U. S. Department of Commerce National Bureau of Standards

RESEARCH PAPER RP1206

Part of Journal of Research of the National Bureau of Standards, Volume 22, May 1939

FURTHER DATA ON GOLD-CHROMIUM RESISTANCE WIRE

By Theodore B. Godfrey

ABSTRACT

By heat treatment, the temperature coefficient of electrical resistance of gold-chromium coils containing 2.1 percent of chromium can be made extremely small within the interval 18° to 35° C, and the resistance of such coils is extremely stable. Consequently, a resistance bridge made with gold-chromium coils and without temperature control should be fully as good as the customary bridge with manganin coils and thermostatic control. Data obtained during the construction and testing of four 10-ohm coils are given.

CONTENTS

I. INTRODUCTION

The gold-chromium resistance alloys investigated by Linde [1] and by Thomas [2] seem to be ideally suited for the construction of very precise electrical-measuring instruments, such as the bridges used in resistance thermometry. It seems probable that a bridge made with gold-chromium alloy coils and without temperature control should be fully as good as the customary bridge with manganin coils and thermostatic temperature control. Since several manufacturers of electrical instruments are interested in the use of this alloy, and as the available information concerning its treatment and properties is limited, it is thought that the data obtained during the construction and testing of four 10-ohm gold-chromium coils and the data on the stability of Thomas' coils over a period of years are of sufficient interest to warrant their publication.

II. CONSTRUCTION OF COILS

Thomas found that in the interval 20° to 30° C the resistivity of gold-chromium alloys as a function of temperature could be represented by equations of the type

$$\rho_t=\rho_{25}[1+\alpha(t-25)+\beta(t-25)^2].$$

[1] J. O. Linde, Ann. Physik **402,** 52 (1931); **407,** 219 (1932).
[2] J. L. Thomas, J. Research NBS **13,** 681 (1934) RP737.

Since his data indicate that for an alloy containing 2.1 percent of chromium, the value of β is zero and the value of α can be lowered to zero by heat treatment, alloy of this composition was chosen for the construction of the four coils. Each coil was wound with bare, hard-drawn wire 0.2 mm in diameter. The wire for coils 1 and 2 was drawn from larger wire obtained from Thomas, and the wire for coils 3 and 4 was drawn from a new melt. The coils were similar in construction to the National Bureau of Standards strain-free type of platinum resistance thermometers,[3] this construction being more convenient, with the materials and equipment immediately available, than the more conventional construction of resistance standards. The two mica side pieces, however, were omitted in the construction of coils 3 and 4, so that each turn of these two coils was supported at only two points. Two gold wires were welded to each end of each coil, making it a four-terminal resistor, and to the gold wires were welded the copper wires for the bridge connections. Both electrowelding and oxy-hydrogen welding were found satisfactory for these operations. After the coils were washed and dried, they were placed within Pyrex tubes. The four terminal wires of coils 1 and 2 were wedged fast by a cork inserted in the end of the tube. The lead wires of coils 3 and 4 were completely insulated by glass. Later, after the heat treatment, the tubes were evacuated, filled with dry air at atmospheric pressure, and sealed with wax.

III. HEAT TREATMENT

Prior to heat treatment, the value of the temperature coefficient of resistance, α, of coils 1 and 2, at room temperature was about $125\times10^{-6}/°C$, and of coils 3 and 4 about 93×10^{-6}.

Coils 1 and 2 initially were heated at 200° C, the heating being interrupted at various times for the purpose of observing the changes in the values of the α's. The values of the α's were derived from resistance measurements at 20° and 30° C and plotted as a function of the time of heating, as shown in figure 1. At first the values of the α's decreased rapidly, falling to about 20×10^{-6} in the first hour. Thereafter, the rate of decrease diminished progressively and eventually became so small that an attempt was made to increase the rate by heating at 250° C. Contrary to expectation, there resulted an increase in the value of α for one coil and no change in the value for the other. After further heating the coils at 200° C, both were again heated at 250° C, and in each case the value of α became more positive. Eventually the value of α for both coils was reduced to less than $0.1\times10^{-6}/°C$.

Relying upon the data obtained with coils 1 and 2, coil 3 was heated initially for 5 hours at 200° C, and the value of α was then found to have been reduced to -3×10^{-6}. Heating the coil at 250° C, instead of reversing the direction of change, made the coefficient fall to still more negative values. After it was found that immersing the coil in liquid air had no effect on the value of α, cold-working was attempted. The wire was held by tweezers at two points about 1 mm apart and bent back and forth several times. This treatment was repeated over the whole length of the wire. In this manner the value of α was brought to 0.2×10^{-6}. This change in the value of the coefficient in

[3] T. S. Sligh, Jr., BS Sci. Pap. 17, 49 (1922) S407; Beattie, Jacobus, and Gaines, Proc. Am. Acad. Arts Sci. 66, 167 (1930).

the positive direction as a result of cold-working is unusual, since for other metals and alloys cold-working generally results in an increase in resistivity, and a negative change in the coefficient.

