# Introduction to the Chemistry of Global Climate Change

**(Includes Carbon Footprint of Bottled Water Calculation)**

**Laura Foster Voss**
**Johns Hopkins University**

## The Nobel Peace Prize 2007

**"for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change"**

IPCC

INTERGOVERNMENTAL
PANEL ON
CLIMATE CHANGE

WMO UNEP

Founded in 1988

Albert Arnold Gore Jr.
b. 1948

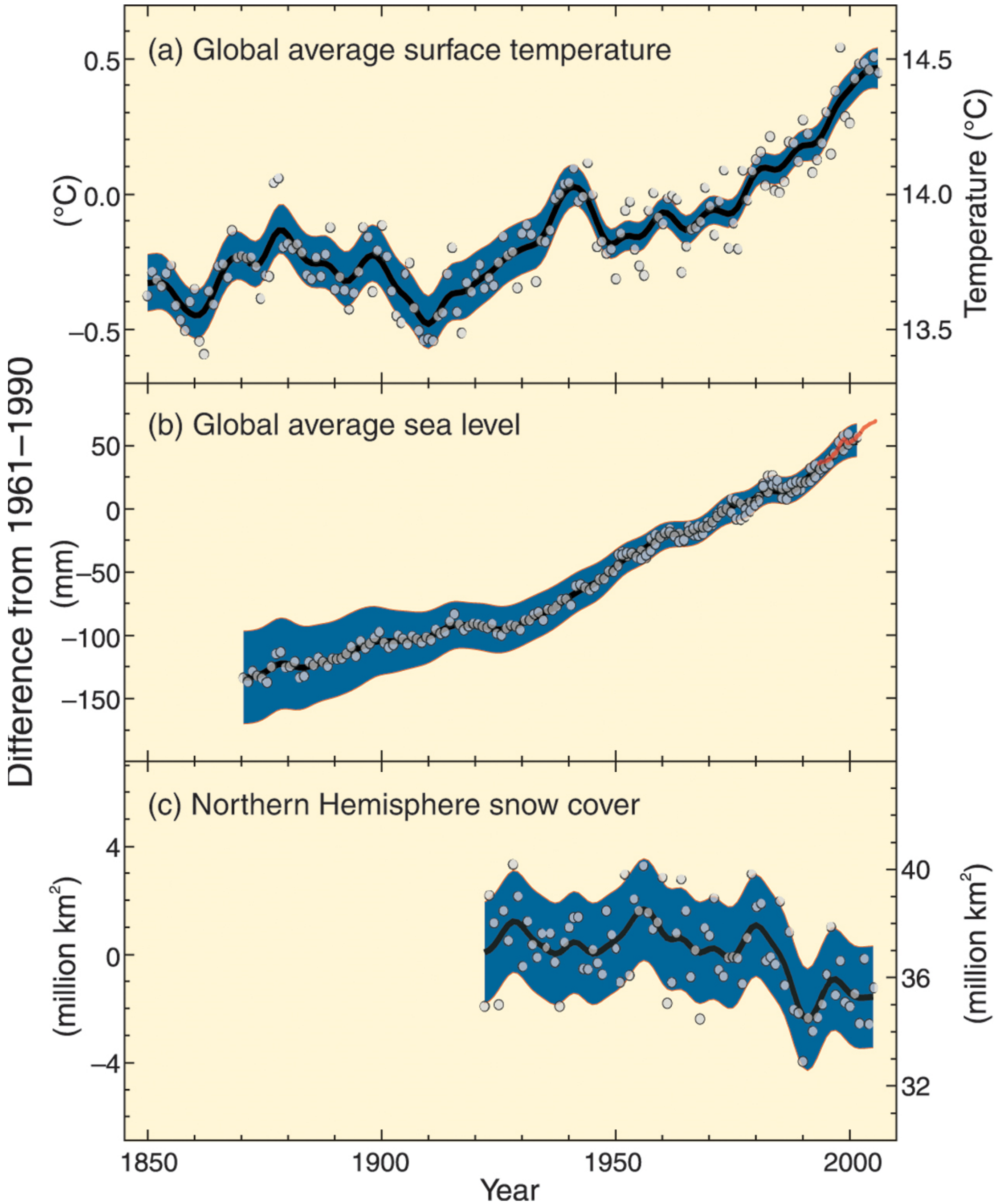
# CLIMATE CHANGE 2007

## SYNTHESIS REPORT

A Report of the Intergovernmental Panel on Climate Change

WMO

UNEP

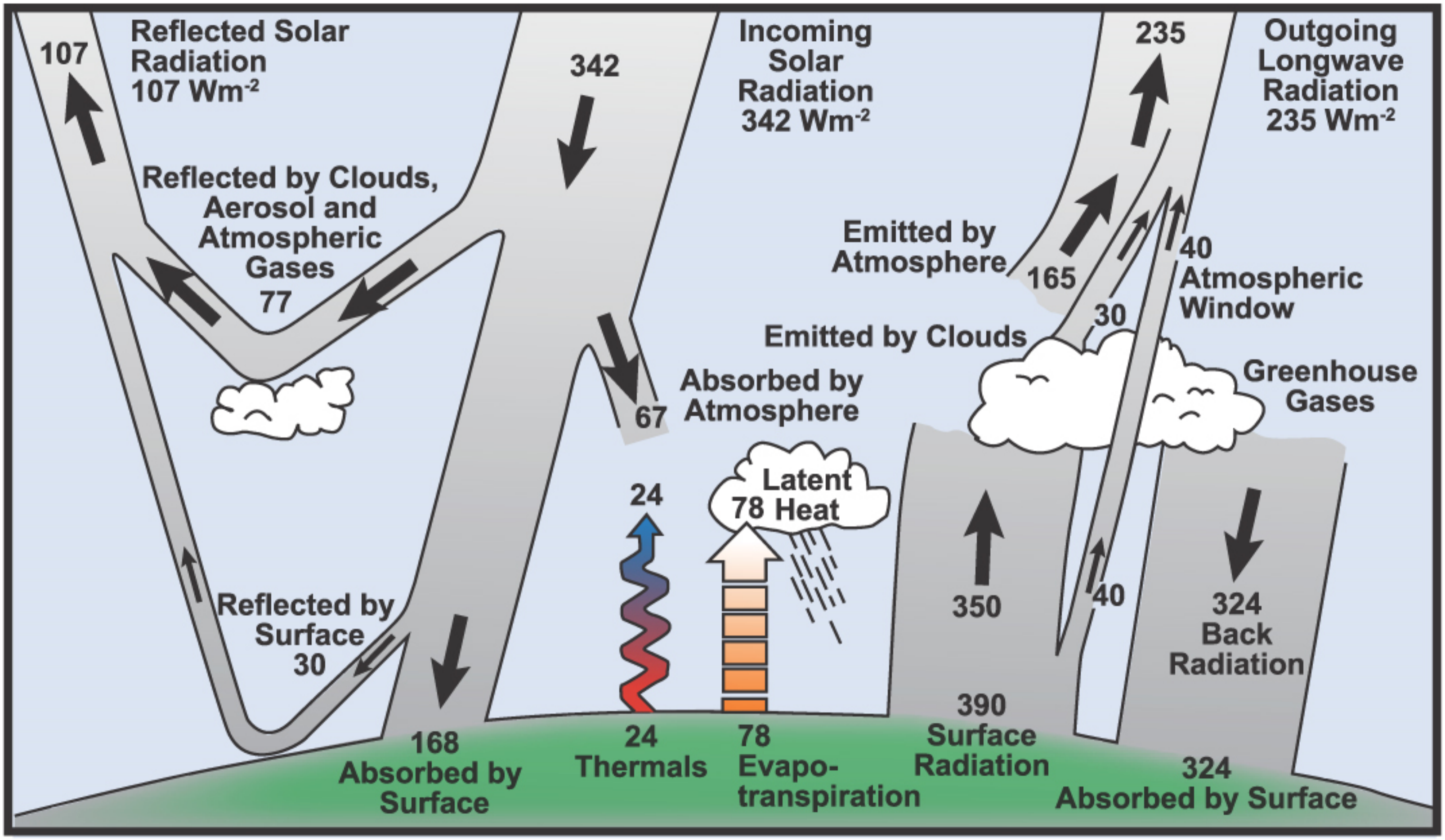



