

# Data Acquisition and Resistance Measurements Using a Simple Program

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The goal of this paper is to describe a simple method for the automated data acquisition and analysis of data taken by programmable instruments. Device controls and communication method are explained and some typical illustrative examples showing the potential applications of the method in real experiments are presented. This method offers a quick and flexible way to control many instruments by using a multi-device arrangement of a stacking method in a parallel operation. The General-Purpose Interface Bus (GPIB) is used here for remote control of the devices. By using Excel and Visa interactive programs and using GPIB interface, easy communication and data transfer between instruments and a PC is accomplished. A special probe system is devised for the small resistant measuring experiments and the DC resistance measurements are performed by using the four-probe method. The related temperatures are measured by using a silicone diode as a resistance thermometer detector. Using this data acquisition method, short circuit voltage measurement, resistance measurements and the temperature dependence of resistance for a thin platinum wire are reported.

## INTRODUCTION

Data collection and conversion of raw data into a more meaningful result seems to be the final goal of most experiments. The capturing of a great number of data points, analysis of such a large volume of data in a small time scale and other requirements motivated many researchers to develop new methods that required hardware/software components. The aim has been the introduction of flexible and more intelligent data capturing techniques and automated analysis procedures. Now there is a variety of hardware, software and control programs that can be implemented for data collection and signal processing. Some aspects of data acquisition are demonstrated in reports by different researchers and companies that produce either hardware or software products [1]. However, much of this sophisticated equipment and most related software programs are not available to small laboratories. The cost of such automation is also, high and cannot be afforded by many average funded research projects.

The goal, here, is to introduce a simple and precise method for data collection and presentation through

a general purpose excel program. The suggested cost effective method uses a General Purpose Interface Bus (GPIB), which is used for remote control of the devices. In some experiments, it is desired to control several instruments. One solution is to have a single GPIB interface to control several instruments and another possible way is to have more than one GPIB interface for the control of such devices. For controlling instruments by GPIB, it is possible to use a single-thread method or a multithreaded instrument control, depending on the applied devices. Multithreaded instrument control is possible for those applications that use more than one GPIB interface [2].

## DATA ACQUISITION

With the GPIB configuration, many different types of device, including instruments, computers, plotters and printers can be connected in parallel. A typical GPIB system uses a single GPIB interface card to communicate with several GPIB instruments. In this arrangement, each device is configured to use a different primary address. The GPIB controller acquires and displays a fixed number of readings from each instrument. If data processing takes too long, then, other devices are in an idle position, which makes the measurement time long. There are two possible solutions, namely; single-threaded and multithreaded,

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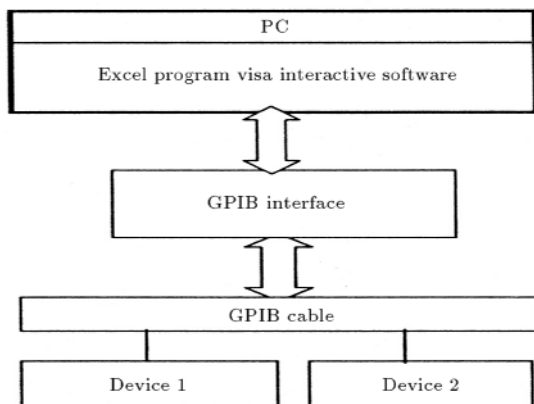
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to overcome this delay. In a single threaded solution, the application program needs to do the following processes, while there are more readings to acquire: Tell device 1 to send data, acquire data from device 1, tell instrument 2 to send data, acquire data from device 2, display acquired data. The type of instruments used can affect the performance benefits that multithreading offers over the single-thread application. Instruments, such as oscilloscopes and spectrum analyzers, capture large volumes of data, compared to a single reading from a digital multimeter (DMM). In addition, users generally perform customized post-processing and use graphs to display the processed waveform data. In situations such as these, multithreading can be used to enhance the performance of the application by acquiring measurements in parallel, rather than in a serial, fashion.

