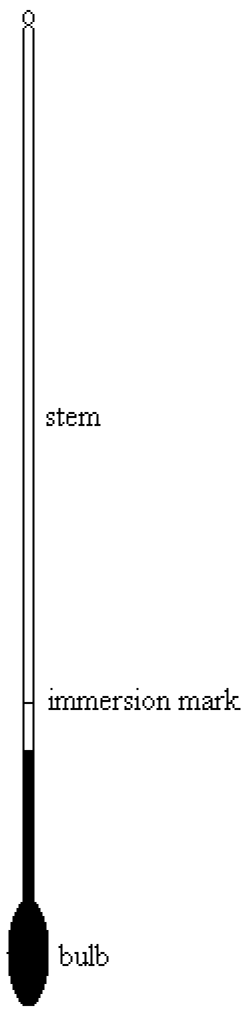
CHEM 109
Introduction to Chemistry
Revision 2.0

Laboratory Exercise: Calibration of a Thermometer

In this exercise we will calibrate two types of thermometers and then use them to measure the Air temperature of the laboratory. We will also examine a sensor designed to measure ambient Air and log room temperatures over an extended period of time.

One of the most common types of laboratory thermometers is the liquid-expansion thermometer. In this type of thermometer, an expansion liquid, usually Mercury or Alcohol, fills a glass bulb attached to a long stem with a uniformly bored expansion column. When heated, the liquid expands up the bore until the bulb reaches thermal equilibrium with the material whose temperature is being measured. The expansion of the liquid is such that the height it reaches in the stem is linear with temperature. These thermometers are typically marked with equal spacings along the stem. They are then calibrated at two different "fixed point" temperatures. Alcohol thermometers are of lower accuracy than Mercury thermometers, but are more commonly used in the chemistry laboratory because Mercury is toxic and difficult to clean-up in the case of breakage. The lower accuracy of an Alcohol thermometer is due to two reasons: (1) Alcohol is more volatile than Mercury and so will vaporize into the space above the liquid in the stem; and (2) Alcohol tends to “wet” the sides of the stem’s bore such that when the temperature drops, part of the liquid remains along the wall of the bore.



Stem Style Thermometer

Thermistors are a competitive alternative to the stem thermometer. They are constructed from resistive materials, such as sintered metal oxides, that respond to temperature changes. A thermometer is constructed by embedding the thermistor into the end of stainless steel tube with conducting leads attached. The leads can then be connected to an electronic device that can measure the resistance of the thermistor at given temperatures. It is found, to a first approximation, that the logarithm of the resistance is linear with inverse temperature changes. A major systematic error associated with thermistors is self-heating; heating that occurs when an electric current flows through the thermistor. (When measuring the resistance, a small current is passed through the thermistor and the voltage drop across it is determined. Applying Ohm's Law allows for the determination of the resistance.)

One application of thermistor based thermometers is to use them as sensors. The thermometer can be deployed as part of a sensor that can be connected directly to a control device, logging system or electronic display. The *Hobo Pendant Data Logger* manufactured by the Onset

Corporation allows for logging of temperature readings in a compact package. The unit can then be docked to an interface that allows for downloading the readings to computer.

PS-2153 Stainless Steel Themistor Probe by Pasco Scientific

UA-002-08 Hobo Pendant Data Logger

As with any measuring device, the <u>accuracy</u> of the device can only be judge by calibration of the device. Calibration is such that a measurement is performed whose result is well known. The instrument is then adjusted such that its reading gives this result. Or, a correction factor is determined such that subsequent readings can be corrected for the known instrument error. For a stem thermometer, because the markings along the stem cannot be adjusted, a Correction Curve is prepared such that thermometer readings can be converted to accurate temperatures. Something similar can be done for a thermisor based thermometer. Known temperature baths for calibration can be generated using the Ice Point and the Boiling Point of Water. These temperature baths are called "fixed points" because of their use as calibration markers for thermometers.

We will calibrate both stem and thermistor based thermometers. Once our thermometers are calibrated, we will use them and the Hobo Pendant sensor to measure the Air temperature of the laboratory. We will then compare the results of all three measurements.

