Fermi and Coulomb Matrix Elements from β-γ (Circularly Polarized) Correlation Measurements on V^{48} and Mn^{52m}†

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β-γ (circularly polarized) correlation measurements have been made for the $T=1$ to $T=2$ beta decays of V^{48} and Mn^{52m}. The spin sequences permit both Gamow-Teller and Fermi contributions in the transitions: $V^{48}[4^+(\beta^+)4^+(\gamma_1)2^+(\gamma_2)0^+]$ and $Mn^{52m}[2^+(\beta^+)2^+(\gamma)0^+]$. The Fermi matrix elements $|M_F|$, impurity coefficients $|\alpha_2(1)|$, and Coulomb matrix elements $|\langle H_C\rangle|$, all of which must be zero for *pure* $\Delta T=1$ β transitions, were deduced from the observed asymmetry parameter A, using the well-established $V-A$ beta interaction form:

	A	$10^3 M_F$	$10^3\alpha_2(1)$	H_C(keV)
V^{48}	$-0.036+0.005$	4.5 ± 0.5	2.2 ± 0.2	12.1 ± 1.3
Mn^{52m}	-0.141 ± 0.016	4.7 ± 3.1	2.4 ± 1.6	8.2 ± 5.4

An average of three earlier measurements on V^{48} is consistent with these results, but has 5.5 times the error. The consistency of these results with each other, and with the over-all behavior of the same quantities characterizing the twenty or so other cases investigated to date, supports the suggestion that isospin conservation for particle-stable nuclear states has a validity which is qualitatively independent of atomic weight or excitation.

INTRODUCTION

IN the most recent[1] of a series of papers describing measurements made at this laboratory on mixed-allowed ($\Delta J=0$, $J\neq0$) β transitions by the technique of β-γ circularly polarized (CP) correlation, we reported our correlation result for the $T=1$ to $T=0$ β decay of F^{20}. From this result we were able to deduce the impurity coefficient and effective Coulomb matrix element by methods described in detail in several sources.[2–4] The comparison of these quantities with the same quantitites deduced from the radiative isospin selection rules for four other states in the same nucleus (the final-state nucleus, Ne^{20})[5] showed that although the impurity coefficients differ by as much as two orders of magnitude, the Coulomb matrix elements ($|\langle H_C\rangle|$) are within a factor of 3 or so of each other and have an upper limit of approximately 30 keV. The Coulomb matrix elements should exhibit less variation in magnitude than the impurity coefficients, since the latter are inversely proportional to the energy difference between the two states of different T which are mixing, while the former are independent of this difference.[2] However, whether a factor of 3 or a factor of 10 or even more should characterize the range of variation of $|\langle H_C\rangle|$ is not known. In the compilation[2] of all β-decay experimental results bearing on this question, $|\langle H_C\rangle|$ showed a variation of from approximately 1–60 keV over an atomic weight range of 24–150. The excitation of the "mixing" state went as high as 10 MeV. The experimental errors make it difficult to ascertain the lower limit of this range of variation, but a factor of 60 or more is not an unreasonable deduction from the data available to date. Since, however, this figure covers a rather wide range of isospins ($T=1$ to $T=14$), it is perhaps useful to inquire whether there is less variation if one considered narrower regions in T, as for instance the factor of 3 mentioned above for the $|\langle H_C\rangle|$ range of variation in Ne^{20}, $T=0$. The $T=2$ to $T=1$ mixed β transitions are a very good group to study in this manner, since experimentally there are quite a few cases available—considerably more than of the $T=1$ to $T=0$ variety—and indeed several measurements have already been made. However, the experimental accuracy and/or discrepancies among many of the earlier measurements have been such as to cloud the question concerning the range of values of $|\langle H_C\rangle|$. In an effort to help answer this question we report herein a remeasurement of the β-γ(CP) correlation for V^{48} which improves by a factor of approximately 5 on the combined precision of the preceding measurements. In addition we have measured the β-γ(CP) correlation for the Mn^{52m} β decay. Both these cases are ostensibly $T=2$ to $T=1$ transitions and both seem to have roughly equal Coulomb matrix elements. Furthermore, these matrix elements are within 50% of the median value of matrix elements reported for the $T=1$ to $T=0$ transitions.[1] Thus, the empirical constancy noted for the $T=1$ to $T=0$ tran-

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TABLE I. Experimental results for V^{48} and Mn^{52m} β-γ(CP) correlation measurements.