The IEEE-488 bus (a standard bus protocol adopted by the IEEE society for the interfacing of electronic modules) is designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. The bus has eight data lines that are used for both data and with most commands. Five of these lines are management lines and three for the handshake lines. A system usually contains one controller and a number of instruments to which commands are given. Device operation is categorized into three operations, controller, talker and listener. Common commands are commands that are common to all devices on the bus, while Standard Commands for Programmable Instruments (SCPI) commands are those that are particular to each device on the bus.

The block diagram of the reported arrangement is shown in Figure 1. It consists of a PC, multimeter devices equipped with the GPIB interface board and standard IEEE-488 connection cables. GPIB bus operation requires hardware, including the GPIB interface board, bus connectors and cables. It also requires



**Figure 1.** Block diagram of the interfacing modules for data acquisition.

the visual basic application program that can be run through a macro from the Excel program. The visa controller is used to control the drivers from this macro and visa standard commands are written for data acquisition. To connect a device to the GPIB bus, a standard IEEE-488 connector is used. As described for parallel connections to one instrument, one can stack the connectors. Such an arrangement is usually used for multi-unit test systems. For minimizing electromagnetic interference, shielded IEEE-488 cables are typically used to connect the device to the GPIB bus of the computer. For selecting the primary address, a number (0-30) can be assigned for addressing the related device. For example, for a model 2000 Keithley multimeter, the selected primary address is 11, for Agilent, 19, and, for the Tektronix oscilloscope is number 1. For an IEEE-bus, only 15 devices, including the controller, can be connected and called GPIB0, GPIB1, etc. Another important parameter in the interactive interfacing is the maximum length of the cable, which should be 20-meters or two meters times the number of devices, whichever is less. In cases where such limitations and precautions are not considered, erratic bus operation may be expected.

Using the Macro option in Excel automates repetitive tasks. In operation, Macro duplicates your keystrokes. If you find yourself doing the same things all the time in Excel, you create a Macro to do them for you. You usually use a Macro when you need to perform any time-consuming repetitive job that requires several commands or clicks. Macro usage requires creating a Macro and running it from the menu. To create a Macro, turn on the Macro recorder, do the chore you want recorded and turn off the recorder. The next time you need to do that chore, you just run that specific Macro. To set up a worksheet with a Macro, you click tools, record the macro and store it in a personal Macro workbook. Running Macros is easier than recording them. Choose tools, Macro, and select the Macro from the list and click run. Excel's Macro language is called visual basic, which is used to communicate directly with Excel. When you want Excel to do things like formatting a cell etc., you ordinarily use the menus or a toolbar button. By using the visual basic, you bypass the menus and buttons and give commands directly.

Customizing the Excel macro using visual basic is an easy task, which does not require a great deal of programming skill. The programming concept includes: Objects, methods and properties. To understand programming, one needs to know about these three concepts. Object is a "thing", for instance, a WORKSHEET, method is something a "thing" can do, like ADD a "thing", and property is a characteristic of a "thing", for example its NAME. For example, the worksheet represents a worksheet object. The active

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workbook is another object type, which represents the active workbook. Another object kind is the range object representing a range of cells in the worksheet. Whenever one first uses an object, one begins with the set key word. Objects take up some memory in the computer, so, the set key word allocates the memory place required for an object. To use a property with an object, a period is placed between them. Every object is a specific type and has its own set of methods and properties. A variable is something defined to record information and used later in the program. There are many tools in the visual basic that helps the programmer.

Taking readings from the multimeter is done by using the “fetch?” command. The advantage of this command is that it provides continuous operation of the multimeter and the instrument does not go into an idle state. The operation of data capturing is displayed in Figure 2. In the written program, dimensions of the variables and strings are defined. The strings and counter for measuring vales are defined. The talk and listen operations are accomplished via visa control

