Angular correlation of cascade gamma rays in ^{94}Nb[†]

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Abstract: The directional correlation and polarization correlation of the 703-871 keV gamma ray cascade following the decay of 20,000 year ^{94}Nb have been measured. On the basis of these measurements the spin and parity of the 1574 keV level in ^{94}Mo has been determined as 4+.

1. Introduction

The decay of the 20,000 year isomer of ^{94}Nb to the excited levels of ^{94}Mo has been studied by a number of authors[1-11] and the decay scheme shown in fig. 1 has been proposed on the basis of these studies.

Snyder and Beard[11] have measured the beta ray spectrum with scintillation counters using plastic scintillators in a 4π geometry. The only beta decay that they observed populated the 1573 keV level in ^{94}Mo. In order to eliminate any distortion from Comptom scatterings of the gamma rays, the spectrum was measured in coincidence with the 1573 keV sum peak. Their conclusion was that the beta spectrum had an endpoint energy of 470 ± 6 keV and that a linear Fermi-Kurie plot could be obtained through the use of a second forbidden non-unique shape correction factor.

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Coulomb excitation experiments [3,4] have shown definitely that the first excited state of ^{94}Mo has a spin of 2 with positive parity. The remaining problem is the determination of the spin and parity of the second excited state. In an effort to determine this, Reich, Schuman and Heath[9] measured the directional correlation of the 703-871 keV gamma ray cascade. Their results were consistent with an assignment of either 2 or 4 to the 1574 keV level. Their analysis of the gamma ray spectrum measured with scintillation counters indicated that if any crossover transition between this level and the ground state existed, its intensity must be less than 0.03%. Such a low intensity strongly favors a high spin assignment thus eliminating the spin 2 possibility. From these data, it was deduced that the 1574 keV level has a spin and parity of 4+ and that the ground state of ^{94}Nb is 6+.

However, a recent paper by Kisslinger and Rote[12] indicated that this assignment for the ground state of ^{94}Nb was difficult to justify on the basis of the simple theoretical model that they used and that a spin and parity of 7+ was more probable. Since the line of reasoning establishing this assignment begins with the deduction of the spin and parity of the 1574 keV level in ^{94}Mo, a more direct determination of the character of this level is desirable. Therefore, the polarization correlation of the 872-702 keV gamma ray cascade was measured and the results are reported in this paper.

2. Experimental Procedure and Results

The ^{94}Nb source was obtained as NbF_3 in a solution of hydrofluoric and hydrochloric acid from Nuclear Science and Engineering Corporation. Ten

microcuries of this source was deposited in a Teflon holder having an inside diameter of 5 mm and length of 1 cm. Although the source was evaporated to dryness, it was not carrier free, and a rather large amount of salt was distributed throughout this volume. This source was sufficiently strong that it could be used in all of the measurements.

A gamma ray spectrum taken with an 8 cm^3 coaxial Ge(Li) detector is shown in fig. 2. It is apparent that there is a trace impurity of about 0.2% of ^{60}Co. However, no chemistry was attempted to remove this impurity since its effect on the experimental measurements was negligible.

The gamma ray energies were determined with this detector using calibration lines from ^{22}Na, ^{54}Mu, ^{88}Y, ^{137}Cs, and ^{207}Bi. A quadratic least squares fit proved to be adequate to fit all of the lines within less than one standard deviation. The values of the ^{94}Nb gamma ray energies were then obtained by interpolation. These are displayed in table 1 and are in good agreement with previous results.

The angular correlation apparatus used was the same as that which was described in another paper.[13] In remeasuring the directional correlation of the 703-871 keV gamma ray cascade, the discriminator of the fixed counter was set to span the 871 keV photopeak. Both the singles and the coincidence spectra of the two moveable counters were recorded in a multichannel analyzer using subgroup programming. From these spectra, only counts in the 703 keV photopeak were used.

