

# Atmosphere

Earth's atmosphere is a layer of gases surrounding the planet Earth and retained by the Earth's gravity. It contains roughly 78% *nitrogen* and 21% *oxygen*, with trace amounts of other gases. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation and reducing temperature extremes between day and night.

The atmosphere has no abrupt cut-off. It slowly becomes thinner and fades away into space. There is no definite boundary between the atmosphere and outer space. Three-quarters of the atmosphere's mass is within 11 km of the planetary surface. In the United States, persons who travel above an altitude of 50.0 miles (80.5 km) are designated as astronauts. An altitude of 120 km (75 mi or 400,000 ft) marks the boundary where atmospheric effects become noticeable during re-entry. The Karman line, at 100 km (62 mi), is also frequently used as the boundary between atmosphere and space.

## Temperature and the atmospheric layers

The temperature of the Earth's atmosphere varies with altitude; the mathematical relationship between temperature and altitude varies between the different atmospheric layers:

- troposphere: From the ***Greek*** word tropos meaning to turn or mix. The troposphere is the lowest layer of the atmosphere starting at the surface going up to between 7 km at the poles and 17 km at the equator with some variation due to weather factors. The troposphere has a great deal of vertical mixing due to solar heating at the surface. This heating warms air masses, which then rise to release latent heat as sensible heat that further buoys the air mass. This process continues until all water vapor is removed. In the troposphere, on average, temperature decreases with height due to expansive cooling.
- stratosphere: from that 7–17 km range to about 50 km, temperature increasing with height.
- mesosphere: from about 50 km to the range of 80 km to 85 km, temperature decreasing with height.
- thermosphere: from 80–85 km to 640+ km, temperature increasing with height.

The boundaries between these regions are named the tropopause, stratopause, and mesopause. The average temperature of the atmosphere at the surface of earth is 14 °C.

## Various atmospheric regions

Atmospheric regions are also named in other ways:

- ionosphere – the region containing ions: approximately the mesosphere and thermosphere up to 550 km.
- exosphere – above the ionosphere, where the atmosphere thins out into space. This is the last major atmosphere
- magnetosphere – the region where the Earth's magnetic field interacts with the solar wind from the Sun. It extends for tens of thousands of kilometers, with a long tail away from the Sun.
- ozone layer – or ozonosphere, approximately 10 - 50 km, where stratospheric ozone is found. Note that even within this region, ozone is a minor constituent by volume.

- upper atmosphere – the region of the atmosphere above the mesopause.
- Van Allen radiation belts – regions where particles from the Sun become concentrated.

### Pressure

Atmospheric pressure is a direct result of the weight of the air. This means that air pressure varies with location and time because the amount (and weight) of air above the earth varies with location and time. Atmospheric pressure drops by ~50% at an altitude of about 5 km (equivalently, about 50% of the total atmospheric mass is within the lowest 5 km). The average atmospheric pressure, at sea level, is about 101.3 kilopascals (about 14.7 pounds per square inch).

### Thickness of the atmosphere

Although the atmosphere exists at heights of 1000 km and more, it is so thin as to be considered nonexistent.

- 57.8% of the atmosphere is below the summit of Mount Everest.
- 72% of the atmosphere is below the common flight height of airplanes, (about 10000 m or 32800 ft).
- 99.99999% of the atmosphere is below the highest X-15 plane flight on August 22, 1963 which reached an altitude of 354,300 ft or 108 km.

Therefore, most of the atmosphere is below 100 km (99.9999%) although in the rarified region above this there are auroras, and other atmospheric effects.

### Composition

Composition of Earth's atmosphere.

Percent composition of  
dry atmosphere, by volume

ppmv: parts per million by volume

Gas	Volume
Nitrogen (N <sub>2</sub> )	78.084%
Oxygen (O <sub>2</sub> )	20.946%
Argon (Ar)	0.9340%
Carbon dioxide (CO <sub>2</sub> )	365 ppmv
Neon (Ne)	18.18 ppmv
Helium (He)	5.24 ppmv
Methane (CH <sub>4</sub> )	1.745 ppmv
Krypton (Kr)	1.14 ppmv
Hydrogen (H <sub>2</sub> )	0.55 ppmv

Not included in above dry atmosphere:

Water vapor (highly variable) typically 1%

Source for figures above: NASA. Carbon dioxide and methane updated (to 1998) by IPCC TAR table 6.1 [1]. The NASA total was 17 ppmv over 100%, and CO<sub>2</sub> was increased here by 15 ppmv. To normalize, N<sub>2</sub> should be reduced by about 25 ppmv and O<sub>2</sub> by about 7 ppmv.

Minor components of air not listed above include:

Gas	Volume
nitrous oxide	0.5 ppmv
xenon	0.09 ppmv
ozone	0.0 to 0.07 ppmv (0.0 to 0.02 ppmv in winter)
nitrogen dioxide	0.02 ppmv
iodine	0.01 ppmv
carbon monoxide	trace
ammonia	trace

- The mean molecular mass of air is 28.97 g/mol.