	Discriminator settings (keV) β	γ	Corrected asymmetry, δ[a] (%)	f_{PE}[b]	f_{VC}[c]	f_{RC}[d]	f_{GG}[e]	f_{PA}[f]	f_{NP}[g]	f_T[h]	Asymmetry parameter, A[i]
${}_{23}V^{48}$	200	475	-0.034 ± 0.006	1.03	1.25	1.12	1.10	1.05	1.72	2.86	-0.036 ± 0.005
	173	474	-0.032 ± 0.015	1.03	1.27	1.04	1.11	1.05	1.72	2.52	-0.032 ± 0.014
											$A_{ave}=-0.036\pm0.005$
${}_{25}Mn^{52m}$	1100	500	-0.201 ± 0.023	0.95	1.03	1.06	1.00	1.02	1.80	1.92	-0.141 ± 0.061

[a] δ, the observed asymmetry is defined as $(N_+-N_-)/(N_++N_-)$, where $\pm$ refer to opposite polarizations of the scattering magnet and $N_\pm$ is the number of observed coincidences. The asymmetry given here is corrected for the magnetic gain shifts in the β and γ singles rates ($\lesssim 0.01\%$).
[b] Energy dependence of the polarization-dependent part of the Compton cross section relative to the standard (Co^{60}).
[c] Reciprocal of average β velocity in units of c.
[d] Correction for random coincidences.
[e] Correction for γ-γ coincidences.
[f] Correction for coincidences due to annihilation radiation.
[g] Correction for coincidences which do not involve scattering of gamma rays from magnetized iron (see Ref. 4).
[h] Total correction factor $f_{PE}\times f_{VC}\times f_{RC}\times f_{PA}\times f_{NP}$.
[i] $A=36.6\times f_T\times\delta$, where 36.6 is the calibration constant of the polarimeter (cf. Ref. 4). The statistical plus a 4% calibration error characterize the final values of A.

sitions would seem to include at least these two $T=2$ to $T=1$ transitions. However, other transitions of this type show evidence of much larger matrix elements, which makes it difficult to speak of any general rule (see Results and Discussion).

EXPERIMENT

The basic β-γ(CP) correlation technique has been described in several sources.[6] Since the details of the rapid-alternation method used in Livermore can also be found in several published accounts[4,7,8] we refer to these articles concerning this part of the experiment. With reference to the sources: Vanadium-48 was obtained from the Oak Ridge National Laboratory in HCl solution. Thin sources were prepared in the usual fashion, by solution evaporation on $\frac{1}{4}$-mil Mylar foils. Because Mn^{52m} has too short a half-life (22 min) to permit a complete asymmetry measurement in a few runs, it was necessary to use the Livermore 90-in. cyclotron for a cyclic rebombardment of the source, which consisted of a foil made up of a slurry of polystyrene and chromium powder. The reaction used was $Cr^{52}(p,n)Mn^{52m}$, which for 14-MeV protons yielded sources of more than adequate activity, approximately 100 μCi, for approximately 0.5 μA of beam current on targets of thickness approximately 11 mg/cm^2 of which 50% was Cr and the rest polystyrene. The bombardment and count intervals were 1 min for 4 min, respectively. This technique required the development of a pneumatic tube and associated equipment capable of transferring the target from the bombardment position to the count position (a distance of 100 ft) in a rapid, repeatable, and precisely positioned manner. The performance of the final transport system was satisfactory in all respects. The transport time from the beam position to the polarimeter was 10 sec.

Since it was important that the activity being manufactured in the foil was Mn^{52m} and nothing else, careful checks were made for both short-lived (a few seconds) and long-lived (minutes to hours) contaminants. At the β-discriminator setting used (1.1 MeV) the inevitable manufacture of long-lived Mn^{52} (5.7 days) was completely unobservable. No other long-lived contaminant of any significance could be found for the β- and γ-discriminator settings used in the experiment (see Table I). This was further checked by an examination of the γ spectrum in a germanium crystal spectrometer which showed only the expected 1.434-MeV γ ray and 511-keV (annihilation radiation) lines with a small contribution from the long-lived Mn^{52} (ground-state) decay spectrum. The examination for possible short-lived contaminants showed the contribution of these to any β-γ coincidences as considerably less than 1%, and so totally negligible for our purposes.

RESULTS AND DISCUSSION

The results of the experiment are given in Tables I and II. Table I gives the observed asymmetries and the correction factors. Terminology is essentially the same as in Ref. 4. As is usual in the work done at Livermore,[4,7] the β-γ(CP) correlation in Co^{60} was used as a standard which yields the formula for the asymmetry parameter A given in the footnote of Table I. Past experience has shown this formula reliable to about 4%. Since our statistical errors are a good deal larger than this, it is clear we are not limited by calibrational uncertainties here.

