

# 1. Ozone Layer and Ozone Depletion

## 1.1. Ozone Layer: Introduction and Need

- Ozone (O<sub>3</sub>) is an **allotrope of oxygen**.
- **About 90%** of the ozone in the atmosphere is contained in the **stratosphere** (the region from about 10 to 50-km), with the **highest concentrations between about 20 and 40 km**.
  - This high concentration belt is called the Ozone Layer [**discovered in 1913** by Charles Fabry and Henri Buisson & properties explored by G.M.B. Dobson].
- Ozone layer is essential for all life forms on the earth. It can **absorb** two of the most **harmful types of UV rays**, viz. UV-B and UV-C.

## 1.2. Types of UV (Ultraviolet) rays

UV rays	Wavelength	Impact	Absorption Level
UVA	315- 399 nm	<ul style="list-style-type: none"><li>• Least harmful.</li><li>• Can contribute to the aging of skin, DNA damage and possibly skin cancer.</li></ul>	Not absorbed by the ozone layer. Its Ozone Layer penetration is almost 100%.
UVB	280-314 nm	<ul style="list-style-type: none"><li>• Hazardous to the eyes, cause Welder's Flash.</li><li>• Damage collagen fibers thereby accelerate aging of the skin.</li><li>• Also linked to skin cancers such as melanoma.</li><li>• Causes DNA damage by generating Thymine dimers.</li><li>• Cause distortion of the DNA helix leading to mutations.</li><li>• Impairs photosynthesis in many species. Reduces size, productivity, and quality in many of the crop plant species.</li></ul>	It is absorbed ~95% by the Ozone Layer.
UVC	100-279 nm	<ul style="list-style-type: none"><li>• Highest energy, most dangerous type.</li><li>• Can cause severe burns of the skin and eye injuries.</li></ul>	It is absorbed ~100% by the Ozone Layer.

## 1.3. Formation of Ozone Layer

- Ozone is formed in the atmosphere when ultraviolet radiation from the Sun splits one oxygen molecule into two oxygen atoms (O<sub>2</sub>).

- The atomic oxygen then combines with another oxygen molecule to form ozone (O<sub>3</sub>).

