

**Name:** \_\_\_\_\_  
**MPO 531 Midterm Spring 2009 (102 points total)**

Multiple choice. Circle the right answer. 2 points each.

1. It is possible for condensation to occur on very small liquid cloud droplets because of the (curvature, solute) effect.
2. Cloud seeding is effective for dispersing fogs consisting of (ice needles, supercooled water droplets, water droplets above freezing).
3. Cloud condensation nuclei exist in (higher, lower, similar) concentrations in the atmosphere to ice nuclei.
4. Cloud condensation nuclei in marine air are (more, less, similarly) numerous to those in continental air.
5. The fall speed of small drops depends (more strongly, less strongly, indifferent to) their radius than do large drops.
6. The number of cloud droplets formed from a given amount of aerosol is (greater, less, unaffected) for stronger updrafts, all else remaining equal.
7. The saturation vapor pressure over an ice surface is (higher, lower) than that over a water surface.
8. In an adiabatic liquid water cloud, cloud droplet size (decreases, increases, doesn't change) with increasing height.
9. For a given supersaturated environment in a warm cloud, the rate of increase in the radius of a large droplet by condensation is (greater than, smaller than, the same as) that of a small droplet.
10. For a given environment in a warm cloud, the rate of increase in the radius of a large drop by collision is (greater than, smaller than, the same as) that of a small drop.
11. Dendrites are an example of ice crystal growth occurring through (deposition, riming, aggregation).
12. Which one of the following substances is most unique to lightning: carbon dioxide molecules, snowflakes, graupel.
13. A typical radius for an aerosol particle capable of serving as a cloud condensation nucleus is (10, 0.001, 0.1) micron.
14. The biggest difference between water and ice saturation pressures occurs at (0, -15, -30) Celsius.
15. Diffusional (vapor-driven) growth is (more rapid, less rapid) for ice than for liquid at -10 C, all else equal.
16. Freezing of pure water drops occurs at approximately (-10 C, -20C, -30C, -40C).

Problems Make an attempt on all of them.

1. (10 pts). Draw a Kohler curve. Label. Explain curvature and solute effect.

2. (5) Draw another Kohler curve on top of the other one corresponding to water containing 10X more solute.

3 (5 pts). The relative humidity of a chamber is 95%. If a solution droplet of radius 1 micron is placed in the chamber, show on the (first) Kohler curve above how the supersaturation over this droplet will change as the radius  $r$  of the droplet changes, as it comes to equilibrium with the air in the chamber. What will be the approximate final radius of the droplet. ?

4 (5 pts). Write down the collisional growth eqn for warm rain in terms of  $dr/dt$ . Include a picture illustrating the different terms.

5. (5pts) Define the 3 main terms (in words) that contribute to the stochastic-coalescence equation.

6. (10) Wettable aerosols of radius 0.1 micron in concentrations of  $1000 \text{ cm}^{-3}$  are detected by an aircraft flying 5 km above ground level. What is the minimum supersaturation necessary for condensation of water vapor to occur onto the aerosol particles if the temperature is 0 Celsius? Recall the increase in energy due to the formation of a water droplet of radius R from water vapor with vapor pressure e is given by  $4\pi r^2 \sigma - 4/3\pi r^3 n k T \ln(e/e_{\text{sat}})$ , where  $\sigma$  is the surface energy of water ( $0.076 \text{ J/m}^2$ ), n the number density of molecules in water ( $3.3 * 10^{28} \text{ m}^{-3}$ ), k the Boltzmann's constant ( $1.38 * 10^{-23} \text{ J/(deg*molecule)}$ ), T temperature, and  $e_{\text{sat}}$  the saturation vapor pressure with respect to a plane surface of water at temperature T. Ignore the solute effect of aerosols. Recall  $\exp(x) \approx 1+x$  for small x.

7. A drop with a radius r of 100 micron falls through a cloud with a uniform liquid water content (LWC) of  $0.3 \text{ g m}^{-3}$ . The cloud is 3 km thick.

a. (5 pts) If the drop experiences a drag force given by  $2k\pi r^2 v$ , where v is the speed of the drop, what is the terminal (equilibrium) fallspeed of the drop when the radius r is 100 micron ?  
 $k = 1 \text{ kg s}^{-1} \text{ m}^{-2}$ .

b. (5 pts) If the drop collects smaller cloud droplets with a collection efficiency E of 0.7, how long will it take for the drop to reach a radius of 1 mm ?

8. (10pts) A supercooled water droplet 10 micron in radius comes into contact with an ice particle at -15 C. Immediately after the contact, partial freezing occurs in the droplet and the temperature of the droplet increases to 0 C. Estimate the mass of the frozen water, assuming that the heat exchange with the ambient air can be neglected (ie the air temperature remains at -15C). Recall: density of liquid water =  $1000 \text{ kg/m}^3$ , latent heat of fusion =  $3.3 * 10^5 \text{ J/kg}$ , specific heat of liquid water =  $4220 \text{ J/(deg*kg)}$ , and specific heat of ice =  $2110 \text{ J/(deg*kg)}$ .