Thermocouple Characteristics

Objectives:

1. To know what is a **Thermocouple**.
2. To know how to convert the thermocouple voltage readings to temperature.
3. To understand the characteristics of the thermocouple.

Introduction:

Thermocouple (TC) is created whenever two dissimilar metals touch and the contact point produces a small open-circuit voltage as a function of temperature. This thermoelectric voltage is known as the Seebeck voltage, named after Thomas Seebeck, who discovered it in 1821.

The TC has been the popular choice over the years for a variety of reasons. Thermocouples are relatively inexpensive and can be produced in a variety of sizes and shapes. They can be of rugged construction, can cover a wide temperature range. However, TCs produce a very small microvolt output per degree change in temperature that is very sensitive to environmental influences.

As Mentioned above any two dissimilar metals may produce a TC, However, there are some standard thermocouples which have calibration tables and assigned letter-designations which are recognized worldwide, Such as, J-type (Iron / Constantan), K-type (Chromel / Alumel), E-type (Chromel / Constantan), N-type (Nicrosil / Nisil), B-type (Platinum / Rhodium), R-type (Platinum / Rhodium) and S-type (Platinum / Rhodium). In order to select the suitable TC for an application, sensitivity and temperature range should be taken into consideration, because each one of these thermocouples has different temperature range and sensitivity.

In the experiment two J type thermocouples are used. The first one is used for the experiments, and the other one is used with temperature controller to control the temperature of the hot plate.

Theory:

To measure a thermocouple Seebeck voltage, you cannot simply connect the thermocouple to a voltmeter or other measurement system, because connecting the thermocouple wires to the measurement system creates additional thermoelectric circuits.

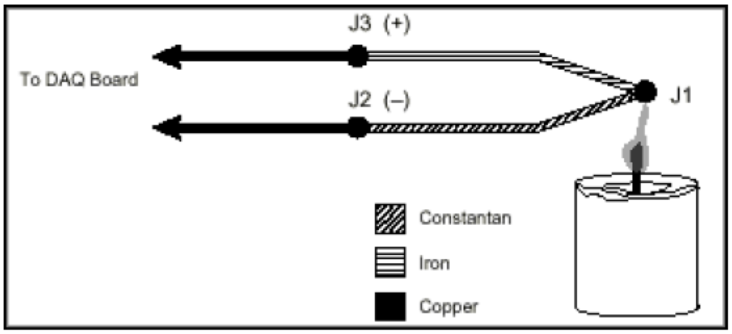

Figure (1): Thermocouple connection

Consider the circuit illustrated in Figure 1, in which a J-type thermocouple is in a candle flame that has a temperature you want to measure. The two thermocouple wires are connected to the copper leads of the measurement device. Notice that the circuit contains three dissimilar metal junctions J1, J2, and J3. J1, the thermocouple junction, generates a Seebeck voltage proportional to the temperature of the candle flame. J2 and J3 each have their own Seebeck coefficient and generate their own thermoelectric voltage proportional to the temperature at the measurement device terminals. To determine the voltage contribution from J1, you need to know the temperatures of junctions J2 and J3 as well as the voltage-to-temperature relationships for these junctions. You can then subtract the contributions of the parasitic junctions at J2 and J3 from the measured voltage at junction J1.

Thermocouples require some form of temperature reference to compensate for these unwanted parasitic "cold" junctions. The most common method is to measure the temperature at the reference junction with a direct-reading temperature sensor and subtract the parasitic junction voltage contributions. This process is called **cold-junction compensation**. You can simplify computing cold-junction compensation by taking advantage of some thermocouple characteristics.
By using the T**hermocouple Law of Intermediate Metals** and making some simple assumptions, you can see that the voltage a data acquisition system measures depends only on the thermocouple type, the thermocouple voltage, and the cold-junction temperature. The measured voltage is in fact independent of the composition of the measurement leads and the cold junctions, J2 and J3.

According to the Thermocouple Law of Intermediate Metals, illustrated in Figure 2, inserting any type of wire into a thermocouple circuit has no effect on the output as long as both ends of that wire are the same temperature, or isothermal.

