TECHNETIUM AS A MATERIAL FOR AC SUPERCONDUCTIVITY APPLICATIONS

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INTRODUCTION

The purpose of this note is to expand the impromptu remarks made at the Summer Study, pointing out the fact that the element technetium has some properties which make it worth considering for use in low loss rf circuits, and particularly in cavities intended for use in accelerators or rf separators. Technetium (Z = 43) is a refractory metal, melting at 2140°C, which does not exist naturally but is formed as a fission product in nuclear reactors. It is presently available in some quantity by reprocessing nuclear fuel cores. It was formerly thought to have a short radioactive half-life, but the availability of purer samples has shown that Tc^{99} has a radioactive half-life of $\sim 2 \times 10^5$ years. The activity is mainly 0.29 MeV β particles which can be readily shielded by a thin layer of plastic or metal foil.

DISCUSSION OF AVAILABLE DATA

Since technetium has been available in sufficient quantity for study for relatively few years, there is not much information on its superconductive properties, and there is still the need for more data. We summarize here some of the existing data.

It has been known for some years that technetium is a superconductor[1] but the originally reported value of transition temperature, which is still being reprinted in some recent textbooks and reviews, is now known to be too high. More recent measurements on much purer samples which have become available indicate a lower transition temperature near 8°K.[2-4] Alloys containing Tc[2,5] are known to have considerably higher transition temperatures, going up to about 16°K for some MoTc compositions.[2]

The results of most interest to us here are reported by Sekula, Kernohan, and Love[4] who measured the magnetization properties of fairly pure, partially annealed samples of Tc, with R(300°K)/R(8°K) $\sim$ 100.

One of their magnetization curves is reproduced in Fig. 1 and their main conclusions of interest to us may be summarized as follows:

Technetium is a type II superconductor with $T_c \approx 7.75$°K. It has a Ginzburg-Landau parameter, κ, of 0.92 at $T = T_c$, which is about the same as niobium and indicates Tc is barely type II. Annealing at 2000°C for an hour in a moderate vacuum results in a fairly reversible magnetization characteristic such as Fig. 1.

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1. J.G. Daunt and J.W. Cabble, Phys. Rev. 92, 507 (1953).
2. V.B. Compton, E. Corenzwit, J.P. Maita, B.T. Matthias, and F.J. Morin, Phys. Rev. 123, 1567 (1961).
3. M.L. Picklseimer and S.T. Sekula, Phys. Rev. Letters 9, 254 (1962).
4. S.T. Sekula, R.H. Kernohan, and G.R. Love, Phys. Rev. 155, 364 (1967).
5. S.H. Autler, J.K. Hulm, and R.S. Kemper, Phys. Rev. 140, A1177 (1965).

As can be seen in Fig. 1, $H_{c1} \approx 900$ Oe at $T = 4.2^{o}K$. At other temperatures it can be estimated by assuming the same temperature dependence for technetium as has been measured in niobium by Finnemore, Stromberg, and Swenson.[6] This is justified by the fact that κ happens to be very nearly the same in the two metals. Thus,

$$H_{c1}(t, \text{technetium}) = \frac{H_o(\text{technetium})}{H_o(\text{niobium})} H_{c1}(t, \text{niobium}) \ ,$$

where $t = T/T_c$ and $H_o = H_c$ (at $t = 0$).

Using H_o(technetium) = 1400 Oe, H_o(niobium) = 1990 Oe, and H_{c1}(t, niobium) from Ref. 6, H_{c1}(t, technetium) is plotted in Fig. 2. H_c and H_{c2} for technetium as measured by Sekula, Kernohan, and Love are also shown in Fig. 2.

CONCLUSIONS

Technetium, with $T_c \approx 7.75^{o}K$ and $H_{c1} \approx 1180$ Oe at $1.8^{o}K$ has the second highest penetration field of all known superconductors and the second highest transition temperature among the elements. Only niobium excels it (by a small margin) in those properties which promise usefulness for high Q microwave cavities operating at high power levels. Niobium, however, has some disadvantages which impair its applicability; one of these is the fact, discussed at this Summer Study, that in actual niobium cavities field penetration and losses become excessive at field strengths of about 450 Oe instead of the expected 1600 Oe. Also, the preparation of the best niobium surfaces is a difficult, expensive process.

Because technetium might turn out to have an actual penetration field higher than that of niobium, and because some of its metallurgical properties suggest that it may be easier to process than niobium,[7] it would seem to be worthwhile to start a study of its applicability to low loss cavities. Pure technetium is presently available in kilogram quantities with hundreds of kilograms awaiting extraction from reactor fuel cores if a suitable use should develop. If its potential advantages as an ac superconductor should turn out to be real, neither its slight radioactivity nor its relative rarity should be prohibitive obstacles to its use on the surface of high Q cavities.

