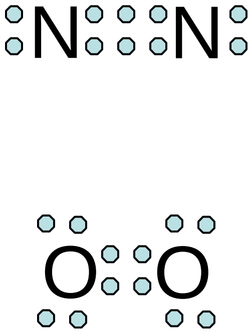
Tentative Course Schedule

Jan 30	Introduction / The Air We Breathe	Ch 1	Survey
Feb 1	The Air We Breathe	Ch 1	Q 1
Feb 6	The Air We Breathe	Ch 1	
Feb 8	The Air We Breathe	Ch 1	Q 2, HW 1
Feb 13	Protecting the Ozone Layer	Ch 2	
Feb 15	Protecting the Ozone Layer	Ch 2	Q 3, HW 2
Feb 20	Protecting the Ozone Layer	Ch 2	
Feb 22	**Exam 1** (Ch 1 and 2)		E 1, HW 3
Feb 27	The Chemistry of Global Warming	Ch 3	
Mar 1	The Chemistry of Global Warming	Ch 3	Q 4, HW 4
Mar 6	The Chemistry of Global Warming	Ch 3	
Mar 8	The Chemistry of Global Warming	Ch 3	Q 5, HW 5
Mar 13	Energy, Chemistry and Society	Ch 4	
Mar 15	Energy, Chemistry and Society	Ch 4	Q 6, HW 6
(March 20 + 22 – no class, Spring Break)			
Mar 27	Energy, Chemistry and Society	Ch 4	
Mar 29	The Water We Drink	Ch 5	Q 7
Apr 3	The Water We Drink (Review)	Ch 5	
Apr 5	**Exam 2** (Ch 3, 4, and parts of 5)		E 2, HW 7

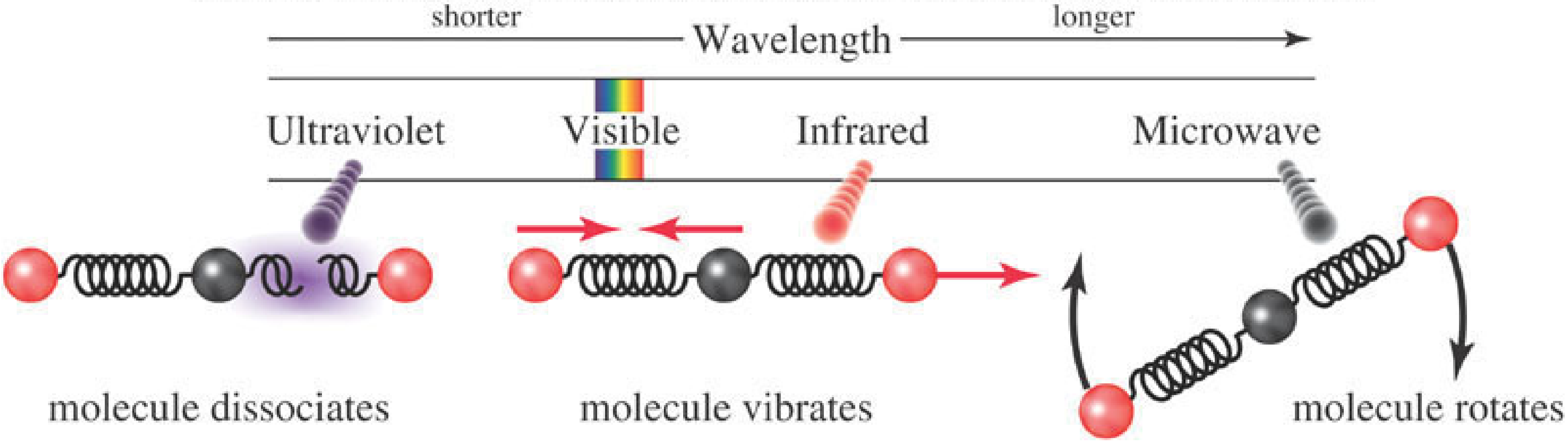
- Greenhouse Gases
  - – H_2O, CO_2, CH_4
- Not Greenhouse Gases
  - – N_2, O_2, Ar
- Molecular Structure
- Molecular Shape



