Conversion Coefficients of Low-Energy Gamma Radiation Following the Decay of ^{81}Se and ^{81m}Se

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A Ge(Li) γ-ray spectrometer and a Si(Li) electron spectrometer were standardized for measurements of internal-conversion coefficients using γ transitions of well-known α_K and α_L values from standard sources. The internal-conversion coefficients of four γ transitions in ^{81}Br and one in ^{81}Se have been measured. The results for the conversion coefficients are as follows: ^{81}Se, 103 keV: $\alpha_K = 7.1 \pm 0.3$, $\alpha_L = 1.6 \pm 0.3$; ^{81}Br, 178 keV: $\alpha_K < 0.05$, $\alpha_L < 0.003$; 260 keV: $\alpha_K = 0.038 \pm 0.001$, $\alpha_L = 0.005 \pm 0.002$; 276 keV: $\alpha_K = 0.009 \pm 0.001$, $\alpha_L = 0.002 \pm 0.001$; 290 keV: $\alpha_K = 0.012 \pm 0.001$, $\alpha_L = 0.002 \pm 0.001$. The multipolarities are deduced to a fair degree of certainty.

I. INTRODUCTION

The excited levels in the nuclide ^{81}Br have been the subject of a considerable number of investigations of various types. These include nuclear reactions,[1] Coulomb excitation,[2] and radioactive-decay[3-6] experiments. The results of the various investigators who have performed the latter type of experiment are not in complete agreement with each other. In the present work we have attempted to measure the conversion coefficients of the low-energy γ radiations from levels in ^{81}Br populated by the β decay of both the ground state and the 103-keV isomeric state of ^{81}Se and thus deduce the multipolarities of these radiations.

II. EXPERIMENTAL

The apparatus for the measurement of conversion coefficients is identical to the one described by the author in a previous work.[7] The method consists of simultaneously measuring the γ and electron spectra by a Ge(Li) and a Si(Li) spectrometer, respectively. The relative efficiencies of the electron and γ detectors were determined over a wide range of energies by using radioactive sources with standard γ rays of well-known internal-conversion coefficients.

The sources were mounted at the center of a thin-walled evacuated aluminum chamber. A Si(Li) detector with a depletion depth of 2 mm and area of 60 mm^2 was also mounted in the same chamber at a distance of 7.5 cm vertically above and facing the source. The detector was cooled to liquid-nitrogen temperature by means of a cold finger arrangement. For the particular detector used, the K conversion line from the γ ray following the decay of ^{137}Cs had a full width at half maximum of ~6 keV. The K conversion peak was well separated from the $L+M\cdots$ peak. A Ge(Li) detector of depletion depth 10 mm and active volume of 20.0 cm^3 was mounted directly beneath the aluminum chamber at a distance of 15 cm from the source. The following γ rays and their conversion lines were used to calibrate the system:

(i) the 145-keV line from the decay of ^{141}Ce,
(ii) the 279-keV line from the decay of ^{203}Hg,
(iii) the 442-keV line from the decay of ^{198}Au, and
(iv) the 662-keV line from the decay of ^{137}Cs.

In each case the γ and electron spectra were stored simultaneously on two analyzers in order to avoid errors due to to decay of the source, if any. If we represent the area under any conversion line A_e and the area under the full energy peak of the γ line A_γ, then the ratio A_e/A_γ must bear some relationship to the corresponding conversion coefficient a. Rather than make an involved calculation involving the efficiencies and solid angles of the detectors and the absorption of the radiations by the various materials (see Ref. 7) intervening between the source and the detector, it is simpler to make a plot of the ratio $r = 1/\alpha(A_e/A_\gamma)$ as a function of the electron energy. It is reasonable to suppose that the quantity r has a smooth variation with electron energy. The conversion coefficient of an unknown radiation can be read off from such a plot.

Radioactive sources of the 18.6-min ^{81}Se and the 57.3-min ^{81m}Se were prepared by irradiating enriched ^{81}Se metal in the Virginia Polytechnic Institute and State University Research Reactor at a flux of 10^{12} neutrons/cm^2/sec for about an hour. The sample was dissolved in nitric acid and evaporated to dryness on a piece of aluminized Mylar, and mounted on a source holder in the chamber referred to above. All the radioactive sources in this experiment were identical in size and shape and prepared by liquid deposition on 1-mg/cm^2

aluminized Mylar foil. An area of 5 mm diameter was punched out of the activated surface and mounted at the center of a Mylar foil of about 2.0 cm in diameter. The self-absorption of electrons in the source is negligible. The measurements were started only after transient equilibrium was attained between the isomeric and the ground state of ^{81}Se.

