# ASEN 2002
# Thermodynamics Experimental Laboratory 1
# Temperature Measurement

Assigned Wednesday 24 Aug

Individual Lab Reports due Wednesday 14 Sept

## OBJECTIVES

- *Learn basic concepts and definitions associated with temperature and temperature measurements.*
- *Develop awareness of sources of error and error analysis.*
- *Use thermocouples to make temperature measurements.*

## REQUIRED DELIVERABLES

- *Attendance at every lab period is required. Instructions for weekly tasks and the individual report will be presented during the scheduled lab time.*
- *Prepare a written brief report of the results of your laboratory exercises. Use the guidelines that will be provided to complete your report.*

## TEMPERATURE BACKGROUND

**Temperature and Temperature Scales**

We usually think of *temperature* in terms of the adjectives "hot" and "cold," i.e., hot associated with a higher temperature than cold. We also know from common experience that a form of energy called *heat* "flows" in a direction from hot to cold. Two bodies in *thermal equilibrium* are at the same temperature so there is no heat flow between them. This is essentially a statement of the *zeroth law of thermodynamics*.

Since substances behave predictably with respect to temperature, the physical behavior of a substance can be used to create a *temperature scale*. Two examples of temperature scales are the Fahrenheit and Celsius scales. Each of these is a *two-point scale*, based on the freezing (or melting) and boiling points of pure water, i.e. the ice and steam points. Note that the ice point is defined as an equilibrium mixture of ice and liquid water at 1 atmosphere of pressure. The steam point is defined as a mixture of liquid water and water vapor at 1 atmosphere of pressure. The freezing and boiling points are arbitrarily assigned a value of 32.00 °F and 212.00 °F, respectively, for the Fahrenheit scale and 0.00 °C and 100 °C, respectively, for the Celsius scale. The Rankine (R) and Kelvin (K) temperature scales are the absolute Fahrenheit and Celsius scales, respectively. The zero point of both absolute scales corresponds to the lowest temperature possible. A more precisely reproducible point to serve as reference for calibrating thermometers is the triple point of water (the state at which all three phases of water coexist in equilibrium). To keep with the tradition of the Celsius scale, the triple point of water was assigned its value on this scale of 0.01°C resulting in the Kelvin scale value for the triple point of water to be 273.16 K (see the link to the International Temperature Scale of 1990 for more details, http://www.its-90.com/ )

Note that $\Delta T(\mathrm{K}) = \Delta T(^\circ\mathrm{C})$ and $\Delta T(\mathrm{R}) = \Delta T(^\circ\mathrm{F})$. The relations between the common Celsius and Fahrenheit scales and the corresponding Kelvin and Rankine absolute scales are:

$$T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273.15 \qquad T(\mathrm{R}) = T(^\circ\mathrm{F}) + 459.67$$

$$T(\mathrm{R}) = 1.8\, T(\mathrm{K})$$

$$T(^\circ\mathrm{F}) = 1.80\, T(^\circ\mathrm{C}) + 32.00$$

**Thermometers**

Fluid-in-Glass Thermometer

A *thermometer* is a device used to measure temperature. The molecular structure of matter responds predictably to temperature changes. This is manifested through changes in certain variables such as volume, electrical resistance, thermal expansion, etc. The thermometer uses the predictable changes in physical variables to measure temperature. For instance, the mercury-in-glass or alcohol-in-glass thermometers that were often used to measure body temperature or the daytime temperature in the shade are based on the principle that over certain temperature ranges, these liquids predictably expand (contract) with an increase (decrease) in temperature.

The bulb of the in-glass thermometer is immersed in the medium for which it is measuring the temperature. The measurement is made once the fluid inside the bulb is in thermal equilibrium with the medium. The location of the meniscus in the capillary tube depends on the volume change of the thermometer fluid. An increase in temperature above some initial value causes the fluid to expand and the meniscus to rise; for a temperature decrease, the meniscus will fall.

An instrument is *calibrated* by comparing its output to a known standard or known input. The thermometer is calibrated for the Celsius, for instance, by assigning marks on the tube associated with the height of the fluid at the ice and steam points. Then a scale of 100 equal increments between these points corresponds to the Celsius temperature scale. Because the glass also expands, the calibration actually corresponds to the difference in expansion of the thermometer fluid and the glass capillary.

Thermocouples

A *transducer* is a device that transforms physical variables into corresponding electrical signals. When two dissimilar metals are brought into contact, an electromotive force (emf) will be generated, this thermoelectric effect is the *Seebeck effect* and the resultant emf is called the *Seebeck voltage*. For certain materials, over specific temperature ranges, the Seebeck voltage can be accurately predicted with a polynomial approximation. This predictable behavior is the basis of the *thermocouple*, a transducer that uses the thermoelectric properties of dissimilar metals in contact to measure temperature.

