Chapter 10

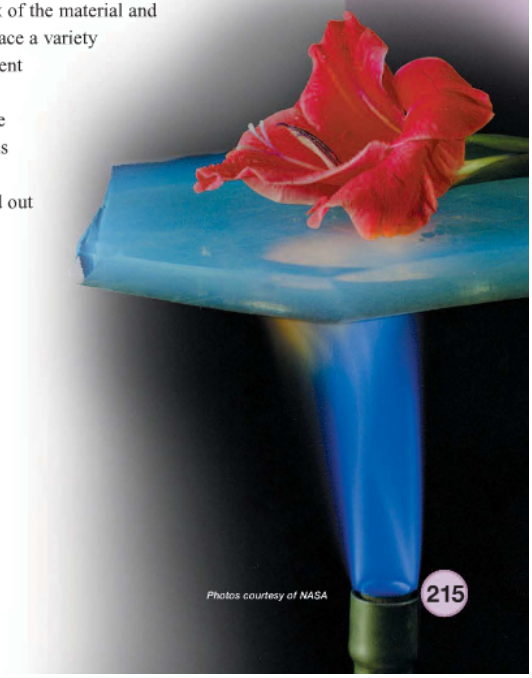
Properties of Matter

Would you believe that someone has invented a solid material that has about the same density as air? It's so light, if someone put a chunk of it your hand you might not even notice. Silica aerogel is a foam that's like solidified smoke. Aerogel is mostly air and has remarkable thermal, optical, and acoustical properties.

Aerogels are fantastic insulators. You could hold a flame under a chunk of the material and touch the top without being burned. Aerogels have the potential to replace a variety of materials used in everyday life. If researchers could make a transparent version of an aerogel, it would almost certainly be used in double-pane windows to keep heat inside your house in the winter and outside in the summer. Opaque aerogels are already being used as insulators. Aerogels have been put to use by NASA in several projects, including the Mars Pathfinder, Soujourner and Stardust missions. Read this chapter to find out more about various types of matter and their properties.

Key Questions

- ✔ *What are some important properties of solids?*
- ✔ *What is a fluid and how are fluids different from solids?*
- ✔ *What is pressure?*
- ✔ *Why does a steel cube sink while a steel boat floats?*



Photos courtesy of NASA

215

10.1 Density

VOCABULARY

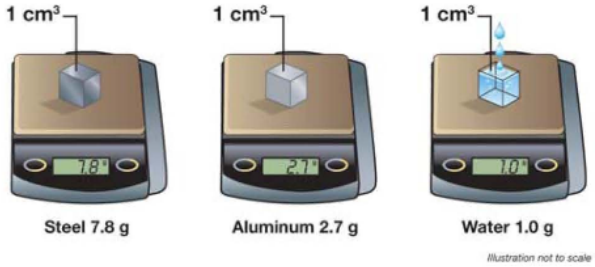
density - the mass per unit volume of a given material. Units for density are often expressed as g/mL, g/cm^3, or kg/m^3.

Mass and volume are different properties of matter, but they are related. For instance, a solid block of wood and a solid block of steel can have the same volume, but they would *not* have the same mass. The steel block has a lot more mass than the wood block. Because of the mass difference, the wood block floats in water and the steel block sinks. Whether an object floats or sinks is related to the object's density. This section will explain density, a property of all matter.

Density is a property of matter

Density is mass per unit volume

Density describes how much mass is in a given volume of a material. Steel has high density; it contains 7.8 grams of mass per cubic centimeter (7.8 g/cm^3). Aluminum, as you might predict, has a lower density; a 1-centimeter cube has a mass of only 2.7 grams (2.7 g/cm^3).



The density of water and air

Liquids and gases are matter, therefore, they have density. The density of water is about 1 gram per cubic centimeter. The density of air is lower, of course—much lower. The air in your classroom has a density of about 0.001 grams per cubic centimeter (0.001 g/cm^3). Density units can be expressed as g/cm^3, g/mL, or kg/m^3 (Figure 10.1).

Figure 10.1: *The density of steel, aluminum, water, and air expressed in grams per milliliter (1 mL = 1 cm^3).*

Next

Units of density

Density in units of g/mL Your laboratory investigations will typically express density in units of grams per milliliter (g/mL). The density of water is one gram per milliliter. This means 1 milliliter of water has a mass of 1 gram.

Density in units of g/cm^3 and kg/m^3 Some problems express density in units of grams per cubic centimeter (g/cm^3). Since 1 milliliter is exactly the same volume as 1 cubic centimeter, the units of g/cm^3 and g/mL are the same. For measuring large objects, it is easier to express density in units of kilograms per cubic meter (kg/m^3). Figure 10.2 gives the densities of some common materials in both units.