**Source: IPCC AR4**

# Boulder Glacier
## Glacier National Park

***George Grant photo*** ***1932***
*Courtesy of Glacier National Park Archives*

***Jerry DeSanto photo*** ***1988***

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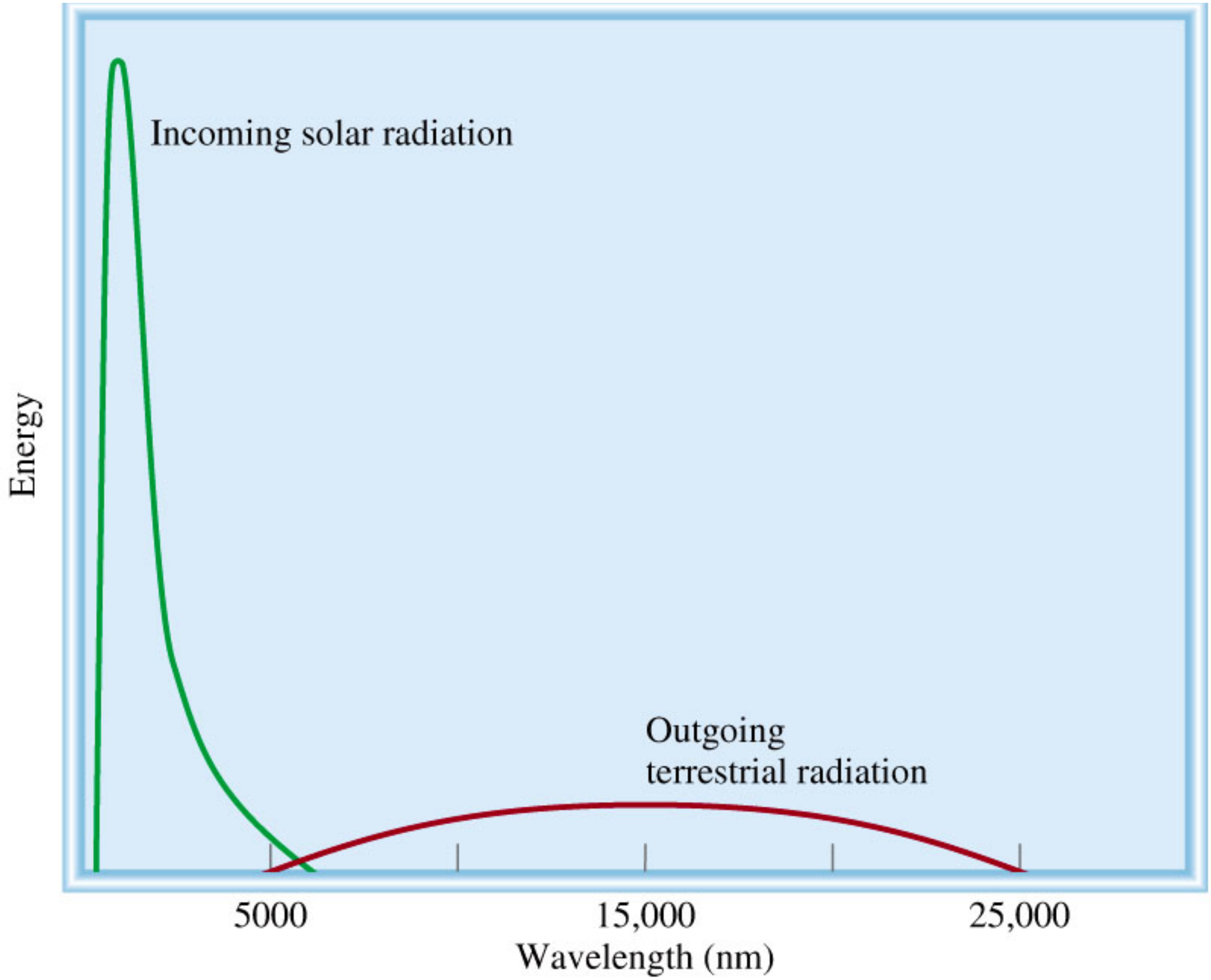
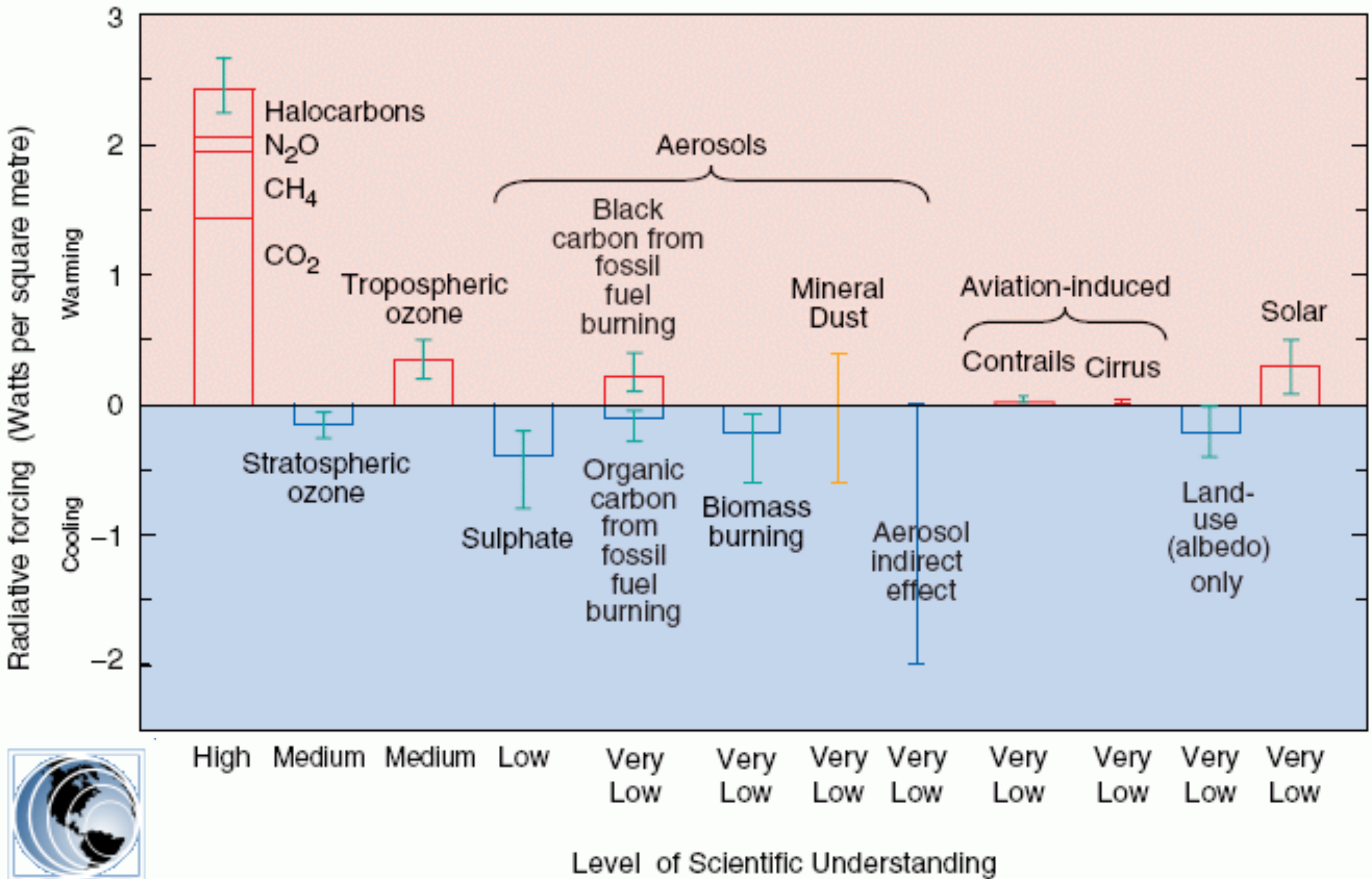



**Source:** ***Chemistry*** **by Chang**

# The global mean radiative forcing of the climate system for the year 2000, relative to 1750




Source: IPCC TAR

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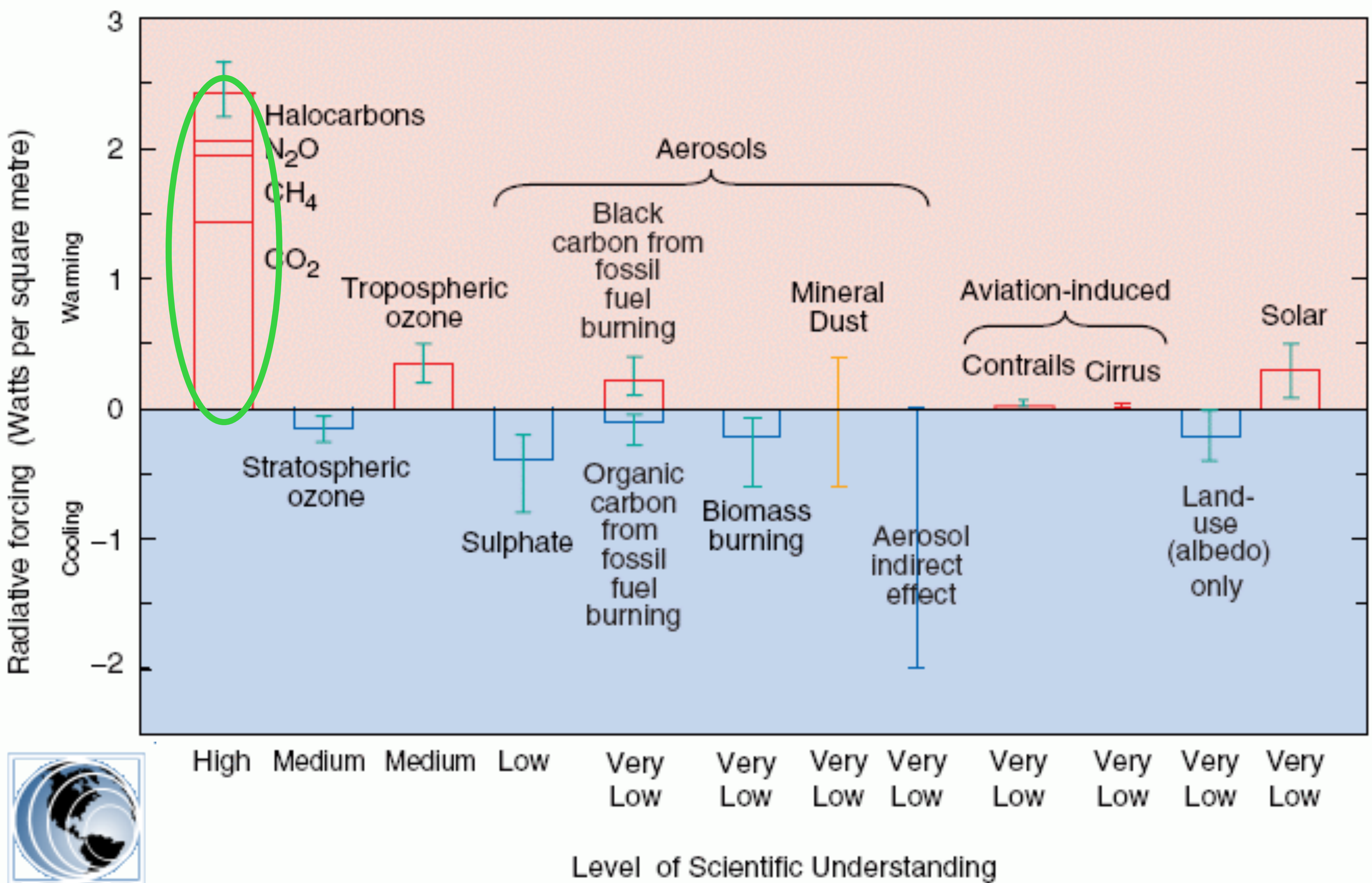



