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Radiative Capture of Thermal Neutrons by Cd^{113}

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Study of the radiative capture of thermal neutrons by Cd^{113} with a scintillation spectrometer gave 9.20 Mev as the neutron binding energy of Cd^{114}, and nuclear levels at 0.57, 1.33, 2.63, 3.49, 4.03, and 4.43 Mev. The relationship between the resolution of the spectrometer and gamma-ray energy is shown.

STUDY of neutron capture gamma-radiation affords a convenient method for the investigation of the energy level structure of the product nucleus. From data obtained with a conventional magnetic pair spectrometer, Kinsey[1] has recently proposed level schemes for several isotopes. Preliminary work with a scintillation spectrometer[2] indicated the value of this approach to the problem, and it is our object to present certain new results concerning, in particular, the gamma-rays arising from the reaction

$$Cd^{113}+n^{1}\rightarrow Cd^{114}+\gamma.$$

Because of the high capture cross section of Cd^{113} for thermal neutrons, this reaction is particularly well suited to the method in question.

The pulses from the scintillation spectrometer (E.M.I. 5311 photomultiplier, $\frac{3}{4}$-in. cube NaI-Tl crystal) were analyzed with a 5-channel kicksorter (Harwell Type 1074 A). The cadmium target was in the form of metallic foil shaped to fit snugly over the crystal. Slow neutrons which were absorbed by the cadmium gave rise to capture gamma-radiation, some of which was detected by the crystal. Neutrons from a 400-mC RaD−Be source were thermalized in a paraffin block, and a 3-in. lead plug was used to absorb gamma-rays coming from the source.

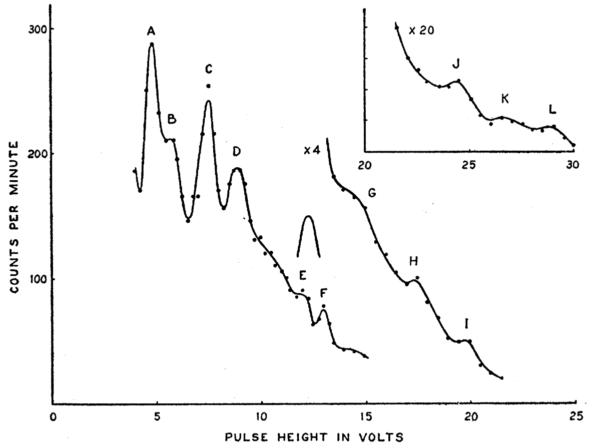

FIG. 1. Scintillation pulse-height distribution for the gamma-rays produced in the reaction $Cd^{113}(n,\gamma)Cd^{114}$. The distribution has been corrected for background radiation.

The spectrum of pair lines associated with the neutron capture gamma-radiation from cadmium, corrected for background, is shown in Fig. 1. With the exception of A, we interpret all the main features of the distribution as being due to the creation of electron pairs in the crystal by high energy gamma-rays. The crystal is sufficiently small for the escape of most of the annihilation radiation to take place, so that the lowest energy pair line ($E_{\gamma}-1.02$ Mev) predominates in each case. The nature of feature A will be discussed shortly. Just above E and F the location of the well-known Po−Be pair line is indicated.[3] This line was used to calibrate the pulse-height axis assuming proportionality of the device for high energy gamma-rays. No evidence for any lack of linearity in the spectrometer was found during the course of this work. Feature L, the pair line of a 9.20-Mev gamma-ray, is associated with the ground-state transition and gives a measure of the binding energy of the last neutron in the Cd^{114} nucleus. The gamma-ray energies of the features of Fig. 1 have been listed in Table I together with some results due to Kinsey,[4] and it can be seen that the two sets of results are reasonably consistent. Energy sums can be selected for those gamma-rays which appear to be in cascade:

$$\left.\begin{aligned} K+0.57\,[5]&=9.12\text{ Mev},\\ J+A&=9.25\text{ Mev},\\ I+B&=9.22\text{ Mev},\\ H+D&=9.34\text{ Mev},\\ E+F&=9.14\text{ Mev},\\ F+C+A&=9.18\text{ Mev}.\end{aligned}\right\}\quad \text{Mean}=9.21\text{ Mev}.$$

Clearly these sums are in good agreement with the energy of the ground-state transition as determined from feature L.

It was realized that determination of the relative intensities of the gamma-rays was complicated by the presence of several Compton distributions, and by the variation of detection efficiency of the spectrometer with energy. A decay scheme, shown in Fig. 2, was drawn up which was consistent with the energies quoted

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[1] See Kinsey, Bartholomew, and Walker, Phys. Rev. **85**, 1012 (1952), for references to earlier work by this group.