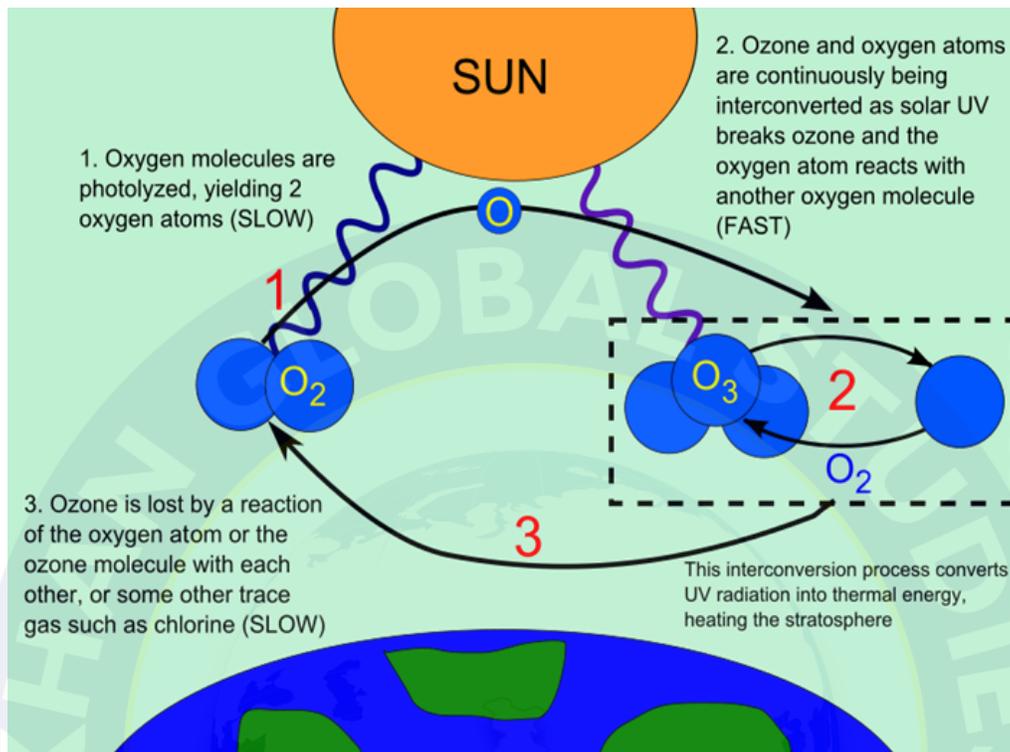


Figure.1. Ozone Formation - Destruction Cycle

#### 1.4. Degradation of the Ozone Layer

- Ozone can be destroyed by a number of **free radical catalysts**, like hydroxyl radical (OH·), nitric oxide radical (NO·), atomic chlorine ion (Cl·) and bromine ion (Br·).
- Most of the OH· and NO· in the stratosphere is of natural origin, but human activity has dramatically increased the levels of chlorine and bromine.
- These elements are found in certain stable organic compounds, especially chlorofluorocarbons (CFCs), which may find their way to the stratosphere without being destroyed in the troposphere **due to their low reactivity**.
- Once in the stratosphere, the Cl and Br atoms are **liberated from the parent compounds** by the action of ultraviolet light, e.g.  $\text{CFCI}_3 + \text{electromagnetic radiation} \rightarrow \text{CFCI}_2 + \text{Cl}$ .
- The Cl and Br atoms can then destroy ozone molecules through a variety of catalytic cycles.
- For example, a chlorine atom reacts with an ozone molecule, taking an oxygen atom with it (forming ClO) and leaving a normal oxygen molecule.
- The chlorine monoxide (i.e., the ClO) can react with a second molecule of ozone (i.e., O<sub>3</sub>) to yield another chlorine atom and two molecules of oxygen.
- The chemical shorthand for these gas-phase reactions is:
  - $\text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2$
  - $\text{ClO} + \text{O}_3 \rightarrow \text{Cl} + 2 \text{O}_2$

- A single chlorine atom would keep on destroying ozone for up to two years (the time scale for transport back down to the troposphere).
- However, certain reactions remove Cl atoms from this cycle by forming reservoir species such as hydrogen chloride (HCl) and chlorine nitrate (ClONO<sub>2</sub>).
- On a per atom basis, bromine is even more efficient than chlorine at destroying ozone, but there is much less bromine in the atmosphere at present.
- Both chlorine and bromine contribute significantly to the overall ozone depletion. Each Cl / Br atom breaks down ~100,000 ozone molecules.

### 1.5. Formation of Ozone Hole

- The ozone hole is the region over Antarctica with a total ozone of **220 Dobson Units or lower**.
  - The Dobson Unit is the most common unit for measuring ozone concentration.
  - The average amount of ozone in the atmosphere is roughly 300 Dobson Units, equivalent to a layer 3 millimeters (0.12 inches) thick.
- A combination of factors is needed to produce the large loss of ozone over Antarctica.
- A first step is that the stratosphere over Antarctica becomes isolated by strong westerly circumpolar winds of up to 100 m/s (up to about 200 knots) during the polar night.
- The temperature drop is such that a special type of cloud, known as a **polar stratospheric cloud (PSC)**, can form at temperatures below about -80° C (-112° F).
- Very fast chemical reactions occur on the surface of these clouds, converting inactive forms of chlorine to molecular chlorine (Cl<sub>2</sub>).
- When sunlight returns in September, **catalytic cycles involving chlorine atoms become active** and destroy the ozone.
- NASA atmosphere scientists reported the biggest ever Antarctic ozone hole (in mean size) in 2006.
- During the peak of the ozone depletion season from September 7 to October 13, the hole in the year 2023 averaged 8.9 million square miles (23.1 million square kilometers), approximately the size of North America.
- The **size and thickness** of the ozone hole **varies from year to year**, becoming larger when temperatures are lower.
- No similar ozone hole has yet been seen in the Arctic because the meteorological conditions in spring are very different from those in the southern hemisphere and much warmer.
- Further, **circumpolar winds are weaker in the North Pole** region due to high land masses.

- However, there are chlorine molecules in the Arctic stratosphere, and on the occasions that temperatures decrease enough to favour ozone depletion, chemical ozone destruction can also take place in the Arctic.