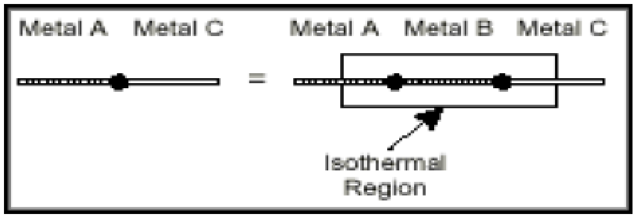

Figure (2): Thermocouple Law Intermediate Metals.

Consider the circuit in Figure 3. This circuit is similar to the previously described circuit in Figure 1, but a short length of constantan wire has been inserted just before junction J3 and the junctions are assumed to be held at identical temperatures. Assuming that junctions J3 and J4 are the same temperature, the Thermocouple Law of Intermediate Metals indicates that the circuit in Figure 3 is electrically equivalent to the circuit in Figure 1. Consequently, any result taken from the circuit in Figure 3 also applies to the circuit illustrated in Figure 1.

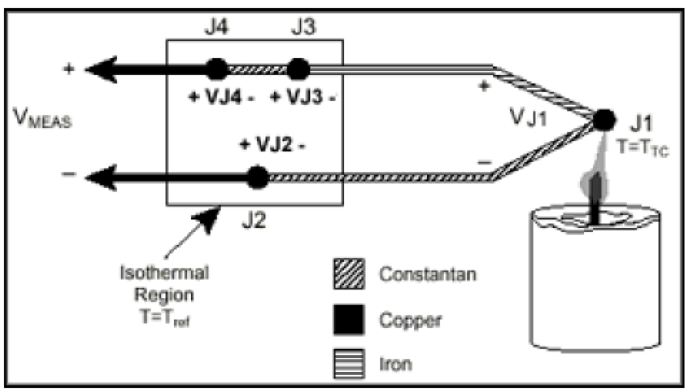

Figure (3): Intermediate Materials effect In Isothermal region.

In Figure 3, junctions J2 and J4 are the same type (copper-constantan); because both are in the isothermal region, J2 and J4 are also the same temperature. Because of the direction of the current through the circuit, J4 contributes a positive Seebeck voltage, and J2 contributes an equal but opposite negative voltage. Therefore, the effects of the junctions cancel each other, and the total contribution to the measured voltage is zero. Junctions J1 and J3 are both iron-constantan junctions, but may be at different temperatures because they do not share an isothermal region. Being at different temperatures, junctions J1, J3 both produce a Seebeck voltage, but with different magnitudes. To compensate for the cold junction J3, its temperature is measured and the contributed voltage is subtracted out of the thermocouple measurement.

Experiment Procedure:

1. Run the **TMT001** Software.

2. A screen named “**Welcome to TMT001**” will appear, containing three buttons: **[Information]**, **[Run the Experiments]** and **[Quit].**

