KEY

CHEM 304
SPRING 2009
HW/Learning Goals #7: Climate: Radiation balance & Greenhouse Gases

1. Sketch a plot with 3 blackbody radiation curves (relative emission energy/power vs. wavelength), one each for 300K, 2000K, and 6000K (assuming each body is the same size (mass)). These are just sketches, but try to make the features correct (peak wavelength as well as "breadth" of the distribution). Calculate the peak wavelengths (I gave a simple formula in class) and label them on the plot.

2. The questions below pertain to the equation below that we derived in class on the basis of a *steady-state* radiation balance. This enables one to calculate the *effective radiation temperature* of an "atmosphereless" planet.

$$T_{eff} = \left\{\frac{(1-A)F_s}{4s}\right\}^{\frac{1}{4}} \quad (s=5.67 \times 10^{-8}\ W/m^2K^4)$$

a. What two "inputs" in the equation above can effect global climate? Do you suppose that either of these could these be altered by human activities?

b. Given that the "solar constant" ($F_s$) for Earth is 1380 W/m², and the "albedo" is 0.29, calculate late effective temperature for earth. If the true average T for earth is 288K, what is the value of Earth's *greenhouse warming*?

c. Assume that the output of the sun varies by ±0.3% (most stars periodically vary by about that much, the sun is apparently bit steadier: ~±0.1%), and calculate the range (i.e. lowest to highest or vice versa) of effective temperatures that would result from this much variation in the solar constant.

d. True or False: Venus is hotter than Earth because it is closer to the sun and its solar constant ($F_s$) is much larger. Explain your answer.

e. The actual temperature of Mars compares rather favorably to the "effective" value (i.e. calculated using the equation above). What does this imply about the Martian atmosphere (did you see *Total Recall*)?

3. Using the diagram showing overall radiation balance, discern the following:

i) The percentage of the total radiation absorbed by the atmosphere from:
a) The Earth's surface. b) The Sun.

ii) The percentage of the total radiation absorbed by the Earth's surface from:
a) The atmosphere. b) The Sun.

iii) What is the implication of this consideration?

4. Which of the following are *potential* greenhouse gases (i.e. can absorb (and emit)) IR radiation:

$O_2$, $H_2O$, $SO_3$, $HNO_3$, Ne, $CH_4$, CO, $N_2$, $NH_3$, $O_3$, Ar, $Cl_2$, HOCl, HCl, $N_2O$, $CF_2Cl_2$, $HCF_2Cl$

5. What are the 2 key features of a substance that will act as a "greenhouse gas"?

6. List the five major greenhouse gases (one is a class of substances) and list their main sources and sinks. → NATURAL + ANTHRO!

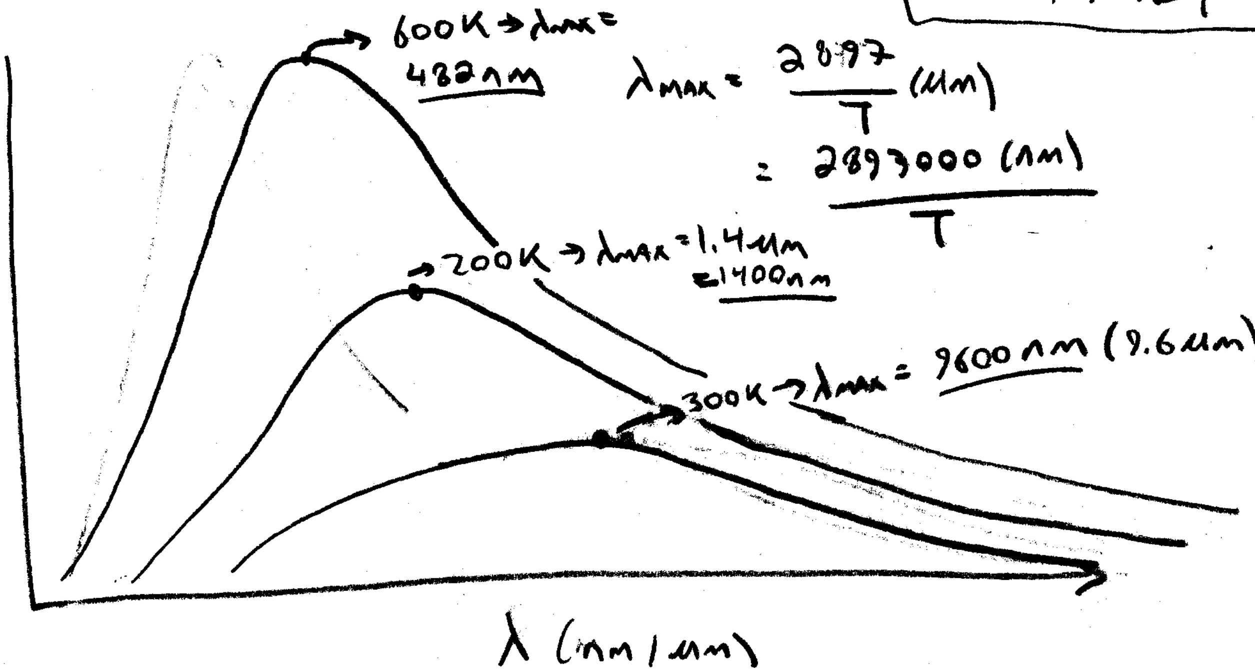
7. Write balanced reactions that correspond to the following processes in the carbon cycle (assuming that all biological carbohydrate-based material is glucose).

   a. respiration
   b. photosynthesis
   c. uptake (by oceans etc.)
   d. (wet) deposition
   e. (dry) deposition
   f. fossil fuel combustion (e.g. for octane).