## 1.6. Consequences of the Ozone Hole

- **Increase in UV-B radiation at ground level:** a one percent loss of ozone leads to a two percent increase in UV radiation.
- Continuous exposure to UV radiation affects humans, animals and plants, and can lead to **skin problems, depression of the immune system, and corneal cataracts.**
- Increased UV radiation may also lead to a **massive die-off of phytoplankton** (a CO<sub>2</sub> "sink") and therefore to increased global warming.
- UV-C exposure can destroy the microbial diversity, many members of which are immensely beneficial to humans.
- **Disturbance of the thermal structure** of the atmosphere, probably results in changes in atmospheric circulation.
- Ozone is considered to be a **greenhouse gas**. Tropospheric ozone (O<sub>3</sub>) is the third most important anthropogenic greenhouse gas after carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>).
- Ozone close to the Earth's surface is a health hazard, as it is one of the major constituents of **photochemical smog**.

## 2. Efforts to protect the Ozone Layer: Vienna Convention and Montreal Protocol

### 2.1. Vienna Convention

- The Vienna Conference in 1985 was the first international conference on ozone layer depletion.
- It was held after a hole in the stratospheric ozone layer was observed in the South Pole by a British team.
- In this conference, the Vienna Convention for the Protection of the Ozone Layer was put forward. This convention entered into force in 1988.
- The convention **does not include legally binding** reduction goals for the use of CFCs and other ODS (Ozone Depleting Substances).
- These legally binding reduction goals for ODS are laid out in the Montreal Protocol.

### 2.2. Montreal Protocol on Substances That Deplete the Ozone Layer

#### 2.2.1. What is the Montreal Protocol?

- The Montreal Protocol on Substances That Deplete the Ozone Layer is a **protocol to the Vienna Convention**.
- It is an international treaty to protect the ozone layer by phasing out the ODS across the world.

#### 2.2.2. Adoption

- The treaty was put forward in 1987, and **entered into force on January 1, 1989.**
- The Protocol is to date one of the rare treaties to achieve **universal ratification. India** has been a **Party** to the Montreal Protocol **since June 1992.**

### 2.2.3. Governing Body

- The **Meeting of the Parties** (MOP) is the governance body for the treaty, with technical support provided by an Open-ended Working Group, both of which meet on an annual basis.
- The Parties are assisted by the Ozone Secretariat, which is based at UN Environment Programme **headquarters in Nairobi, Kenya.**

### 2.2.4. Responsibility of Parties

- Under this treaty, all parties have specific responsibilities related to the phase out of the different groups of ODS, control of ODS trade, annual reporting of data, national licensing systems to control ODS imports and exports, and other matters.
- Developing and developed countries have **equal but differentiated responsibilities,** but both groups of countries have binding, time-targeted and measurable commitments.

### 2.2.5. Multilateral Fund

- The Multilateral Fund for the Implementation of the Montreal Protocol was established in **1991 under Article 10** of the treaty.
- The Fund's objective is to provide financial and technical assistance to developing country parties whose annual per capita consumption and production of ODS is less than 0.3 kg.
- The Multilateral Fund's activities are implemented by four international agencies:
  - UN Environment Programme (UNEP)
  - UN Development Programme (UNDP)
  - UN Industrial Development Organisation (UNIDO)
  - World Bank

### 2.2.6. Phase out of HCFCs – the Montreal Amendment

- Hydrochlorofluorocarbons (HCFCs) is nearly 2,000 times more potent than carbon dioxide in terms of its global warming potential (GWP).
- In **September 2007** the Parties decided to accelerate their schedule to phase out HCFCs.
- Developed countries had to reduce their consumption of HCFCs and completely phase them out by 2020.
- Developing countries agreed to start their phase-out process in 2013 and are following a stepwise reduction until the complete phase-out of HCFCs by 2030.

### 2.2.7. Phase down of HFCs – the Kigali Amendment

- Hydrofluorocarbons (HFCs), were introduced as non-ozone depleting alternatives to support the timely phase-out of CFCs and HCFCs.
- While HFCs do not deplete the stratospheric ozone layer, they have high GWPs ranging from 12 to 14,000.
- The Parties to the Montreal Protocol reached an agreement at their 28th Meeting of the Parties on **15 October 2016 in Kigali, Rwanda** to phase down HFCs.
- The amendment will ensure that:
  - The **developed countries**, led by the United States and Europe, will reduce HFC use **by 85 per cent by 2036** over a 2011-13 baseline.
  - A group of **developing countries** including China, Brazil and South Africa are mandated to reduce their HFC use by **85 percent** of their average value in 2020-22 **by the year 2045**.
  - **India and** some other developing countries — Iran, Iraq, Pakistan, and some oil economies like Saudi Arabia and Kuwait — will cut down their HFCs by **85 percent** of their values in 2024-26 **by the year 2047**.