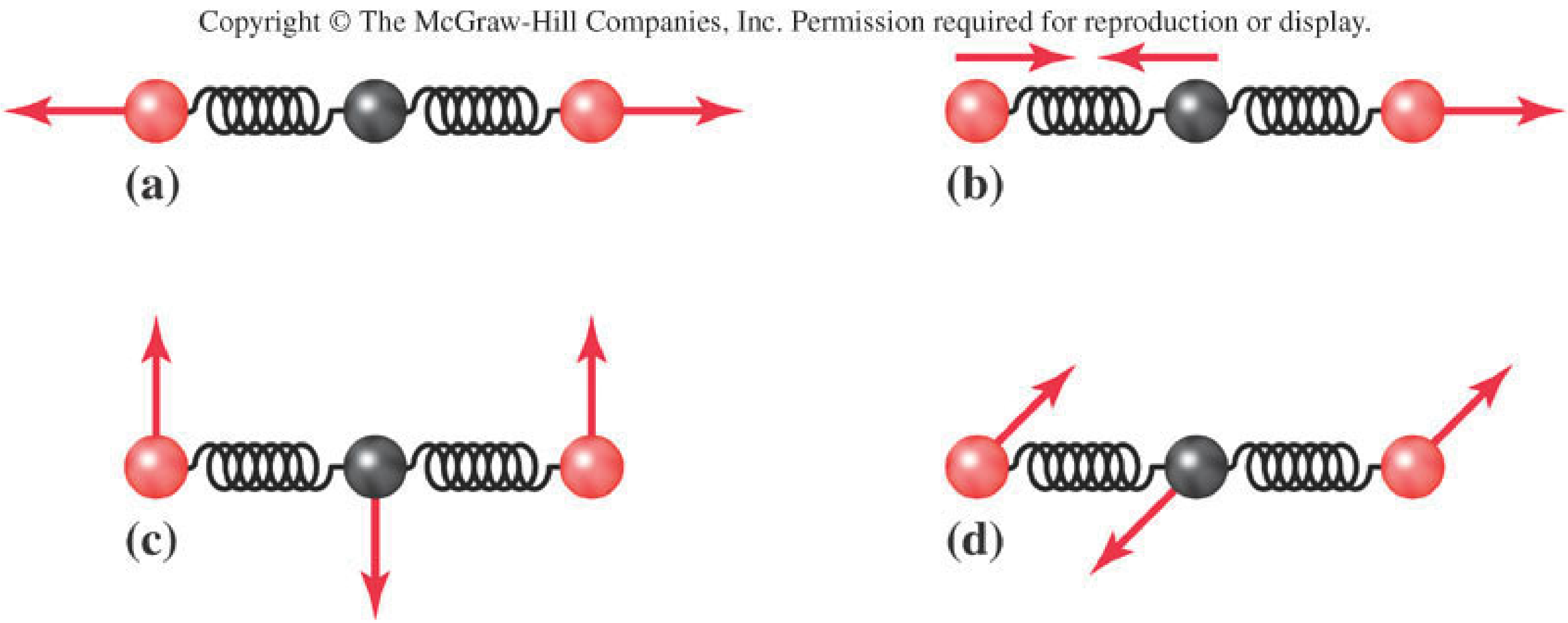
$N\equiv N$

$O=O$

The Interaction of Light with Molecules

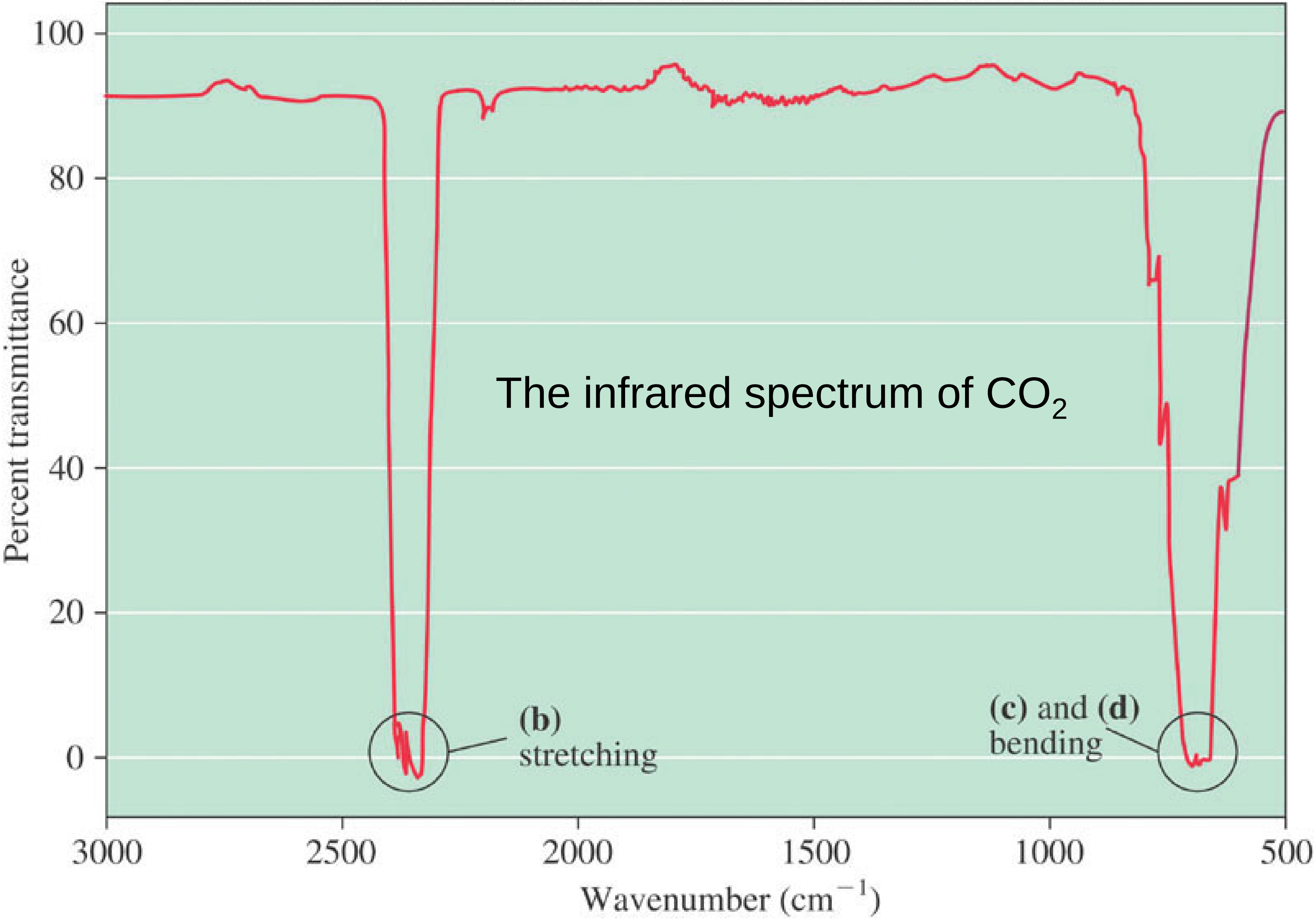


Molecular Vibrations in CO_2



Similarly, each **vibration** of a bond has a given frequency that corresponds to the frequency of IR radiation needed to make it oscillate.

BUT... Not all vibrations absorb infrared radiation!



