Density

The **mass density** or **density** of a material is defined as its mass per unit volume. The symbol most often used for density is ρ (the Greek letter rho). In some cases (for instance, in the United States oil and gas industry), density is also defined as its weight per unit volume;[1] although, this quantity is more properly called specific weight. Different materials usually have different densities, so density is an important concept regarding buoyancy, purity and packaging. Osmium is the densest known substance at standard conditions for temperature and pressure.

Less dense fluids float on more dense fluids if they do not mix. This concept can be extended, with some care, to less dense solids floating on more dense fluids. If the average density (including any air below the waterline) of an object is less than water (1.0 g per mL) it will float in water and if it is more than water's it will sink in water.

In some cases density is expressed as the dimensionless quantities specific gravity (SG) or relative density (RD), in which case it is expressed in multiples of the density of some other standard material, usually water or air/gas. (For example, a specific gravity less than one means that the substance floats in water.)

The mass density of a material varies with temperature and pressure. (The variance is typically small for solids and liquids and much greater for gasses.) Increasing the pressure on an object decreases the volume of the object and therefore increase its density. Increasing the temperature of a substance (with some exceptions) decreases its density by increasing the volume of that substance. In most materials, heating the bottom of a fluid results in convection of the heat from bottom to top of the fluid due to the decrease of the density of the heated fluid. This causes it to rise relative to more dense unheated material.

The reciprocal of the density of a substance is called its specific volume, a representation commonly used in thermodynamics. Density is an intensive property in that increasing the amount of a substance does not increase its density; rather it increases its mass.

History

In a well-known but probably apocryphal tale, Archimedes was given the task of determining whether King Hiero's goldsmith was embezzling gold during the manufacture of a golden wreath dedicated to the gods and replacing it with another, cheaper alloy.[2] Archimedes knew that the irregularly shaped wreath could be crushed into a cube whose volume could be calculated easily and compared with the mass; but the king did not approve of this. Baffled, Archimedes took a relaxing immersion bath and observed from the rise of the water upon entering that he could calculate the volume of the gold wreath through the displacement of the water. Upon this discovery, he leaped from his bath and went running naked through the streets shouting, "Eureka! Eureka!" (Εύρηκα! Greek "I found it"). As a result, the term "eureka" entered common parlance and is used today to indicate a moment of enlightenment.

The story first appeared in written form in Vitruvius' books of architecture, two centuries after it supposedly took place.[3] Some scholars have doubted the accuracy of this tale, saying among other things that the method would have required precise measurements that would have been difficult to make at the time.[4] [5]

Mathematically, density is defined as mass divided by volume:

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

where ρ is the density, m is the mass, and V is the volume. From this equation, mass density must have units of a unit of mass per unit of volume. As there are many units of mass and volume covering many different magnitudes there are a large number of units for mass density in use.

The SI unit of kilogram per cubic metre (kg/m³) and the cgs unit of gram per cubic centimetre (g/cm³) are probably the most common used units for density. (The cubic centimeter can be alternately called a *millilitre* or a *cc*.) One g/cm³ equals 1000 kg/m³. In industry, other larger or smaller units of mass and or volume are often more practical and US customary units may be used. See below for a list of some of the most common units of density. Further, density may be expressed in terms of weight density (the weight of the material per unit volume) or as a ratio of the density with the density of a common material such as air or water.

Measurement of density

The density at any point of a homogeneous object equals its total mass divided by its total volume. The mass is normally measured with an appropriate scale or balance; the volume may be measured directly (from the geometry of the object) or by the displacement of a fluid. Hydrostatic weighing, for instance uses, the displacement of water due to a submerged object to determine the density of the object.

If the body is not homogeneous, then the density is a function of the position. In that case the density around any given location is determined by calculating the density of a small volume around that location. In the limit of an infinitesimal volume the density of an inhomogeneous object at a point becomes: $\rho(\mathbf{r})=dm/dV$, where dV is an elementary volume at position r. The mass of the body then can be expressed as

$$m = \int_V \rho(\mathbf{r})\,dV.$$

The density of granular material can be ambiguous, depending on exactly how its volume is defined, and this may cause confusion in measurement. A common example is sand: if it is gently poured into a container, the density will be low; if the same sand is then compacted, it will occupy less volume and consequently exhibit a greater density. This is because sand, like all powders and granular solids, contains a lot of air space in between individual grains. The density of the material including the air spaces is the bulk density, which differs significantly from the density of an individual grain of sand with no air included.

Changes of density

In general, density can be changed by changing either the pressure or the temperature. Increasing the pressure always increases the density of a material. Increasing the temperature generally decreases the density, but there are notable exceptions to this generalization. For example, the density of water increases between its melting point at 0 °C and 4 °C; similar behavior is observed in silicon at low temperatures.