Table II gives the values of $y=C_VM_V/C_AM_A$ deduced from A using the well-known conserved vector current (CVC) theory of weak interactions[9] (see

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TABLE II. Fermi matrix elements (column 3), impurity coefficients (column 5), and effective Coulomb matrix elements (column 6) for V^{48} and Mn^{52m} β decays, as deduced from results shown in Table I and Figs. 1 and 2. E_x is the excitation in the parent nucleus of the $T=2$ contaminating state. Also shown for the sake of comparison are the averages of all previously published results for V^{48} and Mn^{52} (ground state). Note that the latter requires two groups of experimental results because of their incompatibility.

	C_VM_V/C_AM_A	$10^3\|M_F\|$	E_x (MeV)	$10^3\|\alpha_2(1)\|$	$\|\langle H_C\rangle\|$ (keV)	Reference
${}_{23}V^{48}$	-0.065 ± 0.007	4.5 ± 0.5	5.50	2.2 ± 0.2	12.1 ± 1.3	Present work
${}_{23}V^{48}$	$-0.10\ \pm0.03$	7.0 ± 2.0	5.50	3.5 ± 1.0	$19\ \pm5.5$	4
${}_{25}Mn^{52m}$	-0.030 ± 0.020	4.7 ± 3.1	3.88	2.4 ± 1.6	8.2 ± 5.4	Present work
${}_{25}Mn^{52}$	$+0.007\pm0.013$	1.2 ± 2.2	5.93	0.6 ± 1.1	3.6 ± 7.2	4
	-0.047 ± 0.004	8.4 ± 0.6	5.93	4.2 ± 0.3	$25\ \pm1.8$	11

Figs. 1 and 2 and column 2 of Table II). Also shown in Table II are the deduced results for the Fermi matrix element (column 3). The excitation energy E_x is the calculated[2] position for the analog states of Ti^{48} (2.30 MeV) and Cr^{52} (1.434 MeV) in V^{48} and Mn^{52}, respectively. Both of these are ostensibly $T=2$ states which mix with the $T=1$ states through the action of the Coulomb force (as well as a possible isospin nonconserving part of the nucleon-nucleon strong interaction). The impurity coefficient $\alpha_2(1)$ characterizing this mixing is also shown in Table II. As noted above, the accidental contiguity of two states could produce a fortuitously high impurity coefficient. Therefore, a more reliable index of the importance of the Coulomb mixing is the matrix element of the Coulomb potential $|\langle H_C\rangle|$. This is given in column 6. Since the sign of the Gamow-Teller matrix element is not known, only absolute values for $\alpha_2(1)$ and $\langle H_C\rangle$ can be given. For the sake of comparison, Table II also gives the appropriate averages of all previous results for V^{48} and Mn^{52} (ground state).[4,10,11] In the latter case, two groups of results are given because of the incompatibility of the results using oriented Mn^{52}, and the β-γ(CP) correlation results. The former method gives a result which is significantly larger than any other given in Table II. However, it is still within the 30-keV upper limit characterizing the $T=1$ to $T=0$ decays described earlier. Nonetheless, the discrepancy of a factor of 2 to 5 or more between

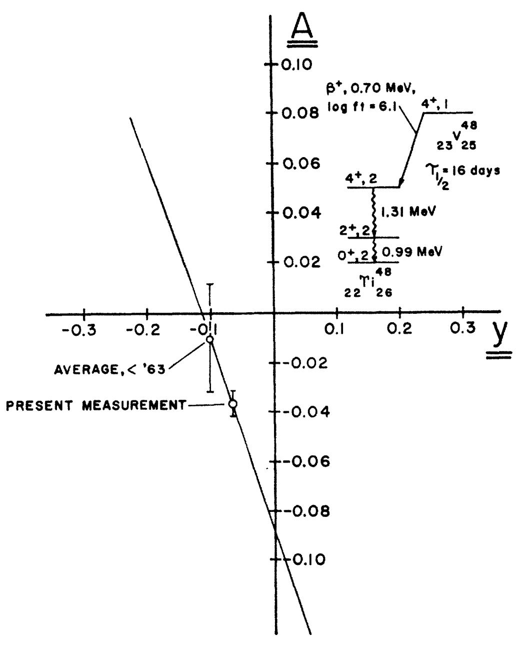

FIG. 1. Plot of A, the asymmetry parameter, versus $y=C_VM_V/C_AM_A$ for the case of V^{48}. Experimentally observed values for A are shown also. The point labeled "Average, '63" represents the average of three earlier measurements (see Results and Discussion).