The infrared spectrum of CO_2

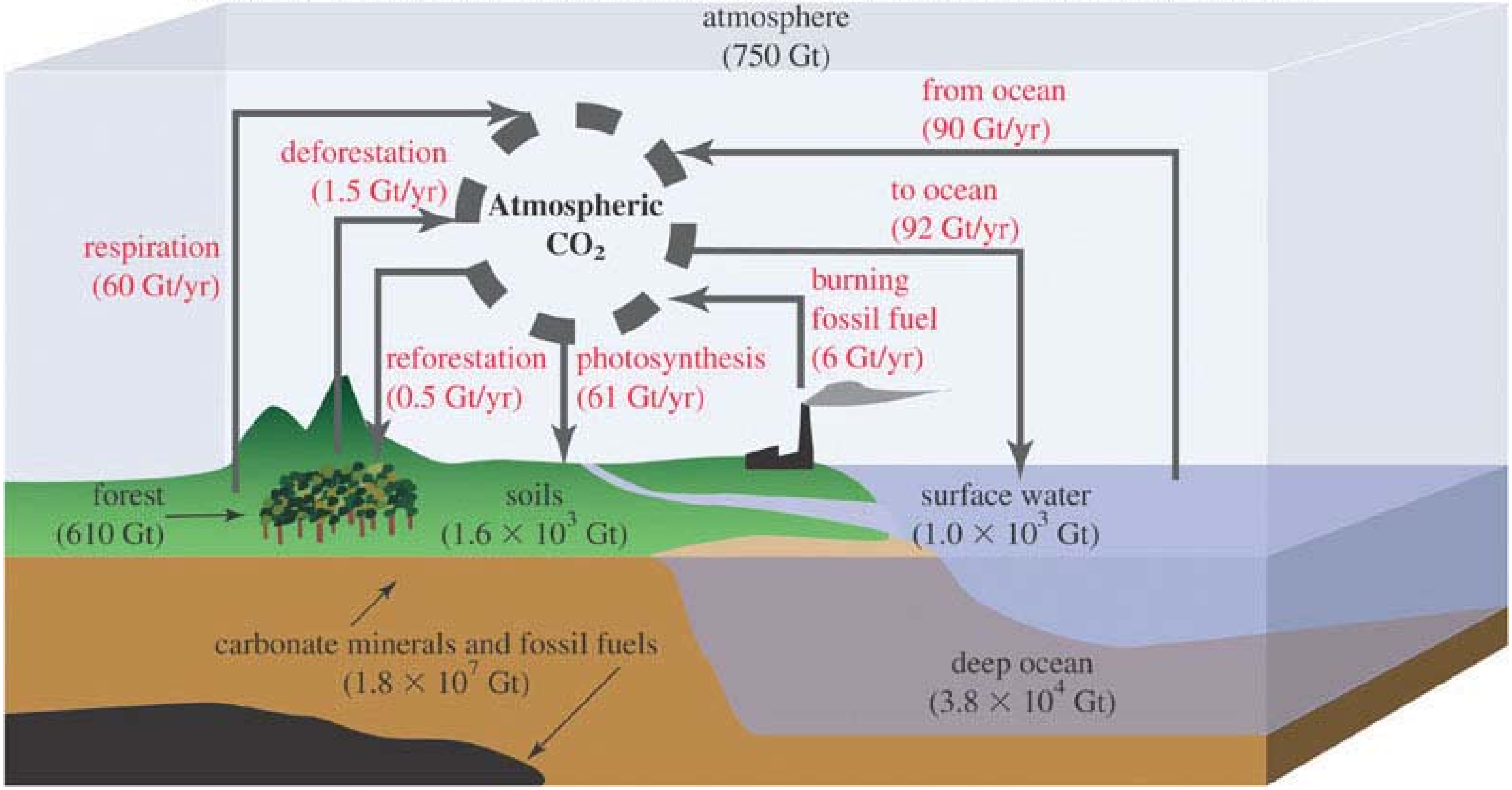
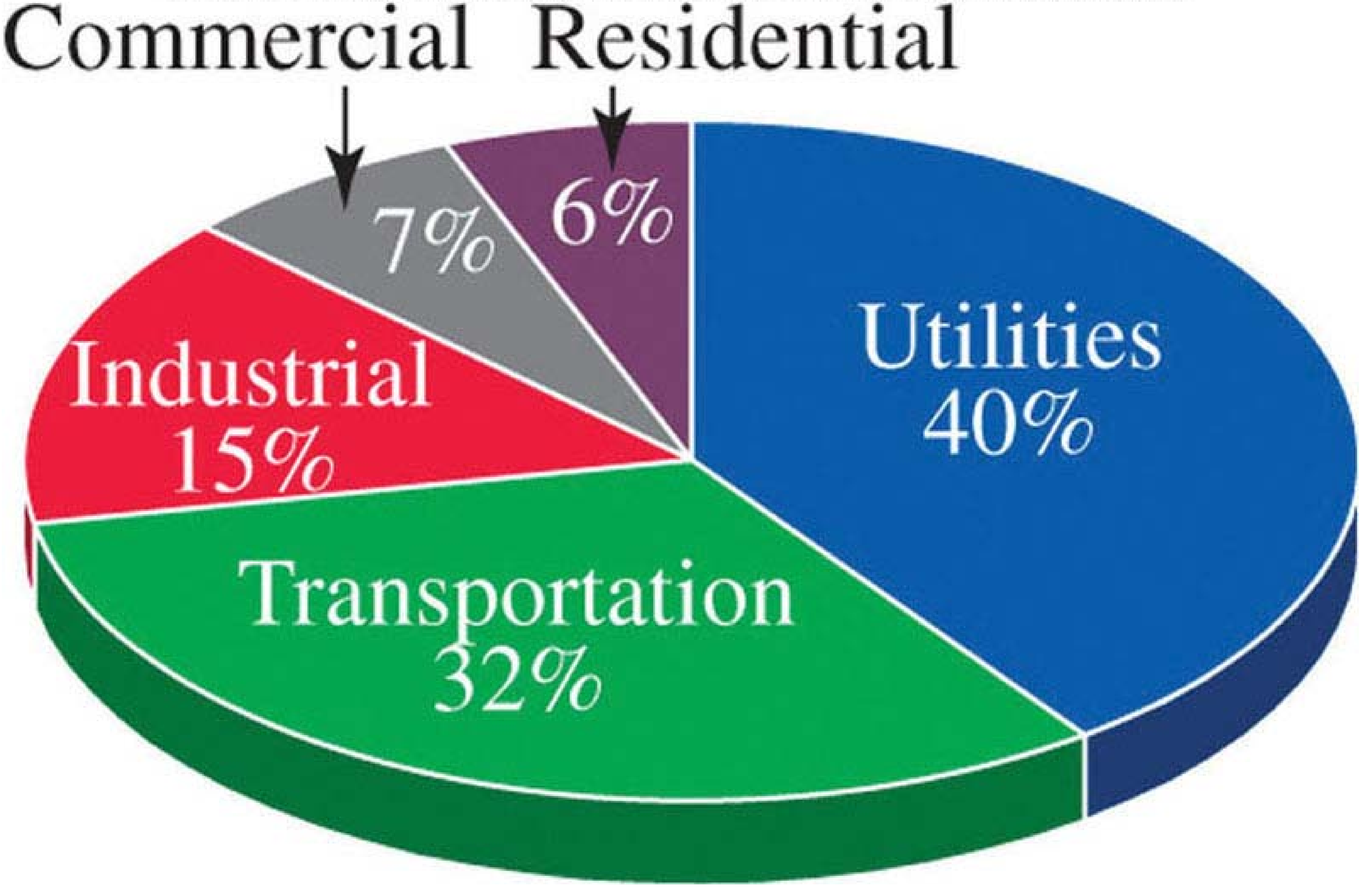

