that it is usually assumed that 85 percent of the decays lead to the energetic Auger transitions, whereas only 65 percent are observed. It is possible that an understanding of this can be obtained by considering a little more in detail the process in which initially a K electron in A^{37} is captured, but where the resulting Cl^{37} atom is formed with a vacancy in the L shell due to the radial correlation between the electrons.[5]

[5] P. Benoist-Gueutal, Ann. Physik 8, 593 (1953).

The author wishes to express his thanks to Professor N. Bohr for his interest in this work. I am also grateful to Mr. A. Nielsen for valuable assistance in the experimental work. A detailed description of the instrument and the results obtained with A^{37} will appear in Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. A discussion of the charge spectrum together with radius of K to L capture and Auger probabilities will be given by A. Winther.

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Energy Levels in $_{66}Dy^{160}$†

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An energy level diagram for $_{66}Dy^{160}$ is proposed which is consistent with most of the experimental data on this activity, as well as with further data reported here. Levels are proposed at 86.2, 282, 496, 962, 1196, 1259, 1352, and 1532 kev. Beta spectra of 851±10, 557±15, 461±20, and 280±40 kev have been observed and support the diagram.

INTRODUCTION

Neutron capture in Tb^{159} leads to Tb^{160} which then decays by beta-minus emission to Dy^{160}. In common with several other even-even nuclear products around this mass number region, a relatively large number of conversion groups were observed by early investigators.[1] Subsequent investigations[2,3] have consistently increased the number of observed transitions, particularly in the higher-energy regions. Reports on the accompanying beta spectra have also varied, not only as to the number and intensities of the spectra, but also in the end-point values. Burson *et al.*[4] recently have summarized in some detail the available information on this activity. In addition, they have reported some new information and have proposed an energy level diagram. In this investigation, additional information has been obtained which suggests a different diagram.

EXPERIMENTAL RESULTS

Gamma Rays

More than seventy gamma rays have so far been observed and classified as to energy. These radiations were detected both through their conversion electrons and by photoelectric analysis, employing lead, tin, and molybdenum radiators. Over eighty beta-ray spectrographic plates have been taken so far with exposure times ranging from a few minutes to several weeks. Magnetic fields ranging from 100 to 800 gauss were used.

Of the many gamma rays observed, twenty-nine of the more intense lines have been incorporated into the decay scheme of Fig. 1, and are presented in Table I.

Beta Spectra

Figure 2 shows a plot of the normalized electron spectrum of Tb^{160} obtained at about 1 percent resolution. The portion of the spectrum below 150 kev is omitted since the density of the source, with backing, was of the order of a few milligrams per square centimeter. Comparison of this source density with those studied by Shull[5] indicates that source scattering effects become noticeable for energies around and below this value.

As remarked earlier, reports on the Tb^{160} beta spectra have shown considerable disagreement among various writers. It is felt here that the major cause of this lack of consistency arises from the presence of a large number of previously unrecognized weak conversion groups superimposed upon the continuous spectrum. Several different runs of the spectrum of Fig. 2, in the 300- to 800-kev region, consistently showed clusters of points several percent too high to allow fitting them with a smooth beta-spectrum type curve. Subsequent observation of spectrographic plates revealed weak conversion groups in the vicinity of all such high point regions. For example, in the region

† Sponsored by the U. S. Atomic Energy Commission.
[1] Cork, Shreffler and Fowler, Phys. Rev. 74, 240 (1948).
[2] Cork, Branyan, Rutledge, Stoddard, and LeBlanc, Phys. Rev. 78, 304 (1950).
[3] Burson, Blair, and Saxon, Phys. Rev. 77, 403 (1950).
[4] Burson, Jordon, and LeBlanc, Phys. Rev. 94, 103 (1954).

[5] F. B. Shull, Phys. Rev. 74, 917 (1948).

2500 to 2750 $B\rho$ of Fig. 2, limited by the letters *b-c*, three weak conversion groups were observed. On the other hand, no groups were observed in the vicinity of the low point *a*. It was therefore assumed that the low points such as *a* should be taken as points on the beta spectrum. The smooth, solid curve of Fig. 2, determined below 2800 $B\rho$ by the low points, is therefore interpreted as the contribution of the continuous spectrum, while the portions of the total spectrum above this curve represent the contributions of conversion groups.