**Source: IPCC TAR**

# Composition of Atmosphere

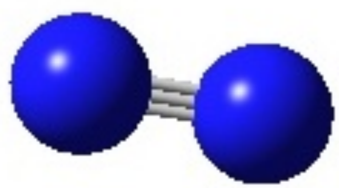
**Composition of Dry Air at Sea Level**

| Gas | Composition (% by Volume) |
|---|---|
| $N_2$ | 78.03 |
| $O_2$ | 20.99 |
| Ar | 0.94 |
| $CO_2$ | 0.038815 * |
| Ne | 0.0015 |
| He | 0.000524 |
| Kr | 0.00014 |
| Xe | 0.000006 |

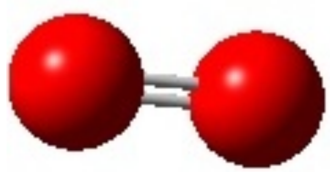
* Source: ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_mlo.txt
(average data for August 2010, Mauna Loa, Hawaii)

Source: *Chemistry* by Chang

# Composition of Atmosphere



$N_2$



$O_2$

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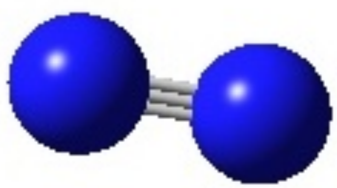

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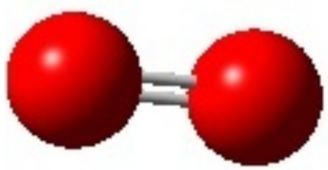

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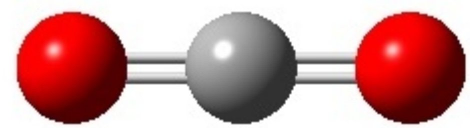
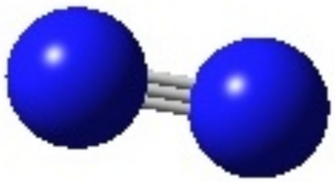


