Fermilab

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CARBON RESISTANCE THERMOMETERS

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INTRODUCTION

The extensive use of cryogenic equipment at Fermilab makes it highly desirable the availability of non-retrievable (cheap) low temperature thermometers. Some carbon resistors used in electronic equipment have temperature coefficients that make them very suitable for this purpose[1]. Among these, some 1/8W resistors[2] obtained from the stockroom are suitable and have negligible price compared with commercial germanium, glassy carbon, or platinum resistors. These carbon resistors are quite sensitive near liquid He or H_2 temperatures where thermocouples cease to be useful.

The major cost on resistors as temperature sensors is their calibration. The going price of a calibrated platinum thermometer is $400.00. In order to meet the internal demand for monitoring (as opposed to precision) thermometers a miniature cryostat capable of calibrating 7 resistors between 4.2K and 300K was built and is now operational. This cryostat has the very convenient feature that it is all contained inside a 1/2" O.D. stainless tube, immersible therefore in any of our

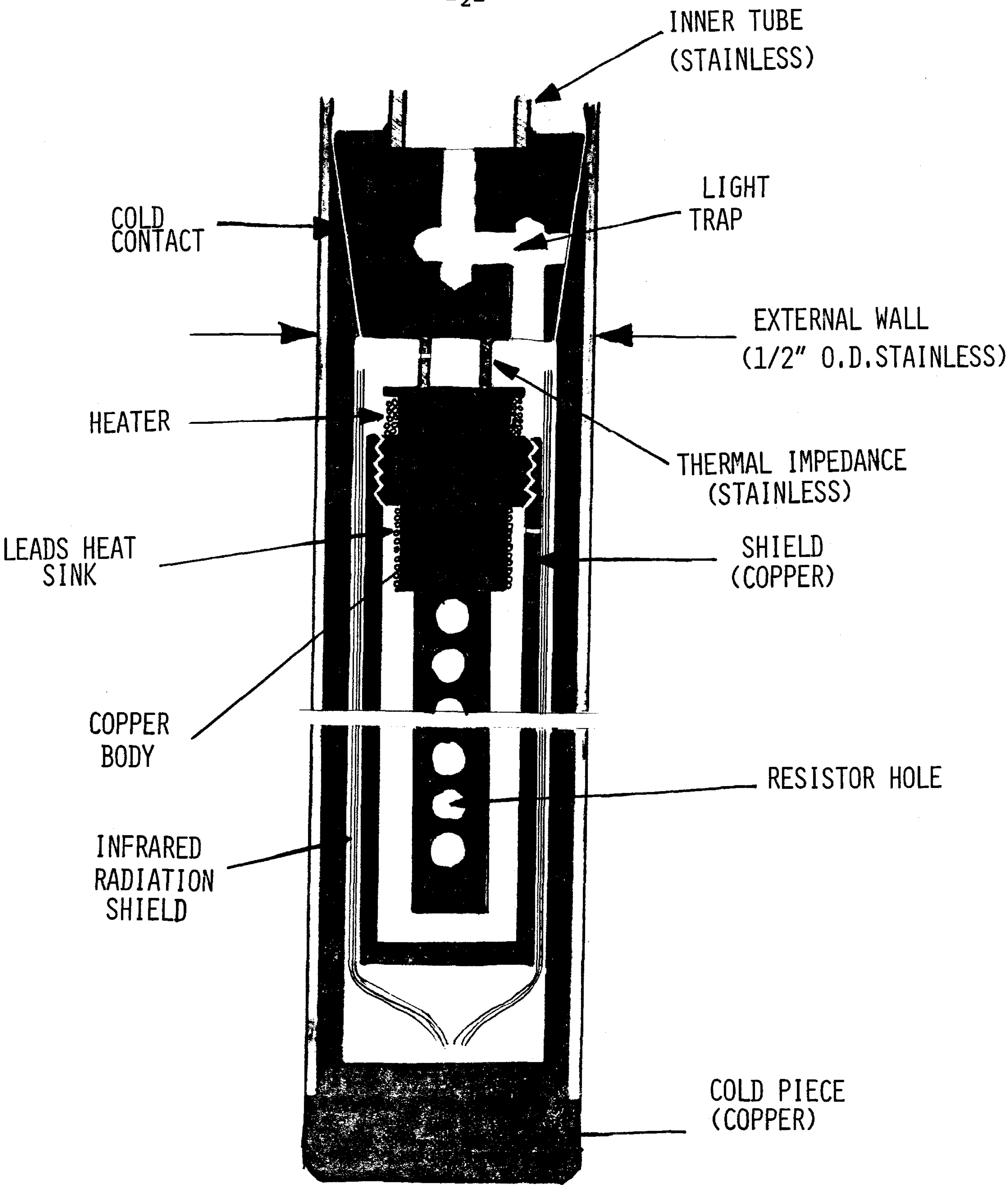

FIGURE 1 - SCHEMATIC OF THE IMMERSIBLE END OF THE CRYOSTAT

standard storage dewars. This permits an 18 points calibration for 7 resistors to be made in 12 hours.