### Heterosphere

Below the turbopause at an altitude of about 100 km, the Earth's atmosphere has a more-or-less uniform composition (apart from water vapor) as described above; this constitutes the homosphere. However, above about 100 km, the Earth's atmosphere begins to have a composition which varies with altitude. This is essentially because, in the absence of mixing, the density of a gas falls off exponentially with increasing altitude, but at a rate which depends on the molecular mass. Thus higher mass constituents, such as oxygen and nitrogen, fall off more quickly than lighter constituents such as helium, molecular hydrogen, and atomic hydrogen. Thus there is a layer, called the heterosphere, in which the earth's atmosphere has varying composition. As the altitude increases, the atmosphere is dominated successively by helium, molecular hydrogen, and atomic hydrogen. The precise altitude of the heterosphere and the layers it contains varies significantly with temperature.

### Density and mass

The density of air at sea level is about 1.2 kg/m<sup>3</sup>. Natural variations of the barometric pressure occur at any one altitude as a consequence of weather. This variation is relatively small for inhabited altitudes but much more pronounced in the outer atmosphere and space due to variable solar radiation.

The atmospheric density decreases as the altitude increases. This variation can be approximately modeled using the barometric formula. More sophisticated models are used by meteorologists and space agencies to predict weather and orbital decay of satellites.

The average mass of the atmosphere is about 5,000 trillion metric tons. According to the National Center for Atmospheric Research, "The total mean mass of the atmosphere is  $5.1480 \times 10^{18}$  kg with an annual range due to water vapor of  $1.2$  or  $1.5 \times 10^{15}$  kg depending on whether surface pressure or water vapor data are used; somewhat smaller than the previous estimate. The mean mass of water vapor is estimated as  $1.27 \times 10^{16}$  kg and the dry air mass as  $5.1352 \pm 0.0003 \times 10^{18}$  kg."

The above composition percentages are done by volume. Assuming that the gases act like ideal gases, we can add the percentages  $p$  multiplied by their molar masses  $m$ , to get a total  $t = \text{sum}(p \cdot m)$ . Any element's percent by mass is then  $p \cdot m / t$ . When we do this to the above percentages, we get that, by mass, the composition of the atmosphere is 75.523% nitrogen, 23.133% oxygen, 1.288% argon, 0.053% carbon dioxide, 0.001267% neon, 0.00029% methane, 0.00033% krypton, 0.000724% helium, and 0.0000038 % hydrogen.

### **The evolution of the Earth's atmosphere**

The history of the Earth's atmosphere prior to one billion years ago is poorly understood, but the following presents a plausible sequence of events. This remains an active area of research.

The modern atmosphere is sometimes referred to as Earth's "third atmosphere", in order to distinguish the current chemical composition from two notably different previous compositions. The original atmosphere was primarily helium and hydrogen. Heat (from the still-molten crust, and the sun) dissipated this atmosphere.

About 3.5 billion years ago, the surface had cooled enough to form a crust, still heavily populated with volcanoes which released steam, carbon dioxide, and ammonia. This led to the "second atmosphere", which was primarily carbon dioxide and water vapor, with some nitrogen but virtually no oxygen (though very recent simulations run at the University of Waterloo and University of Colorado in 2005 suggested that it may have had up to 40% hydrogen). This second atmosphere had approximately 100 times as much gas as the current atmosphere. It is generally believed that the greenhouse effect, caused by high levels of carbon dioxide, kept the Earth from freezing.

During the next few billion years, water vapor condensed to form rain and oceans, which began to dissolve carbon dioxide. Approximately 50% of the carbon dioxide would be absorbed into the oceans. One of the earliest types of bacteria were the cyanobacteria. Fossil evidence indicates that these bacteria existed approximately 3.3 billion years ago and were the first oxygen-producing evolving phototropic organisms. They were responsible for the initial conversion of the earth's atmosphere from an anoxic state to an oxic state (that is, from a state without oxygen to a state with oxygen). Being the first to carry out oxygenic photosynthesis, they were able to convert carbon dioxide into oxygen, playing a major role in oxygenating the atmosphere.

Photosynthesizing plants would later evolve and convert more carbon dioxide into oxygen. Over time, excess carbon became locked in fossil fuels, sedimentary rocks (notably limestone), and animal shells. As oxygen was released, it reacted with ammonia to create nitrogen; in addition, bacteria would also convert ammonia into nitrogen.

As more plants appeared, the levels of oxygen increased significantly, while carbon dioxide levels dropped. At first the oxygen combined with various elements (such as iron), but eventually oxygen accumulated in the atmosphere, resulting in mass extinctions and further evolution. With the appearance of an ozone layer (ozone is an allotrope of oxygen) lifeforms were better protected from ultraviolet radiation. This oxygen-nitrogen atmosphere is the "third atmosphere".