Value of the Li(p,γ) Resonance*

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THE recent publication by Herb, Snowdon, and Sala[1] of the value of the first strong resonance in the F(p,γ) reaction now makes possible a more certain determination of the value of the Li(p,γ) resonance which is known to occur at about 440 kev. The F(p,γ) resonance occurs at 873.5 kev,[1] with an uncertainty of about 0.1 percent; we shall designate this value as V_F.

A preliminary report[2] of a comparison of the fluorine resonance and of the lithium resonance as observed with the diatomic beam (at voltage $2V_{Li}$) has been published. We have since made several additional determinations of the quantity ($2V_{Li}-V_F$) or ΔV, originally reported as 20 ± 6 kev. In our first calculations, the value used for the relative stopping power of a target for protons of energy V_{Li} and V_F was too low; this was also called to our attention by Dr. W. A. Fowler, who has kindly sent us the results on similar measurements[3] on the quantity ΔV which were made at the California Institute of Technology.

A plot of the data of a typical run on a thin target is shown in Fig. 1, and other data are given in Table I.

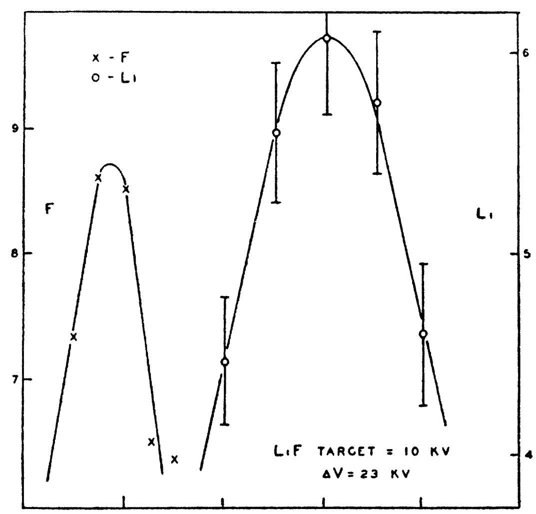

FIG. 1. Position of the first strong resonance in F(p,γ) relative to the Li(p,γ) resonance as observed with the diatomic beam. Voltmeter reading in 10 kv units.

TABLE I. Values of $\Delta V(2V_{Li}-V_F)$ for several runs.

Run No.	Target	Thickness (kev)	ΔV_0*	ΔV
1	LiF	7.5 Thick	8	11.7
2	LiF	13	26	10.8
3	LiF	10	23	11.3
4	LiF	Thick	13	13
5	MnF_2 LiCl	Thick Thick	13	13
6	LiF	15	28	11.4

* ΔV_0 = observed difference between resonance peaks.

Runs were kept as short as possible consistent with obtaining a reasonable statistical accuracy, since we wished to avoid deposition of any film or deterioration of the targets. Gamma-rays were detected by coincidence counters. In order to make certain that no gamma-rays were counted when the lithium resonance was under observation, we placed a centimeter of aluminum between the two counters.

In resolving the data for thick targets, we have measured the voltage difference at half intensity for each resonance curve. For thin target data, we have observed the width of each resonance; the true resonance widths are assumed to be 5.2 kev[4] for the fluorine resonance and 12 kev[5,6] for the lithium resonance as observed with the atomic beam (corrected for continuous radiation). Actual target thickness was then calculated, and in all cases reported this thickness was essentially the same for any pair of runs in which the same target was utilized. Targets were also weighed, and, assuming that 1 kev of equivalent thickness corresponds (at V_F) to slightly over 4 micrograms/cm^2 of LiF, target thickness was computed. The agreement between the values was always satisfactory within estimated limits of error.

The stopping power of LiF for protons at V_{Li} and at V_F was assumed to be in the same ratio as the corresponding value for air, or approximately 1.67.[7] Since the voltage scale for the diatomic beam is doubled, we may write for the true difference between the two resonances $\Delta V=\Delta V_0-1.17t$, where ΔV_0 is the observed difference and t is the thickness of the target for protons of energy V_F.

The existence of thin films[8] on targets would lead to spurious results, and in particular would increase ΔV_0. This may account for the slightly higher values observed with thick targets, which were prepared without heating, but the 1 kev[6] asymmetry correction applied to thick targets of Li compounds may be slightly low. Thin targets were prepared by evaporation. In one case, we heated a thin target to 200°C, then later to 260°C, but no shift in the position of the fluorine resonance was observed.

