Ozone, and CFCs

An Introduction to Chemistry

by Mark Bishop

Ozone, 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.

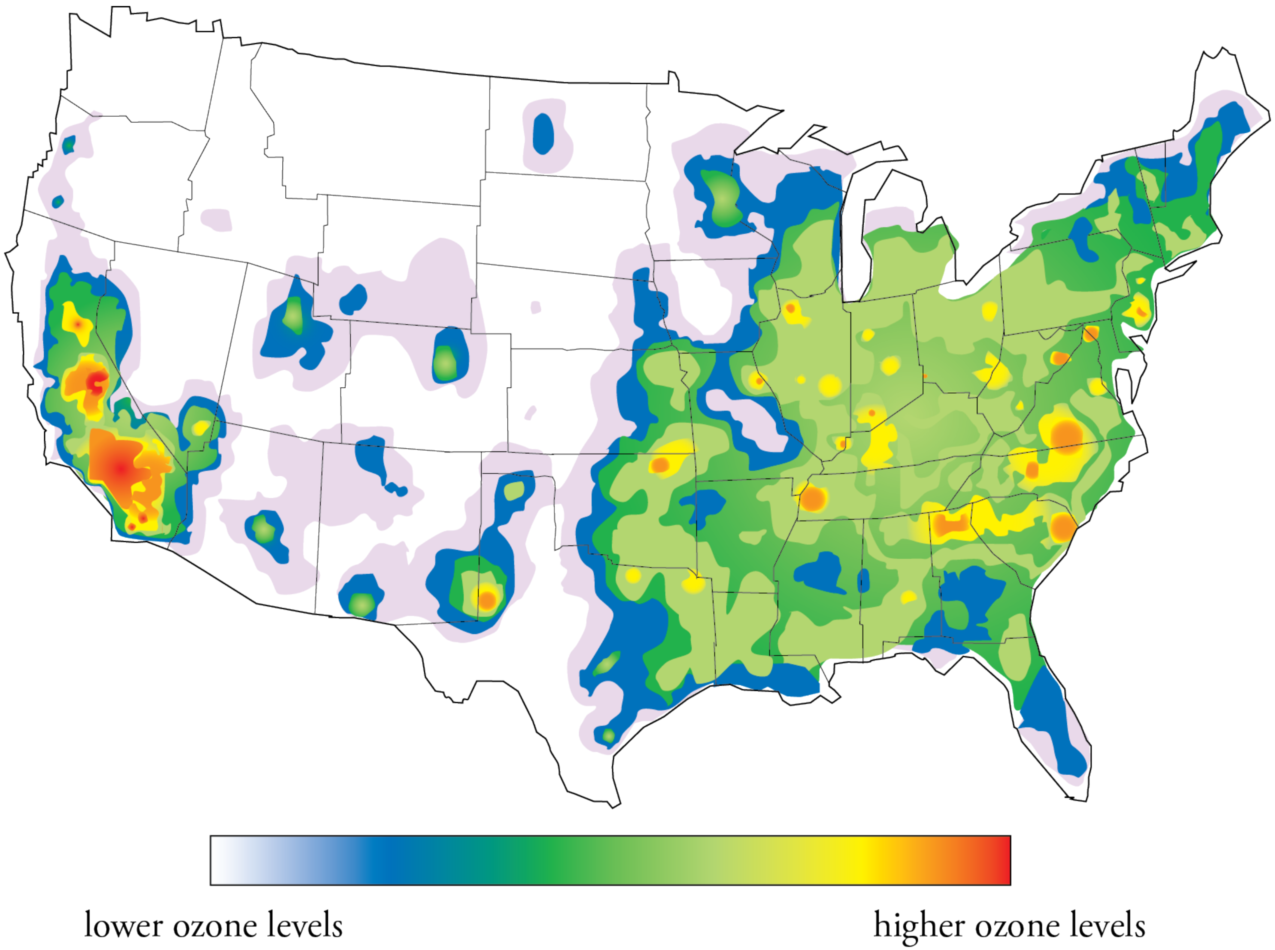
$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