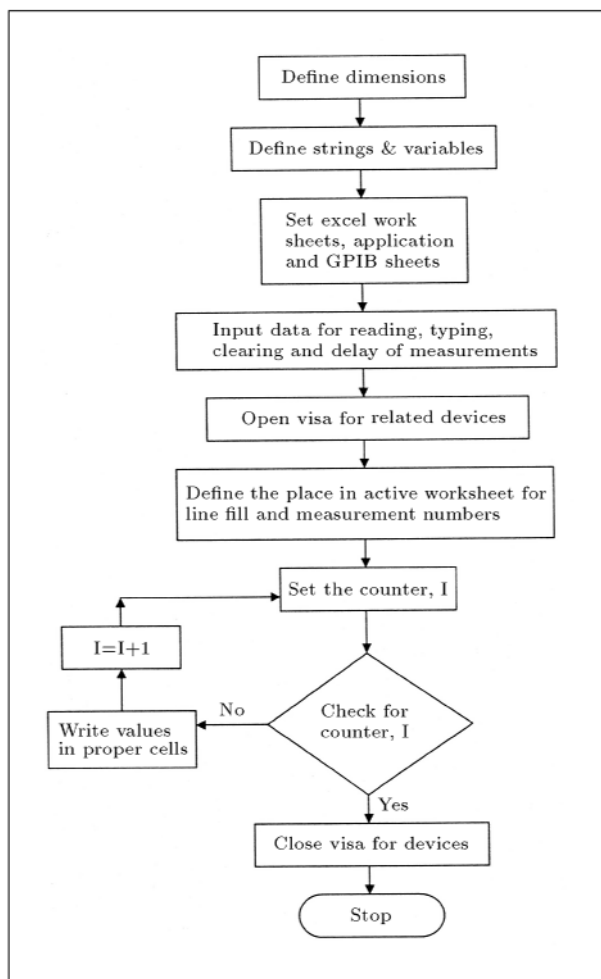


Figure 2. Flow chart for the operating system.

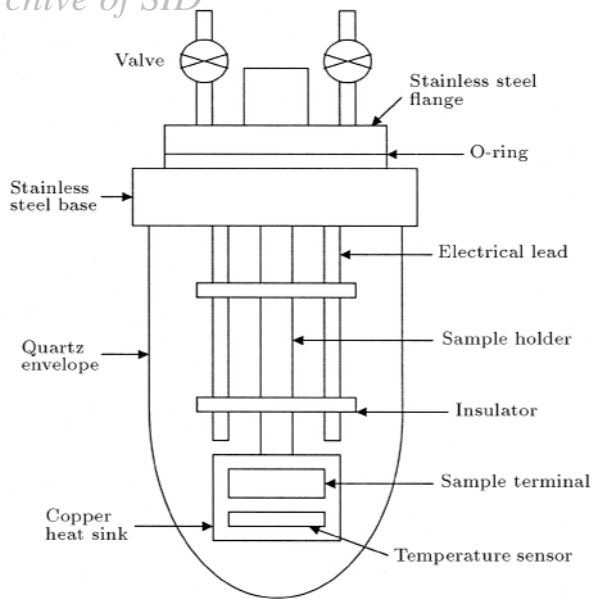
standard commands. The visual basic application included in the Excel macro is used for communication between the PC and the devices. The advantage of the method is its simplicity, which does not require that much program writing and the fact that the Excel program is available to most laboratories. Using this method offers a relatively simple and cost effective technique for data collection, analysis and presentation.

For a single measurement, the command button “Measure” is clicked and, accordingly, the measured values are first displayed and then written in the proper cells in the Excel worksheet. For each measurement, the related temperature is displayed in a small window and, by viewing this temperature, it is possible to write it in the proper place in the data table. If the measured temperature is not the desired one, then, it is monitored at a later time. By completing a table data for a set of measurements, the plotted data can be also displayed and printed. At the end of each run, the button defined as “Reset” clears the inputted numbers in the active worksheet and initializes the system for the next measurement. The button defined as “Help” provides on line help for the command work catalog for general help and probable troubleshooting.

## RESISTANCE MEASUREMENTS

Platinum wires and films [3] are widely used for resistance thermometry and as combustible gas detection sensors [4]. Such sensors offer the highest standard of accuracy and stability of any temperature sensor covering a temperature range from  $-200^{\circ}\text{C}$  to  $650^{\circ}\text{C}$ . Platinum sensors are finding increasing favor in industry because of their higher accuracy, repeatability and stability for moderately rugged vibrational applications [5-7]. It is especially suited for a Resistance Temperature Detector (RTD), as it can withstand high temperatures with good stability and show limited susceptibility to contamination. The RTD is a more linear device than the thermocouple, but it still requires curve fitting.

