ATOC 3500 – Midterm Exam 1
Wednesday, October 4, 2006

There are four questions on this exam worth a total of 100 points. You will not need a calculator for this exam. If you are unsure of an answer, please provide additional information for possible partial credit. You are free to use any notes or your textbook.

1. (24 pts) True or False

___F__ (a) Coarse particles (i.e. those larger than about 1 μm in diameter) are typically produced by the fragmentation of larger particles.

___F__ (b) The mixing ratio of O_2 at the top of Long's Peak is about half of the value at sea level.

___T__ (c)The concentration of a species X in molecules per cm^3, and written as [X], can be calculated from the mixing ratio of X if one knows the number density of air (i.e. [M]).

___T__ (d) A *temperature inversion* refers to an increase in temperature with increasing altitude.

___T__ (e) $O(^1D)$ (oxygen singlet delta) is important in the atmosphere because it reacts with water to form the hydroxyl radical, OH.

___F__ (f) In the troposphere, nitrogen oxides are formed by the reaction of N_2 with ozone.

___T__ (g) Photolysis of nitrogen dioxide (NO_2) leads to the formation of ozone in the troposphere.

___F__ (h) Carbon monoxide and ozone are the main products of complete combustion of hydrocarbons.

___T__ (i) The temperature of dry air decreases more rapidly with altitude than does the temperature of air that is saturated with water.

___T__ (j) A *radical* is an atom or molecule that possesses at least one unpaired electron.

___T__ (k) Winds on Earth result from differences in air pressure that are due to uneven heating of the surface.

___F__ (l) By definition, only emissions from human activities are called "pollution."

2. (26 points) Atmospheric chemists often use the shorthand notation RH to signify hydrocarbons. In this notation, R represents a combination of carbon atoms (C) and hydrogen atoms (H). In this manner, for example, C_3H_8 (propane) can be written as RH where $R=C_3H_7$.

(a) (5 points) Oxidation of hydrocarbons (RH) typically starts with the reaction with the hydroxyl radical, OH. Complete the reaction below by indicating the products of the reaction of RH with OH:

$$RH + OH \rightarrow \_\_R\_ \;+\; \_H_2O\_$$

(b) (10 points) Fill in the blanks below to complete a reaction scheme that describes the formation of ozone in the atmospheric oxidation of a hypothetical hydrocarbon, RH.

$$RH + OH \rightarrow R + H_2O$$

$$R + O_2 + M \rightarrow RO_2 + M$$

$$RO_2 + NO \rightarrow NO_2 + RO$$

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

(c) (6 points) Write a net reaction by summing up the reactions in part (b) above and canceling terms that appear on both sides of the reaction. Which species involved in the overall reaction scheme do not appear in this net reaction?

$$RH + OH + 2O_2 + h\nu \rightarrow O_3 + RO + H_2O$$

Species that don't appear in the overall reaction are HO_2, M, NO, NO_2, and O

(d) (5 points) Define what is meant by "catalyst" and "intermediate", terms that are used to describe the role of species like those you identified in part (c) and are necessary for the overall reaction scheme, but don't appear in the final 'net' reaction.

A catalyst is a species that speeds up the reaction but isn't consumed in the process – that is, it is produced (or regenerated) later so that it can participate in another reaction

An intermediate is a species that is produced in a reaction but subsequently consumed. It does not speed up a reaction like a catalyst does, but it can be an important product in the many steps that are needed for an overall reaction. An intermediate is often very reactive, so that it is hard to detect even though it is essential in the overall reaction.

3. (24 pts) For each of the pairs below, circle the larger of the two quantities or the word "equal" if they are the same (or very nearly the same).