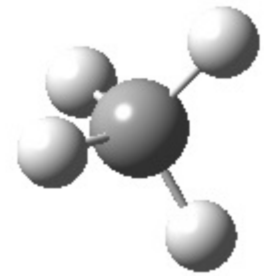
$CO_2$

**Source:** ***Chemistry*** **by Chang**

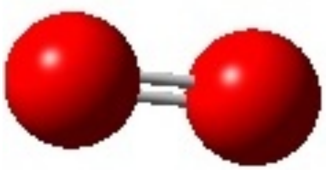


$N_2$

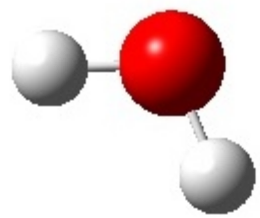
$CO_2$



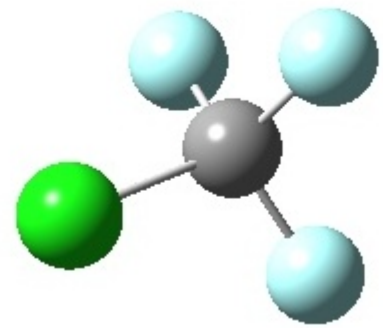
$CH_4$



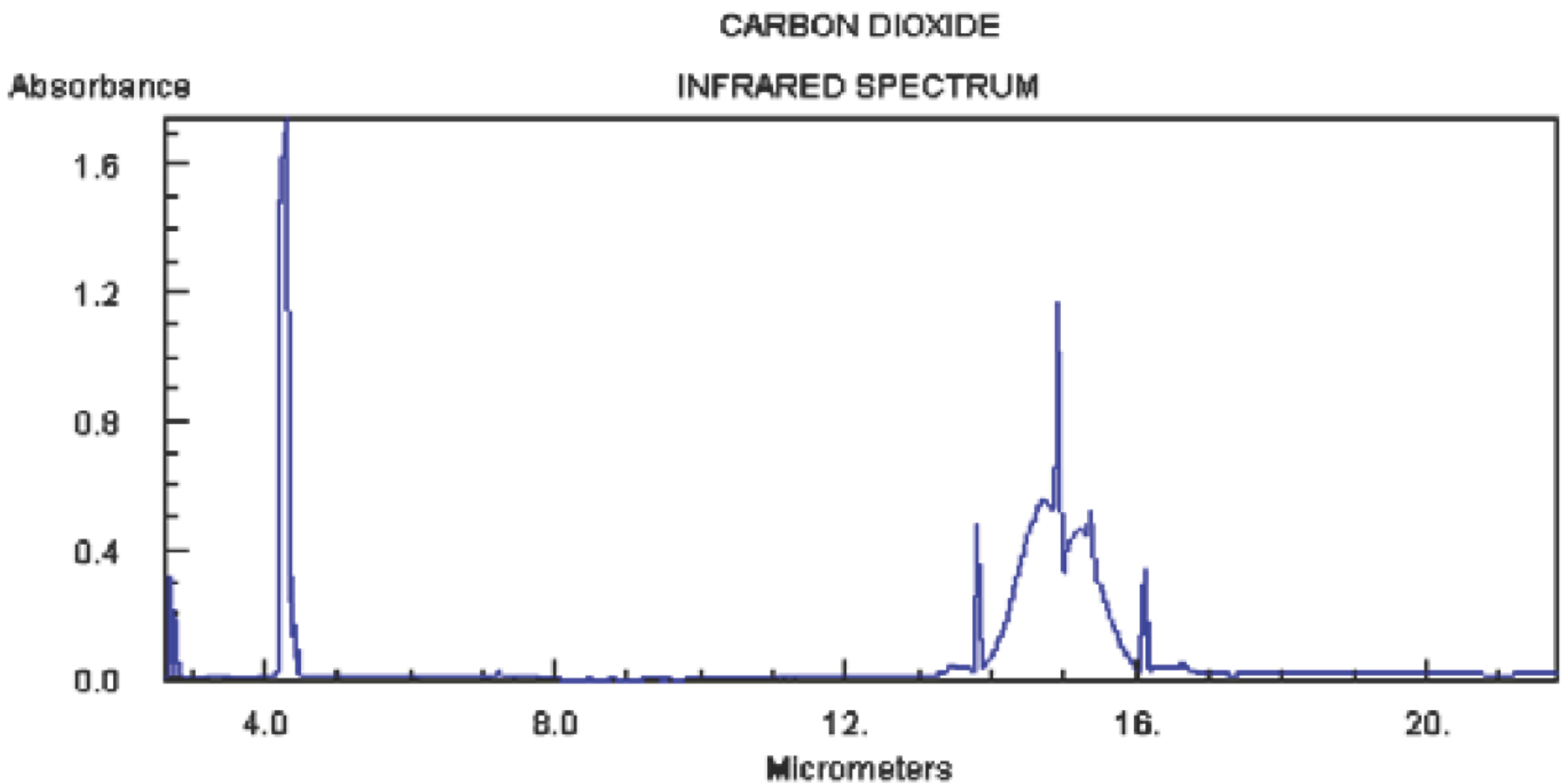
$O_2$

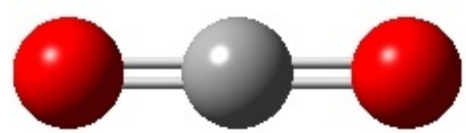


$H_2O$



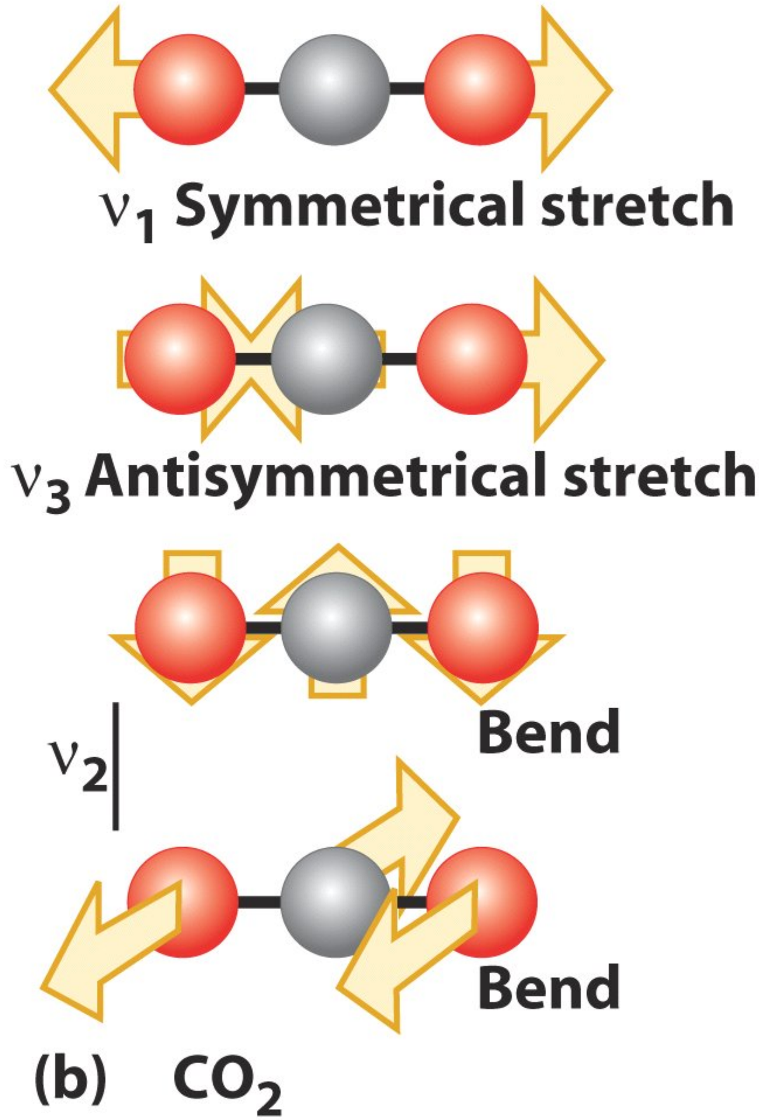
$CF_3Cl$


CARBON DIOXIDE
INFRARED SPECTRUM
Absorbance
1.6
1.2
0.8
0.4
0.0
4.0
8.0
12.
16.
20.
Micrometers

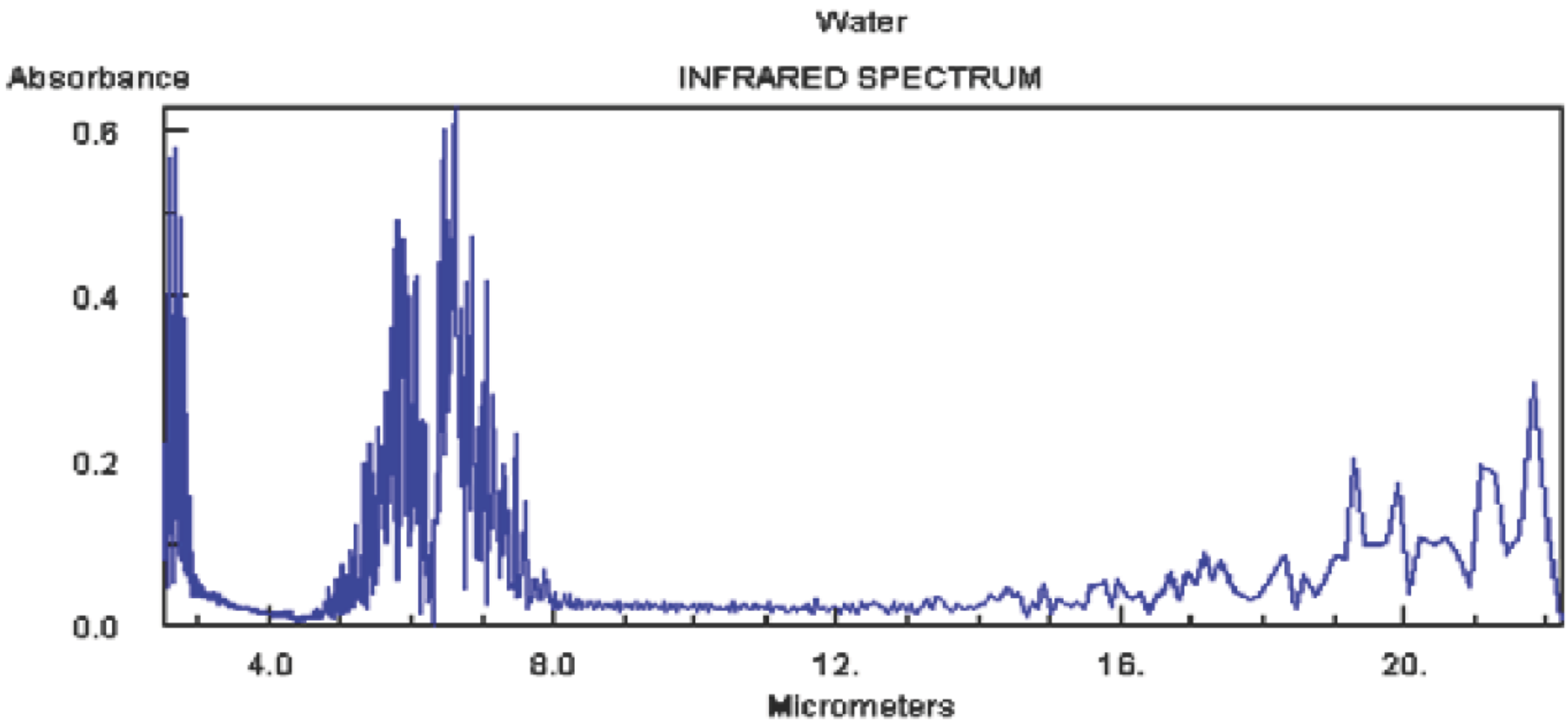


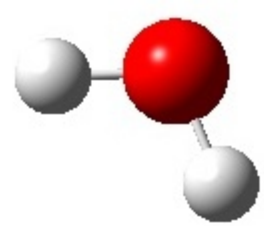
$CO_2$

# Vibrational Modes

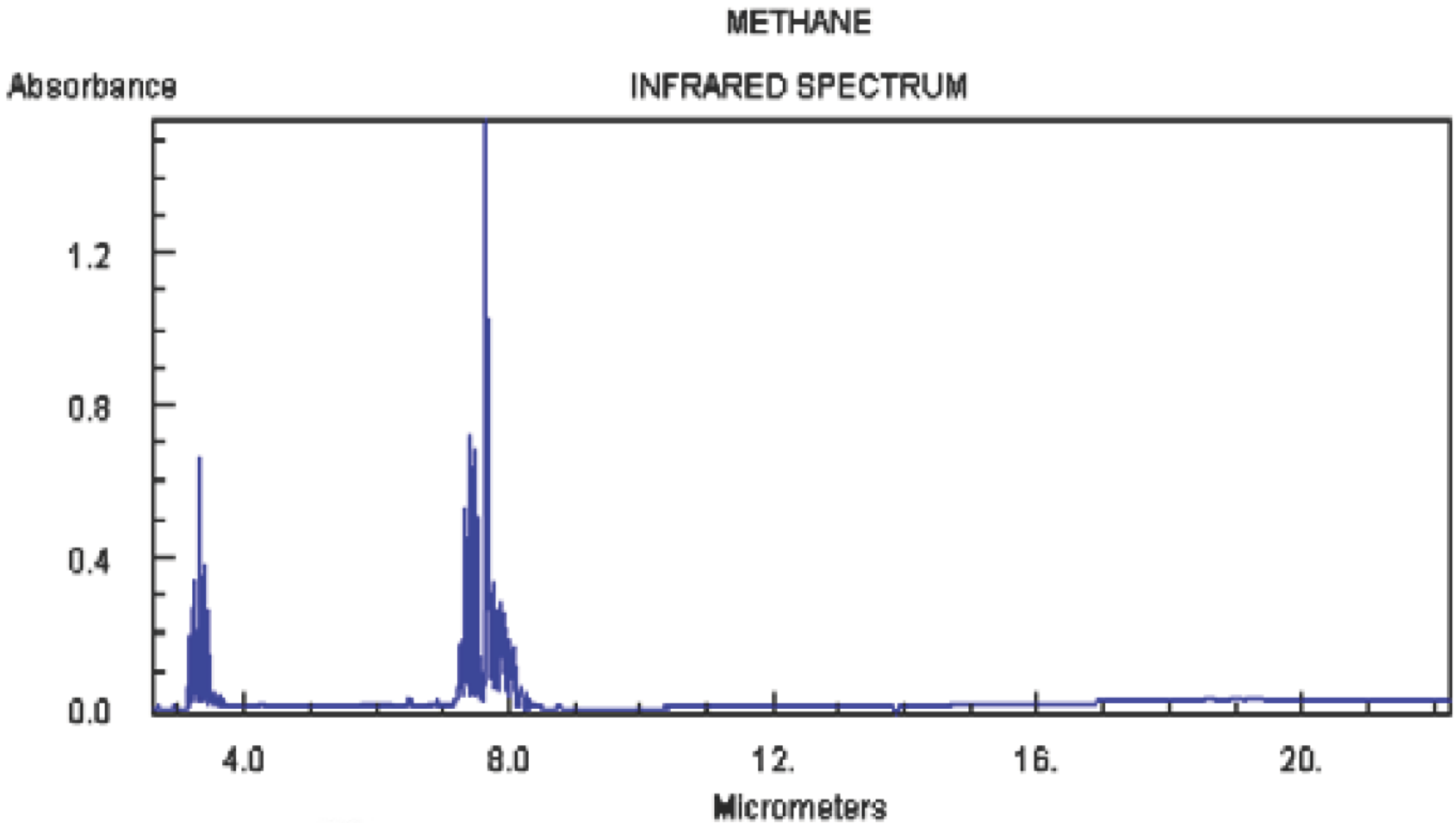


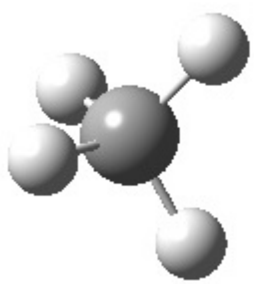

**Source:** ***Chemical Principles*** **by Atkins and Jones**


Water
Absorbance
INFRARED SPECTRUM
0.6
0.4
0.2
0.0
4.0
8.0
12.
16.
20.
Micrometers



