

Name: _____

Date of lab: _____

Section number: M E 345. _____

Lab 10

Precalculations – Individual Portion

Temperature Lab: Experimental Measurement of Temperature

Precalculations Score (for instructor or TA use only):	_____ / 20

1. (12) Write and briefly explain the three thermocouple laws *in your own words* (sketches may be helpful).

Law of intermediate metals:

Law of intermediate temperatures:

Law of additive voltages:

2. (4) Read the sections in the the related learning module describing thermistors and RTDs, and then answer these questions:
- (a) Does resistance of a RTD increase or decrease with temperature?
 - (b) Does resistance of a thermistor increase or decrease with temperature?
3. (4) Suppose a student is measuring temperature with an infrared pyrometer. The temperature displayed by the pyrometer is T_{ind} . The student wants to write a simple equation for the actual temperature T_H of an object, corrected for its emissivity, using a correction factor $C_{\text{correction}}$ as in this equation, $T_H = C_{\text{correction}} T_{\text{ind}}$. The emissivity of the object is approximately 0.73. The infrared pyrometer has been calibrated assuming the emissivity of the object is 0.95 (the same assumption made by the instrument used in this lab). Calculate the correction factor $C_{\text{correction}}$ for the object. If $T_{\text{ind}} = 250^\circ\text{C}$, calculate T_H in $^\circ\text{C}$. Give all answers to 3 significant digits.

Cover Page for

Lab 10

Lab Report – Group Portion

Temperature Lab: Experimental Measurement of Temperature

Name 1: _____ Section M E 345. _____

Name 2: _____ Section M E 345. _____

Name 3: _____ Section M E 345. _____

[Name 4: _____ Section M E 345. _____]

Date when the lab was performed: _____

Group Lab Report Score (For instructor or TA use only):

Lab experiment and results, plots, tables, etc.	_____ / 50
Discussion	_____ / 30
TOTAL	_____ / 80

Lab Participation Grade and Deductions – The instructor or TA reserves the right to deduct points for any of the following, either for all group members or for individual students:

- Arriving late to lab or leaving before your lab group is finished.
- Not participating in the work of your lab group (freeloading).
- Causing distractions, arguing, or not paying attention during lab.
- Not following the rules about formatting plots and tables.
- Grammatical errors in your lab report.
- Sloppy or illegible writing or plots (lack of neatness) in your lab report.
- Other (at the discretion of the instructor or TA).

Name	Reason for deduction	Points deducted	Total grade (out of 80)

Comments (for instructor or TA use only):

Temperature Lab: Experimental Measurement of Temperature

Author: John M. Cimbala; also edited by Mikhail Gordin and Savas Yavuzkurt, Penn State University
Latest revision: 15 November 2013

Introduction and Background *(Note: To save paper, you do not need to print this section for your lab report.)*

Temperature can be measured with a wide variety of instruments, many of which utilize totally different principles of operation. As discussed in the related learning module, there are four primary categories of temperature measuring devices, based on the physical principle employed: **mechanical** (liquid-in-glass thermometers, bimetallic strips, etc.), **thermojunction** (thermocouples), **thermorestive** (RTDs and thermistors), and **radiative** (infrared and optical pyrometers). Detailed discussions about each of these can be found in the related learning module. Five temperature measuring instruments are used in this lab, representing all four of the above categories: **liquid-in-glass thermometer**, **thermocouple**, **thermistor**, **infrared pyrometer**, and **optical pyrometer**. Temperature measurements from several of these instruments are compared.

A **thermocouple** produces its own voltage when the temperature changes; the **thermojunction voltage** so produced is a unique function of temperature and the two metals that form the thermocouple. A commercial quality thermocouple is used in this lab. Also, you will make your own thermocouples by simply twisting together pairs of dissimilar metal wires to form junctions. Common commercial thermocouples cost less than \$100, and are accurate to less than one degree C. The same accuracy can be achieved for a couple dollars with home-made thermocouples by simply connecting thermocouple wire together.

A **thermistor** works on the principle that electrical resistance of the sensor changes as temperature changes. In practice, the resistance of the thermistor is measured and then related to temperature through a calibration curve. Thermistors are usually produced from a silicon material whose electrical resistance changes with temperature. Thermistors are easier to use than **resistance temperature detector (RTD)** probes because of their large resistance change for a small temperature change (higher **sensitivity**). They are also inexpensive – only a few dollars each. However, they are nonlinear in their response, and are not very precise. Calibration curves can fluctuate as much as 5 to 10°C between thermistors. For comparison, a more expensive platinum RTD can be used to attain accuracies of 0.1°C, but can cost \$100 or more.

