Teacher Tune-up

Quick Content Refresher for Busy Professionals

How does the density of an object relate to the mass of an object?

An object's **mass density** is its mass divided by the volume of space the object occupies. Other kinds of density ratios (e.g., cars-per-mile traffic density, buildings-per-acre housing density) may be useful in specific situations, but mass density is one of the most important attributes of matter. Mass density is usually just called "density" for short, and we'll use that convention in what follows.

The *arithmetic* of density is easy, but the *concept* often confuses students. Mathematically, density is analogous to speed: both are ratios of other quantities. Density (mass/volume) is no more a measure of mass or volume than speed (distance/time) is a measure of distance or time. But "miles per hour" is easier for students to understand because it's much more familiar (hardly anyone gets confused about the various quantities involved when driving 50 mph for half and hour versus driving 50 mph for 2 hours). Some students may benefit from an explicit discussion of the difference between **extensive** properties (like mass and volume), which depend on the extent of an object, and **intensive** properties (like density, color, conductivity, and solubility), which don't. Intensive properties are properties of the *materials* objects are made of, rather than just properties of the individual objects themselves.

Density, then, describes a ***concentration* of mass** rather than simply an amount of mass.

Because density depends on concentration of mass rather than total amount, a small piece of iron has the same density as a large piece of iron, as long as both are solid and the same temperature. As far as density goes, the greater mass of the larger piece is exactly balanced by the increased volume it occupies. However, any piece of iron is denser than any piece of wood, and is less dense than any piece of lead. If an object is made of multiple materials, its average density is the total mass divided by the total volume. For example, compressed polystyrene has a density of about 1.04 g/cm^3; but in its foamed form, it is shot through with air bubbles, which have a density of about 0.0012 g/cm^3, so that Styrofoam has an average density of only about 0.05 g/mc^3.

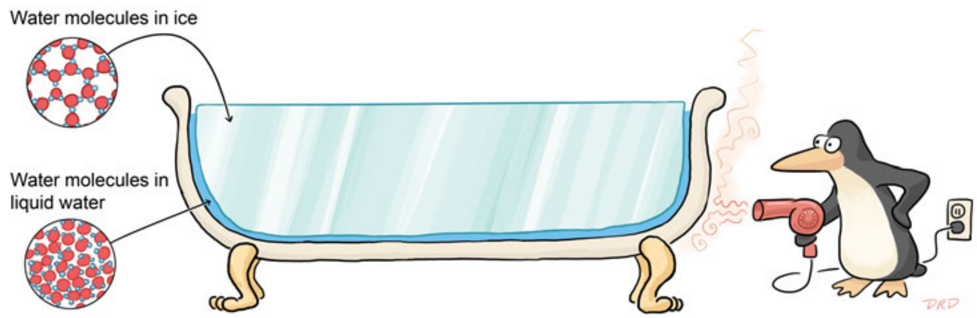
The metric system makes comparing densities easier by defining the unit for mass to match the amount of water that occupies a standard volume. The mass of water that fits into a 1 cubic centimeter (equal to 1 milliliter) is defined to be 1 gram. This definition means that 1 liter (equal to 1000 cm^3) of water has a mass of 1 kilogram. This definition for the unit of mass makes the density of water exactly 1 g/cm^3, which is the same as 1 kg/L, which is the same as 1000 kg/m^3.

Density of various substances (in *grams/cm^3* or *kg/liter*, at 70° F & sea-level air pressure)

Helium	0.00015
Air	0.0012
Styrofoam	0.05
Pine	0.42
Lithium	0.53
Ice	0.93
Water	1
Sand	2.65
Aluminum	2.7
Iron	7.87
Lead	11.34
Mercury	13.56
Gold	19.32

Density differences between substances result from the mass, spacing, and connection pattern of the atoms that make up the substance; and these particulate arrangements are affected by the temperature, pressure, and state (solid, liquid, or gas) of a substance. Gases, whose molecules are not connected at all, are hundreds of times less dense than liquids or solids. Indeed, liquids and solids are collectively known as **condensed** forms of matter because their particles are densely packed together. (Liquids and gases, on the other hand, are both called fluids because their particles are not stuck in a fixed arrangement.)