Figure 3 presents the four spectra of allowed shapes obtained by Fermi-Kurie analysis of the smooth curve of Fig. 2. The end points and estimated uncertainties of the spectra are 851±10, 557±15, 461±20, and 280±40 kev. The relative intensities were found to be 30, 32, 19, and 19 percent, respectively. The end-point uncertainty figures were arrived at by making alterations in the smooth curve of Fig. 2, still omitting the high regions around conversion groups. Some lower displacement of the continuous spectrum from the low points was necessary, since small line tail contributions of nearby conversion groups usually overlapped the beta spectrum contributions at these points. The end-point uncertainty figures are therefore a reflection of the uncertainty of the line tail contributions at the low points.

TABLE I. Transition energies associated with Dy^{160} shown on level diagram of Fig. 1.

Transition energy, kev[a]		Transition energy, kev	
FG	64	*CE*	679
AB	86.2[b,c]	*DG*	762[b]
GH	93 [b,c]	*DH*	856
FH	156	*BE*	876[b,c]
HJ	181	*CF*	915
BC	196 [b,c]	*AE*	962[b,c]
CD	214 [b,c]	*CG*	976
EF	234	*DJ*	1034
GJ	274	*BF*	1110
AC	282 [c]	*BG*	1173[b]
EG	297 [b,c]	*AF*	1196
EH	391 [b,c]	*CJ*	1250
BD	411 [c]	*BH*	1266[b]
DE	466	*BJ*	1447
EJ	569		

[a] Letter notations adjacent to transition energies refer to levels shown on Fig. 1. All transitions listed are supported by both conversion lines and radiator lines. Molybdenum and tin radiators were effective for transitions below 200 kev.
[b] Transitions observed by Burson *et al.* (see reference 4).
[c] Transitions also listed by Cork *et al.* (see reference 2).

Electron-Electron Coincidences

Magnetic-focusing coincidence-spectrometer studies, similar to those described by Fowler and Shreffler,[6] indicated that the *L*-conversion group of the 86.2-kev transition was in coincidence with the *K*-conversion groups of both the 196- and 297-kev transitions. These transitions are shown as *AB*, *BC*, and *EG*, respectively, on Fig. 1.

[6] C. M. Fowler and R. G. Shreffler, Rev. Sci. Instr. **21**, 740 (1950).

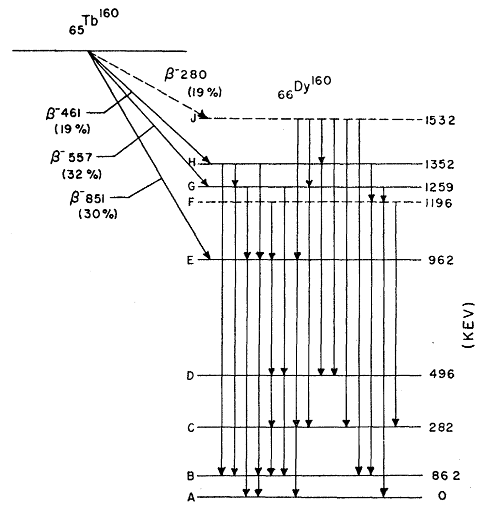

FIG. 1. Proposed energy level diagram for Dy^{166}.

Half-Life Measurements

A single half-life of 72.3±0.5 days has been observed over a time span of nine cycles. The importance of this observation is that it virtually precludes the presence of any activity other than that of Tb^{160}. It is therefore felt that all of the gamma transitions observed here belong to the single activity leading to Dy^{160}.

DISCUSSION

Figure 1 presents features of the energy level diagram of Dy^{160} which are felt to be reasonably well confirmed. The following arguments may be advanced in support of the diagram.

The gamma-ray transition energies are consistent to within experimental accuracy, which is perhaps 1–2 kev for the higher-energy values. Although it is not at present possible to give reliable intensities, the orders of magnitude are consistent. That is, those levels to which intense transitions lead, also have transitions of similar intensity proceeding from them. The transition observed at 1447 kev, shown as (*BJ*) in Fig. 1, con-

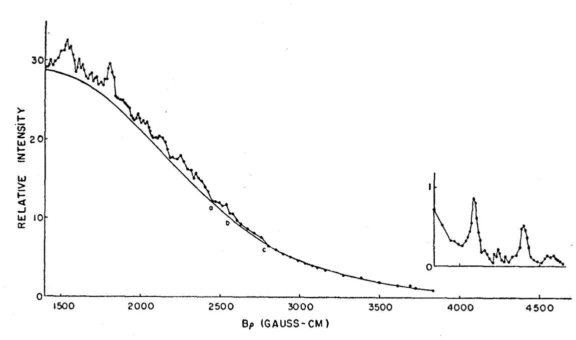

FIG. 2. Normalized electron spectrum of Tb^{160}.

