# Light-Absorbing Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Absorption wavelengths ($\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible/Near-UV/Far-UV absorbers</strong></td>
<td></td>
</tr>
<tr>
<td>Ozone ($O_3$)</td>
<td>&lt; 0.35, 0.45-0.75</td>
</tr>
<tr>
<td>Nitrate radical ($NO_3$)</td>
<td>&lt; 0.67</td>
</tr>
<tr>
<td>Nitrogen dioxide ($NO_2$)</td>
<td>&lt; 0.71</td>
</tr>
<tr>
<td><strong>Near-UV/Far-UV absorbers</strong></td>
<td></td>
</tr>
<tr>
<td>Formaldehyde (HCHO)</td>
<td>&lt; 0.36</td>
</tr>
<tr>
<td>Nitric acid (HNO₃)</td>
<td>&lt; 0.33</td>
</tr>
<tr>
<td><strong>Far-UV absorbers</strong></td>
<td></td>
</tr>
<tr>
<td>Molecular oxygen ($O_2$)</td>
<td>&lt; 0.245</td>
</tr>
<tr>
<td>Carbon dioxide ($CO_2$)</td>
<td>&lt; 0.21</td>
</tr>
<tr>
<td>Water vapor ($H_2O$)</td>
<td>&lt; 0.21</td>
</tr>
<tr>
<td>Molecular nitrogen ($N_2$)</td>
<td>&lt; 0.1</td>
</tr>
</tbody>
</table>

Table 7.1
Gas (Rayleigh) Scattering

Redirection of radiation by a gas molecule without a net transfer of energy to the molecule

Figure 7.4

Probability distribution of where a gas molecule scatters incoming light
Color of the Sky and Sun

Figure 7.6
Yellow Sun at Sunset

M.Z. Jacobson
Red Horizon Over Clouds During Sunset

Mark Z. Jacobson
Effects of Pollution on UV Radiation Reaching Surface

Figure 7.11

Downward UV intensity (W m$^{-2}$)

Hour after first midnight

Mt. Wilson
Central L. A.
Claremont
Riverside

UV 295
-385 nm

Figure 7.11
Primary Rainbow

Commander John Bortniak, NOAA Corps, available from the National Oceanic and Atmospheric Administration Central Library
Radiation Scattering by a Sphere

Ray A is reflected
Ray B is refracted twice
Ray C is diffracted
Ray D is refracted, reflected twice, then refracted
Ray E is refracted, reflected once, and refracted
Processes Affecting Visibility

from "Introduction to Visibility" by William C. Malm
Glacier National Park (MT)

Fig. 3.2. The effect of regional or uniform haze on a Glacier National Park vista. The view is of the Garden Wall from across Lake McDonald. Atmospheric particulate concentrations associated with photographs (a), (b), (c), and (d) correspond to 7.6, 12.0, 21.7, and 65.3 μg/m³.

from “Introduction to Visibility” by William C. Malm
Grand Canyon (AZ)

Fig. 3.9 Smoke trapped by an inversion layer in the Grand Canyon. During the winter months inversions are quite common in almost all parts of the United States.

from “Introduction to Visibility” by William C. Malm
# Meteorological Range

<table>
<thead>
<tr>
<th></th>
<th>Gas scattering</th>
<th>Gas absorption</th>
<th>Particle scattering</th>
<th>Particle absorption</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polluted day</strong></td>
<td>366</td>
<td>130</td>
<td>9.59</td>
<td>49.7</td>
<td>7.42</td>
</tr>
<tr>
<td><strong>Less-polluted day</strong></td>
<td>352</td>
<td>326</td>
<td>151</td>
<td>421</td>
<td>67.1</td>
</tr>
</tbody>
</table>

(Larson et al., 1984)
Table 7.4
Particle Size and Scattering Efficiency

Fig. 2.5 The blue line shows the relative amount of mass typically found in a given particle size range. The orange line shows the relative amount of particle scattering associated with that mass. Note that even though mass is associated with coarse particles, it is the fine particles that are primarily responsible for scattering light.

Fig. 4.9 The five particle types that make up the fine particle mass: sulfates, organics, elemental carbon, soil, and nitrates.

from “Introduction to Visibility” by William C. Malm
Visibility in the US

from the IMPROVE web site
Visibility in the US

Fig. 7.2 Geographical distribution of sulfur dioxide (SO₂), nitrogen oxides (NOₓ), and volatile organic carbon (VOC) gas emissions.

from “Introduction to Visibility” by William C. Malm
EPA’s Regional Haze Plan

Timeline for States to Implement EPA’s Rule

- **EPA** issues final Regional Haze Rule
- **EPA** designates PM 2.5 areas as “nonattainment”, “attainment”, or “unclassifiable”
- Areas designated "Attainment" & "Unclassifiable" - States submit haze plans (establish progress goals and control strategies) 1 year from PM 2.5 designation date
- Areas designated "Nonattainment" - States submit haze plans (establish progress goals and control strategies) 3 years from PM 2.5 designation date
- States submit progress reports on “reasonable progress” goals and strategies (every 5 years thereafter)
- States complete revised haze plans (every 10 years thereafter)

- **1999**
  - PM 2.5 Monitors in place
- **2001**
  - Option Regional Planning
  - States commit to regional planning and submit haze plans one year after EPA designates first area within State
- **2003-5**
  - Option Regional Planning
  - States submit complete haze control strategy plans (establish progress goals and control strategies)
- **2006-8**
  - Option States complete source-specific Best Available Retrofit Technology (BART) controls
- **2008**
  - Option States complete emissions trading or alternative control measures
- **2011-13**
  - States submit haze plans for other Class I areas
- **2013**
  - Latest date for States to submit haze control strategy plans for 16 original areas
- **2016-18**
  - States submit revised haze plans
- **2018**
  - States complete revised haze plans (every 10 years thereafter)

**Option for Grand Canyon Visibility Transport Commission (GCVTTC) Areas**

- **2000**
  - States submit annex to original GCVTTC report (establish SO2 milestones)
- **2003**
  - States submit haze control strategy plans for 16 original areas
- **2008**
  - Latest date for States to submit haze control strategy plans for other Class I areas
- **2018**
  - States complete revised haze plans (every 10 years thereafter)