The purpose of this technical memo is to advertise the availability of "in-house calibrated" carbon thermometers, briefly describe the cryostat and the measuring circuit used in the calibration, as well as to present typical calibration data for what could become a widely used sensor.

MINICRYOSTAT

Figure 1 is a self-explanatory schematic of the lower end of the cryostat. Not shown are the electrical terminal blocks made out of printed circuit board stock and the resistors. The conical cold contact is insured by a screw that adjusts the length of the inner tube.

At the warm end of the cryostat a RAD LAB connection seals the inner tube to the external wall. Another RAD LAB connector after a bellows sealed valve and a safety check valve provides for vacuum connection. Completing the warm end part we have standard hermetic electrical connectors.

THERMOMETER READING CIRCUIT

A 4-lead dc technique is being used to measure the resistances. A constant current (10μA or 100μA) power supply with a reversing switch feeds all the 9 resistors (7 unknown, a temperature calibrated one and a precision resistor at room temperature) connected in series. The voltage leads of each individual resistor is selectable for reading by a digital

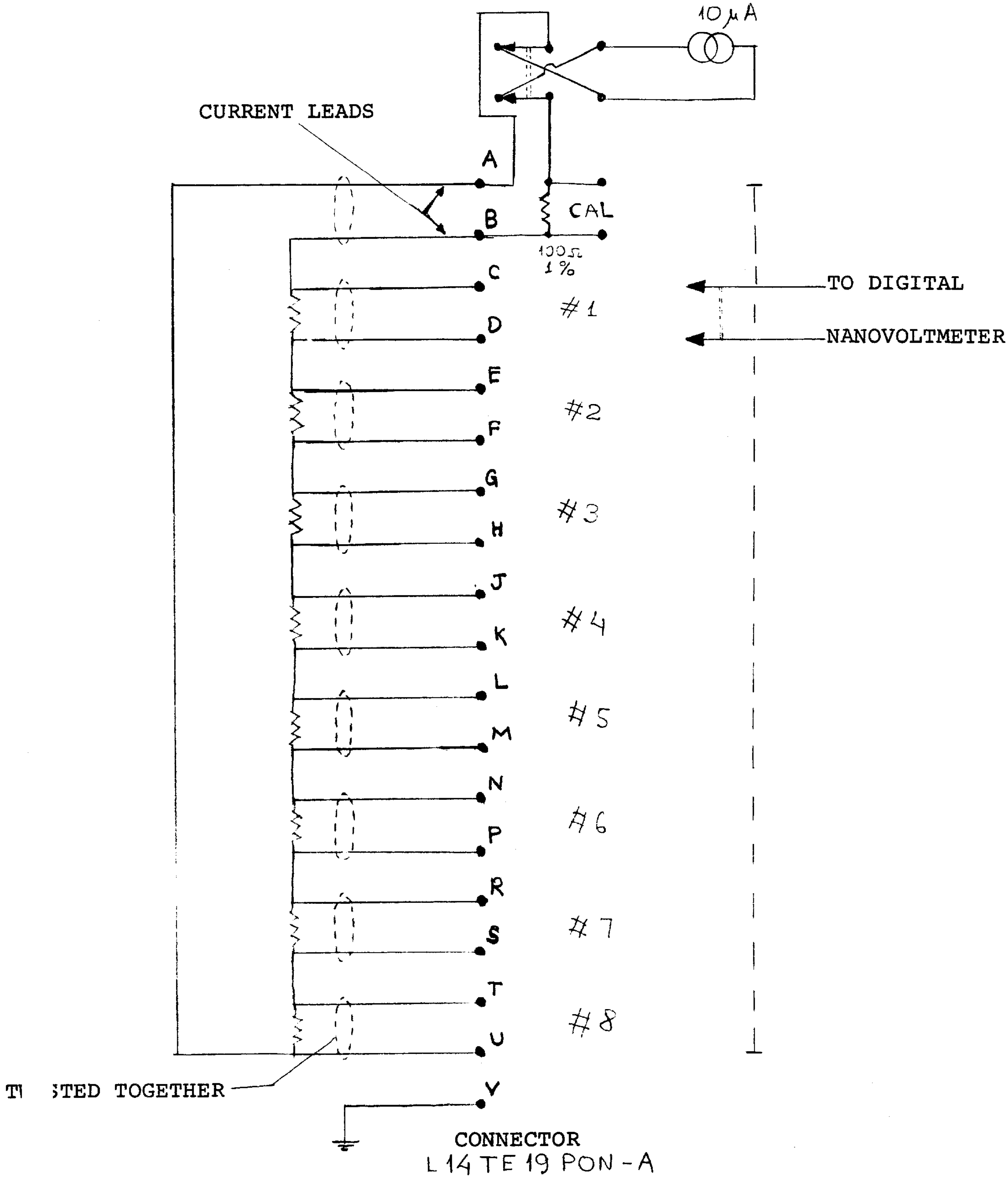

FIGURE 2 - SCHEMATIC OF CIRCUIT USED IN THE MEASUREMENTS SPECIFYING CONVENTIONAL 19 PIN CONNECTOR HOOKUP

nanovoltmeter[3]. Compensation for thermal e.m.f. is obtained by taking 2 readings of each resistance, one for each direction of the current. A 1% precision resistor is used as the standard.

The schematic of the circuit is presented in Figure 2 for the purpose of specifying the convention used in the 19 pin connector, since several of our cryostats follow this convention and interchangeability with the thermometer instrumentation of future cryostats might be desirable.

TYPICAL CALIBRATION DATA

