

Lawrence Berkeley National Laboratory

Recent Work

Title

SUPERCONDUCTIVITY- OF CUBIC NIOBIUM CARBONTRIDES

Permalink

<https://escholarship.org/uc/item/2kq4p8w2>

Authors

Williams, M.W.

Rails, K.M.

Piclcus, M.R.

Publication Date

1966-05-01

University of California Ernest O. Lawrence Radiation Laboratory

SUPERCONDUCTIVITY OF CUBIC NIOBIUM CARBO-NITRIDES

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

Berkeley, California

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.

J. of the Physics and Chem. of Solids

UCRL-16872 Rev.

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

SUPERCONDUCTIVITY OF CUBIC NIOBIUM CARBO-NITRIDES

M.W. Williams, K.M. Ralls, and M. R. Pickus

September 1966

SUPERCONDUCTIVITY OF CUBIC NIOBIUM CARBO-NITRIDES

M.W. Williams, K.M. Ralls and M.R. Pickus*

Inorganic Materials Research Division, Lawrence Radiation Laboratory
Department of Mineral Technology, College of Engineering
University of California, Berkeley, California

ABSTRACT

An investigation has been made of the superconductive properties of the niobium-carbon-nitrogen ternary system. These compounds always have a range of composition, and previous investigators have often neglected the effect of stoichiometry. Both critical temperature (T_c) and upper critical field (H_{c2}) are dependent on composition, although not in the same way. The trend of H_{c2} at 4.2°K with decreasing nitrogen content is always down. The maximum T_c (17.8°K) occurs for nearly stoichiometric compounds having a C/Nb ratio of about 0.3. The critical temperature of substoichiometric NbN, which contains a small amount of carbon rather than the more common impurity oxygen, is 17.2-17.3°K.

* Department of Mechanical Engineering, University of California, Berkeley, California

INTRODUCTION

Cubic niobium carbo-nitrides have been of interest recently because of their high critical temperatures and magnetic fields. A maximum critical temperature of 17.8°K has been reported for a composition of 25 to 30 mol.%NbC in the NbC-NbN pseudo-binary system.^{1,2,3,4} A maximum critical field of 120 kG has been observed at somewhat lower NbC content.²

The transition metal-interstitial compounds are somewhat difficult to study because variations from stoichiometric compositions often strongly affect the superconductive properties. For instance, NbC and TaC exhibit a sharp decrease in critical temperature with departure from stoichiometry.⁵ These compounds always have a range of homogeneity, which has led to ambiguous results in many previous studies.

In our investigation of the niobium-carbon-nitrogen ternary system, a primary objective was control of composition. A careful preparative technique and thorough investigations of the specimens by x-ray diffraction and chemical analyses have made possible a clearer description of superconductive properties in this ternary system.

The maximum T_c (17.8°K) was found for compositions near 30% NbC in NbN, in agreement with previous studies. H_{c2} was found always to decrease with decreasing nitrogen content (either due to departure from stoichiometry or to substitution of carbon for nitrogen). The maximum critical field (132 kG) found in our investigation is the highest yet reported for this ternary system.

PREPARATION PROCEDURE

Powders of Nb^{*} and NbC[†] were weighed to give nominal compositions of Nb, NbC_{.2}, NbC_{.3}, and NbC_{.5} and were dry mixed by tumbling. These powders were coated with polystyrene and extruded as 1/8 in. rods which were broken into 2 in. lengths. The firing procedure was designed to vaporize the styrene and to sinter the rods to a porous mixture of Nb and Nb₂C.⁶

The nitriding reaction was carried out at temperatures of 1280, 1360, or 1470°C, at pressures of 1, 10, 100, 760 or 7600 torr for either 4 or 8 hours. The nitriding procedure, described in more detail elsewhere,⁷ tended to minimize oxygen contamination but could have permitted a change in the carbon content during firing. To prevent nitrogen loss, vacuum sintering of the nitrided specimens was avoided.

COMPOSITIONS

The nitrogen content of the samples was determined from the weight gain of the specimens during nitriding. The carbon content was determined by the amount of NbC in the mixed powders before extrusion. The NbC had a lattice parameter of $4.4700\text{\AA} \pm 0.0005$, corresponding to a composition slightly under stoichiometry.⁸ The initial carbon contents were therefore somewhat below the nominal starting compositions.

As a check on both the carbon and nitrogen contents, several samples were analyzed chemically. The results of the analyses of the sintered but not nitrided compositions (Table I) indicated that the nominally pure niobium had gained approximately 2 at.% carbon during the processing prior to the nitriding treatment, while the other three compositions had lower

* 99.9%, -325 mesh Nb powder from Kaweck Chemical Company, Boyertown, Pa.

† 99.9%, -325 mesh NbC powder from Fansteel Metallurgical Corp., North Chicago, Illinois.

carbon contents than their starting compositions. A metallographic study of the sintered niobium revealed a small amount (~6 vol.%) of uniformly distributed, discontinuous second phase, most likely Nb₂C.

A set of four nitrided samples of different carbon compositions was analyzed for carbon, nitrogen, and oxygen (Table II). The carbon and oxygen contents were nearly the same as the amounts in the sintered but not nitrided samples. The nitrogen contents, however, were not in agreement with weight gain data. As a further check, two pairs of identical samples were analyzed (Table III). In these samples the carbon and oxygen analyses were consistent, while the nitrogen analyses disagreed by as much as 20%.

Because of the disparity in the results of the nitrogen analyses, the weight gain was taken as representative of the bulk composition. The carbon contents of Table I were assumed to be correct and not changed during the nitriding reaction.

Two nitrides prepared at 10 atm were also analyzed and were found to be somewhat contaminated by oxygen (on the order of 0.2 to 0.3 wt.%, i.e., about 1 at.%). A higher oxygen content was to be expected in samples prepared at higher pressures since there was more oxygen available in the atmosphere surrounding the samples. This higher oxygen content was taken into account in the consideration of the physical properties of these samples.

As expected, the nitrogen content increased with nitriding pressure, but was not appreciably affected by the nitriding time. This fact implies that at least a gas-solid equilibrium was obtained, although there is the possibility that complete homogeneity was not reached in the solid.

In almost all cases, the greatest amount of nitrogen was gained at 1280°C (Fig. 1) and the smallest amount at 1470°C. Although there are not

constant pressure, the trend does indicate that the departure of the nitrogen content from ideal stoichiometry becomes significant at the temperatures studied in this investigation.

X-RAY RESULTS

Powder patterns of all samples were taken on a Picker diffractometer with nickel filtered copper radiation ($\lambda_{\text{CuK}\alpha_1} = 1.54051\text{\AA}$). The predominantly cubic niobium nitrides were also checked by the Debye-Scherrer technique for a more precise lattice parameter determination.

The specimens prepared at either 760 or 7600 torr were almost always cubic. In only two of the samples (nitrides prepared at 760 torr and 1470°C) was there any indication of a second phase. This second phase was also cubic but with a lattice parameter of 4.45, indicating it might be $\text{Nb}(\text{C},\text{N})$. At 100 torr the samples with intermediate carbon content ($\text{C}/\text{Nb} = 0.2$ or 0.3) contained significant amounts of two cubic phases with lattice parameters near 4.39 and 4.42\AA . The specimen with the highest carbon content ($\text{C}/\text{Nb} = 0.5$) contained only one cubic phase. At 10 torr, the tetragonal nitride " Nb_4N_3 " was a significant phase.⁹ At 1 torr the hexagonal phase $\text{Nb}_2(\text{C},\text{N})$ predominated.

