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# EFFECTS OF COLD WORKING ON SPECIFIC HEAT OF METALS*

BY

SHIGEKA NISHIOKA

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ABSTRACT

Effects of cold working on the specific heats of constantan, brass and copper have been studied experimentally. It has thus been shown that the effect could not be recognized for the above metals. The effects of cold working on specific resistance, density and thermal expansion have also been investigated for the same metals. Richarz's law as well as Geiss and Liempt's relation have been studied.

## 1. Introduction

A number of workers have investigated the effects of cold working on the specific heats of copper, nickel, lead, platinum, silver, iron and bronze. The results of these investigations may be summarized as follows:

(1) In many investigations (**1**, **2**, **3**) it was found that the specific heat was increased by nearly 1%. But in some investigations (**4**, **5**) the effect was found to be very small.

(2) The experimental error of these measurements was about 0.5% which is of nearly equal order to the effect of cold working. Therefore, in order to decide the matter, a more precise method must be used.

The object of the present investigation is to study the problem for the case of copper, constantan and brass by using a precise method which is reported in the writer's preceding paper. The principle of the method is that, if an electric current of intensity $I$ flows through a wire, the change occurs in length of the wire by Joule's heat, which determines the ratio $A$ of the linear expansion to the time, and the specific heat $c$ can be calculated by the formula:

$$c = \frac{I^2 r \alpha}{J \rho A}, \tag{1}$$

where $r$ and $\rho$ are the resistance and the mass per unit length of the wire respectively, $J$ the mechanical equivalent of heat and $\alpha$ the coefficient of linear expansion which is determined by another separate experiment.

## 2. Case of constantan

The specimen under test is of commercial constantan wire of about 2.64 mm in diameter, the constitution of which is Cu 57.5% and Ni 42.5%. Two kinds of specimen were prepared, namely, (1) three specimens of hard constantan, (2) three specimens of soft constantan which were annealed in vacuum for two hours at 1000° and then cooled

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down slowly to the room temperature. The measured values of density and specific resistance are given in Table I. The lengths, temperatures, heat quantities and electric resistance are expressed in centimeters, degrees, Centigrade, calories and ohm respectively.

TABLE I

| Specimen | | Density at 10° | | Specific resistance at 14.6° | |
|---|---|---|---|---|---|
| Hard | No. 1 | 8.884 | 8.878 | $5.052 \times 10^{-5}$ | $5.059 \times 10^{-5}$ |
| | No. 2 | 8.888 | | 5.058 | |
| | No. 3 | 8.861 | | 5.068 | |
| Soft | No. 4 | 8.901 | 8.899 | $4.903 \times 10^{-5}$ | $4.902 \times 10^{-5}$ |
| | No. 5 | 8.902 | | 4.900 | |
| | No. 6 | 8.894 | | 4.904 | |

As will readily be seen from the above table, the hard constantan is by 0.24% less than the soft one in density and by 3.2% larger in specific resistance.

The linear expansion of the specimen relative to that of fused silica, was determined by using a circular roller with a mirror over the range of temperature from 10° to 100°. The results are expressed by an equation:

$$l_\theta = l_0(1 + 13.94 \times 10^{-6}\theta + 5.2 \times 10^{-9}\theta^2), \qquad (2)$$

where $l_\theta$ and $l_0$ are the length of the wire at $\theta°$ and 0° respectively, while the linear expansion of fused silica itself is expressed by the following equation*:

$$l_\theta = l_0(1 + 0.38 \times 10^{-6}\theta + 1.4 \times 10^{-9}\theta^2). \qquad (3)$$

Thus, the linear expansion of hard constantan may be expressed as:

$$l_\theta = l_0(1 + 14.32 \times 10^{-6}\theta + 6.6 \times 10^{-9}\theta^2). \qquad (4)$$

The difference between the linear expansion of the hard constantan and that of soft one was determined directly by using a circular roller with a mirror. The results show that the expansion of the hard constantan is by 0.02% larger than that of the soft one, the error of this measurement being 0.04%.

The specific heat was determined with the formula (1). The results are given in Table II and summarized as follows:

Specific heat of hard constantan at 15°: $0.09768 \pm 0.00005$.
Specific heat of soft constantan at 15°: $0.09769 \pm 0.00005$.
Difference: 0.01%.

* The mean value of the results obtained by Chapieus (1903), Scheel (1907), Scheel and Heuse (1914), and Scheel (1921).

