

# The Determination of Absolute Zero - A CBL Experiment

## Introduction

The temperature of a system is intimately related with its kinetic energy. For an ideal gas, for example, the more heat we apply to it, the more the gas molecules will move (i.e., we will have more kinetic energy), and therefore its temperature will rise. If this gas is in a rigid container, the increased movement of its molecules will produce more collisions between the gas molecules and the walls of the container. This is reflected collectively as an increase of the pressure of the system. As you know, these properties are related by the **Law of the Ideal Gases** (or **Perfect-Gas Law**), which follows the equation:

$$PV = nRT$$

If we keep raising the temperature of the gas in our rigid container, the pressure will increase until the walls of the container give out and it explodes. The opposite happens when we cool the gas. Since we are now decreasing the kinetic energy of the system, the pressure will start going down. At a certain temperature, the movement of the molecules in the container will ultimately stop, and this will translate to a pressure of 0. This behavior (and temperature) will be the same for any ideal gas. What is this very particular temperature, and how can we determine it? As you probably know, this temperature is known as **Absolute Zero**, and it is the lowest theoretical value that the temperature of any system can reach. It was determined by William Thompson (a.k.a. Lord Kelvin), and its value is  $-273.15\text{ }^{\circ}\text{C}$  (or also,  $0\text{ K}$ ).

There are several ways of determining absolute zero. A simple way of doing it is by measuring the pressure changes of a certain amount of a gas in a container with changes in temperature. If we rearrange the above equation, we can get pressure (**P**) as a function of temperature (**T**):

$$P = nR/V * T$$

If we use a rigid container, the volume (**V**) will not change with changes of pressure or temperature. Since the number of moles of the gas (**n**) and the gas constant (**R**) are fixed, the three can be replaced by a constant **K**:

$$nR / V = K \text{ (constant)}$$

Now, we can clearly see that the pressure should vary linearly with temperature:

$$P = K * T$$

As you know, the temperature in this equation is in units of K. If we had made our measurements using temperature in units of °C, the equation would look like:

$$P = K * (T_c - T_{abs})$$

Where  $T_c$  is the temperature in °C and  $T_{abs}$  the absolute temperature. As we said before, when the pressure is 0, the temperature should be the absolute temperature:

$$0 = K * (T_c - T_{abs}) \rightarrow T_c - T_{abs} = 0 \rightarrow T_{c(\text{for } P = 0)} = T_{abs}$$

Therefore, if we measure the pressure in a rigid container for a series of temperatures using °C units, we should get an equation of the form:

$$P = a * T_c + b$$

Even if we obtain a few temperature and pressure readings near room temperature, we can calculate  $T_{abs}$  by extrapolating to  $P = 0$ :

$$P = 0 = a * T_{abs} + b \rightarrow T_{abs} = -b / a$$

Today we will estimate the value of absolute zero by performing the procedure described above using air as our ideal gas. We will also use a new system for data acquisition, the **Calculator Based Laboratory 2**, or **CBL2**, from Texas Instruments. It will not only allow us to take more data points and more precise data, but should also be a lot of fun to use!

### **Experimental Procedure**

*For this experiment you will work in pairs. Also, this will be a formal lab report, and more details regarding the preparation of the report are found at the end of this handout.*

***We will be working with glass containers under pressure, so it is imperative that you wear your goggles at all times***

#### Loading the ChemBio package into your calculator

The instructor and TA will help you with this part. Take your calculator to the computer room and plug it to the serial cable (gray cable with a three prong-jack) on the back of the PC. If you have a TI-83 plus, the procedure is very simple. You just need and run the application named chembio83plus.exe (a yellow star icon) from the **Principles 113 DO NOT REMOVE** folder located on the **Desktop**.

If you have another calculator model, select the appropriate TI-GraphLink program from the **Principles 113 DO NOT REMOVE** folder. Set your calculator to receive data (it has to either be set on **HOME** mode or in **LINK-RECEIVE** mode depending on the model), and in TI-GraphLink select **Send** from the **Link** menu. When prompted for a file name, go to the **Principles 113 DO NOT REMOVE** folder (windows\desktop\princi~1), and select the chembio.xxg file, where xx is the number of your calculator model. If everything goes right, you should have the ChemBio package on your calculator in less than a minute.

### Setting up the system for data acquisition

Bring your calculator back to the lab, put it on the CBL2 cradle (for obvious reasons, the TI-92 and TI-92 plus will not fit, please don't force it), and plug the two-pronged serial cable between the calculator and the CBL2. Plug the temperature sensor to channel 1 (CH1) and the gas pressure sensor to channel 2 (CH2) of the CBL2.

In a 250 mL round-bottom flask put some blue-colored Drierite (the tip of a spatula will suffice). This will keep the air inside the flask relatively dry and will improve your results. ***Under no circumstances is the inside of this flask to be washed with water or get wet!*** Connect the rubber stopper from the gas pressure sensor to the mouth of the flask securely (twist the stopper firmly as you put it into the mouth of the flask), and after that open and close the valve on the stopper. You should hear a hiss, which is the air under pressure trapped inside the flask escaping. It is important that you let this air escape the flask, or your results will be flawed. After that, put an 800 mL beaker or water bath on top of a hot plate, and secure the flask on a stand so that it is as deep as possible in the 800 mL beaker. Fill the beaker with water so that it covers 3/4 of the flask, and then add approximately 1/2 an inch of ice to the beaker. Secure a thermometer and the temperature sensor from the CBL2 in the water bath so that their tips are not lower than the middle of the round-bottom. Put a large paper clip in the ice-water bath and turn on the stirring.

