TABLE I. Isomeric magnetic dipole transitions.[a]

Nucleus	Energy (kev)	Conversion coefficient	Assignment	Lifetime (sec)	References
Sn^{117}	162	0.10 ± 0.03	$d_{\frac{3}{2}} \to s_{\frac{1}{2}}$	$< 10^{-6}$	b
Sn^{119}	24.2	7.3 ± 1.7	$d_{\frac{3}{2}} \to s_{\frac{1}{2}}$	$< 10^{-6}$	c
Te^{121}	213	0.085 ± 0.035	$d_{\frac{3}{2}} \to s_{\frac{1}{2}}$	$< 3 \times 10^{-9}$	d
Te^{123}	159	0.18 ± 0.08	$d_{\frac{3}{2}} \to s_{\frac{1}{2}}$	$< 4 \times 10^{-9}$	e
Te^{125}	35.4	~ 15	$d_{\frac{3}{2}} \to s_{\frac{1}{2}}$	$< 4 \times 10^{-9}$	f
Xe^{131}	80	~ 0.7	$s_{\frac{1}{2}} \to d_{\frac{3}{2}}$	$(5 \pm 1) \times 10^{-10}$	g
Ba^{133}	11.7	130 ± 30	$d_{\frac{3}{2}} \to s_{\frac{1}{2}}$	$< 5 \times 10^{-7}$	h

[a] See reference 5.
[b] See reference 6.
[c] See references 7, 8, and 9.
[d] See references 10, 11, and 12.
[e] See references 10, 11, and 13.
[f] See references 13, 14, and 15.
[g] See references 16, 17, and 18.
[h] See reference 19.

Very striking evidence for a non-additivity effect is provided by the observation of magnetic dipole transitions in a number of nuclear isomers. The isomers in question are listed with relevant data in Table I;[5-19] these and other data fit very well with the predications of the spin-orbit coupled shell model.[20] On the basis of this model the magnetic dipole transitions are ascribed to one-particle transitions with

$$\Delta l = 2. \tag{1}$$

If the states were pure, the transition would be strictly forbidden for ordinary magnetic dipole effects.

Such transitions are allowed for certain forms of the interaction moment. Forms[1,21] of magnetic moment operator that have been considered in connection with H^3, He^3 are:

$$\Delta\mathbf{M} = \Sigma_{\pi,\nu}(\boldsymbol{\sigma}_\pi - \boldsymbol{\sigma}_\nu)\Phi(r_{\pi\nu}) \times \begin{cases} 1, & (2) \\ P_{\pi\nu}, & (2') \end{cases}$$

$$\Delta\mathbf{M} = \Sigma_{\pi,\nu}([\boldsymbol{\sigma}_\pi - \boldsymbol{\sigma}_\nu]\cdot\mathbf{r}_{\pi\nu})\mathbf{r}_{\pi\nu}\Phi(r_{\pi\nu}) \times \begin{cases} 1, & (3) \\ P_{\pi\nu}, & (3') \end{cases}$$

where the labels π and ν refer to protons and neutrons, respectively, Φ is a scalar function of distance, and $P_{\pi\nu}$ is the Majorana exchange operator. In addition to these terms, which are here interpreted as modifications of the intrinsic moments produced by interactions between pairs, one must also consider the exchange term[22]:

$$\Delta\mathbf{M} = (ie/2\hbar c)\Sigma_{\pi,\nu}(\mathbf{r}_\pi \times \mathbf{r}_\nu)J_{\pi\nu}P_{\pi\nu}, \tag{4}$$

where $J_{\pi\nu}$ is the neutron-proton exchange potential.

If, in accordance with the shell model, it is assumed that all nucleons except the single odd one are coupled to total angular momentum zero, it can be shown that neither Eq. (2) nor Eq. (4) can lead to the transition (1). Furthermore Eq. (3) leads to a transition matrix element, μ, of the same order as the magnetic moment anomaly in H^3 and He^3, i.e., $\frac{1}{4}$ nm. Since the magnetic dipole transition probability is

$$w = 8.5 \times 10^{11}(\hbar\omega/mc^2)^3|\mu|^2(1+\beta)\ \mathrm{sec}^{-1},$$

where β is the conversion coefficient, this value of μ is too small to account for some of the lifetime values. It seems likely that either Eq. (2′) or Eq. (3′) can lead to sufficiently short lifetimes. This point is being investigated in detail.