To see the temperature variation of platinum, which is important to different sensing applications, the temperature dependence of the platinum resistivity is measured using this interface method. The experimental apparatus devised for such a measurement is shown in Figure 3. It consists of a stainless steel base, a stainless steel flange and shaft, a copper heat sink for sample holder, copper wire leads for the electrical connections and alumina rings as an electrical insulator for the copper wires. The chamber head and the shaft of the probe are made of stainless steel tubing, because its low thermal conductivity minimizes the amount of heat conducting down from above. A quartz envelope seals off the stainless steel flange by making use of an o-ring and a quick clamp. Two stainless steel



**Figure 3.** Experimental probe for measuring variation of resistance with temperature.

valves are considered for the system that makes the evacuation and purging of the sample chamber possible. Underneath the quartz envelope, a jack with a top plate is provided that makes vertical adjustment of the Dewar flask possible.

A pair of 4-pin terminals is used for sample holding and handling. One terminal is fixed at the probe tip on the sample holder, while a similar type is utilized for sample fixation. A sample-connected terminal can be easily connected to the fixed terminal. This arrangement makes it easy to plug and unplug terminals in order to change the sample quickly without disturbing the probe tip. A typical sample wire has a length of about 12 mm (Aldrich, 99.99%). The sample is first cleaned and attached to the sample holder with four pins by using conductive silver paste. The sample terminal is then attached to the probe assembly, which is suspended within the quartz tube. A 1-liter dewar is used for  $N_2$  cooling of the system under study. The dewar containing liquid nitrogen, which has a boiling point of 77 K ( $-195^\circ\text{C}$ ), is used for the cooling purpose. The tube is inserted in the dewar and, since the probe is not in direct contact with the liquid nitrogen, it takes about five minutes for the sample to cool to about 80 K.

It must be noted that, for the samples which have a room temperature resistance of less than  $1\text{ m}\Omega$ , it is hard to measure precisely their resistances with a simple multimeter. To avoid the problem of measuring the resistance of the leads, the four-wire probe is often used. Therefore, in the reported experiment, a 4-wire method is used for the measurements. A ribbon cable is connected to the probe leads, which has eight wires. Four of these wires are used for the temperature

determination and the other four for the resistance measurements. Such cable reduces EMI noise in the measurements. The 4-wire probe device also offers the shielded cable leads for low noise interferences.

A small size silicon diode (Scientific Instruments, Si-410B) is attached to the copper heat sink and close to the sample, in order to measure the sample local temperature [8]. It must be pointed out that such diode sensors operate based on the RTD measurements. Therefore, it requires resistance measurements and conversion to the temperature values. For measuring temperature, the resistance measurement is done by using a four-probe method. The temperature sensor operates over a wide temperature range (1.5 K-450 K) with a sensitivity of about  $40\text{ mV/K}$  and an overall accuracy of  $\pm 0.10\text{ K}$ . Two lead and four lead configurations are available, while the four-lead provides the highest accuracy by compensating for the lead wire resistance.

It must be pointed out that there are advanced systems like Quantum Design (Physical Property Measurement System, PPMS model 6700) for measuring the physical properties of the material, however, the initial and operating costs of such a machine are so high that its application is limited and makes the simple home made apparatus so advantageous. However, such a machine provides measurement of the temperature dependence of resistance at lower temperatures of liquid helium rather than of liquid nitrogen.

## RESULTS

In the first experiment, communication and data handling between the PC and devices are checked. These devices include a model 2000 Keithley multimeter, a Tektronix oscilloscope and the four-probe device (Agilent Technologies, 4338 B). For the communication test and short circuit voltage measurements, the digital voltmeter (DVM) and oscilloscope are used. The results for this test can be presented in a worksheet, in order to show the shorted circuit voltage. This voltage is measured with a DVM for a series of measurements. In the second experiment, both DVM devices are used for resistance measurement and the results for a typical resistor with the nominal value of  $600\ \Omega$  are investigated. The four-probe technique is used for both systems to measure a common resistance value. By the way, this method gives a precise way to calibrate a measuring instrument in terms of a known reference resistance value.

