EARTH • ATMOSPHERE • CHEMISTRY

$O_3$

# Ozone

*A complete guide to the molecule that shields life on Earth — its chemistry, its layer in the sky, its role at ground level, and the story of how humanity healed a hole in the sky.*

A ScholarEye Reader

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# 1 What Is Ozone?

> *Ozone is a pale blue gas made of three oxygen atoms bonded together, written chemically as $O_3$. It is both a protector and a pollutant — depending entirely on where in the atmosphere it is found.*

Ozone is a naturally occurring form of oxygen. While the oxygen we breathe consists of two oxygen atoms joined together ($O_2$), ozone is made of three oxygen atoms joined in a bent, triangular shape. This small difference in structure gives ozone completely different properties from the oxygen we rely on for breathing.

At room temperature, ozone is a gas with a sharp, distinctive smell — in fact, its name comes from the Greek word "ozein," meaning "to smell." You may have noticed this odor after a lightning storm, near electrical equipment, or around photocopiers; that sharp, clean scent in the air is ozone.

Ozone exists in two very different parts of Earth's atmosphere, and its effect on life depends entirely on its location:

### Good Ozone (Stratosphere)

Found 15–35 km above the Earth, this ozone forms a protective layer that absorbs the sun's harmful ultraviolet radiation, shielding all life below.

### Bad Ozone (Troposphere)

Found near the ground, this ozone is a harmful air pollutant formed by chemical reactions between pollutants and sunlight.

## 2 The Structure and Chemistry of Ozone

An ozone molecule is composed of three oxygen atoms arranged in a bent, V-shaped structure rather than a straight line. The bond angle between the atoms is approximately 116.8 degrees. This bent shape makes ozone a polar molecule, meaning it has a slightly uneven distribution of electric charge across it.

Ozone is far less stable than ordinary oxygen. It readily breaks apart into a molecule of oxygen ($O_2$) and a single, highly reactive oxygen atom. This reactive atom is what makes ozone such a powerful oxidizing agent — it is eager to react with other substances, which is the very property that allows it to absorb ultraviolet radiation, kill bacteria, and also damage lung tissue and plant life.

$O_3 \rightarrow O_2 + O$ (ozone breaks down into oxygen and a reactive oxygen atom)

| Property | Detail |
|---|---|
| Chemical formula | $O_3$ |
| Molar mass | Approximately 48 grams per mole |
| Color | Pale blue (as a gas); deep blue as a liquid |
| Smell | Sharp, pungent, "electric" odor |
| Stability | Unstable; readily decomposes into $O_2$ |

| | |
|---|---|
| Molecular shape | Bent (V-shaped), bond angle ≈ 116.8° |

## 3 How Ozone Forms in Nature

Ozone forms naturally whenever oxygen molecules are exposed to a strong source of energy that can split them apart. The two most important natural sources of this energy are ultraviolet radiation from the sun and electrical discharges such as lightning.

- **Ultraviolet radiation:** High in the stratosphere, sunlight splits $O_2$ molecules into individual oxygen atoms. These atoms then collide with other $O_2$ molecules to form $O_3$.
- **Lightning and electrical discharge:** Near the ground, the energy from a lightning strike can also split oxygen molecules, producing small, short-lived amounts of ozone — this is the source of the "fresh" smell after a thunderstorm.

**Did You Know?**

Roughly 90 percent of all the ozone in Earth's atmosphere is found in the stratosphere, forming what we call the ozone layer, while only about 10 percent exists closer to the ground.

## 4 The Ozone Layer

The ozone layer is a region of the stratosphere, roughly 15 to 35 kilometers above the Earth's surface, where ozone concentration is naturally much higher than elsewhere in the atmosphere. Although the ozone here is still a trace gas — making up only a few parts per million of the surrounding air — it is concentrated enough to absorb the majority of the sun's biologically damaging ultraviolet-B and ultraviolet-C radiation.

Without this layer, the intensity of ultraviolet radiation reaching the Earth's surface would rise dramatically, posing serious risks to skin, eyes, immune systems, and the plants and marine organisms that form the base of the food chain.

### Why the Ozone Layer Matters

It absorbs about 97 to 99 percent of the sun's harmful ultraviolet radiation before it reaches the ground, making it one of the essential conditions that allows complex life to exist on land.