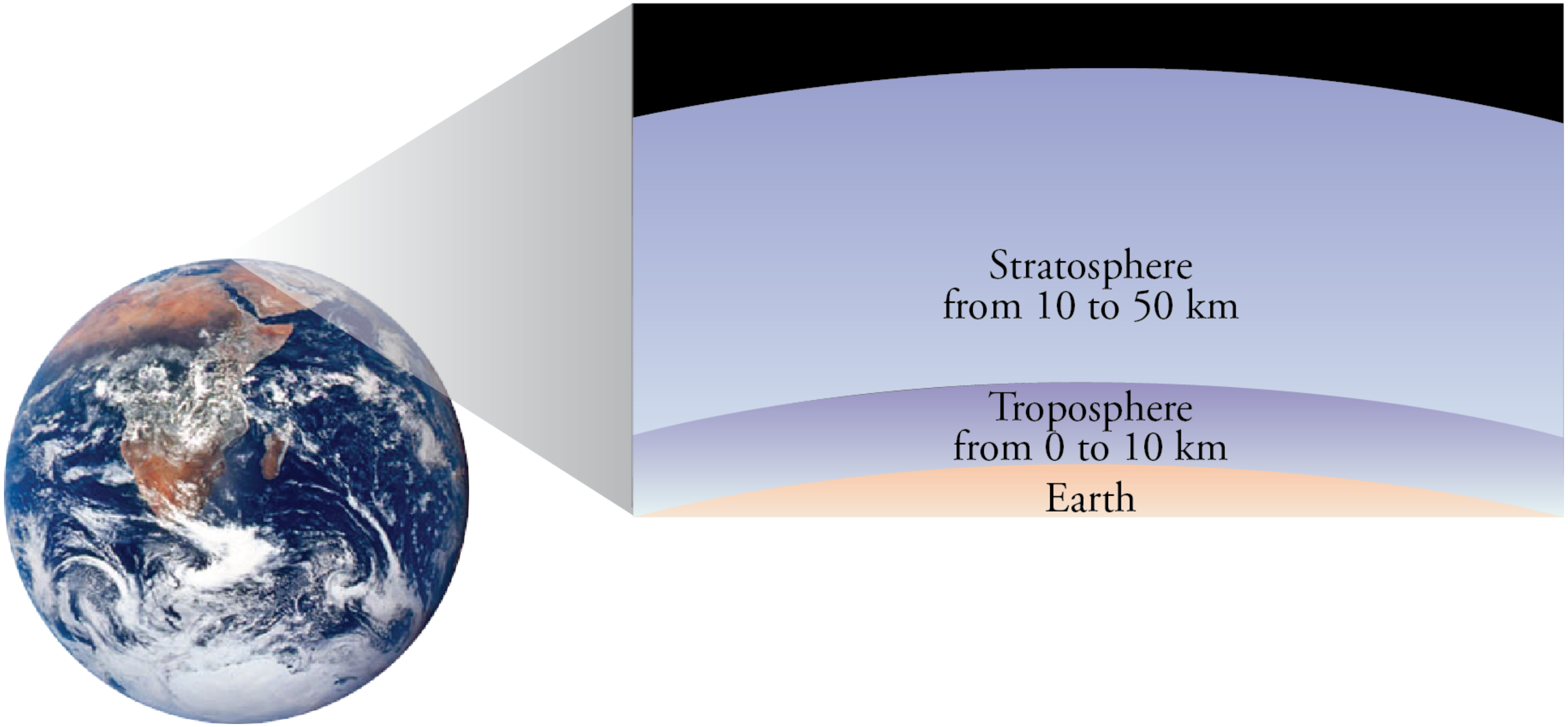
$$NO_2(g) \xrightarrow{\lambda < 400\ \text{nm}} NO(g) + O(g)$$