The resistivity of the sample under study is measured, using the similar four-probe technique (Agilent Technologies, 4338B). This instrument is used to acquire the DC resistance measurement of a platinum wire. For temperature determination using the calibration formula, the resistance is converted to voltage

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readings and, from those, the operating temperature is deduced. The reported method offers some advantages for such measurements. One advantage is that, for example, the true value of temperature can be obtained by using the look up table or the calibration formula for that particular temperature probe. The calibration formula gives the temperature versus voltages. Using the math function potential of Excel, one can obtain accurate values for the temperature by using the resistance or voltage values.

For example, in the case of temperature dependence, as mentioned, a silicon diode probe can be used for temperature measurements. Using such references, one can deduce the temperature variation of the sample resistance. Usually, the calibration table or formula is given for such temperature sensors. For a polynomial formula, the coefficients are shown in Figure 4. The first column in the table shown in Figure 4 shows the applied voltage and the second column next to it shows the determined temperatures, according to the given coefficients for this kind of RTD sensor. In this case, based on the voltage value, the temperature is deduced. The applied voltage is determined by measuring resistance and knowing the excitation current. The result of such measurements is displayed as a worksheet in Figure 5. As indicated in Figure 5, the first column shows a typical resistance, the second column the applied voltage and the third column shows

the determined temperature values corresponding to the assumed coefficients. The last column represents the resistance value for a typical resistance value.

The last experiments are performed for the temperature variation study of a platinum wire sample. The goal here is to measure the temperature dependence of the platinum thin wire and to compare the measured results with the theory. Figure 6 shows the variation of the platinum wire resistance with temperature for the case of increasing temperature. For a better comparison, the variation of wire resistance versus temperature, according to Equation 1, is also shown in Figure 6. The temperature measurements are performed experimentally in the range of 81 to 298 K. Since the theoretical estimation given by Equation 1 is valid for the range of 73 K to 273 K, therefore, in Figure 6, the experimental measured values for this range of 81-273 K is plotted and compared with the theoretical predication.

As can be seen in Figure 6, the resistance of the wire is increased with the temperature in the range of 80 K to 273 K. However, as indicated by many others [9,10], such variation is nonlinear in nature and the calibration of such a probe needs curve fitting. The Callendar-Van Dusen equation has been used for years to approximate the resistance temperature conversion [11]. A third degree polynomial formula for the range of -200°C (73 K) to 0°C (273 K) is given