Procedure

Stem Thermometer

Thermometer Identification

1. If possible, note the manufacturer, serial number and manufacture date of the thermometer.
2. Note the temperature Range of the thermometer.
3. Note the precision of the thermometer. (What is the "uncertain" digit to which readings can be made?)
4. Note whether or not the thermometer is a Total Immersion or Partial Immersion type. Partial Immersion thermometers will have an Immersion Mark and are designed so that only that part of the stem is exposed to the temperature being measured. Total Immersion thermometers are designed so that both the bulb and the entire liquid column must be exposed to the temperature being measured.
5. Check to make sure that the liquid in the stem of the thermometer has not separated. If it has, ask your laboratory instructor for a new thermometer.

Calibration at the Ice Point of Water

1. Fill a styrofoam container with crushed Ice. (You will have to share a container with another group, so become friendly with your neighbors.)
2. Add enough **pre-cooled** **distilled** Water to cover the Ice, but not so much Water such that the Ice floats.
3. Thoroughly stir the Ice-Water mixture.
4. Hang your thermometer by a string from a clamp attached to a ring-stand until it is appropriately inserted into the Ice-Water.
5. Allow the temperature shown by the thermometer to stabilize. (~10 minutes is required to establish thermal equilibrium.) After 3 minutes at the stable temperature, record the temperature to the correct precision.
6. The Ice Point of Water is remarkably stable at 0.00^oC. What is the Percentage Error in your measurement?

Calibration at the Boiling Point of Water

1. Set up a hot plate with a 500 mL Florence Flask resting on it. The flask should be supported by a clamp from a ring stand.
2. Fill the flask about **half full** with distilled Water. Add a few boiling chips to promote smooth boiling.
3. Hang the thermometer from the ring stand as before such that the immersion mark is in the neck of the flask. (Once at reflux, both the Water and its vapor will be at the boiling point. Using a Florence Flask helps promote the reflux. Why?)
4. Turn on the hot plate and allow the Water to come to its Boiling Point.
5. Allow the temperature shown by the thermometer to stabilize. (~10 minutes after a rolling-boil has been achieved.) After 3 minutes at the stable temperature, record the temperature to the correct precision.

6. The Boiling Point of Water is extremely sensitive to the atmospheric pressure. You will be provided with the day's atmospheric pressure. Use this, along with the data in the Appendix, to determine the correct Boiling Point of Water. You may have to interpolate the data in the Table. If so, a computer program that performs interpolation calculations will be provided. What is the Percentage Error in your measurement?

Thermistor

Calibration

Your laboratory instructor will set-up the calibration of the thermistor based temperature probe. You will make readings of thermistor's resistance once thermal equilibrium has been established in each fixed-point bath.

1. When your instructor announces that the temperature probe has reached thermal equilibrium in the Ice Water Bath, make a reading of the thermistor's resistance. (Make all readings in kiloOhms.)

2. When your instructor announces that the temperature probe has reached thermal equilibrium in the Boiling Water Bath, make a reading of the thermistor's resistance.

Air Temperature

The Air temperature in the room will be measured by measuring the temperature of a large Water bath that has been allowed to come to thermal equilibrium with the Air.

1. Obtain a Hobo Sensor and see your instructor to have it activated.

2. Hang it and your stem thermometer from the ring stand into the Water bath provided. (Everyone will share the same large bath.) Your instructor will do the same with the thermistor probe.

3. Allow for thermal equilibrium to be established. Make the appropriate readings.

4. Take your Hobo sensor to your instructor for download of the temperature data.

Appendix

Atmospheric Pressure (mmHg)	Boiling Point Water (^oC)
760	99.996
750	99.629
740	99.257
730	98.880
720	98.499
710	98.112
700	97.720
690	97.323
680	96.921
670	96.512
660	96.098
650	95.676
640	95.249
630	94.814
620	94.371
610	93.921
600	930463

Data taken from:

http://hyperphysics.phy-astr.gsu.edu/Hbase/Kinetic/vappre.html#c5

See reference for details and approximations.

Data Sheet

Stem Thermometer

Thermometer Identification

Manufacturer ________________________________

Manufacture Date ________________________________

Temp Range ________________________________

Thermo. Precision ___________ ^oC

Calibration at the Ice Point of Water

Thermo. Reading ___________ ^oC

Percentage Error ___________ %

Calibration at the Boiling Point of Water

Thermo. Reading ___________ ^oC

Atm. Pressure ___________ mmHg

Corr. BP Water ___________ ^oC

Percentage Error ___________ %

Thermistor

Calibration

Ice Bath Resistance Meas. ______________ kΩ

Boiling Bath Resistatnce Meas. ______________ kΩ

Air Temperature

Stem Thermo. __________ ^{O}C

Thermistor __________ kΩ

Attach a Printout of Your Hobo Sensor Readings to this Report.

