Atmospheric Sciences 5200
Final Exam Sample Questions

Answer or explain the statements in problems 1 to 6.

1. CCN (cloud condensation nuclei) tend to be much more numerous in continental air than in marine air, therefore raindrops are more likely to form in marine clouds than in continental clouds with the same maximum LWC (liquid water content).
2. Actual LWC values in cumulus clouds are usually less than the corresponding adiabatic values.
3. Cloud droplets growing near the base of a cloud affect each other primarily by their combined influence on the ambient air (within a few centimeters) rather than by direct interactions such as collision and coalescence.
4. Large supersaturations with respect to liquid water are rare in the atmosphere but large supercoolings of droplets are common.
5. Large water droplets rarely supercool by more than a few degrees.
6. Supercooled fogs are easier to disperse by artificial means than are warm fogs ($T > 0°$ C).
7. What is the radius of a typical cloud droplet?
8. What is the radius of a typical rain drop?
9. How many typical cloud droplets are needed to form one typical rain drop?
10. What are the two types of nucleation that can form a cloud droplet? Which type most commonly occurs? Why?
11. What are haze particles?
12. What is an *activated* droplet? In a rising supersaturated parcel, what factors determine which droplets become activated?
13. What processes grow cloud droplets after they are activated? For what droplet size range is each process most important?
14. What factors favor rapid formation of rain drops from cloud droplets?
15. Cold clouds are clouds that exist at temperatures less than 0° C.
    (a) What is a *mixed-phase* cloud?
    (b) What is a *glaciated* cloud?
16. List and briefly describe the four ways in which ice particles can be formed or *nucleated*.
17. When ice crystals coexist with supercooled cloud droplets, what happens?
18. Once an ice particle is formed, it may grow by three processes.
    (a) List and briefly describe these processes.
    (b) Which of these processes can grow ice particles most rapidly?

19. What factor determines the basic *habit* (shape or form) of an ice crystal?

20. What factors favor strong downdrafts driven by rain evaporation?

21. Many parcel models do not use the droplet growth equation to calculate the liquid water content. How is this possible? Describe the method.

22. (a) What is the mathematical expression that describes the probability that a droplet will capture a smaller droplet during a unit time interval? Label each factor.
(b) Why does this probability increase rapidly as the collector drop radius increases?

23. (15 points) For the conditions described below, calculate the rates of growth (dr/dt) for droplets of radius $r = 10$ and 40 μm due to (a) condensation, and (b) collection (of smaller droplets that are 10 μm in radius), . The supersaturation S is 0.2 percent, T is 10° C, p is 800 hPa, and the liquid water content of the smaller droplets is 1 g m^{-3}.

    For condensation growth, if we neglect curvature and solute effects:

$$r\frac{dr}{dt} = GS.$$

    For the given T and p, the growth parameter $G = 100\ \mu\text{m}^2\ \text{s}^{-1}$.

    For coalescence growth, if we assume that $R \gg 10\mu$m:

$$\frac{dr}{dt} = \frac{EM}{4\rho_L}u(r),$$

    where M is the LWC and ρ_L is the density of liquid water. The collection efficiencies E are 0 and 0.55, for $r = 10$ and 40 μm, respectively. Stokes' Law is applicable so that the droplet fall speed is $u(r) = k_1 r^2$, with $k_1 = 1.2 \times 10^6\ \text{cm}^{-1}\text{s}^{-1}$.

    Answer:
    The table below lists dr/dt for condensation and collection in units of nm s^{-1}.
    The rates are equal at about 27 μm.

