

FIG. 2. Maximum and integrated (γ, n) cross sections as a function of atomic number. The curve is derived from photoneutron yields; the points are independent activation measurements of the integrated cross section.

tion of atomic number. Since the absolute cross-section values of Table I were not used in the computation of the average shape, these points and the other values from references 1, 3, and 8 are plotted in Fig. 2 and constitute a satisfactory independent check on the general curve.

Only one (γ, pn) and no $(\gamma, 2n)$ reactions have yet been investigated in detail. The integrated cross section for $S^{32}(\gamma, pn)P^{30}$ is 0.003 Mev-barns,² or 2 percent of the integrated (γ, n) cross sections in that region of the periodic table. This may indicate that $(\gamma, 2n)$ reactions are more important than (γ, pn) reactions, or that the extra neutron yields are much less in light elements.

I am indebted to Dr. L. Katz for valuable discussions.

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New Superconducting Borides and Nitrides

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THE pronounced metallic character of many borides, carbides, and nitrides of the transition metals is evident from the fact that the electrical resistivity of these compounds has a positive temperature coefficient in the neighborhood of room temperature and is, in several cases, less than the resistivity of the constituent metal.¹ Meissner² found that many of these compounds show superconducting behavior, the carbides of molybdenum and tungsten being of special interest in this respect, since the metals themselves appear to be nonsuperconducting down to very low temperatures ($<1^\circ\text{K}$). A knowledge of the extent to which such apparently nonsuperconducting elements form superconducting compounds is obviously important for a satisfactory theory of superconductivity; but, on reviewing the available data against the general background of the periodic system, one is struck by the large number of interesting compounds which have so far not been tested, little having been done since the pioneer work of Meissner. This situation led us to embark some time ago on an experimental survey of metallic compounds, the object being to throw more light on the chemical and structural conditions governing the occurrence of superconductivity. We have adopted a magnetic detection method, which, as pointed out by Shoenberg,³

TABLE I. Experimental results. Superconducting compounds are shown in boldface type together with their transition temperatures. The numbers in parentheses represent the lowest temperatures of measurement for those compounds which did not become superconducting.

	Nb	Ta	Mo
B	NbB 6° Nb ₂ B ₄ (1.27°) NbB ₂ (1.27°)	TaB (1.29°) Ta ₂ B ₄ (1.30°) TaB ₂ (1.32°)	MoB 4.4° Mo ₂ B ₃ (1.32°)
N	NbN 14.7° ^a Nb ₂ N (9.5°) ^a	TaN (1.88°) ^a Ta ₂ N (9.5°) ^a	Mo₂N 5° MoN 12.0°

^a See reference 7.

provides a direct measure of the amount of superconducting material present, and avoids the difficulty occurring in electrical resistance measurements that a small quantity of superconducting impurity may shunt the bulk of the specimen, thus producing a large but spurious effect. Although we have so far examined only about 60 semimetallic and intermetallic compounds down to 1.3°K, it seems worthwhile to describe 4 new superconductors which have recently been found in the boride and nitride groups.

Superconductivity was observed in the monoborides of *niobium* and *molybdenum*, with the transition temperatures⁴ shown in the first row of Table I. X-ray analyses for these compounds and also for other borides which did not become superconducting down to the lowest temperatures of measurement (shown in parentheses in Table I) were in good agreement with the recent structural data of Kiessling,⁵ who found NbB orthorhombic and MoB tetragonal. It is interesting to note that the only other previously reported superconducting boride, ZrB, tested by Meissner² in electrical resistance measurements, is, according to Kiessling,⁵ nonexistent. The latter evidence, coupled with the uncertainty of the resistance method, throws considerable doubt on the superconductivity of ZrB, so that NbB and MoB must be regarded as the only borides at present definitely known to be superconducting.

Superconductivity was also observed in two nitrides of *molybdenum*, with the transition temperatures shown in the lower part of Table I. The x-ray analyses were in these cases in agreement with the results of Hägg,⁶ who assigns a face-centered cubic structure (with N/2 missing) to Mo₂N and a hexagonal lattice to MoN. In the preparation of Mo₂N by nitriding molybdenum metal, the formation of some mononitride can hardly be avoided. The magnetization of a mixed specimen of about 85 percent Mo₂N, 10 percent MoN, and 5 percent Mo is plotted against temperature in Fig. 1; and from the relative heights of the two plateau regions we conclude that while Mo₂N becomes normal at about 5°K, MoN remains superconducting up to 12.0°K. In the latter, remarkably high transition temperature, which was studied in detail by surrounding the specimen with solid hydrogen, MoN is second only to NbN,⁷ a situation seen to be even more striking

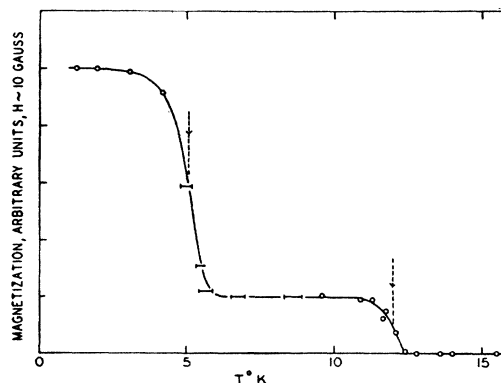


FIG. 1. Temperature variation of low field-strength magnetization of mixed molybdenum nitride specimen.

in the light of Shoenberg's⁸ observation that molybdenum metal is itself nonsuperconducting down to 0.3°K.

Measurements on compounds of other transition metals together with details of preparations, analyses, and apparatus will be reported later.

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⁴ The transition temperature is taken to be the temperature at which the low field strength magnetization attains half its maximum value (e.g., dotted lines, Fig. 1); owing to poor thermal equilibrium, temperatures between 4° and 10°K are at present known only to about one degree.