Pyrometry relies on a quantitative measurement of the radiation that is emitted from an object. The main advantage of pyrometers is that they work **without physical contact with the hot object**. The two types of pyrometers that are used in this lab are the **optical pyrometer** and the **infrared pyrometer**.

An **infrared pyrometer** uses a **radiation detector** which, when pointed at an object, detects the amount of **infrared radiation** impinging on the detector. The temperature of the detector is measured (usually with a thermopile or other electronic device), and the infrared radiation emitted from the source is **inferred**. The **emissivity** ε of the object must be known for accurate temperature measurement, since the infrared pyrometer is calibrated for a body with known emissivity. The instrument used in the present lab is set up such that the displayed temperature, i.e., the **indicated temperature** T_{ind} , is **the temperature of a radiating object with an emissivity of 0.95**. In other words, the infrared pyrometer **assumes** that the hot object being measured has an emissivity of 0.95. If the actual emissivity of the object is **not** 0.95, a correction to the indicated temperature must be made. For the instrument used in this lab, the relation

between the indicated temperature (T_{ind}) and the object's true temperature (T_H) is given by
$$T_H = \left(\frac{0.95}{\varepsilon} \right)^{1/4} T_{\text{ind}}.$$

Note: Temperatures in this equation must be absolute (Rankine or Kelvin). Do not use °C or °F in this equation!

An **optical pyrometer** works by comparing the **visible radiation** that is emitted from a radiation source to the visible radiation emitted from a **filament wire**. The current supplied to the filament wire is adjusted until the wire “disappears”, inferring that it is at the same temperature as the object whose temperature is being measured. The temperature of the filament wire is a known function of the supplied current, and therefore the temperature of the object is inferred.

More details about each of these temperature measuring devices can be found in the related learning module for this course.

Objectives

1. To become familiar with common temperature measuring techniques and calibration procedures.
2. To gain hands-on experience using and comparing various thermocouples, a thermistor, a liquid-in-glass thermometer, an infrared pyrometer, and an optical pyrometer.
3. To design and carry out procedures to verify the three thermocouple laws.

Equipment

- optical pyrometer (shared by all groups)
- blackbody calibration oven (shared by all groups)
- *Temperature Lab* plastic container, including:
 - pliers (for pinching together two thermocouple wires)
 - thermistor (the one with the gray-colored insulation around the wires)
 - thermocouple wires (they are color coded by convention):
 - copper (blue)
 - constantan (red)
 - iron (white)
 - infrared pyrometer
 - insulated gloves (for use with the hot beakers so you don't burn your fingers)
 - wire strippers (for use with the thermocouple wires)
- commercial type K (yellow) thermocouple
- liquid-in-glass thermometer
- digital multimeter (DMM), with type K thermocouple capability
- second DMM or LCR meter (measures inductance, capacitance, and resistance, but not voltage)
- hot plate
- ice (*Note:* Bags of ice are purchased by the TAs at a convenience store downtown – keep receipts.)
- 3 Pyrex beakers for water baths:
 - boiling water
 - ice-water mixture
 - room temperature water
- test stand with clamps (to hold thermometers and probes as needed)
- stopwatch, wristwatch, tablet, cell phone, etc. with a stopwatch app

Procedure

Initial preparation

1. A room temperature water bath is required for some of the experiments. Since it may take some time for the water to settle to room temperature, the water bath should be prepared *now*. Pour water into one of the Pyrex glass beakers until it is $\approx 1/3$ full. Put this beaker to the side for later use as a room temperature bath.
2. Prepare an **ice-water bath** in a second Pyrex glass beaker. *To maintain a good ice bath, there should always be more ice than water.*
 - o Put ice cubes into an empty beaker, with the ice filling less than $1/3$ of the full beaker height.
 - o Add water until most of the ice is submerged (with some of it sticking up above the water level); the top of the ice should be no higher than about $1/3$ of the beaker height.
 - o Wait a few minutes for the bath to reach steady state temperature.
3. (2) Stir the bath. Then, using both the **liquid-in-glass thermometer** and the **commercial type K thermocouple**, measure and record the temperature of the ice-water bath. (Temperature can be read directly in $^{\circ}\text{C}$ from the DMM when the multimeter dial is set to TEMP.) Make sure the ice-water bath has come to a steady-state temperature, and make sure the thermocouple probe has been allowed sufficient settling time. If prepared properly, the ice bath temperature should be close to 0°C .

