

Q1

What is ozone, how is it formed, and where is it in our atmosphere?

Ozone is a gas that is naturally present in our atmosphere. Each ozone molecule contains three atoms of oxygen and is denoted chemically as O_3 . Ozone is found primarily in two regions of the atmosphere. About 10% of Earth's ozone is in the troposphere, which extends from the surface to about 10–15 kilometers (6–9 miles) altitude. About 90% of Earth's ozone resides in the stratosphere, the region of the atmosphere between the top of the troposphere and about 50 kilometers (31 miles) altitude. The part of the stratosphere with the highest amount of ozone is commonly referred to as the "ozone layer". Throughout the atmosphere, ozone is formed in multistep chemical processes that are initiated by sunlight. In the stratosphere, the process begins with an oxygen molecule (O_2) being broken apart by ultraviolet radiation from the Sun. In the troposphere, ozone is formed by a different set of chemical reactions that involve naturally occurring gases as well as those from sources of air pollution.

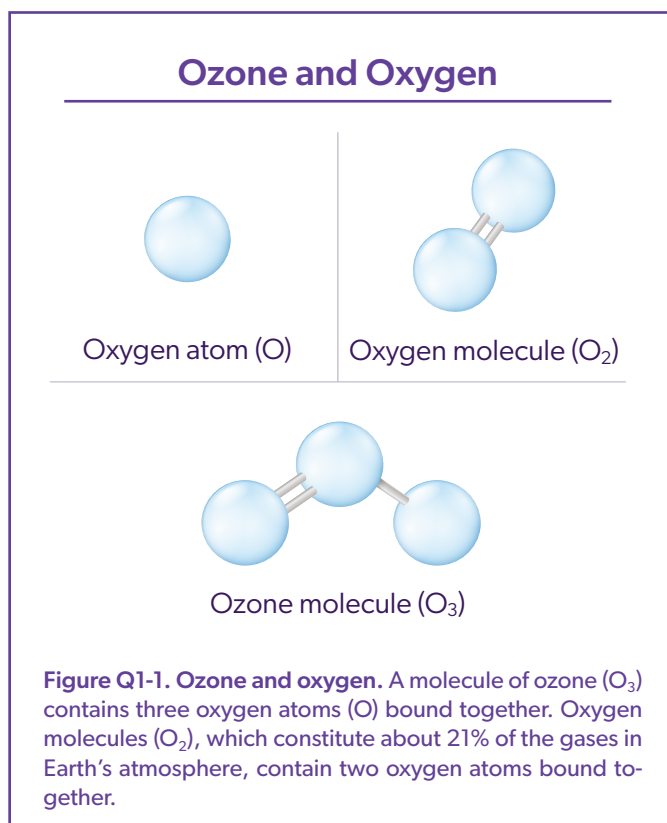
Ozone is a gas that is naturally present in our atmosphere. Ozone has the chemical formula O_3 because an ozone molecule contains three oxygen atoms (see **Figure Q1-1**). Ozone was discovered in laboratory experiments in the mid-1800s. Ozone's presence in the atmosphere was later discovered using chemical and optical measurement methods. The word ozone is derived from the Greek word *ὄζειν* (*ozein*), meaning "to smell." Ozone has a pungent odor that allows it to be detected even at very low amounts. Ozone reacts rapidly with many chemical compounds and is explosive in concentrated amounts. Electrical discharges are generally used to produce ozone for industrial processes such as air and water purification and bleaching of textiles and food products.

Ozone location. Most ozone (about 90%) is found in the stratosphere, which begins about 10–15 kilometers (km) above Earth's surface and extends up to about 50 km altitude. The stratospheric region with the highest concentration of ozone, between about 15 and 35 km altitude, is commonly known as the "ozone layer" (see **Figure Q1-2**). The stratospheric ozone layer extends over the entire globe, with some variation in its altitude and thickness. Most of the remaining ozone (about 10%) is found in the troposphere, which is the lowest region of the atmosphere, between Earth's surface and the stratosphere. Tropospheric air is the "air we breathe" and, as such, excess ozone in the troposphere has harmful consequences (see Q2).

