# Density of air

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The **density of air** ρ (Greek: rho) (air density) is the mass per unit volume of Earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature and humidity. At sea level and at 15°C air has a density of approximately 1.225 $kg/m^3$ (1225.0 $g/m^3$, 0.0023769 slug/(cu ft), 0.0765 lb/(cu ft)) according to ISA (International Standard Atmosphere).

Air density is a property used in many branches of science, engineering, and industry, including aeronautics;[1][2][3] gravimetric analysis;[4] the air-conditioning[5] industry; atmospheric research and meteorology;[6][7][8] agricultural engineering (modeling and tracking of Soil-Vegetation-Atmosphere-Transfer (SVAT) models);[9][10][11] and the engineering community that deals with compressed air.[12]

## Contents



## Density of air calculations

Depending on the measuring instruments, use, and necessary rigor of the result, different sets of equations for the calculation of the density of air are used. Air is a mixture of gases and the calculations always simplify, to a greater or lesser extent, the properties of the mixture.

### Density of air variables

#### Temperature and pressure

The density of dry air can be calculated using the ideal gas law, expressed as a function of temperature and pressure:

$$\rho = \frac{p}{R_{\text{specific}} T}$$

where:

$\rho =$ air density ($kg/m^3$)[note 1]
$p =$ absolute pressure (Pa)[note 1]
$T =$ absolute temperature (K)[note 1]
$R_{\text{specific}} =$ specific gas constant for dry air (J/(kg·K))[note 1]

The specific gas constant for dry air is 287.058 J/(kg·K) in SI units, and 53.35 (ft·lbf)/(lb·°R) in United States customary and Imperial units. This quantity may vary slightly depending on the molecular composition of air at a particular location.

Therefore:

- At IUPAC standard temperature and pressure (0 °C and 100 kPa), dry air has a density of 1.2754 $kg/m^3$.
- At 20 °C and 101.325 kPa, dry air has a density of 1.2041 $kg/m^3$.
- At 70 °F and 14.696 psi, dry air has a density of 0.074887 $lb/ft^3$.

The following table illustrates the air density–temperature relationship at 1 atm or 101.325 kPa:

**Effect of temperature on properties of air**

| Temperature $T$ (°C) | Speed of sound $c$ (m/s) | Density of air $\rho$ (kg/m$^3$) | Characteristic specific acoustic impedance $z_0$ (Pa·s/m) |
|---|---|---|---|
| 35 | 351.88 | 1.1455 | 403.2 |
| 30 | 349.02 | 1.1644 | 406.5 |
| 25 | 346.13 | 1.1839 | 409.4 |
| 20 | 343.21 | 1.2041 | 413.3 |
| 15 | 340.27 | 1.2250 | 416.9 |
| 10 | 337.31 | 1.2466 | 420.5 |
| 5 | 334.32 | 1.2690 | 424.3 |
| 0 | 331.30 | 1.2922 | 428.0 |
| −5 | 328.25 | 1.3163 | 432.1 |
| −10 | 325.18 | 1.3413 | 436.1 |
| −15 | 322.07 | 1.3673 | 440.3 |
| −20 | 318.94 | 1.3943 | 444.6 |
| −25 | 315.77 | 1.4224 | 449.1 |

**Humidity (water vapor)**

The addition of water vapor to air (making the air humid) reduces the density of the air, which may at first appear counter-intuitive. This occurs because the molar mass of water (18 g/mol) is less than the molar mass of dry air[note 2] (around 29 g/mol). For any gas, at a given temperature and pressure, the number of molecules present is constant for a particular volume (see Avogadro's Law). So when water molecules (water vapor) are added to a given volume of air, the dry air molecules must decrease by the same number, to keep the pressure or temperature from increasing. Hence the mass per unit volume of the gas (its density) decreases.

The density of humid air may be calculated by treating it as a mixture of ideal gases. In this case, the partial pressure of water vapor is known as the vapor pressure. Using this method, error in the density calculation is less than 0.2% in the range of −10 °C to 50 °C. The density of humid air is found by:

$$\rho_{\text{humid air}} = \frac{p_d}{R_d T} + \frac{p_v}{R_v T} = \frac{p_d M_d + p_v M_v}{RT}$$ [13]

where:

$\rho_{\text{humid air}}$ = Density of the humid air (kg/m³)
$p_d$ = Partial pressure of dry air (Pa)
$R_d$ = Specific gas constant for dry air, 287.058 J/(kg·K)
$T$ = Temperature (K)
$p_v$ = Pressure of water vapor (Pa)
$R_v$ = Specific gas constant for water vapor, 461.495 J/(kg·K)
$M_d$ = Molar mass of dry air, 0.028964 kg/mol
$M_v$ = Molar mass of water vapor, 0.018016 kg/mol
$R$ = Universal gas constant, 8.314 J/(K·mol)

The vapor pressure of water may be calculated from the saturation vapor pressure and relative humidity. It is found by:

$$p_v = \phi p_{\text{sat}}$$

where:

$p_v$ = Vapor pressure of water
$\phi$ = Relative humidity
$p_{\text{sat}}$ = Saturation vapor pressure

The saturation vapor pressure of water at any given temperature is the vapor pressure when relative humidity is 100%. One formula [14] used to find the saturation vapor pressure is:

$$p_{\text{sat}} = 6.1078 \times 10^{\frac{7.5T}{T+237.3}}$$

where $T$ = is in degrees C.

note:

- This equation will give the result of pressure in hPa (100 Pa, equivalent to the older unit millibar, 1 mbar

= 0.001 bar = 0.1 kPa)

The partial pressure of dry air $p_d$ is found considering partial pressure, resulting in:

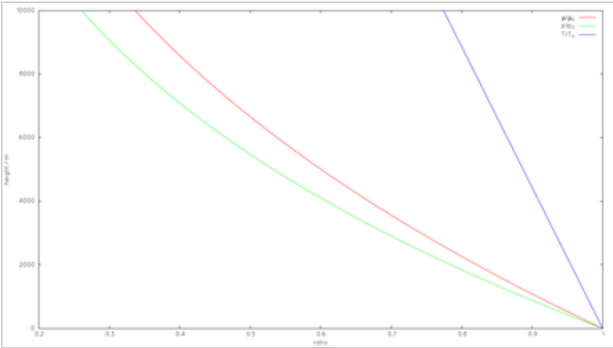
$$p_d = p - p_v$$

Where $p$ simply denotes the observed absolute pressure.

*The movement of the helicopter rotor leads to a difference in pressure between the upper and lower blade surfaces, allowing the helicopter to fly. A consequence of the pressure change is local variation in air density, strongest in the boundary layer or at transonic speeds.*

### Altitude

To calculate the density of air as a function of altitude, one requires additional parameters. They are listed below, along with their values according to the International Standard Atmosphere, using for calculation the universal gas constant instead of the air specific constant:



Standard Atmosphere: $p_0$ = 101.325 kPa, $T_0$ = 288.15 K, $\rho_0$ = 1.225 kg/m$^3$

$p_0$ = sea level standard atmospheric pressure, 101.325 kPa
$T_0$ = sea level standard temperature, 288.15 K
$g$ = earth-surface gravitational acceleration, 9.80665 m/s$^2$
$L$ = temperature lapse rate, 0.0065 K/m
$R$ = ideal (universal) gas constant, 8.31447 J/(mol·K)
$M$ = molar mass of dry air, 0.0289644 kg/mol

Temperature at altitude $h$ meters above sea level is approximated by the following formula (only valid inside the troposphere):

$$T = T_0 - Lh$$

The pressure at altitude $h$ is given by:

$$p = p_0 \left(1 - \frac{Lh}{T_0}\right)^{\frac{gM}{RL}}$$

Density can then be calculated according to a molar form of the ideal gas law:

$$\rho = \frac{pM}{RT}$$

where:

$M$ = molar mass
$R$ = ideal gas constant
$T$ = absolute temperature
$p$ = absolute pressure

### Composition

**Composition of dry atmosphere, by volume**[▽note 1]

| Gas (and others) | | Volume by various[15][▽note 2] | | Volume by CIPM-2007[16] | | Volume by ASHRAE[17] | | |
|---|---|---|---|---|---|---|---|---|
| | | ppmv[▽note 3] | percentile | ppmv | percentile | ppmv | percentile | |
| Nitrogen | ($N_2$) | 780,800 | (78.080%) | 780,848 | (78.0848%) | 780,818 | (78.0818%) | |
| Oxygen | ($O_2$) | 209,500 | (20.950%) | 209,390 | (20.9390%) | 209,435 | (20.9435%) | |
| Argon | (Ar) | 9,340 | (0.9340%) | 9,332 | (0.9332%) | 9,332 | (0.9332%) | |
| Carbon dioxide | ($CO_2$) | 397.8 | (0.03978%) | 400 | (0.0400%) | 385 | (0.0385%) | |
| Neon | (Ne) | 18.18 | (0.001818%) | 18.2 | (0.00182%) | 18.2 | (0.00182%) | ▼ *Tap this text to expand or collapse the table* ▲ |
| Helium | (He) | 5.24 | (0.000524%) | 5.2 | (0.00052%) | 5.2 | (0.00052%) | |
| Methane | ($CH_4$) | 1.81 | (0.000181%) | 1.5 | (0.00015%) | 1.5 | (0.00015%) | |
| Krypton | (Kr) | 1.14 | (0.000114%) | 1.1 | (0.00011%) | 1.1 | (0.00011%) | |
| Hydrogen | ($H_2$) | 0.55 | (0.000055%) | 0.5 | (0.00005%) | 0.5 | (0.00005%) | |
| Nitrous oxide | ($N_2O$) | 0.325 | (0.0000325%) | 0.3 | (0.00003%) | 0.3 | (0.00003%) | |
| Carbon monoxide | (CO) | 0.1 | (0.00001% ) | 0.2 | (0.00002%) | 0.2 | (0.00002%) | |
| Xenon | (Xe) | 0.09 | (0.000009%) | 0.1 | (0.00001%) | 0.1 | (0.00001%) | |
| Nitrogen dioxide | ($NO_2$) | 0.02 | (0.000002%) | - | - | - | - | |
| Iodine | ($I_2$) | 0.01 | (0.000001%) | - | - | - | - | |
| Ammonia | ($NH_3$) | trace | trace | - | - | - | - | |
| Sulphur dioxide | ($SO_2$) | trace | trace | - | - | - | - | |
| Ozone | ($O_3$) | 0.02 to 0.07 [▽note 4] | (2 to $7 \times 10^{-6}$%) [▽note 4] | - | - | - | - | |
| Trace to 30 ppm [▽note 6] | (----) | - | - | - | - | 2.9 | (0.00029%) | |
| **Dry air total** | **(air)** | 1,000,065.265 | (100.0065265%) | 999,997.100 | (99.9997100%) | 1,000,000.000 | (100.0000000%) | |
| **Not included in above dry atmosphere:** | | | | | | | | |
| Water vapor | ($H_2O$) | **~0.25% by mass over full atmosphere, locally 0.001%–5% by volume.**[21] | | | | | | |