3. The “**Welcome screen”** is shown in the figure below:

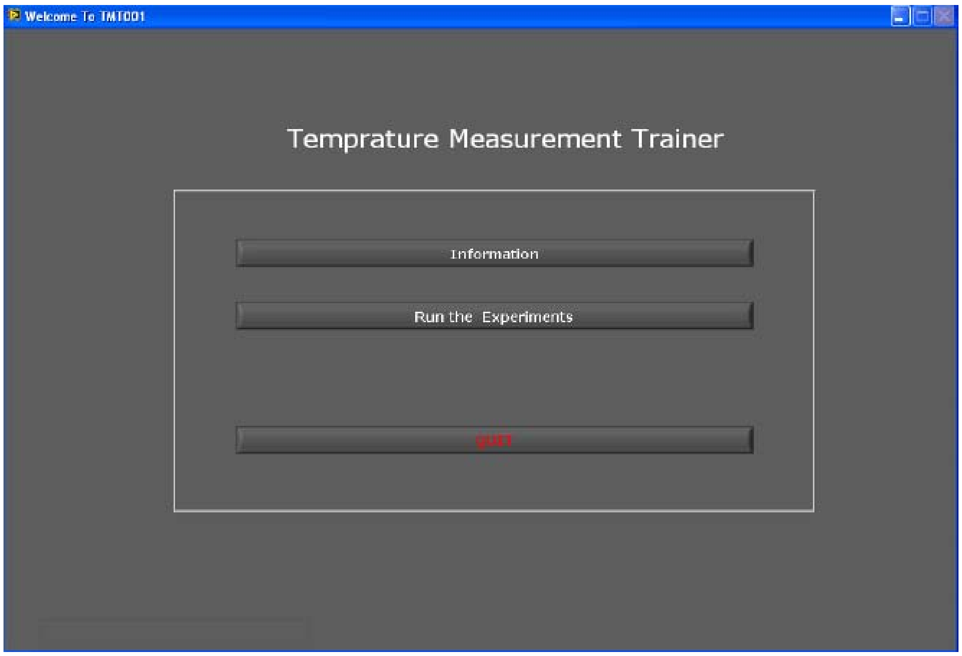

Figure (4): Welcome Screen.

4. Press the **[Information]** button to go to the Information screen.
5. The “**Information Screen**” is shown in the figure below:

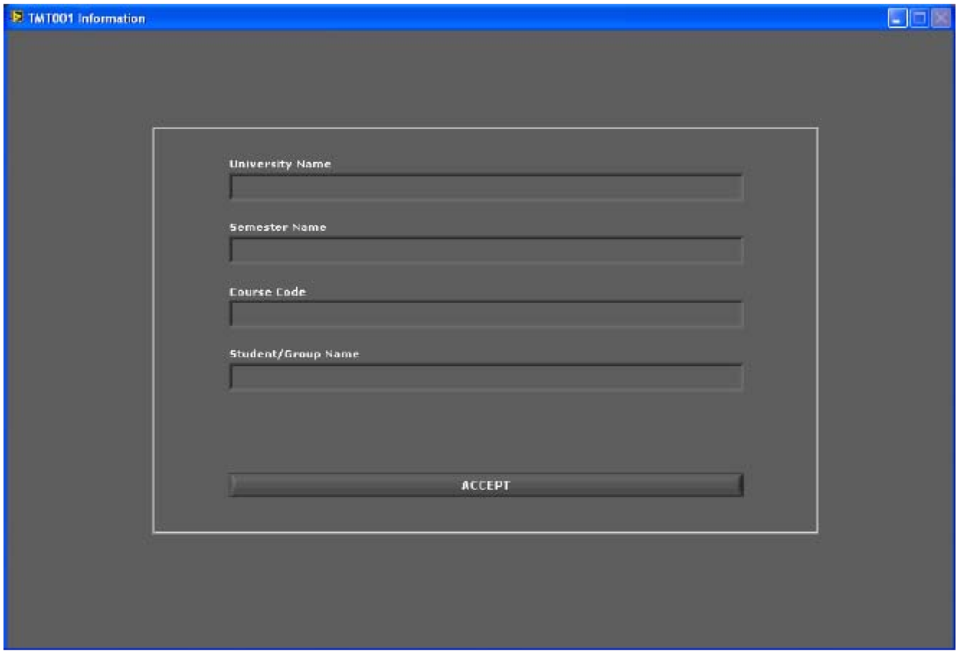

Figure (5): Information Screen.

6. Fill in the fields with your information, Press the **[Accept]** button and a confirmation message will appear asking you to press **[Accept]** the information you have entered, or **[Cancel]** if you need to go back to change anything. Pressing **[Accept]** will let you go back to the "**Welcome Screen"**.
7. Press **[Run the Experiments]** button to go to the **"Experiments screen"**.
8. The "**Experiments Screen"** is shown in the figure 6, containing four experiments; **Thermocouple Characteristics**, **RTD Characteristics**, **Thermistor Characteristics** and **Thermometers Comparison**.