atmosphere
(750 Gt)
from ocean
(90 Gt/yr)
deforestation
(1.5 Gt/yr)
Atmospheric
CO_2
to ocean
(92 Gt/yr)
respiration
(60 Gt/yr)
burning
fossil fuel
(6 Gt/yr)
reforestation
(0.5 Gt/yr)
photosynthesis
(61 Gt/yr)
forest
(610 Gt)
soils
(1.6 × 10^3 Gt)
surface water
(1.0 × 10^3 Gt)
carbonate minerals and fossil fuels
(1.8 × 10^7 Gt)
deep ocean
(3.8 × 10^4 Gt)

Table 3.1 The Earth's Carbon Reservoirs

	Size (Gt Carbon)
Reservoir	
Atmosphere	750
Forests	610
Soils	1,580
Surface ocean	1,020
Deep ocean	38,100
Total carbon, excluding fossil fuels	42,060
Fossil fuels	
Coal	4,000
Oil	500
Natural gas	500
Total fossil fuel	5,000
Total, all sources	47,060

Source: From James F. Kasting, "The Carbon Cycle, Climate, and the Long-Term Effects of Fossil Fuel Burning," *Consequences, The Nature & Implications of Environmental Change*, Vol. 4, No. 1, 1998. Reprinted with permission.


Commercial
Residential
7%
6%
Utilities
40%
Industrial
15%
Transportation
32%

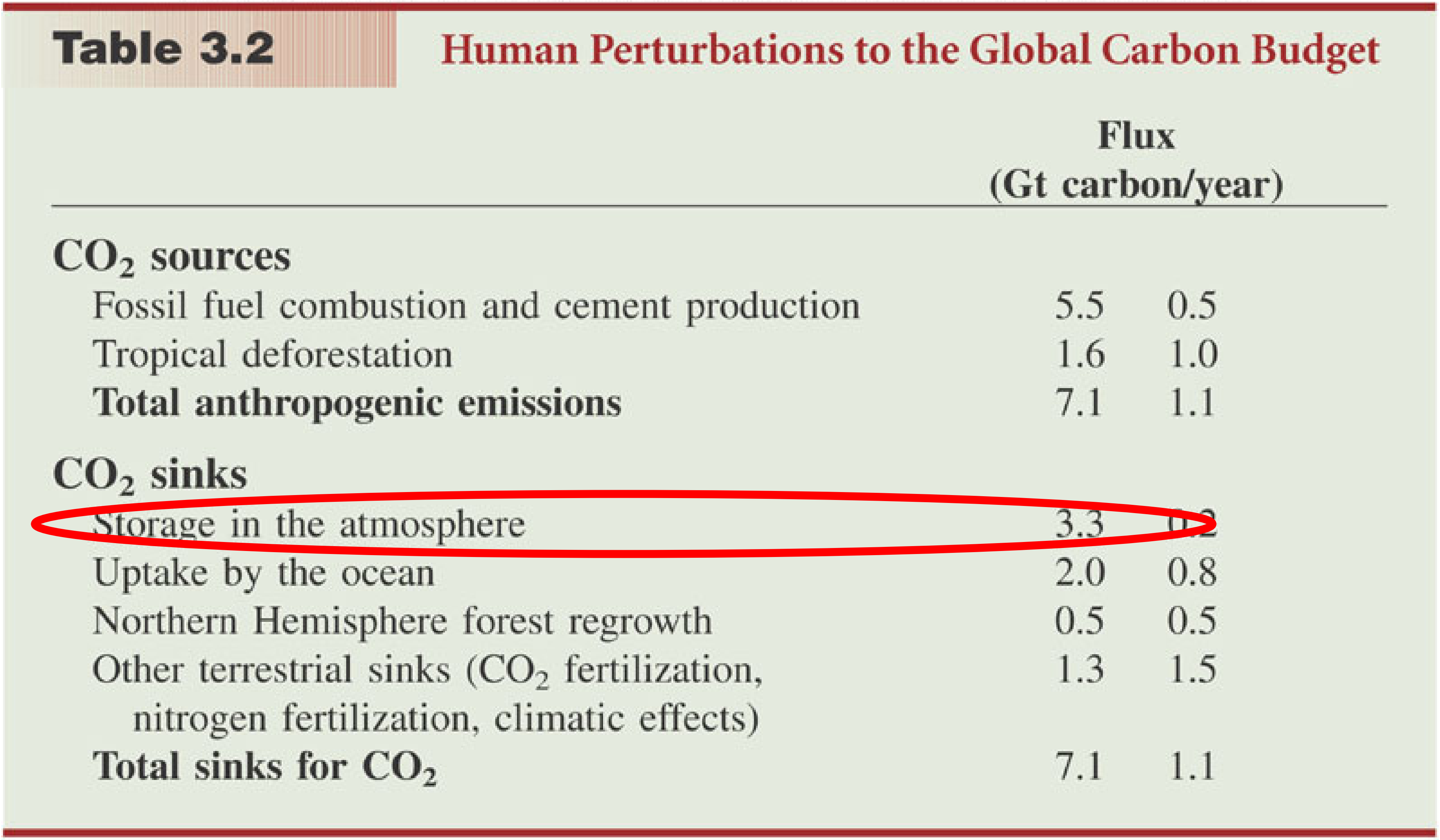
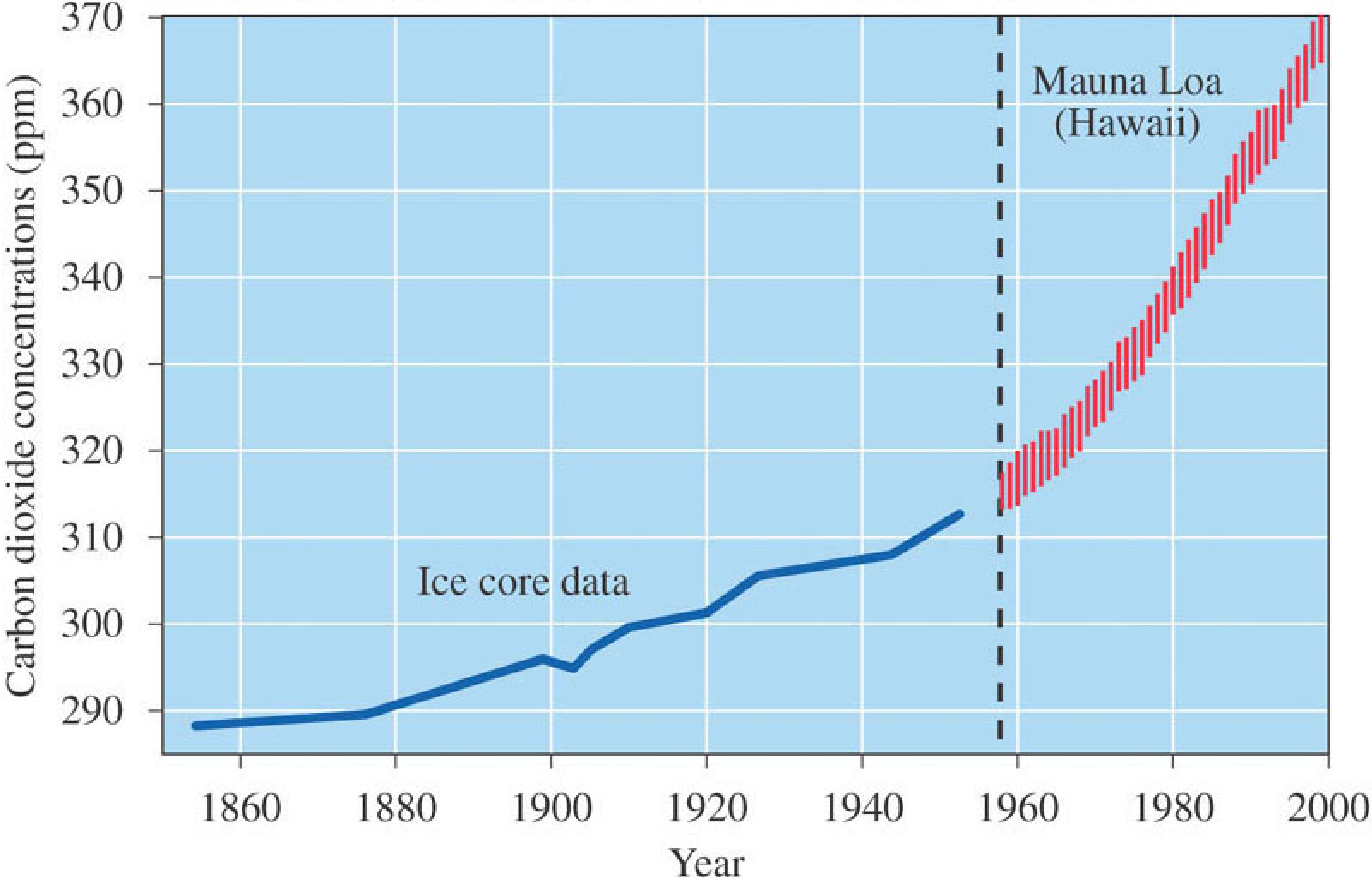