We tend to weight our data, therefore, to the low side of the average, and believe that $\Delta V=11.2$ kev, the average of the thin target data, is probably closest to the true value. Using $V_F=873.5$, one obtains $V_{Li}=442.4$ kev, with an estimated over-all error of about 1.5 kev.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
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[3] W. A. Fowler, private communication. We are indebted to Dr. Fowler for calling this to our attention and for a summary of his results. We have used the same constants (references 4–7) in evaluating our data, and our results are in agreement within about 0.5 kev.
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Disintegration of Cs^{137}

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DECAY by the emission of a single group of beta-rays with an end point of 0.550 Mev to a metastable state of Ba^{137} (156 secs.) has been reported for Cs^{137} (33 years).[1,2] From this state an internally converted gamma-ray of energy 0.663 Mev is emitted. A simple decay scheme was suggested from these results. Mitchell and Peacock[3] measured the ratio N_K/N_L for the internally converted electrons as well as the internal conversion coefficient $\alpha_K{}^l$. Their measurement of these quantities, as well as the known half-life for the metastable state, indicate that the transition Ba^{137} (metastable)→ Ba^{137} is electric 2^5 pole. They also pointed out certain difficulties with the proposed decay scheme.

In the present experiments the beta-ray spectrum of Cs^{137} has been measured using a 180-degree type magnetic spectrometer of about one percent resolving power. The detector consisted of a Geiger-Mueller counter with a thin Zapon window which will detect electrons of 3 kev and above. The source had a surface density of not greater than 0.1 mg/cm^2 mounted on Zapon of 0.01 mg/cm^2.

The spectrum consists of two groups—the main group having an energy of 0.521 Mev and relative abundance 95 percent and a much weaker group having an energy of approximately 1.2 Mev and relative abundance 5 percent. Figure 1 shows a Fermi plot of the low energy group. In this plot the Coulomb factor has been corrected to the atomic number of barium ($Z=56$). The shape of this plot does not indicate an allowed transition since it is distinctly concave toward the energy axis.

A thicker source was used to investigate the higher energy beta-rays since this group is only 5 percent abundant. A Fermi plot of the results is shown in Fig. 2, in which a maximum energy of approximately 1.2 Mev is indicated. The shape of this plot may not be significant due to the low intensity.

The energy of the gamma-ray causing the internal conversion electrons has been remeasured and found to be 0.669 ± 0.005 Mev. In addition a line of very low intensity appears at 25 kev and can be ascribed to Auger electrons arising as a result of the internally converted gamma-ray. The gamma-ray and the two beta-ray groups appear to form a consistent energy level scheme.

Since the spectrum of the low energy group is the first case which has been found in which the Fermi plot is concave toward the energy axis, although such a shape has been predicted for some time, we have endeavored to fit various shape factors, as given by Konopinski and Uhlenbeck[4,5] to these data. The (ft.) value for the low energy group is 2.3×10^9 and that for the high energy group 1.4×10^{12}. One would suppose, therefore, that the low energy group is second forbidden, which entails no change of parity, and the high energy group third forbidden. In order to fit the data to a theoretically forbidden shape, it is necessary to multiply the allowed $F(Z, W)$ by certain coefficients C_2, given by Konopinski in his article, and see if the plot $(N/F(Z, W_0)\cdot C_2)^{\frac{1}{2}}$ against the total energy gives a straight line. Using Gamow-Teller rules, the coefficients C_2 depend on certain combinations of matrix elements (S_{ijk} for $\Delta_j=\pm 2, \pm 3$; T_{ij}, A_{ij} for $\Delta_j=\pm 2$) together with certain energy dependent factors a, c, D_+, D_-, and E.

The best fit to the data for the low energy group, is obtained using the quantity a only. This gives a remarkably good straight line as is shown in Fig. 3 and Fig. 1b. The curve obtained using c is also shown for reference, from which it will be seen that a curve, concave upwards, is obtained. The only coefficient containing c alone is C_{2A} (axial vector) with $\Delta_j=\pm 3$ and $S_{ijk}\neq 0$. It would appear, therefore, that $\Delta_j=\pm 3$ is ruled out. Of the remaining second forbidden type shape factors (G-T rules) all contain combinations of the matrix elements A_{ij}, T_{ij}, and S_{ijk}. Several of these curves have been plotted in Fig. 3 for various values of the ratios $T_{ij}/A_{ij}=x$, $S_{ijk}/A_{ij}=y$, and $S_{ijk}/T_{ij}=Z$. The shape of these curves is extremely sensitive to these ratios and no fit can be obtained for a second forbidden shape except for A_{ij} very large compared to the other quantities. This, of course, may happen perhaps through the operation of further selection rules than those on total angular momentum and parity.

