Li^9—New Delayed Neutron Emitter*

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An investigation has been made of a new delayed neutron activity from targets bombarded in the Berkeley 184-inch cyclotron beam. When the daughter product of a beta-decay is neutron unstable, the neutron comes out immediately. Because the decay in neutron intensity is then the same as that of the beta-particle, this process is usually referred to as delayed neutron emission. Only one other delayed neutron emitter, N^{17}, is known[1] outside of the fission products.

Deuteron bombardment of Be and of elements immediately above it, and proton bombardment of B and of elements immediately above it, give rise to such neutrons displaying a decay in intensity with a 0.168-sec half-life.

The targets were $1\frac{1}{8}$-in. diameter cylinders of approximately 3-in. length, placed in the external beam of the cyclotron. A BF_3 ion chamber embedded in paraffin surrounded the target. A low noise triode preamplifier was used which was coupled into a standard linear amplifier, giving an over-all gain of 5×10^5. The neutron detection efficiency for RaBe neutrons was 5 percent.

The half-life measurement was made by irradiating the target for several seconds, shutting the cyclotron off, and recording the decaying neutron activity by photographing the pulses displayed on an oscilloscope. The activity was followed over more than 5 half-lives, and a complete record of the position of each event in time was secured on the film. The resolution of the equipment was 10 μsec. About 500 pulses per cycle were obtained with a boron target under deuteron bombardment. The results of these measurements give a half-life as shown in Fig. 1 of $T_{\frac{1}{2}}=0.168\pm0.004$ sec. The cross section for this reaction for deuterons on boron is approximately 4 millibarns.

The elements from Li through N were surveyed for this activity, using both protons and deuterons. The relative yields/atom for the various elements are:

	Li	Be	B	C	N	Ratio B/Be
deuterons	<2	45	100	10	3	2.2
protons	<2.5	<2.5	100	13	5	>40.

A Cu target was also used as one type of background determination. The relative copper to boron yield/atom ratio was less than 1 percent. From the above table it is seen that the relative yield under deuteron bombardment is appreciable beginning with Be, while under proton bombardment the yield is not significant until boron is used. That is, within the accuracy allowed by the background; this activity is induced by deuterons on Be, but not by protons. An examination of the isotope chart indicates the most likely reaction to be

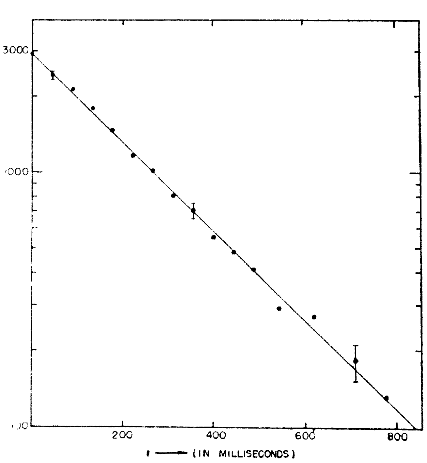

FIG. 1. Neutron decay.

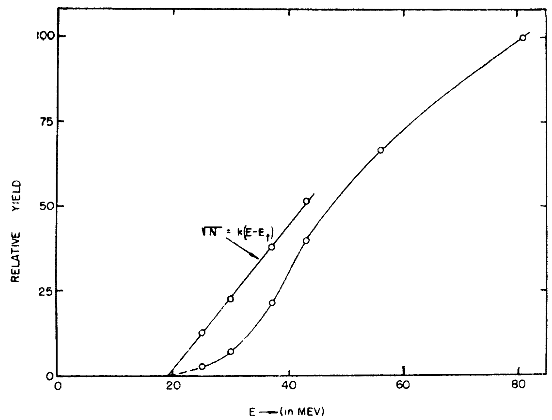

FIG. 2. Excitation function.

$$Be^9+d\rightarrow Li^9+2p$$

under deuteron bombardment.

The fact that under proton bombardment the lightest element to yield the neutrons is boron is also consistent with the Li^9 assignment, assuming

$$B^{11}(p, 3p)Li^9.$$

The Li^9 decay scheme is assumed to be

$$Li^9\rightarrow Be^{9*}+\beta^-$$
$$Be^{9*}\rightarrow Be^8+n.$$

Evidence for an excited level in Be^9 which is unstable to neutron emission has been given by Davis and Hafner.[2] The Be^8 breaks up immediately into two alphas, and, the possibility of investigating the neutron-alpha-coincidence as a corroboration of this decay scheme is being considered.

Li^9 and the above decay scheme hold an analogous position in the isotope chart to that of N^{17}. A mass calculation of Li^9 by Barkas[3] permits a threshold for this reaction to be estimated as $\leqq$18.5 Mev. Experimental data on this point were secured by moving a Be target in along the radius of the cyclotron gap with a deuteron beam. The excitation function is shown in Fig. 2. Theoretical indications that this function is of the form $N=k_1(E-E_t)^2$ are further substantiated by the fact that a straight line is a good fit to the experimental points replotted as $\sqrt{N}=k(E-E_t)$. The threshold determined from this intercept is 19 ± 1 Mev, which is in agreement with the calculated threshold. The Li^9 mass indicates that an electron energy of ~11 Mev is quite likely. An attempt to measure a high energy electron in coincidence with the neutron has not yet been successful.

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Beta-Ray Spectrum of K^{40}

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The beta-ray spectrum of K^{40} has been measured by observing the distribution in size of the light flashes which are generated in a crystal of KI-Tl by the natural radioactivity of the potassium content of the crystal. The crystal, 5.26 g of optically perfect Harshaw KI (0.5 percent Tl added to the melt) gave a total K^{40} beta-count of about 2000 counts/minute. The crystal gave pulses about one-fifth as large as NaI-Tl pulses of the same energy. The energy resolution width was greater than that of NaI-Tl by the square root of the pulse size ratio.

