SIO 217a Atmospheric and Climate Sciences I: Atmospheric Thermodynamics

Fall 2011 Midterm Exam (No calculators, notes, books, PDAs.)

Curry and Webster, Ch. 1-4 (and Section12.1)

Here are some numerical values, some of which may be useful on this exam:
Average radius of Earth: 6370 km
Mean reflectivity of the Earth: 0.31
Mean molecular weight of dry air: 29 g/mole
Mean molecular weight of water vapor: 18 g/mole
Gas constant for dry air, $\boldsymbol{R_d}$: 287 J deg^{-1} kg^{-1}
Gas constant for water vapor, $\boldsymbol{R_v}$: 461 J deg^{-1} kg^{-1}
Specific heat at constant pressure, $\boldsymbol{c_p}$: 1004 J deg^{-1} kg^{-1}
Specific heat at constant volume, $\boldsymbol{c_v}$: 717 J deg^{-1} kg^{-1}
Latent heat of vaporization for water at 273K, $\boldsymbol{L_{lv}}$: 2.5×10^{6} J kg^{-1}
Solar luminosity: 3.92×10^{26} W
Earth-sun distance: 1.50×10^{11} m
Stefan-Boltzmann constant, $\boldsymbol{\sigma}$: 5.67×10^{-8} W m^{-2} K^{-4}

1. An article in *Science* (Dusek et al., 2006) was entitled "Size matters more than chemistry for cloud-nucleating ability of aerosol particles." Explain the roles of size and chemistry in nucleating cloud droplets and include an illustrative particle size distribution. Name and state any relevant theories. Describe a set of measurements or calculations you would make to evaluate the hypothesis posed in the title of this article.

2. An amateur meteorologist (and reality-TV hopeful) calls 911, concerned that his 9-year old boy was accidentally launched into the air in his home-made, flying-saucer shaped balloon. Assuming that the amateur knows (1) the weight of the boy and (2) the mass of Helium used to fill the balloon (based on the empty cylinders at the site), describe how you could solve his dilemma without resorting to a multi-helicopter TV chase of the errant balloon. State what principle is used in this assessment, and what approximate assumptions you have made.

3. Define the following terms in 10 words or less; an equation, graph, or sketch may be added if appropriate:
   a. radiative equilibrium
   b. positive feedback
   c. CAPE
   d. conditionally stable
   e. Kelvin effect.

4. Based on the ROAST presentations or other material presented in the course, answer <u>TWO</u> of the following questions.
   a) What is the "climate penalty" of clean fossil fuel combustion?
   b) What is the implication of the Earth's energy imbalance?
   c) What is a simple relationship between cloud drops and particles?
   d) What trend in aerosols explains climate effects in this century?
   e) What role does water vapor play in the radiative forcing of aerosols?

5. A local company has proposed to produce freshwater from the water vapor in ambient air at Point Loma. Assume the air at their Point Loma site is 20°C and 100% RH (as in problem (1) above). The saturation vapor pressure (of water) at a temperature of 20°C is 23.4 hPa. Then they cool the air using passive geothermal cooling to 10°C. (Assume that no water actually freezes, so that you remain just above freezing throughout.) State how you would find the values below for the air (after this cooling), including any laws, equations, and assumptions used, and simplifying as much as possible:
   a. saturation vapor pressure (of water) at 10°C.
   b. relative humidity.
   c. specific humidity
   d. mixing ratio
   e. virtual temperature
   f. the amount of water expected to condense to liquid for each kg of air cooled.

6. The saturation vapor pressure (of water) doubles approximately every 10°C in typical atmospheric conditions. This *strong dependence* of saturation vapor pressure on temperature (i.e. this large change of doubled pressure per 10°C increase in temperature) provides many of the unique cloud feedbacks that govern climate on Earth.

(a) Give *the differential form* of the equation that describes this increase in saturation vapor pressure with temperature.
(b) State the laws and assumptions used to derive the equation in (a).
(c) Identify the water property *that appears in equation (a)* that makes this dependence strong. (Hint: The answer is a quantity related to water that is *not saturation vapor pressure*.)
(d) Describe the characteristic of the *water molecule* that makes the property in (c) so unique.

7. Warm clouds (such as those found frequently in La Jolla) include liquid water droplets and water vapor. Typical temperatures are 20°C. In this question, you are asked to apply your knowledge of phase equilibrium to the behavior of water shown in the diagram below.

a. Using the diagram, label the region of temperature and pressure where liquid and vapor coexist for 20°C, *at equilibrium*, assuming pure water. (Hint: RH~100%, e_s=23 hPa at T=293K.) **Label this region A.**

b. If water condenses releasing latent heat *at constant pressure*, what equation would determine the new location on the diagram? Indicate the direction of change from A by **an arrow labeled B**.

c. What would happen to the cloud droplets (i.e. the liquid water) at B?

d. Does this happen to clouds? Why or why not?

e. Now consider an ice cloud with solid and vapor water present; **label this region C** where an ice cloud could be at equilibrium in a pure water system.

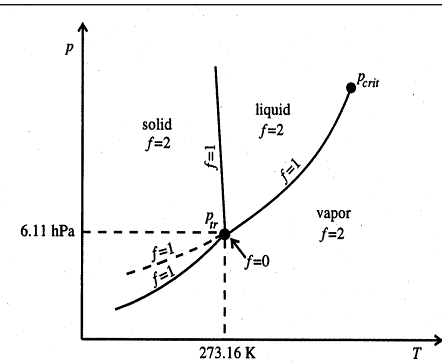

Figure 4.3 *p,T* phase diagram for water. The three curves indicate those points for which two phases coexist at equilibrium. The dashed curve is the extension of the vapor-pressure curve for liquid water to temperatures below 273.16 K. The solid curve below 273.16 K connects the points at which ice and vapor coexist at equilibrium. p_{crit} indicates the pressure and temperature values beyond which liquid water and water vapor are no longer distinguishable from one another. p_{tr} indicates the triple point, the unique *p,T* point at which all three phases coexist.