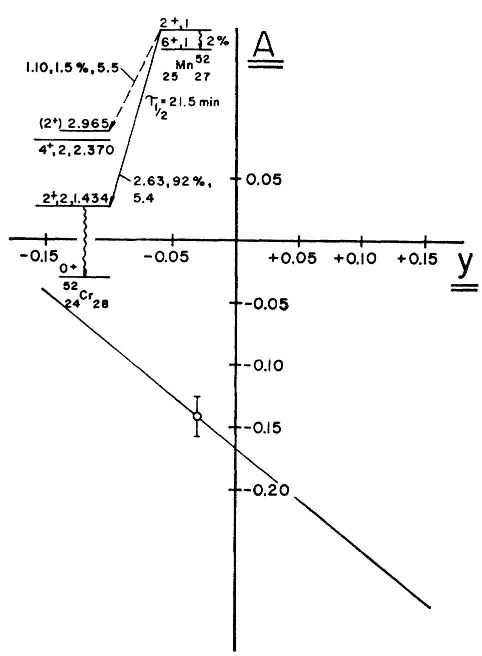

FIG. 2. Plot of A, the asymmetry parameter, versus $y=C_VM_V/C_AM_A$ for the case of Mn^{52m}.

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the two results is disturbing. Also, with the exception of the $0^+ \rightarrow 0^+$ transition in Ga^{64}, the $|\langle H_C \rangle|$ deduced[11] from the oriented nuclear experiments with Mn^{52} is the largest Coulomb matrix element between states of differing isospin yet determined for a particle-stable nuclear state. $|\langle H_C \rangle|$ for Ga^{64} is approximately 40 keV. This result depends on the 0^+ assignment for Ga^{64} which is supported by some recent measurements at this laboratory.[12] The size of the Ga^{64} Coulomb matrix element makes it difficult to say that there is a general rule keeping $|\langle H_C \rangle|$ less than 30 keV for $T \leq 1$. If there are special reasons applying to this case they are still unknown. In any case the present results are quite consistent with the general pattern of an upper limit of $\sim$30 keV for the effective Coulomb matrix elements, regardless of atomic weight or excitation, which in turn indicates a roughly uniform validity for the isospin quantum number under the same range of conditions.

A final comment on the V^{48} result which is worth making is that although small, it is clearly nonzero by nine standard deviations. The result for $|M_F|$ corresponds to a log ft of 8.49±0.04. Such a log ft for an ostensibly allowed transition is certainly indicative of the operation of a strong inhibition principle (in this case isospin conservation). Still, it is not large enough that second-forbidden corrections should be significant, since the average log ft for such transitions is 12±1.[13,14] Thus it is clear that although the Coulomb effects are small, they are still quite observable.

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Angular-Momentum Effects in the $Mg^{24}(\alpha,Be^7)$ and $Al^{27}(p,Be^7)$ Reactions at 35–65 MeV

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The reaction $Mg^{24}(\alpha,Be^7)Ne^{21}$ is investigated with alpha particles in the energy range 35–63 MeV. The measured cross sections are compared with the cross sections for $Al^{27}(p,Be^7)Ne^{21}$, a reaction which proceeds through the same compound nucleus, Si^{28}. At fixed excitation energy of the compound nucleus (C.N.), the alpha-induced reaction has a higher cross section for $E_{C.N.}>40$ MeV. The cross-section ratio $\sigma(\alpha)/\sigma(p)$ increases from 4.4±1.0 at $E_{C.N.}=50$ MeV to 6.3±1.4 at $E_{C.N.}=60$ MeV. Part of this significant difference is shown to be due to angular-momentum effects in compound-nuclear processes. The balance is attributed to the multinucleon pickup by the He ion. A similar effect is observed in the reactions $Al^{27}(p,\alpha pn)$ and $Mg^{24}(\alpha,\alpha pn)$.

I. INTRODUCTION

In the vicinity of 30 MeV and above, compound nuclear processes have been shown to be of significance in the emission of complex nuclei such as Li^6, Li^7, and Be^7 in bombardments with protons and He ions.[1–7] The He-ion- and proton-induced reactions leading to these emissions have notable differences and the angular-momentum effects involved are an interesting experimental question. At bombarding energies below about 70 MeV, one naturally contemplates two reaction mechanisms for the He-ion-induced reaction: simple compound-nuclear emission into the spectrum of available states, and multiparticle pickup by the He ion. However, only one mechanism is assumed to occur in the proton-induced reaction: emission by a compound nucleus.

If channel spins are negligible, the angular momentum of a compound nucleus formed by absorption of an incident particle is directed approximately at a right angle to the impinging beam. As is well known, this can

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