CRITICAL TEMPERATURES

Critical temperatures were measured by the technique of Merriam and Von Herzen.¹⁰ Many transitions, particularly those above 17°K , took place over 0.1 or 0.2°K . In some transitions, there was a "low-temperature tail" characteristic of these compounds, but in general the transitions were quite sharp.

Our results for the samples prepared at 760 torr (Fig. 2b) are generally in agreement with those of Pessall et al.,^{2,3} except for the

critical temperature of NbN. Our results indicate a higher critical temperature for NbN than previously reported.

The dependence of T_c on C/Nb ratio is similar for samples prepared at the three highest nitriding pressures. The broad maximum in critical temperature near 30% NbC has been confirmed for three different nitriding pressures. Whereas slightly different T_c values resulted for the different nitriding temperatures, the spread of T_c midpoints for specimens with constant C/Nb was usually less than 0.4°K for 760 torr and for 7600 torr in spite of the apparent differences in nitrogen content (Fig. 1a,b,c,d). For 100 torr the specimens nitrided at 1360°C had the highest critical temperatures and those nitrided at 1470°C had the lowest critical temperatures, although the spread in midpoints was usually less than 0.6°K for specimens with constant C/Nb. Therefore, for clarity in the figures, the critical temperature data presented (Figs. 2a,b,c and 3a,b,c,d) are averaged over the three nitriding temperatures. It should be pointed out that the total interstitial contents of samples of all four carbon compositions were approximately the same for samples prepared at constant pressures of 100, 760, or 7600 torr (Fig. 1a,b,c,d). Figures 2a,b,c therefore approximate constant stoichiometry plots.

All critical temperatures of the cubic samples near stoichiometry were near 17 to 17.8°K. All three of the nominally pure nitrides prepared at 7600 torr had lower values of T_c than those prepared at 760 torr (Fig. 3a). These lower transitions could have been due in part to the oxygen contamination of the 7600 torr specimens.

The effect of pressure on the carbo-nitrides was less pronounced (Fig. 3b,c,d). While the T_c of the nitride prepared at 7600 torr was lower than that of the nitride prepared at 760 torr, the critical temperatures of the samples with C/Nb = 0.2 prepared at those two pressures were

essentially the same; the other two compositions, showed a higher transition temperature in samples nitrided at the higher pressure.

CRITICAL MAGNETIC FIELDS

Critical fields (H_{c2}) at 4.2°K were measured by a pulsed field magnetization technique.¹¹ As a check, a few transitions were measured by resistive methods. The results agreed within 2-3%.

The variation of H_{c2} with nitriding pressure was different from the trend of T_c in that the critical field always increased as the nitriding pressure increased (Fig. 3a,b,c,d). Even in the cases in which the transition temperature began to decrease with increasing pressure, the critical magnetic field continued to increase.

As a function of carbon content, H_{c2} showed a different trend than had been found by other investigators. At all pressures, except 10 torr, the pure nitride possessed the highest critical field. The trend in critical field was downward with increasing carbon content (Fig. 4a,b,c). The highest critical field found in this investigation was 132 kG for the nitride fired at 1280°C at 7600 torr for 4 hrs.

It should perhaps be mentioned that the critical fields of our specimens nitrided at 760 torr generally agree quite well with the fields reported by Pessall et al.² The exception is the critical magnetic field of the pure nitride. We believe that the critical field of NbN is 118-132 kG, and is therefore the highest in the ternary system. We therefore contend that there is no maximum critical field at an intermediate composition in the NbC-NbN pseudo-binary system.

DISCUSSION

There are two possible explanations for the existence of two phases in the low stoichiometry portion of the cubic solid solution range: an equilibrium miscibility gap or a non-equilibrium situation in the solid. Since the starting material for the intermediate carbon contents was a mixture of Nb and Nb₂C, the final result after nitriding could be a mixture of phases with compositions near NbN and NbC_{0.5}N_{0.5}. If there had not been enough time for diffusion to occur, these phases would remain unmixed.

An isothermal diagram (Fig. 5) indicates that only the samples prepared at low nitrogen pressures are in nonequilibrium states. It is not possible to draw an equilibrium phase diagram with the points as shown in Fig. 5. The three phase field¹² which must exist between the two cubic phase region and the cubic plus tetragonal region did not appear in any of our samples and cannot be drawn on the diagram in conformation with the thermodynamic requirements of such a field. Because the x-ray patterns did indicate a single phase in the samples prepared at higher pressures, we believe that these samples are near equilibrium.

In the presentation of our data, the bulk composition of the samples based on weight gain has been used. This composition is somewhat ambiguous in samples containing more than one phase, but we do consider it a representation accurate enough to indicate trends in the data. A better parameter than composition might be the lattice parameter. In the event of inhomogeneity in the specimen, the x-ray data would reflect the most abundant phase while the superconducting transitions would tend to show all compositions, weighting the size of the transition signal according to the volume of the phases. Indeed, two transitions did appear in some

samples containing two phases. Since the lattice parameter can be varied either by stoichiometry or by carbon content, there is no accurate way to determine the composition of a cubic phase coexisting with another phase solely on the basis of lattice parameter. Furthermore, since the samples prepared at or above 100 torr are largely single phase, we consider the weight gain to be a reasonably accurate parameter on which to base our discussion.

One of the important parameters considered in connection with superconductivity is the ratio of electrons per atom. One critical value is generally taken to be about 4.75. Since these non-stoichiometric compounds have many vacant interstitial sites which do not contribute electrons, the ratio used for these samples was electrons per niobium atom. This ratio changes with stoichiometry and is equal to twice the value of electrons per atomic site based on two atomic sites per formula NbC_xN_y . The choice of this parameter is based on the hypothesis that the fcc niobium d-band is of primary importance in determining the superconducting properties of the niobium carbo-nitrides. It should be noted, however, that Geballe et al. have recently proposed that these materials are sp-band superconductors with strong electron-phonon coupling.¹³

Figures 6a,b,c,d, show critical temperature as a function of electrons per atom based on the bulk composition. The NbN shows a broad maximum in T_c at 9.5-9.9 valence electrons per niobium atom.* The decrease of T_c (Fig. 6a) for higher values of C/Nb is probably due to the higher oxygen contents for the NbN specimens prepared at 7600 torr. Nevertheless, when data existing in the literature are considered in addition to these

* cf. ref. 7. Compositions determined from lattice parameter data for NbN give the maximum T_c at about $NbN_{0.95}$ - $NbN_{0.96}$, 9.65-9.8 valence electrons per niobium atom.

data presented here, it appears that the decrease of T_c is real.⁷ The carbon-containing specimens also show broad maxima in T_c with valence electrons per niobium atom (Figs. 6b,c,d); however, there is almost no indication of decreasing T_c at higher values of C/Nb. This may be due to the limited range of composition attained here since few carbo-nitride samples approached ideal stoichiometry. Although there is considerable overlap of e/Nb for the T_c maxima, they are so broad and indefinite that it is impossible to say they occur at the same e/Nb value. Furthermore, reduction of the data in Fig. 6a,b,c,d to a single master curve is not possible. This is reasonable in view of the clearly established importance of the effect of lattice dilatation.¹⁴

Whereas e/Nb does not uniquely determine T_c , it does appear that increasing e/Nb through nitriding at pressures higher than 7600 torr will raise T_c further for three of the carbon contents reported here (Fig. 3b,c,d).