Ozone abundance. Ozone molecules constitute a small fraction of the gas molecules in the atmosphere. Most air molecules are either oxygen (O_2) or nitrogen (N_2). In the stratosphere, near the peak concentration of the ozone layer, there are typically a few thousand ozone molecules for every *billion* air molecules (1 billion = 1,000 million). In the troposphere near Earth's surface, ozone is even less abundant, with a typical range of 20 to 100 ozone molecules for each billion air molecules. The highest ozone values near the surface occur in air that is polluted by human activities. Throughout this document the word "abundance" refers to the concentration or amount of an atmospheric gas or some other physical quantity.

As an illustration of the low relative abundance of ozone in our

atmosphere, one can imagine bringing all the ozone molecules in the troposphere and stratosphere down to Earth's surface and forming a layer of pure ozone that extends over the entire globe. The resulting layer would have an average thickness of about three millimeters (0.12 inches), which scientists would report as 300 Dobson Units (see Q3). Nonetheless, this extremely small fraction of the atmosphere plays a vital role in protecting life on Earth (see Q2).



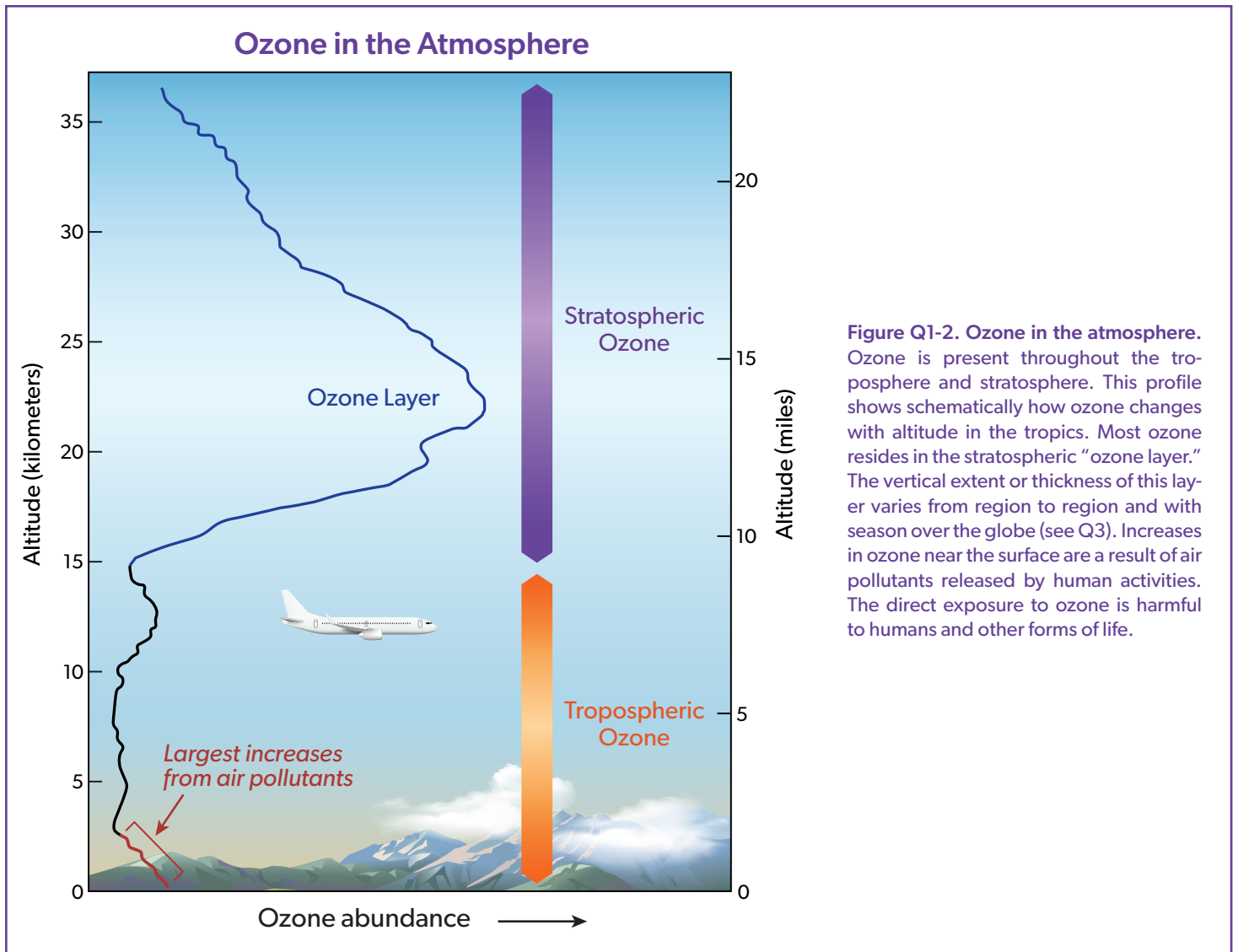


Figure Q1-2. Ozone in the atmosphere. Ozone is present throughout the troposphere and stratosphere. This profile shows schematically how ozone changes with altitude in the tropics. Most ozone resides in the stratospheric “ozone layer.” The vertical extent or thickness of this layer varies from region to region and with season over the globe (see Q3). Increases in ozone near the surface are a result of air pollutants released by human activities. The direct exposure to ozone is harmful to humans and other forms of life.

Stratospheric ozone. Stratospheric ozone is formed naturally by chemical reactions involving solar ultraviolet radiation (sunlight) and oxygen molecules, which make up about 21% of the atmosphere. In the first step, solar ultraviolet radiation breaks apart one oxygen molecule (O_2) to produce two oxygen atoms ($2 O$) (see **Figure Q1-3**). In the second step, each of these highly reactive oxygen atoms combines with an oxygen molecule to produce an ozone molecule (O_3). These reactions occur continually whenever solar ultraviolet radiation is present in the stratosphere. As a result, the largest ozone production occurs in the tropical stratosphere.

