

The LM741C Integrated Circuit As A Differential Amplifier Building The Electronic Thermometer

INTRODUCTION:

A thermistor is a device that can change its resistance with temperature. When placed in series with a current limiting resistor, the voltage across the thermistor will change with temperature. Such a voltage change is usually very small. However, the signal can be amplified with the use of an operational amplifier. In this lab, the LM741C operational amplifier is used in conjunction with the thermistor and the current-limiting resistor to construct an electronic thermometer. As the temperature changes, the voltage will also change. A calibration curve, which correlates certain temperature to certain voltages, will thus give the basis for the thermometer measurements. To build the electronic thermometer as accurately as possible, drift and noise of the signal will also be recorded in an attempt to quantify the uncertainty in the voltage reading. Drift is the change in value of the voltage over time. Noise is the interference of the signal due to interruptions from the surroundings.

A thermometer that is constructed in such a fashion will give results more rapidly and accurately than a conventional mercury thermometer. Using such principle, a digital thermometer, used heavily in fetal intensive care units, can thus be built.

METHODS & MATERIALS:

The amplifier circuit was built according to Figure 1 below:

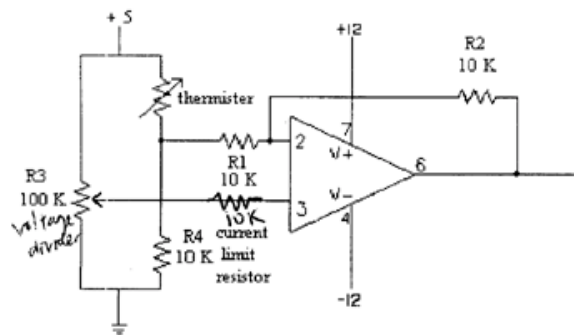


Figure 1: Schematic of the electronic thermometer

A voltmeter was connected to pin 6 and ground. Trials were conducted in order to obtain data to construct a voltage versus temperature plot when $R_2 = 10\text{K}\Omega$ (Gain = $R_2/R_1 = 1$) and when $R_2 = 33\text{K}\Omega$ (Gain = 3.3). First, the circuit was balanced at 0°C to read 0V with $R_2 = 10\text{K}\Omega$. The thermistor was placed in ice and the potentiometer was adjusted so that the voltmeter read 0V . Next, water was heated and cooled to various temperatures so that voltages readings were taken for water temperatures ranging from 0°C to approximately 100°C in approximately 10°C intervals. The voltage outputs that registered for each temperature were recorded. Next, $R_2 = 10\text{K}\Omega$ was replaced with a $33\text{K}\Omega$ resistor. The circuit was balanced again at 0°C and voltages recorded for various temperatures of water in the same manner as the first trial.

Next, the cooling of a known temperature and known volume of heated water was followed in order to calculate heat loss in calories/minute. A 50ml volume of water was heated to approximately 76°C . The thermistor was placed in the water and voltage data was collected with the aid of Virtual Bench for approximately fifteen minutes.

To obtain a measure of the drift and noise of the signals produced, the thermistor was placed in room temperature water for fifteen minutes and data was collected with the aid of Virtual Bench. The Virtual Bench Logger provided data for the drift of the signal and the Virtual Bench Oscilloscope provided data for the noise of the signal.

RESULTS:

In determining a correlation between the output voltage values of the electronic thermometer and the actual temperature of the water medium, a voltage versus temperature graph was plotted. Figure 2 on the following page displays these graphs and the calibration curves of the two electronic thermometers. A strong linear relationship was found between the two variables, as evident with the high R^2 values. Equations (1) and (2) below displays the equations of the two circuits:

$$\underline{\text{Gain} = 1}: \text{Voltage} = -0.044 \times \text{Temperature} - 0.047 ; R^2 = 0.993 \quad (1)$$

$$\underline{\text{Gain} = 3.3}: \text{Voltage} = -0.149 \times \text{Temperature} - 0.290 ; R^2 = 0.997 \quad (2)$$

As evident from Figure 2, the voltage values for the circuit with Gain = 3.3 remained constant as temperature increased above 70°C. Because of this upper limit of the circuit, data points above 70°C were not included in the linear fit.