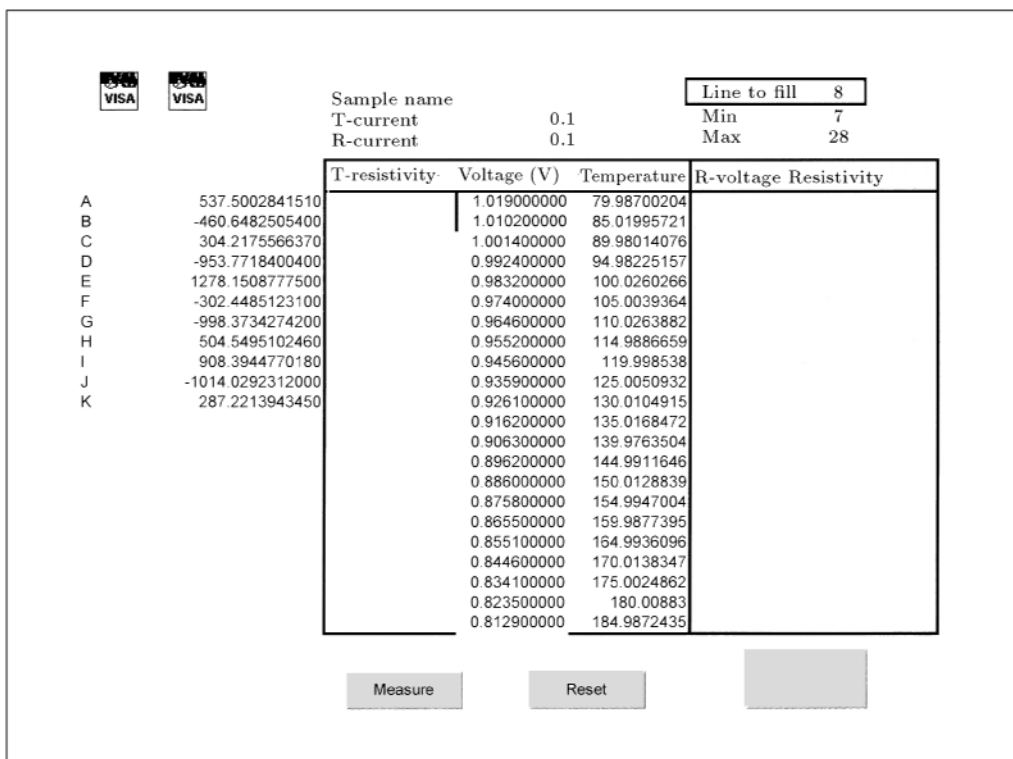


Figure 4. Calibration curve for the RTD measurements.

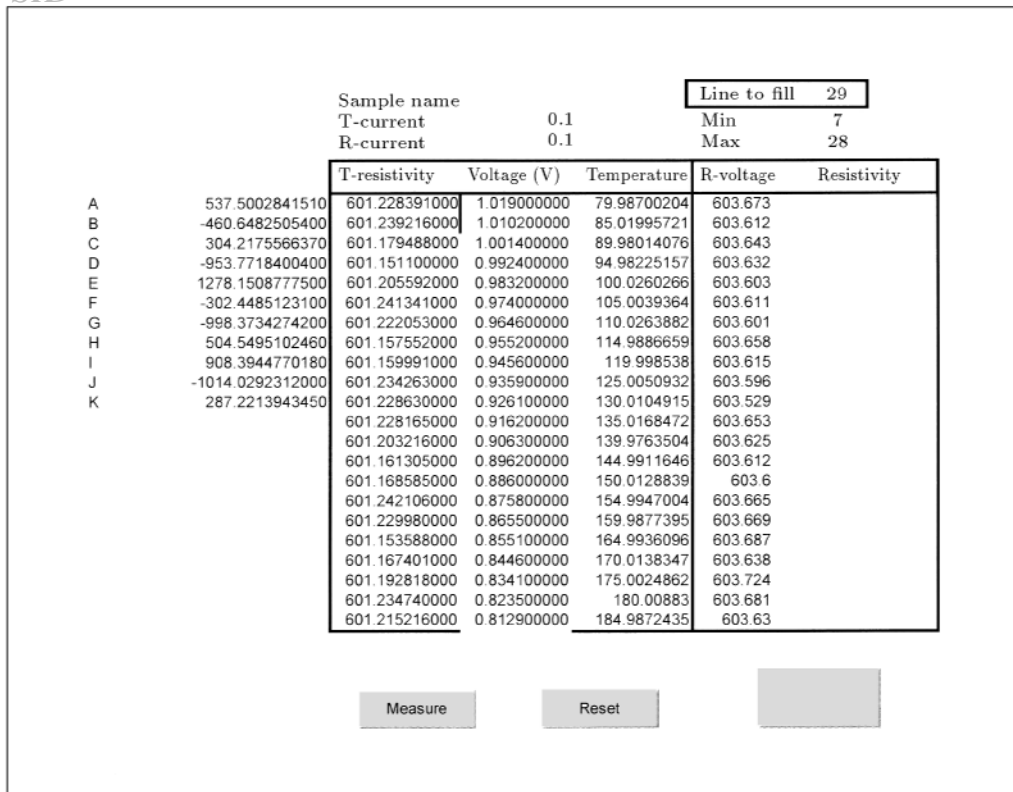


Figure 5. Typical data for the sample temperature and resistance measurements.

by [12,13]:

$$R(T) = R_0[1 + AT + BT^2 + C(T - 100)T^3], \quad (1)$$

where  $T$  is the temperature in degree Celsius,  $R_0$  is the resistance at zero degree Celsius,  $A = 3.9083 \times 10^{-3} \text{ } ^\circ\text{C}^{-1}$ ,  $B = 5.775 \times 10^{-7} \text{ } ^\circ\text{C}^{-2}$  and  $C = 4.183 \times 10^{-12} \text{ } ^\circ\text{C}^{-4}$  for a typical Pt100 thermometer. According to Equation 1, the resistance at  $T = 193^\circ\text{C}$  (80 K) is 9 m $\Omega$ , while it increases to about 42 m $\Omega$  for the  $T = 0^\circ\text{C}$  (273 K).