Table 3.2 Human Perturbations to the Global Carbon Budget

	Flux (Gt carbon/year)	
CO_2 sources		
Fossil fuel combustion and cement production	5.5	0.5
Tropical deforestation	1.6	1.0
Total anthropogenic emissions	7.1	1.1
CO_2 sinks		
Storage in the atmosphere	3.3	0.2
Uptake by the ocean	2.0	0.8
Northern Hemisphere forest regrowth	0.5	0.5
Other terrestrial sinks (CO_2 fertilization, nitrogen fertilization, climatic effects)	1.3	1.5
Total sinks for CO_2	7.1	1.1

Source: From James F. Kasting, "The Carbon Cycle, Climate, and the Long-Term Effects of Fossil Fuel Burning," *Consequences, The Nature & Implications of Environmental Change*, Vol. 4, No. 1, 1998. Reprinted with permission.


Carbon dioxide concentrations (ppm)
370
360
350
340
330
320
310
300
290
Mauna Loa
(Hawaii)
Ice core data
1860
1880
1900
1920
1940
1960
1980
2000
Year

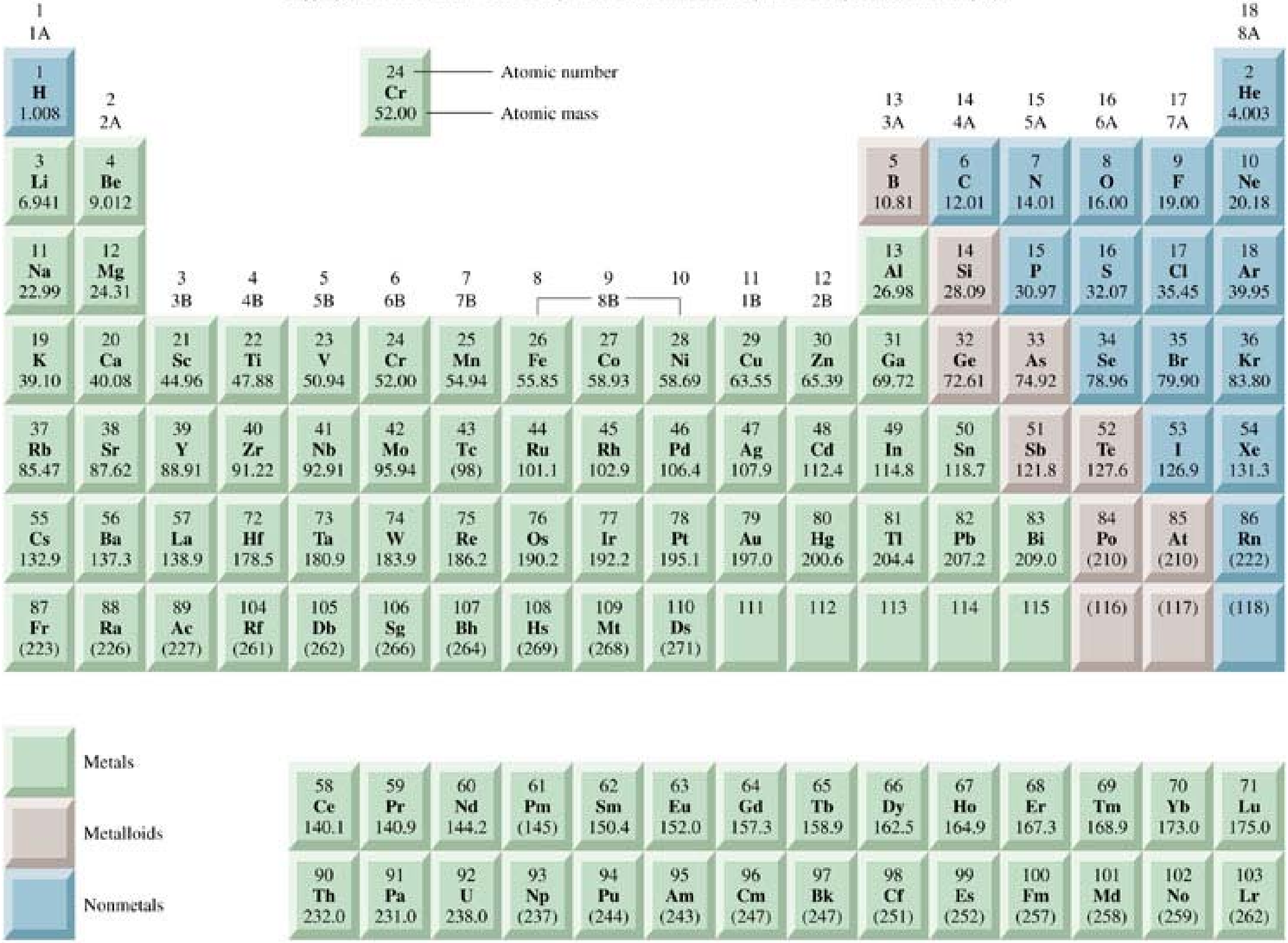
- 3.3 Gt of carbon added to the atmosphere every year.
  - 1 Gt = 10^9 t
  - 1t = 10^3 kg
  - 1kg = 10^3 g
  - So 1 Gt = $10^{(9 + 3 + 3)}$ g = 10^{15} g

3.3 x 10^{15} g Carbon added to the air each year

Atomic Mass

$^{12}_{6}C$

- Mass Number of 12
- Atomic Number of 6
  - 6 Protons
  - 6 Neutrons
- One atom of carbon-12 has a mass of 12 atomic mass units (amu)



24 — Atomic number
Cr
52.00 — Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (269)	109 **Mt** (268)	110 **Ds** (271)	111	112	113	114	115	(116)	(117)	(118)

🟩 Metals

🟫 Metalloids

🟦 Nonmetals

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

The 1–18 group designation has been recommended by the International Union of Pure and Applied Chemistry (IUPAC) but is not yet in wide use. In this text we use the standard U.S. notation for group numbers (1A–8A and 1B–8B). No names have been assigned for elements 111–115. Elements 116–118 have not yet been synthesized.

1 amu = 1.66 x 10^{-24} g

Carbon weighs 12.01 amu, so one carbon atom weighs

$$12.01 amu\, C \times \frac{1.66 \times 10^{-24} g}{1 amu} = 1.99 \times 10^{-23} g\, C$$

- How about carbon dioxide?
  - Each molecule contains 1 carbon atom and 2 oxygen atoms
  - The mass of one molecule of CO_2 = mass of 1 carbon atom plus mass of 2 oxygen atoms

$$m_{CO_2} = m_C + 2m_O = 12.01 amu + 2(16.00 amu) = 44.01 amu$$

$$44.01 amu \times \frac{1.66 \times 10^{-24} g}{1 amu} = 7.30 \times 10^{-23} g$$

If we have 0.1 mg of CO_2, how many atoms does that contain?

$$0.1 mg\, CO_2 \times \frac{1 g}{1000\, mg} \times \frac{1 molecule\, CO_2}{7.30 \times 10^{-23}\, gCO_2} = 1.37 \times 10^{18}\, molecule\, CO_2$$

- Atomic Mass – defined as the mass in grams of the same number of atoms that are found in 12 g of carbon-12.

$$12.00 g\, CO_2 \times \frac{1\, atom\, C}{1.99\times 10^{-23} g\, C} = 6.02\times 10^{23} atoms\ of\ \ C$$

- This number is defined as Avogadro’s Number
- $N_A = 6.02 \text{ x } 10^{23}$

- If you have Avogadro’s number of ANYTHING you have a MOLE of whatever you are counting. (Think “dozen”)
  - If you have 6.02×10^{23} golf balls then you have a mole of golf balls.
  - If you have 6.02×10^{23} carbon atoms then you have a mole of carbon atoms.
  - If you have 6.02×10^{23} carbon dioxide molecules then you have a mole of carbon dioxide molecules.

- Molar Mass – the mass of one Avogadro’s number, or mole, of whatever particles are specified.
  - 1 mole of C contains 6.02 x 10^{23} carbon atoms and weighs 12.01 g
    - Carbon has molar mass of 12.01 g/mol
  - 1 mole of O contains 6.02 x 10^{23} oxygen atoms and weighs 16.00 g
    - Molar mass of oxygen is 16.00 g/mol
  - 1 mole of He contains 6.02 x 10^{23} helium atoms and weighs 4.003 g
    - Molar mass of helium is 4.003 g/mol
  - 1 mole of U contains 6.02 x 10^{23} uranium atoms and weighs 208.0 g
    - Molar mass of uranium is 208.0 g/mol

- One mole of CO_2 contains how many molecules of CO_2?
  - 6.02 x 10^{23} CO_2/mol
- How many moles of carbon in one mole of CO_2?
  - Since one molecule of CO_2 contains 1 atom of C, one mole of CO_2 contains 1 mole of C.
- How many moles of oxygen in one mole of CO_2?
  - Since one molecule of CO_2 contains 2 atoms of O, one mole of CO_2 contains 2 moles of O.