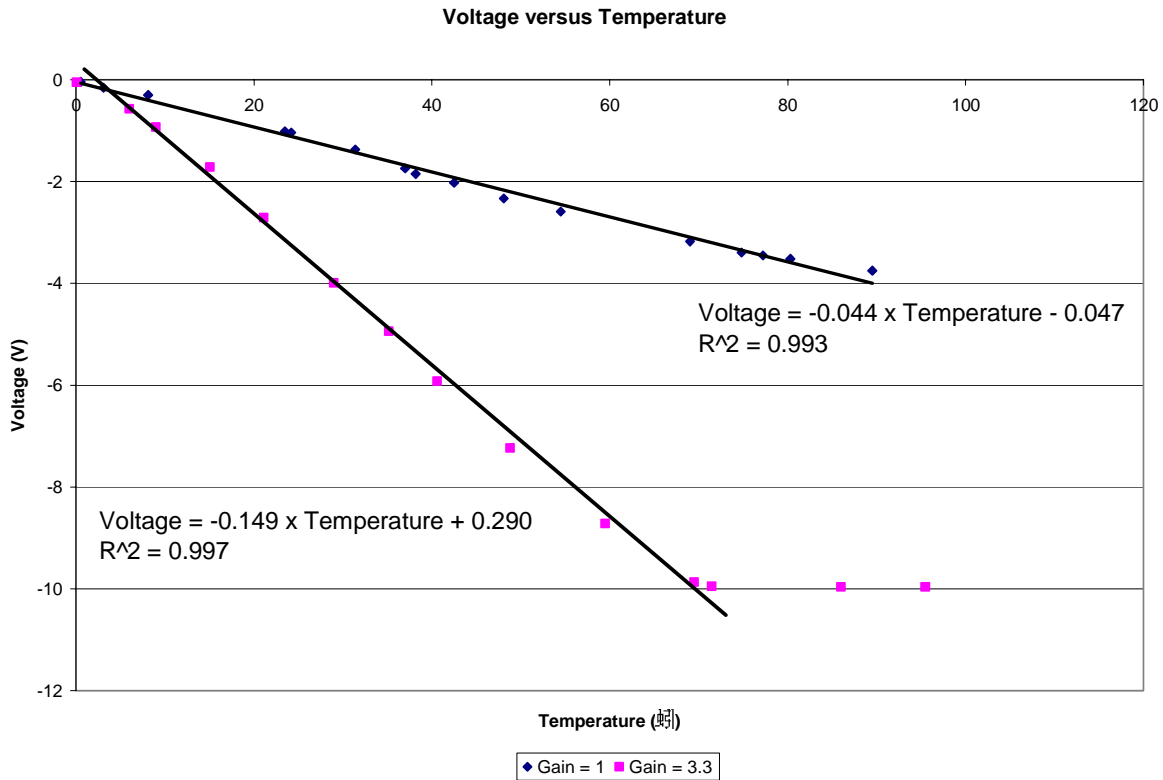


Figure 2: Voltage versus Temperature graph for circuits of two different gains

The y-intercept of the above equations is dependent on how the voltage divider of the circuits was adjusted. The slope, however, is independent of this adjustment. A relationship is suggestive between the ratio of the gains and the ratio of the respective slope values. This is shown in equation (3) below:

$$\frac{\text{Gain of circuit 2}}{\text{Gain of circuit 1}} = \frac{3.3}{1} \quad ? \quad \frac{\text{Slope of circuit 2}}{\text{Slope of circuit 1}} = \frac{-0.149}{-0.044} \quad (3)$$

$$3.3 \quad ? \quad 3.39$$

Voltage data was collected while the electronic thermometer of Gain = 1 was placed at a constant temperature. Figure 3 on the following page displays how the voltage values varied through the course of time:

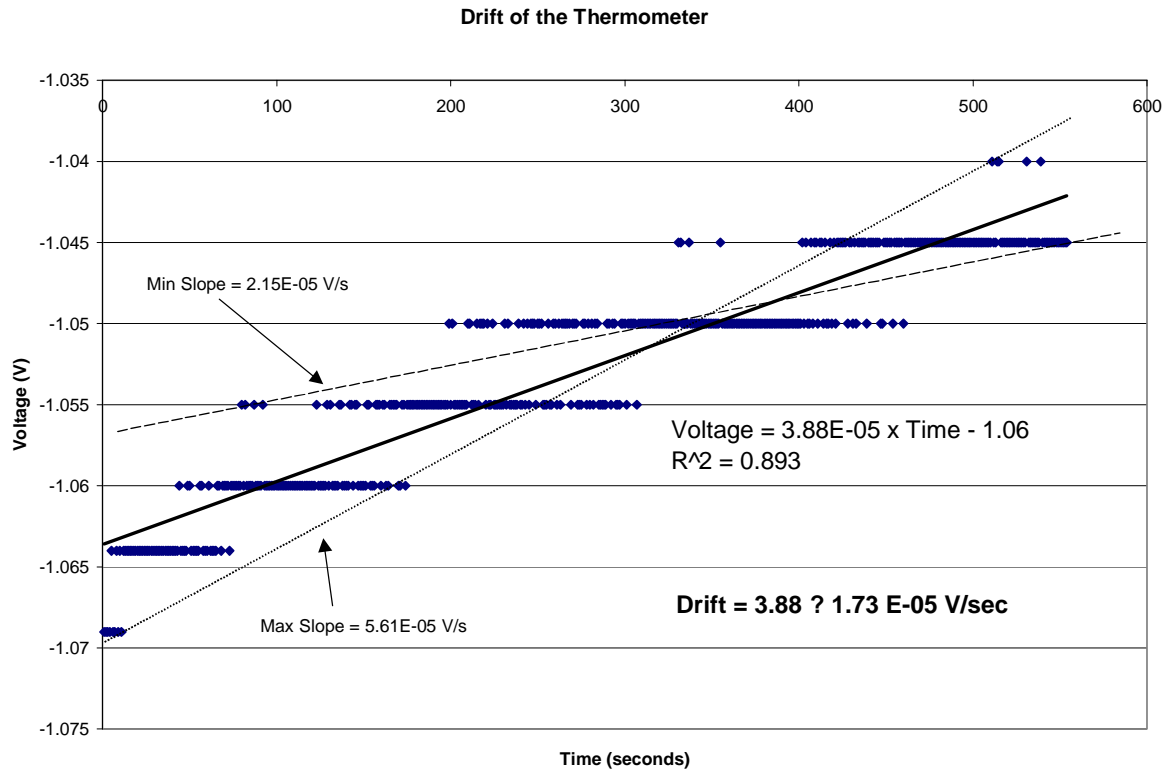


Figure 3: Thermometer held at room temperature; Evidence of drift

A linear fit was produced from these data points. Equation (4) below displays this equation and resultant R^2 value:

$$\text{Voltage} = 3.88 \times 10^{-5} \times \text{Time} - 1.06 ; R^2 = 0.893 \quad (4)$$

The y-intercept of this equation is dependent to the chosen fixed temperature. The slope of the line represents the drift of the circuit. Calculating the maximum and minimum possible slopes of the line and taking half the difference between them determined error for this drift. Equation (5) below displays the average and range of the drift:

$$\text{Drift} = 3.88 \pm 1.73 \times 10^{-5} \text{ V/sec} \quad (5)$$

Alone with drift, noise is inherent in a circuit. The oscilloscope was used to obtain a range of values of the noise. Equation (6) below displays this result:

$$\text{Noise} = 938 \pm 70 \mu\text{V} \quad (6)$$

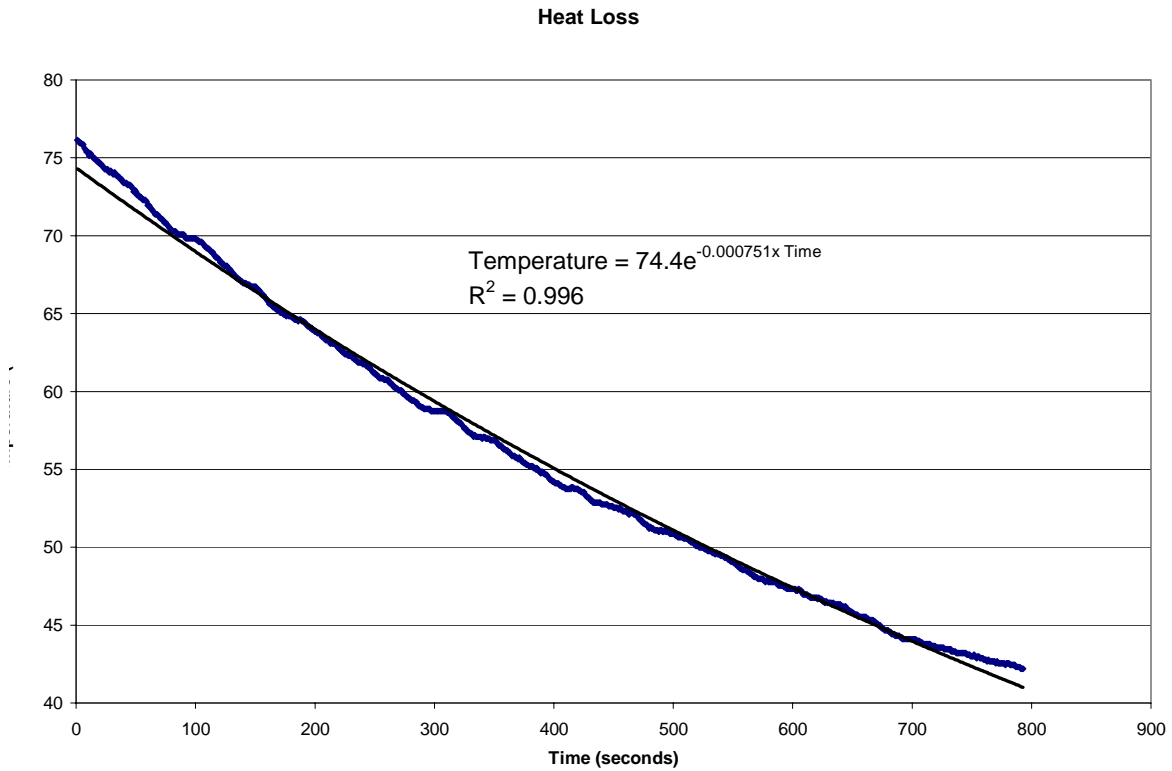


Figure 4: Heat loss of 50 mL of water

Figure 4 above displays the temperature loss over time of 50 mL of water starting at a temperature of 76°C. The electronic thermometer of gain = 1 was used as the sensor. The recorded data was in terms of voltages, but was converted into temperature using equation (1). Heat loss fits more of an exponential trend. The equation of this trend and the resultant R^2 value is shown in equation (7) below:

$$\text{Temperature} = 77.4 \times e^{-0.000751 \times \text{Time}} ; R^2 = 0.996 \quad (7)$$

A calorie is the amount of heat required to raise the temperature of 1 gram (1 mL) of water 1°C. Through the duration of the collected data (793 seconds), the temperature of the 50 mL water decreased 34.0°C. Therefore, the average heat loss in calories per minute is calculated as in equation (8) below:

$$\text{heatloss} = \frac{\Delta 34.0^\circ\text{C} \cdot 50\text{mL}}{793\text{sec}} \cdot \frac{1\text{cal}}{\Delta 1.0^\circ\text{C} \cdot 1\text{mL}} \cdot \frac{60\text{sec}}{1\text{min}} = 128.6\text{cal/min} \quad (8)$$

Similar calculations were made at different time intervals. Table 1 below displays the varied rate of heat loss at these intervals.

Table 1: Varied rate of heat loss with different time intervals	
<i>Elapsed time from $t_{\text{initial}} = 0 \text{ sec}$</i>	<i>Average Rate of Heat Loss</i>
200 seconds	186.0 cal/min
400 seconds	165.0 cal/min
600 seconds	144.5 cal/min
793 seconds	128.6 cal/min

DISCUSSION:

The slope of voltage versus temperature when $R_2=10\text{K}\Omega$ was $-0.044 \text{ V}/^\circ\text{C}$ and when R_2 was changed to $33\text{K}\Omega$, the slope of voltage versus temperature was $-0.149 \text{ V}/^\circ\text{C}$. Thus, when the value of R_2 was changed to 3.3 times its original value, the slope of voltage versus time was approximately 3.3 times the original slope. This data is consistent with Ohm's Law. When resistance is increased voltage increases as well; voltage and resistance are directly related. Consequently, when the resistance of R_2 was changed to 3.3 times its original value, the voltage output was 3.3 times the value it was for a given temperature.

The rate of heat loss in calories per minute of a 50mL volume of hot water with starting temperature of 76.2°C varied as the time interval varied. This implies that the rate of heat loss for a medium is not linear, but more exponential, as shown in equation (7). Errors encountered in this measurement include an uncontrolled cooling of the water. The cooling of the water could have been easily disrupted by light breezes in the room, for example. Also, the 50mL volume was the volume measured before heating. The volume reduced with heating by an

unknown amount. The decrease in volume was fairly unnoticeable but it nevertheless attributed to the error in the measurement of the rate of heat loss.

The electronic thermometer built in this lab is analogous to the technology used in making digital thermometers. A change in temperature causes a change in resistance in the thermistor in the thermometer, which in turn causes a change in voltage. This change in voltage corresponds to a specific temperature. Digital thermometers convert a change in voltage to be displayed as the temperature that was sensed.

