

## Review sheet for ATM S 340 Final Exam (18 March 2009)

Notes:

- 1) “state”, “define” or “explain” means verbally
- 2) “express” means state mathematically (although the indicated equations will be given during the exam); “express” also implies knowing what the symbols mean and being prepared to apply the equation
- 3) **SHOW YOUR WORK!!** Solve equations first in symbol form, putting in the numbers at the very end.
- 4) The final exam is worth 450 points (45% of your grade). About 3/4 of the points will be on material since the midterm.

### Basic Thermodynamics

- Express various forms of the ideal gas equation (**GIVEN**). Know what all symbols mean.
- Define the molecular weight of a substance.
- Explain the difference between  $R^*$  and  $R$ .
- State the 1<sup>st</sup> law of thermodynamics.
- Express the 1<sup>st</sup> law in differential form (**GIVEN**).
- Express the 1<sup>st</sup> law of thermodynamics in differential form for an ideal gas (**GIVEN**)
- Express the Clausius-Clapeyron equation (**GIVEN**).
- Know what the curve implied by the Clausius-Clapeyron equation looks like on a graph of  $e_s$  vs.  $T$ .
- Express the hypsometric equation (**GIVEN**).
- Define “scale height”.
- Express scale height (**GIVEN**).

### Atmospheric Thermodynamics

- Define and express potential temperature (**GIVEN**), and know that it is conserved following dry adiabatic motions.
- Be able to identify dry adiabats, or lines of constant  $\theta$ , on a skew-T chart (Rule 1).
- Express the ideal gas equation for pure water vapor (**GIVEN**).
- Express the ideal gas equation for moist air (**GIVEN**).
- Explain the concept of virtual temperature.
- Define saturation mixing ratio,  $w_s(T,p)$ .
- Define and express (**GIVEN**) relative humidity.
- Define dewpoint temperature,  $T_d$ . Know its relationship to saturation mixing ratio on a skew-T chart (Rule 2).
- Define the “lifted condensation level” or LCL. Be able to find it on a skew-T chart (Rule 3).

- Define (but need not express) the moist adiabatic lapse rate (MALR),  $\Gamma_m$ . Is it less than or greater than the DALR (Rule 4)?
- Know how to determine the adiabatic liquid water mixing ratio (cloud water) produced during a moist adiabatic ascent from a skew-T chart (Rule 5).
- Define (need not express) equivalent potential temperature,  $\theta_e$ . Be able to find a parcel's value of  $\theta_e$  from a skew-T chart (Rule 6).
- Define wet-bulb temperature,  $T_w$ . Why is it significant (3 reasons)? Be able to find a parcel's wet—bulb temperature from a skew-T chart (Rule 7).
- Know Normand's Rule and how to use it.
- Define wet-bulb potential temperature,  $\theta_w$ . Know how to determine it from a skew-T chart (Rule 8).
- Know that  $\theta_e$  and  $\theta_w$  are conserved under dry or moist adiabatic conditions.
- Express the combine stability conditions for a moist air parcel (absolutely stable, dry neutral, conditionally unstable, moist neutral, absolutely stable) in terms of how the environmental lapse rate,  $\Gamma = -dT/dz$ , compares to the DALR and MALR.
- Express the condition under which layer lifting can lead to the release of convective (a.k.a. potential) instability:  $d\theta_e/dz < 0$ . Be able to demonstrate this on a skew-T chart.
- Lifted parcel stability concepts: Define, and know how to find, “convective inhibition” (CIN), “level of free convection” (LFC), “convective available potential energy” (CAPE), and “equilibrium level” (EL).
- Know that CIN and CAPE are represented by the negative and positive area between the environmental temperature profile and the lifted parcel temperature profile.

### Cloud Processes

- Be able to briefly describe the three main processes of cloud formation
- Define the meteorological meaning of the Latin roots *cirrus*, *cumulus*, *stratus*, *alto*, and *nimbo*
- Explain the difference between homogeneous and heterogeneous nucleation of cloud droplets
- Express Kelvin's equation for the equilibrium vapor pressure over a pure water droplet of radius  $r$  (**GIVEN**). Know what it looks like on a graph of RH (or S.S.) vs.  $r$ .
- Explain how the lower aerosol concentrations over the ocean result in clouds that can more easily produce precipitation.
- Understand Kohler's equation (“curvature” and “solution” effects) for the equilibrium vapor pressure over a solution droplet of radius  $r$ . Know what it looks like on a graph of RH (or S.S.) versus  $r$  in comparison to the Kelvin curve, though need not express Kohler's equation (it will be **GIVEN** if needed).
- Know implications of Kohler's curve for formation of haze at  $RH < 100\%$ .
- Explain the difference between a condensation nucleus (CN) and a cloud condensation nucleus (CCN).
- Express growth of drops by condensation (**GIVEN**).