It may be noted that the dependence of T_c on both pressure and carbon content is somewhat different from the behavior of H_{c2} . Once the crystal structure is predominantly cubic ($\log P$ (torr) ≥ 2) the variation in T_c is proportionately less than that of H_{c2} . H_{c2} decreases quite rapidly either with decreasing N/Nb and constant carbon content or with increasing C/Nb for constant nitriding pressure. Furthermore, the optimum composition for high critical fields is near the stoichiometric nitride rather than the carbo-nitrides which have the highest critical temperature.

H_{c2} can be described in terms of the product of electronic specific heat coefficient (γ), critical temperature, and normal resistivity (ρ_n). T_c increases slightly with increasing carbon content at constant nitriding pressure. This fact implies that the product $\rho_n \gamma$ must be decreasing as

carbon content increases. Because of the unfavorable sample shape (1/8" dia. by 1" length) and unknown effective cross sections no resistivity measurements were made. Nevertheless the high H_{c2} for NbN prepared at 7600 torr (Fig. 4c) is probably related to a high value of ρ_n due to the oxygen content.

There are indications based largely on empirical correlations that the density of states (and consequently, γ) decreases between the compositions NbN and NbC.¹⁵⁻¹⁷ Extensive measurements of the electronic specific heat in this ternary system have not been made. Therefore, any attempt to describe the variation in critical field with composition in terms of γ and ρ_n would be highly speculative. Recent experimental determinations of γ for a few niobium nitrides, niobium carbides and a niobium carbo-nitride gave surprisingly low values which did not vary in the same sense as T_c/θ_D .¹³ If cubic niobium carbo-nitrides are strong coupling superconductors,¹³ then the dependence of H_{c2} upon γ , ρ_n and T_c cannot be specified.

CONCLUSIONS

Critical temperatures and upper critical fields for cubic niobium carbo-nitrides both depend upon composition whether it is varied by substitution of carbon for nitrogen or by deviation from stoichiometry. The variation of H_{c2} with composition is not identical to that of T_c . The maximum critical temperature (17.8°K) occurs for nearly stoichiometric carbo-nitrides with C/Nb \approx 0.5, although niobium nitride (containing C/Nb = 0.026 and O/Nb = 0.002) prepared at 760 torr has a critical temperature nearly as high (17.2-17.3°K). The maximum critical fields at 4.2°K (118-132 kG) occur for niobium nitride prepared at 760-7600 torr. Whereas the higher value of H_{c2} may be attributed to slight oxygen

contamination, the 118 kG value resulted for niobium nitride containing a very low oxygen content ($O/Nb \approx 0.001$). We therefore believe that the optimum composition for a high H_{c2} is the "pure" niobium nitride and that any departure from this composition will result in a lowering of the critical field.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to Prof. Mark R. Parker and Prof. Victor F. Zackay for their interest in this investigation, and to Mr. Masaki Suenaga for his assistance in the critical field measurements.

This work was performed under the auspices of the United States Atomic Energy Commission.

REFERENCES

1. Matthias, B. T., Phys. Rev., 92, 874 (1953).
2. Pessall, N., C. K. Jones, H. A. Johansen, and J. K. Hulm, Appl. Phys. Letters, 7, 38 (1965).
3. Pessall, N., C. K. Jones, and H. A. Johansen, Westinghouse Research Laboratories, Res. Sci. Paper 65-9J00-HITRA-P2. Presented at International Symposium on Magnet Technology at Stanford University, September 1965.
4. Darnell, F. J., P. E. Burstedt, W. O. Forschey, and R. K. Waring, Jr., Phys. Rev., 140, A1581 (1965).
5. Giorgi, A. L., E. G. Szklarz, E. K. Storms, A. L. Bowman, and B. T. Matthias, Phys. Rev., 125, 837 (1962).
6. Pickus, M. R., and M. Wells, Powder Metallurgy 8, 351 (1965).
7. Williams, M. W., K. M. Ralls, M. R. Pickus (to be published).
8. Kempter, C. P., E. K. Storms, and R. J. Fries, J. Chem. Phys., 33, 1873 (1960).
9. Brauer, G., and R. Esselborn, Z. Anorg. Allgem. Chem., 309, 151 (1961).
10. Merriam, M. F., and M. Von Herzen, Phys. Rev., 131, 637 (1963).
11. Suenaga, M., and K. M. Ralls (J. Appl. Phys.).
12. Brauer, G., and R. Lesser, Z. Metall., 50, 482 (1959).
13. Geballe, T. H., B. T. Matthias, J. P. Remeika, A. M. Clogston, V. B. Compton, J. P. Maita, and H. J. Williams, Physics 2, 293 (1966).
14. Pessall, N. and J. K. Hulm, Physics 2, 311 (1966).
15. Toth, L. E., V. F. Zackay, M. Wells, J. Olson, and E. R. Parker, Acta Met., 13, 379 (1965).
16. Dempsey, E., Phil. Mag., 8, 285 (1963).
17. Bilz, H., Z. Physik, 153, 338 (1958).

Table I Analyzed Compositions Before Nitriding*

Nominal Composition	Nb	NbC _{.2}	NbC _{.3}	NbC _{.5}
C (wt.%)	.34	2.3	3.5	5.7
O (wt.%)	<.001	.018	.020	.015
(C/Nb)	.026	.183	.280	.466

*

Performed by Anamet Laboratories, Berkeley, California. Carbon determined by combustion; oxygen determined by vacuum fusion.

Table II Analyzed Compositions After Nitriding
1360°C, 4 hrs, 760 torr*

Nominal Composition	NbN	NbN _{.8} C _{.2}	NbN _{.7} C _{.3}	NbN _{.5} C _{.5}
C (wt.%)	.266	2.28	3.26	5.73
N (wt.%)	12.76	9.67	7.76	5.10
O (wt.%)	.031	<.005	<.005	<.005
Formula based on analysis	NbN _{.969} C _{.023}	NbN _{.726} C _{.200}	NbN _{.576} C _{.281}	NbN _{.379} C _{.511}
Formula based on carbon analysis and weight gain	NbN _{.919} C _{.026}	NbN _{.745} C _{.183}	NbN _{.657} C _{.280}	NbN _{.466} C _{.466}

*

Performed by Oak Ridge National Laboratories; nitrogen and oxygen determined by vacuum fusion.

Table III Analyzed Compositions of Identical Samples*

Nitriding Conditions	Sample Number	C (wt.%)	N ₂ (wt.%)	O ₂ (wt.%)
1280°C, 100 torr 8 hrs.	1	0.28%±.015	11.4%±.5	0.030%±.005
1280°C, 100 torr 8 hrs.	2	0.30%	12.4%	0.024%
1280°C, 10 torr 4 hrs.	3	0.59%	12.6%	0.096
1280°C, 10 torr 4 hrs.	4	0.58%	10.5%	0.086%

* Performed by Anamet Laboratories, Berkeley, California.
Carbon determined by combustion.
Oxygen and nitrogen determined by vacuum fusion.

