distribution for high energies. It is not felt that the statistics at the present time are sufficient to make any definite statements about this asymmetry. The amount of this asymmetry, however, is of the order of that given by the theory of Rose and Goertzel,[4] i.e., in their notation $A_0(u) = (L/\zeta^4)^2 \sin^2\theta$. A rough calculation at ten and twenty Mev of the cross section by this theory, however, gives an energy dependence which is slightly steeper than that given by the Bethe-Peierls expression.

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* Assisted by the joint program of the ONR and AEC.
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The Thermal Neutron Absorption Cross Section of K^{39}

JOHN L. HANSEN AND JOHN E. WILLARD
Department of Chemistry, University of Wisconsin, Madison, Wisconsin
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THE thermal neutron capture cross section for natural potassium (93.3 percent K^{39}, 0.012 percent K^{40}, 6.7 percent K^{41})[1] has been measured by Lapointe and Rasetti[2] by determining the concentration of boron in a water solution of boric acid necessary to produce the same intensity decrease in thermal neutrons as that produced by a solution of potassium fluoride of known concentration. The thermal neutron capture cross section for the reaction $K^{41}(n,\gamma)K^{42}$ has been determined to be 1×10^{-24} cm^2 by Seren, Friedlander, and Turkel[3] by measuring the K^{42} activity induced in potassium by a thermal neutron irradiation of known flux and duration. A direct determination of the capture cross section of K^{39} by measurement of induced K^{40} activity has not been reported, probably because the long half-life[4] of K^{40}, together with the necessity of counting the induced activity against the background of the natural K^{40} activity, require very intense irradiation of long duration to produce a measurable amount of activity.

We have determined the ratios of the counting rate of K^{40} in samples of KCl which have received neutron exposures of 1.3×10^{18}, 2.3×10^{18} and 8.1×10^{19} neutrons/cm^2 [5] to the counting rate of ordinary KCl under identical conditions. From these ratios, the neutron exposures, and the percentage abundance of K^{40} and K^{39} in natural K a value for the thermal neutron absorption cross section of K^{39} has been obtained.

The irradiated KCl samples were rigorously purified with respect to Cl^{36}, S^{35} and P^{32} activities produced by the $Cl^{35}(n,\gamma)Cl^{36}$ $Cl^{35}(n,p)S^{35}$ and $Cl^{35}(n,\alpha)P^{32}$ reactions. Other radioactive nuclear species originally present were sufficiently short-lived to decay before the measurements of K^{40} activity were made. The most difficult activity to remove was the S^{35}, which was present at a specific activity more than 10^6 times as great as the K^{40} in the most active sample and which before removal gave rise to a high counting rate of brehmsstrahlung produced by the absorption of its weak (0.17 Mev) beta-particles in the thick KCl samples used.

The last step of purification was always the precipitation of the potassium as KCl by bubbling HCl gas into the aqueous solution. This salt was then fused, powdered and placed in a brass cup 3.8 cm in diameter and 1 cm deep. An absorption curve for the radiation of the sample was determined with the aid of a mica window Geiger-Mueller counter and aluminum absorbers. An absorption curve of an unexposed sample of reagent grade KCl of the same weight, fused, powdered, and mounted in the same way was determined in the same position under the same counting tube.

An irradiated sample was considered to be radiochemically pure when its absorption curve was parallel to the curve for an identical sample of KCl which had not been irradiated. The ratio of the ordinate of the curve for the irradiated sample to that for the unirradiated sample at any absorber thickness is equal to the factor by which the irradiation increased the K^{40} content of the irradiated sample, there being no need for knowledge of the absolute counting efficiency of the equipment. Following the counting of the solid samples they were dissolved to make solutions of equal concentration which were counted by placing them in an annular jacket around a thin glass-walled Geiger-Mueller counter tube.[6]

Absorption curves for the most active purified irradiated sample of KCl and for a duplicate unirradiated comparison sample are given in Fig. 1. A summary of the results from this sample is given in Table I. The values in the third column for the counting

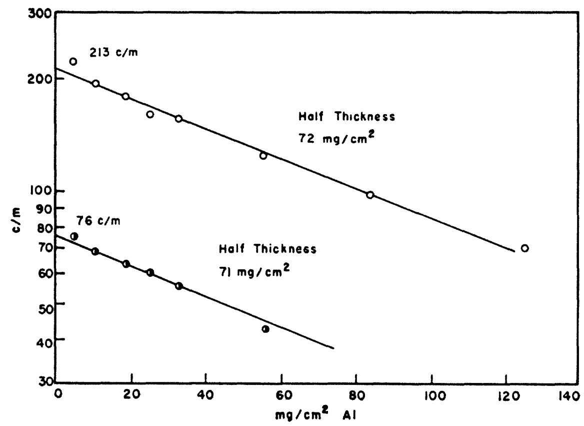

FIG. 1. Absorption curves taken on KCl samples. Upper curve: after neutron irradiation and subsequent purification from radioactive species other than K^{40}. Lower curve: KCl which was not irradiated.