### 2.2.8. India and Montreal Protocol

- India phased out Chlorofluorocarbons, Carbon tetrachloride, Halons, Methyl Bromide and Methyl Chloroform for controlled uses as on 1 January 2010.
- Currently, Hydrochlorofluorocarbons are being phased out as per the accelerated schedule of the Montreal Protocol.
- Hydrochlorofluorocarbons Phase-out Management Plan (HPMP) Stage - I has been successfully implemented from 2012 to 2016.
- Hydrochlorofluorocarbons Phase-out Management Plan (HPMP) Stage - II is under implementation from 2017 and will be completed by 2024.
- Stage III of the HPMP, the **last of the HPMPs**, will be implemented **from 2023 - 2030**.
- The **phase-out of HCFCs in all manufacturing sectors**, comprising refrigeration and air-conditioning manufacturing sectors, will be completed **by January 2025**.
- India will complete its phase down of production and consumption of HFCs for controlled uses in 4 steps from 2032 onwards with cumulative reduction of 10% in 2032, 20% in 2037, 30% in 2042 and 85% in 2047.

### 2.2.9. 35th Meeting of the Parties to the Montreal Protocol (MOP 35)

- MOP 35 was held in Nairobi, Kenya from 23 to 27 October, 2023.
- High on the agenda at the 35th Meeting of Parties was replenishment of the Multilateral Fund (MLF), which exists to support developing countries as they phase out

ozone-depleting substances (ODS) and climate-damaging hydrofluorocarbons (HFCs). Parties agreed on a replenishment of almost \$1 billion.

- This money will be enough to start an accelerated phase-down of HFCs in developing countries, while still supporting the ODS phase-outs and providing funding to tackle additional challenges such as energy efficiency and the recovery and safe destruction of old equipment.
- At the meeting, Parties agreed on a series of decisions to ensure they have all the scientific and technical information needed to tackle ongoing and future threats to ozone layer and climate system.
- These included several decisions requesting updated information from two of the Montreal Protocol's dedicated assessment panels, the Scientific Assessment Panel (SAP), and the Technology & Economic Assessment Panel (TEAP).

### 3. Acid Rain

#### 3.1. Introduction

- Acid rain is a form of precipitation with a **pH level below 5.6**.
- It is caused by the release of **sulphur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>)** into the atmosphere.
- These pollutants can be emitted from both human activities and natural sources.

#### 3.2. Two Types of Acid Precipitation

##### Wet Acid Precipitation

- SO<sub>2</sub> and NO<sub>x</sub> react with water vapor in the atmosphere, forming acids (sulfuric acid, nitric acid).
- Acids incorporated into rain, snow, fog, or other types of precipitation.
- Falls to the ground, acidifying soil and water bodies.
- Damages terrestrial and aquatic ecosystems.

##### Dry Acid Precipitation

- Acidic pollutants (SO<sub>2</sub>, NO<sub>x</sub>, particulate matter such as Ammonium sulfate-(NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> and Ammonium nitrate-NH<sub>4</sub>NO<sub>3</sub>) directly deposited onto the Earth's surface.
- Pollutants settle on vegetation, buildings, soil, and bodies of water.
- Causes damage, corrosion, or contamination.
- Pollutants can be re-suspended in the air and inhaled, posing potential health risks.

#### 3.3. Causes of Acid Rain

### **Anthropogenic Sources**

- Burning of fossil fuels in power plants, factories, and transportation.
- Industrial processes such as metal smelting and coal mining.
- Agricultural practices, including fertilizer and pesticide application.

### **Natural Sources**

- Volcanic eruptions releasing sulphur dioxide and other acidic gases.
- Forest fires emitting nitrogen oxides.
- Lightning generates nitrogen oxides through high-temperature reactions in the atmosphere.

## **3.4. Effects of Acid Rain**

### ***On the Environment***

#### **Terrestrial Ecosystems**

- **Damage to forests:** leaves and needles of trees become susceptible to disease and pests.
- **Leaching** of essential nutrients (calcium, magnesium, potassium) from the soil, hindering plant growth.
- **Mobilization of toxic metals** (aluminum, lead, mercury) in the soil, contaminating groundwater and surface water.

#### **Aquatic Ecosystems**

- **Lowering of pH** in lakes and rivers, negatively affecting fish and aquatic life.
- **Acidification of surface waters** leading to loss of biodiversity and disruption of food chains.
- Increased aluminium concentrations in water, impairing fish gill function and reducing fish populations.