$H_2O$

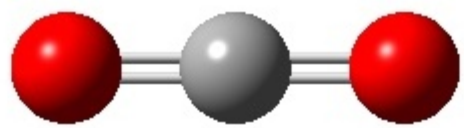

METHANE
INFRARED SPECTRUM
Absorbance
1.2
0.8
0.4
0.0
4.0
8.0
12.
16.
20.
Micrometers



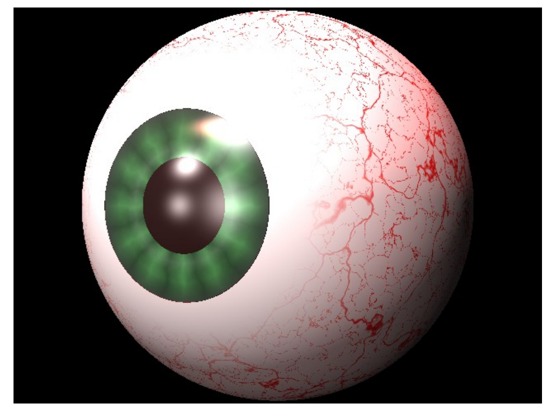
$CH_4$

$$A = \varepsilon l c$$

blackbody radiator



$CO_2$



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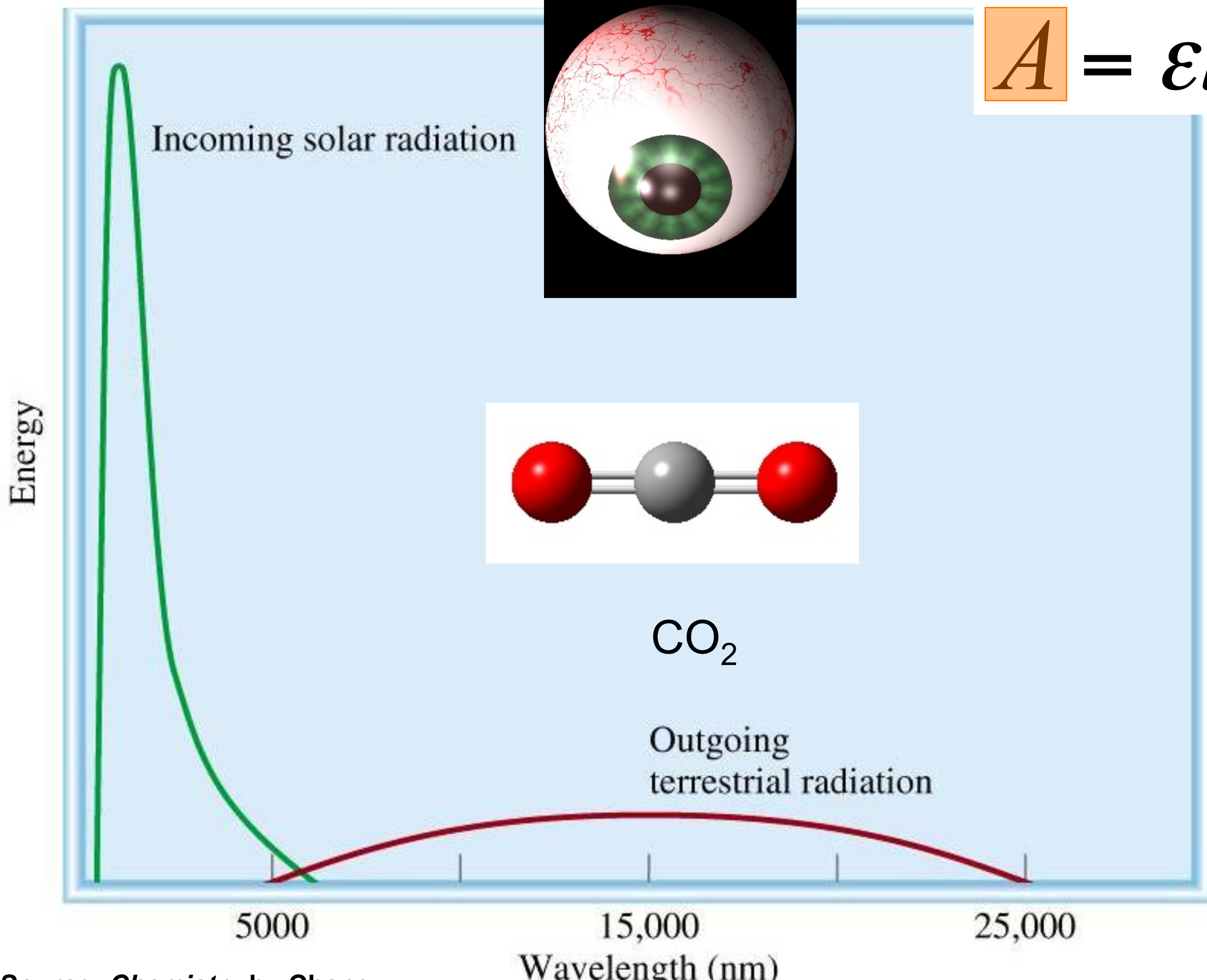
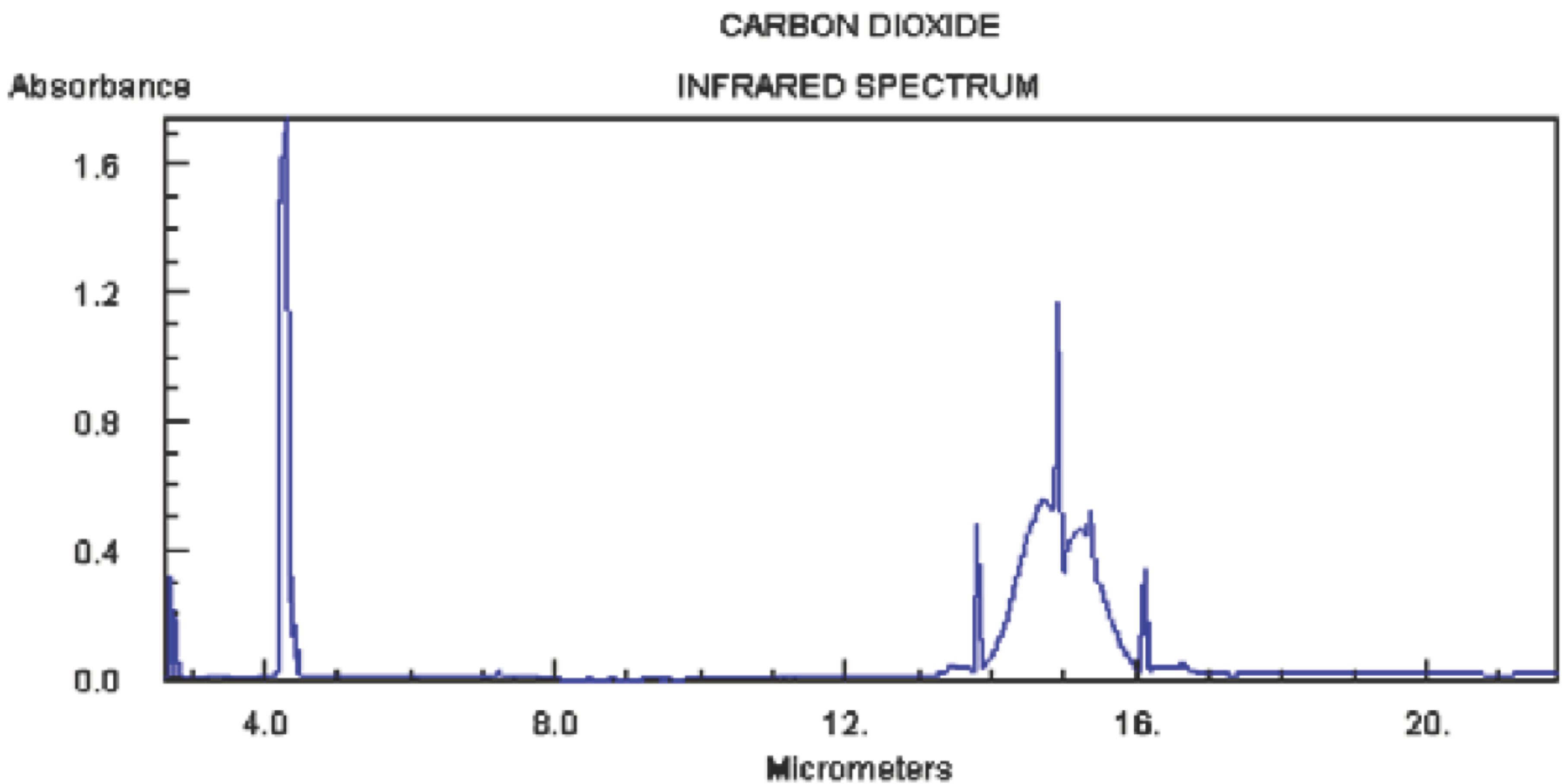



