

Lawrence Berkeley National Laboratory

Recent Work

Title

LOW-TEMPERATURE HEAT CAPACITIES OF DILUTE SOLUTIONS OF Fe IK Cu

Permalink

<https://escholarship.org/uc/item/3ms5d2mj>

Authors

Brock, J.C.F.

Ho, J.C.

Schwartz, G.P.

et al.

Publication Date

1968-08-01

UCRL-18385

cy. 2

RECEIVED
LAWRENCE
RADIATION LABORATORY

NOV 6 1968

LIBRARY AND
DOCUMENTS SECTION

University of California

Ernest O. Lawrence
Radiation Laboratory

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545*

LOW-TEMPERATURE HEAT CAPACITIES OF
DILUTE SOLUTIONS OF Fe IN Cu

J. C. F. Brock, J. C. Ho, G. P. Schwartz
and N. E. Phillips

August 1968

Berkeley, California

UCRL - 18385
cy. 2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Talk to be presented at the
11th International Conference on
Low Temperature Physics in St.
Andrews, Scotland, August 22-29, 1968.

UCRL-18385
Preprint

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California
AEC Contract No. W-7405-eng-48

LOW-TEMPERATURE HEAT CAPACITIES OF DILUTE SOLUTIONS OF Fe IN Cu

J. C. F. Brock, J. C. Ho, G. P. Schwartz
and N. E. Phillips

August 1968

LOW-TEMPERATURE HEAT CAPACITIES OF DILUTE SOLUTIONS OF Fe IN Cu.* J. C. F. Brock,[†] J. C. Ho,[‡] G. P. Schwartz, and N. E. Phillips. Inorganic Materials Research Division, Lawrence Radiation Laboratory, and Department of Chemistry, University of California, Berkeley, California 94720.

Most measurements of the heat capacities of dilute magnetic alloys have been interpreted in terms of the indirect (via the conduction electrons) exchange interaction between the magnetic ions. Overhauser⁽¹⁾ and Marshall⁽²⁾ have derived, from somewhat different models, similar expressions for the low-temperature heat capacity that predict a concentration-independent term proportional to temperature. Measurements on dilute Fe in Cu by Franck, Manchester and Martin⁽³⁾ above 0.4°K did not show this behavior but it was possible to extrapolate the data to 0°K in a way consistent with the predictions. More recently, experimental and theoretical evidence for the existence of a low-temperature spin-compensated state for isolated localized moments has been obtained,⁽⁴⁾ and expressions predicting concentration-proportional heat capacities varying (at temperatures well below the Kondo temperature, T_K) as T ,^(5,6) $T \ln T$,⁽⁷⁾ and $T^{1/2}$ ⁽⁸⁾ have been derived. Separation of the two heat capacity contributions (arising from interactions between magnetic ions and from the thermal break-up of the spin-compensated state) therefore require measurements over a wide range of concentrations. We report here

* Work supported by the United States Atomic Energy Commission.

† Present address: University of the Witwatersrand, Johannesburg, South Africa.

‡ Present address: Battelle Memorial Institute, Columbus, Ohio.

some preliminary results of new measurements on dilute solutions of Fe in Cu that cover concentration regions in which each contribution is expected to dominate the heat capacity.

The samples were prepared under vacuum in an induction furnace and chill-cast from the melt. Chemical analysis of portions from opposite ends of the samples and microprobe analysis failed to show any evidence of inhomogeneity or precipitation of the Fe. The 4.2-°K resistivity also suggests that the samples are uniform and free of effects of oxidation.

