EFFECTS OF COLD WORKING ON
SPECIFIC HEAT OF METALS*

BY

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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:

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

(1)

where r and ρ are the resistance and the mass per unit length of the wire respectively,
J the mechanical equivalent of heat and α 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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* Communicated by Professor S. Tomotika.

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.

<div align="center">TABLE I</div>

Specimen		Density at 10°	Specific resistance at 14.6°
Hard	No. 1	8.884 ⎫	5.052 × 10⁻⁵ ⎫
	No. 2	8.888 ⎬ 8.878	5.058 ⎬ 5.059 × 10⁻⁵
	No. 3	8.861 ⎭	5.068 ⎭
Soft	No. 4	8.901 ⎫	4.903 × 10⁻⁵ ⎫
	No. 5	8.902 ⎬ 8.899	4.900 ⎬ 4.902 × 10⁻⁵
	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:

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

where l_θ 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[*]:

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

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

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

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 ± 0.00005.
Specific heat of soft constantan at 15° : 0.09769 ± 0.00005.
Difference: 0.01%.

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[*] 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 ⎫	7.859 × 10⁻⁶ ⎫
	No. 2	8.489 ⎬ 8.489	7.823 ⎬ 7.853 × 10⁻⁶
	No. 3	8.482 ⎭	7.876 ⎭
Soft	No. 4	8.469 ⎫	7.285 × 10⁻⁶ ⎫
	No. 5	8.465 ⎬ 8.469	7.325 ⎬ 7.302 × 10⁻⁶
	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 × 10⁻⁶	1.8142 × 10⁻⁶
	No. 2	8.909		1.8144	
	No. 3	8.909		1.8138	
Soft	No. 4	8.903	8.908	1.7814 × 10⁻⁶	1.7803 × 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	$\varDelta r$	$\varDelta c$	$\varDelta \rho$	$\varDelta \alpha$
Copper	1.9 %	0	− 0.01 %	0.09 %
Constantan	3.2	0	− 0.24	0
Brass	7.6	0	0.23	0

$\varDelta r$, $\varDelta c$, $\varDelta \rho$ and $\varDelta \alpha$ 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 $\varDelta r$ 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 β the specific heat and temperature coefficient respectively for recrystallized metal at $0°$, and α 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 Δr and Δc in Table VIII and the usual existing data of β and α.

(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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