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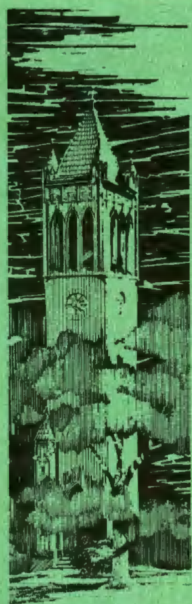

IOWA STATE UNIVERSITY

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AMES LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

A calibration of gold iron thermocouples is given.

Berman and Huntley [1] have shown that Au doped with a few hundredths of a percent Fe makes a satisfactory thermocouple element at low temperatures. They find that a gold + 0.03 at. % iron vs silver normal thermocouple is reproducible to better than 0.5% and has a sensitivity greater than 10 μV/°K in the temperature range from 1 to 20°K. We have measured the thermoelectric voltage of Au 0.07 at. % Fe vs Cu and find results complementary to those of Berman.[1]

The Au-Fe wire, prepared by Engelhard Industries, Inc.,* is drawn into 0.006 in. diam wire, annealed at 550°C for 12 h in a reducing atmosphere and then insulated with heavy formvar. For the second wire of the thermocouple we have chosen copper because high purity wires are readily available. For applications where thermal conductivity must be low, silver normal would be a more appropriate second element. The voltages are measured with a Leeds and Northrup type K-3 potentiometer and a 0.0006 μA/mm Leeds and Northrup galvanometer.

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*Engelhard Industries, Inc., Baker Platinum Division, 113 Astor St., Newark 14, New Jersey.

Temperatures in the range from 4.2 to 20°K are determined by the constant volume gas thermometer shown in Fig. 1. The entire 135 cc gas bulb is machined from high purity copper. Eight deeply recessed holes are cut in the top block to accommodate either germanium resistors or Au-Fe thermocouples. The copper rod which runs down the center of the bulb contains both the 2 cc vapor pressure bulb and a threaded hole for affixing other experiments. A special groove is cut in the main block for an astatically wound manganin heater. Another groove just above the heater provides an area for thermally connecting the electrical leads to the copper block before they go to the resistors or thermocouples. A shield which surrounds the gas bulb provides a thermal reservoir at a temperature approximately 0.1°K below the gas bulb temperature. All connections to the gas bulb are thermally connected to this shield. The vapor pressure line is a 0.052 in. i.d. stainless steel capillary; the gas bulb line is a 0.020 in. i.d. stainless steel capillary. A copper-constantan thermocouple is cemented to the gas bulb capillary at approximately 30°K to assist in the calculation of the dead volume correction. With the assumption that the thermal conductivity of the capillary varies linearly with temperature, we calculate the maximum dead volume correction to be one part in 900. The filling pressure of 3 Torr/°K gives a maximum non-ideality[2] correction of 0.016°K. Thermomolecular corrections are determined from the calculations of Roberts and Sydoriak.[3] If we assume that He^4 has a saturated vapor pressure of 760.00 Torr at 4.215°K, then we measure the temperature of equilibrium hydrogen at a saturated vapor pressure

