Using a Constant Pressure Gas Thermometer to Determine Absolute Zero Temperature

Goal: Measure the volume of a fixed mass of air at atmospheric pressure as a function of temperature. Use the results, in conjunction with the ideal gas law, to estimate absolute zero temperature.

Caution: This lab uses steam, which can be very hot, and mercury, which is poisonous!

Introduction:

In this constant pressure gas thermometer, a fixed mass of air is sealed within a long thin glass tube by a fixed rubber stopper at one end and by a drop of mercury at the other. The gas expands or contracts as its temperature is changed, moving the drop of mercury such that the trapped air always remains at atmospheric pressure (which must be the case since the tube is open to air beyond the mercury droplet). The volume $V$ of the trapped air is therefore an indicator of the gas temperature $T$. Since the diameter of the tube is (presumably) uniform and does not change (much) with temperature, the length $L$ of the trapped air column is reasonably proportional to $V$. Assuming this proportionality to be exact, the position of the mercury droplet provides a indicator of the gas temperature.

To change the gas temperature, the experimental apparatus allows ice water, warm water, and steam to be run through a tubular “jacket” that surrounds and encloses the inner tube containing the trapped gas. The ideal gas law, $PV = nRT$, states that the volume of a fixed amount of gas at fixed pressure is proportional to the absolute temperature, $T$. Assuming ideal gas behavior, only two measurements at fixed temperatures (e.g., at the normal freezing and boiling points of pure water) are needed to calibrate the gas thermometer. Measurements at additional temperatures are useful, however, in order to test the linearity of the ideal gas law. Hence rather than using only the known fixed temperatures (such as the normal freezing and boiling point of water) we will use cooling/heating baths of four different temperatures and base the calibration on the temperature of the baths as measured with a conventional thermometer. This will provide sufficient data to check the linearity of the $V(T)$ dependence. It will also allow an error analysis in the determination of the absolute zero of temperature, as extracted by extrapolating a linear fit to the data to the temperature at which $V = 0$. (The ideal gas law itself must fail at sufficiently low temperature, but data be taken only at high temperature, where the law is presumably valid.)

General Procedure:

Fill the steam generator about half full of water and turn on the hot-pad. Caution: the steam generator will get very hot! It takes a while for the water to boil, so to work efficiently you will want to carry out the measurements with ice water and then warm water while the steam generator is heating.

Begin by recording room temperature as indicated by the big wall thermometer. Measure the room-temperature length of the column of trapped gas between the rubber stopper and the mercury drop. Be sure to record the position of both ends of the air column. The aluminum square may help you to mark the mercury drop's position along the meter stick. At room temperature, the drop should be about 2/3rds of the way from the stopper to the open end of the jacket. If it isn't, ask the professor or TA to re-position it. Caution: Mercury is poisonous! If for some reason the mercury gets out of the tube, inform the professor or TA immediately.

Arrange the plumbing so that the funnel is connected to the jacket. When running water (warm or ice) through the jacket, tilt the tube such that the water will flow slightly uphill from intake to drain. This prevents bubbles from accumulating in the jacket. Make sure you catch the drain water in one of the beakers! For runs with ice water, partially fill the funnel with ice and pour cold water through it. You'll probably have to recycle the ice water through the funnel several times before the temperature stabilizes.

Measure the tube's temperature by temporarily inserting the probe of the metal thermometer into the drain rubber hose. Don't leave the thermometer in place permanently, though, or you'll restrict the flow and it
will take longer to reach a stable temperature. Once the temperature stabilizes, measure the length of the air column.

Finally, re-arrange the plumbing to attach the steam trap to the jacket input. Caution: The jacket and thermometer will get very hot! The tube should now be tilted the other way so that the steam moves slightly downhill in passing through, allowing any condensate to flow out the drain end. In theory, the trap dries the steam and there will be little condensate. After the temperature stabilizes, again measure the length.

**Lab Report:**

The specific style and format of the lab report are up to you, but it should be word-processed and/or neatly printed. Be concise. You will want to include:

- a description of the experimental apparatus, with appropriate sketch(es),
- all original data, in appendices,
- a plot and discussion of the measured relation between trapped air volume and temperature, along with a discussion of the expected theoretical relation between $V$ and $T$ based on the ideal gas law,
- your estimate of the absolute zero of temperature in degrees Celsius,
- an estimate of the uncertainty ("error") in your value of absolute zero in °C as extracted from a linear fit to the plotted experimental data points (Hint: Use the Excel Linear Regression Tools).
- a discussion of why the ideal gas law expected to fail at low temperatures and how its failure might affect your estimation of absolute zero.

There are likely systematic errors in your estimate of absolute zero in °C. Some sources of systematic error might be thermal expansion of the glass tube or the presence of temperature gradients within the heating/cooling jacket. Pick one such factor and give a thoughtful and at least semi-quantitative estimate of how it affects your estimated value of absolute zero, e.g.:

"Proper inclusion of thermal expansion of the glass tube in our analysis would change our estimate of absolute zero by $X.X ^\circ$C. As detailed in Appendix B, thermal expansion of the glass tube causes the diameter of the tube to vary with temperature, which has been neglected in the foregoing calculations. An estimate of this volume change, based on a thermal expansion coefficient of ..."

**Submission:** Lab work is a team effort and only a single lab report is to be submitted by each team. However, every member of the team must preserve a copy of every lab report and all data and computer files that are part of the lab report. All of this, including files on floppy disk, must be saved by each student in a special lab binder, which will be used during hour exams and the final exam for questions pertaining explicitly to the lab work. Students who fail to save their lab reports or do not understand the lab work will fare poorly on such exam questions.

Specify the specific contributions of each team member to the lab work. These roles MUST change from week to week. The specific style and format of the lab report are up to the team, but the report must be neat, readable, and carefully organized. It must be self-contained, so that an intelligent reader is able to understand what was measured and why without additional information or insight. A copy of this lab handout is available on the class web page. All relevant original data must be included in the lab report as an appendix and preserved on floppy disk in the lab binders of each student. Most of any spreadsheet analysis can also go into appendices, with relevant data tables and graphs copied into the main report. Do not include pages of spreadsheet numbers, but rather a graphical presentation of the data and calculations along with any mathematical formulas used in the spreadsheet. Questions posed in the lab handout must be answered in the lab report. Calculations, graphs, predictions, etc. that are requested in the handout must be presented in the report. Include sketches of the experimental apparatus to supplement any descriptions.