Measured temperature of ice bath (Thermometer) = _____ $^{\circ}\text{C}$

Measured temperature of ice bath (Thermocouple) = _____ $^{\circ}\text{C}$

Optical pyrometer experiment

1. This portion of the lab takes only a few minutes, and can be performed *any time* during the lab period when the optical pyrometer station is available.
2. The instructor or teaching assistant will guide you through this portion of the lab.
3. (2) Measure and record the temperature inside the blackbody calibration oven, using the **optical pyrometer**. Also record the temperature indicated on the oven temperature controller. *Be careful not to drop or bump the instrument!*

Measured temperature of oven = _____ $^{\circ}\text{C}$

Displayed (actual) temperature of oven = _____ $^{\circ}\text{C}$

Thermistor calibration

1. (2) Insert the **thermistor** into the ice-water bath. Using the second multimeter (or the LCR meter), measure and record the **electrical resistance** of the thermistor, using the brown and green leads. Again, make sure the thermistor probe has been allowed sufficient settling time.

Measured thermistor resistance, $R_{\text{thermistor}}$ = _____ Ω

2. Place the ice-water bath on the hot plate, and turn it on. *Do not touch the hot plate surface, or you may burn your hand.* Insert both the thermistor and the thermocouple probe into the water, using the test stand to hold the probes in place. **Do not let the probes touch the bottom of the beaker, because the temperature there is hotter, and your readings would not be correct.**
3. Monitor the water temperature with the thermocouple. (Note: In this lab, *it is assumed that the commercial thermocouple temperature reading is "correct"*; i.e., we will calibrate the thermistor resistance as a function of the commercial thermocouple temperature reading.)
4. In Excel, record thermistor resistance as a function of water bath temperature *as the bath is heated from freezing temperature to boiling point*. For accurate calibration, reading at approximately 2°C to 5°C intervals is suggested.
5. Keep the water boiling; this is now the **boiling water bath** for subsequent measurements. Add more water to the bath as necessary, making sure that the beaker is never less than about $1/4$ full at all times.
6. Using Excel, create a scatter plot of temperature as a function of thermistor resistance. Note: *Do not plot the other way (resistance vs. temperature), since the curve fit to be done must be temperature vs. resistance.*
7. Generate a calibration equation for the thermistor. If the data are linear, perform a **linear regression analysis** to determine the equation for the best-fit straight line. If the data are *not* linear, use Excel's curve fitting options to generate a reasonable curve fit. In Excel, curve fitting (Excel calls it establishing a "**trendline**") is performed directly on a chart as described below:
 - (a) Select the chart, and **Chart-Add Trendline** (Excel 2003) or **R-Add Trendline** (Excel 2007, 2010).
 - (b) In the **Add Trendline** window, select a **trend type** (there are several options). Note: If a polynomial fit is selected, the **order** of the polynomial must also be chosen. Click **OK** to plot the curve on the chart.

- (c) Hit Excel's Undo button if the curve is not appropriate.
 - (d) Experiment with different curve fits until a good fit is produced (some trial and error may be required).
 - (e) When satisfied with the curve fit, Add Trendline again. In the *Add Trendline* window, choose the desired type of fit again, and then Options. Select Display equation on chart, and OK. An equation for the curve fit is displayed automatically on the chart.
 - (f) On the equation, R-Format Data Labels-Number. Increase the number of displayed digits so that the equation is more precise. (*Note: This option is not available for all types of trendlines.*)
8. **(5 for #6-8)** Record the curve-fit equation – it will be used as the *calibration equation* for the thermistor. You should include your plot and curve fit at the end of this lab report, with proper labeling.

Calibration equation for the thermistor:

9. **(5)** Your table already had two columns – measured temperature and thermistor resistance. Add a third column to your table: “Curve-fitted temperature”. Apply your calibration equation to each of the cases used for the curve fit, thereby comparing the actual measured temperature with the curve-fitted temperature. If your curve fit is reasonable, the agreement should also be reasonable. Attach a printout of both the table and the plot showing both the measured data (symbols only, no curve) and the trendline (curve only, no symbols).