III. RESULTS

Because of the comparable lifetimes and comparable thermal-neutron cross sections of ^{81}Se and ^{81m}Se one can only produce a composite source by neutron irradiation, and thus also the composite electron and γ spectra. In Fig. 1 we show the γ spectrum below 300 keV from the Ge(Li) detector as stored in a 512-channel analyzer, and in Fig. 2 the conversion-electron spectrum from the Si(Li) detector in a 1024-channel analyzer. From several such spectra we were able to obtain the K and $(L+M)$ conversion coefficients of the 103-keV isomeric transition in ^{81}Se, the 260-, 276-, and 290-keV transitions in ^{81}Br with reasonable accuracy. We were also able to set an upper limit to the K conversion coefficient of the 178-keV transition. We have made no attempt to establish a decay scheme for the energy levels in ^{81}Br, but the one published by Zoller and Walters[6] appears to us to be the most reasonable one, which is the basis for Fig. 3. The results of our measurement of K and L conversion coefficients are summarized in Table I. We include in this table the plausible multipolarity of the γ transitions in the last column of the table.

IV. CONCLUSIONS

The measurement of the conversion coefficient of γ radiations is primarily useful for the determination of their multipolarities. By comparison with theoretically predicted conversion coefficients, one is often able to extract the mixing ratios of the various types of multipole radiations involved in a given transition. We have compared our results with the theoretical prediction due to

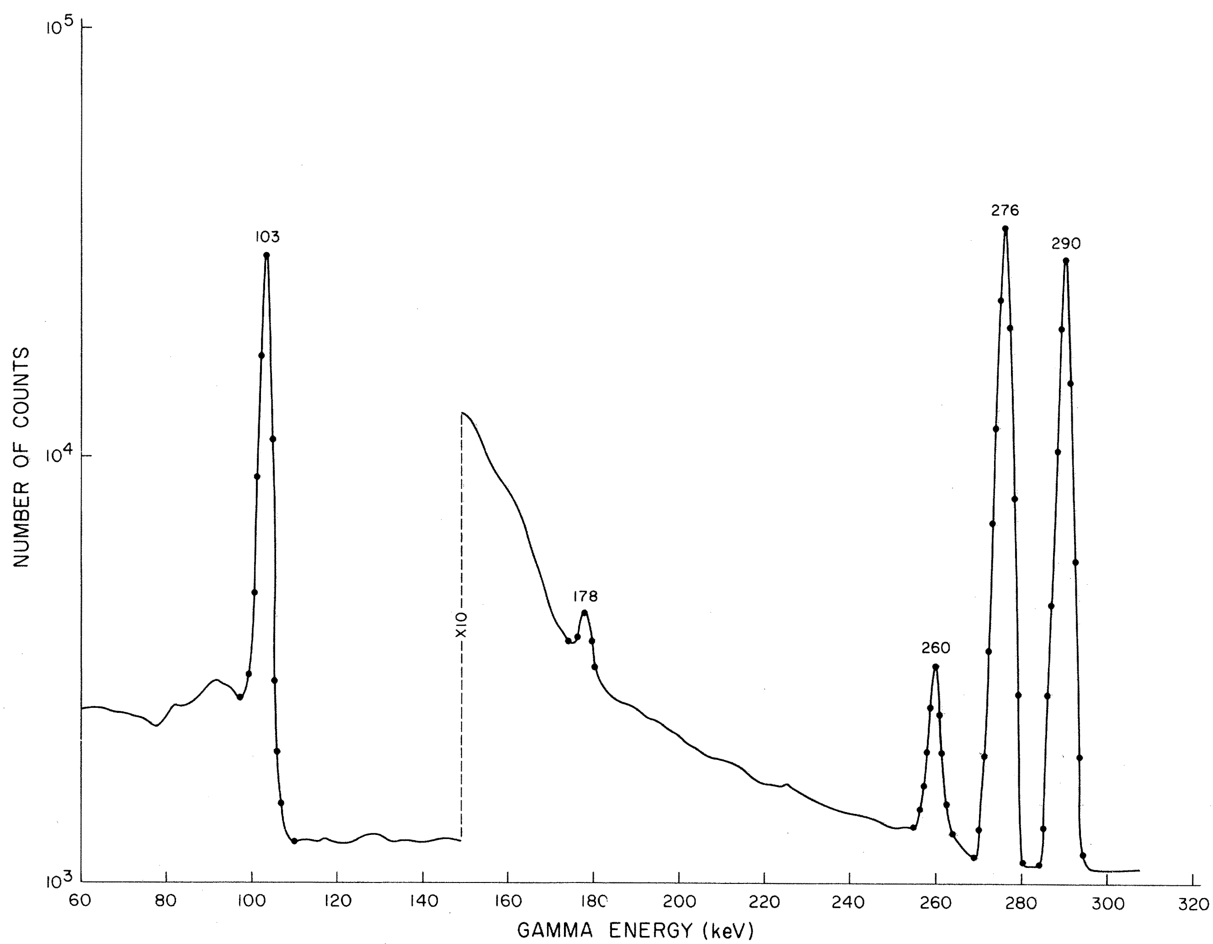

FIG. 1. Low-energy γ-ray spectrum from ^{81}Se and ^{81m}Se.