The angular correlation coefficients were corrected for solid angle attenuation using the method of Rose.[14] While it has recently been found[15] that this method is not exact, the error in the correction itself, for this apparatus, is approximately 5%. The conclusions reached in this experiment

are not dependent on a precise knowledge of the directional correlation coefficients since the polarization correlation has also been measured. Therefore, the error in the solid angle correction is negligible.

The values of the Legendre polynomial coefficients measured in this experiment are shown in table 2 are in good agreement with those values obtained by other investigators. As can be seen in fig. 3, however, these results are insufficient in themselves to identify the spin and parity of the 1574 keV level. The data is consistent with the assignment of 2,3 or 4 for the spin of this level.

A measurement of the linear polarization of the 702 keV gamma ray is sufficient to distinguish among these possibilities. As previously described,[13] the polarization correlation apparatus consisted of a direction counter and a Compton polarimeter. Although the measurement is straightforward, the polarization sensitivity of this apparatus is energy dependent and must be determined before the polarization can be evaluated. Measurements in the past on well known transitions have yielded empirical values for the sensitivity over a range of energies. The 871 keV transition in ^{94}Mo is pure electric quadrupole and, using the known polarization of such a transition, the sensitivity at 871 keV could then be measured and added to the set of values. A simple extrapolation to 703 keV gave a value of 2.8 ± 1.0 for the polarization sensitivity at this energy. Using this value, the polarization of the 703 keV gamma ray transition was found to be 1.4 ± 0.2.

The result of the linear polarization measurement can be most easily compared with the theoretically possible values using the graph shown in fig. 4. A spin assignment of 2 is clearly excluded. If the spin assignment were 3, the parity of the level would be negative, and the 703 keV transition would

be 96% electric dipole with a 4% mixture of magnetic quadrupole. Such a large admixture is quite unlikely and effectively rules out this assignment.

Therefore, the 703 keV gamma ray must be a pure electric quadrupole transition and the spin and parity of the 1574 keV level must be 4+. From the beta decay experiments, the ground state of ^{94}Nb should be 6+. In order to confirm this assignment, other experiments such as the beta-gamma directional correlation should be carried out. On the basis of the present experimental data, however, it would appear that the model used by Kisslinger and Rote does not adequately predict the ground state spin of ^{94}Nb and that more detailed model is necessary.

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List of figures

Table 1

Transition energies following ^{94}Nb decay

Present investigation (keV)	ref.[9])	ref.[11])	ref.[16])
702.5±0.1	703	702.6±0.5	
870.8±0.1	872	871.3±0.5	871.1±0.7

Table 2

Directional correlation coefficients for 871-703 keV cascade

Present investigation		ref.[9])	ref.[6])	ref.[8])
A_2	0.101±0.017	0.101±0.003	0.0865±0.0080	0.0965±0.0076
A_4	0.023±0.043	0.0121±0.0043	0.0243±0.0125	0.019±0.011