Before starting the regular heat treatment, coil 4 was kept for some time in boiling water to remove the borax flux which had been used in welding, and was dried at 150° C. The total time required for this was about 4 hours. The value of the coefficient was then found to

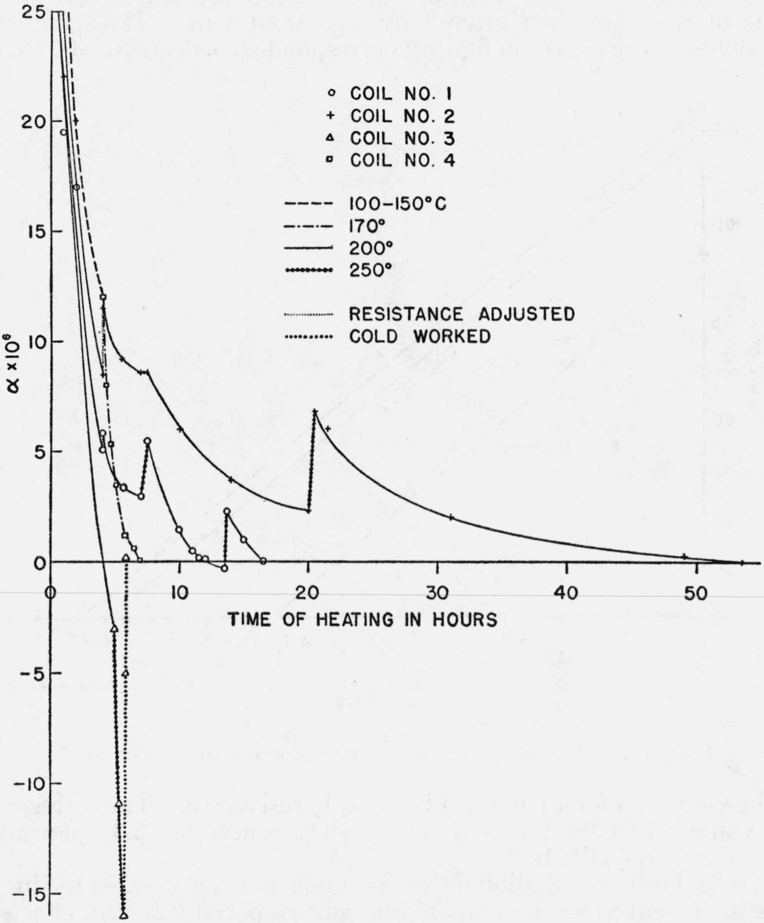

FIGURE 1.—*Changes in the temperature coefficient of resistance produced by heating.*

have dropped to 12×10^{-6}. Subsequent heating at 170° and 200° C quickly brought it to zero.

In the course of the heat treatment, resistance adjustments were made several times, either by shortening the coils at the lower end and welding the pieces together, or by scraping the wires at the upper ends of the coils. All such adjustments increased the value of α, although, except in two instances, the change was too small to be shown in figure 1.

As noted by Thomas, there is a linear relationship between the changes in the resistance of a gold-chromium coil at room temperature and the value of α during the heat treatment, the resistance increasing as the coefficient decreases, as shown for coils 1, 2, and 3 in figure 2. When coils 1 and 2 were heated at 250° C, the resulting unexpected increases in the value of α were accompanied by decreases in resistance consistent with this relationship, but when coil 3 was cold-worked, the relationship was not maintained, very probably because the dimensions of the wire were altered by this treatment. The average of the slopes of the curves in figure 2 corresponds to a decrease of 22×10^{-6}