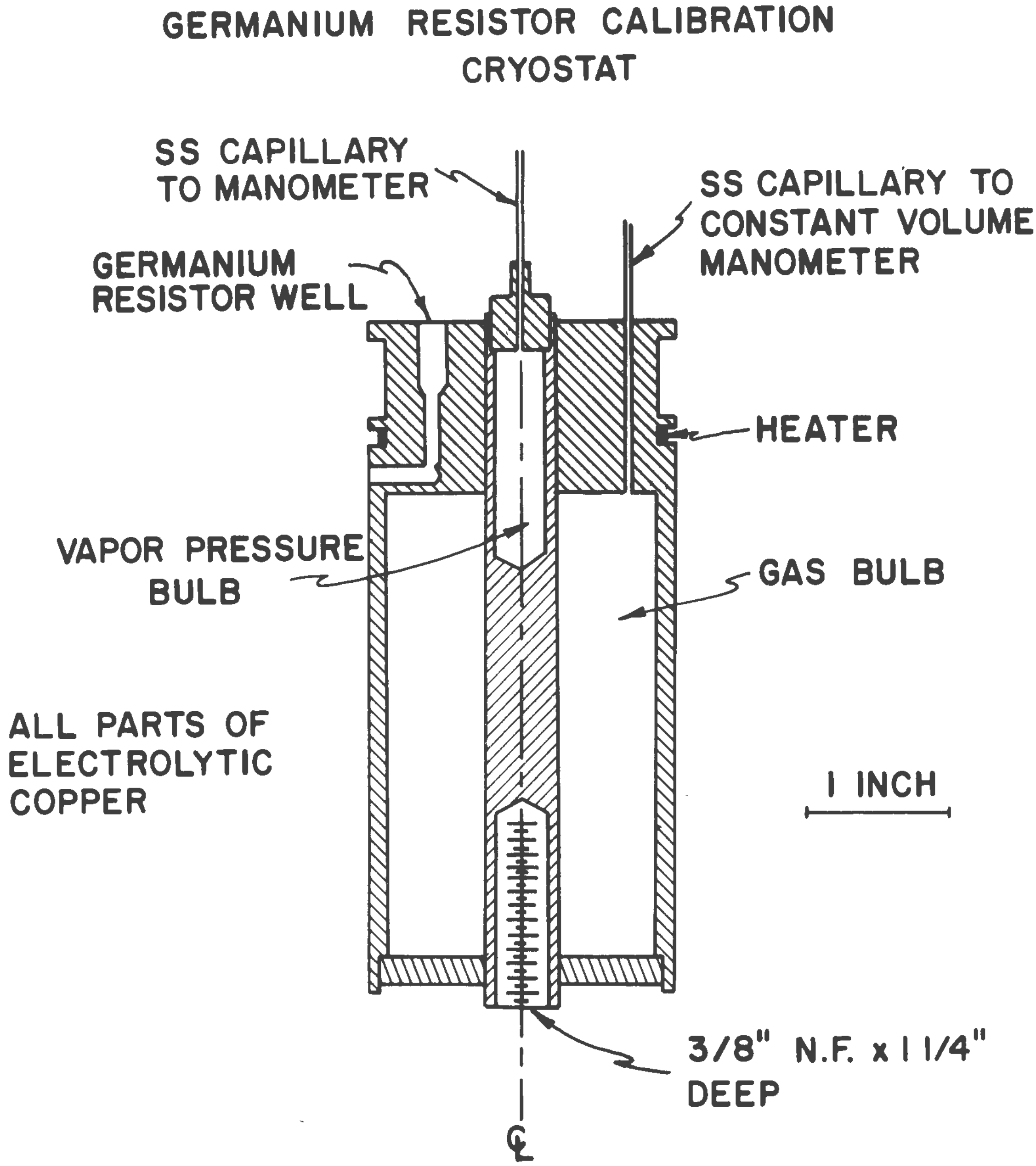

Fig. 1. Constant volume gas thermometer.

of 760.00 Torr to be 20.253 ± 0.03°K. This value is within 0.01°K of that derived from the work of Moessen *et al.*,[4] but is 0.025°K less than the value given by Hilsenrath *et al.*[5] As an additional check on the thermometry we have measured the vapor pressure of He^4 from 4.2 to 5.0°K and confirm the work of Berman and Swenson[6] (hence T-58)[7] to ± 0.003°K.

Results of the measurements (see Table I) are shown in Fig. 2. The striking feature of this curve is its linearity over a long temperature range. It is this feature which strongly recommends Au-Fe thermocouples as a secondary thermometer. This linear behavior is shown even more clearly on Fig. 3. The sensitivity remains between 13.5 and 14.0 μV/°K all the way from 6 to 20°K. Even at 78°K the sensitivity has fallen only to 8 μV/°K. For comparison we show in Fig. 3 the sensitivity for Au 0.02 at. % Fe (absolute thermopower).[8] Note that the lower Fe concentration has a higher sensitivity at low temperatures but it falls off more rapidly at high temperatures. This reflects the fact that the magnetic ordering takes place at a lower temperature for the smaller Fe concentrations. Different voltage characteristics can be obtained by proper selection of the Fe concentration. These Au-Fe thermocouples provide a quick, easy and reliable method for determining temperatures to an accuracy of 0.05°K in the range from 4.2 to 20°K.

