The terms heavy and light are commonly used in two different ways. We refer to weight when we say that an adult is heavier than a child. On the other hand, something else is alluded to when we say that rock is heavier than soil. A small rock would obviously weigh less than a roomful of soil, but rock is heavier in the sense that a rock of given size weighs more than the same-size sample of soil. What we are actually comparing is the mass per unit volume, that is, the density. In order to determine these densities, we might weigh a cubic centimeter of each sample. If the rock sample weighed 2.71 g and the soil 1.20 g, we could describe the density of the rock as $2.71 \text{ g cm}^{-3}$ and that of the soil as $1.20 \text{ g cm}^{-3}$. Even though sand is made of rock fragments, its density is less because the porosity of sand lowers its bulk density (as shown below). (Note that the negative exponent in the units cubic centimeters indicates a reciprocal. Thus $1 \text{ cm}^{-3} = 1/\text{cm}^3$ and the units for our densities could be written as $\frac{g}{\text{cm}^3}$, or $g \text{ cm}^{-3}$. In each case the units are read as grams per cubic centimeter, the per indicating division.) We often abbreviate "cm$^3$" as "cc", and $1 \text{ cm}^3 = 1 \text{ mL}$ exactly, by definition.

Table \(\PageIndex{1}\): Density of Soils and Rocks

<table>
<thead>
<tr>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
</tr>
<tr>
<td>sandy loam</td>
</tr>
<tr>
<td>loam</td>
</tr>
<tr>
<td>silt loam</td>
</tr>
<tr>
<td>clay loam</td>
</tr>
<tr>
<td>clay</td>
</tr>
<tr>
<td>amphibolite</td>
</tr>
<tr>
<td>dolomite</td>
</tr>
<tr>
<td>gneiss</td>
</tr>
<tr>
<td>limestone</td>
</tr>
<tr>
<td>marble</td>
</tr>
<tr>
<td>schist</td>
</tr>
<tr>
<td>shale</td>
</tr>
<tr>
<td>slate</td>
</tr>
<tr>
<td>pyrite</td>
</tr>
</tbody>
</table>
Soil Type

Densities of many more materials are easily found.

The Soil and Rock Density Tables show that the density of classic sedimentary rocks varies, because it increases (under overburden pressure) as the rocks are progressively buried. A process called cementation, where dissolved minerals fill the interstices, also decreases the porosity and increases the density.

The bulk densities are given for sedimentary rocks as well as soils, because sedimentary rocks typically have variable porosity. Bulk density includes both the grains and the interstitial spaces. The grain density is the actual density of the particles, which might be a mineral. The bulk density is less than the grain density of the constituent mineral (or mineral assemblage), depending on the porosity. For example, sandstone (characteristically quartzose) has a typical dry bulk density of 2.0–2.6 g/cm$^3$, with a porosity that can vary from low to more than 30 percent. The density of quartz itself is 2.65 g/cm$^3$. If porosity were zero, the bulk density would equal the grain density.

The bulk density of a soil sample is determined by weighing a known volume of soil which is usually dried by heating. The average grain density of a soil may be determined by pouring a weighed sample of the soil into a graduated cylinder containing enough water to cover the soil, and noting the increase in volume of the water. This is the volume of the grains. It is easy to calculate the porosity from the bulk and grain densities.

In general it is not necessary to weigh exactly 1 cm$^3$ of a material in order to determine its density. Bulk density is a measure of the weight of the soil per unit volume (g/cc), usually given on an oven-dry (110° C) basis (figure 1). We simply measure mass and volume and divide volume into mass:

\[
\text{Density} = \frac{\text{mass}}{\text{volume}}
\]

or

\[
\rho = \frac{m}{V}
\]

where \(\rho\) = density \(m\) = mass \(V\) = volume

Example: Density Calculation

Calculate the density of (a) a piece of rock whose mass is 37.42 g and which, when submerged, increases the water level
in a graduated cylinder by 13.9 ml; (b) an rock core sample which is a cylinder of mass 25.07 g, radius 0.750 m, and height 5.25 cm.