## 5 The Ozone-Oxygen Cycle (Chapman Cycle)

The continuous creation and destruction of ozone in the stratosphere is described by a natural process known as the Chapman cycle, named after the scientist Sydney Chapman, who first described it in 1930. This cycle keeps the amount of ozone in the stratosphere in a rough, dynamic balance.

The cycle happens in four basic steps:

1. **Splitting:** Ultraviolet radiation breaks an oxygen molecule ($O_2$) into two single oxygen atoms.
2. **Formation:** A single oxygen atom collides with an intact $O_2$ molecule, forming ozone ($O_3$).
3. **Absorption:** Ozone absorbs incoming ultraviolet radiation, which breaks it back apart into $O_2$ and a single oxygen atom, releasing heat in the process.
4. **Recombination:** The freed oxygen atom may combine with another ozone molecule to form two $O_2$ molecules, or the cycle repeats.

This constant formation and breakdown of ozone is precisely what makes the ozone layer such an effective shield — every time ozone absorbs ultraviolet light and breaks apart, it prevents that radiation from reaching the Earth's surface, and new ozone is continually formed to replace it.

## 6 Measuring Ozone: Dobson Units

Scientists measure the total amount of ozone in a column of the atmosphere using a unit called the Dobson Unit (DU), named after G. M. B. Dobson, a pioneer of atmospheric ozone research. One Dobson Unit represents a very thin layer of pure ozone — just 0.01 millimeters thick — if all the ozone in that column were compressed to ground-level pressure and temperature.

Typical ozone levels around the globe range between 300 and 500 Dobson Units, though this varies by season and latitude. A reading below approximately 220 Dobson Units is generally considered a sign of significant depletion, and this threshold is commonly used to define the boundary of the Antarctic ozone hole.

## 7 Ozone Depletion and the Ozone Hole

Beginning in the mid-twentieth century, scientists observed that the ozone layer was thinning, particularly over Antarctica, where a dramatic seasonal thinning became known as the "ozone hole." This depletion was traced to human-made chemicals released into the atmosphere, most notably chlorofluorocarbons, or CFCs.

### What Causes Ozone Depletion

CFCs were widely used in the twentieth century in refrigerators, air conditioners, aerosol sprays, and foam packaging because they were stable, non-flammable, and inexpensive.

However, that same stability allowed them to drift, largely unchanged, all the way up into the stratosphere. Once there, ultraviolet radiation breaks CFC molecules apart, releasing chlorine atoms.

A single chlorine atom can destroy tens of thousands of ozone molecules through a repeating chain reaction, because the chlorine is regenerated at the end of each reaction and goes on to destroy more ozone. Bromine, released from related compounds called halons, acts in a similarly destructive way.

$$Cl + O_3 \rightarrow ClO + O_2 \qquad ClO + O \rightarrow Cl + O_2$$

### Why Antarctica Is Hit Hardest

Each Southern Hemisphere spring, extremely cold temperatures over Antarctica cause polar stratospheric clouds to form. These icy clouds provide surfaces on which chlorine compounds are converted into forms that rapidly destroy ozone once sunlight returns in September and October, producing the seasonal ozone hole.

**A Global Concern**

Ozone depletion allows more ultraviolet radiation to reach the Earth's surface, increasing risks of skin cancer and cataracts in humans, and harming crops, forests, and ocean phytoplankton — the tiny organisms that form the base of the marine food chain.

## 8 The Montreal Protocol — Healing the Sky

In 1987, nations around the world came together to sign the Montreal Protocol, an international treaty designed to phase out the production and use of ozone-depleting substances. It is widely regarded as one of the most successful environmental agreements in history.

- It has been ratified by every member state of the United Nations, making it a rare example of truly universal international cooperation.
- Production of major ozone-depleting chemicals, including CFCs and halons, has been almost entirely eliminated worldwide.
- Scientific assessments show the ozone layer is now on a path to recovery, with the Antarctic ozone hole expected to return to pre-1980 levels around the middle of this century.