Converting units of density To convert from one unit of density to the other, remember that 1 g/cm^3 is equal to 1,000 kg/m^3. To go from g/cm^3 to kg/m^3, you multiply by 1,000. For example, the density of ice is 0.92 g/cm^3. This is the same as 920 kg/m^3. To go from kg/m^3 to g/cm^3, you divide by 1,000. For example, the density of aluminum is 2,700 kg/m^3. Dividing by 1,000 gives a density of 2.7 g/cm^3.

Material	(kg/m^3)	(g/cm^3)
Platinum	21,500	21.5
Lead	11,300	11.3
Steel	7,800	7.8
Titanium	4,500	4.5
Aluminum	2,700	2.7
Glass	2,700	2.7
Granite	2,600	2.6
Concrete	2,300	2.3
Plastic	2,000	2.0
Rubber	1,200	1.2
Liquid water	1,000	1.0
Ice	920	0.92
Ash (wood)	670	0.67
Pine (wood)	440	0.44
Cork	120	0.12
Air (avg.)	0.9	0.0009

Figure 10.2: *Density of some common materials.*

SOLVE IT!

Ipe (pronounced ee-pay) is a Brazilian hardwood that can be used as a durable (but expensive!) construction material for decks, docks, and other outdoor projects. Every cubic foot of ipe weighs 69 pounds. Use dimensional analysis to convert the density of ipe to g/cm^3. How does the density if ipe compare to other woods and materials in the list above?

Next

Density of solids and liquids

Density of a material does not change with quantity or shape

Density is a property of material that is independent of quantity or shape. For example, a steel nail and a steel cube have different amounts of matter and therefore different masses (Figure 10.3). They also have different volumes and shapes. But they have the same density. Dividing mass by volume gives the same density for the nail and the cube, because both are made of steel.

Density of a material is the same no matter what the size or shape of the material

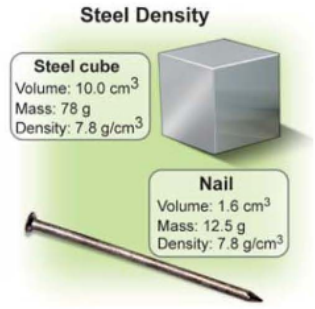
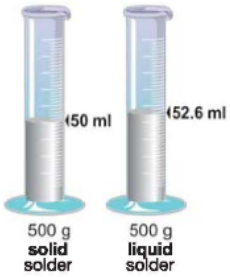


Figure 10.3: *The density of a steel nail is the same as the density of a solid cube of steel.*

Liquids tend to be less dense than solids of the same material

The density of a liquid is usually a little *less* than the density of the same material in solid form. Take the example of solder (pronounced sod-der). Solder is a metal alloy used to join metal surfaces.



500 g of solid solder fills a volume of 50 mL. The density of solid solder is 10 g/mL. The same mass (500 g) of melted (liquid) solder has 52.6 mL of volume. Liquid solder has a lower density of 9.5 g/mL. The density of a liquid is lower because the atoms are not packed as tightly as they are in a solid. Imagine a brand-new box of toy blocks. When you open the box, the blocks are tightly packed, like the atoms in a solid. Now imagine dumping the blocks out of the box, and then pouring them back into the original box again. The same number of jumbled blocks take up more space, like the atoms in a liquid (Figure 10.4).

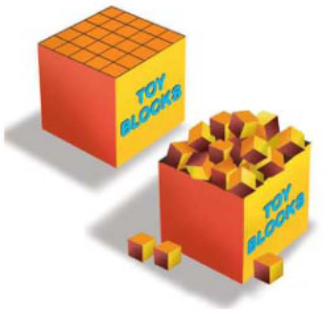


Figure 10.4: *The same number (or mass) of blocks arranged in a tight, repeating pattern take up less space than when they are jumbled up.*

Water is an exception

Water is an exception to this rule. The density of solid water, or ice, is *less* than the density of liquid water. When water molecules freeze into ice crystals, they form a pattern that has an unusually large amount of empty space. The water molecules in ice are actually farther apart than they are in liquid water. Because of this, ice floats in liquid water.

Determining density

Finding density To find the density of a material, you need to know the mass and volume of a sample of the material. You can calculate density using the formula below.