- How many atoms of carbon in one mole of CO_2?

$$1\,mol\,CO_2 \times \frac{6.02\times 10^{23}\,CO_2\ molecule}{1\,mol\,CO_2} \times \frac{1\,C\ atom}{1\,CO_2\ molecule} = 6.02\times 10^{23}\,C\ atoms$$

- How many atoms of oxygen in one mole of CO_2?

$$1\,mol\,CO_2 \times \frac{6.02\times 10^{23}\,CO_2\ molecule}{1\,mol\,CO_2} \times \frac{2\,O\ atom}{1\,CO_2\ molecule} = 1.20\times 10^{24}\ O\ atoms$$

- If 3.3 Gt (3.3 x 10^{15} g) of carbon is added to the atmosphere every year, how much CO_2 is that?

$$3.3\times10^{15}\,g\,C\times\frac{1\,mol\,C}{12.01\,g\,C}\times\frac{1\,mol\,CO_2}{1\,mol\,C}\times\frac{44.01\,g\,CO_2}{1\,molCO_2}=1.2\times10^{16}\,g\,CO_2$$

- 1.2 x 10^{16} g CO_2 emitted/year
- 12 Gt/year

How is CO_2 produced by the combustion of fossil fuels?

Coal (solid carbon)

$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$

Gasoline (primarily octane)

$C_8H_{18}\ (l) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (g)$

Natural gas (methane)

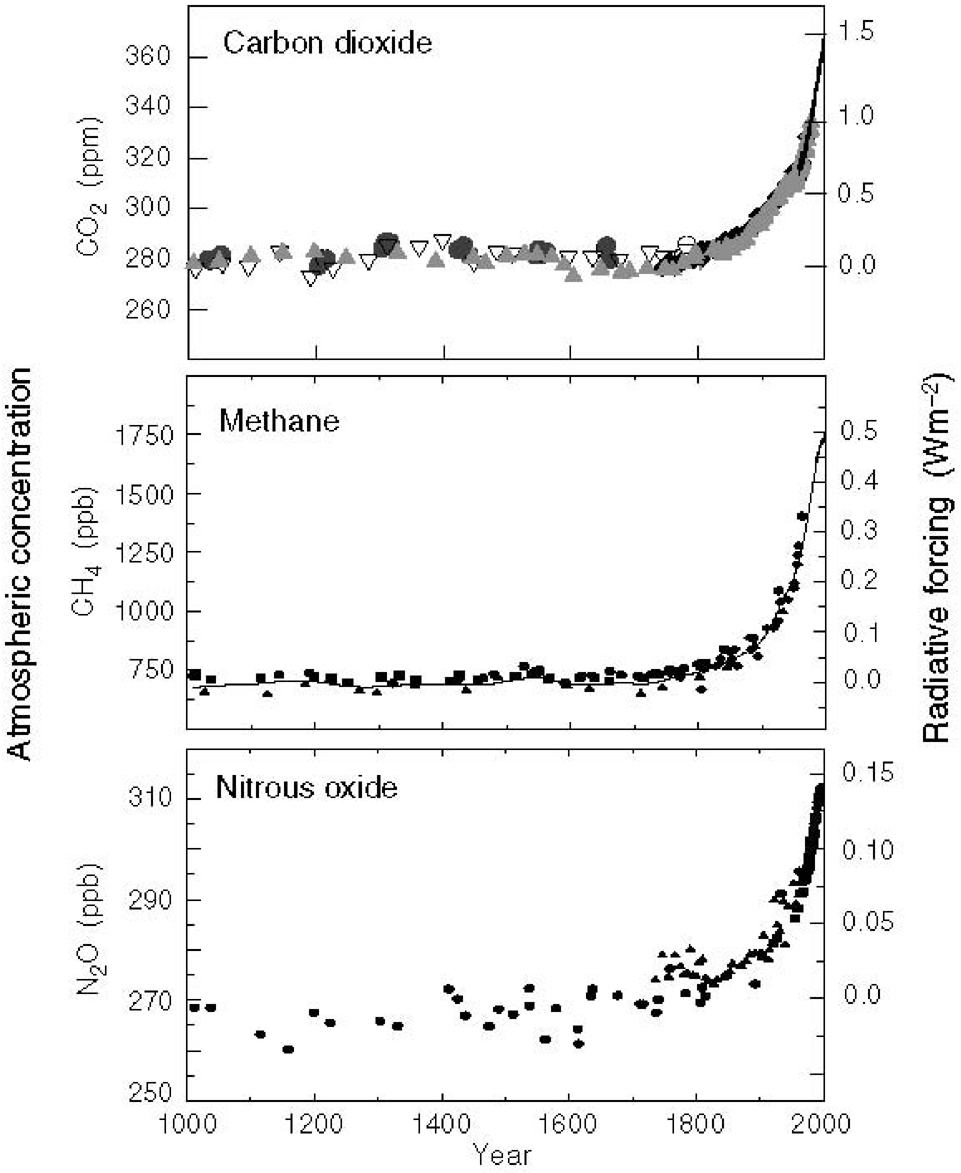
$CH_4\ (g) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (g)$