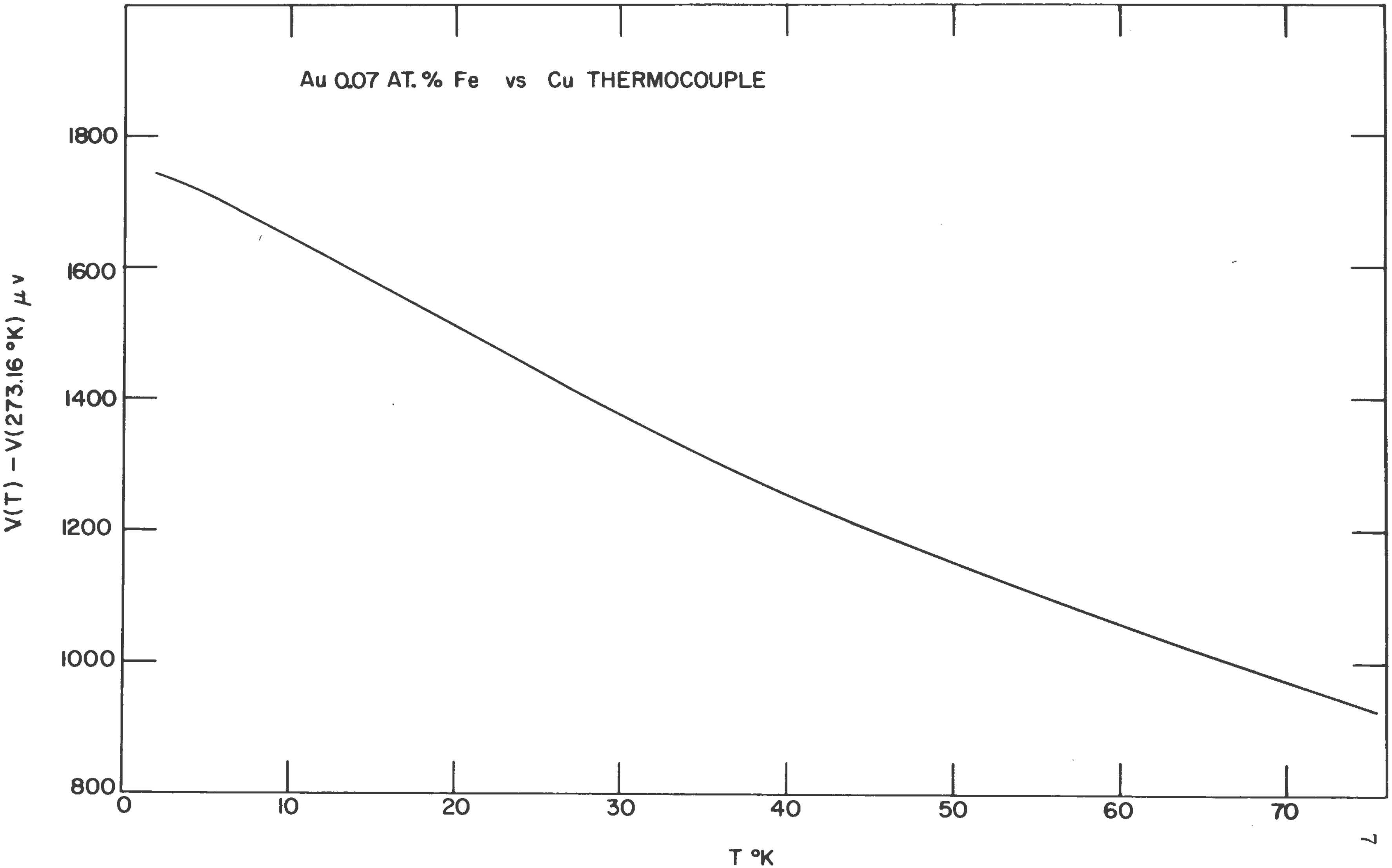

Fig. 2. Voltage plot for Au 0.07 at. % Fe vs Cu thermocouple. The ice point is used as a reference temperature.