$CO_2$

Source: *Chemistry* by Chang


CARBON DIOXIDE
INFRARED SPECTRUM
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1.6
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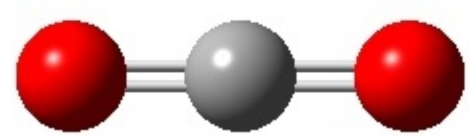
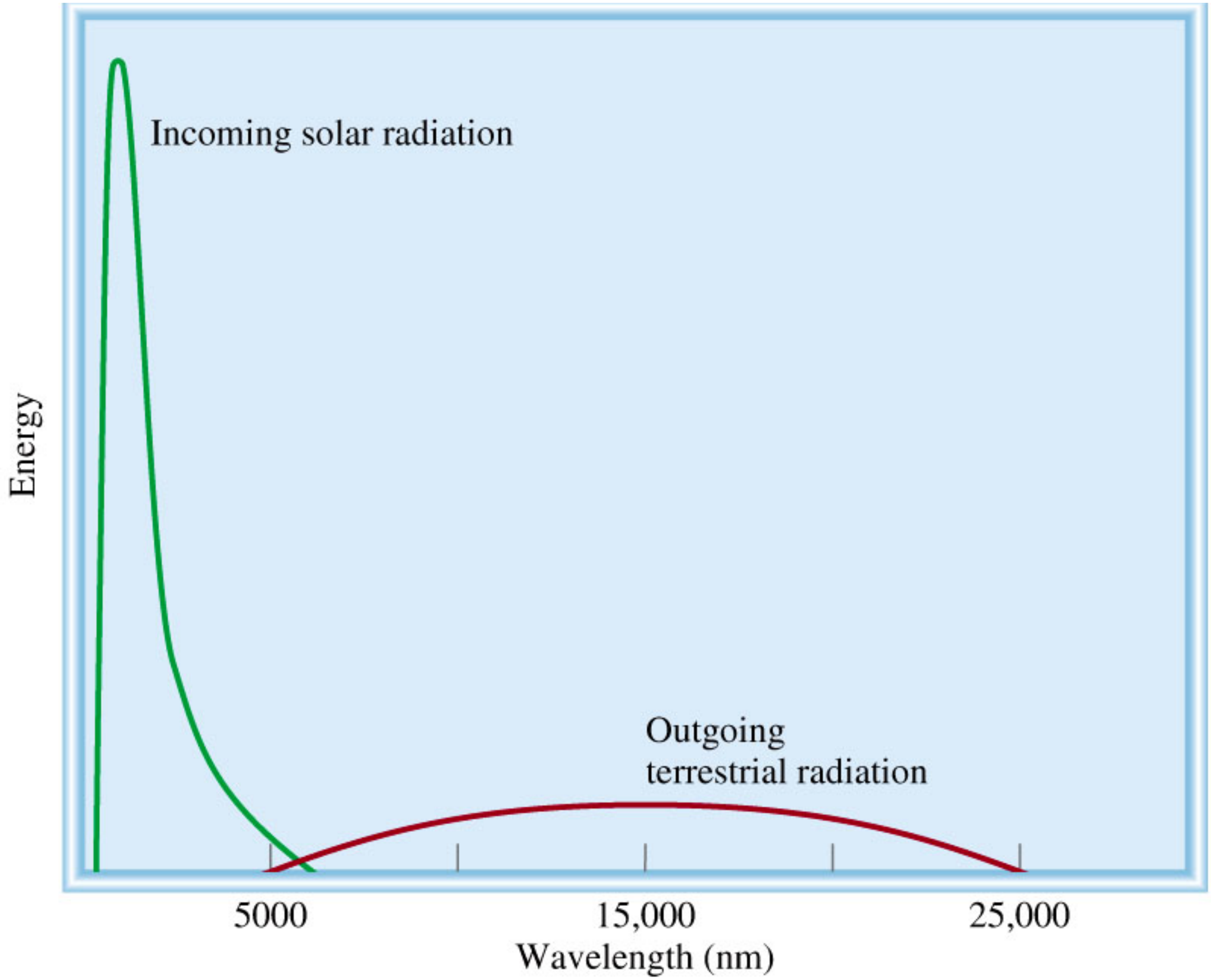


$CO_2$

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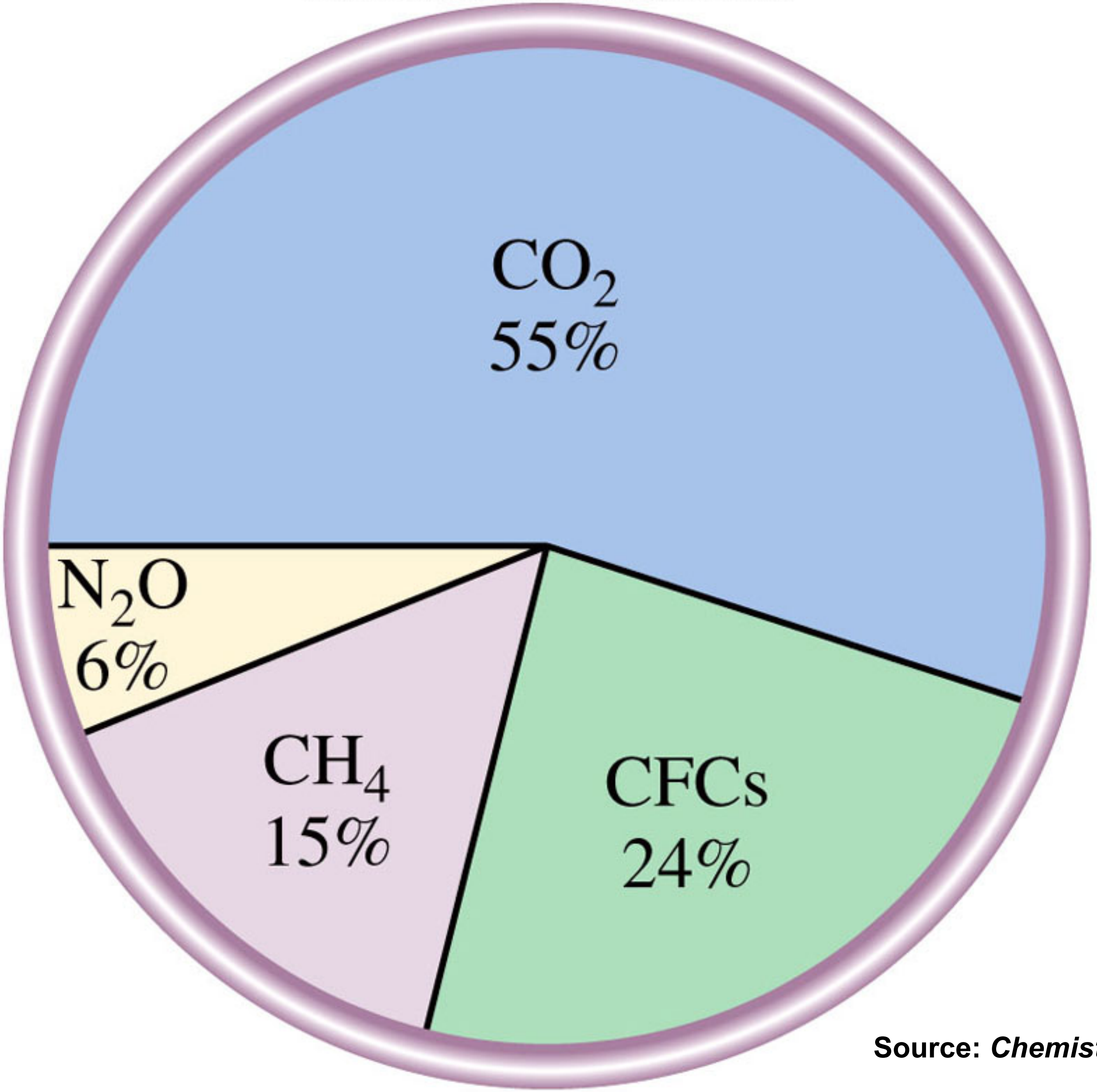


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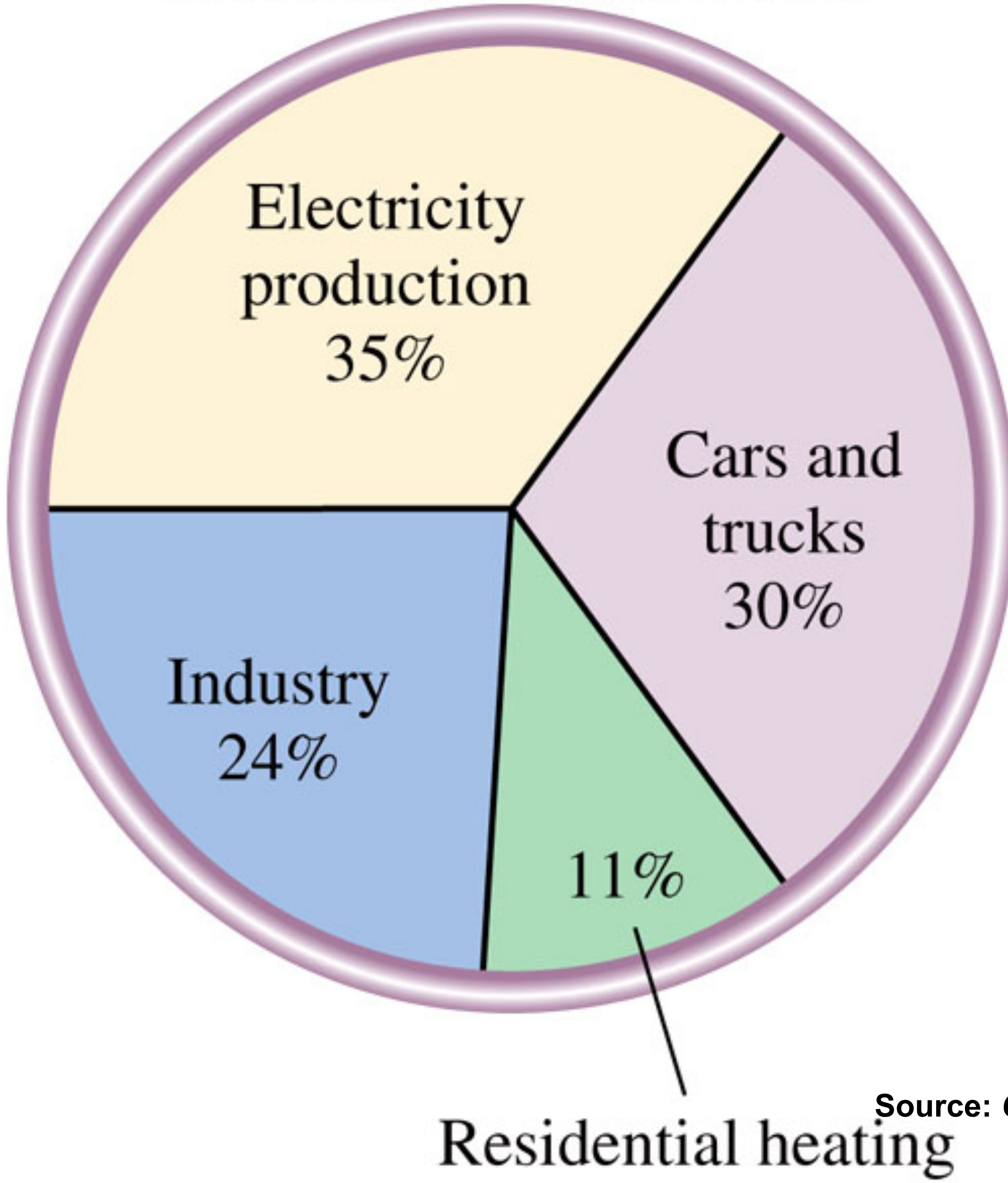


