Name:

Student number:

Answer each of these (note weight). Show all your work, including skewT calculations, on all questions (needed for partial credit). Be sure to put your name on any detached skewT pages.

1. (15) Use the attached tephigram labeled "heat engine" to sketch the following thermodynamic cycle. You have an air parcel containing **1 kg of dry air and 14 grams of water**. Initially it is at a pressure of **900 hPa and a temperature of 25** °C (Point A). It then is taken through the following stages:

   - adiabatic expansion until the internal pressure is 700 hPa to Point B
   - isothermal compression back to 900 hPa (Point C)
   - isobaric (constant pressure) heating back to 900 hPa (Point A)

   Find the following (you can use $l_v = l_{v0}$ and $c_p = c_{pd}$) :

   - The equivalent potential temperatures of point A and point C (Kelvins)
   - The heating of the cannister Q_{in} (during C → A) and cooling Q_{out}) during B → C (in Joules/kg)
   - The efficiency of this heat engine (in percent)

2. (15) Use the tephigram labeled “stability sounding” to answer the following:

   (a) Find the LCL for the top and bottom of the layer and label them on the figure.

   (b) Draw the θ_e profile between 900-800 hPa

   (c) Explain your reasoning as you answer the following. Is the layer:

      i. Absolutely stable?

      ii. Conditionally unstable?

      iii. Convectively unstable?

   (d) What is the wet bulb potential temperature (θ_w) for air at 900 hPa? (also show on tephigram).

   (e) Suppose the layer is lifted until the top is at 700 hPa and the bottom is a 800 hPa. Draw the new (T,Td) sounding. Has cloud formed? In which part of the layer? Is there convective overturning?

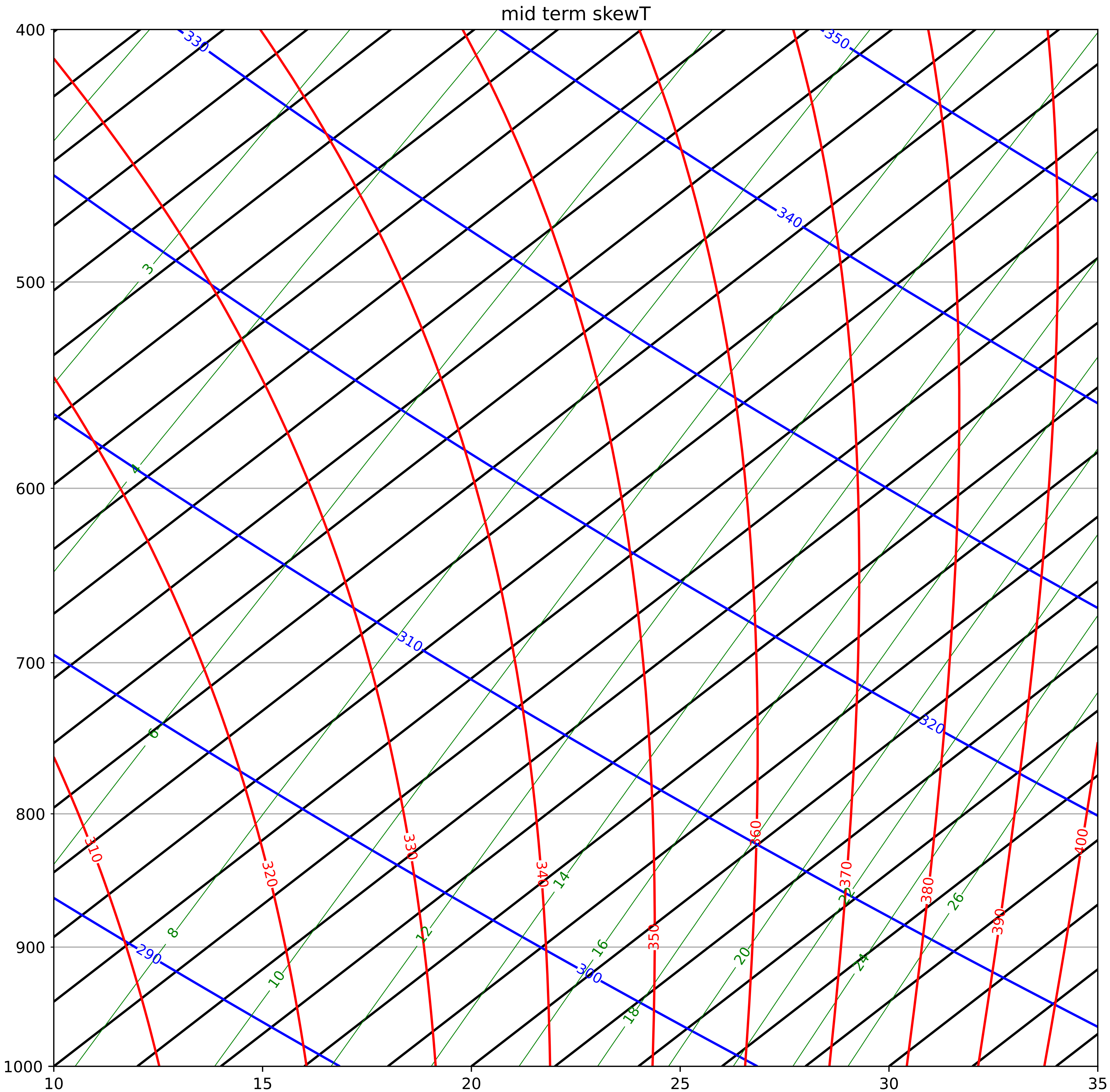
3. (15) Use the page labeled "mixing problem" to answer the following:

   Suppose that at 700 hPa a cloud parcel with temperature **5** °C and total water mixing ratio of **10 g/kg** is mixed **50/50** by mass with environmental air at a temperature **10** °C with a total water mixing ratio of **3 g/kg**. Using the tephigram (writing the values below and also labeling them on the tephigram).

   (a) (6) The LCL and θ_e of the environment and the cloudy air.

   (b) (6) The LCL, wT and θ_e of the 50/50 mixture mixture

   (c) (3) The temperature and liquid water mixing ratio (g/kg) of the mixture at 700 hPa


mid term skewT
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Equation sheet

$$du = q\,dt - w\,dt = q\,dt - p\,d\alpha \tag{1}$$

$$e = \rho_v\,R_v\,T \tag{2}$$

$$p = \rho\,R_d\,T_v \tag{3}$$

$$w\,dt = p\,d\alpha \tag{4}$$

$$h = u + p\,\alpha \tag{5}$$

$$T_v = T(1 + 0.608 w_v - w_l) \tag{6}$$

$$w_v = \rho_s/\rho_d = \epsilon\frac{e_s}{p - e_s} \tag{7}$$

$$dh = c_{px}\,dT \;(dry\ air\ or\ liquid) \tag{8}$$

$$dh = c_p\,dT\; + l_v\,dw_v \;(air/water\ mixture) \tag{9}$$

$$dh = T\,ds + \alpha\,dp \;(reversible) \tag{10}$$

$$ds = c_p\frac{d\theta}{\theta} = c_p\frac{dT}{T} - R_d\frac{dp}{p} \tag{11}$$

$$ds \geq \frac{q\,dt}{T} \tag{12}$$

$$l_v = h_v - h_l \tag{13}$$

$$dp = -\rho\,g\,dz \tag{14}$$

$$dh_m = c_p\,dT + l_v\,dw_v + g\,dz \tag{15}$$

$$ds = c_p\frac{d\theta_e}{\theta_e} = c_p\frac{d\theta}{\theta} + \frac{l_v\,dw_s}{T} \tag{16}$$

$$ds = c_p\frac{d\theta_l}{\theta_l} = c_p\frac{d\theta}{\theta} - \frac{l_v\,dw_l}{T} \tag{17}$$

$$b = g\frac{\rho_e - \rho_p}{\rho_e} \approx g\frac{T_{vp} - T_{ve}}{T_{ve}} = g\frac{T_v'}{\overline{T_v}} \approx g\frac{\theta'}{\overline{\theta}} \tag{18}$$

$$dw_v = \frac{w_v}{p - e}\left(\frac{p}{e}de - dp\right) \tag{19}$$

$$\begin{aligned} f(x) &= f(x_0) + f'(x_0)(x - x_0) \\ &+ \frac{f''(x_0)}{2}(x - x_0)^2 + \dots \end{aligned} \tag{20}$$

c_{pd}	1006 $\mathrm{J\,kg^{-1}\,K^{-1}}$
c_{pv}	1870 $\mathrm{J\,kg^{-1}\,K^{-1}}$
c_l	4190 $\mathrm{J\,kg^{-1}\,K^{-1}}$
R_d	287 $\mathrm{J\,kg^{-1}\,K^{-1}}$
R_v	461 $\mathrm{J\,kg^{-1}\,K^{-1}}$
k	1.381×10^{-23} $\mathrm{J\,K^{-1}}$ molecule^{-1}
l_{v0}	2.5×10^{6} J kg at 0 deg C