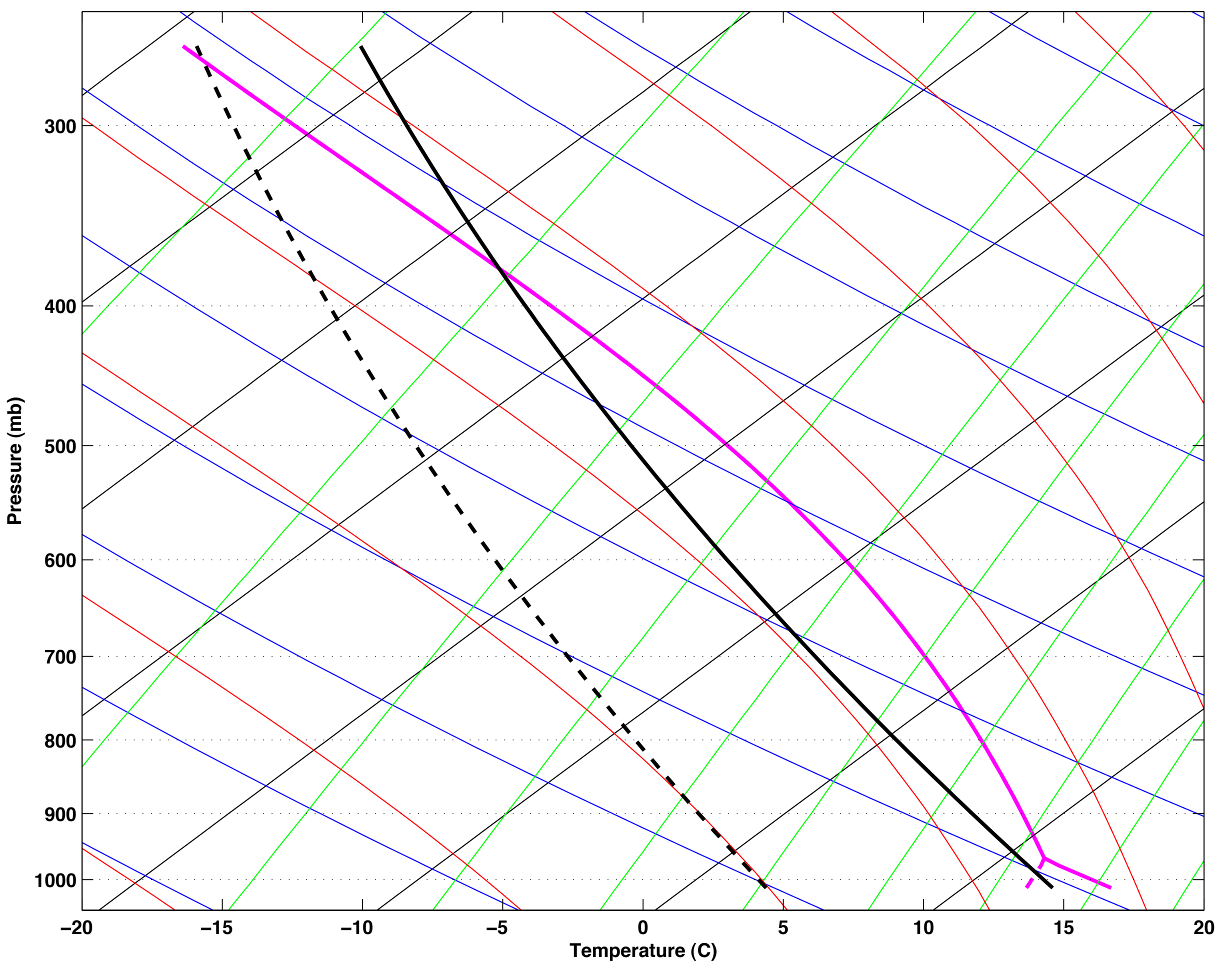
R	E	Cond	Coll
10	0	20.0	0.0
20	0.17	10.0	2.0
30	0.37	6.7	10.0
40	0.55	5.0	26.4

24. (8 points) We derived an expression for the cloud-base precipitation rate, P, for a steady-state cloudy (saturated) updraft with cloud-base temperature = T_b, cloud-base pressure = p_b, cloud-top temperature = T_t, cloud-top pressure = p_t, and constant vertical mass flux = M_b ($\equiv \rho w$, where ρ is air density and w is vertical velocity). In the cloudy updraft, air is rising from cloud base to cloud top at a constant rate M_b (kg m^{-2} s^{-1}). The updraft's temperature decreases from T_b at cloud base to T_t at cloud top.
(a) What is the expression for the cloud-base precipitation rate, P, that we derived?

    (b) Based on this expression, what thermodynamic conditions tend to produce the largest cloud-base snowfall rates?

25. (20 points) A drop with an initial radius of 50 μm falls through a cloud containing 250 droplets cm^{-3} that it collects with an efficiency of 0.9. If all cloud droplets have a radius of 10 μm, how long will it take for the drop to reach a radius of 1 mm? Assume that the terminal fall speed of a drop of radius r (m) is $v(r) = 6 \times 10^3 r$ (m s^{-1}). Assume that cloud droplets are stationary and that the updraft speed in the cloud is negligible.

26. (8 points) The skew T-log p diagram below shows the temperature and dewpoint profiles in the environment (solid and dashed black lines, respectively), and in a non-entraining parcel (solid and dashed magenta lines, respectively).
(a) Sketch the temperature profile for a parcel that entrains environmental air between the parcel's LCL and LNB.
(b) Do the same for a parcel that entrains at the same rate but with environmental air that has a significantly lower relative humidity than is plotted.



Useful constants

0° C = 273.16 K
$g = 9.8$ m s^{-2} (acceleration of gravity)
$\rho_w = 1000$ kg m^{-3} (density of liquid water)
$c_w = 4186$ J kg^{-1} K^{-1} (specific heat capacity of liquid water)
$c_p = 1004$ J kg^{-1} K^{-1} (specific heat at constant pressure for dry air)
$c_v = 717$ J kg^{-1} K^{-1} (specific heat at constant volume for dry air)
$R_d = c_p - c_v = 287$ J kg^{-1} K^{-1} (gas constant for dry air)
$R^* = 8.31$ J mol^{-1} K^{-1} (universal gas constant)
$m_d = 28.97$ g mol^{-1} (mean molecular weight of dry air)
$m_v = 18.02$ g mol^{-1} (molecular weight of water vapor)
$L_v = 2.5 \times 10^6$ J kg^{-1} (latent heat of vaporization)