FIGURE CAPTIONS

- Fig. 1 The dependence of nitrogen to niobium atomic ratio on nitriding pressure for four different carbon contents. a) C/Nb = 0; b) C/Nb = 0.2; c) C/Nb = 0.3; d) C/Nb = 0.5.
- Fig. 2 The variation of critical temperature (T_c) with carbon content at constant nitriding pressure. a) P = 100 torr; b) P = 760 torr; c) P = 7600 torr. \circ Present investigation; \square Pessall et al.
- Fig. 3 The variation of critical temperature (T_c) and critical magnetic field (H_{c2}) at 4.2°K with nitriding pressure. a) C/Nb = 0; b) C/Nb = 0.2; c) C/Nb = 0.3; d) C/Nb = 0.5.
- Fig. 4 The variation of critical field (H_{c2}) at 4.2°K with carbon content at constant nitriding pressures. a) P = 100 torr; b) P = 760 torr, c) P = 7600 torr. \circ Present investigation; \square Pessall et al.
- Fig. 5 Isothermal section (1470°C) showing compositions and phases found in this investigation. \square cubic; Δ tetragonal; \circ hexagonal; \square 2 cubic; Δ tetragonal and cubic; \circ hexagonal and cubic.
- Fig. 6 The dependence of critical temperature (T_c) on electrons per niobium atom. a) C/Nb = 0; b) C/Nb = 0.2; c) C/Nb = 0.3; d) C/Nb = 0.5.

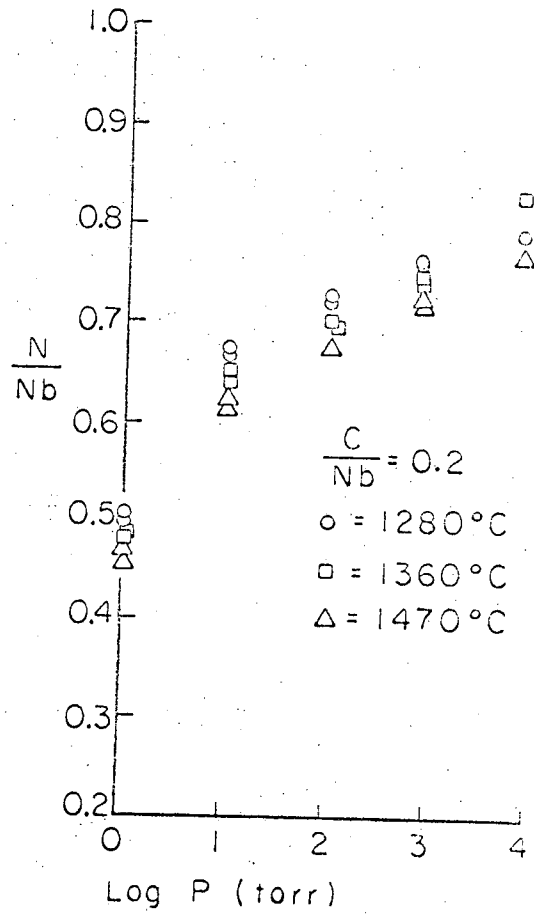
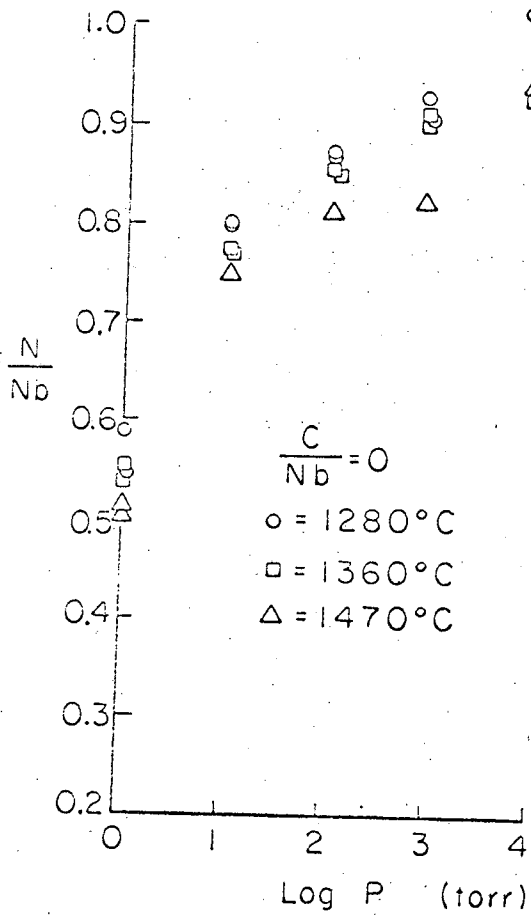


Fig. 1 (a,b)