An investigation of the non-additivity effect on the static nuclear moments has led to the conclusion that Eqs. (2) and (3) produce a correction to the moment of only $\frac{1}{4}$ to $\frac{1}{2}$ nm. This is much too small to account for the deviations from the Schmidt lines. Contributions to static moments from Eq. (4) have been estimated by Spruch[23] but no reliable estimates were obtained for the heavy nuclei. Equations (2′) and (3′) may yield larger contributions to the static moments, but the calculation of these terms has still to be completed.

In summary, it can be said that the isomeric transitions give strong evidence for a departure from additivity of the intrinsic nucleon moments, and they impose certain restrictions on the possible forms of the interaction moment. However, it must be kept in mind that these conclusions depend on the assumption that the states are rather pure shell model states.

In order to investigate further the validity of these ideas, more precise determinations of lifetimes and of conversion coefficients for the listed transitions and other similar transitions are required. Lifetimes may provide information concerning the mixing of states or concerning the magnitude of the interaction moment. Conversion coefficients are needed to fix the magnetic dipole character of the transitions. At present this property has been established in some cases by means of the K/L conversion ratio.[20]

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[1] N. Austern and R. G. Sachs, Phys. Rev. **81**, 710 (1951).
[2] H. Miyazawa, Prog. Theor. Phys. **6**, 263 (1951).
[3] A. de-Shalit, Helv. Phys. Acta **24**, 296 (1951).
[4] F. Bloch, Phys. Rev. **83**, 1062 (1951).
[5] This table was prepared with the assistance of Professor R. D. Hill.
[6] J. W. Mihelich and R. D. Hill, Phys. Rev. **79**, 781 (1950).
[7] Scharff-Goldhaber, der Mateosian, Goldhaber, Johnson, and McKeown, Phys. Rev. **83**, 480 (1951).
[8] J. C. Bowe and P. Axel, Phys. Rev. (to be published).
[9] R. D. Hill, Phys. Rev. **83**, 865 (1951).
[10] R. D. Hill, Phys. Rev. **76**, 333 (1949).
[11] Katz, Hill, and Goldhaber, Phys. Rev. **78**, 9 (1950).
[12] M. Deutsch and W. E. Wright, Phys. Rev. **77**, 139 (1950).
[13] F. K. McGowan, Phys. Rev. **77**, 138 (1950).
[14] Hill, Scharff-Goldhaber, and Friedlander, Phys. Rev. **75**, 324 (1949).
[15] Friedlander, Perlman, and Scharff-Goldhaber, Phys. Rev. **80**, 1103 (1950).
[16] F. R. Metzger and M. Deutsch, Phys. Rev. **74**, 1640 (1948).
[17] Kern, Mitchell, and Zaffarano, Phys. Rev. **76**, 94 (1949).
[18] R. L. Graham and R. E. Bell (private communication) (1951).
[19] Hill, Scharff-Goldhaber, and McKeown, Phys. Rev. **84**, 387 (1951).
[20] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[21] F. Villars, Helv. Phys. Acta **20**, 476 (1947).
[22] R. G. Sachs, Phys. Rev. **74**, 433 (1948); erratum, Phys. Rev. **75**, 1605 (1949).
[23] L. Spruch, Phys. Rev. **80**, 372 (1950).

Half-Lives of Excited States of Hg^{199}, Xe^{131}, and Hg^{198}

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THE delayed coincidence techniques described previously[1] have been used to measure the half-lives of the 158-kev excited state of Hg^{199}, the 80-kev excited state of Xe^{131} and the 411-kev excited state of Hg^{198}, using sources of Au^{199}, I^{131}, and Au^{198}, respectively. In all cases thin radioactive sources were mounted at the center of a pair of lens beta-ray spectrometers placed end to end, so that the radiations falling on both stilbene counters of the coincidence circuit were magnetically selected. Resolving times $2\tau_0$ ranged from 2 to 6×10^{-9} second.

