"Coffee"-Cooling Experiment
***Physics** 222*

NAME: _____
LAB DATE: _____
LAB PARTNER(S): _____

Goals of the Laboratory Exercise

Part of the beauty of Physics is its application in the explaining how everyday phenomenon work at a fundamental level. In the "Coffee"-Cooling experiment we'll do just that. Specifically, we will apply some fundamental physics to model the temperature over time while a cup of coffee cools.

There are two parts to this exercise. First, we will acquire data in a controlled experiment. Second, we will try to model the results using some of the theory learned in lecture with input using the parameters from the controlled experiment.

Collecting the Data

This is an extremely simple experiment. Follow the steps outlined below. Please read them all before you proceed.

1. Fill a beaker with 200-500 milliliters of water. Measure and record the volume of water V as exactly as you can using the scale on the side of the beaker.
2. Measure and record both the height of the water h and the radius of the beaker L.
3. Measure and record the ambient air temperature of the room T_{room} in the vicinity of your experimental setup.
4. Bring the water to a boil after placing the beaker on a hot plate.
5. Take the beaker off the hot plate.
6. Place a thermometer into the middle of the body of water and wait until the thermometer reaches its maximum value. Then begin to measure and record the temperature every 5 seconds. **Note**: as the rate of change of temperature decreases, feel free to increase the time interval between measurements. Note also: DO NOT stir the water with the thermometer.

Time, t (sec)	Temperature, T_{water} (°C)	$\Delta T = T_{water} - T_{room}$
0		
5		
10		
15		

7. Continue to measure until the temperature of the water reaches about 40 °C.
8. Measure and record the height and volume of the water at the end of the experiment.

Modeling the Data

Theoretical Basis

In this section you will be modeling your observed values of temperature ΔT vs. time t for a cooling cup of coffee with the following equation (we will discuss the derivation of this equation in the lecture):

$$\Delta T_{\text{th}} = \Delta T_0 e^{-t/K} \quad , \qquad (1)$$

where
ΔT_{th} is the temperature difference (theoretical) between the room and the water through time
ΔT_0 is the temperature difference between the room and the water at the beginning of the experiment

The constant K is given by $K = mcr / kA$, where
m = the mass of the water = ρV
c is the specific heat of water (c = 4186 J/kg·°C)
r is the radius of the beaker
k is the thermal conductivity of water (k = 0.6 W/m·°C)
A is the <u>total</u> surface area of the body of water, see Fig. 1.

Calculate the constant K using your measurements.
Carefully check the units!

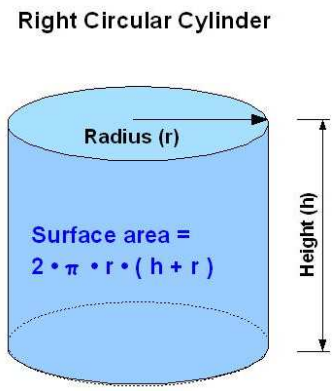

Fig. 1. Total surface area of a right circular cylinder.

Modeling Procedure

To do the modeling in MS Excel™, follow the "recipe" given below.

Step 1. Enter "t" and the observed value of ΔT in two adjacent columns in Excel. Start three columns over to the right and three rows down. Label each column at the top (e.g., "Observed ΔT") and add a title for the entire spreadsheet in the upper leftmost cell. **Save the file!**

Step 2. Put the value of the constant K in one cell in the second column with a label for it in the first column.

Step 3. Calculate a theoretical value for ΔT_{th} in the next column to the observed value ΔT using Eq. (1). To do this you need to type in this equation in the *Insert function* line in the following form $f_x = \Delta T_0$ *EXP(- ##/$#$#), where ## is the number of the first cell of the column for ΔT_{th}, $#$# is the number of the cell with the value of constant K.

Step 4. Plot the observed and theoretical values of ΔT and ΔT_{th} versus time t <u>together on one graph</u>. Put the graph in a permanently visible part of your window. To do this, first select simultaneously all the data and headings corresponding to t_i and the observed and theoretical values of ΔT . Then select the *Insert →Scatter →Scatter with only markers*.
Label the graph and the axes. Print out this plot.

Step 5. Calculate the squared difference between the theoretical ΔT_{th} and observed ΔT in the next column.(f_x=(## first cell TheoreticalTD – ## first cell ObservedTD)^2.
The best fit between theory and experimental results will be obtained when this value is minimized (closest to zero).

Step 6. Calculate the sum of the squared difference between the theoretical ΔT_{th} and observed ΔT. (f_x = SUM(##first cell: ##last cell)). Put this number in a cell in the second column.

Step 7. Now, obtain the best fit between theory and experiment results by changing the value of K (minimize the sum of the square using the *Solver* tool). Highlight the sqrd diff column, then go to *Data→ Solver→ min →Set target cell* #(sqrd diff)→ *By changing cell* #(K) → *Solve*. By this procedure you will get a new value of the constant K.

If you never have used the *Solver* tool you should add it to the *Menu* line. To do this go to *File→Options→Add-Ins→Manage Excel Add-Ins→Go→Solver Add-In→OK*. The *Solver* tool will appear in *Data* in the *Menu* line.

Step 8. If the *Solver* finds the solution the best fitted graph ΔT vs time will automatically appear on the plot. Print it out.

1. The sheet with your data (Excel).
2. Your graphs:
a) Observed and theoretical values for ΔT vs time on one graph. Indicate the value of K for the theoretical curve.
b) Observed and the best fitted theoretical values for ΔT vs time on one graph.
Indicate the value of K for the best fitted theoretical curve.