MUB-10010

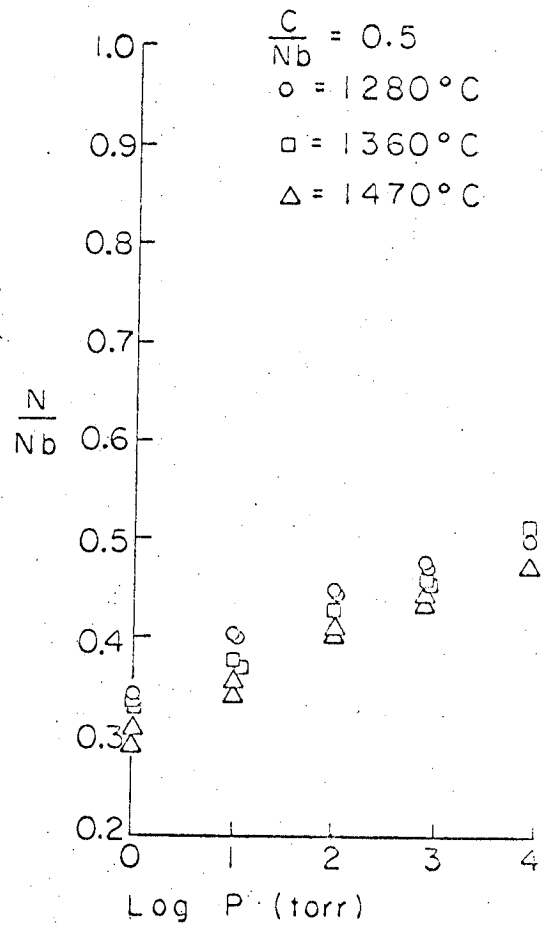
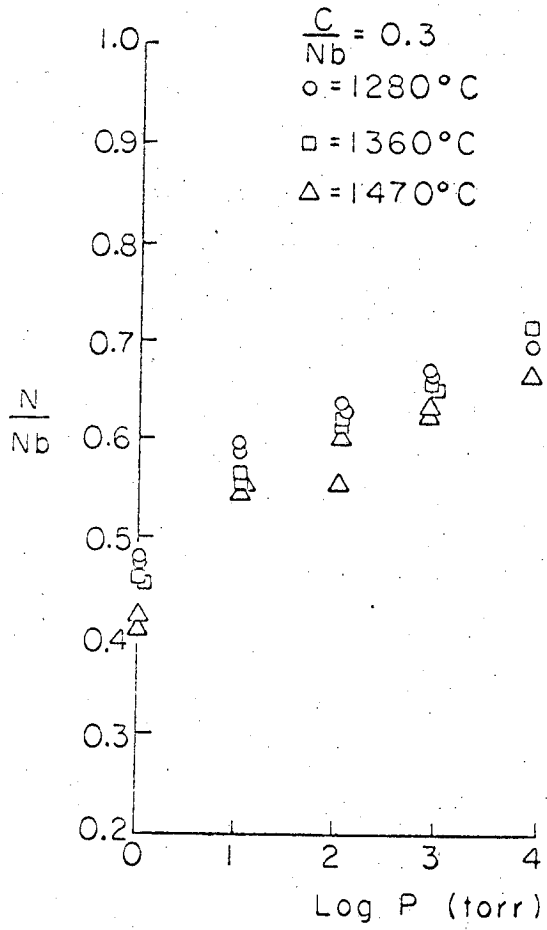
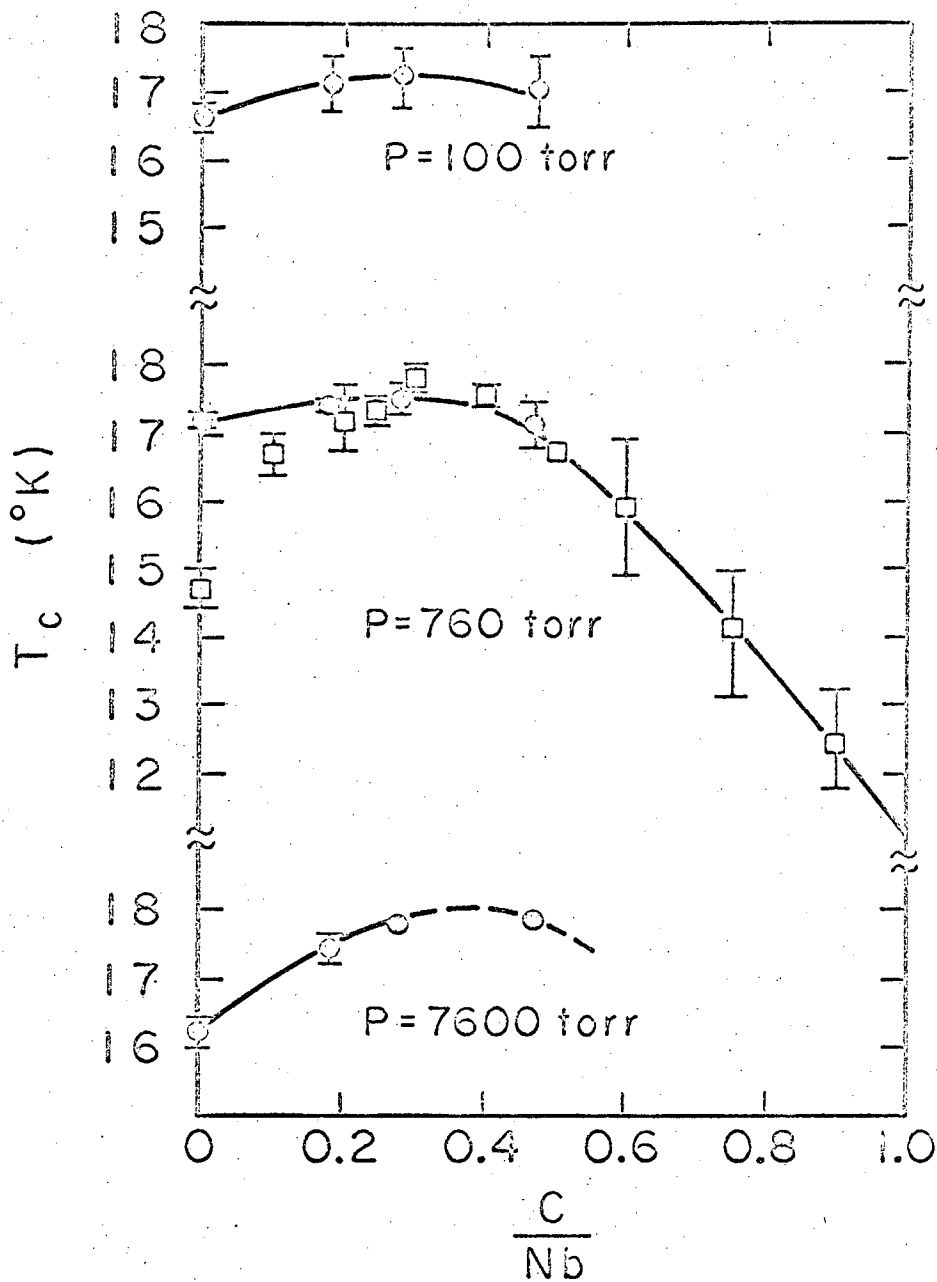


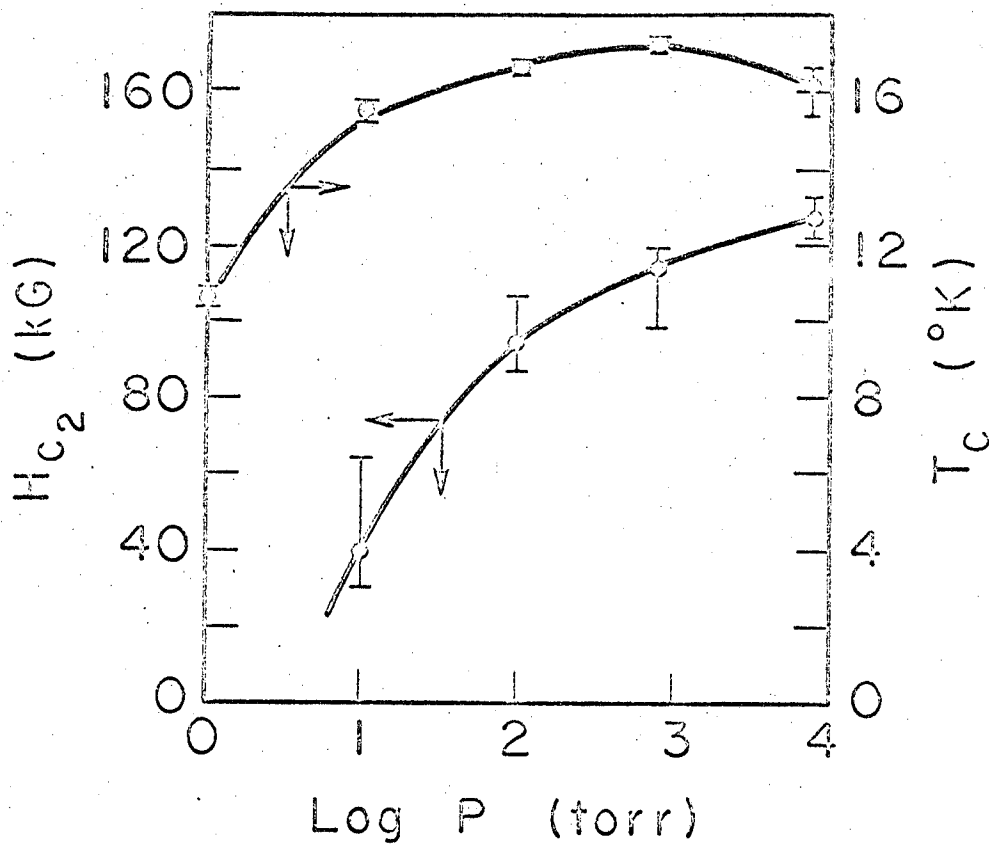
Fig. 1 (c,d)