### ***On Human Health***

- **Respiratory problems**, including asthma and bronchitis, due to high levels of sulfur dioxide and nitrogen oxides in the air.
- Worsening of existing cardiovascular conditions and increased **risk of heart attacks**.
- Exposure to toxic metals (lead, mercury) in contaminated water, leading to **neurological** and developmental problems.

## **3.5. Prevention and Control**

### **Regulatory Measures**

- Clean Air Act in the United States and similar regulations in other countries to reduce emissions of sulfur dioxide and nitrogen oxides.

- Pollution control technology in power plants, such as flue gas desulfurization (scrubbers) and selective catalytic reduction systems.
- Stricter emission standards for vehicles and industrial processes.

### Individual Actions

- Energy conservation to reduce the demand for fossil fuels.
- Utilizing public transportation, carpooling, and using electric or hybrid vehicles.
- Proper disposal of hazardous waste and recycling to minimize pollution.

### Alternative Energy Sources

- Encouraging the use of renewable energy sources, such as solar, wind, and hydropower, to reduce reliance on fossil fuels.
- Promoting energy efficiency and green building designs.
- Supporting research and development of cleaner technologies

## 3.6. Acid Rain in India: Causes, Effects, and Solutions

### Causes in India

- **Rapid industrialization and urbanization** leading to increased fossil fuel consumption
- **Inefficient coal-fired power plants** releasing large amounts of sulphur dioxide and nitrogen oxides.
- **Vehicular emissions** from the growing number of automobiles.

### Effects in India

#### *Taj Mahal*

- Acid rain causing damage to the Taj Mahal in Agra, a UNESCO World Heritage site.
- Acidic pollutants eroding the white marble surface, leading to discoloration and structural damage.
- Acid rain reacts with the calcium carbonate in the marble, forming gypsum, which can flake off and weaken the structure.
- Deterioration of the intricate carvings and architectural features, threatening the long-term preservation of the monument.

### Solutions for India

#### *Regulatory Measures*

- Implementing **stricter emission standards** for industries and vehicles to reduce sulfur dioxide and nitrogen oxide emissions.
- Mandating the **installation of pollution control technology** in power plants and factories.
- Encouraging the **adoption of cleaner fuels**, such as natural gas and renewable energy sources.

### ***Public Awareness and Education***

- Raising public awareness about the causes and effects of acid rain, and promoting individual actions to reduce emissions.
- Integrating environmental education in school curriculums to foster a sense of environmental responsibility.
- Conducting regular air quality monitoring and reporting to keep the public informed about pollution levels.

### ***Restoration and Preservation Efforts***

- Undertaking **restoration projects** to repair the damage caused by acid rain to the Taj Mahal and other historical monuments.
- **Applying protective coatings** or treatments to the surfaces of vulnerable structures to minimize the impact of acid rain.
- Establishing **buffer zones** around cultural heritage sites (like the Taj Trapezium) to limit industrial development and vehicular traffic, reducing local pollution.

### ***Promoting Sustainable Development***

- Encouraging **urban planning** that incorporates green spaces, public transportation infrastructure, and pedestrian-friendly designs.
- Supporting the **growth of the renewable energy** sector to reduce reliance on fossil fuels and decrease emissions.
- Implementing policies to promote energy efficiency in residential, commercial, and industrial sectors.

### **3.7. The Taj Trapezium Zone (TTZ)**

- The Taj Trapezium is a defined area around the Taj Mahal in Agra, India, that encompasses approximately **10,400 square kilometers**.
- The trapezium-shaped zone was established to protect the Taj Mahal and other historical monuments from the detrimental effects of pollution, particularly acid rain and airborne particulate matter.
- The zone includes parts of the Agra, Firozabad, Mathura, Hathras, and Etah districts in Uttar Pradesh, and Bharatpur district in Rajasthan.
- The Taj Trapezium Zone (TTZ) was **created in response to a Supreme Court of India order in 1996**, which aimed to reduce pollution levels and preserve the iconic Taj Mahal.
- The court order mandated several measures to control pollution within the TTZ, including:
  - Shutting down or relocating polluting industries, particularly those using coal or other high-emission fuels.

- Encouraging the use of cleaner fuels in industries and transportation.
- Implementing strict emission standards for vehicles and industries operating within the zone.
- Promoting green spaces and afforestation to improve air quality and create a buffer against pollution.
- Developing infrastructure for public transportation and pedestrian-friendly areas to reduce vehicular pollution.