$$O(g) + O_2(g) \rightarrow O_3(g)$$

National Ozone Concentrations



The Earth’s Atmosphere



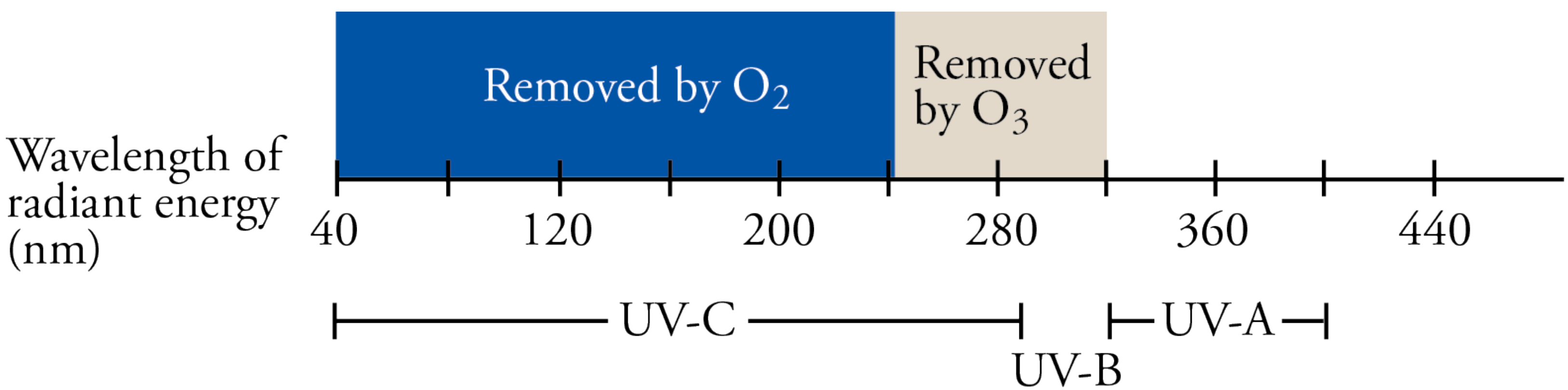
Ultraviolet Radiation

- **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 (≈260 nm) and protein (≈280 nm)

Removal of UV in Stratosphere

$$O_2(g) \xrightarrow{\text{UV with } \lambda < 242 \text{ nm}} 2O(g)$$

$$O_3(g) \xrightarrow{\text{UV with } \lambda \text{ from 240 to 320 nm}} O(g) + O_2(g)$$