The production of stratospheric ozone is balanced by its destruction in chemical reactions. Ozone reacts continually with sunlight and a wide variety of natural and human-produced chemicals in the stratosphere. In each reaction, an ozone molecule is lost and other chemical compounds are produced. Important reactive gases that destroy ozone are hydrogen and nitrogen oxides and those containing chlorine and bromine (see Q7). Some stratospheric ozone is regularly transported down into the troposphere and can occasionally influence ozone amounts at Earth’s surface.

Tropospheric ozone. Near Earth’s surface, ozone is produced by chemical reactions involving gases emitted into the atmosphere from both natural sources and human activities. Ozone production in the troposphere primarily occurs by reactions of hydrocarbon and nitrogen oxide gases, and all require sunlight for completion. Fossil fuel combustion and deforestation are the primary sources of pollutant gases that lead to production of tropospheric ozone. As in the stratosphere, ozone in the troposphere is destroyed by naturally occurring chemical reactions and by reactions involving human-produced chemicals. Tropospheric ozone can also be destroyed when ozone reacts with a variety of surfaces, such as those of soils and plants.

Balance of chemical processes. Ozone abundances in the stratosphere and troposphere are determined by the balance between chemical processes that produce and destroy ozone. The balance is determined by the amounts of reactive gases and how the rate or effectiveness of the various reactions varies with sunlight intensity, location in the atmosphere, temperature, and other factors. As atmospheric conditions change to favor ozone-producing

reactions in a certain location, ozone abundances increase. Similarly, if conditions change to favor other reactions that destroy ozone, abundances decrease. The balance of production and loss reactions, combined with atmospheric air motions that transport and mix air with different ozone abundances, determines the glob-

al distribution of ozone on timescales of days to many months (see also Q3). Global stratospheric ozone decreased from the 1970s to the late 1990s (see Q12 and Q13) because the amounts of reactive gases containing chlorine and bromine in the stratosphere increased due to human activities (see Q6 and Q15).