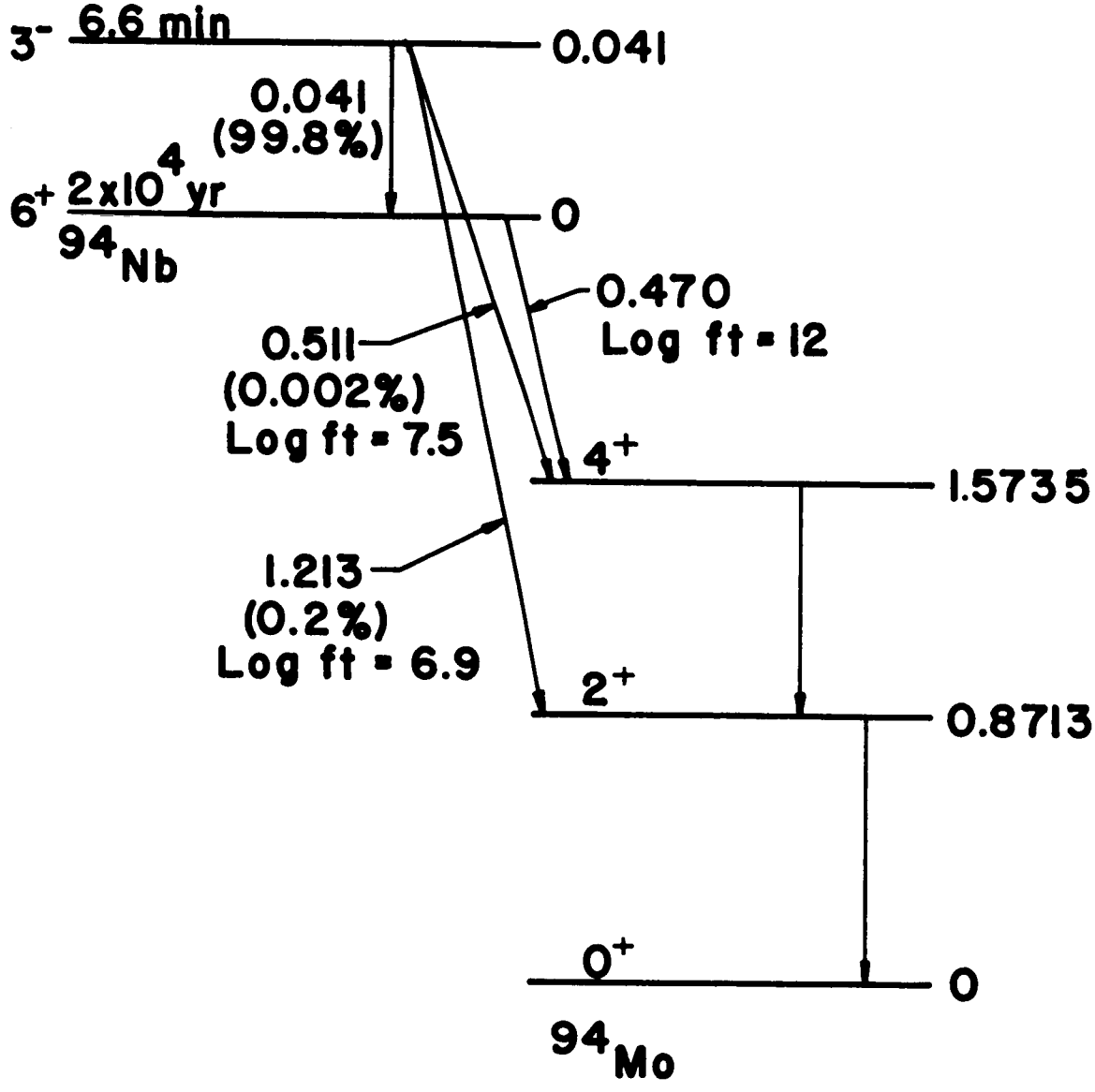