The effect of pressure and temperature on the densities of liquids and solids is small. The compressibility for a typical liquid or solid is 10^{-6} bar^{-1} (1 bar=0.1 MPa) and a typical thermal expansivity is 10^{-5} K^{-1}. This roughly translates into needing around ten thousand times atmospheric pressure to reduce the volume of a substance by one percent. (Although the pressures needed may be around a thousand times smaller for sandy soil and some clays.) A one percent expansion of volume typically requires a temperature increase on the order of thousands of degrees Celsius.

In contrast, the density of gases is strongly affected by pressure. The density of an ideal gas is

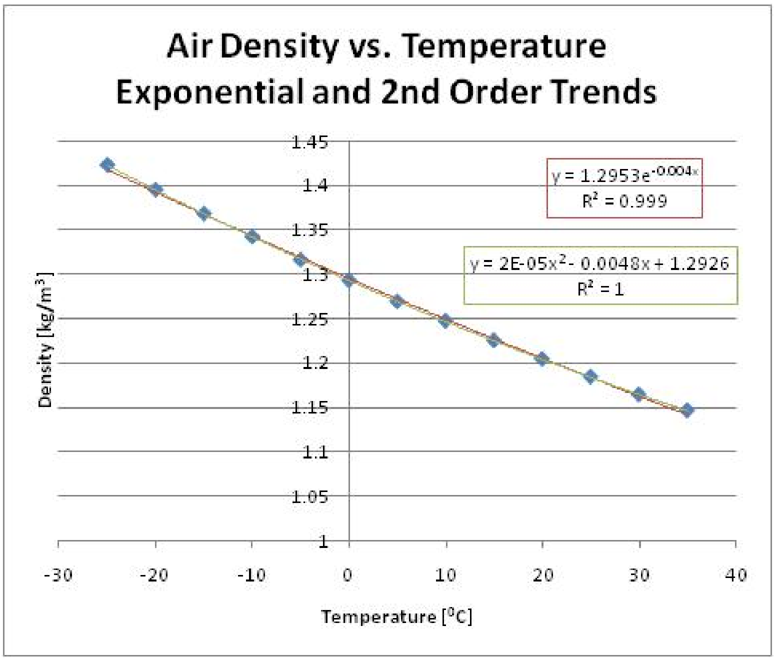
$$\rho = \frac{MP}{RT},$$

where M is the molar mass, P is the pressure, R is the universal gas constant, and T is the absolute temperature. This means that the density of an ideal gas can be doubled by doubling the pressure, or by halving the absolute temperature.

Density of water (at 1 atm)

Temp (°C)	**Density (kg/m^3)**
100	958.4
80	971.8
60	983.2
40	992.2
30	995.6502
25	997.0479
22	997.7735
20	998.2071
15	999.1026
10	999.7026
4	999.9720
0	999.8395
−10	998.117
−20	993.547
−30	983.854
The density of water in kilograms per cubic metre (SI unit) at various temperatures in degrees Celsius. The values below 0 °C refer to supercooled water.	

Density of air (at 1 atm)



Density *vs.* Temperature

T **in °C**	ϱ **in kg/m^3**
−25	1.423
−20	1.395
−15	1.368
−10	1.342
−5	1.316
0	1.293
5	1.269
10	1.247
15	1.225
20	1.204
25	1.184
30	1.164
35	1.146

Density of solutions

The density of a solution is the sum of mass (massic) concentrations of the components of that solution.

Mass (massic) concentration of a given component ρ_i in a solution can be called partial density of that component.

$$\rho = \sum_i \rho_i$$

Expressed as a function of the densities of pure components of the mixture and their volume participation, it reads:

$$\rho = \sum_i \rho_o i \frac{V_o i}{V}.$$

Densities of various materials

Material	ϱ in kg/m^3	Notes
Interstellar medium	10^{-25} – 10^{-15}	Assuming 90% H, 10% He; variable T
Earth's atmosphere	1.2	At sea level
Aerogel	1 – 2	
Styrofoam	30 – 120[6]	
Cork	220 – 260[6]	
Potassium	860[]	At STP
Sodium	970	At STP
Ice	916.7	
Water (fresh)	1000	At STP
Water (salt)	1030	
Plastics	850 – 1400	For polypropylene and PETE/PVC
Magnesium	1740	At STP