MUB-10009



MUB-10736

Fig. 2 (a,b,c)



MUB-9496-B

Fig. 3 (a)

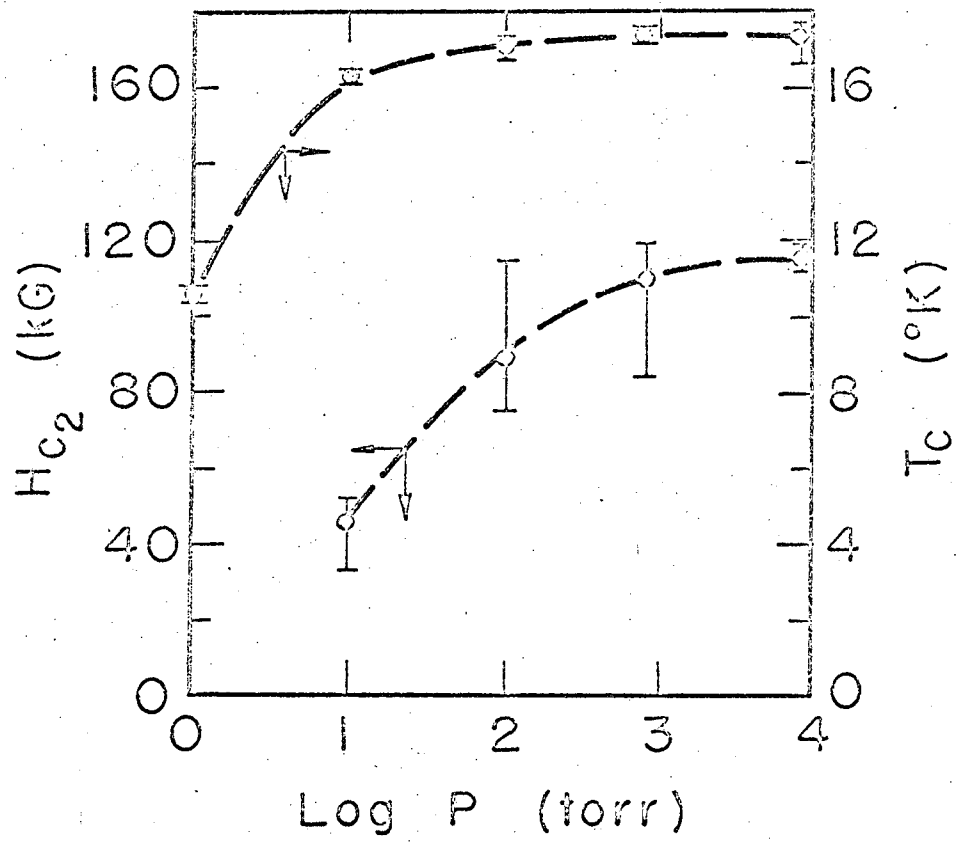


Fig. 3 (b)

MUB-10448

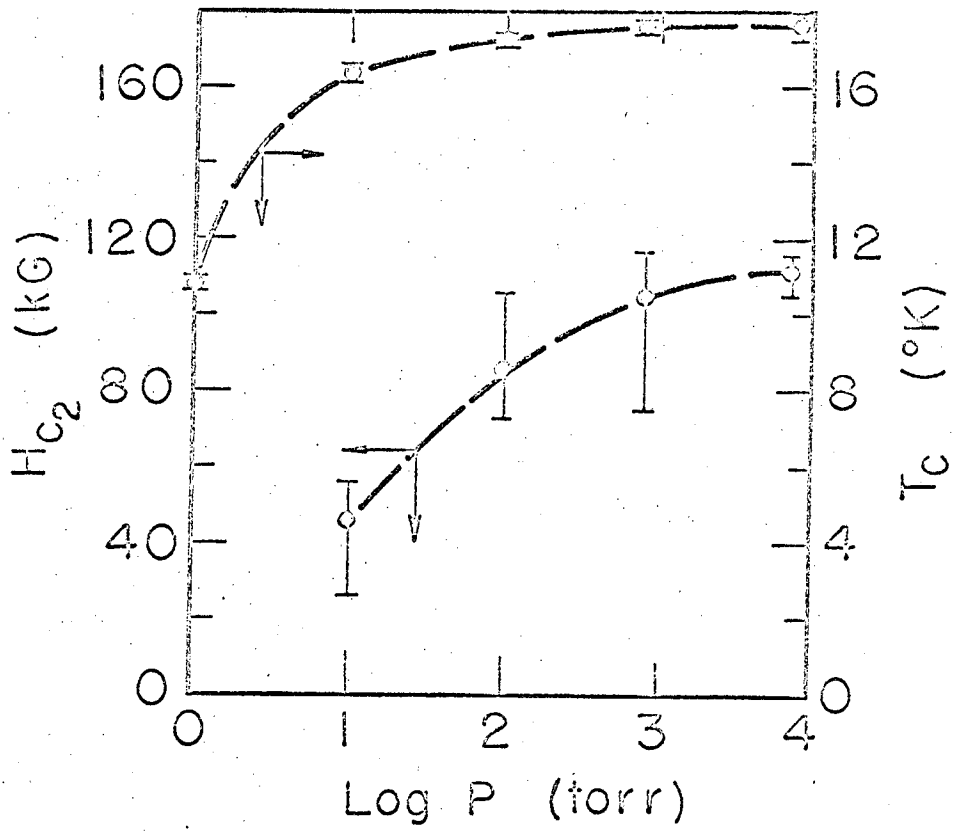
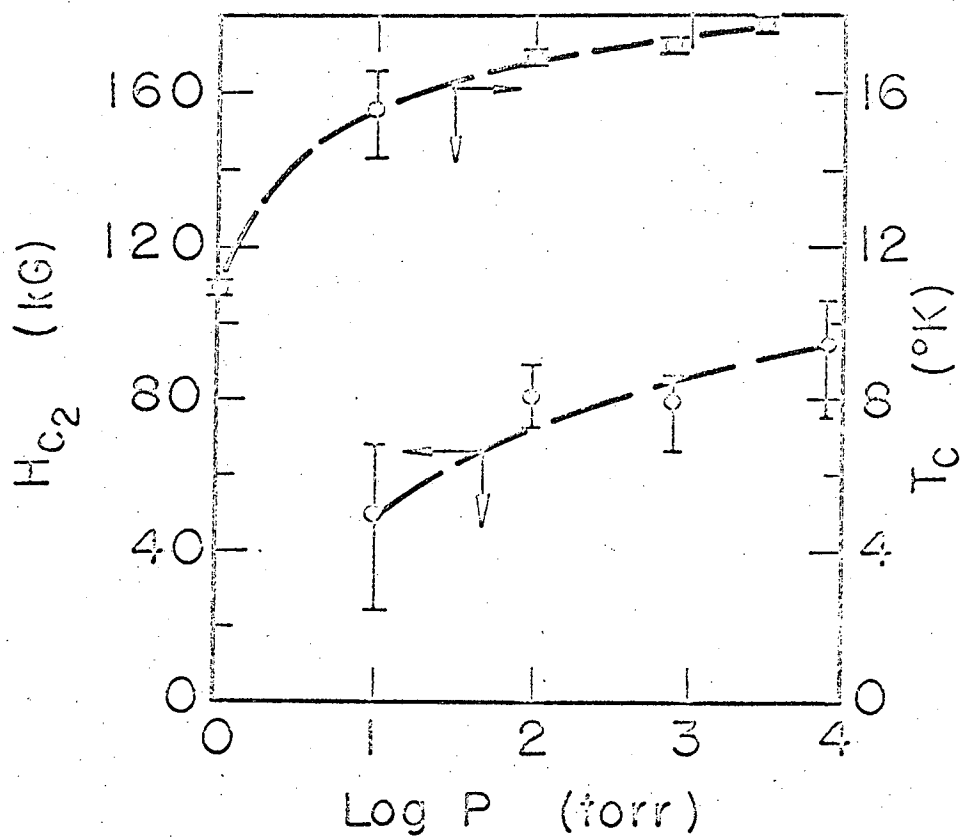


