An Introduction to Chemistry

by Mark Bishop
Ozone, $\text{O}_3$, as Oxidizing Agent

- Used to sanitize hot tubs
- Used in industry to bleach waxes, oils, and textiles.
- Strong respiratory irritant that can lead to shortness of breath, chest pain when inhaling, wheezing, and coughing
- Damages rubber and plastics, leading to premature deterioration of products made with these materials.
- Ozone damages plants.
Ozone as Pollutant

- Highest concentrations found in large industrial cities with lots of cars and lots of sun.

\[
N_2(g) + O_2(g) \rightarrow 2NO(g)
\]
\[
2NO(g) + O_2(g) \rightarrow 2NO_2(g)
\]
\[
\lambda < 400 \text{ nm}
\]
\[
NO_2(g) \rightarrow NO(g) + O(g)
\]
\[
O(g) + O_2(g) \rightarrow O_3(g)
\]
National Ozone Concentrations

lower ozone levels

higher ozone levels
The Earth’s Atmosphere

Stratosphere from 10 to 50 km

Troposphere from 0 to 10 km

Earth
Ultraviolet Radiation

- **UV-A** 320-400 nm
  - reaches the surface of the Earth
  - helps create Vitamin D
- **UV-B** 290-320 nm
  - some reaches the surface of the Earth
  - leads to sunburn, skin aging, and skin cancer
- **UV-C** 40-290 nm
  - mostly removed in upper atmosphere
  - alters DNA ($\approx$260 nm) and protein ($\approx$280 nm)
Removal of UV in Stratosphere

\[ \text{O}_2(g) \xrightarrow{\text{UV with } \lambda < 242 \text{ nm}} 2\text{O}(g) \]

\[ \text{O}_3(g) \xrightarrow{\text{UV with } \lambda \text{ from 240 to 320 nm}} \text{O}(g) + \text{O}_2(g) \]

Wavelength of radiant energy (nm)

- Removed by \( \text{O}_2 \)
- Removed by \( \text{O}_3 \)

- UV-C
- UV-B
- UV-A
Ozone Destruction

NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)
NO_2(g) + O(g) \rightarrow NO(g) + O_2(g)

Net reaction

O_3(g) + O(g) \rightarrow 2O_2(g)
Chlorofluorocarbons (CFCs)

- CFC-11  \( \text{CFCl}_3 \)
  - average lifetime in atmosphere is \( \approx 50 \) years
- CFC-12  \( \text{CF}_2\text{Cl}_2 \)
  - average lifetime in atmosphere is \( \approx 102 \) years
- used as propellants in aerosol cans, solvents, blowing agents for foams, coolant in refrigerators, and other uses
- very stable, nontoxic, and can be liquefied with minimal pressure
The propellant evaporates into the space above the liquid and gives an internal pressure that is slightly greater than the external pressure.

When the valve is pushed, it opens a passageway through which the liquid in the can moves. Because the pressure above the liquid in the can is greater than the external pressure, liquid is pushed out of the can.

As the volume occupied by the gas above liquid in the can increases, more propellant evaporates, keeping the pressure above the liquid constant. Therefore, the liquid is expelled from the can with the same pressure when the can is full and when it is almost empty.
Refrigeration

- The refrigerant is a substance that is a gas at normal pressures but one that can be converted into a liquid at slightly greater than normal pressures.
- Outside the refrigerator, gas is compressed to liquid. Increased attractions leads to increased stability, lower PE, and the release of energy into the room.
- Inside the refrigerator, the liquid is allowed to form a gas. Decreased attractions leads to decreased stability, higher PE, and energy is absorbed. This decreases the temperature inside the refrigerator.
CF$_2$Cl$_2$(g) $\rightarrow$ CF$_2$Cl(g) + Cl(g)

Cl(g) + O$_3$(g) $\rightarrow$ ClO(g) + O$_2$(g)

ClO(g) + O(g) $\rightarrow$ Cl(g) + O$_2$(g)

net reaction

O$_3$(g) + O(g) $\rightarrow$ 2O$_2$(g)

Cl catalyst
Another Possible Mechanism for the CFC Threat to Ozone

\[ \text{CF}_2\text{Cl}_2(g) \xrightarrow{\lambda < 215 \text{ nm}} \text{CF}_2\text{Cl}(g) + \text{Cl}(g) \]

\[ 2\text{Cl}(g) + 2\text{O}_3(g) \rightarrow 2\text{ClO}(g) + 2\text{O}_2(g) \]

\[ 2\text{ClO}(g) \rightarrow \text{ClOOCl}(g) \]

\[ \text{ClOOCl}(g) \rightarrow \text{ClOO}(g) + \text{Cl}(g) \]

\[ \text{ClOO}(g) \rightarrow \text{Cl}(g) + \text{O}_2(g) \]

**net reaction**

\[ 2\text{O}_3(g) \xrightarrow{\text{Cl catalyst}} 3\text{O}_2(g) \]
\[
\text{CH}_4(g) + \text{Cl}(g) \rightarrow \text{CH}_3(g) + \text{HCl}(g)
\]

\[
\text{ClO}(g) + \text{NO}_2(g) \rightarrow \text{ClONO}_2(g)
\]
Ozone Hole - Reactions on the surface of ice crystals

\[
\text{ClONO}_2(g) + \text{HCl}(s) \rightarrow \text{Cl}_2(g) + \text{HNO}_3(s)
\]

\[
\text{ClONO}_2(g) + \text{H}_2\text{O}(s) \rightarrow \text{HOCl}(g) + \text{HNO}_3(s)
\]

\[
\text{HOCl}(g) + \text{HCl}(s) \rightarrow \text{Cl}_2(g) + \text{H}_2\text{O}(s)
\]

\[\text{radiant energy}\]

\[
\text{HOCl}(g) \rightarrow \text{Cl}(g) + \text{OH}(g)
\]

\[\text{radiant energy}\]

\[
\text{Cl}_2(g) \rightarrow 2\text{Cl}(g)
\]