mechanism of Buoyancy: Pressure

As you dive down in the ocean, you will experience greater and greater pressure from the water. And if you take a balloon with you, you will gradually see it get smaller as the water pressure compresses the air in the balloon.

Let's say you are 3 meters below the surface of the water. What is the pressure in Pascals (newtons per square meter)? You can think of the water as a column of water crushing down upon you. The pressure over a square meter is the weight of 3 cubic meters of water pressing down.

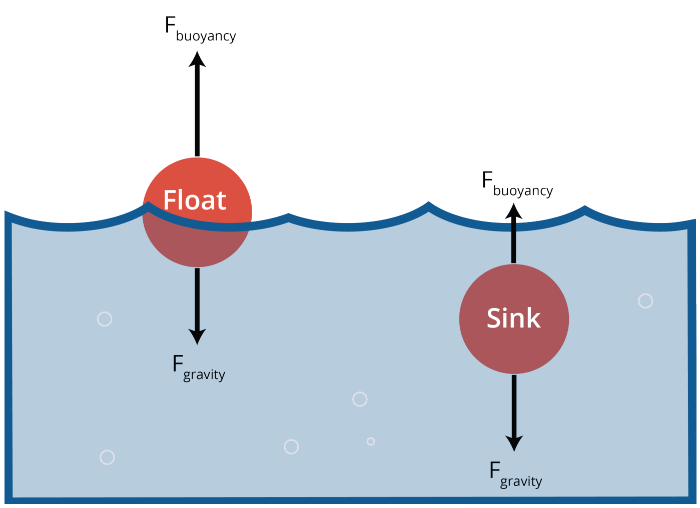
$$p = (3)(1000)(9.8) = 29,400 \text{ Pa}$$

This is called *hydrostatic pressure*. The general rule for hydrostatic pressure in Pascals p is

$p = dgh$

Where d is the density of the fluid in kg per cubic meter, g is the acceleration due to gravity in m/s^2, and h is the height of the column of fluid above you.

So, where does buoyant force come from? Basically, the pressure pushing up on the deepest part of the object is higher than the pressure pushing down on the shallowest part of the object. That is where bouyancy comes from.



Exercise 2 Hydrostatic Pressure

Working Space

You dive into a tank of olive oil on Mars. How much more hydrostatic pressure does your body experience at 5 meters deep than it did at the surface?

The density of olive oil is about 900 kg per square meter. The acceleration due to gravity on Mars is 3.721 m/s^2.

Answer on Page 5

1.2 The Mechanism of Buoyancy: Density

Notice that although the pressure is increasing as you go deeper, the buoyant force will *not increase* because the buoyant force is always equal to the weight of the fluid that is displaced, regardless if that is 1 meter or 100 meters underwater.

Due to the added minerals, saltwater is denser than freshwater. This causes objects float better in the sea than they do in, say, a river. Lipids, like fats and oils, are less dense than water, allowing them to float on top of a glass of water. When you're facing a grease fire, you're told not to put water on it. That's because the water sinks below the grease, then boils, throwing burning grease everywhere.

Appendix A

Answers to Exercises

Answer to Exercise 1 (on page 2)

Equilibrium will be achieved when the box has displaced 10 kg of water. That is, when it has displaced 0.01 cubic meters.

The area of the base of the box is 0.12 square meters. So if the box sinks x meters into the water it will displace $0.12x$ cubic meters.

Thus at equilibrium $x = \frac{0.01}{0.12} \approx 0.083$ m. So, the box will sink 8.3 cm into the water before reaching equilibrium.

Answer to Exercise 2 (on page 4)

$$p = dgh = (900)(3.721)(5) = 16,744.5 \text{ Pa}$$

Index