TABLE I. Determination of thermal neutron absorption cross section of K^{39} (using 0.60 gram of a KCl sample irradiated with 8×10^{19} neutrons per cm^2).

KCl sample	Type of sample counted	Counts per minute	σ of K^{39} (cm$^2\times10^{24}$)
Irradiated	Solid	213	2.9
Not irradiated	Solid	76	
Irradiated	Solution	147 ± 2.2	2.6
Not irradiated	Solution	56 ± 2.7	

rates of the solid samples have been obtained by extrapolating the absorption curves of Fig. 1 to zero absorber. The values of the individual points making up the absorption curves have been determined with a statistical counting error of less than ±4 percent at the 0.95 reliability level. The 0.95 error of the solution counts is included in column 5 of Table I.

The calculated value of the cross section of K^{39} depends upon the value used for the neutron exposure and for the abundance of K^{40} in natural K. The value for the neutron exposure is believed to be accurate to ±25 percent,[5] and that for the abundance of K^{40} has been stated to have a probable error of ±10 percent.[1] Self-shielding probably made the average neutron exposure of the sample about 0.8 of the maximum (the sample of KCl exposed was about 0.9 cm thick, 10 cm long and weighed 10 g). It seems reasonable, therefore, to assign a value of $3\pm1.5\times10^{-24}$ cm^2 to the capture cross section of K^{39} for the pile neutrons with which these samples were bombarded.

This value is in agreement with the value of 3.9×10^{-24} cm^2 obtained from the total absorption cross section value of Lapointe and Rasetti[2] if the latter is corrected for the changed value of the cross section of boron, for the absorption due to K^{41},[3] and for the abundance of K^{39}.

Five samples purified from KCl which had received neutron exposures of 1.3×10^{18} and 2.3×10^{18} neutrons/cm^2 gave an average value in agreement with that obtained from the more active sample, but the increase in counting rate as a result of irradiation in these experiments was in the range of only 5–15 counts per minute so the accuracy with which it could be determined was relatively low.

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[2] C. Lapointe and F. Rasetti, Phys. Rev. **58**, 554 (1940). The value of 3.2×10^{-24} cm^2 which they give is based on the assumption that the thermal neutron absorption cross section of boron is 600×10^{-24} cm^2. If the more recent value of 703×10^{-24} cm^2 for boron is used the value obtained by these authors for potassium would be 3.7×10^{-24} cm^2. Way and Haines, United States AEC Declassified Document 2138, cite a value of 2.5×10^{-24} cm^2 for the natural potassium cross section.
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[5] The samples, obtained from the Oak Ridge National Laboratory of the U. S. AEC, were the result of irradiations made for the purpose of producing high specific activity Cl^{36}. The values for neutron exposures were kindly furnished by J. A. Cox of the Isotopes Office of the Oak Ridge National Laboratory.
[6] Further details of these determinations are given in a M.S. thesis field with the University of Wisconsin library in August, 1948, by John L. Hansen.

Investigation of the Attractive Forces between the Persistent Currents in a Superconductor and the Lattice*

E. U. Condon and E. Maxwell
National Bureau of Standards, Washington, D. C.
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We have investigated the behavior of a superconducting sphere in a magnetic field in order to answer the question of whether the persistent surface currents can move with respect to the metal or are rigidly bound to it. An early experiment of Tuyn's[1] has been interpreted as indicating that the supercurrents are in fact rigidly fixed in the superconductor. Since Tuyn employed a hollow sphere, one would expect the intermediate state to set in and produce a strong frozen-in moment. Therefore his experiment is not conclusive.

