**GLOBAL WARMING GREENHOUSE EFFECT**

**FIGURE 8.8.** Solar energy passing through a "hoop" with the same radius as that of the earth hits the earth. Radiation that misses the hoop also misses the earth.

**FIGURE 8.9.** Simple global temperature model.

\[
(1 - \alpha) \pi R^2 = \sigma 4 \pi R^2 T_e^4
\]

SOLVE for \( T_e \):

\[
T_e = \left[ \frac{S (1 - \alpha)}{4\sigma} \right]^{1/4}
\]

\[
T_e = \left[ \frac{(1370 \text{ W/m}^2)(1 - 0.3)}{4 \left( \frac{5.7 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4}{\text{K}^4} \right)} \right]^{1/4} = 254 \text{ K} = -19^\circ \text{C}
\]

\( S \) varies w/ orbit, etc
\( \alpha \) varies w/ ice cover
**General Pattern:**
Gradual Cooling, Rapid Warming
Why such rapid warming?

One explanation:

**Autocatalytic Processes**
("self reinforcing"; positive feedback)

1. **Large Ice Cover**
   - Large Albedo
   - Less Net Heat

   **As Ice Retreats**
   - Albedo Drops
   - Reinforces Warming Trend

- AT RATHER "RAPID"

- AT: NOT THAT BIG COMPARED TO, SAY, CARBONIFEROUS PERIOD (DINOSAURS)

- BUT AT OF FEW DEGREES = HIGHEST T IN 10^6 YRS
RE 8.6 Orbital variations affect the timing of ice ages. (a) The current orbit; (b) The tilt angle variation, with period 41,000 years; (c) eccentricity variation, with period 100,000 years; (d) precession, with period 23,000 years.

Milankovitch oscillations
GLOBAL WARMING

1st: Must understand Composition of Atmosphere

**TABLE 8.1** Composition of Clean, Dry Air (fraction by volume in troposphere, 1994)

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Formula</th>
<th>Percent by volume</th>
<th>Parts per million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>78.08</td>
<td>780,800</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>20.95</td>
<td>209,500</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>0.93</td>
<td>9300</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>0.035</td>
<td>358*</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>0.0018</td>
<td>18</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>0.0005</td>
<td>5.2</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>0.00017</td>
<td>1.7*</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
<td>0.00011</td>
<td>1.1</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N₂O</td>
<td>0.00003</td>
<td>0.3*</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>0.00005</td>
<td>0.5</td>
</tr>
<tr>
<td>Ozone</td>
<td>O₃</td>
<td>0.000004</td>
<td>0.04</td>
</tr>
</tbody>
</table>

\[
\Delta F = \frac{\Delta Q}{A} \text{ W/m}^2
\]

\[
\Delta F = \frac{1.56 + 0.47 + 0.28 + 0.14}{4} = 0.65 \text{ W/m}^2
\]

"FORCING"

Can see true relative importance of gases

\[2.45 \text{ W/m}^2\]
8.11 Absorptivity as a function of wavelength for water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), oxygen and ozone (O₂, O₃), and nitrous oxide (N₂O), and the total absorptivity of the atmosphere. Shown here are spectra for incoming solar energy and outgoing thermal energy from the 288 K surface of the earth. Note the 10th scale change at 4 μm.

RADIATIVE "WINDOW" TO SPACE

\[ \lambda = \sim 7 - 12 \, \mu m \]
Monthly Mean Carbon Dioxide
NOAA CMDL Carbon Cycle Greenhouse Gases

Atmospheric carbon dioxide mixing ratios determined from the continuous monitoring programs at the 4 NOAA CMDL baseline observatories. Principal investigator: Dr. Peter Tans, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678, ptans@cmdl.noaa.gov.
Top: Global average atmospheric carbon dioxide mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend.
Methane Measurements
NOAA CMDL Carbon Cycle Greenhouse Gases

Top: Global average atmospheric methane mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend.

Bottom: Global average growth rate for methane. Principal investigator: Dr. Ed Dlugokencky, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6228. edlugokencky@cmld.noaa.gov
Global Distribution of Atmospheric Carbon Dioxide
NOAA CMDL Carbon Cycle Greenhouse Gases

Three dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigators: Peter Tans and Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-5678, ptans@cmdl.noaa.gov.
But what about negative feedback processes? (Warming creates results that cancel out further warming)

2. E.g. Cloud cover:

- Warmer oceans
- More evaporation
- More clouds
- More albedo
- Tends to negate warming.

But not always that simple.

\[ R = 0 \cdot T_c^4 \]

\[ T_c \approx -50^\circ C \]

\[ T_s = 30^\circ C \]

\[ T_s = 34^\circ C \]

\[ \approx 20\% \text{ less heat loss} \]