DENSITY

$$D = \frac{m}{V}$$

Density (g/cm³ or g/mL) = D; m = Mass (g); V = Volume (cm³ or mL)

Density gives information about atoms and molecules Density gives us information about how tightly the atoms or molecules of a particular material are "packed." Diamond is made of carbon atoms and has a density of 3.5 g/cm^3. The carbon atoms in diamond are relatively tightly packed. Paraffin wax is also made mostly of carbon atoms, but the density is only 0.87 g/cm^3. The density of paraffin is low because the carbon atoms are mixed with hydrogen atoms in long molecules that take up a lot of space. The molecules in paraffin are not as tightly packed as the atoms in diamond.

The density of solid objects Suppose you have a piece of aluminum foil, a length of aluminum wire, and an aluminum brick. At the same temperature and pressure, the aluminum making each of these has the same density. It does not matter whether the aluminum is shaped into a brick, flat sheet, or long wire. The density is 2.7 g/cm^3 as long as the object is made of solid aluminum.

The average density of a hollow object If an object is hollow, its average density is less than the density of the material from which the object is made. Suppose a small block of aluminum with a mass of 10.8 grams is used to make a soda can (Figure 10.5). Both the solid block of aluminum and the soda can have a mass of 10.8 grams, but the hollow can has a much larger volume. The can has 100 times the volume of the block, so its density is 100 times less.

Aluminum block
Mass = 10.8 grams
Volume = 4 cm³
Density = 2.7 g/cm³

Aluminum soda can
Mass = 10.8 grams
Volume = 400 cm³
Average density = 0.027 g/cm³

Figure 10.5: *The aluminum block and the soda can have the same mass but different volumes and densities. The density of the aluminum can is called its average density because it also includes the air inside the can as part of the volume.*

Solving Problems: Calculating Density

A solid wax candle has a volume of 1,700 mL. The candle has a mass of 1.5 kg (1,500 g). What is the density of the candle?

1. Looking for: You are asked for the density.

2. Given: You are given the mass and volume.

3. Relationships: Density is mass divided by volume.

4. Solution: Density = 1,500 g ÷ 1,700 mL = 0.88 g/mL

Your turn...

a. Look at Figure 10.7. A student measures the mass of five steel hex nuts to be 96.2 g. The hex nuts displace 13 mL of water. Calculate the density of the steel in the hex nuts.

b. The density of granite is about 2.60 g/cm^3. How much mass would a solid piece of granite have that measures 2.00 cm × 2.00 cm × 3.00 cm?

c. Ice has a density of about 0.920 g/cm^3. What is the volume of 100.0 g of ice?

To Find:	Use:
density	$D = \frac{m}{V}$
volume	$V = \frac{m}{D}$
mass	$m = D \times V$

Figure 10.6: *Using the density equation.*

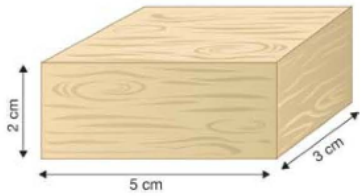
Figure 10.7: *A student measures the volume and mass of five steel hex nuts.*

SOLVE FIRST LOOK LATER

a. 7.4 g/mL; b. 31.2 g; c. 109 cm^3

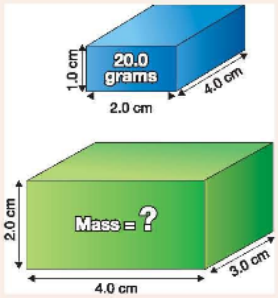
Section 10.1 Review

1. Define density, write the formula (from memory!), and give two different units used to measure density.
2. One cubic centimeter (cm^3) is the same volume as one _____.
3. A material's density is the same, no matter how large or small the sample is, or what its shape is, as long as it is a solid, uniform piece of the material. Explain how this is possible and give an example.
4. The density of balsa wood is about 170 kg/m^3. Convert to g/cm^3. Why do you think balsa wood, rather than oak or ash, is commonly used for building models? (Use evidence from Figure 10.2 on page 217.)
5. A certain material has a density of 0.2 g/cm^3. Is this material better for building a bridge or for making sofa cushions? Explain, using evidence from Figure 10.2 on page 217.



6. The piece of wood shown above has a mass of 20 grams. Calculate its volume and density. Then, use Figure 10.2 on page 217 to determine which type of wood it is. What are the two factors that determine a material's density?
7. The density of maple wood is about 755 kg/m^3. What is the mass of a solid piece of maple that has a volume 640 cm^3?

SOLVE IT!



Two toy blocks are made of the same type of material. One has a mass of 20.0 grams and its dimensions are 2.0 cm × 4.0 cm × 1.0 cm. The second block measures 4.0 cm × 3.0 cm × 2.0 cm. Calculate the mass of the second block.