It also appears that the hypothesis of currents rigidly bound to the metal is incompatible with the Meissner effect. Since

$$\mathbf{B}=\mathbf{H}+4\pi\mathbf{I}, \tag{1}$$

we may regard the condition $\mathbf{B}=0$, the Meissner effect, as resulting from the building up of a $4\pi\mathbf{I}$ in the metal which is everywhere equal to $\mathbf{H}$ and oppositely directed to it, inasmuch as (1) is a vector equation and $\mathbf{I}=-\mathbf{H}/4\pi$ vectorially. If we were now to regard the surface currents, or what amounts to the same thing, the magnetization $\mathbf{I}$, as fixed to the metal sphere, then on turning the sphere in a magnetic field, the vector $\mathbf{I}$ would rotate with respect to $\mathbf{H}$, and therefore the condition $\mathbf{H}+4\pi\mathbf{I}=0$ could not be fulfilled.

We have investigated this matter experimentally by suspending a tin spheroid of radius 1.8 cm in a magnetic field and observing the period of oscillation of the resulting torsion pendulum as a function of the field strength. Observations have been made at temperatures down to 1.74°K and at field strengths sufficiently below the critical field to avoid the appearance of the intermediate state. The earth's field was compensated to within one or two milligauss before cooling so as to avoid the possibility of frozen-in moments.

If the currents were rigidly fixed to the sphere, then we should have, in addition to the restoring torque of the suspension, a torque of $\mathbf{H}^2/4\pi$ dyne-cm/rad. cm^3 due to the interaction between the currents and the applied field. We have observed no torques greater than about 1 percent of this quantity and therefore conclude that except for effects of the order of 1 percent or less, the currents do not remain bound to the metal.

We have, however, observed a restoring torque which is 1 percent or less of the value $\mathbf{H}^2/4\pi$ and which is an interesting function of the applied field strength. Since we used a rather soft suspension (approximately 130 dyne-cm/rad.) these effects were well within the precision of measurement. A typical result is plotted in Fig. 1

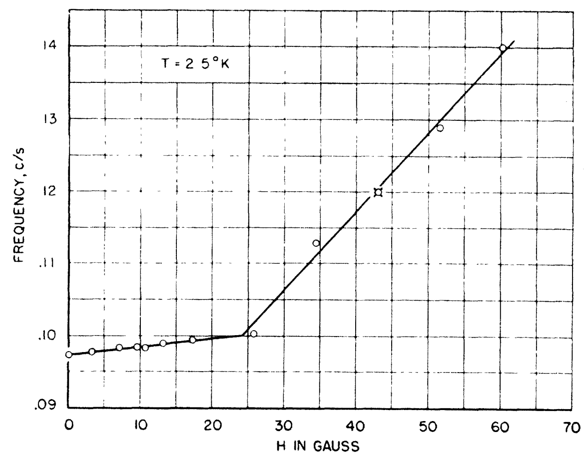

FIG. 1. Relation between frequency of oscillation and magnetic field for tin spheroid. ⊙ Points taken with ascending magnetic field. × Point taken with descending field.

which gives the frequency of oscillation *vs.* the applied field for a temperature of 2.5°K. Note the curious discontinuity in the slope at 24 gauss. The same general behavior has been observed at other temperatures. No hysteresis is apparent as long as we do not exceed the critical field.

The experiments are still in a preliminary stage so that it is entirely possible that the effect we observe is due to small departures from true cylindrical symmetry or other secondary features. We have some indication of dependence on the relative orientation of field and spheroid and are investigating this point further. It is also planned to measure the torque under static conditions, to extend the measurements to other superconductors, and possibly to study the effect using a long cylinder with circumferential persistent currents.

After we observed these phenomena it was brought to our attention that effects of this sort have been observed and briefly reported on by Mendelssohn.[2]

* Supported by the ONR.
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Thresholds for Photo-Neutron Reactions in Mn, Zn, Zr, Mo, Cd, Pr, Nd, Au, Hg, Tl and Pb

A. O. Hanson, R. B. Duffield, J. D. Knight, B. C. Diven, and H. Palevsky
Physics Research Laboratory, University of Illinois, Champaign, Illinois
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Measurements on thresholds for photo-neutron reactions, using x-rays from the 22-Mev betatron, have been extended to include a number of other elements. The experimental arrangements are similar to those already described.[1] The energy scale is again determined relative to the threshold for the 10-minute activity from the $Cu^{63}(\gamma,n)Cu^{62}$ reaction which is taken as 10.9 Mev.

The thresholds for the production of characteristic radioactivities were measured in samples which varied from a single 10-mg sample enriched in Zn^{70} to a number of large cylindrical samples of the more common elements. Metallic samples were used in all cases with the exception of the Zn^{70}, Pr, and Nd which were in the form of oxides.