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THE HEAT CAPACITY OF TITANIUM FROM 15° TO 305° K

by

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TR 280-8

February 24, 1953

Technical Report

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## FOREWORD

This work was carried out at The Ohio State University Cryogenic Laboratory under contract with U.S. Navy, Office of Naval Research Contract Number N6ori-17, Task Order IV, ONR Project Number NR 058 039, with The Ohio State University Research Foundation. This report covers information obtained during the study entitled: "High Temperature Thermodynamics of Inorganic Substances." It represents the 8th Technical Report of this series.

Director - H.L. Johnston

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## ABSTRACT

The heat capacities of titanium have been measured in the temperature range  $15^{\circ}$  to  $305^{\circ}$  K, and the derived thermal functions have been calculated and tabulated at integral values of the temperature over this range. The entropy at  $298.16^{\circ}$  K is  $7.33 \pm 0.02$  e.u.

## INTRODUCTION

Low temperature heat capacity measurements on titanium have been made by Kelley<sup>2</sup> between  $53^{\circ}$  and  $295^{\circ}$  K, but his sample contained over 1% of impurities. The titanium used in the present research was of much greater purity than Kelley's, and hence the thermal data reported should be more accurate.

## APPARATUS AND MATERIALS

The sample of iodide-process titanium was generously donated by the New Jersey Zinc Co., Palmerton, Pa. The principal contaminants were 0.0082% Mn, 0.007% Si, and 0.0066% Al, with a total of 0.02% of N, Fe, Pb and Cu. The rough rod was cut into small pieces on a shaper and these pieces were annealed in a high vacuum at  $800^{\circ}$  C.

"Solid Calorimeter No. 3," one of the group of seven vacuum calorimeters described in the first paper of this series,<sup>1</sup> was used for the heat capacity measurements on 121.656 g (2.5481 g atoms) of titanium.

## EXPERIMENTAL RESULTS AND CALCULATIONS

The experimental heat capacity data are presented in Table I. These deviate from a smooth curve by an average 0.2 of 1%. Skinner<sup>3</sup> noticed that his data on zirconium were higher than Todd's data below  $130^{\circ}$  K and lower than Todd's data above  $130^{\circ}$  K. The discrepancy was attributed to oxygen in Todd's sample. The present data show a similar discrepancy with Kelley's data, the temperature of intersection of the two heat capacity curves being about  $180^{\circ}$  K, and again the reason seems to be due to the contaminants in Kelley's titanium.

The heat capacity and derived thermal functions for titanium at integral values of the temperature are presented in Table II. The entropy at  $298.16^{\circ}$  K is  $7.33 \pm 0.02$  e.u. of

which only 0.13 e.u. was obtained by extrapolation by the Debye  $T^3$  law. This compares with the value 7.24 e.u. obtained by Kelley.<sup>2</sup>

TABLE I

HEAT CAPACITY OF TITANIUM  
At Wt = 47.90 g      2.5481 g atoms

| Mean T<br>°K | C <sub>p</sub><br>cal/deg/g<br>atom | Mean T<br>°K | C <sub>p</sub><br>cal/deg/g<br>atom |
|--------------|-------------------------------------|--------------|-------------------------------------|
| 15.44        | 0.046                               | 94.76        | 3.252                               |
| 17.36        | .056                                | 104.49       | 3.583                               |
| 18.75        | .067                                | 114.76       | 3.887                               |
| 20.04        | .081                                | 127.07       | 4.215                               |
| 21.31        | .090                                | 137.63       | 4.439                               |
| 22.87        | .117                                | 148.70       | 4.654                               |
| 24.60        | .149                                | 160.37       | 4.855                               |
| 26.71        | .192                                | 172.74       | 5.020                               |
| 29.32        | .260                                | 185.70       | 5.161                               |
| 32.23        | .349                                | 198.46       | 5.305                               |
| 35.26        | .456                                | 212.40       | 5.427                               |
| 38.67        | .590                                | 215.29       | 5.466                               |
| 43.54        | .808                                | 224.52       | 5.536                               |
| 49.04        | 1.085                               | 234.03       | 5.602                               |
| 53.89        | 1.350                               | 248.05       | 5.682                               |
| 58.00        | 1.572                               | 259.30       | 5.768                               |
| 59.33        | 1.653                               | 271.73       | 5.865                               |
| 63.95        | 1.873                               | 283.32       | 5.913                               |
| 70.27        | 2.173                               | 293.57       | 5.950                               |
| 77.00        | 2.489                               | 299.58       | 5.958                               |
| 85.62        | 2.880                               | 305.51       | 6.005                               |

TABLE II

## THERMAL FUNCTIONS OF TITANIUM

| T, °K  | $C_p^0$<br>cal/deg/g<br>atom | $S^0$<br>cal/deg/g<br>atom | $H^0-H_0^0$<br>cal/deg/g<br>atom | $-(F^0-H_0^0)/T$<br>cal/deg/g<br>atom |
|--------|------------------------------|----------------------------|----------------------------------|---------------------------------------|
| 15     | 0.040                        | 0.013                      | 0.15                             | 0.003                                 |
| 25     | .157                         | .054                       | .94                              | .017                                  |
| 50     | 1.136                        | .414                       | 15.31                            | .108                                  |
| 75     | 2.402                        | 1.123                      | 50.1                             | .322                                  |
| 100    | 3.434                        | 1.963                      | 133.7                            | .626                                  |
| 125    | 4.155                        | 2.811                      | 229.0                            | .979                                  |
| 150    | 4.684                        | 3.652                      | 339.9                            | 1.386                                 |
| 175    | 5.043                        | 4.403                      | 461.9                            | 1.764                                 |
| 200    | 5.321                        | 5.095                      | 591.5                            | 2.137                                 |
| 225    | 5.539                        | 5.735                      | 727.3                            | 2.502                                 |
| 250    | 5.713                        | 6.328                      | 868.0                            | 2.856                                 |
| 275    | 5.864                        | 6.879                      | 1012.8                           | 3.196                                 |
| 298.16 | 5.976                        | 7.334                      | 1149.9                           | 3.478                                 |

#### REFERENCES

1. H.L. Johnston and E.C. Kerr, J. Am. Chem. Soc. 72, 4733 (1950).
2. K.K. Kelley, Ind. Eng. Chem. 36, 865 (1944).
3. G.B. Skinner and H.L. Johnston, J. Am. Chem. Soc. 73, 4549 (1951).
4. S.S. Todd, J. Am. Chem. Soc. 72, 2914 (1950).

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