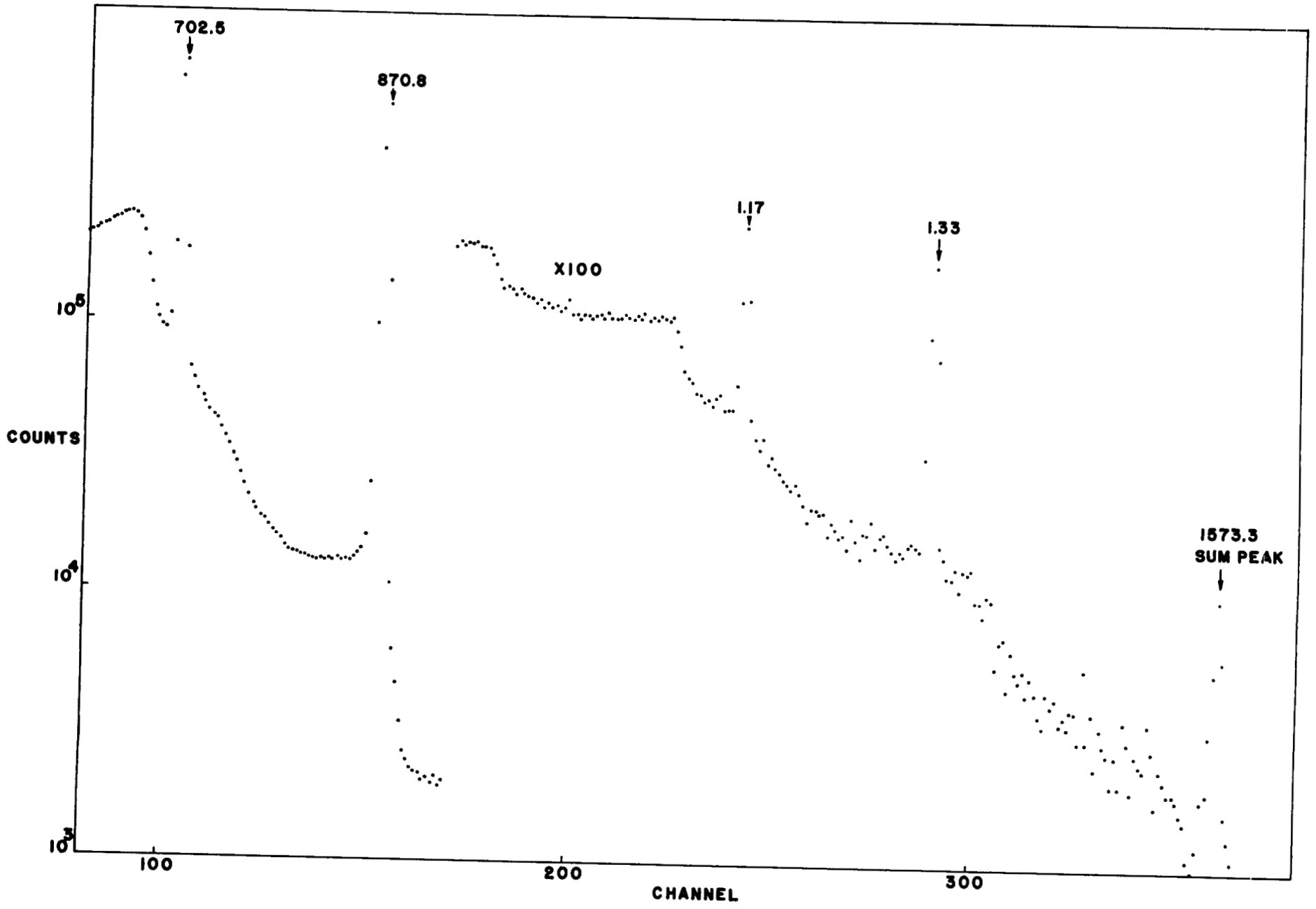