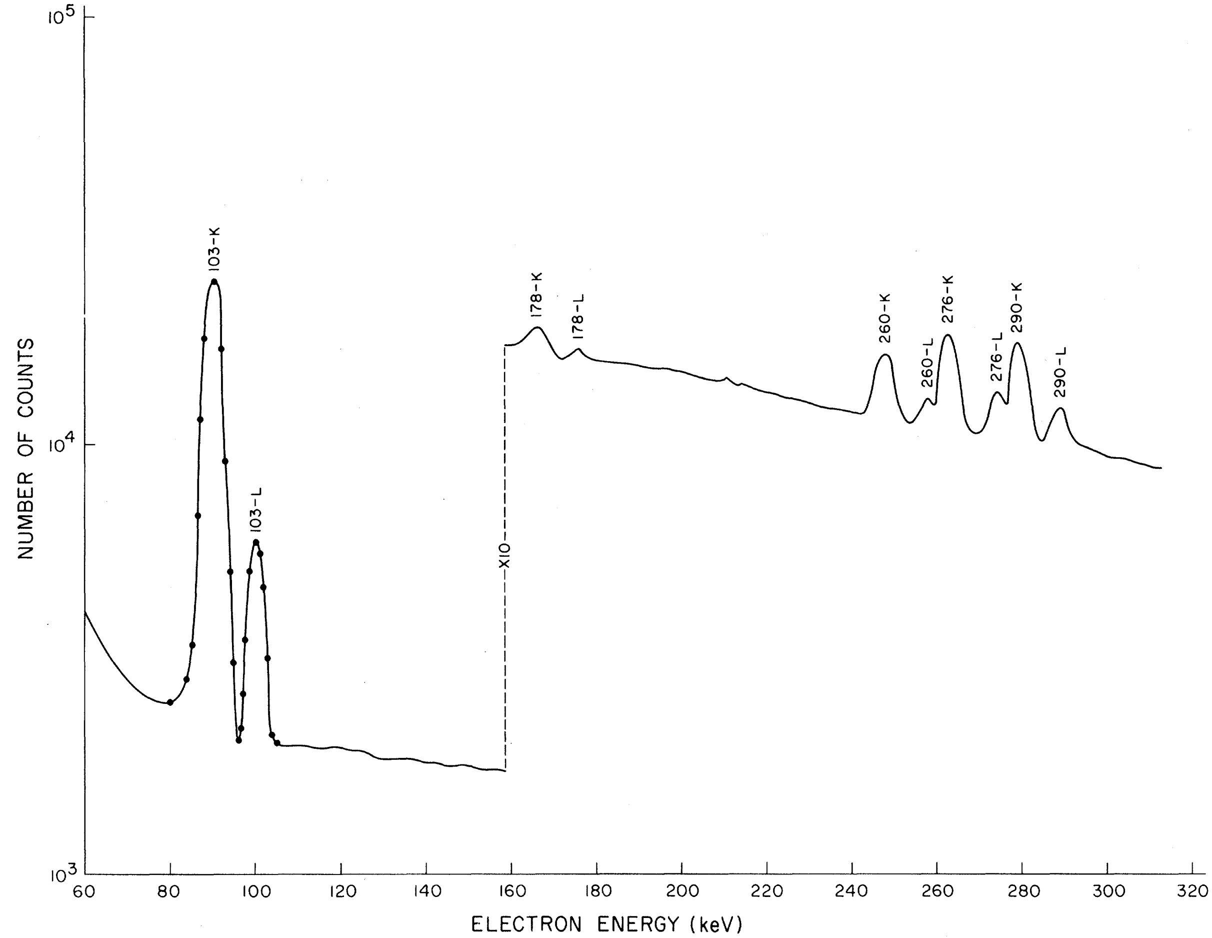

FIG. 2. Low-energy electron spectrum from ^{81}Se and ^{81m}Se.

Sliv and Band.[8]

As seen from the table, the value of $\alpha_K(7.1 \pm 0.3)$ for the 103-keV transition in ^{81}Se is consistent with the value given by Drabkin, Orlov, and Rusikov,[9] while it disagrees slightly with that of Rao and Fink.[10] The latter authors, on the basis of their measurement, have obtained a value 4.5 ± 0.6 as the percentage of $M4$ admixture in this predominantly $E3$ transition. Our results would indicate $2.6 \pm 0.5\%$. The L conversion coefficient of 1.6 ± 0.3 is not accurate enough to determine the admixture ratio to any degree of certainty, but one can place an upper limit of 3% to the $M4$ admixture ratio. It would appear then that our method of measurement, although simple in concept, is a reasonably accurate one.