When the 145-kev L-conversion peak of the 158-kev gamma-ray of Hg^{199} was focused in the north spectrometer, while the south spectrometer was focused on a point of the beta-continuum of Au^{199}, the delayed resolution curve $F(x)$ of Fig. 1 was obtained. The prompt resolution curve $P(x)$ was obtained by replacing the source of Au^{199} by a source of ThB and using the 147-kev F-line, shown separately to have a half-life less than 10^{-10} second. A least-squares fit of the part of $F(x)$ lying to the right of $x = 4 \times 10^{-9}$ second yields $T_{\frac{1}{2}} = (2.26 \pm 0.12) \times 10^{-9}$ second, while the shift of the centroid[2] of $F(x)$ to the right of that of $P(x)$ yields $T_{\frac{1}{2}} = (2.43 \pm 0.12) \times 10^{-9}$ second. Making an allowance for systematic errors, we quote for the half-life of the 158-kev excited state of Hg^{199},

$$T_{\frac{1}{2}} = (2.35 \pm 0.20) \times 10^{-9}\ \text{second},$$

consistent with the theoretical expectation for electric quadrupole radiation.[3]

Figure 2 shows a similar pair of curves for the 45-kev K-conversion line of the 80-kev gamma-ray of Xe^{131}. The prompt curve $P(x)$ in this case was obtained from the same source using the 364-kev gamma-ray of Xe^{131}, shown separately to have a half-life less than 10^{-10} second. The centroid-shift analysis yields $T_{\frac{1}{2}} = (4.8 \pm 0.8)$

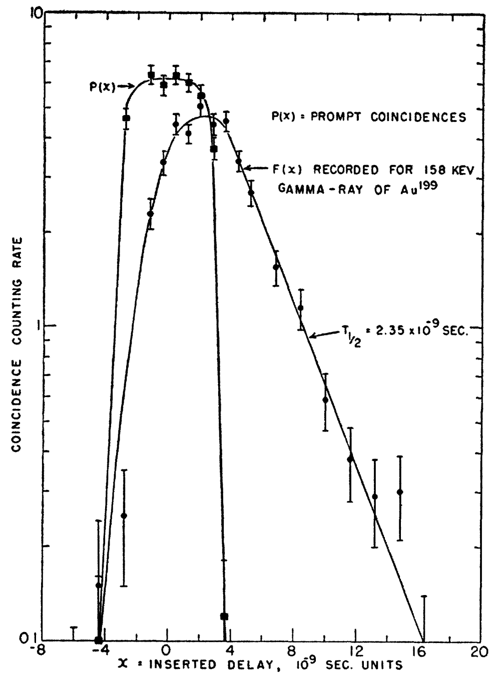

FIG. 1. Delayed resolution curve $F(x)$ showing the half-life of the 158-kev gamma-transition of Hg^{199}, with a prompt resolution curve $P(x)$ for comparison.

$\times 10^{-10}$ second. In view of the extreme shortness of this half-life, the standard deviation should be increased, and we quote for the half-life of the 80-kev excited state of Xe^{131}

$$T_{\frac{1}{2}} = (4.8 \pm 2.0) \times 10^{-10} \text{ second,}$$

consistent with the theoretical expectation for magnetic dipole radiation.[3]

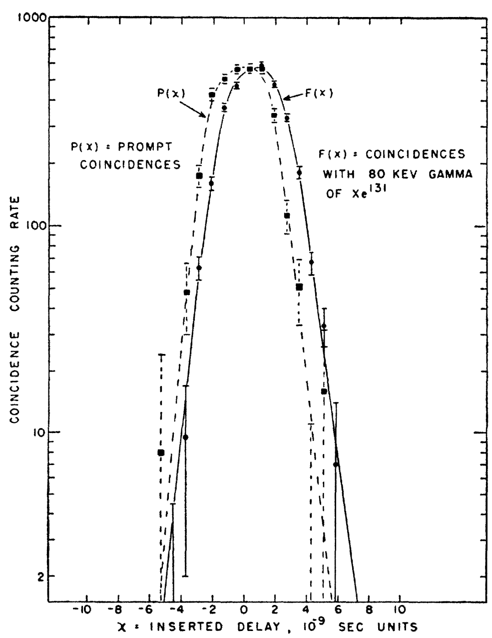

FIG. 2. Delayed resolution curve $F(x)$ for the 80-kev gamma-transition of Xe^{131}, with a prompt resolution curve $P(x)$ for comparison.