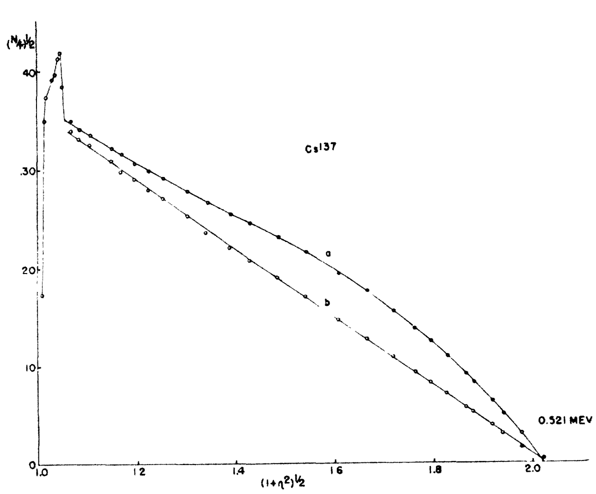

FIG. 1. (a) Fermi plot of low energy beta-ray group in Cs^{137}. (b) Best fit to data using the quantity a only for the correction factor.

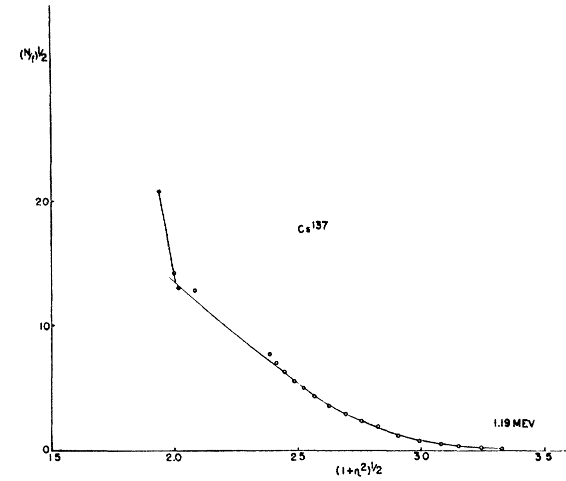

FIG. 2. Fermi plot of high energy beta-ray group.

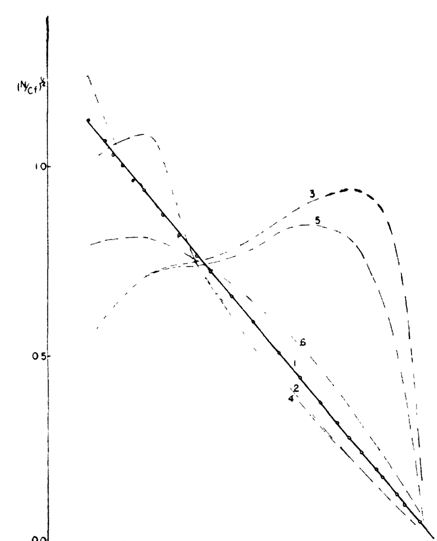

FIG. 3. Fermi plots of the low energy group of beta-rays of Cs^{137} corrected as follows:

(1) $C=a$ only
(2) $C=c$ only
(3) $C=C_{2T}$ with $x^2=1/30$ and $S_{ijk}=0$
(4) $C=C_{2T}$ with $x^2=0.01$ and $S_{ijk}=0$
(5) $C=C_{2T}$ with $x^2=1/30$ and $y^2=0.28$
(6) $C=C_{2A}$ with $Z^2=8.4$

In the first forbidden interactions, however, the coefficients C_{1T} and C_{1A} contain a alone. It seems likely, therefore, that the low energy group belongs to the first forbidden class with a spin change $\Delta_j = \pm 2$, and a change of parity. If this be first forbidden, the long lifetime would have to be attributed to selection rules other than those considered in the general theory. The high energy group could be second forbidden with $\Delta_j = \pm 3$ and no change of parity. On this basis, one would predict a spin of 9/2 for Cs^{137}.

We are indebted to Professor E. J. Konopinski for many helpful discussions. This research was supported jointly by the Office of Naval Research and the Atomic Energy Commission.

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Charged Particles Emitted by Carbon Bombarded by 90 Mev Neutrons

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SECONDARY charged particles from nuclei bombarded by 90 Mev neutrons[1] produced in the 184-inch cyclotron of the University of California Radiation Laboratory were examined in a series of preliminary experiments by Herbert F. York. He measured the range of these particles at various scattering angles from the neutron beam using a telescope of proportional counters. His preliminary results indicated that, if the particles were all protons, the energy distribution in the forward direction showed a broad maximum at about 40 to 50 Mev and the number per unit solid angle fell to half value at about 12 degrees. This result was difficult to reconcile with the ideas of a semi-transparent nucleus which seemed to indicate that a forward peak of protons with energies near 80 Mev was to be expected. Further, the relatively low energy maximum of the observed protons was difficult to reconcile with the pronounced forward angular peak. It was expected theoretically that large energy loss would be associated with several collisions of the emitted particle in the nucleus and a resulting more isotropic angular distribution.