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The Beta-Spectrum of Cl³⁶

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IT was pointed out by Longmire, Wu, and Townes¹ that the Fermi theory of beta-decay fails to account for the D_2 shape of the Cl³⁶ beta-spectrum found by Wu and Feldman,² unless a mixture of interactions is assumed. The arguments were based upon the measured³ spin of two for Cl³⁶, and upon the assumption of a spin of zero for A³⁶. It was shown that the observed spectrum could be accounted for by use of any one of three different mixtures of interactions: (2S, 2T); (2V, 2T); or (2V, 2A).

We have examined the Cl³⁶ beta-spectrum by use of a high pressure argon-filled proportional counter⁴ and have obtained experimental results which disagree with those mentioned above.

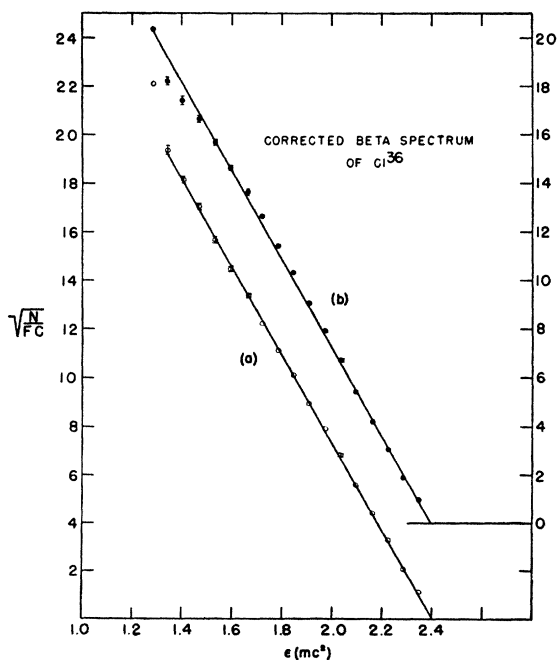


FIG. 1. Corrected beta-spectrum of Cl³⁶. Curve (a) was obtained by use of the C_{2T} correction factor. Curve (b) was obtained when the D_2 correction factor was applied to the same data. The error symbols represent standard deviations. Resolving power corrections have been applied to the original data, but their chief effect is to raise the end point energy slightly. The average thickness of the finely divided KCl source used here was 1.2 mg/cm². The backing was 0.2-mg/cm² Al foil.

The chief disagreement is at the low energy end of the spectrum, where we find fewer electrons, with the result that our points lie very near to a second forbidden tensor spectrum. (See Fig. 1.)

The $2T$ spectrum involves contributions from two different matrix elements. In the terminology of Longmire, Wu, and Townes,

$$C_{2T} = a(T_{ij}^2 \text{ shape}) + b(A_{ij}^2 \text{ shape}) - c(T_{ij}A_{ij} \text{ shape}),$$

where a , b , and c are real numbers, with $a \geq 0$, $b \geq 0$, $c^2 \leq 4ab$. We have found a fit for $c^2 = 4ab$ and $b = 25.73a$. The quantities in parenthesis are defined exactly by Konopinski and Uhlenbeck.⁵

The initial experiment has been repeated six times over a period of six months, with the proportional counter operating under various conditions, and with source thicknesses varying from 0.2 mg/cm² to 5.0 mg/cm²; each of the distributions found agrees better with the $2T$ shape than with the D_2 shape.

The samples of Cl³⁶ were obtained by a careful chemical separation of chlorine from an Oak Ridge irradiation unit of KCl. The KCl was treated with concentrated sulfuric acid, and the HCl given off was collected and reconverted into KCl. This procedure should be quite effective in separating chlorine from any radioactive impurity expected to be present. The chief radioactivity in the raw unit was S³⁵. Traces of S³⁵ in the final sample could not have affected our results seriously, because of the low (170-kev) energy limit of the S³⁵ beta-rays and because any ordinary radioactive impurity would have caused the intensity of the low energy end of the spectrum to be raised, not lowered.

Our method, although relatively new, has faithfully reproduced a number of known spectra such as those of Y⁹¹ and Be¹⁰. (See Fig. 2.) (The Be¹⁰ and Cl³⁶ spectra shown here were obtained within

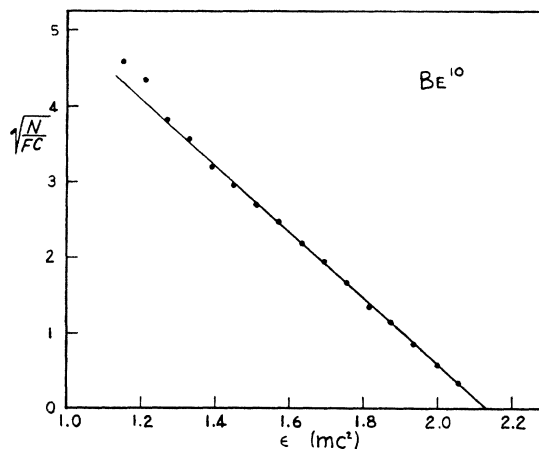


FIG. 2. Corrected beta-spectrum of Be¹⁰ for comparison with the Cl³⁶ spectrum. The plot of this D_2 beta-spectrum is straight down to about 1.3 mc². BeO crystalline source of average thickness about 1.9 mg/cm² on 0.2-mg/cm² Al foil. Coulomb corrections have been applied to both spectra.

a few hours of each other under identical operating conditions.) We have acquired some confidence in its use, both from those results and from an analysis of its operation. A detailed description of the method will be published later.

We conclude that it may well be possible to account for the shape of the Cl³⁶ beta-spectrum by means of a single interaction, $2T$ (or $2V$).

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