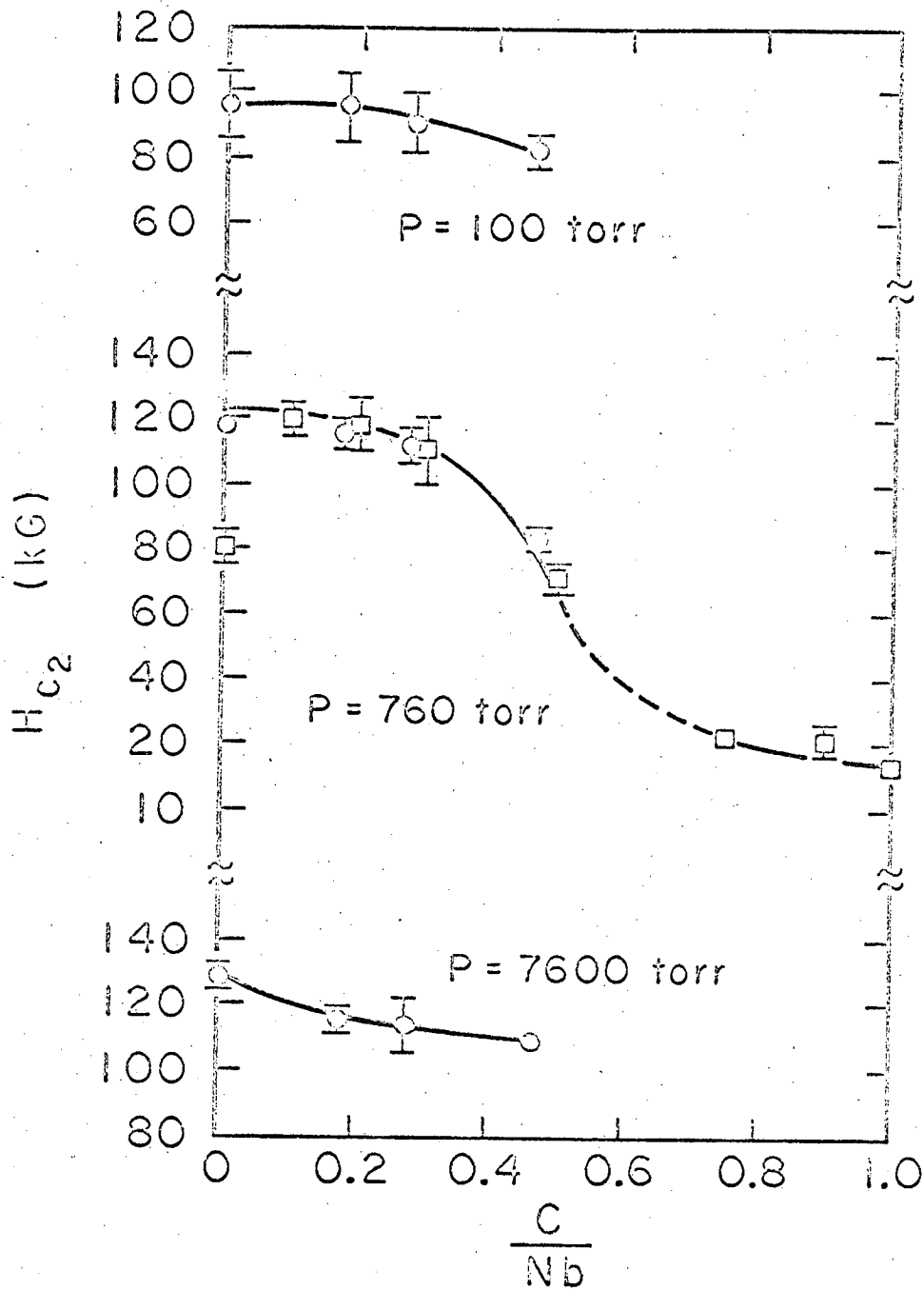
Fig. 3c

MUB-10447



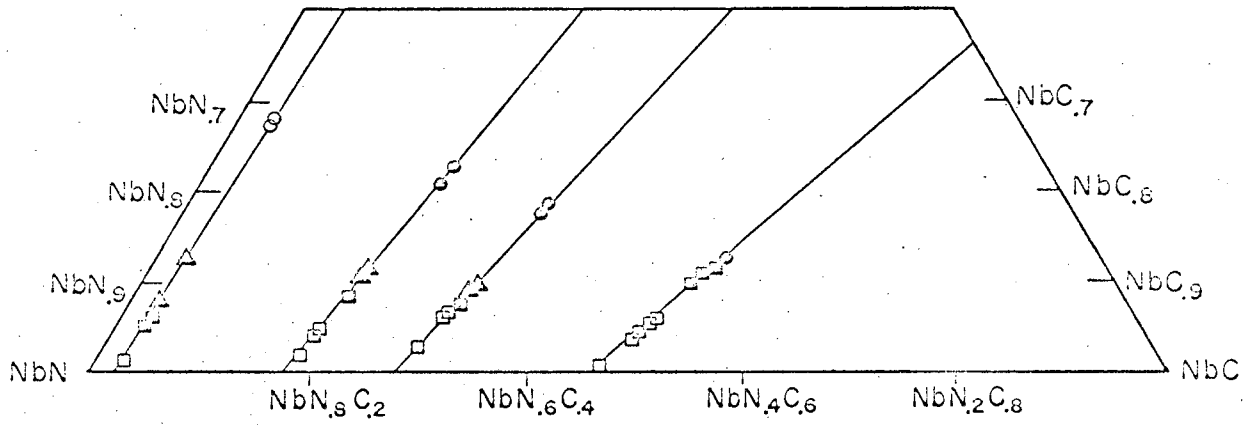
MUB-10446

Fig. 3 (a)



MUB-10735

Fig. 4 (a,b,c)