See attached, Table number _____

See attached, Figure number _____

Comparison of temperature measuring devices

1. For this portion of the lab, you need *three* water baths:
 1. A *boiling water bath*, which should already be available from the previous portion of this lab.
 2. A *room temperature water bath*, which should also be available – retrieve it from where it had been set aside at the beginning of the lab.
 3. An *ice-water bath*, which needs to be prepared using the third beaker.
2. Using the *liquid-in-glass thermometer*, measure the temperature of each bath. To avoid possible breakage, *do not move the thermometer directly from the ice bath to the boiling water bath, or vice-versa*. *Note: If your thermometer is in English units, convert to SI units using the formula $^{\circ}\text{C} = 5(^{\circ}\text{F} - 32)/9$* . Record your readings in the table below:

Bath	$T_{\text{glass thermometer}}$ ($^{\circ}\text{C}$)	$T_{\text{thermocouple}}$ ($^{\circ}\text{C}$)	$T_{\text{infrared pyrometer}}$ ($^{\circ}\text{C}$)	$R_{\text{thermistor}}$ (Ω)	$T_{\text{thermistor}}$ ($^{\circ}\text{C}$)
Ice					
Room temperature					
Boiling water					

3. Repeat the three temperature measurements using the *commercial type K thermocouple*, and enter your data into the above table.
4. **(2)** Using the stopwatch, perform a quick experiment to estimate how much time it takes for the thermocouple to reach steady state after being exposed to a sudden change in temperature (from ice to boiling or vice-versa).

Measured time = _____ s

5. Repeat the three temperature measurements using the *infrared pyrometer*, and enter in the above table. *Note: Measure the temperature of the water in the beaker by pointing down at the water surface from above the beaker. Be very careful with the boiling water case. Do not allow the radiation sensor to be exposed directly to steam, since condensation can distort the readings; worse yet, the steam could damage the instrument.* There is no need to correct the temperature reading, since the emissivity of water is approximately 0.95.
6. Take a few minutes to “play” with the infrared pyrometer. It is not necessary to record any results for this step; none of these measurements is required for the lab report – they are simply for your enjoyment. For example, measure the skin temperature of each person in your lab group. Human skin has an emissivity of about 0.95, so there is no need to correct the measurement. *Who is the coolest student in your group? Who is*

the hottest? Measure the temperature inside someone's mouth. Is the inside of the mouth hotter than the surface of the skin? Measure other things in the lab such as the top of the computer monitor, etc. Keep in mind that the emissivity of these various objects is unknown, and the actual surface temperature displayed may not be an accurate representation of the object's correct temperature.

7. Repeat the three temperature measurements using the *thermistor probe*. (Actually, the thermistor's electrical resistance will be measured and recorded, which must then be converted to temperature.)
8. (6 for #2-8) Using the calibration equation created previously, calculate the temperatures measured by the thermistor at the three water bath temperatures, and record the temperatures in the above table.
9. Using the *thermocouple* reading as the "correct" temperature (use this reading as the denominator in the percentage error calculation), calculate the percentage error between the temperature reading from the liquid-in-glass thermometer and that from the commercial thermocouple. Do this for the room temperature water bath and for the boiling water bath, but not the ice bath.
10. (6 for #9,10) Repeat for the thermistor and for the infrared pyrometer, and enter all your results in the table below.

Bath	% error, glass thermometer (%)	% error, thermistor (%)	% error, infrared pyrometer (%)
Room temperature			
Boiling water			

Verification of thermocouple laws

1. For the following part of the lab, you will *write your own procedure*. Your goal is to *verify the three basic thermocouple laws discussed in the related learning module*.
2. To perform this portion of the lab you need the digital multimeter, three types of thermocouple wires: iron, constantan, and copper, and three water baths – ice water, boiling water, and room temperature water.
3. You will make your *own* thermocouple junctions, as needed, by twisting the wires together. Pliers are useful.
4. (10) Conduct three experiments to verify the three thermocouple laws. *Record not only the results, but also the procedures*, since the procedures themselves are "results" of this lab exercise. Write the procedures clearly with the following goal in mind: *A reader of the report should be able to repeat the procedure step-by-step to reproduce your results*. Sketches are helpful.

5. **(10)** Finally, discuss the results of your procedure for all three cases. In other words, record the measured voltages and temperatures, the wires used, how you connected them, etc. to verify the thermocouple laws. You may write in the space below, and/or attach typed (preferred) or neatly hand-written pages following this page.

Discussion Questions

1. (5) Was the temperature of the boiling water bath exactly 100°C ? Why or why not?

2. (5) Was the temperature of the ice-water bath exactly 0°C ? Why or why not?

3. (4) Which instrument, liquid-in-glass thermometer, thermistor, or infrared thermometer, is most accurate when measuring the temperature of boiling water? Why? What about room temperature water? Why?

4. (4) Did the commercial thermocouple behave as a first- or second-order system? Estimate the *order of magnitude* of its time constant (a fraction of a second?, a few seconds?, tens of seconds?, minutes?).

5. (4) Were you able to verify all three of the thermocouple laws? If not, why not?

6. (4) How accurate is the optical pyrometer at measuring blackbody calibration oven temperature?

7. (4) Think of an application where an optical pyrometer would really be useful.