In its first run, besides calibrating 7 resistors, we collected data on the thermal characteristic of the cryostat which should speed up future calibrations. Of these 7 resistors, 6 are 100Ω at room temperature[2] and 1 is 1000Ω at room temperature[4] and more suitable for higher temperatures. The factory calibrated sensor used in these measurements was a glassy carbon resistor[5].

Table I presents the data obtained in this first run. The points at 15.66K and 15.77K were taken 12 minutes apart and indicate the kind of equilibrium we waited for. The average of the values for the six 100Ω at room temperature resistors, is presented in the last column and plotted in Figure 3. The closeness of their calibration curves suggest that an even cheaper calibration, "calibration by kinship", can be used (at some risk) for resistors from the same batch.

It can be argued that the stability of carbon resistors as thermometers is improved by thermal shocking them several times.

TABLE I

RESISTANCE OF CARBON RESISTORS[2,4] AS FUNCTION OF TEMPERATURE

T	#1[2]	#2[2]	#3[2]	#4[2]	#5[2]	#6[2]	#7[4]	Average of #1 thru #6
4.34K	866. Ω	865. Ω	865. Ω	854. Ω	858. Ω	878. Ω		864. Ω
6.30	519.	521.	521.	514.	515.	526.		517.
7.23	442.	444.	444.	438.	439.	448.		443.
9.12	351.	352.	353.	348.	349.	355.	6935. Ω	351.
11.73	285.	287.	287.	283.	284.	288.	5088.	286.
15.66	234.	236.	236.	232.	233.	237.	3800.	235.
15.77	233.	234.	235.	231.	232.	236.	3778.	233.
20.83	199.	201.	201.	198.	198.	201.	2994.	200.
28.79	171.	172.	173.	170.	170.	173.	2392.	171.
39.09	152.	153.	153.	151.	151.	153.	1997.	152.
52.42	137.	139.	139.	136.	137.	139.	1718.	138.
77.08	123.	124.	124.	122.	122.	124.	1449.	123.
96.54	116.	117.	118.	115.	116.	117.	1329.	116.
123.69	110.	112.	112.	110.	110.	111.	1223.	111.
153.95	106.	107.	108.	106.	106.	107.	1148.	107.
248.59	100.4	101.5	101.4	99.8	100.3	101.3	1041.4	100.8
265.73	100.3	101.2	100.7	99.7	100.0	101.1	1036.1	100.5
271.42	99.9	100.9	100.6	99.2	99.7	100.7	1030.3	100.2

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Although we have not seen a conclusive proof of it, we have "trained" these resistors by cycling them at least 6 times into liquid He (liquid N_2 for the 1000Ω resistor) from room temperature before calibrating.