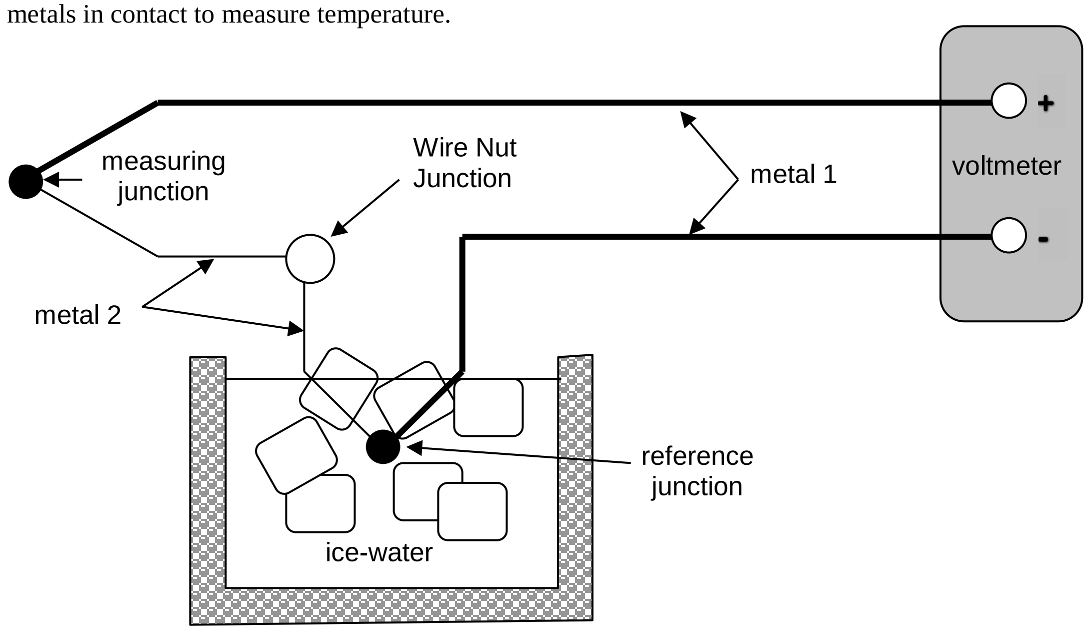


**Figure 1** Thermocouple schematic: voltmeter with ice reference for cold junction.

Unless the terminals of the voltmeter are made of exactly the same material as the wires that are attached to it, a Seebeck voltage is generated and must be accounted for. To get around this problem, the leads and the terminals can be of the same material and a second junction is created and kept at a known reference temperature. As shown in Figure 1, the reference junction is often put into an ice-water mixture such that it is at a known reference temperature, with the voltage measured by a voltmeter.