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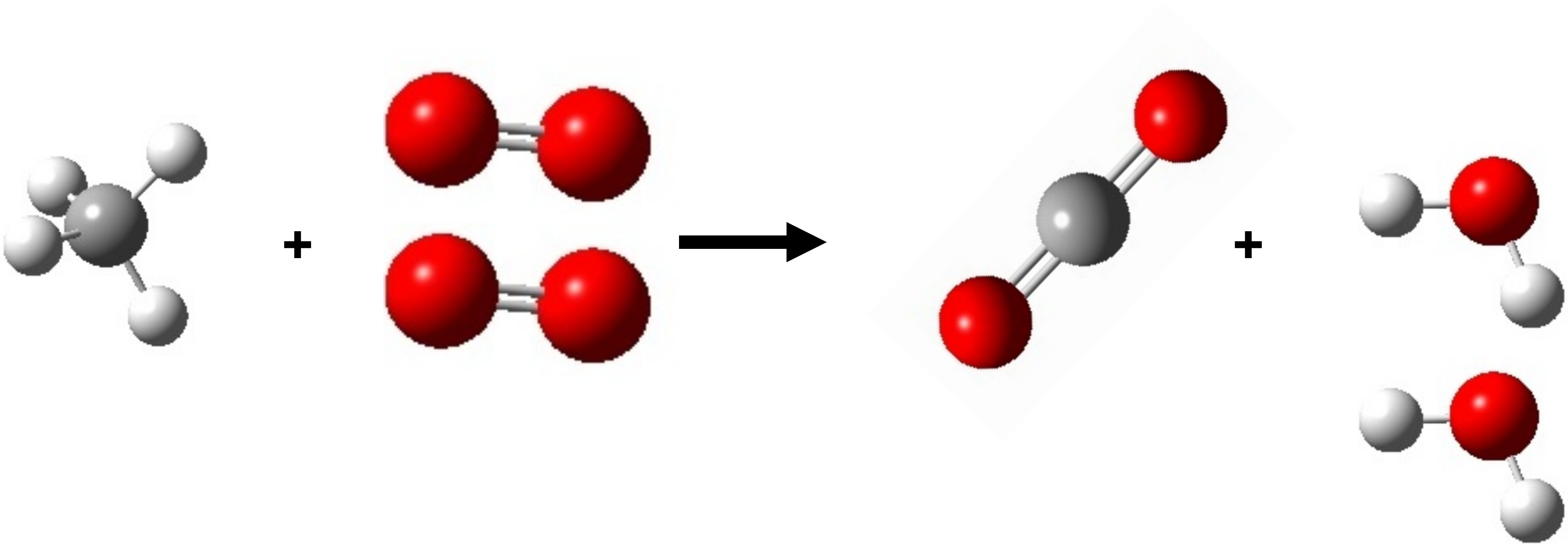


$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

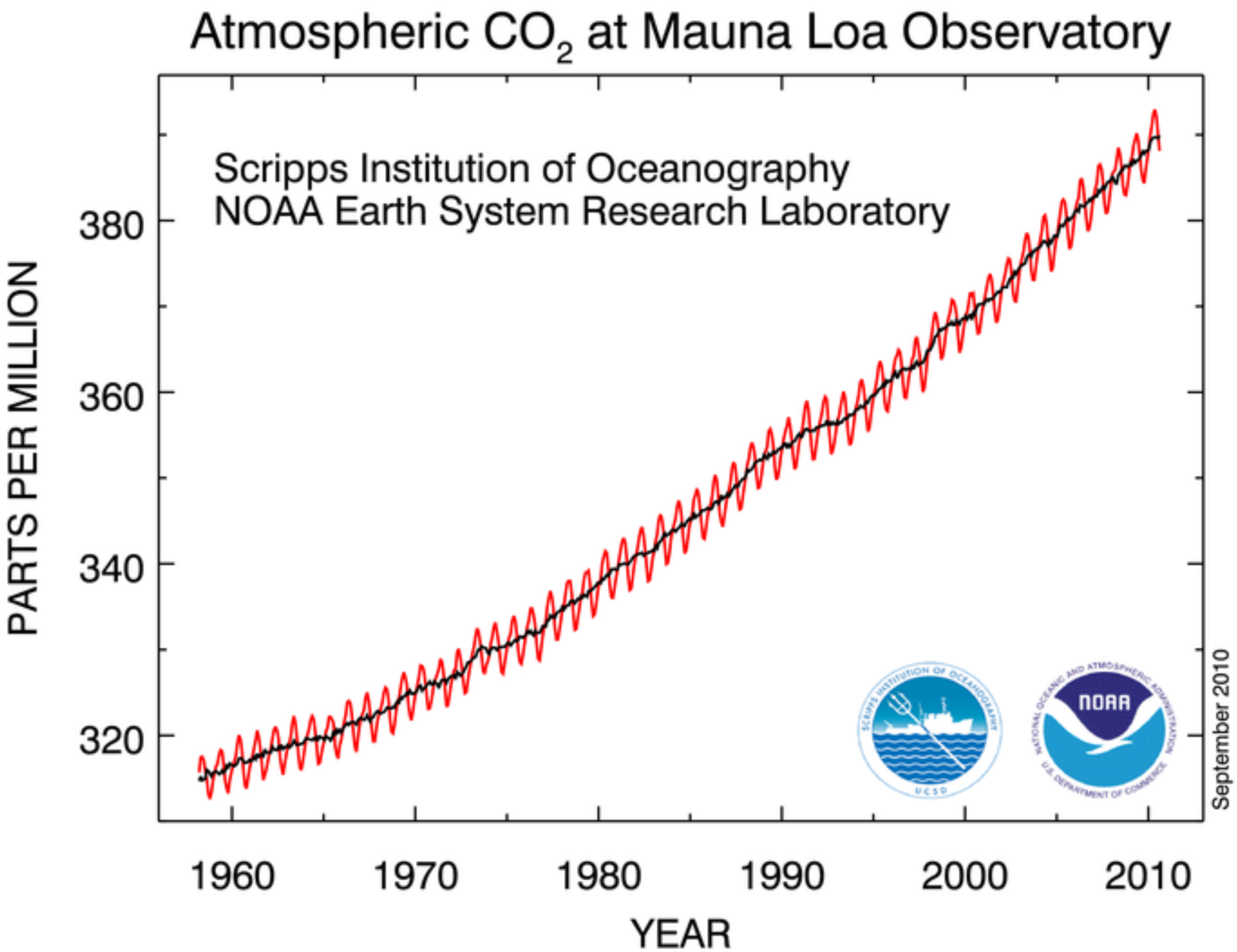
## Standard Enthalpies of Combustion at 25°C ($kJ \cdot mol^{-1}$)*

| Substance | Formula | $\Delta H_c°$ |
|---|---|---|
| benzene | $C_6H_6(l)$ | −3268 |
| carbon | C(s, graphite) | −394 |
| ethanol | $C_2H_5OH(l)$ | −1368 |
| ethyne (acetylene) | $C_2H_2(g)$ | −1300. |
| glucose | $C_6H_{12}O_6(s)$ | −2808 |
| hydrogen | $H_2(g)$ | −286 |
| methane | $CH_4(g)$ | −890. |
| octane | $C_8H_{18}(l)$ | −5471 |
| propane | $C_3H_8(g)$ | −2220. |
| urea | $CO(NH_2)_2(s)$ | −632 |