Heat capacity measurements have been made on 0.070, 0.13, 0.18, and 0.27 at% samples between $\approx 0.06^\circ\text{K}$ and 1°K , and on a

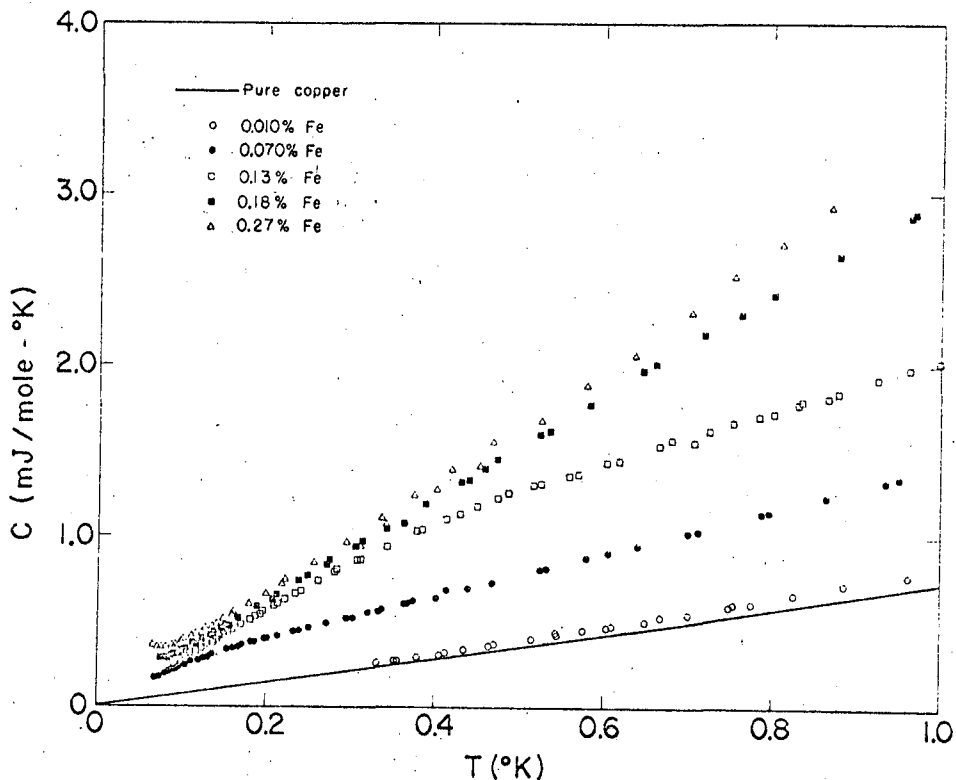


Fig. 1. The low-temperature heat capacities of dilute solutions of Fe in Cu.

0.01 at% sample between 0.3°K and 20°K. The results are shown in Fig. 1. At the lowest temperatures a small T^{-2} term, approximately proportional to concentration, is observed. For the 0.07 to 0.27 at% samples, subtraction of the T^{-2} term leaves a well-defined linear term extending to about 0.11°K for the 0.07 at% sample, and to higher temperatures for the others, in qualitative agreement with the extrapolations made by Franck *et al.*⁽³⁾ The linear term however is not concentration independent, but increases by about 40% as the concentration increases from 0.07 to 0.27 at%. This trend is similar to, but larger in magnitude than, that observed by Hill and Pickett⁽⁹⁾ at higher temperatures and