[2] R. W. Pringle and G. Isford, Phys. Rev. **83**, 467 (1951).

[3] Pringle, Roulston, and Standil, Phys. Rev. **78**, 627 (1950).

[4] Private communication from Dr. Bartholomew.

[5] Mei, Mitchell and Zaffarano, Phys. Rev. **76**, 1883 (1949); C. T. Hibdon and C. O. Muehlhause, Phys. Rev. **87**, 222 (1952).

TABLE I. Gamma-ray energies associated with the $Cd^{113}(n,\gamma)Cd^{114}$ reaction.

Feature	γ-ray energy (Mev) Kinsey	Present determination
A	...	1.33
B	...	2.61
C	...	3.14
D	...	3.49
E	4.58	4.43
F	4.82	4.71
G	5.26	5.17
H	5.96	5.85
I	6.60	6.61
J	7.81	7.92
K	8.50	8.55
L	9.33	9.20

above, the shape of the pulse-height distribution, and the known variation with energy of the relative cross sections for the photoelectric and pair production processes in iodine.

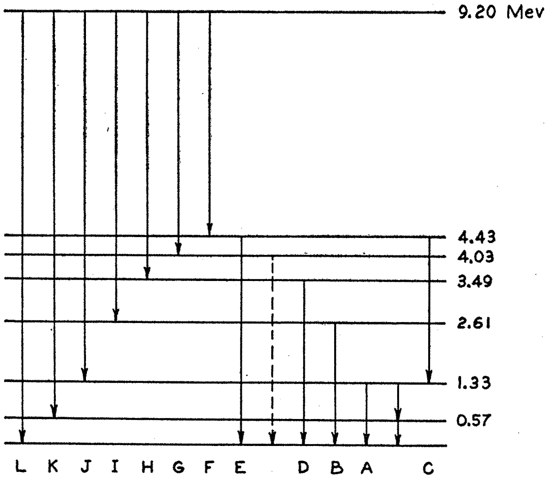

FIG. 2. Level scheme for Cd^{114} proposed on the basis of the Fig. 1 results.

Two levels in Cd^{114}, one at 0.57 Mev and the other at 1.27 Mev, seem to be well established[5] from a study of the *K*-capture process in In^{114}. Feature *A* was assumed to be a photoelectric, rather than a pair, line corresponding, within experimental error, to the ground state transition from the 1.27-Mev level. The gamma-ray arising from a transition between the level at 4.03 Mev and the ground state was not observed although the shape of the pulse-height distribution between *D* and *E* suggests the possible existence of such. A transition between the 1.33 and 0.57 Mev levels (Mei *et al.*, reference 5) suggests that a feed to the former other than *J* should be present in the scheme. It was observed that *C* could serve as a feed to the 1.33-Mev level and thus resolve the difficulty.

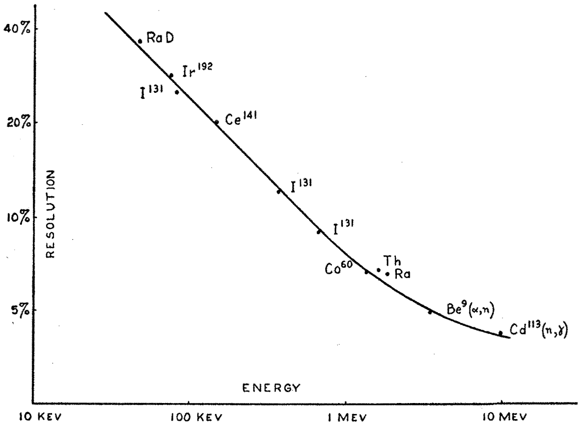

FIG. 3. Resolution—energy relationship for the scintillation spectrometer.

In view of a few additional gamma-rays which were found by Kinsey *et al.*, it is clear that the level scheme proposed here is incomplete, for it must contain only those levels associated with the most intense gamma-rays of the capture gamma-ray spectrum.

The radiative capture of slow neutrons by aluminum and chromium has also been studied by this method. Gamma-rays from excited states in aluminum were found at 7.20 and 7.70 Mev, the latter in good agreement with work done by Kinsey,[6] and in chromium at 8.17 and 9.35 Mev. Intensity and resolution difficulties prevented the precise measurement of a number of gamma-ray energies below those quoted above.

In this neutron capture gamma-ray analysis a large energy range is covered and it is important to know how certain properties of the spectrometer vary as functions of energy. Figure 3 serves to indicate the resolution-energy relationship which has been attained. The resolution is defined as the full width of a line at half height. It will be noted that a resolution of 4 percent is obtained at an energy of 10 Mev.

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[6] Kinsey, Bartholomew, and Walker, Phys. Rev. **83**, 519 (1951).