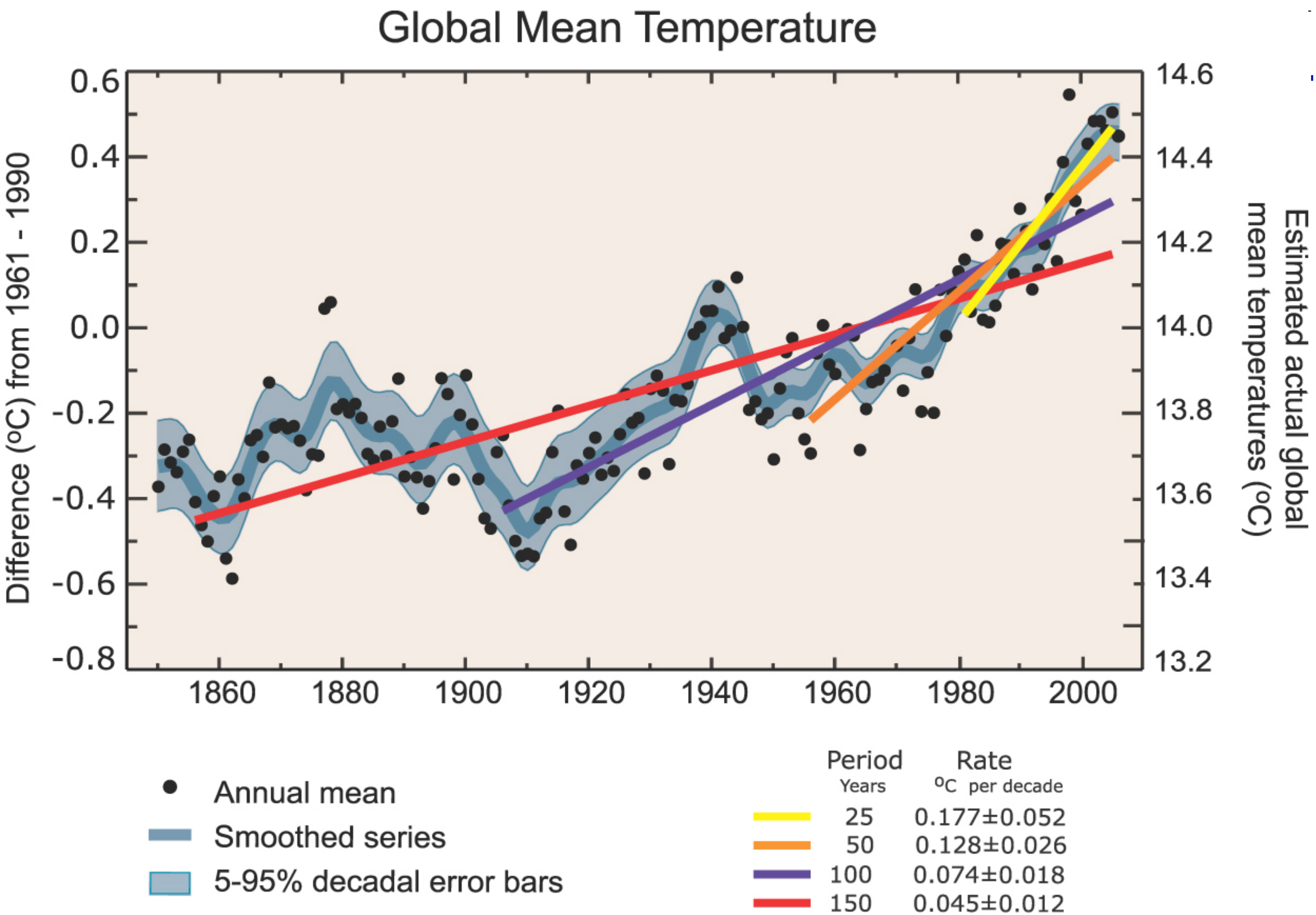
*In a combustion, carbon is converted into carbon dioxide, hydrogen into liquid water, and nitrogen into nitrogen gas. More values are given in Appendix 2A.

**Source:** ***Chemical Principles*** **by Atkins and Jones**

# Yearly $CO_2$ Concentration Variation Mauna Loa, Hawaii




**http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full**




**Source: IPCC AR4**

Surface

Troposphere


**Photo credit: Chris Jordon**

An empty 1 liter bottle is made of approximately 25 grams of polyethylene terephthalate (PET).

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**

An empty 1 liter bottle is made of approximately 25 grams of polyethylene terephthalate (PET).

It takes 6.5 kilograms of oil to produce one 1000 grams of PET, using 294 kilograms of water and producing 3700 grams of carbon dioxide.

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**

An empty 1 liter bottle is made of approximately 25 grams of polyethylene terephthalate (PET).

It takes 6.5 kilograms of oil to produce one 1000 grams of PET, using 294 kilograms of water and producing 3700 grams of carbon dioxide.

Shipping water also consumes fuel and results in carbon dioxide emissions. These emissions can be expressed in units of grams per ton per kilometer.

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**Sustainability Engineer**
**ClimateCHECK**

An empty 1 liter bottle is made of approximately 25 grams of polyethylene terephthalate (PET).

It takes 6.5 kilograms of oil to produce one 1000 grams of PET, using 294 kilograms of water and producing 3700 grams of carbon dioxide.

Shipping water also consumes fuel and results in carbon dioxide emissions. These emissions can be expressed in units of grams per ton per kilometer.

| | |
|---|---|
| container ship: | 17 g/(ton·km) |
| train: | 56 g/(ton·km) |
| truck: | 102 g/(ton·km) |
| jet: | 570 g/(ton·km) |

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**

- 25 grams of polyethylene terephthalate (PET) per bottle
- 3700 grams of $CO_2$ produced per 1000 grams of PET
- 102 grams of $CO_2$ produce transporting one ton one kilometer
- Aquafina water is bottled in Wichita, Kansas
- 2822.5 km from Wichita, Kansas to Brunswick, Maine

**Source: Pablo Päster**
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**ClimateCHECK**

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## Production of Bottle

$$1\,\text{bottle} \times \frac{25\text{g PET}}{1\,\text{bottle}} \times \frac{3700\,\text{g CO}_2}{1000\,\text{g PET}} \times \frac{1\,\text{mol CO}_2}{44\,\text{g CO}_2} \times \frac{22.4\,\text{L CO}_2}{1\,\text{mol CO}_2}$$

$$\times \frac{1000\text{mL CO}_2}{1\,\text{L CO}_2} \times \frac{1\,\text{cm}^3\ \text{CO}_2}{1\,\text{mL CO}_2} = 47{,}091\,\text{cm}^3\ \text{CO}_2$$

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**Sustainability Engineer**
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- 2822.5 km from Wichita, Kansas to Brunswick, Maine

## Transportation

$$1\ \text{bottle} \times 2822.5\ \text{km} \times \frac{1000\ \text{mL H}_2\text{O}}{1\ \text{bottle}} \times \frac{1\ \text{g H}_2\text{O}}{1\ \text{mL H}_2\text{O}} \times \frac{1\ \text{kg H}_2\text{O}}{1000\ \text{g H}_2\text{O}}$$

$$\times \frac{1\ \text{ton H}_2\text{O}}{1000\ \text{kg H}_2\text{O}} \times \frac{102\ \text{g CO}_2}{1\ \text{ton H}_2\text{O} \times 1\ \text{km}} \times \frac{1\ \text{mol CO}_2}{44\ \text{g CO}_2}$$

$$\times \frac{22.4\ \text{L CO}_2}{1\ \text{mol CO}_2} \times \frac{1000\ \text{mL CO}_2}{1\ \text{L CO}_2} \times \frac{1\ \text{cm}^3\ \text{CO}_2}{1\ \text{mL CO}_2} = 146{,}565\ \text{cm}^3\ \text{CO}_2$$

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**

- 25 grams of polyethylene terephthalate (PET) per bottle
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- 2822.5 km from Wichita, Kansas to Brunswick, Maine

**Total = Production + Transportation**

$$47{,}091\,\text{cm}^3\ CO_2 + 146{,}565\,\text{cm}^3\ CO_2 = 193{,}656\,\text{cm}^3\ CO_2$$

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**

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- 102 grams of $CO_2$ produce transporting one ton one kilometer
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## Volume of sphere with 16” diameter

$$\frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times 8^3 \text{ inches}^3 \times \frac{2.54^3 \text{ cm}^3}{1 \text{ inch}^3} = 35{,}145 \text{ cm}^3$$

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**

- 25 grams of polyethylene terephthalate (PET) per bottle
- 3700 grams of $CO_2$ produced per 1000 grams of PET
- 102 grams of $CO_2$ produce transporting one ton one kilometer
- Aquafina water is bottled in Wichita, Kansas
- 2822.5 km from Wichita, Kansas to Brunswick, Maine

**Number of 16" diameter balls filled with carbon emissions from one liter of water:**

$$\frac{1\ \text{ball}}{34{,}145\ \text{cm}^3\ CO_2} \times \frac{193{,}656\ \text{cm}^3\ CO_2}{1\ \text{bottle}} = 5.5\ \frac{\text{ball}}{\text{bottle}}$$

**Source: Pablo Päster**
**Sustainability Engineer**
**ClimateCHECK**


**Photo credit: Chris Jordon**

**Plastic Bottles, 2007**

60x120" by Chris Jordon

**Plastic Bottles, 2007**
60x120" by Chris Jordon

# “Depicts two million plastic beverage bottles, the number used in the US every five minutes.”

## Sources and Resources


- *Chemistry, 9th Edition* by Raymond Chang, McGraw Hill, 2007.
- *Chemical Principles: The Quest for Insight, 4th Edition* by Peter Atkins & Loretta Jones, W. H. Freeman, 2008.
- *Climate Change 2007: Synthesis Report* (Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change) Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, 2007.
- *Earth Under Siege, 2nd Edition* by Richard P. Turco, Oxford University Press, 2002.