our principal interest has been the spectrometric determination of gamma-rays by conversion electrons, observations are also made of the half-life and the energy of penetrating gamma-rays by absorption.

Vanadium. Since a single isotope of stable vanadium of mass 51 occurs in nature, the isotope formed by neutron capture should have the mass 52. The decay as observed showed clearly 2 half-lives; one of 16 hours and another of about 635 days. A half-life of 600 days had previously been reported for V47, which isotope could not possibly be produced here. Conversion electrons indicate the existence of gamma-rays of energy 80.5 and 119.3 kev for the long-lived emitter.

Molybdenum. A single radioactive isotope of molybdenum of probable mass 99, having a half-life of 68.3 hours, is produced. By absorptions in lead there appears to be a gamma-ray of energy about 0.78 Mev and conversion electrons indicate gamma-energies of 139.6, 167.6, and 179.3 kev.

Tungsten. The decay curve of tungsten is complex, showing a half-life of 25.0 hours (previously reported 24.1) and a long-lived emitter of half-life 76 days. Associated with the latter activity are two electron lines which, if interpreted as an *L–M* combination, yield a single gamma-ray at 133.7 kev.

This investigation is supported jointly by the ONR and the AEC.

Photo-Disintegration of Deuterium by Seven- to Twenty-Mev X-Rays*

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July 5, 1949

A PRELIMINARY study has been made of the angular distributions and distribution in energy of the protons arising from the photo-disintegration of deuterium by the continuous x-ray spectrum from 20.8 Mev electrons in the betatron. The x-rays were collimated into a beam having a full angular width of forty-six minutes by means of a laminated lead collimator placed between the coil boxes of the betatron. The collimated x-ray beam passed through a scattering chamber filled with deuterium gas. Ilford, type C-2, one hundred micron nuclear emulsions were placed inside the scattering chamber to one side of the x-ray beam to detect the protons resulting from the photo-disintegration of the deuterium gas in the beam. Plates were exposed with three atmospheres of deuterium to emphasize the high energy end of the spectrum, with one atmosphere of deuterium to emphasize the low energy end, and with one and three atmospheres of hydrogen. The exposures made with the chamber filled with hydrogen were used to determine the background due to the photo-neutrons coming from the lead collimator and shielding. At all energies this background was a small effect and at high energies it was completely negligible.

To date the analysis has been completed of about four square centimeters of the plates exposed with the chamber filled with three atmospheres of deuterium and the corresponding hydrogen background plates. The energy of each proton track as it entered the plate was determined from the range-energy relations for the Ilford emulsions.[1] These energies were then corrected for the range of each track in the gas of the chamber before it reached the emulsion. From the known geometry of the plates with respect to the x-ray beam and angular measurements made on each track it was possible to determine the angle each track made with respect to the direction of the incident quanta. Angles could be determined between 20 and 160 degrees in the laboratory system. The quantum energy corresponding to each track was calculated from the measured angle and energy of each track in the laboratory system.

Using the intensity spectrum of the betatron as determined by Koch and Carter,[2] Fig. 1 shows the relative cross section as a function of quantum energy for the photo-disintegration of deuterium as determined from these data. The scale on the left is in arbitrary units while that on right has been normalized such that the cross section at seven Mev is $11.7(10)^{-28}$ cm^2, the value given by the Bethe-Peierls expression. The dashed curve is the Bethe-Peierls expression for the cross section as a function of energy. The solid curve, which seems to fit the data at the high energy end, is for a cross section which varies as $1/(E)^{\frac{1}{2}}$, where E is the energy of the incident quantum. The various theoretical values calculated at 17.5 Mev by Rarita and Schwinger[3] have also been plotted.

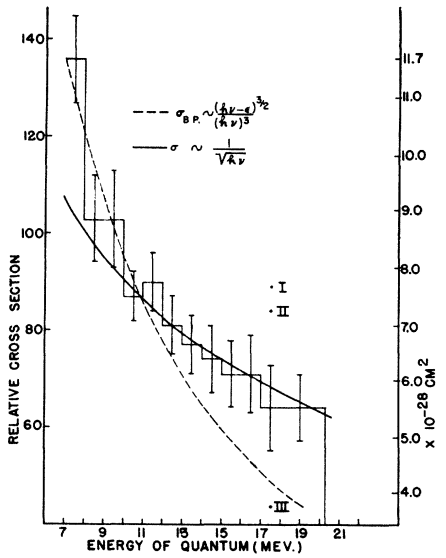

FIG. 1. Relative cross section for photo-disintegration of deuterium. Scale on right normalized to give cross section of $11.7(10)^{-28}$ cm^2 at 7 Mev. Points calculated by Rarita and Schwinger: *I* symmetrical theory, *II* charged theory, *III* neutral theory.

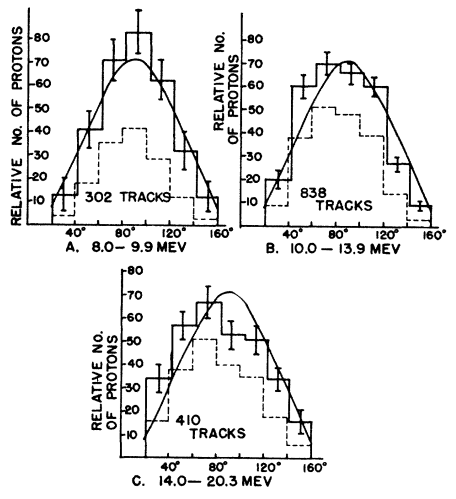

FIG. 2. Angular distributions of photo-protons. Dashed block diagrams: Relative numbers of tracks observed on plate in laboratory system. Solid block diagrams: Relative numbers of tracks per unit solid angle in center of mass system. Smooth curves: $\sin^2\theta$ distributions.

In Fig. 2 angular distributions have been plotted. In each case the dashed block diagram represents the observed distribution on the plate after correction for background. The solid block diagrams represent the distributions per unit solid angle normalized to the same area after conversion to the center of mass system. The smooth curve in each figure represents a $\sin^2\theta$ distribution. These data seem to indicate a possible forward asymmetry in the angular

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.

The author is grateful for the encouragement and advise of Professor A. O. Hanson who initiated this work. He also wishes to acknowledge the helpful discussions of the work held with Professors S. M. Dancoff and Mr. J. S. Blair.

* Assisted by the joint program of the ONR and AEC.

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The Thermal Neutron Absorption Cross Section of K^{39}

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June 27, 1949

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

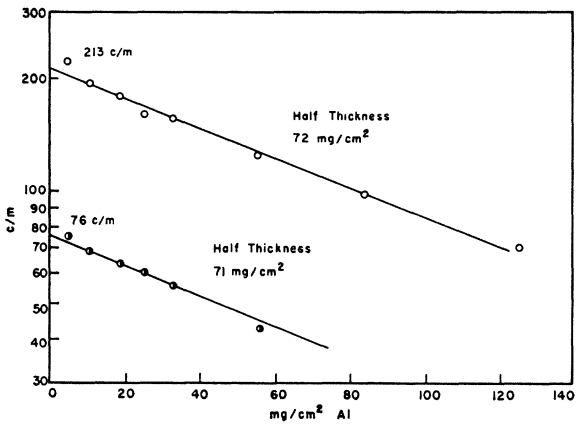

FIG. 1. Absorption curves taken on KCl samples. Upper curve: after neutron irradiation and subsequent purification from radioactive species other than K^{40}. Lower curve: KCl which was not irradiated.

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}.