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6. D.K. Finnemore, T.F. Stromberg, and C.A. Swenson, Phys. Rev. 149, 231 (1966).
7. For example, it is much easier to remove interstitial oxygen and nitrogen from technetium than from niobium, R. Kemper and C.C. Koch, private communication.

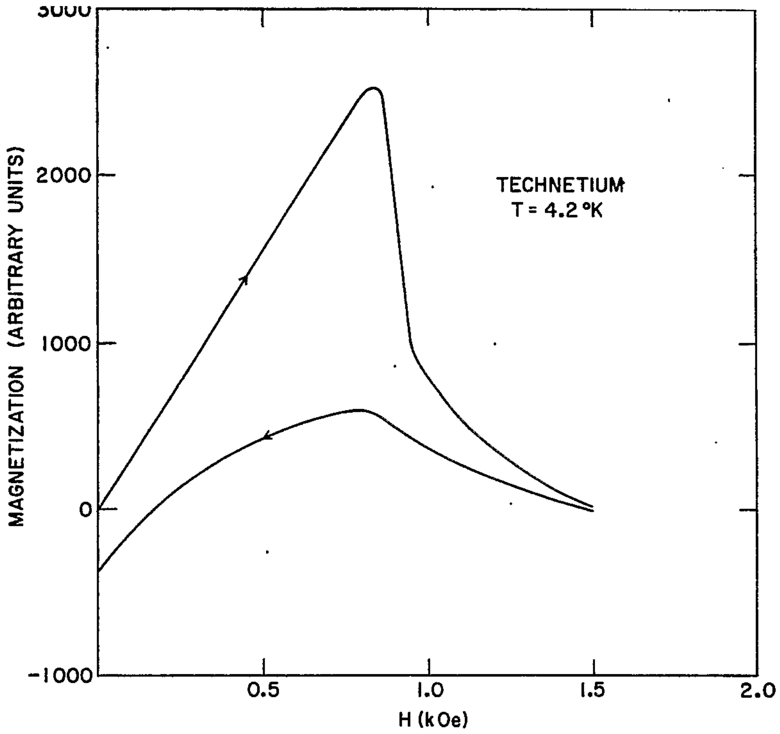

Fig. 1. Magnetization of a sample of technetium annealed at 2000°C for one hour (after Sekula, Kernohan, and Love). T_c for this sample is 7.75°K.

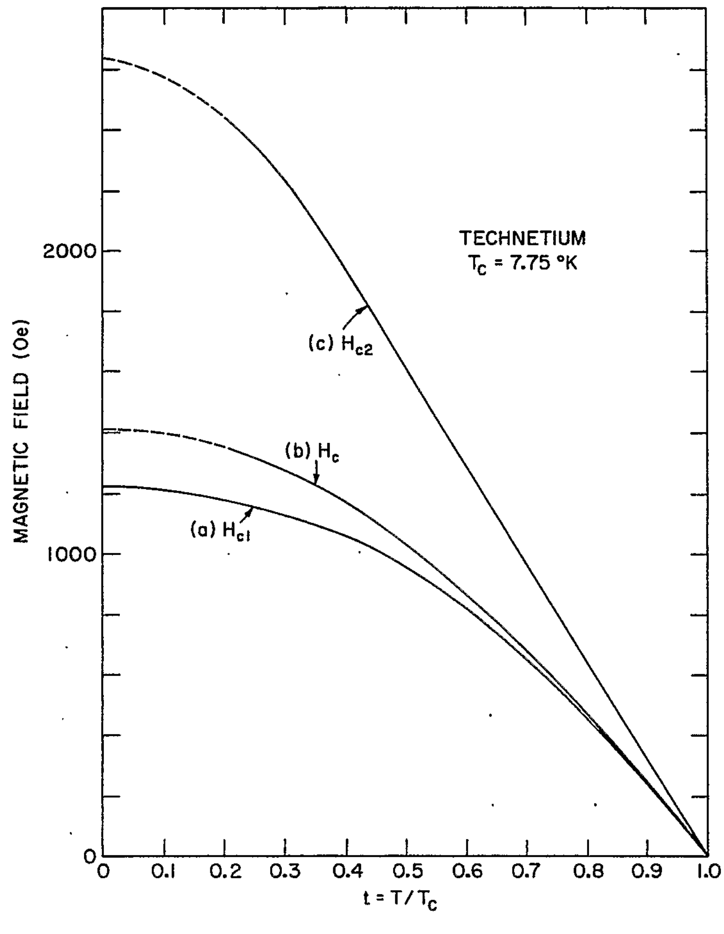

Fig. 2. Critical fields vs reduced temperature for technetium:
(a) Lower critical field, H_{c1}.
(b) Thermodynamic critical field, H_c.
(c) Upper critical field, H_{c2}.
Curves (b) and (c) are taken from Sekula, Kernohan, and Love. Curve (a) is estimated by the author.