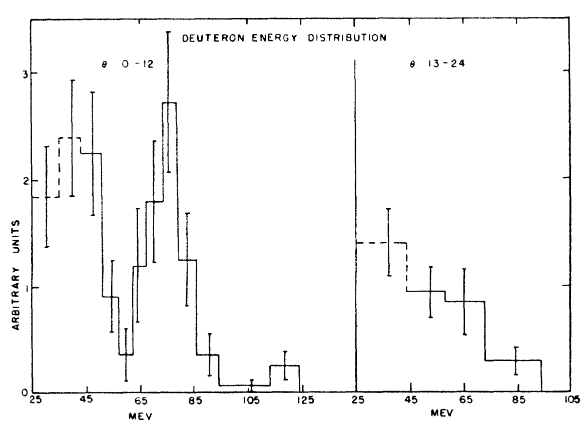

FIG. 1. (a) Energy distribution of the deuterons leaving carbon within 12° of the neutron beam. (b) Energy distribution of the deuterons leaving carbon with angles between 13° and 24° from the neutron beam. The errors indicated are standard deviations based only on the number of tracks used to determine the values.

It occurred to us that some of these particles might be deuterons, because in earlier cloud-chamber experiments, tracks had been observed with momenta too high to be accounted for by the known neutron energy distribution. Further experiments were made immediately by Herbert F. York,[2] Hugh Bradner,[3] and us[4] to find out what was taking place, and the results obtained with a cloud chamber are reported here.

A 22-inch cloud chamber with a magnetic field of 21,700 gauss was used. The neutron beam collimated to $\frac{1}{2}'' \times \frac{1}{2}''$ was passed along a diameter of the chamber, through a $\frac{1}{8}''$ carbon target, and through a $\frac{3}{4}'' \times \frac{7}{8}''$ hole in a $\frac{1}{8}''$ glass absorbing plate. The glass plate was located in the center of the chamber normal to the neutron beam direction, and the carbon target was 8 inches from the glass. A fraction of the secondary particles from the carbon struck the glass absorber and could be identified by $H\rho$ before and after passing through the glass. The lighted region of the chamber limited the measurement of tracks to those which struck the glass absorber along a strip $9'' \times 1.1''$.

Protons with energies from 32 to 107 Mev, deuterons from 25 to 124 Mev, and tritons from 56 to 95 Mev could be identified with very small uncertainty in the type of particle and about a ±6 percent probable error in energy. The angular range from 0 to 36° was included, with a probable error of about ±2° in angle.

386 recoil particles were measured and identified as 202 protons, 162 deuterons, and 22 tritons. The energy distributions of the protons and deuterons in the angular intervals of 0–12 degrees and from 13–24 degrees are given in Figs. 1a and 1b. The angle at which the angular distribution per unit solid angle drops to half maximum is given in Table I. The

TABLE I. Angular width at half maximum.

	Protons
32–62 Mev	Isotropic within probable errors
62–98 Mev	18±3 degrees
	Deuterons
30–58 Mev	18±3 degrees
58–93 Mev	11±2 degrees

data have been corrected for the geometry of the experiment and for the finite thickness of the carbon target. These corrections are less than 20 percent for the major part of the data.

Further analysis of 207 deuterons with energies above 50 Mev has confirmed the presence of the distinct group of deuterons at 70 Mev indicated in Fig. 1a.

TABLE II. Cross sections.

	Protons, Energy 32–107 Mev
0–12°	3.7±1.8 millibarns
13–24°	7.6±3.8 millibarns
	Deuterons, Energy 25–124 Mev
0–12°	2.9±1.5 millibarns
13–24°	4.5±2.2 millibarns

The cross sections for these phenomena can be estimated from other cloud-chamber work. It has been found that in carbon and oxygen stars produced by 90 Mev neutrons, 12±3 percent give high energy particles which would have been included in this analysis. Theoretical and experimental work[5] indicate that the cross section for star formation, i.e., for the emission of a charged particle from the nucleus, is about $\frac{1}{3}$ of the total carbon cross section of 0.550±0.011 barn[6] and can be taken as 0.20±0.05 barn with sufficient accuracy