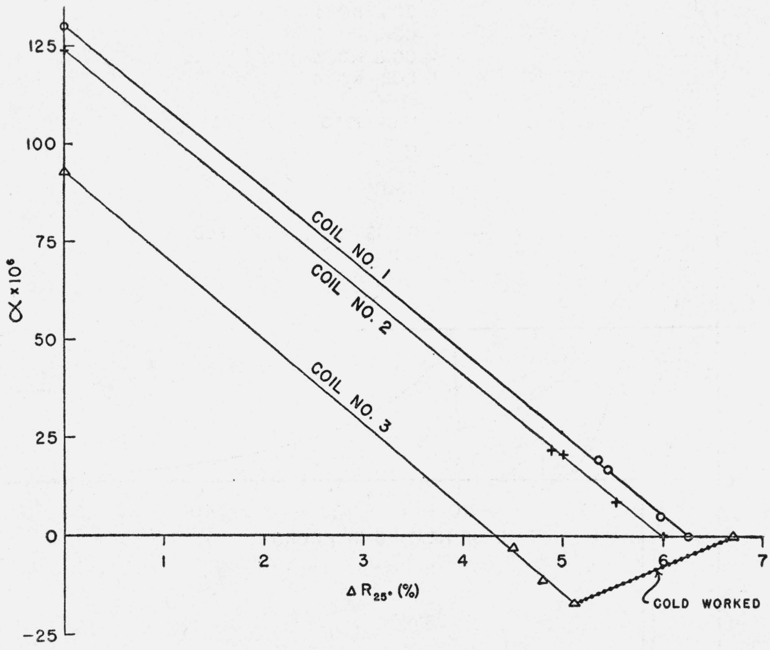

FIGURE 2.—*Linear relationship between a and resistance at 25° C.*

in the value of α for a 1-percent increase in resistance. The corresponding value found by Thomas, for an alloy containing 2.35 percent of chromium, was 26×10^{-6}.

It has been found difficult to account for the differences in the effects of heat treatment upon the coils, especially in the effects of heating at 250° C. At first it was thought that the increases in the value of α of coils 1 and 2 were caused in some way by strain in mounting, since when these coils were in place within their protecting tubes, the mica side pieces (omitted in the construction of coils 3 and 4) were forced toward the center by the glass, thus straining the wire. To test this possibility, the outer edges of the mica side pieces of coil 1 were sheared off so that they no longer pressed against the glass, and, in addition, were cut through radially every four or five turns. The coil was then replaced in its tube and heated at 250° C for 15 minutes. The value of α again increased as before (not shown in fig. 1), rising from 0 to 2.2×10^{-6}. Another coil of wire of the same lot, wound on a quartz tube, after heating at 200° C, also showed the increase in the value of α when heated at 250° C. Consequently, it seems that the effect is a characteristic of the wire obtained from the first melt and not a result of the method of mounting.

In this last experiment with coil 1, the heating at 250° C was continued for some time, to see whether the value of α would continue

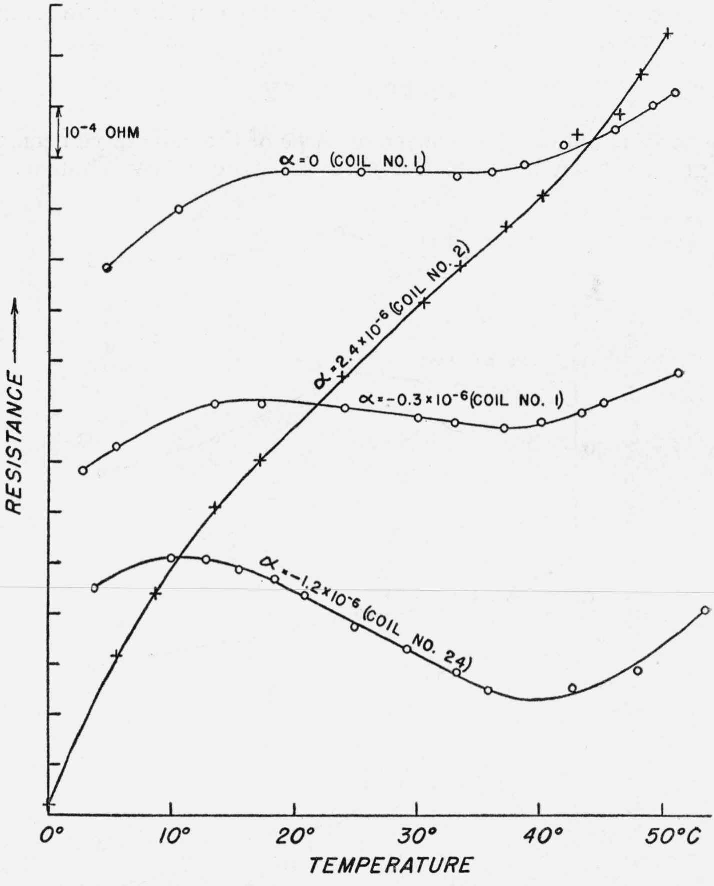

FIGURE 3.—*Resistance-temperature curves of 10-ohm coils at various stages of heat treatment.*

to increase. At the end of an hour, the value of α reached a maximum of 2.5×10^{-6} and then started to decrease at a rate which soon became comparable with the rate of decrease at 200° C.