(a) 1 ppm EQUAL 1 ppb

(b) mixing ratio of O_3 in the troposphere EQUAL mixing ratio of O_3 in the stratosphere

(c) temperature of the stratosphere EQUAL temperature of the tropopause

(d) density of air at 1000 mbar and 300 K EQUAL density of air at 1000 mbar and 250 K

(e) density of air at 1000 mbar and and 300 K EQUAL density of air at 500 mbar 300 K

(f) mixing ratio of X multiplied EQUAL [X], the concentration of X by [M]

(g) altitude where pressure is 800 mbar EQUAL altitude where pressure is 80 mbar

(h) density of an ideal gas at EQUAL density of an ideal gas at

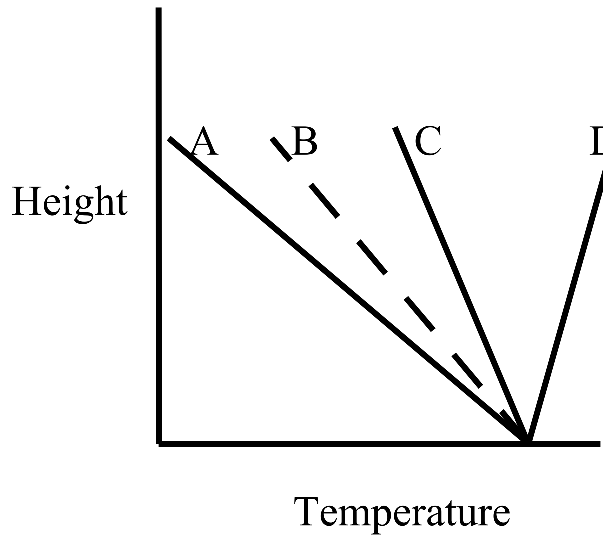
(i) concentration of O_2 on the top of Longs Peak (14,000 feet) EQUAL Concentration of O_2 at Boulder (5200 feet)

(j) mixing ratio of O_2 on the top of Longs Peak (14,000 feet) EQUAL mixing ratio of O_2 at Boulder (5200 feet)

(k) diameter of a 'coarse mode" particle EQUAL diameter of a "fine mode" particle

(l) solar energy per unit area incident on the polar regions EQUAL solar energy per unit area incident on the tropics

(26 points) Stability of the lower atmosphere is important for trapping pollutants near the surface, where they can then build up to high levels and become hazardous to health. The following figure shows four lines that signify lapse rates (rates of temperature change with height) in the atmosphere. The dashed line is called the “adiabatic lapse rate.”



(a) (9 points) To what does the term “adiabatic lapse rate” refer, and why is it important?

“ALR” refers to the temperature change with altitude that a parcel of air will experience if it moves vertically without exchange of heat with the environment (“without exchange of heat” is what adiabatic means, and “lapse rate” means change of temperature with height). It is important because it is this quantity that we use to determine whether a measured (or actual) lapse rate is stable or unstable. If a parcel that rises adiabatically will find itself warmer than its surroundings, it will continue to rise because it will be less dense than the surrounding air (we call this “buoyant”). This means that the surrounding air is unstable, and very soon there will be convection. If the air is colder than the surroundings it won’t rise, so the air won’t turnover. This is called “stable” because the situation won’t change with time unless the parcel is heated or the air above it is cooled.

(b) (6 points) Which of the atmospheric temperature lapse rates (A, C, and D) are unstable and which are stable? How did you determine this?

A is unstable (a parcel that rises along the ALR (B) will be warmer than A, so there will be convection). C and D are both warmer than the ALR, so they are stable (i.e. a parcel that follows the ALR (B) will be colder than C and D and so it can’t rise.

(c) (5 points) Which of the lapse rates (A, B, C, or D) is called an “inversion” and why?

D is an inversion, which means that temperature in the atmosphere is actually increasing as you go up. A parcel that follows the ALR as it rises adiabatically will always be colder than the air above, so it won’t rise. An inversion is superstable because it requires the air below it to be heated substantially for it to rise.

(d) (6 points) If B represents the "dry adiabatic lapse rate", in which direction (i.e. "toward C" or "toward A") would you find a similar line that defines the "wet adiabatic lapse rate?" Why do the dry and wet adiabatic lapse rates differ?

Toward C. This is because the condensation of water releases heat that will warm the parcel relative to what the temperature would be if it were following the dry adiabatic lapse rate (or B in this case). This heat is called "latent heat". It is due to the formation of bonds between water molecules that we call "hydrogen bonds". They aren't super strong, but they are sufficient to require some heat to break them (this is the same heat that you apply to water to turn it from a liquid into a vapor, something we call a phase change.