1. ▽Concentration pertains to the troposphere
2. ▽The NASA total value do not add up to exactly 100% due to roundoff and uncertainty. To normalize, $N_2$ should be reduced by about 51.46 ppmv and $O_2$ by about 13.805 ppmv.
3. ▽ppmv: parts per million by volume (note: volume fraction is equal to mole fraction for ideal gas only, see volume (thermodynamics))
4. ▽values disregarded for the calculation of total dry air
5. ▽($O_3$) concentration up to 0.07 ppmv ($7 \times 10^{-6}$%) in summer and up to 0.02 ppmv ($2 \times 10^{-6}$%) in winter
6. ▽volumetric composition value adjustment factor (sum of all trace gases, below the ($CO_2$), and adjusts for 30 ppmv)

## See also

- Air
- Density
- Atmosphere of Earth
- International Standard Atmosphere
- U.S. Standard Atmosphere
- NRLMSISE-00

## Notes

1. In the SI unit system. However, other units can be used.
2. like the dry air is a mixture of gases his molar mass is a pondered molar mass of their components

## References

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14. Shelquist,R (2009) Algorithms - Schlatter and Baker (http://wahiduddin.net/calc/density_algorithms.htm)
15. Partial sources for figures: Base constituents, Nasa earth factsheet (http://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html), (updated 2014-03). Carbon dioxide, NOAA Earth System Research Laboratory (http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo), (updated 2014-03). Methane and Nitrous Oxide, The NOAA Annual greenhouse gas index(AGGI) Greenhouse gas-Figure 2 (http://www.esrl.noaa.gov/gmd/ccgg/aggi.html), (updated 2014-03).
16. A., Picard, R.S., Davis, M., Gläser and K., Fujii (2008), Revised formula for the density of moist air (CIPM-2007), Metrologia 45 (2008) 149–155 doi:10.1088/0026-1394/45/2/004, pg 151 Table 1
17. S. Herrmann, H.-J. Kretzschmar, and D.P. Gatley (2009), ASHRAE RP-1485 Final Report Thermodynamic Properties of Real Moist Air,Dry Air, Steam, Water, and Ice pg 16 Table 2.1 and 2.2
18. Thomas W. Schlatter (2009), Atmospheric Composition and Vertical Structure pg 15 Table 2
19. ICAO, Manual of the ICAO Standard Atmosphere (extended to 80 kilometres (262 500 feet)), Doc 7488-CD, Third Edition, (1993), ISBN 92-9194-004-6. pg E-x Table B
20. U.S. Committee on Extension to the Standard Atmosphere (COESA) (1976) U.S. Standard Atmosphere, 1976 pg 03 Table 3
21. Wallace, John M. and Peter V. Hobbs. Atmospheric Science; *An Introductory Survey*.Elsevier. Second Edition, 2006. ISBN 13:978-0-12-732951-2. Chapter 1


## External links

- Conversions of density units ρ by Sengpielaudio (http://www.sengpielaudio.com/ConvDensi.htm)
- Air density and density altitude calculations and by Richard Shelquist (http://wahiduddin.net/calc/density_altitude.htm)
- Air density calculations by Sengpielaudio (section under Speed of sound in humid air) (http://www.sengpielaudio.com/calculator-airpressure.htm)
- Air density calculator by Engineering design encyclopedia (http://www.enggcyclopedia.com/calculators/physical-properties/air-density-calculator/)
- Atmospheric pressure calculator by wolfdynamics (http://www.wolfdynamics.com/tools/atmospheric-pressure-calculator.html/)
- Air iTools - Air density calculator for mobile by JSyA (https://itunes.apple.com/en/app/air-itools/id598469643?mt=8)