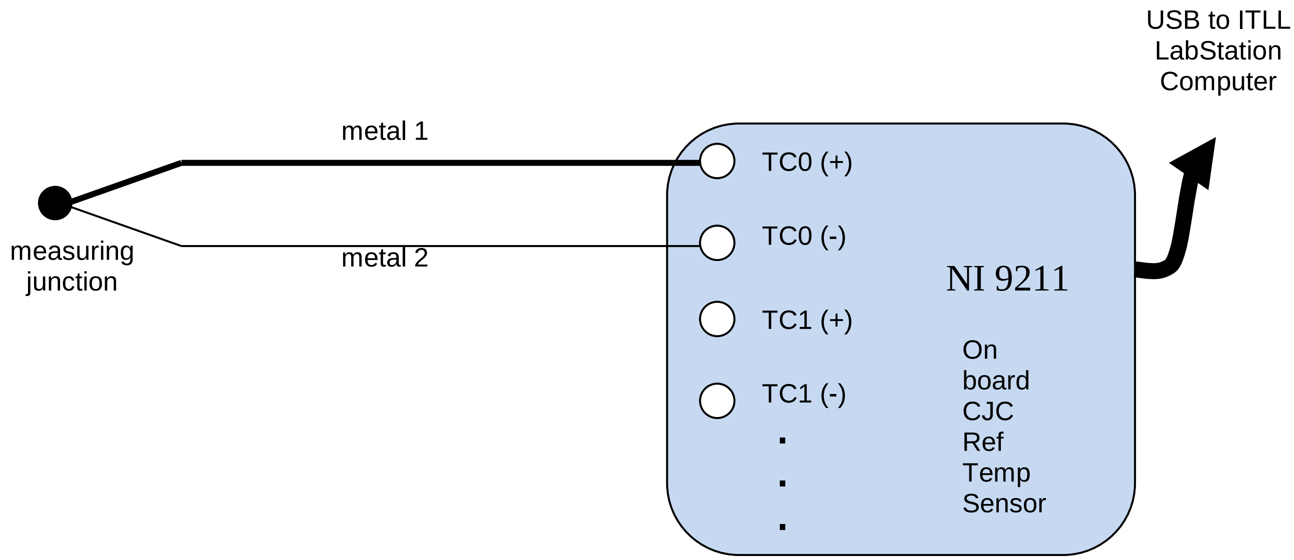


**Figure 2** Thermocouple schematic: data acquisition card connection with software cold junction compensation.

More sophisticated methods use hardware or software to compensate for the additional voltage at the reference junction such as shown in Figure 2. The thermocouple is connected directly to specialized data acquisition (DAQ) hardware designed for taking temperature measurements. A thermistor or resistance temperature detectors (RTD) located inside the DAQ hardware measures the CJC (Cold Junction Compensation) temperature at the point where the dissimilar metals attach to the measuring hardware. The CJC temperature is used as the known reference temperature in the LabVIEW VI program and is used in place of the known 0°C ice bath in Section 1. A detailed thermocouple tutorial is provided in National Instruments Application Note 043.

For this laboratory exercise, we employ a yellow “type-K” thermocouple that uses nickel-chromium and nickel-aluminum wires. There are different types of thermocouple wire each having its own temperature measuring range. The nickel-chromium wire is covered with yellow insulation and connect to the “+” terminal, and the nickel-aluminum wire is covered with red insulation and connects to the “–” terminal.

## ERROR ANALYSIS BACKGROUND

Refer to the Seebeck Voltage PowerPoint presentation and 34461A Multimeter Accuracy PDF on D2L to understand the error calculations.

# Section 1 & 2 (Wed 26 Aug & Wed 2 Sep)

**!!!! Take good notes of experimental setup, record data, and consider possible errors in measurements !!!!!**

## 1 Learn the basic concepts and definitions associated with temperature and temperature measurement.

a) Refer to the Temperature Background material, class textbook, and the more detailed thermocouple discussion in National Instruments Application Note 043 located on D2L.

## 2 Identify quantities to be measured and required instruments.

a) Read through this entire document and develop a test matrix that describes the experiments and measurements to be performed. Refer to the "Thermocouple TestMatrix.xlsx" file as a starting point.

b) **ACTION ITEM:** Confirm with a class TA, CA or LA that the test matrix is accurate and complete before proceeding to carrying out experiments.

c) Record instrument information including pertinent manufacturer information. Record EXACTLY which instruments you use, including serial numbers. In case your data is suspect later you can repeat or compare your measurement equipment.

## 3 Thermocouple Pair Construction

a) Label each thermocouple with an identifiable marking (like your initials and a number) and a marking to keep track of which thermocouple is being used as the reference and which as the measurement thermocouple.

b) Combine two thermocouples together by teaming up with your assigned partner and build an ice-referenced thermocouple system as shown in Figure 1 above. Attach a banana plug to each end of the metal 1 wires. Attach the other two ends of metal 2 wires TOGETHER using a wire nut.

c) Verify the thermocouples are functioning properly. Connect the thermocouple pair to a desktop multimeter and verify that voltage changes when you hold each thermocouple weld. **ACTION ITEM:** *Check the voltage polarity and make sense of whether a positive or negative polarity should be used.*

## 4 Perform simple temperature measurements using an ice-water reference point and a boiling water reference point. (Perform as a group and share data among group members). Use your test matrix to confirm that all tests have been performed.

a) Turn on the hot-plates first and allow time for the water to boil.

b) All testing must take place on a teal cart, do not place any testing materials on the ITLL LabStation top! (Water and heat are hazardous to the computers!)

c) Ice is available in the freezer in the ITLL fume hood room.

