A Search for Short-Lived Nuclear Isomers*†

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A search for short-lived isomeric transitions has been initiated. Using a delayed coincidence apparatus having an over-all resolution of 2×10^{-9} second, sixteen gamma-transitions were investigated for half-lives in the 2×10^{-9} to 10^{-7} second range. Metastable states in K^{41}, 1.3 Mev above ground and in Ta^{181}, 471 kev above ground were verified, while the remaining transitions were found to have half-lives less than 2×10^{-9} second. Weisskopf's formula relating spin change and half-life, together with internal conversion information, were applied to these data, and definite spin changes were assigned to five of the transitions.

RECENT improvements in electronic circuitry and techniques have made it possible to extend the method of delayed coincidences, as applied by DeBenedetti and McGowan[1] to the measurement of half-lives of nuclear excited states, into the milli-microsecond region. When applied to Weisskopf's formula[2] relating the half-life of a gamma-transition to its energy and the spin change involved, these data are useful in assigning spins and parities to the excited states of nuclei.

A fast coincidence circuit, having a time resolution of 1×10^{-9} second, was designed and constructed. One channel (I) of this circuit is excited by the beta-radiation leading to the formation of an excited state, and the other (II) is sensitive to the gamma-rays associated with the decay of the excited state. Both nuclear detectors are 5819 photomultiplier tubes, fitted with stilbene phosphors for minimum rise time. The stilbene crystal in channel I is ½ mm thick in order to make it insensitive to gamma-radiation, while the crystal in the gamma-channel is one cm thick and shielded with sufficient absorber to remove all beta-radiation. The voltage pulses from the cathode followers in each channel are led through variable delays, consisting of calibrated lengths of C-11T coaxial cable and amplified by 250-Mc wide band distributed amplifiers. When the pulses are shaped to achieve maximum resolution, by means of the shorted delay-line technique, the delayed coincidence apparatus is capable of measuring half-lives greater than 2×10^{-9} second.

The results of a search for gamma-transitions having a half-life detectable with this apparatus are given in Table I, where the spin changes have been calculated from Weisskopf's formula, using the experimental half-life data. In two cases, i.e., K^{41} and Ta^{181}, the results are in substantial agreement with those obtained by Elliott[3] and Barber,[4] respectively, and lead to an unambiguous assignment of spin change. Figure 1 is included as representative of the type of data obtained in these experiments. Curve (a) is the delayed coincidence curve for the 1.3-Mev transition in K^{41}; the half-life of the transition is obtained from the slope of the curve at large values of the delay. Curve (b) is a typical resolution curve, obtained when the half-life of the particular transition is less than 2×10^{-9} second.

For the cases in which the delayed coincidence measurement serves only to set an upper limit on the half-life, considerable information about spin changes can

TABLE I. Experimental values of half-lives and associated spin changes for gamma-ray transitions.

Parent isotope	Daughter isotope	Energy of gamma (Mev)	Experimental half-life (sec)	Spin change
Co^{60}	Ni^{60}	1.17	$<2\times10^{-9}$	1, 2
Co^{60}	Ni^{60}	1.33	$<2\times10^{-9}$	1, 2
Na^{24}	Mg^{24}	1.38	$<2\times10^{-9}$	2
Mn^{56}	Fe^{56}	0.845	$<2\times10^{-9}$	2
A^{41}	K^{41}	1.3	6.6×10^{-9}	2
Cu^{66}	Zn^{66}	1.04	$<2\times10^{-9}$	1, 2
Cu^{61}	Ni^{61}	0.655	$<2\times10^{-9}$	1, 2
V^{48}	Ti^{48}	1.320	$<2\times10^{-9}$	1, 2
V^{48}	Ti^{48}	0.990	$<2\times10^{-9}$	1, 2
Hf^{181}	Ta^{181}	0.471	10.4×10^{-9}	2
W^{185}	Re^{185}	0.134	$<2\times10^{-9}$	1, 2
Hg^{203}	Tl^{203}	0.280	$<2\times10^{-9}$	1, 2
Sb^{124}	Te^{124}	0.607	$<2\times10^{-9}$	1, 2
Ce^{141}	Pr^{141}	0.145	$<2\times10^{-9}$	1, 2
Pr^{144}	Nd^{144}	0.795	$<2\times10^{-9}$	1, 2
Ru^{103}	Rh^{103}	0.499	$<2\times10^{-9}$	2

