6.3: Density

Learning Objectives

By the end of this section, you will be able to:

- Define density.
- Calculate the mass of a reservoir from its density.
- Compare and contrast the densities of various substances.

Which weighs more, a ton of feathers or a ton of bricks? This old riddle plays with the distinction between mass and density. A ton is a ton, of course; but bricks have much greater density than feathers, and so we are tempted to think of them as heavier (Figure $6.3.1$).

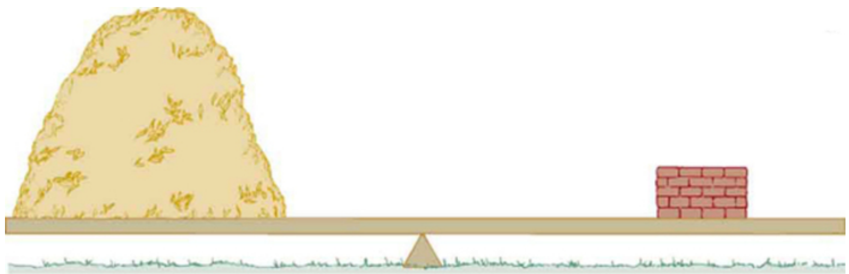

Figure $6.3.1$: A ton of feathers and a ton of bricks have the same mass, but the feathers make a much bigger pile because they have a much lower density.

Density, as you will see, is an important characteristic of substances. It is crucial, for example, in determining whether an object sinks or floats in a fluid.

Definition: Density

Density is mass per unit volume.

$$\rho = \frac{m}{V}, \tag{6.3.1}$$

where the Greek letter ρ (rho) is the symbol for density, m is the mass, and V is the volume occupied by the substance.

In the riddle regarding the feathers and bricks, the masses are the same, but the volume occupied by the feathers is much greater, since their density is much lower. The SI unit of density is kg/m^3, representative values are given in Table $6.3.1$. The metric system was originally devised so that water would have a density of $1\ g/cm^3$, equivalent to $10^3\ kg/m^3$. Thus the basic mass unit, the kilogram, was first devised to be the mass of 1000 mL of water, which has a volume of $1000\ cm^3$.

Table $6.3.1$: Densities of Various Substances

Substance	$\rho(10^3 \frac{kg}{m^3}\ or\ \frac{g}{mL})$	Substance	$\rho(10^3 \frac{kg}{m^3}\ or\ \frac{g}{mL})$	Substance	$\rho(10^3 \frac{kg}{m^3}\ or\ \frac{g}{mL})$
Solids		**Liquids**		**Gases**	
Aluminum	2.7	Water (4ºC)	1.000	Air	1.29×10^{-3}
Brass	8.44	Blood	1.05	Carbon dioxide	1.98×10^{-3}
Copper (average)	8.8	Sea water	1.025	Carbon monoxide	1.25×10^{-3}
Gold	19.32	Mercury	13.6	Hydrogen	0.090×10^{-3}
Iron or steel	7.8	Ethyl alcohol	0.79	Helium	0.18×10^{-3}
Lead	11.3	Petrol	0.68	Methane	0.72×10^{-3}
Polystyrene	0.10	Glycerin	1.26	Nitrogen	1.25×10^{-3}
Tungsten	19.30	Olive oil	0.92	Nitrous oxide	1.98×10^{-3}

Substance	$\rho(10^3 \frac{kg}{m^3} \ or \ \frac{g}{mL})$	Substance	$\rho(10^3 \frac{kg}{m^3} \ or \ \frac{g}{mL})$	Substance	$\rho(10^3 \frac{kg}{m^3} \ or \ \frac{g}{mL})$
Uranium	18.70			Oxygen	1.43×10^{-3}
Concrete	2.30–3.0			Steam 100^o	0.60×10^{-3}
Cork	0.24				
Glass, common (average)	2.6				
Granite	2.7				
Earth's crust	3.3				
Wood	0.3–0.9				
Ice (0°C)	0.917				
Bone	1.7–2.0				

As you can see by examining Table $6.3.1$, the density of an object may help identify its composition. The density of gold, for example, is about 2.5 times the density of iron, which is about 2.5 times the density of aluminum. Density also reveals something about the phase of the matter and its substructure. Notice that the densities of liquids and solids are roughly comparable, consistent with the fact that their atoms are in close contact. The densities of gases are much less than those of liquids and solids, because the atoms in gases are separated by large amounts of empty space.

TAKE-HOME EXPERIMENT SUGAR AND SALT

A pile of sugar and a pile of salt look pretty similar, but which weighs more? If the volumes of both piles are the same, any difference in mass is due to their different densities (including the air space between crystals). Which do you think has the greater density? What values did you find? What method did you use to determine these values?

Example $6.3.1$: Calculating the Mass of a Reservoir From Its Volume

A reservoir has a surface area of $50 \ km^2$ and an average depth of 40.0 m. What mass of water is held behind the dam? (See Figure $6.3.2$ for a view of a large reservoir—the Three Gorges Dam site on the Yangtze River in central China.)

Figure $6.3.2$: Three Gorges Dam in central China. When completed in 2008, this became the world's largest hydroelectric plant, generating power equivalent to that generated by 22 average-sized nuclear power plants. The concrete dam is 181 m high and 2.3 km across. The reservoir made by this dam is 660 km long. Over 1 million people were displaced by the creation of the reservoir. (credit: Le Grand Portage)

Strategy

We can calculate the volume V of the reservoir from its dimensions, and find the density of water ρ in Table $6.3.1$. Then the mass m can be found from the definition of density (Equation $6.3.1$).

Solution

Solving Equation $6.3.1$ for m gives

$$m = \rho V.$$

The volume V of the reservoir is its surface area A times its average depth h:

$$\begin{aligned} V &= Ah \\ &= (50.0\, km^2)(40.0\, m) \\ &= \left[(50.0\, km^2)\left(\frac{10^3\, m}{1\, km}\right)\right](40.0\, m) \\ &= 2.00 \times 10^9\, m^3 \end{aligned}$$

The density of water ρ from Table $6.3.1$ is $1.000 \times 10^3\, kg/m^3$. Substituting V and ρ into the expression for mass gives

$$\begin{aligned} m &= (1.00 \times 10^3\, kg/m^3)(2.00 \times 10^9\, m^3) \\ &= 2.00 \times 10^{12}\, kg. \end{aligned}$$

Discussion

A large reservoir contains a very large mass of water. In this example, the weight of the water in the reservoir is $mg = 1.96 \times 10^{13}\, N$, where g is the acceleration due to the Earth's gravity (about $9.80\, m/s^2$). It is reasonable to ask whether the dam must supply a force equal to this tremendous weight. The answer is no. As we shall see in the following sections, the force the dam must supply can be much smaller than the weight of the water it holds back.

Summary

- Density is the mass per unit volume of a substance or object. In equation form, density is defined as

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

- The SI unit of density is kg/m^3.

Glossary

density

the mass per unit volume of a substance or object

Contributors and Attributions

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