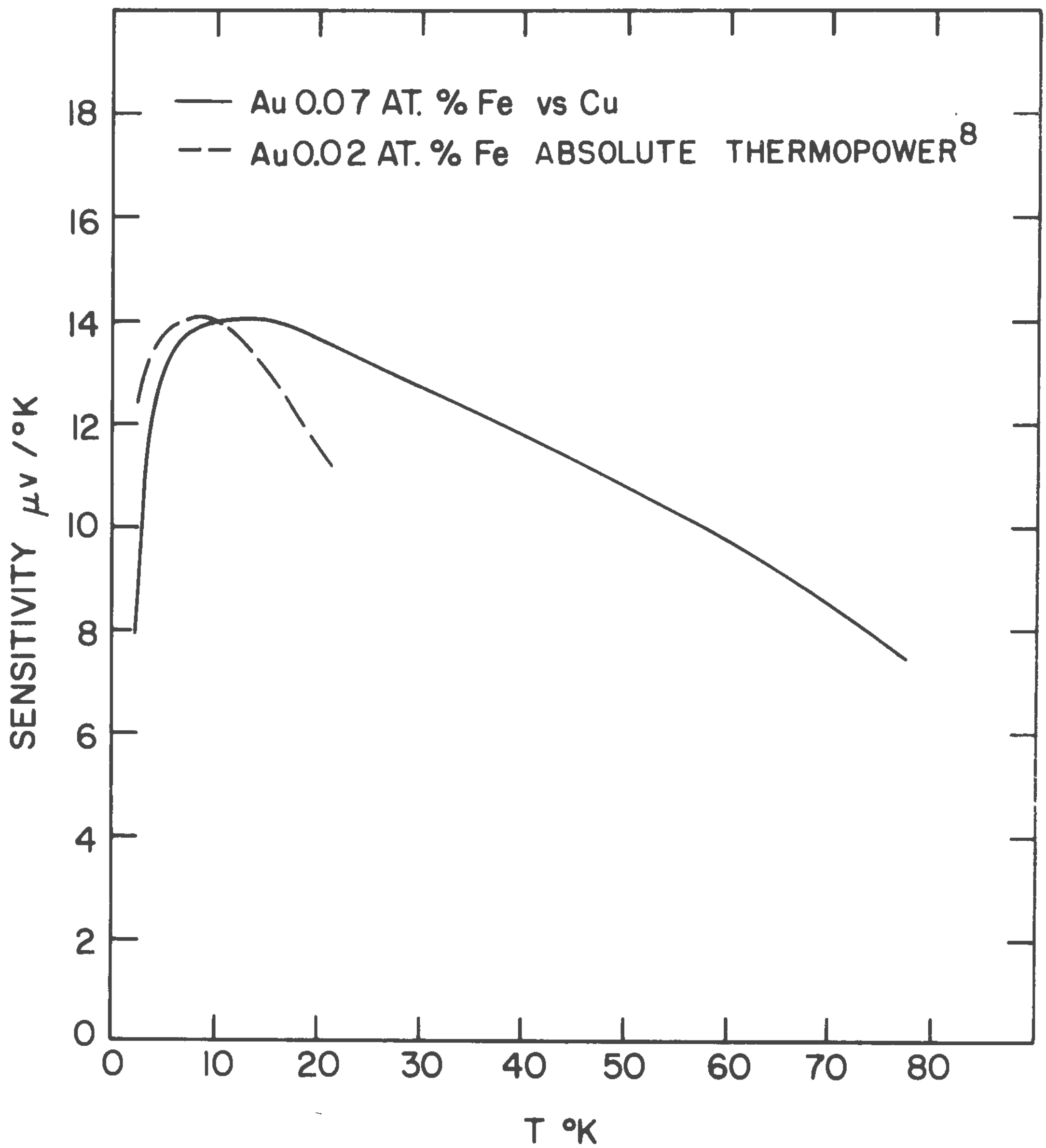

Fig. 3. Sensitivity plots for Au 0.07 at. % Fe vs Cu and Au 0.02 at. % Fe absolute thermopower.

REFERENCES

[1]R. Berman and D. J. Huntley, Cryogenics 3, 70 (1963).

[2]J. E. Kilpatrick, W. E. Keller and E. F. Hammel, Phys. Rev. 97, 9 (1955).

[3]T. R. Roberts and S. G. Sydoriak, Phys. Rev. 102, 304 (1956).