d) **Thermocouple Check:** Test thermocouple integrity by placing the measurement thermocouple and the reference thermocouple in the water-ice mixture. Do not let the thermocouples touch and try to keep them both away from the walls of the container. Wait to record the voltage until a mostly steady voltage value has been reached. **ACTION ITEM:** *Record your readings and evaluate how well the thermocouple setup measures the expected value for ice water of 0.00℃. This method should allow you to evaluate systematic and statistical errors in your setup. Theoretically the measured voltage should be close to zero. If the voltage reading is a millivolt or more than check with Lab assistants about a faulty thermocouple.*

e) **Room Temperature Measurement with Ice-Bath Reference:** Place your reference thermocouple in the water-ice reference bath (make sure the bath remains a water-ice mix during your measurements) and let the measurement thermocouple sample the air. Use the multimeter to measure the total voltage. Wait to record the voltage until a mostly steady voltage value has been reached (about 30 seconds). Note that the least significant digit on the multimeter will be changing all the time and relates to the precision of the measurement. **ACTION ITEM:** Record the full reading of the measured voltage and estimate the value for the least significant digit. Also record an observed error estimate of your measured voltage by observing the range of values that occur in the least significant figure. This measured voltage and observed error will be used to estimate the room temperature using the voltage-to-temperature conversion from *National Instruments Application Note 043*. **ACTION ITEM:** *Record the room temperature and pressure in the plaza from ITLL's thermometer to compare with the thermocouple estimate.*

f) **Body Temperature Measurement with Ice-Bath Reference:** Use your measurement thermocouple to measure one group member's body temperature by placing the thermocouple in the inside bend of the elbow. **ACTION ITEM:** Record the voltage.

Cycle through TEN times. NOTE: a single measurement constitutes the placing of the thermocouple on the object and recording a temperature after the specified transient testing times listed below, then remove the thermocouple, wait 5 seconds and then repeat the measurement.

Transient Testing Times: 1 minutes for body temperature.

g) **Boiling Water Temperature Measurement with Ice-Bath Reference:** Use the measurement thermocouple to record the voltage for estimating the temperature of ¼-liter of water once it begins to boil. Wait to record the voltage until a mostly steady voltage value has been reached.

h) **Room Temperature Measurement with Boiling Water Reference:** Now place your reference thermocouple in the boiling water and record the voltage using the measurement thermocouple to determine room temperature. Wait to record the voltage until a mostly steady voltage value has been reached. Use the voltage-temperature conversion from National Instruments Application Note 043 to account for the added voltage introduced by the boiling water reference. **ACTION ITEM:** *Remember to have recorded the room from the plaza barometer.*

# Section 3 (Wed 9 Sep)

## 5 Connect a single thermocouple to DAQ hardware for cold-junction compensation.

a) Disassemble the thermocouple pair you made in the last lab section. Connect all four thermocouples in the group to the DAQ hardware, which does the cold-junction compensation, taking the place of the second thermocouple. Make a note identifying (by name) which thermocouple you are using and update in your testing matrix.

b) Connect one thermocouple to the NI 9211to channel TC0 using the screw terminals of the DAQ. Ensure that the Nickel-Chromium (yellow) is connected to the positive terminal TC0 (+) and the Nickel-Aluminum (red) is connected to the negative channel TC0 (-). If you want to add more thermocouples simply repeat the above connection on the next channel, i.e. TC1. Note: The NI 9211 can handle up to four thermocouple connections.

c) Now connect the NI 9211 to the USB carrier (NI USB-9162) if not already connected and plug into USB port of your lab station computer.

## 6 Measure temperature using the LabVIEW software.

d) Log onto a lab station computer and open the *Temperature History USB.vi* located in the *ASEN 2002/Exp 1* folder.

e) Before running the program you must ensure that the VI is pointing at the right device (NI 9211). To do this open *Measurement and Automation (NI MAX)* located on your desktop. Under *My System* expand the *Devices and Interfaces* folder. This will show all the "devices" that are connected to the computer including the NI USB-9211A. Verify that the NI USB-9211A is listed as “Dev2”. If not right click the icon and select *rename* and rename it Dev2.

f) Exit out of *Measurement and Automation*.

g) Back in the LabVIEW VI notice that there are four buttons corresponding to the four input channels on the DAQ. Before pushing run on the VI select the channels that you have plugged thermocouples into.

h) Run the VI by clicking on the right arrow button located in the top left menu bar.

i) When finished recording data, hit the “Stop” button. You can now access the data you collected by opening up the tab-delimited text file readable in Excel or Matlab. Note: The LabVIEW program is a virtual instrument (VI) that collects the data only. Do not use the File/Save menu within LabVIEW to try to save your data, as this saves the LabVIEW program and has nothing to do with your collected data.

*j)* **ACTION ITEM:** *Record measurements of the room temperature and boiling water temperature as in part e and g in last week’s experiments.*

Tip: When taking multiple measurements with the DAQ and LabBVIEW software, it is suggested you run the LabVIEW VI for each individual measurement, i.e., create multiple data files, one for each measurement.