The K- and L-shell conversion coefficients of the 276-keV transition from the first excited state in ^{81}Br are 0.009 ± 0.001 and 0.002 ± 0.001, respectively. This would indicate a predominantly $M1$ type of radiation with less than 20% admixture of $E2$. Wolicki, Fagg, and Geer,[11] have performed

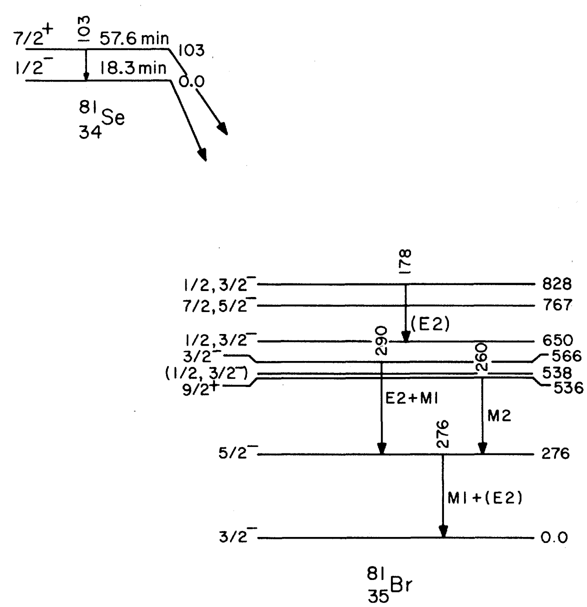

FIG. 3. The relevant level scheme of ^{81}Br.

TABLE I. K and L conversion coefficients of γ rays following the decay of ^{81}Se and ^{81m}Se; and comparison with the theoretical conversion coefficients of plausible multipole radiations.

γ-transition energy (keV)	Element	α_K Present experiment	α_K Theoretical (Ref. 8)	α_L Present experiment	α_L Theoretical (Ref. 8)	Multipolarity
103	^{81}Se	7.1 ±0.3	5.470($E3$); 70.00($M4$)	1.6 ±0.3	1.3700($E3$); 9.7000($M4$)	$E3+M4$
178	^{81}Br	<0.05	0.090($E2$); 0.023($M1$)	<0.003	0.0110($E2$); 0.0020($M1$)	$E2$?
260	^{81}Br	0.038 ±0.001	0.040($M2$); 0.020($E3$)	0.005 ±0.002	0.0049($M2$); 0.0149($E3$)	$M2$
276	^{81}Br	0.009 ±0.001	0.019($E2$); 0.007($M1$)	0.002 ±0.001	0.0022($E2$); 0.0008($M1$)	$M1+E2$
290	^{81}Br	0.012 ±0.001	0.015($E2$); 0.006($M1$)	0.002 ±0.001	0.0018($E2$); 0.0006($M1$)	$E2+M1$

Coulomb-excitation experiments on ^{81}Br and have shown that the reduced transition probability of excitation $\epsilon B(E2)_{exc}$ is of the order of 0.029×10^{-48} $e^2\,\text{cm}^4$. The value is about 15 times larger than the single-particle estimate, indicating an enhancement due to collective phenomena. The level scheme proposed by Zoller and Walters[6] would also indicate a collective character for the lower excited states. It is, therefore, a bit puzzling that this γ radiation is mostly $M1$ type, a result that is very consistent with the single-particle picture.

The K conversion coefficient 0.038 ± 0.002 and the L conversion coefficient 0.005 ± 0.002 for the 260-keV γ radiation are thoroughly consistent with $M2$ character for this transition. Thus the spin and parity assignment $\frac{9}{2}^+$ due to Zoller and Walters[6] for the 536-keV level in ^{81}Br is in agreement with the result of our measurement, because the first excited state to which this level decays is well known to have spin and parity $\frac{5}{2}^-$. The lifetime of the 536-keV level has been measured by two groups who give a value close to 37 μsec.[12,13] This result is also consistent with an $M2$ character for this transition.[14]

The 290-keV transition from the 566- to 276-keV level has K and L conversion coefficients 0.012 ±0.001 and 0.002 ± 0.001 indicating that this transition is a mixture of about 65% $E2$ and 35% $M1$ radiation. The result is consistent with the decay scheme proposed by Zoller and Walters,[6] as well as Rao and Fink.[5] Our measurement for the conversion coefficient of the 178-keV transition from the 828- to 650-keV level is not accurate enough to make any conclusive statements regarding its multipolarity. We simply include the upper limit of the coefficients in the table.

Conversion coefficients of γ radiation in the odd-Z region between 29 and 40 should provide much valuable information regarding the systematics of the $N=3$ shell. We hope to fill this need in the near future with γ rays from radioactive decay and Coulomb excitation.

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