> *"The Montreal Protocol stands as proof that when the world unites around clear scientific evidence, even a global environmental crisis can be turned around."*

## 9 Ground-Level (Tropospheric) Ozone

Unlike the protective ozone high in the stratosphere, ozone that forms near the ground is considered a harmful air pollutant. It is not emitted directly but instead forms through a chemical reaction between nitrogen oxides and volatile organic compounds, in the presence of sunlight. Because sunlight drives the reaction, ground-level ozone tends to peak on hot, sunny afternoons and is a major component of urban smog.

Common sources of the pollutants that create ground-level ozone include:

- Vehicle exhaust from cars, trucks, and buses
- Emissions from power plants and industrial facilities
- Chemical solvents, paints, and certain consumer products
- Gasoline vapors and fuel combustion

# 10 Health and Environmental Effects

## Effects on Human Health

Breathing ground-level ozone, even at relatively low concentrations, can irritate the respiratory system. It can trigger coughing, throat irritation, chest discomfort, and worsened symptoms for people with asthma or other lung conditions. Repeated exposure over time may contribute to longer-term reductions in lung function, and outdoor workers, children, and the elderly are typically the most vulnerable groups.

## Effects on Plants and Ecosystems

Ground-level ozone can also damage vegetation. It interferes with photosynthesis, causes visible leaf damage, and can reduce crop yields for sensitive plants such as wheat, soybeans, and certain trees, making it a concern for both agriculture and natural ecosystems.

## Effects of Stratospheric Depletion

By contrast, a thinning of the protective stratospheric ozone layer allows more ultraviolet radiation to reach the surface, which is associated with increased rates of skin cancer, cataracts, and weakened immune responses in humans, along with harm to sensitive aquatic organisms.

# 11 Everyday Uses of Ozone

Despite its reputation as a pollutant at ground level, ozone's strong oxidizing power also makes it genuinely useful in controlled, industrial settings:

| Application | How Ozone Is Used |
|---|---|
| Water treatment | Disinfects drinking water by killing bacteria, viruses, and parasites without leaving chemical residues |
| Air and surface purification | Used in controlled industrial systems to deodorize air and sanitize surfaces |
| Food industry | Applied to wash and sanitize fruits, vegetables, and food-processing equipment |
| Bleaching | Used in some pulp and paper processing as an alternative to chlorine-based bleaching |
| Medical and laboratory use | Used in some sterilization and wound-care applications for its antimicrobial properties |

## 12 Ozone and Climate Change

Ozone and climate change are closely connected in more than one way. Stratospheric ozone depletion and climate change are driven by different chemicals, but many ozone-depleting substances, including CFCs, are also potent greenhouse gases, meaning the Montreal Protocol has delivered significant climate benefits alongside its ozone protection.

At the same time, ground-level ozone itself acts as a short-lived greenhouse gas, contributing to warming in addition to its role as an air pollutant. Climate change can also influence stratospheric temperatures and circulation patterns, which in turn affect the rate of ozone formation and depletion, showing how interconnected these atmospheric systems truly are.

## 13 Interesting Facts About Ozone

- Ozone was first identified in 1839 by the German-Swiss chemist Christian Friedrich Schönbein, who named it after the Greek word for "smell."
- If all the ozone in the atmosphere were compressed to sea-level pressure, it would form a layer only about three millimeters thick.
- The Antarctic ozone hole was first identified in 1985 by British Antarctic Survey scientists, sparking global scientific and political action.
- Ozone is also found on other planets and moons in the solar system, including in the atmospheres of Mars and some of Jupiter's moons.
- Ozone's smell is detectable by the human nose at extremely low concentrations, long before it reaches harmful levels.

## 14 Conclusion

Ozone is a striking example of how the very same molecule can be both a life-saving shield and a harmful pollutant, depending entirely on where it exists in the atmosphere. High above us, in the stratosphere, it quietly absorbs the sun's most damaging radiation, making life on land possible. Near the ground, formed from pollution, it becomes a health hazard and environmental stressor.

The story of the ozone layer is also, in many ways, a hopeful one. It shows what focused scientific understanding and coordinated global action, through agreements like the Montreal Protocol, can achieve in the face of a genuine planetary threat. As the ozone layer continues its slow recovery, it stands as a reminder that environmental damage, even on a global scale, is not necessarily irreversible.

— End of Guide —

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