1. *Wet bulb temperature*
   a. *Use eq. (16) from the diffusion to cloud droplet notes*

$$\frac{\left[\rho_v(\infty)-\rho_v(r_{drop})\right]}{\left[T\left(r_{drop}\right)-T(\infty)\right]}=\frac{K}{LD_v} \tag{16}$$

to determine the relation between the wet bulb temperature and the dew point temperature.

$$\frac{\left[\rho_{v-env}-\rho_{v-wb}\right]}{\left[T_{wb}-T_{env}\right]}=\frac{K}{LD_v}$$

$$T_{wb}=T_{env}-\left[\rho_{v-wb}-\rho_{v-env}\right]\frac{LD_v}{K}$$

$$\rho_{v-env}=\rho_{v-wb}-\frac{K}{LD_v}\left[T_{env}-T_{wb}\right]$$

$$\rho_{v-env}=\frac{e_{wb}}{R_vT_{wb}}-\frac{K}{LD_v}\left[T_{env}-T_{wb}\right]=\frac{e_s(T_{wb})}{R_vT_{wb}}-\frac{K}{LD_v}\left[T_{env}-T_{wb}\right]$$

   b. *determine the vapor pressure of the environment*

$$e_{env}=\rho_{v-env}R_vT_{env}=R_vT_{env}\left\{\frac{e_s(T_{wb})}{R_vT_{wb}}-\frac{K}{LD_v}\left[T_{env}-T_{wb}\right]\right\}$$

   c. *determine the relative humidity of the environment*

$$RH=\frac{e_{env}}{e_s(T_{env})}=\frac{R_vT_{env}\left\{\frac{e_s(T_{wb})}{R_vT_{wb}}-\frac{K}{LD_v}\left[T_{env}-T_{wb}\right]\right\}}{e_s(T_{env})}$$

Assume the air pressure is 1000 mb, the air temperature is 283 K and the wet bulb temperature is 273K,

   d. *what is the water vapor mass density of the air*

      9.4e-4 kg/m^3.

   e. *what is the water vapor pressure of the air*

      123 Pa = 1.23 mb

   f. *what is the relative humidity of the air.*

      RH = 1.23 mb/12.2 mb = 10%

   g. *Show that the dew point depression (T-T_d) is indeed about 3 times the wet bulb depression (T-T_{wb})*

$T_d = 255 = -18^oC$.

$T\text{-}T_d = 28^oC$ which is roughly 3 (actually 2.8) times larger than $T\text{-}T_{wb} = 10^oC$.

2. *Based on the figure at the end of the* ***Diffusion of water vapor onto a cloud droplet*** *notes, approximately how long would it take for a cloud droplet to grow to 1 mm in radius?*

It scales as the radius squared. Pick a point on the figure and scale it to 1 mm. The answer is roughly 2,000,000 seconds = 23 days.

3. *For a NaCl CCN of mass $3x10^{-19}$ kg, and a temperature of 288 K*
   a. *Determine the CCN radius before the water begins condensing on it*

Use the table at the end of the cloud droplet activation notes

   b. *Determine the constants, a and b in eq. (10) in* ***Cloud Droplet Formation*** *notes*

$$e_s(r,T) = e_s(r=\infty,T)\exp\left(\frac{2\sigma}{rR_v\rho_L T}\right) = e_s(r=\infty,T)\exp\left(\frac{a}{r}\right)$$

$$a = \frac{2\sigma}{R_v\rho_L T} = 1.13\text{e-9 m.}$$

$$b = \frac{3im_v M}{4m_s\pi\rho_L} = 4.4\text{e-23 m}^3.$$

$\sigma = 0.075$ Newtons/m, $m_v = 0.018$ kg/mole, $M = 3x10^{-19}$ *kg*, $i = 2$, $m_s = 0.0584425$ kg/mole (for NaCl), $\rho_L = 1000$ kg/m^3.