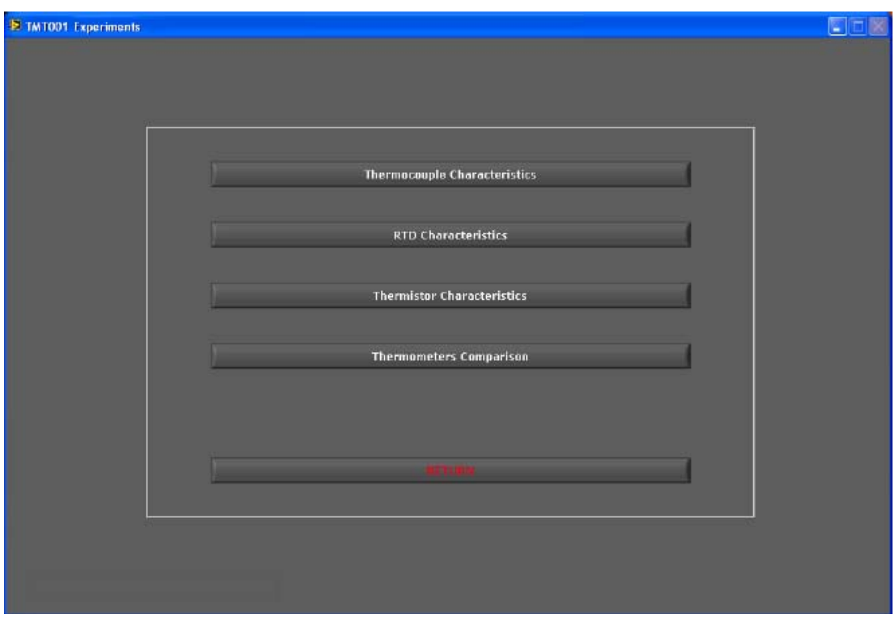

Figure (6): Experiments Screen.

9. Choose Experiment 1: **“Thermocouple Characteristics”.**
10. Study the front panel carefully and observe the buttons on the screen.

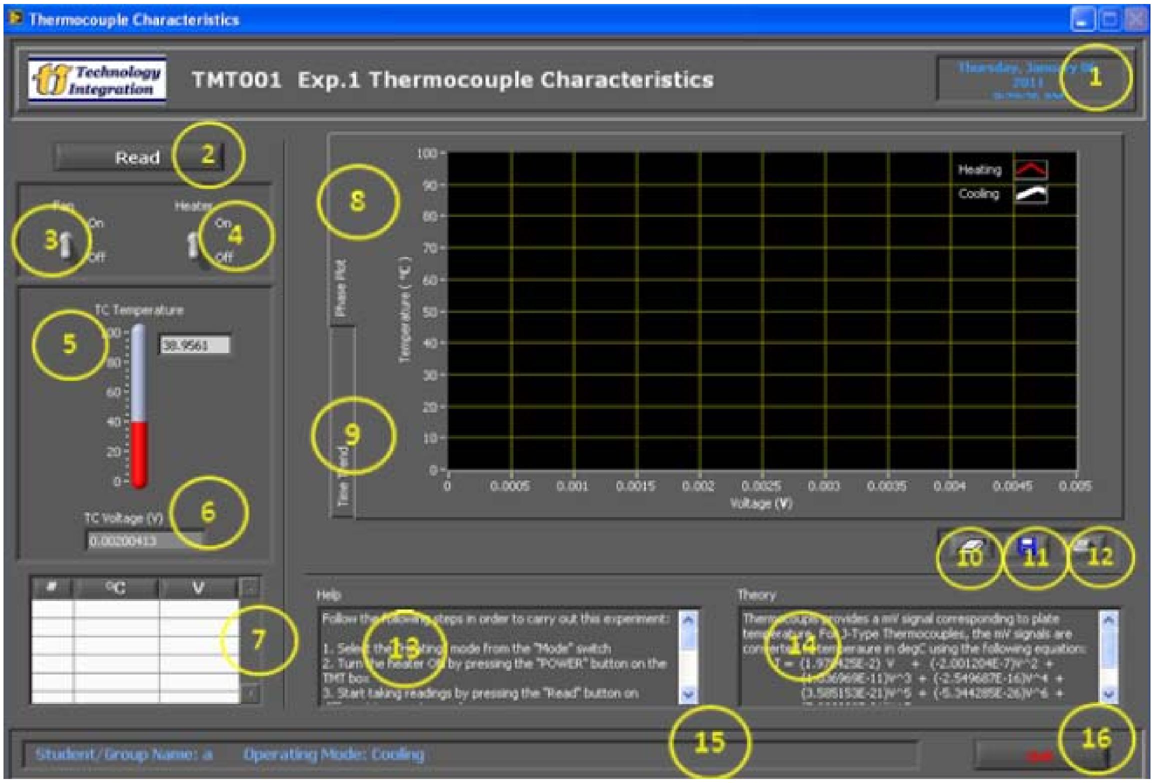

Figure (7): Thermocouple Characteristics Screen.