IV. TEMPERATURE-RESISTANCE CURVES

At various times during the heat treatment and after its completion, measurements were made of the resistances of the four coils over a range of temperature extending from 0° to 50° C. Some of the results obtained are shown in figure 3, together with measurements on one of

Thomas' 10-ohm coils (coil 24). The curves all indicate that in this range of temperature an equation of the second degree is incapable of representing the resistance as a function of temperature, but that an equation of third or higher degree would be required. The values of α shown are the slopes of the straight parts of the curves. It will be noted that the range of temperature (18° to 35°C) in which the slope of the upper curve for coil 1 is not measurably different from zero includes the temperatures ordinarily prevailing in a laboratory, and that even outside of this range the slope of the curve as shown does not exceed 2×10^{-6}.

V. STABILITY

The early changes in resistance of three of the coils have been somewhat greater than those of the coils constructed by Thomas. The

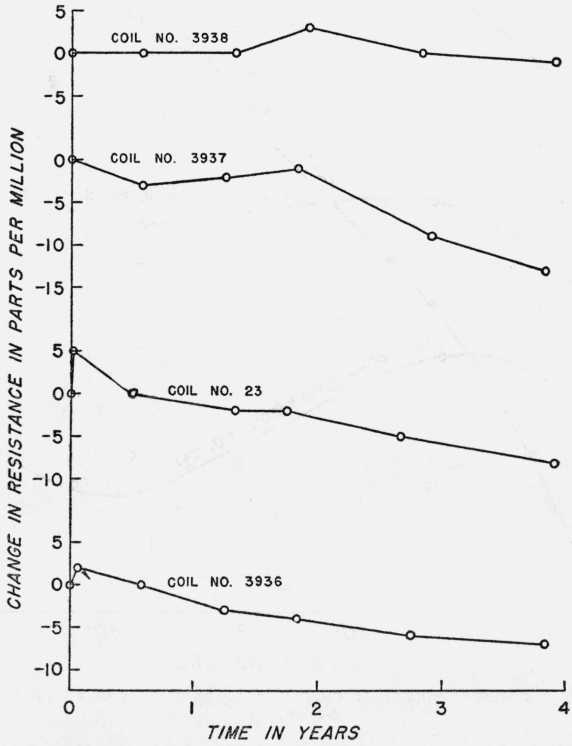

FIGURE 4.—*Resistance changes of four gold-chromium coils over a period of 4 years.*

resistance at room temperature of coil 1 has decreased 4 parts in a million in 2½ months; that of coil 2, after increasing 7 parts in a million in 45 days, has since remained constant for a month; that of coil 3 has increased 16 parts in a million in 3 months. Coil 4, however, in 3 months has shown no measurable change in resistance. This coil not only was mounted most nearly in a truly strain-free manner, but also was not subjected to cold working after mounting.

Thomas has kindly supplied later data on the changes in resistance of the gold-chromium coils for which resistance-time curves are shown in his figure 4.[4] These curves, extended to cover a period of 4 years, are shown in figure. 4 Coil 3938, which was originally the most stable of the four, has remained practically constant in resistance. The resistances of the others have decreased 5 or 10 parts in a million below their original values. These coils were mounted in salvaged oil-filled containers, and it is probable that moisture has entered some of the containers. Even so, the coils compare favorably in stability with well-made manganin coils of usual construction. As might be expected, in view of the relation, discussed above, between changes in resistance and changes in the value of the coefficient, there has been no measurable change in the temperature coefficients of resistance of any of these gold-chromium coils.

VI. PRESSURE COEFFICIENT OF RESISTANCE

The resistance of coil 1 was measured at pressures from 0 to 3 atmospheres. The pressure coefficient of resistance of this coil determined from these measurements was positive, as in the case of manganin, and small—the value obtained being 1.1×10^{-6} per atmosphere.

VII. CONCLUSIONS

Further investigation has confirmed Thomas' data showing that gold-chromium alloy containing 2.1 percent of chromium is well suited for the construction of the coils of precise electrical-measuring instruments. Although coils made of wire taken from different melts, and even coils made of wire from the same melt, have shown large differences in their response to heat treatment, it has been possible to make the temperature coefficient of resistance of any coil as low as desired in the range of temperature 18° to 35° C. Whereas heating a coil usually lowers the value of the coefficient, mechanical working raises it, and may be resorted to if a negative value of the coefficient has resulted from carrying the heat treatment too far. However, for highest stability of resistance, the results indicate that mechanical working as well as strain in mounting should be avoided.

The pressure coefficient of resistance of a gold-chromium coil was measured and found to be equal to 1.1×10^{-6} per atmosphere.

I am indebted to J. L. Thomas, J. R. Coe, Jr., and D. C. Ginnings for data on coils which they have constructed, and to E. F. Mueller for helpful discussion.

WASHINGTON, March 21, 1939.

[4] J. L. Thomas, J. Research NBS **13**, 681 (1934) RP737.