ATSC 5010 – Physical Meteorology I Lab
Lab 3 – Adiabatic Processes & Thermodynamic Diagrams

➔ Begin with the first law of thermodynamics:
$du = dq - dw$ (1)

> where:
> dq is <u>heat</u> input to a gas
> du is the increase in internal energy
> dw is the work done by the gas; in atmosphere—only concerned with work due to expansion, thus *dw=pdv:*

$du = dq - pdv$ (2)

Equation (2) is true for a <u>reversible process in a P-V-T system</u>. In class, we also defined enthalpy: *h=u+pv* to derive the *enthalpy* form of the first law:

$dh = dq + vdp$ (3)

We define the specific heat constant as the change in heat with respect to temperature ($\delta q/\delta T$) and at constant pressure this is equal to c_p. Thus, we can rewrite equation (3) as:

$c_p dT = dq + vdp$ (4)

➔ For an *adiabatic* process, no heat is added or lost from the system:
$dq = 0$, and eqn (4) becomes: $c_p dT = vdp$, which can be simplified considering a reversible process for a P-V-T system:

$$c_p dT = RT \frac{dp}{p} \quad (5)$$

Integrating eqn (5) from initial state (T_0, P_0) to final state (T,P) leads to one of the 3 Poisson relationships:

$$c_p \int_{T_0}^{T} \frac{dT}{T} = R_d \int_{P_0}^{P} \frac{dp}{p} \quad \rightarrow \quad \frac{T}{T_0} = \left(\frac{P}{P_0}\right)^{R/c_p}$$

➔ For P_0 equal to 10^5 Pa (1000 mb), then we define the *Potential Temperature, θ,* as T_0. Further, if we only consider dry air, then we can use the dry air gas constant and specific heat at constant volume:

$$\theta = T \left(\frac{10^5}{P}\right)^{R_d/c_{pd}}$$

Exercises:
Today you will construct a thermodynamic diagram called an *emagram*. An emagram can be used to determine the relationship between temperature, pressure, and potential temperature. You will use your emagram to answer questions about how a parcel's state changes as it undergoes different processes. As in previous labs, your procedure well be named:
'atsc5010_{yourname}_lab3.pro'

An emagram has an abscissa (x-axis) of temperature and an ordinate (y-axis) of *log*(p), with highest pressure at the bottom part of the graph.

1. In today's lab you will build a procedure that will construct an emagram with temperature starting at -30 and and ending at +30 C (x-axis), and pressure starting from 1000 mb and ending at 200 mb (y-axis). Show temperature gridlines every 10 C and minor tickmarks every 5 C. Show pressure gridlines every 100 mb.

   You should call *phycon* in your procedure to use any physical constants.

   Within your procedure you will first need to create a 1D array of temperatures and 1D array of pressures over the appropriate range. Create your temperature and pressure arrays with 0.1C and 1 mb resolution, respectively. Use double precision!

   You will then need to create a 2D array of theta (potential temperature) values, where columns (or rows) represent constant pressure and rows (or columns) represent constant temperature. By using the matrix multiplier (MATRIX_MULTIPLY function) you can construct your 2D array without the use of a FOR loop, (you may use a FOR loop, if you prefer).

   Using the "CONTOUR" function produce a emagram into a window that has 800 pixels in the x-direction and 900 pixels in the y-direction. Contour theta values versus the temperature and pressure variables. Contour every 10 K in theta, ranging from 250 K to 470 K, label every other contour (starting with 260 and ranging to 460).

   For ease in reading, make your gridlines dotted (or dashed) and make you constant theta lines thicker and green.
   Label your axes.