Ozone Destruction

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

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

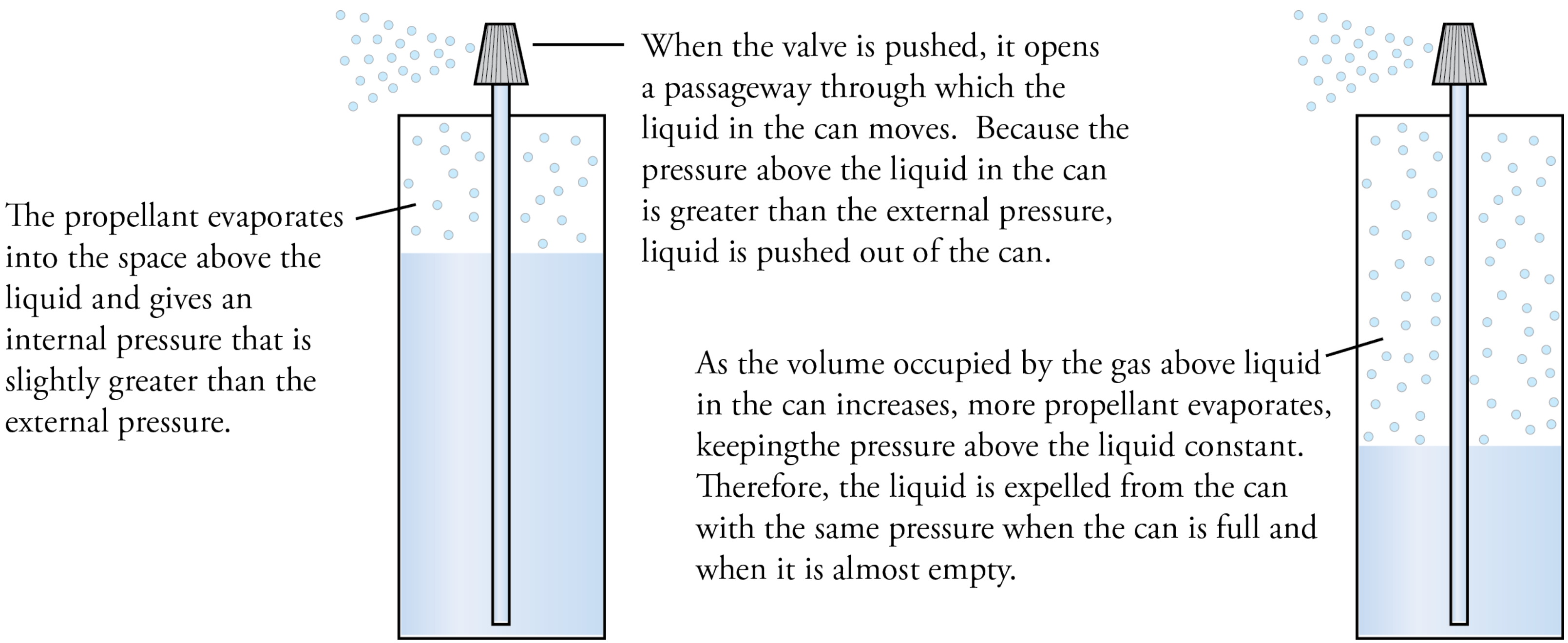
net reaction

$$O_3(g) + O(g) \xrightarrow{\text{NO catalyst}} 2O_2(g)$$

Chlorofluorocarbons (CFCs)

- CFC-11 $CFCl_3$
  - average lifetime in atmosphere is ≈ 50 years
- CFC-12 CF_2Cl_2
  - average lifetime in atmosphere is ≈ 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

Aerosol Can Propellants



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.

CFC Threat to Ozone (1974) Mario Molina and F. Sherwood Rowland

$$CF_2Cl_2(g) \xrightarrow{\lambda < 215\text{ nm}} CF_2Cl(g) + Cl(g)$$

$$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$$

$$ClO(g) + O(g) \rightarrow Cl(g) + O_2(g)$$

net reaction

$$O_3(g) + O(g) \xrightarrow{\text{Cl catalyst}} 2O_2(g)$$

Another Possible Mechanism for the CFC Threat to Ozone

$$CF_2Cl_2(g) \xrightarrow{\lambda < 215\text{ nm}} CF_2Cl(g) + Cl(g)$$

$$2Cl(g) + 2O_3(g) \rightarrow 2ClO(g) + 2O_2(g)$$

$$2ClO(g) \rightarrow ClOOCl(g)$$

$$ClOOCl(g) \rightarrow ClOO(g) + Cl(g)$$

$$ClOO(g) \rightarrow Cl(g) + O_2(g)$$

net reaction

$$2O_3(g) \xrightarrow{\text{Cl catalyst}} 3O_2(g)$$

Inactive Chlorine

$$CH_4(g) + Cl(g) \rightarrow CH_3(g) + HCl(g)$$

$$ClO(g) + NO_2(g) \rightarrow ClONO_2(g)$$

Ozone Hole - Reactions on the surface of ice crystals

$$ClONO_2(g) + HCl(s) \rightarrow Cl_2(g) + HNO_3(s)$$

$$ClONO_2(g) + H_2O(s) \rightarrow HOCl(g) + HNO_3(s)$$

$$HOCl(g) + HCl(s) \rightarrow Cl_2(g) + H_2O(s)$$

$$HOCl(g) \xrightarrow{\text{radiant energy}} Cl(g) + OH(g)$$

$$Cl_2(g) \xrightarrow{\text{radiant energy}} 2Cl(g)$$