MUB-10445

Fig. 5

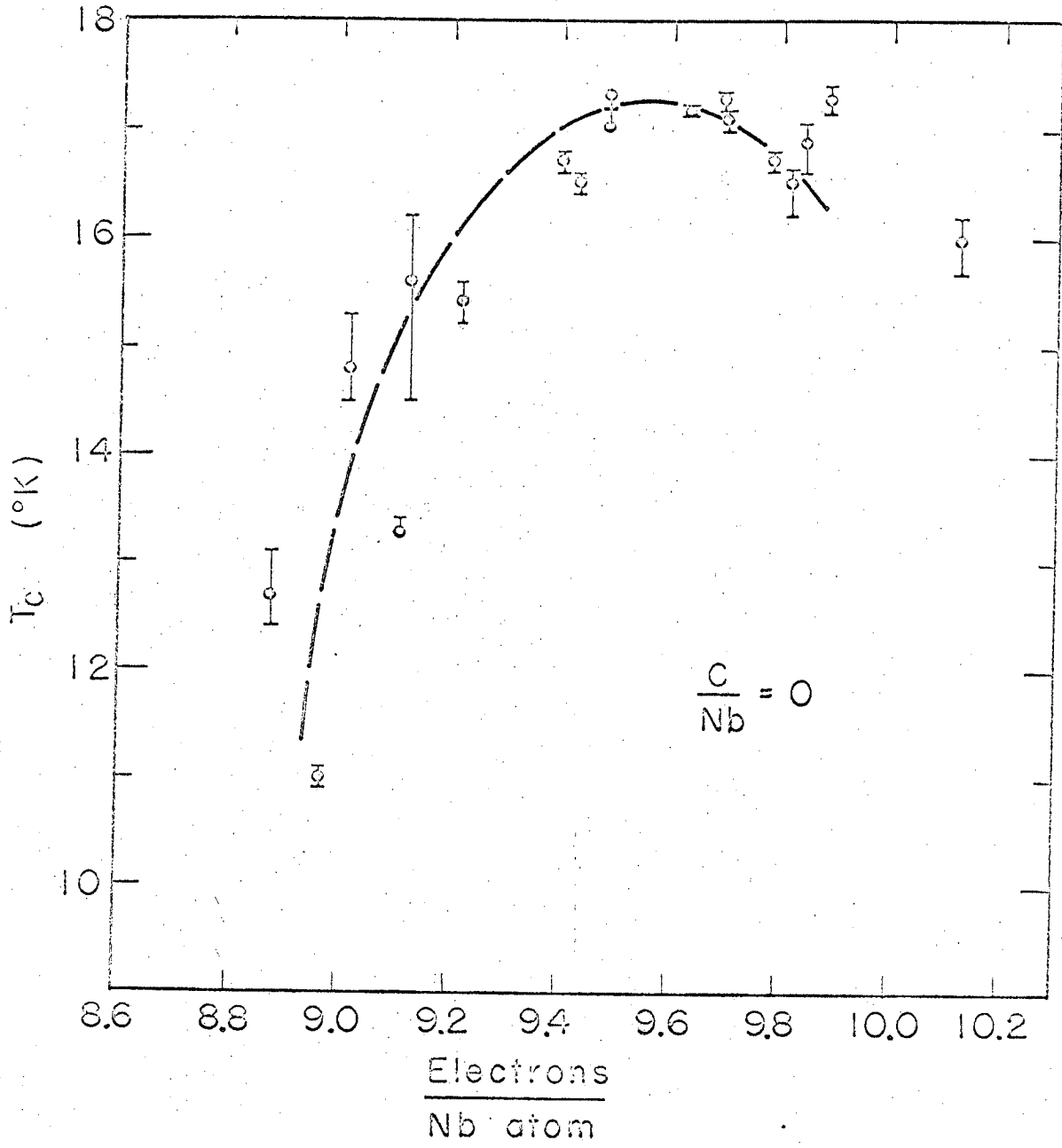


Fig. 6 (a).

MUB-10452

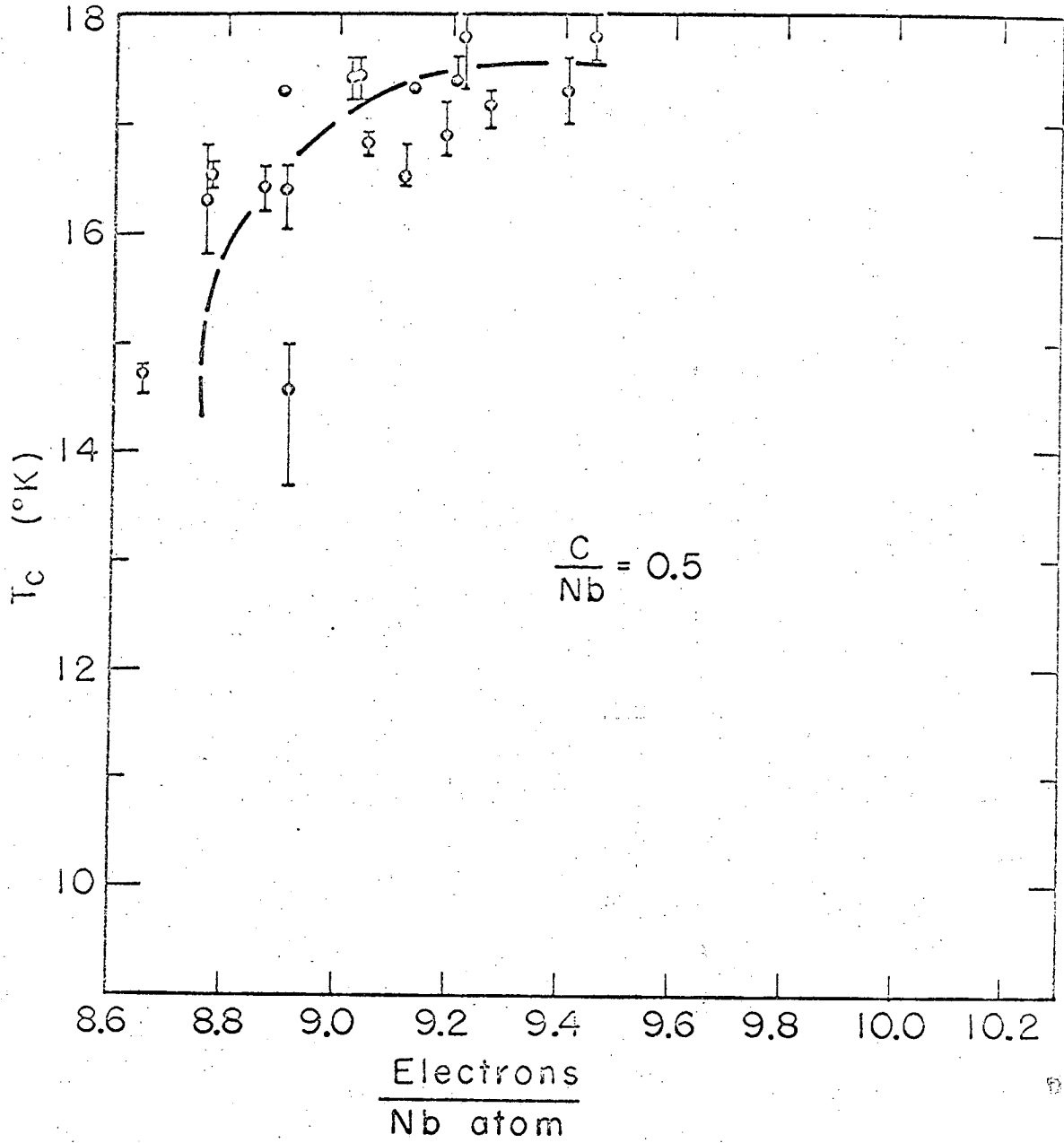


Fig. 6 (d)

MUB-10449

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.