The Jordan and Bell amplifier was used, modified to employ delay line pulse shaping. At the pulse width used (3 μsec) the slow components of the light decay in KI-Tl[1] yielded delayed pulses of about the same size as the thermionic emission background of the photomultiplier tube. This indicated that the mean time interval between photoelectrons of the slow components was greater than the amplifier pulse width, so that the delayed pulses were essentially of single-electron size. These slow component pulses were too small to affect the experiment. The fast component, on the other hand, decayed in much less than the amplifier rise time used (1 μsec).

The energy calibration and resolution width were determined from the photopeak of the annihilation radiation of Cu^{64}. Background ($\approx$1 percent) was measured with the aid of a NaI-Tl crystal. The small ($\approx$2 percent) effect of the detection by the crystal of its own K^{40} gamma-radiation (1.46 Mev) was calculated, using the known gamma-ray rate,[2] the geometry, and a pulse-height distribution obtained with an external gamma-ray source (K^{42}, 1.51 Mev).[3] The beta-ray distribution was corrected for resolution.[4] A further distortion of the spectrum exists, caused by those beta-particles which emerge from the surface of the crystal. A method was developed whereby this distortion could be approximately calculated, using an empirical electron range-energy curve. The energy distribution was then corrected for this effect, and a Kurie plot analysis made.

An "allowed" plot of the data, not corrected for resolution or the above-mentioned surface effect, is shown in Fig. 1. The convexity of this plot is a good indication that the deviation from an allowed shape is real. The "allowed" plot of the corrected data Fig. 2 ($c=1$), is quite nonlinear. The result of applying the unique axial vector or tensor theoretical correction factor corresponding to the known spin change of four, and assuming a parity change, is shown in Fig. 2 ($c=c$). The fit to a straight line is quite good, in agreement with recent measurements.[5-7] However, the deviations from linearity are much smaller in the present experiment. This confirmation, by a different method, of agreement with theory for a third-forbidden transition, further strengthens the evidence for the correctness of either the axial vector or tensor interaction in beta-decay.

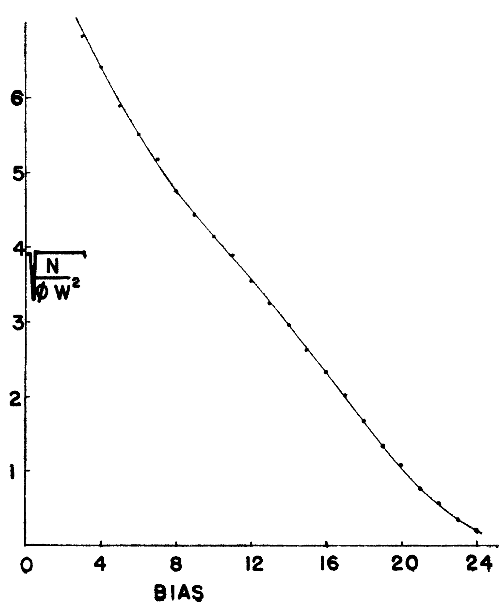

FIG. 1. "Allowed" Kurie plot of uncorrected data.

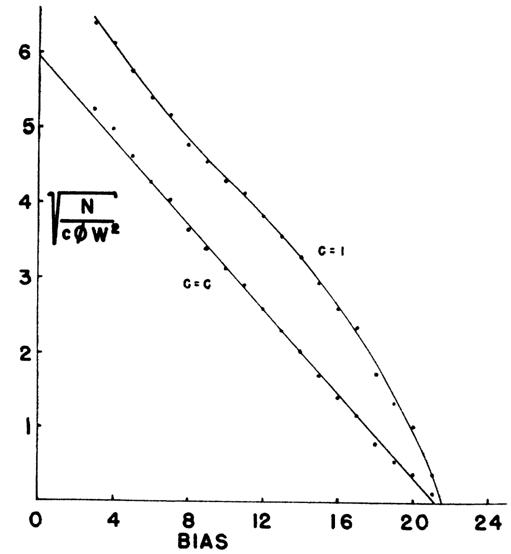

FIG. 2. Kurie plot analysis of corrected data.

The end point energy obtained is 1.28±0.03 Mev, somewhat lower than previous measurements.[5-7]

The linearity of the Kurie plot allows an extrapolation of the total counting rate to zero energy to be made easily. In this way the beta-decay rate was measured as 27.1±0.6 betas/sec/gram K, or $\lambda_\beta=4.67\pm0.15\times10^{-10}$ yr^{-1} (using the relative abundance K^{40}/K of $1.19\pm0.01\times10^{-4}$ given by Nier[8]). This has been corrected for all the effects mentioned above, using integral forms of the corrections. The value is in agreement with that of Sawyer and Wiedenbeck,[9] who also used a 4π geometry. They obtained 28.3±1.0 betas/sec/gram K.

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Contribution to the Theory of Impurity Centers in Silicon

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AN electron bound to an impurity is usually treated like a hydrogen atom in which the electrostatic force is reduced by the dielectric constant ϵ of the crystal.[1] We shall use a more detailed treatment for a phosphorus impurity in silicon.

The electron moves in the field of the ion, in the dipole field of the polarized atoms, and in the periodic field of the crystal. The atoms are polarized by the ion and electron charge and by all other dipoles. The polarizability of a silicon atom $\alpha=3.81A^3$ is obtained from the equation of Clausius-Mosotti with $\epsilon=13$. The