Since their implementation into the biomedical field, digital thermometers have metamorphosed from convenience into necessity as technological advances produced self-adjusting machines. Such an example is prevalent in fetal intensive care units

Electronic apparatuses such as the one utilized throughout this experiment accommodate a superior accuracy reading of the temperatures present within a system relative to conventional mercury thermometers, thus the ability to transduce a mechanical force into electrical resistance is crucial for accurate expression of data. Despite its efficiency, however, electronic thermometers are by no means perfect, and sources of error are, in fact, inherently more numerous than those exhibited within mechanical experimentation. Perhaps the most prevalent of these errors is that due to electrostatic noise. Electronic systems such as the circuit utilized throughout the procedure of this examination are subject to numerous sources of noise simply due to the fact that almost all electronic equipment generate considerable quantities of electrostatic interference. This interference induces the flow of current throughout the circuit, thus skewing the signals interpreted by the sensors. In order to dampen such effects, ground wires may be utilized to filter excess noise out of the system, however the use of more than one ground wire can create added interference; a system implementing two ground wires which have disparate charges will attempt to balance charge through the system, thus creating added external current and further skewing the true voltage values. Due to the small size of our circuit, it was unnecessary to have more than one ground wire, thus such error was averted.

Numerous electrical devices generated noise encountered throughout the experiment, including computer monitors, radio waves, and halogen lighting within the room (which runs at an approximate frequency of 60 Hz). Such noise creates a situation in which a representative line passing through the center of the averaged noise values (empirical assumption of an ideal system) is difficult to determine, thus rendering the augmentations in voltage due to increased

temperature inaccurate. Although it is virtually impossible to completely eradicate all traces of electrostatic interference, decreased noise can be achieved by turning off the monitors and lights within the room; this technique, however, is not a realistic solution..

The other quantified source of error present in this experiment is drift. Drift is the change in voltage value of the circuit due to external environmental changes such as temperature, noise, friction, and static electricity. Drift is graphically represented by the decreasing average value of voltage over time, shown in Figure 3 by the positively sloped best-fit line. Ironically, error is added to error once one factors in the fact that the water used to calculate the drift deviated slightly from equilibrium temperature. This produced small changes in temperature, due to the table, air, and other factors as the sample water equilibrated, thus skewing the results of the test for drift error.

Another ever-present source of error is the accumulation of the imperfection of the cables, and voltmeter. The wires utilized to construct the apparatus are not ideal and therefore carry a small amount of resistance; these individually insignificant resistances created by wires, once combined, form a considerable aggregate resistance throughout the system. Furthermore, the lack of perfection of the resistor facilitates a small absorption of current, where an ideal resistor has infinite resistance and therefore absorbs no current. This small loss of current, combined with the resistance throughout the adjoining wires, creates added error within the system. This error is reasoned to be even larger, due to the minute values of current collected by the thermistor; the smaller the current value the larger effect such imperfections have throughout the system. Although this error is assuredly present, it exists only as a diminutive source of deviation. The remaining error is most likely due to a combination of noise and drift.

The most transparent procedural error encountered throughout this experiment was the product of equipment deficiency. Due to the fact that divisions of the mercury thermometer were very small, readings based off of this thermometer were inherently prone to error. Another closely related error became evident through the process of the experiment as well. Namely, inaccuracies ensued from the distance that separated the mercury from the temperature marks on the outside of the thermometer. This created a dependency on the angle at which the measurement was read—an angle which could not accurately be maintained and whose error was amplified by the lack of adequate space between temperature divisions. Refer to Figure 5 on the following page for a pictorial description:

Error Resulting From Mercury Thermometer Reading

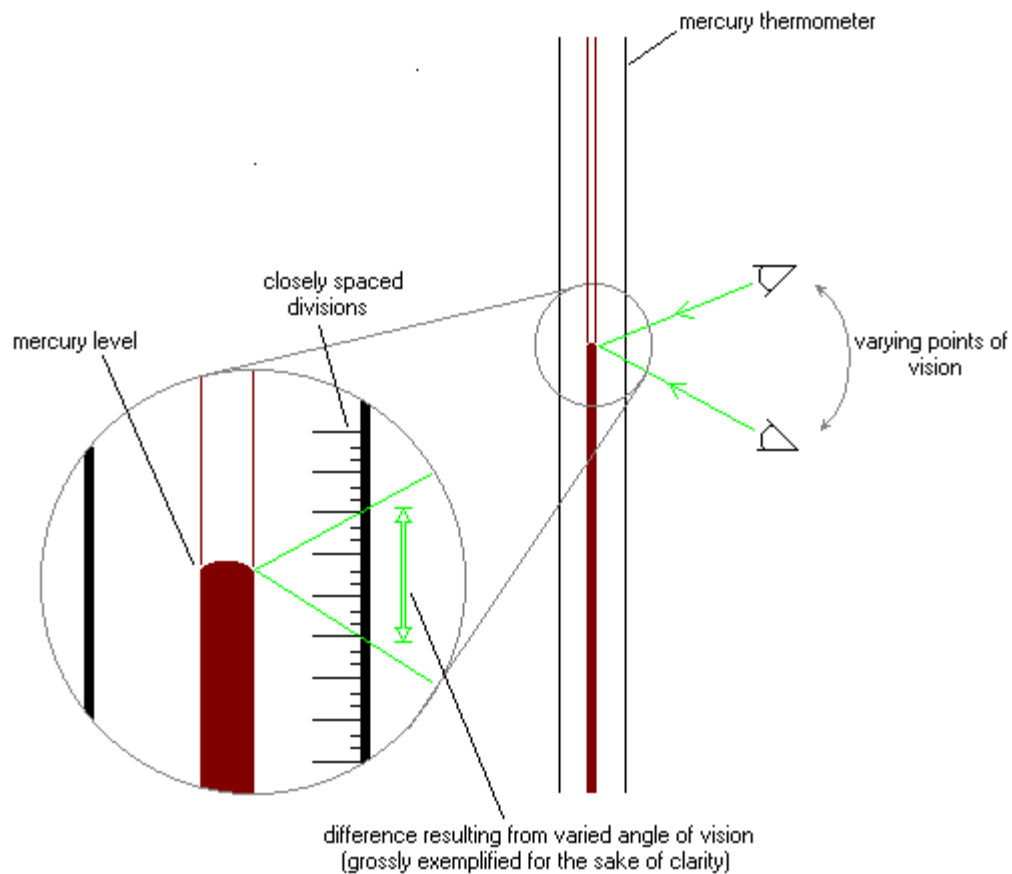


Figure 5: Error resulting from a mercury thermometer reading

Both of these errors are due to the lack of readability of the thermometer itself, and both add substantial error to the calibration of the electronic thermometer, which in turn skews all results obtained from it. A simple modification of the experiment to include a more readable thermometer would greatly enhance the accuracy of calibration of the electronic thermometer and thus the readings subsequently ascertained from it.

Added error was also present as the heat loss of a known volume of water calculated. The error arises in the fact that volume of the water is not known, as once the water is brought to near boiling temperature, evaporation is accelerated, consequently decreasing the volume within

the container. Small volumes of water are also lost as the water measured in the graduated cylinder is transferred over to the heating container; obviously not every drop of water can be accounted for during the transfer, and the volume of the sample is once again decreased.

CONCLUSION:

The purpose of this lab was to build an electronic thermometer. Usage of the thermistor, coupled with a current limiting resistor and an LM741C operational amplifier, allowed for the change of voltage according to varying temperature. Using this principle, two electronic thermometers were constructed, in which one of the resistors was altered to change the gain. From this, two calibration curves of voltage versus temperature were constructed. The first calibration curve, with a resistance of $10\text{K}\Omega$, showed a trend line of $Voltage = -0.044 \times Temperature - 0.047$. The second calibration curve, with a resistance of 33Ω , showed a trend line of $Voltage = -0.149 \times Temperature - 0.290$. The slope of the second calibration curve was approximately 3.3 times of the first calibration curve. This correlates exactly with the change of the resistor value from 10 K to 33 K, a factor of 3.3. The data showed that electronic thermometer made by using a resistor value of $33\text{K}\Omega$ was inadequate for the range of temperature measured since temperature above 70°C showed no voltage changes. The thermometer showed a drift of $3.88 \pm 1.73 \times 10^{-5}$ V/sec and a noise value of 938 ± 70 μV . Using the thermometer thus constructed, it was determined that temperature decreased exponentially with time. As the temperature of the water became closer and closer to room temperature, the rate of heat loss decreased. Thus, the rate of heat loss is not constant for varied time intervals. The thermometer setup in this experiment can be incorporated in digital thermometers to give quick and accurate reading of the temperature, as needed in fetal intensive care units.