In general, there is a good agreement between the measured values and the predicted ones from the Callendar-Van Dusen equation. Using the theoretical results of Equation 1, the resistance of the sample at 81 K is 9.2 m $\Omega$ , which is different from the 5.5 m $\Omega$  measured experimentally. As can be seen, there is a difference between the measured and the computed values that is acceptable for such an experiment. The resulting difference at the low temperature regime is within the experimental margin of error. However, at higher temperature regions agreement with the fitted results, according to the Callendar-Van Dusen equation, is so good that the experimental measured points overlap, exactly, the theoretical ones.

However, it must be pointed out that there are different types of platinum material with different

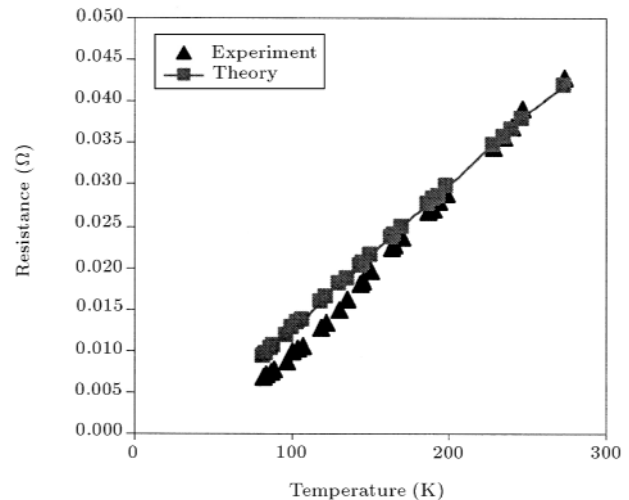


Figure 6. Variation of the platinum wire resistance with temperature.

percentages of impurity and the assumed coefficient values in Equation 1 could be a little different from the values assumed in this calculation. The possible deviation in assumed values explains the observed difference between the experimental and the predicted results. As shown in Figure 6, there is good agreement between the obtained experimental and calculated results, which shows the effectiveness of the reported

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method. The main goal, however, here, is to show the effectiveness of the method rather than the results, which can be used for the resistance measurements and temperature dependence for other thin fiber type conductive materials.

The graph presented in Figure 6 is for the case of increasing temperature when gradually taking out the probe from the liquid nitrogen. From the experimental results, at  $T = 294$  K,  $R = 50.47$  m $\Omega$  and  $T = 81$  K, the resistance is  $R = 5.5$  m $\Omega$  ( $\Delta T = 213$  K,  $\Delta R = 44.97$  m $\Omega$ ). A similar study is performed for the case of decreasing temperature while inserting the probe in the liquid nitrogen. In the cooling process, at  $T = 81$  K, the measured resistance is  $R = 6.68$  m $\Omega$ , and, at  $T = 298$  K,  $R = 54.44$  m $\Omega$  is obtained ( $\Delta T = 217$  K and  $\Delta R = 47.76$  m $\Omega$ ). The line slope of increasing temperature is 0.21 m $\Omega$ /K, in comparison with the 0.22 m $\Omega$ /K in the case of the cooling process. As can be seen from these results, there is a good consistency in measured resistance values in both increasing and decreasing temperature schemes, with a low amount of hysteresis for this range of operation.

In summary, a great advantage of the GPIB is that it is a standard module, which supports worldwide standards, such as IEEE 488. This interface allows the instruments to be controlled by an external PC that sends commands or instructions to instruments and receives data from them. It also defines handshaking, addressing and the general protocol used for transmitting individual bytes of data. Overall results show that the developed data acquisition method can be effectively used to collect data from different instruments, interoperate them and, finally, display the results. Useful information concerning the temperature dependence of resistivity is obtained and the same set up can be used for measuring the resistance variation of very thin filaments or fibers. The great potential of the Excel program makes it possible to add additional features to the written program, in order to increase the efficiency of the reported on-line measurement method.

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