1) **Current Date and Time Indicator.**
2) **Read Button:** To read and plot the current temperature and voltage (resistance) of the current thermometer (here it is the **Thermocouple**).
3) **Fan Switch:** To turn the Fan ON or OFF.
4) **Heater Switch:** To turn the Heater ON or OFF.
5) **Thermometer Temperature (˚C):** Displays the current temperature of the current thermometer.
6) **Thermometer Voltage (Resistance):** Displays the current voltage (resistance) of the current thermometer.
7) **Readings Table:** Displays the current Temperature and Voltage (resistance) readings taken each time the **[Read]** button is pressed.
8) **Phase Plot:** Contains the Temperature vs. Voltage (Resistance) graph which displays the readings that have been taken by the user. Each point represents the Thermometer Temperature (˚C) with its corresponding Voltage (V) or Resistance (Ohm).

9) **Time Trend:** Contains the Temperature vs. Time graph which displays the temperature profile of the thermometer.
10) **Clear Chart Button:** To clear the Phase Plot graph.
11) **Save Report Button:** To save a report, the report will be saved in the **"Temperature Trainer Files"** folder on the desktop.
12) **Print Report Button:** To print a report, the report will be printed using your default printer.
13) **Help Window:** Displays the procedures needed to carry out the experiment
14) **Theory Window:** Displays the conversion theory of the thermometer of the current experiment (how to change from voltage (resistance) to temperature).
15) **Status Bar:** Displays the current Student/Group name as well as the current operating mode (Heating or Cooling).
16) **Quit Button:** To quit from this experiment and return to the **"Experiments"** window.

11. Turn the **Heater** ON by pressing ON the **Heater Switch** on the screen (Heating Mode).
12. Start taking readings by pressing **[Read]** button on different temperature values.
13. The acquired readings appear on the **Temperature-Voltage graph** as red points.
14. Compare the read temperature with the temperature of the **glass thermometer**. Is it the same temperature? Why?

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15. Turn the **Heater** OFF by pressing OFF the **Heater Switch** on the screen.
16. Turn the **Fan** ON by pressing ON the **Fan Switch** on the screen (Cooling Mode).
17. Start taking readings by pressing **[Read]** button over different temperature values.
18. Notice that the acquired reading appears on the **Temperature-Voltage graph** as white points.
19. Is the cooling curve the same as the heating curve? Why?

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20. In order to save the readings you have taken, press **[Save Report]** button, your report will be saved on your desktop in a folder named **Temperature Trainer Files**.
21. To print the report, press **[Print Report]** button.

22. Notice the **Temperature vs. Voltage** curve and answer the following questions:

    22.1 Is the curve linear?
    a) Yes
    b) No

    22.2 Does the thermocouple equation in the **"Theory"** window describe the curve on the **Temperature vs. Voltage graph**? If your answer is "No", what is the difference and why?
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23. Choose one of the readings taken before from the **Readings Table** and write down its Voltage (V) and Temperature (^{o}C) readings:

    23.1 Current Voltage (V) ………………………..
    23.2 Current temperature (^{o}C)…………………....
    23.3 Apply the current voltage in the thermocouple equation below

$$T = V(1.978425 * 10^{-2}) + V^2(-2.001204 * 10^{-7}) + V^3(1.036969 * 10^{-11}) + V^4(-2.549687 * 10^{-16}) + V^5(3.585153 * 10^{-21}) + V^6(-5.344285 * 10^{-26}) + V^7(5.099890 * 10^{-31})$$

    Where: T : Calculated temperature in (^{o}C)
    V : Thermocouple voltage in microvolt ($V*10^6$)

    23.4 Write down the Calculated temperature (^{o}C)……………….....
    23.5 Compare the calculated temperature with the current temperature.

24. Press **[Clear Chart]** button if you want to clear the chart.
25. Press **[Quit]** button to return to the "**Experiments**" window.

Conclusions

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