   NOTE – THERE IS A BUG IN IDL – YOU MIGHT FIND THAT WHEN YOUR PLOT IS COMPLETE, SOME OF THE CONTOUR LABELS ARE UPSIDE AND/OR BACKWARDS. A WORK-AROUND TO THIS BUG IS TO FLIP YOUR Y-RANGE ONCE AND THEN BACK AGAIN. IN OUR CASE WE WANT OUR Y AXIS RANGE TO START AT 1000 AND GO TO 200. SO WE WOULD DO THE FOLLOWING:
   FLIP IT ONCE: p.yrange=[200,1000] {where p is whatever your plot object is}
   AND FLIP IT BACK: p.yrange=[1000,200]

2. Using your emagram, by hand answer the following questions:
   a. If a parcel of air is at 0 C and 700 mb, what is its potential temperature?
   b. If that parcel undergoes isothermal compression to 900 mb; what is its new temperature, pressure and potential temperature? Has the parcel been heated (or cooled) in this process? If the <u>heat</u> energy has changed, where did it go/come from?
   c. Start with a parcel at 10 C and 500 mb. What is the potential temperature? The parcel then undergoes isobaric cooling to -20 C, what is the new temperature, pressure and potential temperature of the parcel? Has the heat energy changed during this process? If so where did it come from?
   d. Start with a parcel at 0 C and 800 mb, the parcel then undergoes *adiabatic* expansion to 700 mb. What is its new temperature, pressure and potential temperature? Has the parcel been heated (or cooled) during this process?
   e. Let the same parcel in (d) then undergo adiabatic compression to 1000 mb. What is the new temperature, pressure, and potential temperature?

3. After answering the questions in (2) by hand, add to your procedure lines of code that will utilize the *WHERE* function within idl to search indices to determine the answers to the above questions. For Parts (d) and (e) you will also need to use the MIN function.

   For example: If you want to know the potential temperature at 0C and 700 mb:
      index1 = (WHERE(temperature EQ 0.0))[0]
      index2 = (WHERE(pressure EQ 700))[0]
      print, "at T=10C & P=800mb, Pot. Temperature is: ", theta(index1,index2)
   *note that WHERE function returns an array of 1 value in the above statement, we force it to a scalar by placing the function in parentheses and taking the zeroth element...essentially setting indexXX to the first (and only) element in the 1 element array

   2(d&e) may be a little tricky...If you are searching for a particular value in an array it may not exist in your array that you are searching...so look for the closest value to what you are searching. You can do this using the MIN function in idl
      For example if I am looking for the index and value in an array that is closest to the value 5.3:
            arr = findgen(10) ;vector of ten values ranging from 0 to 9
            val = MIN((arr -5.3), arr_index, /ABSOLUTE)
      In the above example, val is returned with a value of 0.3, arr_index is returned with a value of 6. So if you were then to interrogate arr[6] you would find the value in arr closest to 5.3 is 5.

Procedures/Functions used in making the Emagram:

DINDGEN (to make my x- and y- variables)

MATRIX_MULTIPLY (to create my two-dimensional potential temperature matrix)

INDGEN (to define what contours to plot and their values)

CONTOUR (to make the plot, note that temperature will be your X argument, pressure will be your Y argument, and theta will be your Z argument)

> *Keywords I used for contour function:* AXIS_STYLE, DIMENSIONS (there are contained within the function-call to contour)

> *Properties I used to annotate my plot:*
> COLOR (set the contour color)
> YLOG (make the y-axis log scale)
> YRANGE & XRANGE (set range for x and y axis)
> C_VALUE & C_LABEL_SHOW (describe which contours to label and what to label them)
> XMINOR, XTICKLEN, XSUBTICKLEN, YTICKLEN, XGRID, YGRID (setup the dotted grid lines at T and P values and the short ticklines at other T values)
> YTICKVALUES (what values to label the Y axis gridlines)
> XTITLE, YTITLE, TITLE (titles around the chart)

An example using MATRIX_MULTIPLY:

> arr1 = [1,2]
> arr2 = [3,4]
> $\text{MATRIX\_MULTIPLY}(arr1,arr2) = \begin{bmatrix} 1*3 & 2*3 \\ 1*4 & 2*4 \end{bmatrix} = \begin{bmatrix} 3 & 6 \\ 4 & 8 \end{bmatrix}$

To compute theta, we could use matrix multiply to multiply two arrays:
(1) temperature and (2) $[10^5/\text{pressure}]^{\wedge}(R_d/c_{pd})$

ATSC5010, Lab 3: Emagram