TABLE II

| Hard constantan | | | Soft constantan | | |
|---|---|---|---|---|---|
| Specimen | Temp. | Specific heat | Specimen | Temp. | Specific heat |
| No. 1 | 15.2 | 0.09736 | No. 4 | 13.7 | 0.09744 |
| | 14.2 | 9755 | | 16.5 | 9766 |
| | 15.4 | 9774 | | 13.7 | 9757 |
| | 14.6 | 9789 | | 16.1 | 9745 |
| | | | | 13.8 | 9732 |
| No. 2 | 15.6 | 9769 | No. 5 | 14.7 | 9736 |
| | 14.0 | 9765 | | 14.2 | 9772 |
| | 15.1 | 9766 | | 14.6 | 9743 |
| | 16.0 | 9804 | | 15.8 | 9773 |
| | 9.4 | 9719 | | 13.9 | 9795 |
| No. 3 | 18.4 | 9768 | No. 6 | 17.0 | 9812 |
| | 16.2 | 9788 | | 13.9 | 9760 |
| | 13.6 | 9739 | | 16.1 | 9819 |
| | 11.8 | 9789 | | 16.5 | 9805 |
| | | | | 9.9 | 9753 |
| Mean | 14.5 | 0.09766 | Mean | 14.7 | 0.09768 |

### 3. Case of brass

The specimen of hard brass wire of 5 mm in diameter was prepared by drawing, by which the cross-sectional area was reduced to 50% of its original value. The specimen of soft brass was prepared by annealing in vacuum for 30 minutes at 600°. The constitution was Cu 70% and Zn 30%. The specific resistance and density of the specimens are shown in Table III.

TABLE III

| Specimen | | Density at 22.5° | | Specific resistance at 28° | |
|---|---|---|---|---|---|
| Hard | No. 1 | 8.497 | 8.489 | $7.859 \times 10^{-6}$ | $7.853 \times 10^{-6}$ |
| | No. 2 | 8.489 | | 7.823 | |
| | No. 3 | 8.482 | | 7.876 | |
| Soft | No. 4 | 8.469 | 8.469 | $7.285 \times 10^{-6}$ | $7.302 \times 10^{-6}$ |
| | No. 5 | 8.465 | | 7.325 | |
| | Nc. 6 | 8.474 | | 7.296 | |

The experimental value of the linear expansion for hard brass was found to be expressed as follows:

$$l_\theta = l_0(1 + 17.99 \times 10^{-6}\theta + 7.0 \times 10^{-9}\theta^2).$$

The error of this measurement was 0.04%. The linear expansion of the hard brass was by 0.015% larger than that of the soft one, the error being 0.04%.

The specific heat was determined as in the case of constantan. The results are given in Table IV and summarized as follows:

Specific heat of hard brass at 23°: 0.09073 ± 0.00006.
Specific heat of soft brass at 23° : 0.09072 ± 0.00005.
Difference: 0.01 %.

TABLE IV

| Hard brass | | | Soft brass | | |
|---|---|---|---|---|---|
| Specimen | Temp. | Specific heat | Specimen | Temp. | Specific heat |
| No. 1 | 23.3° | 0.09072 | No. 4 | 23.5° | 0.09030 |
| | 24.4 | 9104 | | 21.9 | 9088 |
| | 22.9 | 9099 | | 22.9 | 9052 |
| | 22.9 | 9090 | | 24.9 | 9028 |
| | 23.8 | 9071 | | 23.4 | 9073 |
| No. 2 | 23.1 | 9056 | No. 5 | 22.6 | 9126 |
| | 21.6 | 9064 | | 22.6 | 9086 |
| | 22.3 | 9086 | | 23.6 | 9091 |
| | 24.3 | 9115 | | 23.1 | 9090 |
| | 24.7 | 9135 | | 23.5 | 9110 |
| No. 3 | 22.7 | 9065 | No. 6 | 23.7 | 9067 |
| | 23.3 | 9025 | | 22.3 | 9032 |
| | 23.2 | 9025 | | 22.7 | 9086 |
| | 22.4 | 9038 | | 23.0 | 9081 |
| | 23.6 | 9044 | | 24.5 | 9036 |
| Mean | 23.2 | 0.09073 | Mean | 23.2 | 0.09072 |

## 4. Case of copper

The electrolytic copper was used. The specimen of hard copper wire of 2.9 mm in diameter was prepared by drawing, by which the cross-sectional area was reduced to 50% of its original value. The specimen of the soft copper was prepared by annealing in vacuum for 30 minutes at 550°. The experiments were carried out when three months had passed after the preparation of the specimens. The specific resistance and density of the specimens are given in Table V below.

TABLE V

| Specimen | | Density at 24° | | Specific resistance at 26.9° | |
|---|---|---|---|---|---|
| Hard | No. 1 | 8.904 | 8.907 | $1.8143 \times 10^{-6}$ | $1.8142 \times 10^{-6}$ |
| | No. 2 | 8.909 | | 1.8144 | |
| | No. 3 | 8.909 | | 1.8138 | |
| Soft | No. 4 | 8.903 | 8.908 | $1.7814 \times 10^{-6}$ | $1.7803 \times 10^{-6}$ |
| | No. 5 | 8·910 | | 1.7786 | |
| | No. 6 | 8.910 | | 1.7810 | |

The experimental value of the linear expansion for the copper was found to be expressed as:

$$l_\theta = l_0(1 + 16.123 \times 10^{-6}\theta + 6.45 \times 10^{-9}\theta^2).$$

The error of this measurement was 0.04%. This linear expansion of the hard copper was by 0.09% larger than that of the soft one, the error being 0.02%.