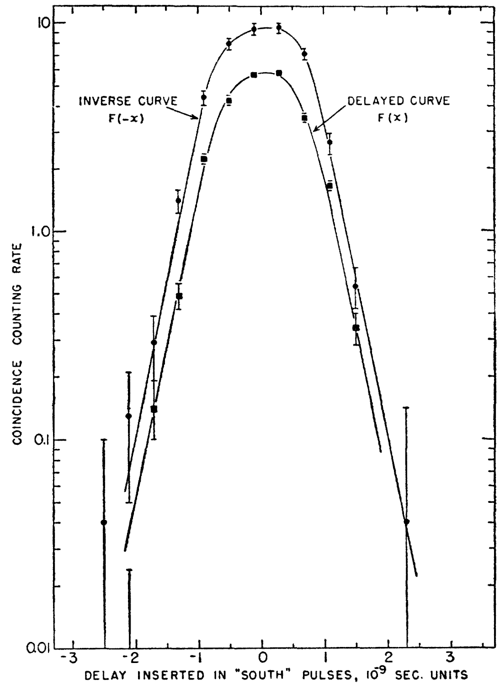

FIG. 3. Delayed resolution curve $F(x)$ and its experimental inverse $F(-x)$ for the 411-kev gamma-transition of Hg^{198}.

For the case of the 411-kev excited state of Hg^{198} the more sensitive "self-comparison" method was used, in which the delayed-coincidence resolution curve is compared with its own inverse. The delayed curve is obtained with the north spectrometer focused on the 328-kev K-conversion line of the 411-kev gamma-ray, and the south spectrometer focused on the beta-continuum just below the line. To obtain the inverse curve, the current in both spectrometers is increased by the same small amount, so that the north spectrometer is on the beta-continuum just above the line, and the south is on the line. Spurious shifts in the resolution curves are canceled by this procedure, and the true effect is doubled. The results are shown in Fig. 3, the centroid analysis yielding $T_{\frac{1}{2}} = (1.0 \pm 1.7) \times 10^{-11}$ second. This result means that the half-life of the 411-kev state is less than, say, 3×10^{-11} second; Moon,[4] however, has shown by a resonant nuclear scattering experiment that it is not much less than a few times 10^{-11} second. The combination of the two results means that the half-life is near 10^{-11} second, consistent with the theoretical expectation for electric quadrupole radiation.[3]

Similar self-comparison experiments have established upper limits of 10^{-10} second for the half-lives of the F-line of ThB and the 364-kev gamma-ray of Xe^{131}, and 2×10^{-10} second for the 207-kev gamma-ray of Hg^{199}. The apparatus and procedure of these measurements are described more fully elsewhere.[5]

[1] R. E. Bell and H. E. Petch, Phys. Rev. **76**, 1409 (1949); R. E. Bell and R. L. Graham, Phys. Rev. **78**, 490 (1950).
[2] Z. Bay, Phys. Rev. **77**, 419 (1950).
[3] V. F. Weisskopf and J. Blatt, chapter from forthcoming book, *Nuclear Theory*, privately circulated.
[4] P. B. Moon, Proc. Phys. Soc. (London) **A64**, 76 (1951).
[5] Bell, Graham, and Petch, Can. J. Phys., to be published.

Cross-Over Transition in Te^{123}

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THE disintegration scheme[1] of Te^{123} (100 days) consists of an 88.5-kev gamma-ray followed by a 159-kev line. The shell model predicts an $s_{\frac{1}{2}}$ ground state with $d_{\frac{3}{2}}$ and $h_{11/2}$ as the first