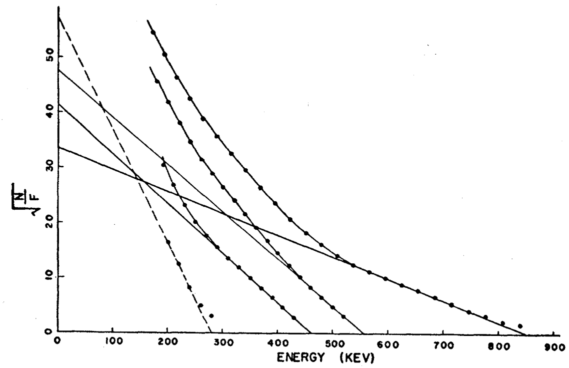

FIG. 3. Fermi-Kurie resolution of Tb^{160} for four components.

flicts with the diagram proposed by Burson *et al.*,[4] which imposes an upper transition limit of 1259 kev.

The beta-spectrum components have energy values which lend themselves to unforced fits with the diagram and again are consistent from the standpoint of intensities.

The scintillation coincidence spectrometer data obtained by Burson *et al.*[4] are interpreted readily by this diagram with one exception. These investigators found that the 214-kev gamma ray (*CD*) was in coincidence with another radiation near the strong 962-kev transition (*AE*). They accordingly postulated a transition of 957 kev which accounted for the coincidence result, and also served to support their diagram. High-energy transitions in this neighborhood, shown in Fig. 1, which should yield coincidences with the 214-kev transition are (*DH*) of 856 kev and (*DJ*) of 1034 kev. Neither transition, however, seems close enough in energy to the 962-kev transition to match the graphical data they present. There is, however, a fairly intense gamma ray of 948 kev, which has not been incorporated into the diagram of Fig. 1. Postulation of a level at 1444 kev would require the 948-kev transition to level *D*. Some other observed transitions, not listed here, also support such a level. The over-all evidence for this additional level however, is not as firm as that for the other levels, and it has therefore not been shown on Fig. 1.

The two levels *F* and *J*, indicated by dashed lines on Fig. 1 are subject to some criticism. Measurements of some of the very weak transitions which support these levels were not too accurate. It was also stated earlier that the uncertainty of the 280-kev beta spectrum end point was quite large.

The energies of levels *B*, *C*, and to a lesser extent *D* are fairly well in line with the Bohr-Mottelson[7] formulation. The spins and parities of these levels would therefore be expected to be 2+, 4+, and 6+. The level *E* at 962 kev also fits approximately into this formulation from an energy standpoint. However, the evidence presented here suggests a 1− assignment for this level, clearly at variance with the 8+ assignment predicted by this theory. The 1− assignment is based upon conversion coefficient data for the two intense transitions *EA* and *EB*. The spectrometer measurements of Fig. 2, together with reasonable branching assumptions, place the *K*-conversion coefficients for those transitions between 0.001 and 0.004. On the other hand, rough measurements of photoelectron intensities along with the *K*-conversion ratios, show that the conversion coefficients are about the same for these transitions. These requirements, coupled with the 0+ and 2+ designations of levels *A* and *B*, lead most plausibly to a 1− assignment for level *E*.

It should finally be remarked that a large number of weak transitions observed have not yet been incorporated into the proposed level diagram. There are, perhaps, a few more higher-energy levels such as those already listed in Fig. 1, which would account for some of these transitions. It is the feeling here, however, that some of the low-energy levels already listed exhibit a fine structure in the sense that there are close-lying levels near them. A number of the weak transitions observed but not shown on Fig. 1 can be explained as transitions to or from such levels, although the evidence is based solely upon transition energy measurements. For example, a number of very weak low-energy transitions have been observed which would support levels near *B* of 80, 84, and 95 kev, and levels of 275 and 285 kev near *C*. Work is still in progress on this phase of the investigation.

[7] A. Bohr and B. R. Mottelson, Phys. Rev. **90**, 717 (1953).