The specific heat was determined as in the case of constantan. The results are given in Table VI and summarized as follows:

Specific heat of hard copper at 28.5°: 0.09184 ± 0.00004.

Specific heat of soft copper at 28.5° : 0.09188 ± 0.00004.

Difference: 0.04%.

TABLE VI

| Hard copper | | | Soft copper | | |
|---|---|---|---|---|---|
| Specimen | Temp. | Specific heat | Specimen | Temp. | Specific heat |
| No. 1 | 26.8° | 0.09165 | No. 4 | 26.9° | 0.09186 |
| | 26.3 | 9211 | | 26.3 | 9177 |
| | 28.8 | 9211 | | 28.0 | 9201 |
| | 27.8 | 9180 | | 28.9 | 9180 |
| | 30.4 | 9208 | | 30.5 | 9164 |
| | 30.9 | 9203 | | 30.5 | 9205 |
| No. 2 | 25.9 | 9150 | No. 5 | 26.7 | 9201 |
| | 25.9 | 9172 | | 26.8 | 9160 |
| | 27.5 | 9234 | | 27.4 | 9166 |
| | 28.5 | 9153 | | 28.2 | 9189 |
| | 31.0 | 9180 | | 31.6 | 9206 |
| | 31.1 | 9170 | | 31.3 | 9202 |
| No. 3 | 26.5 | 9203 | No. 6 | 26.1 | 9206 |
| | 26.9 | 9155 | | 26.7 | 9191 |
| | 28.0 | 9150 | | 28.2 | 9172 |
| | 28.8 | 9192 | | 29.0 | 9183 |
| | 32.0 | 9189 | | 31.1 | 9233 |
| | 30.4 | 9190 | | 30.2 | 9171 |
| Mean | 28.5 | 0.09184 | Mean | 28.6 | 0.09189 |

## 5. Summary

(1) The results for constantan, brass and copper are summarized in Table VII.

TABLE VII

| Substance | $\Delta r$ | $\Delta c$ | $\Delta \rho$ | $\Delta \alpha$ |
|---|---|---|---|---|
| Copper | 1.9 % | 0 | − 0.01 % | 0.09 % |
| Constantan | 3.2 | 0 | − 0.24 | 0 |
| Brass | 7.6 | 0 | 0.23 | 0 |

$\Delta r$, $\Delta c$, $\Delta \rho$ and $\Delta \alpha$ represent the increase of the specific resistance, the specific heat, the density and the linear expansion due to cold working respectively. The value of increase which is within the experimental error is denoted by zero.

It is well known that the electrical resistance is one of the physical properties which are remarkably affected by cold working and that the change of resistance generally increases as the degree of cold working. Hence the amount of $\Delta r$ in Table VII indicates the approximate degree of cold working.

TABLE VIII

| Experimenter | Kind of working | Increase of specific heat due to cold working |
|---|---|---|
| Regnault (6) | Hammering | 1.4 % |
| Kahlbaum, Roth & Siedler (4) | Hammering | very small |
| Gaudino (2) | Stretching | 1.5 % |
| Jaeger, Rosenbohm & Bottema (3) | Stretching | 1 % The effect decreases with the lapse of time and vanishes at last. |

(2) As will be seen evidently from Table VII, the changes of the specific heat for copper, constantan and brass are not larger than the experimental error. The results of investigations by other authors for copper are summarized in Table VIII for comparison. There are large discrepancies among the results. Regnault and Gaudino reported considerably large effects in comparison with that of Kahlbaum. It is not considered however that these discrepancies are attributable mainly to the kind and degree of working. The writer could not see the time-effect such as reported by Jaeger. The investigations for constantan and brass have never been published so far.

(3) Geiss and Liempt (7) deduced the following relation and verified its validity for nickel and tungsten:

$$c_k - c_r = \left(\frac{R_k}{R_r} - 1\right)\frac{c_0\beta}{\alpha},$$

where $c_k$ and $R_k$ are the specific heat and specific resistance for metals worked respectively, $c_r$ and $R_r$ are the specific heat and specific resistance of recrystallized metal, $c_0$ and $\beta$ the specific heat and temperature coefficient respectively for recrystallized metal at 0°, and $\alpha$ is the temperature coefficient of resistance. It is verified that this relation is not valid for copper, constantan and brass by adopting the values of $\Delta r$ and $\Delta c$ in Table VIII and the usual existing data of $\beta$ and $\alpha$.

(4) The fact that the specific heat of metals increases with decreasing amount of their density, is known as Richarz's law (9). Schlett (1) verified this relation experimentally using platinum and nickel. As will readily be seen from Table VII, this relation is not applicable to constantan and brass, however.

(5) Jubitz (9) reported that the coefficient of thermal expansion of metals belonging to cubic system is not affected by cold working. The results of the present experiment show that the results for constantan and brass are in good agreement with Jubitz's results, but in the case of copper there occurs an increase of about 0.1%, contrary to Jubitz's results.

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