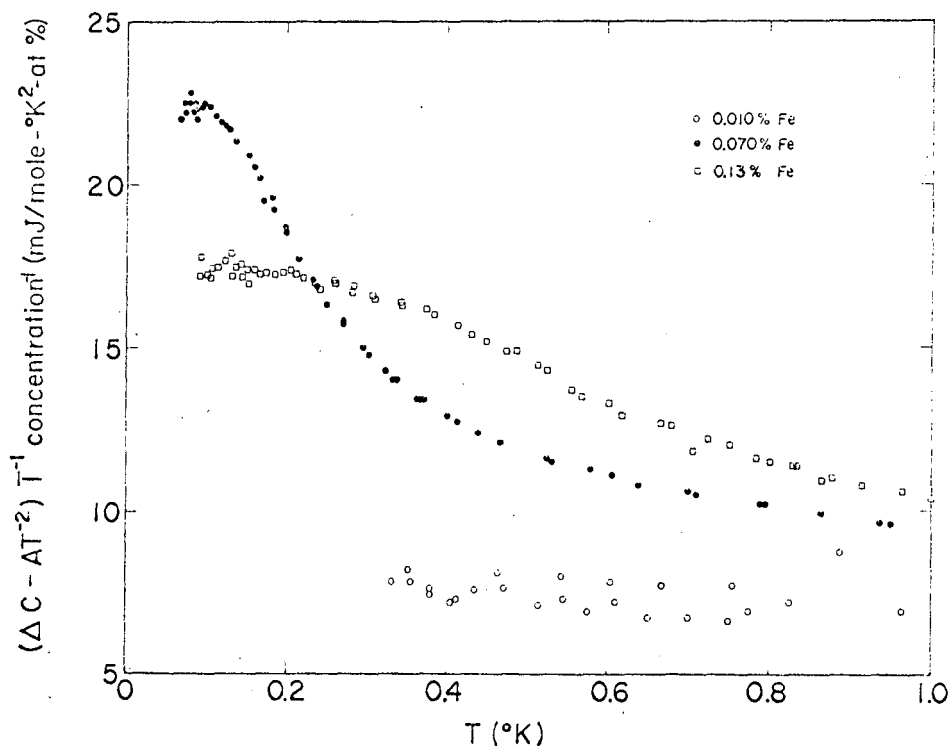


Fig. 2. The excess heat capacities of the dilute solutions (over that of pure copper) divided by T and by concentration.

concentrations. The decrease in the linear term with decreasing concentration may itself be a consequence of the occurrence of the spin compensated state, since the formation of this state, in the more dilute solutions, can be expected to reduce the interactions between the localized moments. At the higher temperatures and lower concentrations the heat capacity in excess of that of pure copper becomes more nearly proportional to concentration (see Fig. 2.), as suggested by the earlier work.⁽³⁾ The 0.010 at% sample does not appear to show the low-temperature rise in C/T associated with the "concentration-independent" interaction term, and the results for this sample may correspond to the concentration-proportional limit expected for the spin-compensated state. Further experiments are necessary to establish this definitely but it is already clear that in this limit C varies more rapidly than $T^{1/2}$, and may in fact be proportional to T or to $T \ln T$.

Daybell et al.,⁽¹⁰⁾ have recently reported measurements between 0.04 and 1°K on 0.011 and 0.038 at% samples, and interpret the results as showing a $T^{1/2}$ heat capacity for the spin-compensated state throughout this range. The 0.010 at% results reported here are more precise by a factor of 5 than their 0.011 at% results at comparable temperatures and, although they agree in magnitude, show that between 0.3 and 1°K C is varying much more nearly as T . Furthermore, the marked deviations from proportionality to concentration found in this work strongly suggest that the low-temperature upturn in C/T reported by Daybell et al., is associated with interactions between the Fe ions.

1. A. W. Overhauser, Phys. Rev. Letters 3, 414(1959); J. Phys. Chem. Solids 13, 71(1960).
2. W. Marshall, Phys. Rev. 118, 1519(1960).
3. J. P. Franck, F. D. Manchester, and D. L. Martin, Proc. Roy. Soc. A 263, 494(1961).
4. M. D. Daybell and W. A. Steyert, Rev. Mod. Phys. 40, 380(1968), have recently reviewed the work on the spin-compensated state and give references to the original publications.
5. Y. Nagaoka, Phys. Rev. 138, A1112 (1965).
6. A. P. Klein; Phys. Letters 26A, 57(1967).
7. J. A. Appelbaum and J. Kondo, Phys. Rev. Letters 19, 906(1967).
8. P. E. Bloomfield and D. R. Hamann, Phys. Rev. 164, 856(1967).
9. R. W. Hill and G. R. Pickett, Proceedings of the 10th International Conference on Low Temperature Physics, Moscow, 1966.
10. M. D. Daybell, W. F. Pratt, Jr., and W. A. Steyert, Phys. Rev. Letters, 21, 353(1968).

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.