While the temperature and pressure settle inside the flask, you should start the ChemBio program on your calculator. After executing the program (the commands vary with the calculator model), you should enter an easy to follow menu. In the **\*\*MAIN MENU\*\***, select **1: SET UP PROBES**. Enter the number of probes, which should be **2**. On the next menu, **\*\*SELECT PROBES\*\***, you should first select **1: TEMPERATURE**. When prompted for a channel for this probe, enter **1**. You should now be back on the **\*\*SELECT PROBES\*\*** menu. You should now pick **3: PRESSURE**. At this point, enter **2** when prompted for a channel number. The calculator will now be in the **\*\*CALIBRATION\*\*** menu. Just enter **1: USE STORED**. At the **PRESSURE** prompt, select **1: GAS PRESSURE**, and then at the **PRESSURE UNITS** select **3: MM HG**. You should be back on the **\*\*MAIN MENU\*\***. Move down and select **2: COLLECT DATA**. At the **DATA COLLECTION** menu, select **2: TIME GRAPH**. Enter **60** seconds for the time interval between samples, and **30** for the number of samples. The next screen should tell you that the experiment will run for 1800 seconds. On the next screen,

**\*\*CONTINUE?\*\*, you have the option to correct the time step and number of data points. If everything is right, select **1: USE TIME SETUP**. At this point, check that the temperature of the water bath is approximately 10 °C on the thermometer, and turn on the heater on the hot plate to a setting between **2.5** and **3**. Wait 1 minute, and start the data acquisition. At the same time, start recording the time with your wristwatch. The experiment will run for 30 minutes, but since the program was designed for an older version of the CBL, you will not see the **READY** prompt on the CBL. Let the CBL2 acquire data for 35 minutes (to ensure that all the data is collected properly) and then press enter.**

While the CBL2 is acquiring data, check the temperature on the water bath with the thermometer periodically, and make sure that there is a 1 to 1.5 °C temperature increase per minute. If the temperature rises faster than this, lower the hot plate setting by 0.5 units. ***Do not let the temperature of the water bath rise above 70 °C, as the stopper may pop out of the round-bottom, or even worse, the round-bottom may shatter.***

Once the data collection has stopped, your calculator should be back on the **\*\*MAIN MENU\*\***. Select **6: RETRIEVE DATA**. This will put the time data in list **L1** of the calculator, temperature data in list **L2**, and pressure in list **L3**. Ignore any error messages after this point. **You are done!** All the data is in the calculator, and you can go back to the computer room to download it into the PC.

#### Downloading the Pressure - Temperature data to the PC

Plug your calculator to the PC using the gray serial cable, and select the appropriate TI-GraphLink program from the **Principles 113 DO NOT REMOVE** folder. On TI-GraphLink, select **Receive** from the **Link** menu. On the calculator, select the three lists that were just created, **L1**, **L2**, and **L3**, and set the calculator to send these files (again, different calculator behave differently). If everything goes right, the program will ask you for a directory to save the files. If you have a floppy, save them to a floppy (i.e., bring a floppy disk to lab).

Now, select **Open** from the **File** menu, and open the 3 files. They should be columns with 30 rows, one for time, one for temperature, and one for pressure. Open SigmaPlot from the **START** menu, and copy and paste these three columns from TI-GraphLink to a SigmaPlot sheet. On SigmaPlot, you can correct for probe miscalibration (see below) and plot P versus T, and a linear regression will give all the information you need to calculate the value of  $T_{abs}$ , absolute temperature, by extrapolation to **P = 0**.

*After this step you will have to do a second run to obtain a second estimate of absolute temperature*

#### Correcting for probe miscalibration

This step will be explained during in the laboratory, and it involves pretty much the same steps you have already performed. It will hopefully give slightly better results than the ones obtained with the raw data acquired with the CBL2.

## Formal report preparation

In your **Introduction**, you should describe what the purpose of the lab was, and also explain in your own words what is absolute zero. ***Do not copy the introduction of this handout in your introduction.*** This will be considered plagiarism, and you will receive 0 points.

In your **Materials and Methods**, describe the system we used in the determination of absolute zero (what size of round-bottom flask was used, the CBL2, your calculator model, how SigmaPlot was employed in the calculations). Also, describe if there were corrections applied to the raw data or not, and how they were performed.

In **Results and Discussion**, present the **P** versus **T** data tables for both runs. Include raw and corrected data if applicable. Present the two graphs of **P** versus **T** also. Show the calculations you used to estimate absolute zero for both sets of data, and report your final estimation of absolute zero as the average of both results.

For the **Conclusions** section, compare your result to the accepted value of absolute zero ( $-273.15\text{ }^{\circ}\text{C}$ ), and explain what factors may have affected your results. Finally, as this is a new laboratory experiment, we not only want to see how you did, but also how we did. Include a paragraph with your opinion regarding the lab, and compare it to other labs we have performed this year.