[4]G. W. Moessen, J. G. Aston and R. G. Ascah, Temperature, Its Measurement and Control in Science and Industry, edited by C. M. Herzfeld (Reinhold Publishing Corporation, New York, 1962), Vol. III, p. 91.

[5]J. Hilsenrath, C. Beckett, W. Benedict, L. Fano, J. Masi, R. Nuttall, Y. Touloukian and H. Woolley, Tables of Thermodynamic and Transport Properties of Air, Argon, Carbon Dioxide, Carbon Monoside, Hydrogen, Nitrogen, Oxygen and Steam (Pergamon Press, Inc., New York, 1960).

[6]R. Berman and C. A. Swenson, Phys. Rev. 95, 311 (1954).

[7]F. G. Brickwedde, H. van Dijk, M. Durieux, J. R. Clement and J. K. Logan, J. Res. Natl. Bur. Standards 64A, 1 (1960).

[8]D. K. C. MacDonald, W. B. Pearson and I. M. Templeton, Proc. Roy. Soc. A266, 161 (1962).

Table I

Au-Fe vs Cu Thermocouple Calibration

Temperature °K	V(t)-V(273.16°K) uV	Temperature °K	V(t)-V(273.16°K) μV
1.925	1742.1	5.643	1702.1
2.295	1738.8	5.800	1700.6
2.295	1738.8	5.897	1699.0
2.456	1737.3	5.958	1698.4
2.666	1735.1	5.958	1698.3
2.942	1732.3	5.959	1698.3
3.052	1731.1	6.029	1697.6
3.271	1729.0	6.311	1694.1
3.271	1729.0	6.644	1689.9
3.325	1728.4	6.953	1686.1
3.589	1725.6	7.065	1684.4
3.599	1725.5	7.193	1683.1
3.599	1725.6	7.374	1680.5
3.717	1724.1	7.461	1679.6
3.718	1724.1	7.588	1677.5
3.769	1723.6	7.594	1677.6
3.820	1723.0	7.658	1677.0
3.820	1723.1	7.852	1674.3
3.883	1722.5	7.938	1673.1
3.884	1722.5	8.154	1670.4
3.920	1722.1	8.176	1670.0
3.994	1721.3	8.266	1668.9
4.085	1720.4	8.355	1667.8
4.088	1720.4	8.391	1667.3
4.089	1720.4	8.494	1665.9
4.089	1720.4	8.564	1664.9
4.093	1720.2	8.629	1664.0
4.156	1720.4	8.708	1663.0
4.292	1718.0	8.803	1661.8
4.542	1715.1	8.852	1661.0
4.764	1712.6	8.902	1660.3
5.048	1709.4	8.963	1659.6
5.051	1709.4	9.060	1658.3
5.195	1707.6	9.146	1657.0
5.302	1706.4	9.185	1656.5

Table I (Cont.)

Temperature °K	V(t) - V(273.16°K) μV	Temperature °K	V(t) - V(273.16°K) μV
9.302	1655.0	14.373	1585.6
9.387	1654.0	14.374	1585.6
9.393	1654.0	14.747	1580.3
9.447	1653.0	14.956	1577.2
9.540	1651.9	14.958	1577.8
9.615	1650.9	15.298	1572.8
9.618	1650.9	15.505	1569.6
9.701	1649.7	15.843	1564.6
9.746	1649.2	15.847	1564.7
9.848	1647.7	15.874	1564.7
9.902	1647.1	16.533	1556.1
9.969	1646.1	17.322	1545.2
10.053	1644.9	17.808	1538.6
10.113	1644.3	18.384	1530.5
10.114	1644.3	18.732	1525.7
10.189	1643.0	19.235	1518.9
10.277	1641.9	19.240	1518.9
10.331	1641.0		
10.392	1640.4		
10.559	1638.2		
10.744	1635.4	64.00	1021.6
11.014	1631.8	66.18	1004.5
11.229	1628.9	67.85	989.7
11.232	1628.9	70.19	970.4
11.464	1625.7	72.22	953.9
		74.60	934.8
11.695	1622.5	77.48	913.6
11.975	1618.5		
12.486	1611.6		
12.693	1608.8		
12.956	1605.1		
13.206	1601.6		
13.517	1597.4		
13.762	1593.9		
14.109	1589.2		
14.360	1585.5		