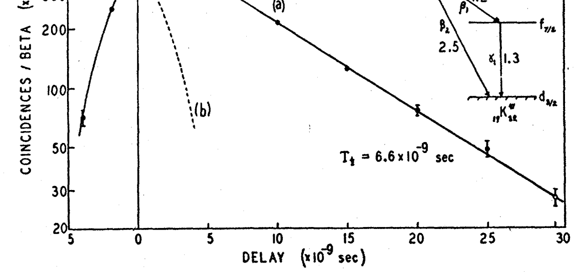

FIG. 1. Delayed beta-gamma coincidences on A^{41}, showing a half-life of 6.6×10^{-9} second for the 1.3-Mev excited state in K^{41}.

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still be obtained. In all cases, the upper limit of 2×10^{-9} second on the half-life rules out the possibility of a spin change of three or more units of angular momentum. This, then, permits an unambiguous assignment of a spin change of two to the transitions in Mg^{24} and Fe^{56}, for the results of the large angle scattering experiments of Pollard and Alburger[5] indicate that these transitions are not of a dipole nature. Similarly, in the case of the 499-kev transition in Rh^{103}, the K/L ratio of 8.5, obtained by Cork *et al.*,[6] fits $E2$, $E3$, and $M3$ processes, so the half-life measurement rejects the latter two assignments and definitely characterizes the transition as $E2$.

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Nuclear Radiofrequency Spectra of D_2 and H_2 in Intermediate and Strong Magnetic Fields*

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The molecular beam apparatus previously described has been improved and has been used to make measurements on the nuclear radiofrequency spectrum of H_2 at intermediate and high magnetic fields. These measurements are the first to provide a test of the theory of molecular H_2 at intermediate magnetic fields and provide a more accurate test of the theory at strong magnetic fields. Agreement of the intermediate field results with the predictions from the high and very low field measurements was found to within experimental error. The numerical values of the interaction constants c and d occurring in the Hamiltonian and the physical quantities that can be calculated therefrom were improved by these measurements. The best values of c and d for H_2, obtained from the intermediate field measurements, are $113\,904\pm 30$ cps and $57\,671\pm 24$ cps, respectively. Measurements were also made on the nuclear spectrum of D_2 at a stronger external magnetic field than any used previously. These measurements improved the numerical values of interaction constants for D_2. The best values of c and d for D_2 are 8788 ± 40 cps and $25\,237\pm 10$ cps, respectively. The comparison of c for H_2 and D_2 indicates that the magnetic shielding of the nuclei should differ in these molecules in accordance with ${}^{D}\sigma/{}^{H}\sigma=1.006\pm 0.005$.

I. INTRODUCTION

THE original experiments on the radiofrequency spectra of H_2 and D_2 by Kellogg, Rabi, Ramsey, and Zacharias[1] were made using the molecular beam magnetic resonance method proposed by Rabi.[2] These experiments were performed only in strong magnetic fields. Kolsky, Phipps, Ramsey, and Silsbee[3] have recently repeated these experiments with the greater accuracy resulting from the use of the molecular beam resonance technique with separated radiofrequency magnetic fields which was proposed by Ramsey.[4] In addition to this, they studied the radiofrequency spectra of H_2 and D_2 in the limit of very weak magnetic fields. Up to the present, however, there have been no experiments in magnetic fields of intermediate strength; i.e., such that the interactions of the nuclei with the external magnetic fields are of the same order in magnitude as the interactions internal to the molecules. Measurements in intermediate fields are of value both as a check on the validity of the theory which is used in interpreting the experimental results on H_2 and D_2 and as a means of determining more accurate values for the interaction constants concerned.[5] Two sets of measurements on the H_2 nuclear spectrum were made at an intermediate magnetic field in the present experiment.

Measurements at a strong magnetic field were made on both the D_2 and H_2 nuclear spectra. The D_2 measurements are of particular interest because they were taken at a stronger field than any used previously, while the H_2 strong field measurements provide more accurate values for the interaction constants than were obtained in previous similar measurements. This is important for purposes of comparing high and low field values in order to determine the validity and completeness of the present Hamiltonian. Both the D_2 and H_2 measurements were taken with greater accuracy than that achieved in previous work.

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