Solution

a) Since the submerged rock displaces its own volume,
\[
\text{Density} = \rho = \frac{\text{m}}{\text{V}} = \frac{37.42 \text{ g}}{13.9 \text{ mL}} = 2.69 \text{ g/mL or } 2.69 \text{ g mL}^{-1}
\]

b) The volume of the cylinder must be calculated first, using the formula
\[
\text{V} = \pi r^2 h = 3.142 \times (0.750 \text{ cm})^2 \times 5.25 \text{ cm} = 9.278 \text{ cm}^3
\]

Then
\[
\rho = \frac{\text{m}}{\text{V}} = \frac{25.07 \text{ g}}{9.278 \text{ cm}^3} = 2.70 \frac{\text{g}}{\text{cm}^3}
\]

Note that unlike mass or volume, the density of a substance is independent of the size of the sample. Thus density is a property by which one substance can be distinguished from another. A sample of the rock in the example can be trimmed to any desired volume or adjusted to have any mass we choose, but its density will always be 2.70 g/cm$^3$ at 20°C.

Tables and graphs are designed to provide a maximum of information in a minimum of space. When a physical quantity (number × units) is involved, it is wasteful to keep repeating the same units. Therefore it is conventional to use pure numbers in a table or along the axes of a graph. A pure number can be obtained from a quantity if we divide by appropriate units. For example, when divided by the units gram per cubic centimeter, the density of aluminum becomes a pure number 2.70:
\[
\frac{\text{Density of aluminum}}{\text{1 g cm}^{-3}} = \frac{2.70 \text{ g cm}^{-3}}{\text{1 g cm}^{-3}} = 2.70
\]

Therefore, a column in a table or the axis of a graph is conveniently labeled in the following form:
\[
\frac{\text{Quantity}}{\text{units}}
\]

This indicates the units that must be divided into the quantity to yield the pure number in the table or on the axis. This has been done in the second column of Soil and Rock Density Tables.

Converting Densities

In our exploration of Density, notice that chemists may express densities differently depending on the subject. The density of pure substances may be expressed in kg/m$^3$ in some journals which insist on strict compliance with SI units; densities of soils may be expressed in lb/ft$^3$ in some agricultural or geological tables; the density of a cell may be expressed in mg/µL; and other units are in common use. It is easy to transform densities from one set of units to another, by multiplying the original quantity by one or more unity factors:

Example: Density Conversion
Convert the density of water, 1 g/cm³ to (a) lb/cm³ and (b) lb/ft³

a. The equality 454 g = 1 lb can be used to write two unity factors,

\[
\frac{454 \text{ g}}{1 \text{ lb}} \text{ or } \frac{1 \text{ lb}}{454 \text{ g}}
\]

The given density can be multiplied by one of the unity factors to get the desired result. The correct conversion factor is chosen so that the units cancel:

\[
\frac{1 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ lb}}{454 \text{ g}} = 0.002203 \frac{\text{lb}}{\text{cm}^3}
\]

b. Similarly, the equalities 2.54 cm = 1 inch, and 12 inches = 1 ft can be use to write the unity factors:

\[
\frac{2.54 \text{ cm}}{1 \text{ in}}, \frac{1 \text{ in}}{2.54 \text{ cm}}, \frac{12 \text{ in}}{1 \text{ ft}} \text{ and } \frac{1 \text{ ft}}{12 \text{ in}}
\]

In order to convert the cm³ in the denominator of 0.002203 \(\frac{\text{lb}}{\text{cm}^3}\) to in³, we need to multiply by the appropriate unity factor three times, or by the cube of the unity factor:

\[
0.002203 \frac{\text{g}}{\text{cm}^3} \times \left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right)^3 = 0.0361 \frac{\text{lb}}{\text{in}^3}
\]

This can then be converted to lb/ft³:

\[
0.0361 \frac{\text{lb}}{\text{in}^3} \times \left(\frac{12 \text{ in}}{1 \text{ ft}}\right)^3 = 62.4 \frac{\text{lb}}{\text{ft}^3}
\]

Note

It is important to notice that we have used conversion factors to convert from one unit to another unit of the same parameter.

From ChemPRIME: 1.8: Density

References

3. ↑ http://www.geology.iupui.edu/research...ocedures/bulk/
4. ↑ http://www.geology.iupui.edu/research...bulk/Index.htm
Contributors

- Ed Vitz (Kutztown University), John W. Moore (UW-Madison), Justin Shorb (Hope College), Xavier Prat-Resina (University of Minnesota Rochester), Tim Wendorff, and Adam Hahn.