8. a) How much $CO_2$ (in gr C) is emitted annually by fossil fuel combustion?
   b) What percentage of this total is from the US? (BTW: 5% of global population is US)
   c) How does this compare (by percentage) to the total from terrestrial respiration?

9. a) Define the term *Global Warming Potential.*
   b) By default, what is the GWP for $CO_2$?
   c) Why is the GWP of $CH_4$ larger than that for $CO_2$?
   d) Why does the GWP of $CH_4$ decrease with time?
   e) Why is the GWP of $CF_4$ larger than that for $CO_2$?
   f) Why does the GWP of $CF_4$ increase with time?

(1)




$$\lambda_{MAX} = \frac{2897}{T} (\mu m) = \frac{2897000 \, (nm)}{T}$$

THE POINT → AS T INCREASES THE CURVE GETS:

1) BIGGER (LARGER AREA)

2) SHARPER (NARROWER "BANDWIDTH")

3) SHIFTED TO LOWER λ (SHORTER $\lambda_{MAX}$)
↳ HIGHER E

(2) a) THE 2 INPUTS ARE: $F_S$ → SOLAR FLUX, AND A → ALBEDO

HUMANS CAN, DO, AND HAVE AFFECTED ALBEDO – $F_S$ IS OUT OF OUR HANDS.

b) $$T_{eff} = \left( \frac{(1.0 - .29)\, 1380 \, W/m^2}{4 \cdot 5.7 \times 10^{-8} \frac{W}{m^2 K^4}} \right)^{1/4} = 256 \, K$$

GREENHOUSE WARMING = 288 − 256 = 32°C

c) THE RANGE IS ONLY 256.2 − 256.5 → .3°C (LESS THAN 1/2 OF THE OBSERVED WARMING.

(2) CONT, d) FALSE → VENUS IS HOTTER B/C OF GREENHOUSE WARMING → ALBEDO OF .7 MAKES TEMP LOWER THAN OURS!

e) THERE IS ALMOST NO ATMOSPHERE ON MARS (6 mbar $CO_2$)

(3.) i) ABS BY ATMOSPHERE (EXCLUDING LATENT/SENSIBLE HEAT)

FROM SURFACE : $\frac{99}{23+99} = 81\%$

FROM SUN : $\frac{23}{23+99} = 19\%$

} MUCH MORE FROM <u>SURFACE</u>.

ii) ABS BY SURFACE:

FROM SUN: $\frac{48}{48+86} = 36\%$

FROM ATM : $\frac{86}{48+86} = 64\%$

} MUCH MORE FROM ATM

iii) THE POINT: ATM + SURFACE "TRADE" MORE ENERGY AS RADIATION THAN SUN DOES W/ EITHER ATM OR SURFACE.

(4.) ON COVER →

(5.) (1) IT MUST ABSORB IR (2) IT MUST HAVE LONG $\tau$

→ NOTE! IN THE IPCC REPORT THEY ARE CAREFUL TO USE THE TERM "LONG-LIVED GREENHOUSE GASES"

→ IN MY VERBEAGE → GHG = "LONG LIVED"

(6.) $H_2O$: REGARDED AS 100% NATURAL DUE TO REGULATION BY $H_2O$ CYCLE.

SOURCES: EVAPORATION - RESPIRATION

SINK: PRCIPITATION ) CONDENSATION

$CO_2$: SOURCES: NATURAL: RESPIRATION*, AEROBIC DECAY

HUMAN: FOSSIL FUELS*, DEFORESTATION

SINKS: UPTAKE, PHOTOSYNTHESIS*

* MAIN SOURCES

$CH_4$: SOURCES:

NATURAL: ANAEROBIC DECAY

HUMAN: LIVESTOCK*, LAND FILLS,* COAL MINES, GAS LEAKS.

SINKS: REACT w/ OH*, OR DIFFUSE TO STRAT.

$N_2O$: SOURCES: HUMAN: FERTILIZER + NYLON PRODUCTION (40-60%)

NATURAL: BACTERIA, SOILS (40-60%)

SINKS: DIFFUSE TO STRAT.

HALOCARBONS: CFC'S, HCFC'S, $CF_4$, $SF_6$ → BASICALLY ALL HUMAN SOURCES - NO SINKS ASIDE FROM DIFFUSION TO STRAT.

(7) A) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

B) $6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_{12}O_6$

C) $CO_2 + H_2O \rightarrow H_2CO_{3\,(aq)} \, (\rightleftharpoons H^+ + HCO_3^-) \rightleftharpoons (H^+ + CO_3^{-2})$

D) $Ca^{+2} + CO_3^{-2} \rightleftharpoons CaCO_{3\,(s)}$

E) $CaO + CO_2 \rightleftharpoons CaCO_{3\,(s)}$

F) $C_8H_{18} + \frac{25}{2}O_2 \rightarrow 8CO_2 + 9H_2O$

(8.) A) 6.0 Pg / YEAR

B) 1.5 Pg (25%)

C) ABOUT 10% RELATIVE TO THE 60%

(9.) A) WARMING EFFECT (RADIATIVE FORCING) RELATIVE TO $CO_2$ ON A Kg-TO-Kg BASIS - OVER SOME SPECIFIED TIME HORIZON. (A UNITLESS #)

B) 1

C) IT ABSORBS ON THE EDGE OF THE ATMOSPHERIC WINDOW

D) IT HAS A SHORTER $\tau$

E) IT ABSORBS IN THE WINDOW

F) IT HAS A VERY LONG $\tau$ (50,000 YEARS!)