Other Greenhouse Gases

- H_2O
- CH_4
- N_2O
- O_3
- CFCs
- SF_6

Indicators of the human influence on the atmosphere during the Industrial Era

(a) Global atmospheric concentrations of three well mixed greenhouse gases



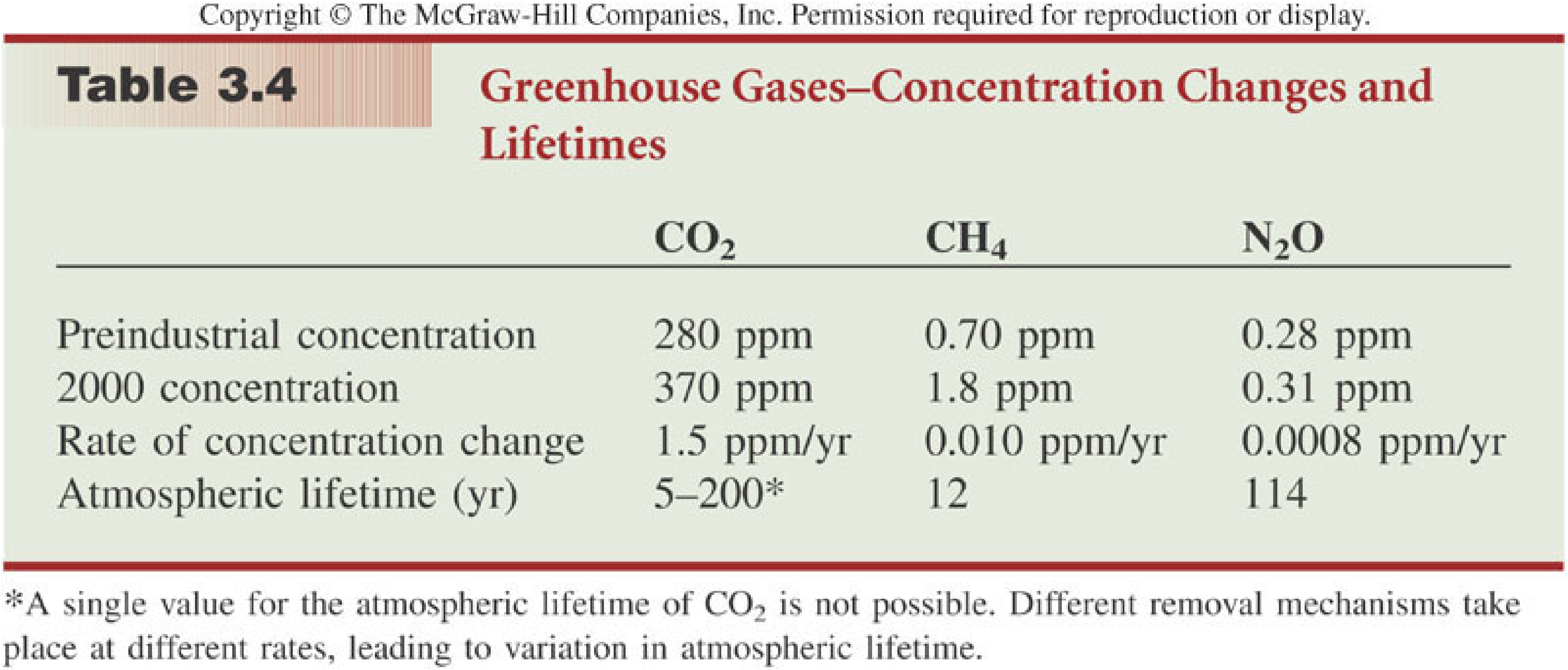


Table 3.4 Greenhouse Gases–Concentration Changes and Lifetimes

	CO_2	CH_4	N_2O
Preindustrial concentration	280 ppm	0.70 ppm	0.28 ppm
2000 concentration	370 ppm	1.8 ppm	0.31 ppm
Rate of concentration change	1.5 ppm/yr	0.010 ppm/yr	0.0008 ppm/yr
Atmospheric lifetime (yr)	5–200*	12	114

*A single value for the atmospheric lifetime of CO_2 is not possible. Different removal mechanisms take place at different rates, leading to variation in atmospheric lifetime.

- Global Warming Potential (GWP)
  - A number that represents the relative contribution of a molecule of the indicated substance to global warming.
    - Ability to absorb IR radiation
    - Atmospheric lifetime

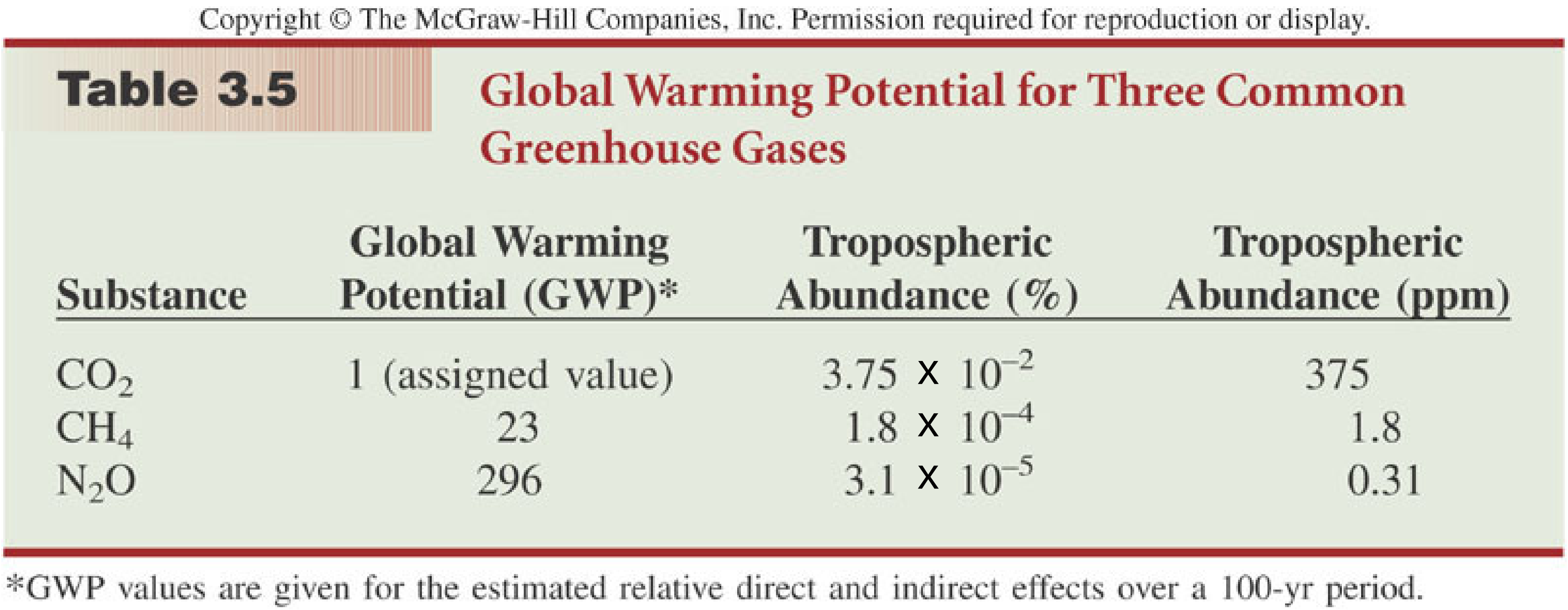


Table 3.5 Global Warming Potential for Three Common Greenhouse Gases

Substance	Global Warming Potential (GWP)*	Tropospheric Abundance (%)	Tropospheric Abundance (ppm)
CO_2	1 (assigned value)	3.75×10^{-2}	375
CH_4	23	1.8×10^{-4}	1.8
N_2O	296	3.1×10^{-5}	0.31

*GWP values are given for the estimated relative direct and indirect effects over a 100-yr period.