Name: ________________________________ Date: _____________________

Signature: ________________________________

Data Analysis

Construction of Calibration Curves

Stem Thermometer

A Calibration Curve will allow us to convert direct thermometer readings to correct temperature values.

1. Obtain a sheet of graph paper.

2. Along the *x*-axis, plot actual thermometer readings.

3. Along the *y*-axis, plot correct temperatures.

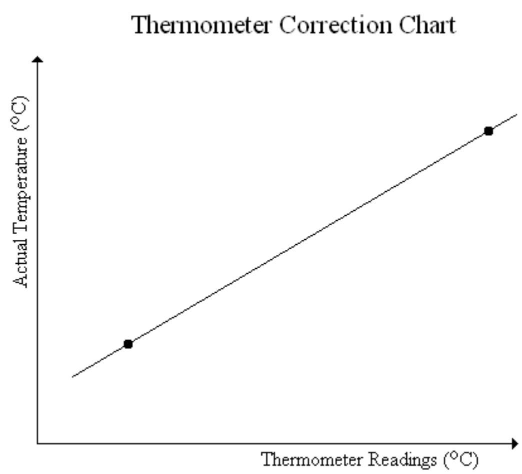
4. Plot your two data points on this graph and draw a straight line between them.

5. Be sure the axes of the graph are correctly labeled and that each label has an appropriate unit.

6. Be sure the graph has a correct title.

7. Be sure the graph fills most of the sheet of paper.

8. An example is below:



Thermistor

A similar Calibration Curve is to be prepared for the thermistor probe. In this case, the logarithm of the thermistor's resistance is linear in the inverse temperature.

1. Plot along the *y*-axis ln(R); the natural log of the resistance.

2. Plot along the *x*-axis 1/(t + 273.15); where *t* is the temperature in Celsius.

Data:

Temp. [^{o}C]	Resistance [kΩ]	1/(t + 273.15)	ln(R)
________	________	________	________
________	________	________	________

Use of Your Calibration Curves

Use your Calibration Curves to determine the "correct" Air temperature for the room as measured by both the stem and thermistor thermometers. Compare your results with each other and with the Hobo sensor measurements.

Results:

Air Temp (Stem Thermo) _______________ ^{o}C

Air Temp (Thermistor) _______________ ^{o}C

Air Temp (Hobo Sens) _______________ ^{o}C *

* Pick an appropriate time point once equilibrium has been established for reporting the temperature measurement.

Post Lab Questions:

1. Will "wetting" by the expansion liquid in a stem thermometer along the stem's bore lead to a Systematic or a Random Error in the temperature measurement? Explain your reasoning.

2. The Tap Water used in preparing the Ice used in our Ice Point Calibration will contain dissolved salts. What does adding salt to Ice typically do to the Freezing Point? Will this lead to a Systematic or Random Error in our calibration procedure? Explain your reasoning.

3. How will the systematic errors mentioned regarding an alcohol thermometer affect the thermometer's reading?

4. In calibrating our thermometer at the Boiling Point of Water, we brought the system to "reflux." What does this mean? How does the design of the Florence Flask help the system attain reflux?

5. Why do we use a large Water bath to measure the Air temperature in the room?

6. Go to the Pasco Scientific website and look for the specifications for the PS-2153 temperature probe. What is the temperature range for this probe? The technical notes for this probe can be found by typing "441" into the *Search* bar. What is the listed design constraint for this probe? Do you find this to be true? (You will need to consult your Calibration Curve.)

7. Consult the Hobo Sensor's specification sheet. What is the reported accuracy of the sensor at our room temperature? For our room's temperature, over what range could the sensor read? What is the sensor's reported precision? Does it make sense to have a device with a precision that is smaller than its accuracy? Explain. What is the response time of the sensor? (Remember, everything must come to thermal equilibrium before an accurate measurement can be made.)

8. For high precision work, thermometers are often calibrated in Water triple-point cells. What is a triple-point cell and what is its calibration temperaure?

9. The U.S. government has established the National Institute for Standards and Technology to maintain measurement standards. Data concerning its Thermometry services can be found at:

   http://www.nist.gov/thermometry.cfm

   How much would it cost to have the *NIST* calibrate our stem thermometer?