- Express growth of drops by collection (collision and coalescence) (**GIVEN**).
- Define collision efficiency ( $E$ ), coalescence efficiency ( $E'$ ), and collection efficiency ( $E_c = EE'$ ).
- Know which process gets slower and faster (in terms of  $dr/dt$ ) as the drop gets bigger - growth by condensation versus growth by collection.
- Describe two reasons why the presence of ice can hasten the growth of ice in clouds.
- Define homogeneous and heterogeneous nucleation of ice in clouds.
- What is required for a particle to act as a good ice nucleus?
- Know dependence on temperature of number of ice nuclei available for nucleation.
- Express the growth of ice crystals by vapor deposition (**GIVEN**).
- Understand the general shape of a graph of  $G_i S_i$  vs.  $T$  for water-saturated conditions. At what temperature is it a maximum?
- Ice crystal habits: What is meant by the basal face, the prism face, and the corners? What types of crystal habits are produced when growth is preferentially at basal faces? Prism faces? Corners?
- Define growth of an ice crystal by riming and aggregation.
- Know that the continuous collection equation (**GIVEN** – same as for growth of drops by collection) can be used to quantify growth of ice particles by riming or by aggregation.
- Explain why collection efficiency of ice particles (and hence, aggregation) is enhanced at  $T = -15^\circ\text{C}$  and  $0^\circ\text{C}$ .
- What is the thermoelectric effect?
- How does the formation/presence of graupel lead to charge separation in thunderclouds? Where do positive and negative charges accumulate?
- What is the sequence of a cloud-to-ground lightning stroke? [downward stepped leader, upward spark, upward return stroke, possible additional downward “dart” leader and upward return stroke combinations (stroke)]
- Why does thunder occur and why does it sometimes rumble?

## Given Equations for Final Exam in ATM S 340 Winter 2009

$$\frac{e_{sd}}{e_s} = \exp\left[\frac{2\sigma}{\rho_l R_w T r_{eq}}\right] = \exp\left[\frac{2\sigma}{nkT r_{eq}}\right] \quad \frac{dr}{dt} = \frac{D S e_s(T)}{\rho_l R_w T r}$$

$$\frac{dm}{dt} = \pi(r_1 + r_2)^2 (v_1 - v_2) w_l E_c \quad \frac{dr_1}{dt} = \frac{v_1 w_l E_c}{4\rho_l} \quad \frac{dm}{dt} = \frac{C}{\varepsilon_0} D S_i \frac{e_{si}(T)}{R_w T} = \frac{C}{\varepsilon_0} G_i S_i$$

$$r_{eq} = \frac{2\sigma}{\rho_l R_w T \ln\left(\frac{e}{e_s}\right)}$$

$$\theta = T \left(\frac{p_0}{p}\right)^{\frac{R}{c_p}}$$

$$e = \rho_v R_v T \quad \text{or} \quad e \alpha_v = R_v T \quad R_w = \frac{R^*}{M_w} = 461 \text{ J K}^{-1} \text{ kg}^{-1}$$

$$p = \rho R_d (1 + 0.61w) = \rho R_d T_v \quad \text{where} \quad T_v = (1 + 0.61w)T$$

$$RH = 100\% \times \left[\frac{e}{e_s(T)}\right] \approx 100\% \times \left[\frac{w}{w_s(T, p)}\right]$$

$$p = \frac{NkT}{V} = \frac{nR^*T}{V} = \frac{mRT}{V} = \rho RT = \frac{RT}{\alpha} \quad \Gamma_d = \frac{g}{c_p}$$

$$dQ = dU + dW \quad dq = du + dw \quad dQ = C_v dt + PdV \quad dq = c_v dT + pd\alpha$$

$$\frac{de_s}{dT} = \frac{L_v}{T(\alpha_v - \alpha_l)} \quad \frac{dp}{dz} = -\rho g = \frac{-g}{\alpha}$$

$$z_2 - z_1 = \frac{R\bar{T}}{g} \ln\left(\frac{p_1}{p_2}\right) \quad H = \frac{R\bar{T}}{g}$$