The current flowing through the resistors was 10μA, a higher current will increase sensitivity but care should be used to avoid internal heating of the sensor. This condition will be avoided if the current is kept below the maximum current allowed indicated in Figure 3. An important point in the use of these sensors is good thermal contact of the sensor with the object whose temperature is being measured. The stability of these resistors is expected to be ≈1% provided they are treated with the care usually extended to germanium resistors.

REFERENCES

1. A.C.Anderson - Carbon Resistance Thermometry - Fifth Symposium on Temperature, Instrument Society of America; June 1971.
2. Carbon Resistors 1/8W 100Ω 5% made by Allen Bradley package labelled: JAN RCR 05G 101 J5 01121.
3. Model 180 Digital Nanovoltmeter, Keithley Instruments.
4. Carbon Resistor 1/8W 1000Ω 5% distributed by Allen Bradley.
5. Glassy Carbon Resistor Serial #C503; Calibration Certificate #1005251-11; Lake Shore Cryotronics; 9631 Sandrock Road, Eden, N.Y. 14057.

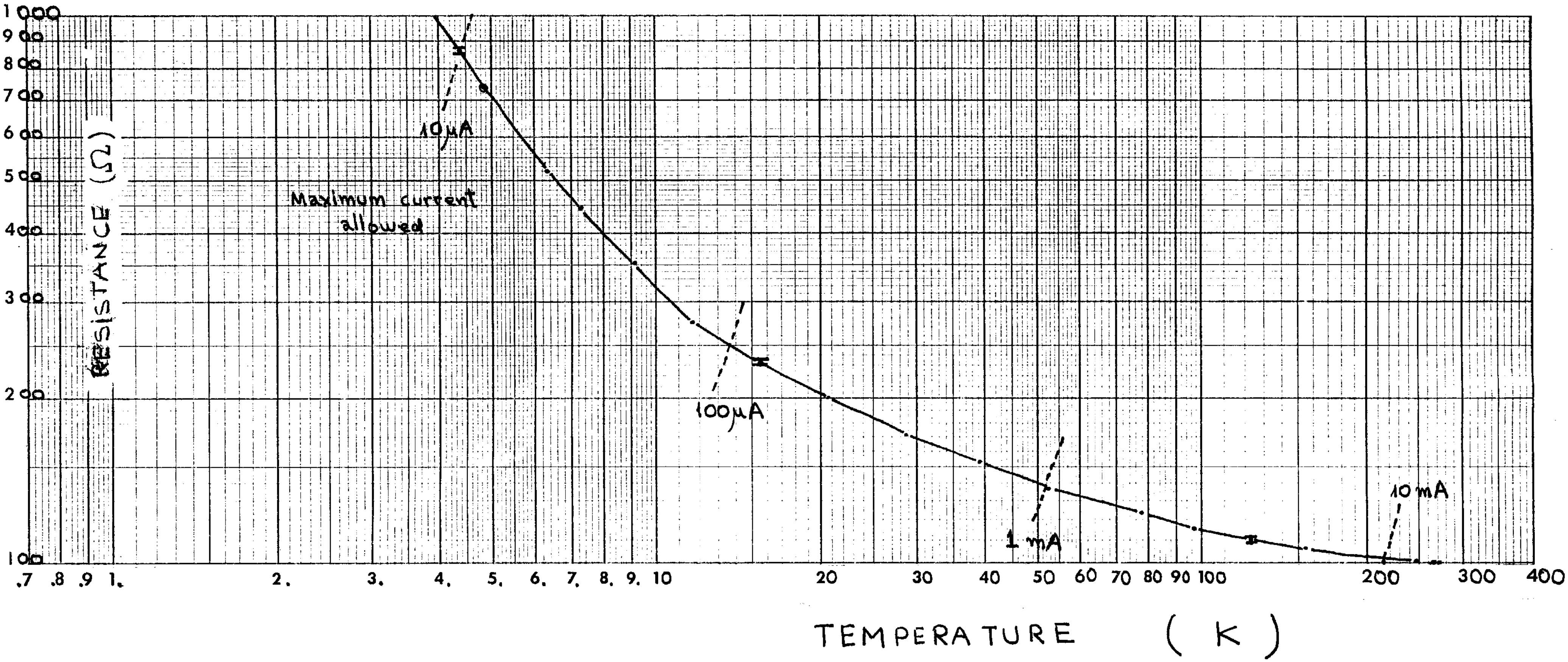

FIGURE 3 - AVERAGE CALIBRATION CURVE FOR 6 CARBON RESISTORS[2].
ERROR BARS INDICATE MAXIMUM INDIVIDUAL DEVIATION OBSERVED.

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