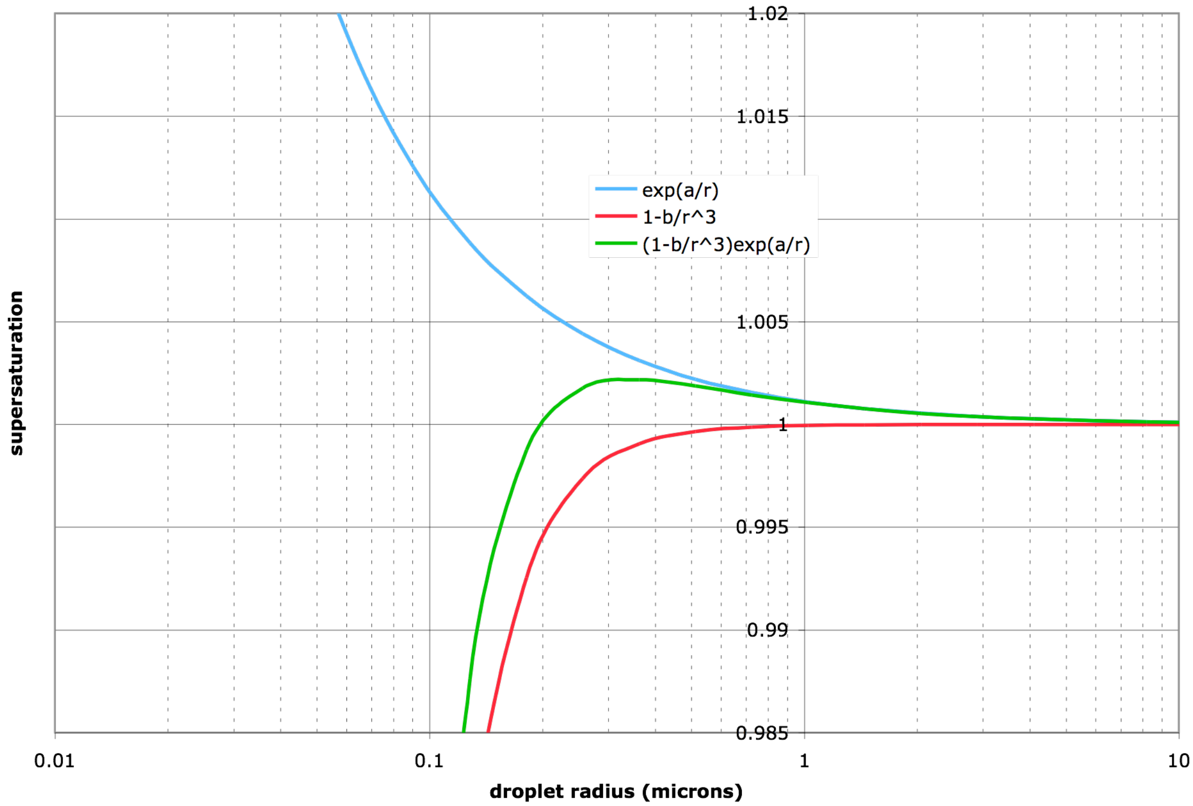
   c. *Determine the peak supersaturation, S*, in the Kohler curve for this CCN*

$$S^* = 1 + \sqrt{4a^3/27b} = 1.0022$$

   d. *Determine the corresponding radius, r**

$$r^* = \sqrt{3b/a} = 0.34 \text{ microns}$$

   e. *Plot the Kohler curve for this CCN*



4. *Aerosol indirect effects*
   a. *Explain the two aerosol indirect effects and their relation to autoconversion*

Increasing the number density of CCNs increases the number of cloud droplets that will form. More droplets means more surface area for a given total amount of condensed water per volume.

Increasing the number of CCNs can reduce the water condensed into each droplet. The reduced amount of water per droplet means the average size of the droplets will decrease.

Autoconversion refers to the situation where the largest cloud droplets achieve a radius of 20 microns or more and begin falling relative to the other smaller droplets colliding with those other droplets and coalescing into larger droplets that fall even faster and collide more and grow more.

   b. *Explain why an increase in manmade aerosols may reduce global warming*

Increasing the number of CCNs (which seems to be happening) will increase the reflectivity of low level clouds (see the ship track picture) by increasing the number of clouds.

The second effect seems to reduce the precipitation from the low level clouds reducing a mechanism where the clouds loose water, causing the clouds to retain more liquid water. This increases the average size of the droplets relative to the tendency for the size of the cloud droplets to shrink in size due to the first indirect effect by itself. Larger droplets have more surface area and therefore the surface area of the clouds increases.

Measurements of clouds in ship tracks seem to indicate that these two effects are real.