The liquid phase of a substance is *usually* slightly less dense than the solid phase because the molecules of liquids are not bound to each other as tightly, but there are some exceptions, most notably water: ice is less dense than liquid water because of the way water molecules organize themselves when water crystalizes. That's why ice floats in water.

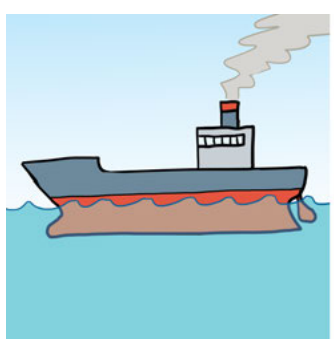


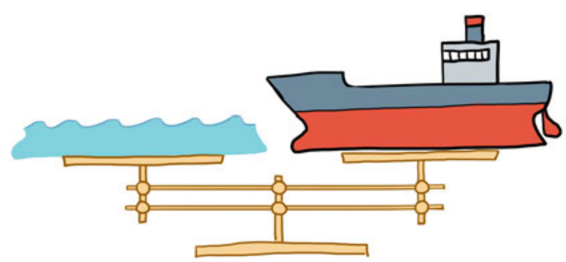
Whether a solid object sinks or floats when placed in a fluid medium (liquid or gas) depends on the relative densities of the object and the fluid, not on the amount of fluid or the size of the object. To persuade your imagination that it is the densities of object and medium that matter, not their volume or mass, try this thought experiment: imagine a bathtub full of water that is frozen solid. Now imagine that the tub is warmed slightly from the outside (by a blow dryer or something), so that a thin layer of the ice touching the tub melts. Intuitively, one might imagine a massive block of ice would push down through a thin layer of water and touch the tub, squeezing the water up over the top of the ice; but gravity doesn't care about that intuitive impression. Gravity pulls the denser substance closer. As soon any liquid water forms, it will be denser than the ice—so the ice will be floating in it! So there is really no lower limit to the volume of fluid needed to float a less dense object.

Certain substances flout our intuition about what should float. There are a couple of metals (lithium and sodium) that float on water, and a few types of wood (e.g., ebony) dense enough to sink in it. Lead will sink in water, but will float on liquid mercury. An object will stop sinking into a liquid when the weight of the displaced liquid becomes as large as the weight of the object, but this will only happen if the liquid is denser than the object.

Speaking of floating, buoyancy can puzzle students. For example, how can a boat made of iron float in water, when iron is clearly more dense than water? The answer is that it is not just the iron, but the air in the hull of the ship, that allows it to float (just as the helium in a latex balloon allows it to float in air, even though latex is denser than air). Remember how polystyrene achieves such a low density when filled with air bubbles? The ship is a bit like a large piece of iron with a really big air bubble inside—the average density is lower than that of water.

A ship is lifted by a buoyant force equal to the weight of the water it displaces (as a helium balloon is lifted by a buoyant force equal to the weight of the air it displaces). If you load cargo in or out of a ship, it will lower or rise in the water so that it displaces an amount of water with exactly the mass (and weight) of the ship and everything on it.





Because density, mass, and weight are closely related concepts, there is some ambiguity (and often confusion) in the usage of the terms “heavy” and “light.” The fundamental meanings refer to weight, but the terms are often used in everyday speech and even some technical work to refer to density (e.g., “gasoline is lighter than water”) or to the relative mass of atoms (as in “heavy-metal poisoning”). Careful writing will use “denser” or “more massive” in place of “heavier” where appropriate. Making statements like, “a liter of gasoline is lighter than a liter of water,” is another way to avoid ambiguity.