3- 6.6 min
0.041
0.041
(99.8%)
6+ 2x10^4 yr
0
94Nb
0.470
Log ft = 12
0.511
(0.002%)
Log ft = 7.5
4+
1.5735
1.213
(0.2%)
Log ft = 6.9
2+
0.8713
0+
0
94Mo

Fig. 1

Fig. 2


702.6
870.8
1.17
1.33
X100
10^5
10^4
10^3
COUNTS
1573.3
SUM PEAK
100
200
300
CHANNEL

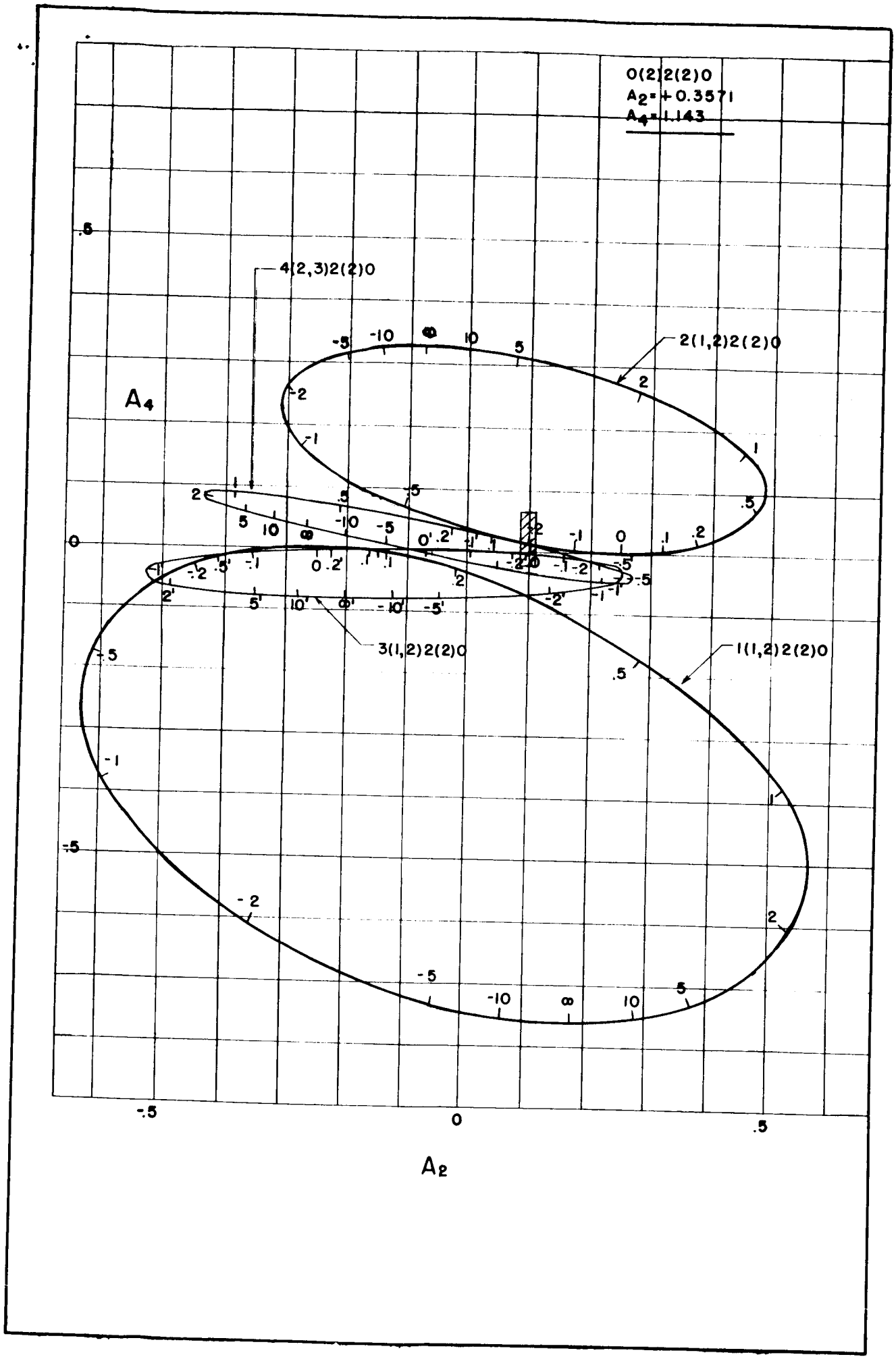


Fig. 3

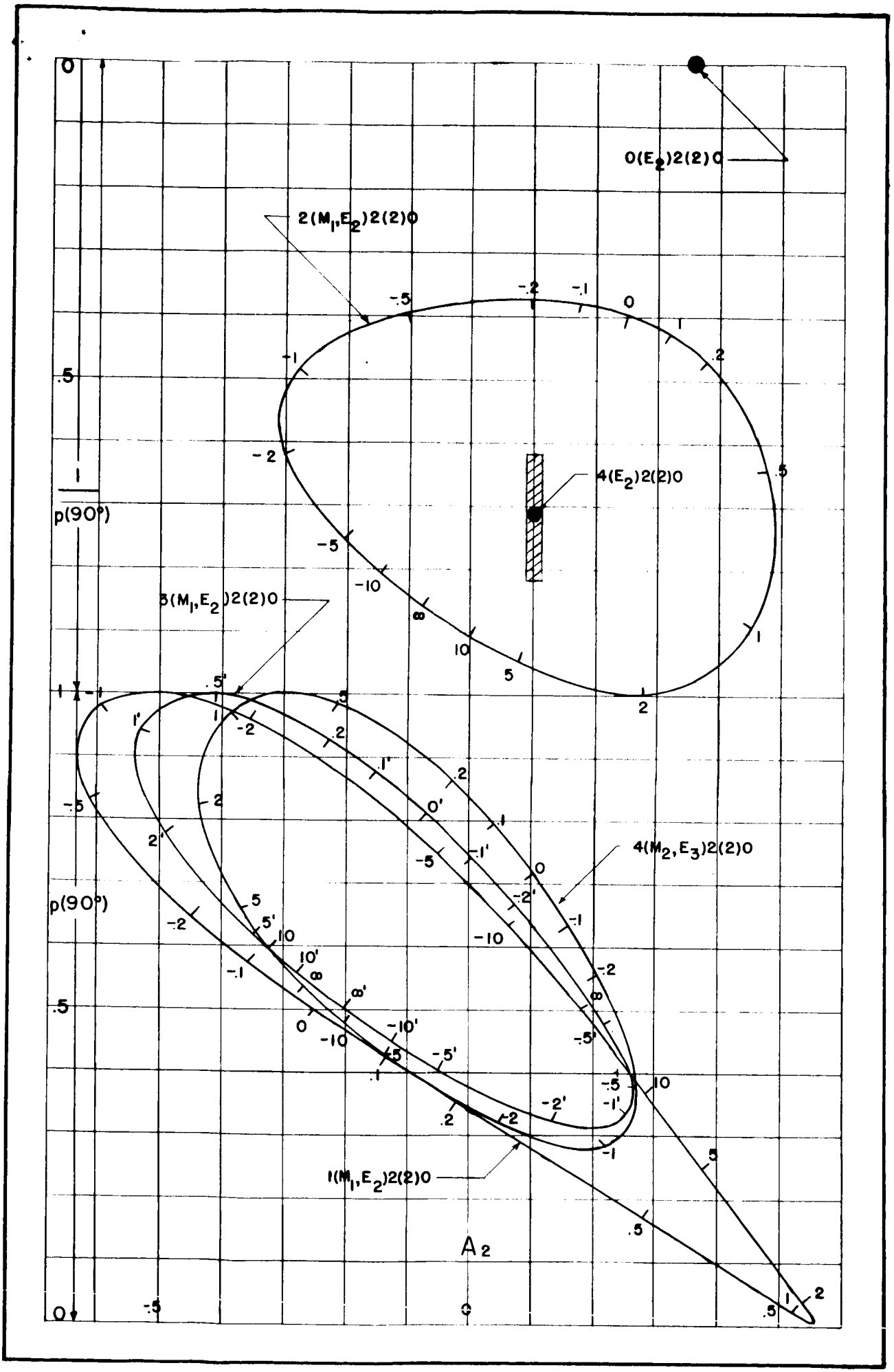

0(E2)2(2)0
2(M1,E2)2(2)0
4(E2)2(2)0
3(M1,E2)2(2)0
4(M2,E3)2(2)0
1(M1,E2)2(2)0
p(90°)
p(90°)
A2

Fig. 4