Beryllium	1850	At STP
Glycerol[7] [8]	1261	
Silicon	2330	At STP
Aluminium	2700	At STP
Titanium	4540	At STP
Selenium	4800	At STP
The Earth	5515.3	Mean density
Vanadium	6100	At STP
Antimony	6690	At STP
Zinc	7000	At STP
Chromium	7200	At STP
Manganese	7210 - 7440	At STP
Tin	7310	At STP
Iron	7870	At STP
Niobium	8570	At STP
Cadmium	8650	At STP
Cobalt	8900	At STP
Nickel	8900	At STP
Copper	8920 – 8960	Near room temperature
Bismuth	9750	At STP
Molybdenum	10220	At STP
Silver	10500	At STP
Lead	11340	Near room temperature
Thorium	11700	At STP
Rhodium	12410	At STP
The Inner Core of the Earth	~13000	As listed in Earth
Mercury	13546	At STP
Tantalum	16600	At STP
Uranium	18800	At STP
Tungsten	19300	At STP
Gold	19320	At STP
Plutonium	19840	At STP
Platinum	21450	At STP
Iridium	22420	At STP
Osmium	22570	At STP
The core of the Sun	~150000	
White dwarf star	1×10^9[9]	
Atomic nuclei	2.3×10^{17} [10]	Does not depend strongly on size of nucleus

Neutron star	$8.4 \times 10^{16} - 1 \times 10^{18}$	
Black hole	4×10^{17}	Mean density inside the Schwarzschild radius of an Earth-mass black hole (theoretical)

Density of composite material

In the United States, ASTM specification D792-00[11] describes the steps to calculate the density of a composite material.

$$\rho = \frac{W_a}{W_a + W_w - W_b} \left(\rho_{water}\right)$$

where:

ρ is the density of the composite material, in g/cm^3

and

W_a is the weight of the specimen when hung in the air

W_w is the weight of the partly immersed wire holding the specimen

W_b is the weight of the specimen when immersed fully in distilled water, along with the partly immersed wire holding the specimen

ρ_{water} is the density in g/cm^3 of the distilled water at testing temperature (for example 0.9975 g/cm^3 at 23 °C)

Other common units

The SI unit for density is:

- kilograms per cubic metre (kg/m³)

Litres and metric tons are not part of the SI, but are acceptable for use with it, leading to the following units:

- kilograms per litre (kg/L)
- grams per millilitre (g/mL)
- metric tons per cubic metre (t/m³)

Densities using the following metric units all have exactly the same numerical value, one thousandth of the value in (kg/m³). Liquid water has a density of about 1 kg/dm³, making any of these SI units numerically convenient to use as most solids and liquids have densities between 0.1 and 20 kg/dm³.

- kilograms per cubic decimetre (kg/dm³)
- grams per cubic centimetre (g/cc, gm/cc or g/cm³)
- megagrams per cubic metre (Mg/m³)

In U.S. customary units density can be stated in:

- Avoirdupois ounces per cubic inch (oz/cu in)
- Avoirdupois pounds per cubic inch (lb/cu in)
- pounds per cubic foot (lb/cu ft)
- pounds per cubic yard (lb/cu yd)
- pounds per U.S. liquid gallon (lb/gal)
- pounds per U.S. bushel (lb/bu)
- slugs per cubic foot.

In principle there are Imperial units different from the above as the Imperial gallon and bushel differ from the U.S. units, but in practice they are no longer used, though found in older documents. The density of precious metals could conceivably be based on Troy ounces and pounds, a possible cause of confusion.

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External links

- Glass Density Calculation - Calculation of the density of glass at room temperature and of glass melts at 1000 - 1400°C (http://glassproperties.com/density/room-temperature/)
- List of Elements of the Periodic Table - Sorted by Density (http://www.science.co.il/PTelements.asp?s=Density)
- Calculation of saturated liquid densities for some components (http://ddbonline.ddbst.de/DIPPR105DensityCalculation/DIPPR105CalculationCGI.exe)
- field density test (http://www.denichsoiltest.com/field/field-density-test.html)
- On-line calculator for densities and partial molar volumes of aqueous solutions of some common electrolytes and their mixtures, at temperatures up to 323.15 K. (http://www.aim.env.uea.ac.uk/aim/density/density_eletrolyte.php)
- Water - Density and Specific Weight (http://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html)
- Temperature dependence of the density of water - Conversions of density units (http://www.sengpielaudio.com/ConvDensi.htm)
- A delicious density experiment (http://www.adamequipment.com/education/Documents/EdExp1.pdf)
- Water density calculator (http://linkingweatherandclimate.com/ocean/waterdensitycalc.php) Water density for a given salinity and temperature.
- Liquid density calculator (http://www.enggcyclopedia.com/welcome-to-enggcyclopedia/calculators/liquid-density) Select a liquid from the list and calculate density as a function of temperature.
- Gas density calculator (http://www.enggcyclopedia.com/welcome-to-enggcyclopedia/thermodynamics/gas-density) Calculate density of a gas for as a function of temperature and pressure.

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