ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E6 - 11819

Z.Hons

COMPUTER-BUILDING OF GAMMA-RAY DECAY SCHEMES ON THE BASIS OF GAMMA-GAMMA COINCIDENCES

1978

E6 - 11819

Z.Hons

COMPUTER-BUILDING OF GAMMA-RAY DECAY SCHEMES ON THE BASIS OF GAMMA-GAMMA COINCIDENCES

Submitted to "Nuclear Instruments and Methods"

Гонс З. **Е6 - 11819**

Построение схем распада атомных ядер с помощью ЭВМ на основе результатов по гамма-гамма совпадениям

Предлагается метод построения сложных схем распада атомных ядер на основе результатов по гамма-гамма совпадениям. Метод учитывает полные интенсивности и энергии гамма-переходов. Предлагается набор основных правил, которым удовлетворяет большинство опубликованных схем распада. На основе таких правил разрабатывается метод сложения каскадов, удобный в случае полной информации о совпадениях, и обобщается для реалистических наборов данных. Программа, написанная на основе предыдущего метода, была использована для поиска шестнадцати схем распадов атомных ядер. Полученные результаты совпадают с опубликованными схемами распада (энергии уровней и размещение переходов) в 85-100% случаев.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1978

Hons Z. **E6 - 11819**

Computer-Building of Gamma-Ray Decay Schemes on the Basis of Gamma-Gamma Coincidences

A method is given for building gamma-ray decay schemes based on gamma-gamma coincidences. This method takes into account total intensities and energies of gamma transitions. The set of initial rules which satisfy the predominant majority of the published decay schemes is formulated. The composing cascade method convenient for complete coincidences is given and its extended version for a general case of realistic data is suggested. A computer programme based upon this method has been used for determining sixteen decay schemes. The obtained results show 85-100% agreement with the published ones in the transition placement and the energy levels.

The investigation has been performed at the Laboratory of Nuclear Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1978

1. INTRODUCTION

At present, the experimental apparatus and procedures of γ-ray spectroscopy allow one to observe hundreds of γ-transitions and their numerous coincidences. In these cases γ-ray decay scheme construction can be a tedious process. To be able to use computer aid, it is necessary to formulate as accurately as possible the rules permitting us to suggest an algorithm of decay scheme construction on the basis of currently available experimental data.

The so far published papers take as a basis the transition energy balance above all, eventually calculate and evaluate the probabilities of the accidental occurrences of the found levels[1-9]. Only Rester[10] has employed coincidence. The knowledge of a decay scheme fragment has been required in many cases[1-10].

The coincident measurement yields relatively the most complete information which is necessary for constructing a decay scheme. Therefore the present method is based on $\gamma\gamma$-coincidences above all, taking into account the total intensities and energies of the γ-transitions. The knowledge of a decay scheme fragment is not required, though it can be utilized.

2. *INITIAL RULES*

After studying numerous published decay schemes, we have come to a conclusion that the predominant majority of them satisfy the following rules:

1) the most intensive transition of the placed ones populates the ground state of the decay scheme;

2) transition energy equals, within corresponding errors, the difference of the level energies between which the transition is placed;

3) the transitions coinciding with each other are arranged in cascades;

4) none of the transitions is placed twice in the decay scheme;

4) the level energies do not exceed a decay energy value.

3. *COMPOSING CASCADE METHOD*

The set of the above rules would be almost sufficient for constructing the decay scheme if observed transitions created an ideal scheme [9] and if observed coincidences were complete and their intensities measured, only the precising of the third rule is necessary to make in this case. The whole procedure is as follows:

1. Choose among the observed transitions the most intensive coinciding one and denote it by P. Denote by Mp the set of the transitions coinciding with P and the Cp set of relevant coincidences. We shall construct all possible cascades created by Mp on the basis of Cp , so that

a) the lowest cascade transition is P,

b) all the cascade transitions coincide with each other,

c) the order in which the cascades are constructed is determined by their length (number of transitions),

d) the transition order in cascades is determined by the decrease of coinciding intensities in the upward direction.

2. The composition of the cascades is performed so that the levels with the identical energies occuring in various cascades merge. It yields an initial fragment of the determined decay scheme.

3. To find the final decay scheme, it is sufficient to repeat the abobe method till the set of coinciding transitions is empty and to compose the obtained fragments according to 2.

Another way is to look for transitions coinciding with some of the already placed on (denote it by P′), create cascades from these transitions in agreement with the b) and c) conditions and attach the cascade under the already placed relevant transition. The lowest transitions of the cascade populate the ground state of the initial decay scheme fragment.

The results of single data processing (*Tables 1,2*) by the composing cascade method (CCM) are shown in *Fig. 1*. The 530 transition can be placed according to the 2 rule.

Table 1

Summary of the γ-ray data for illustration of CCM

Energy	Total Intensity
30 [b]	60
130 [b]	15
150 [b]	25
180 [b]	30
220 [a]	100
250	80
280 [b]	20
310 [b]	.5
400	5
530	6

a) P transition, b) transitions creating the Mp set.

Table 2

Quantitative coincidence relationships among γ-rays, which are given in *Table 1*

Energy	30	130	150	180	220	250	280	310	400
30		2.7[a]	10.7[a]		60[a]		8.6[a]		
130			6.3[a]	7.5[a]	10.2[a]	3.6			1.3
150					10.7[a]	14.3			
180					30[a]				
220							8.6[a]	0.5[a]	
250							11.4		
280									
310									
400									

a) coincidences creating the Cp set.

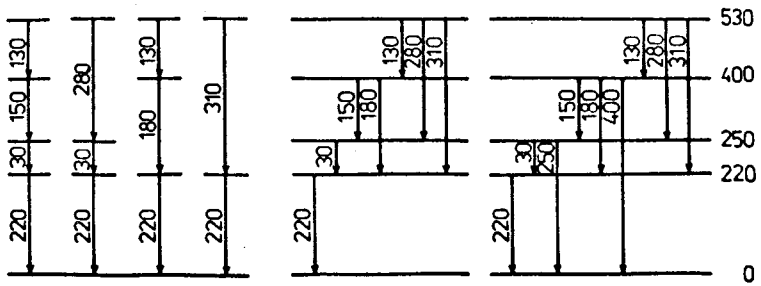

Fig. 1. The results obtained, when the data of tables 1 and 2 were processed by the CCM. The first, second and third parts of Fig. 1. show the set of obtained cascades, the initial decay scheme fragment and final decay schemes, if the first, second and third steps of the CCM are applied, respectively.

4. *UTILIZATION OF CROSS-OVER FOR ESTABLISHING THE TRANSITION ORDER IN CASCADES*

Suppose that coincidences are complete but their intensities cannot yield the right transition order in cascades (a case of relatively great errors of coincidence intensities or only yes-no coincidences). To find the correct transition order in the cascades we employ the existing cross-overs for creating an individual cascased; the transition order with the greatest number of cross-overs will be accepted; only the cross-overs non-coinciding with parallelly placed transitions will be considered.

5. *METHOD OF DECAY SCHEME CONSTRUCTION*

In case of realistic data neither observed transitions usually create ideal level scheme nor coincidences are complete. Consequently, the following difficulties appear: the cross-over criterion is not always unambiguous, the first step of the CCM can yield an incorrect ground state position and the third step of the CCM does not affect all possible cases. Since the incorrect transition order in the cascade can cause incomplete utilization of Cp coincidences (see *Fig. 2*), the number of unused coincidences can be accepted as a criterion for removing possible ambiguity of the cross-over criterion. The final modification of the d rule of the first CCM step is as follows:

d_1) the transition order in a cascade is determined by the number of cross-overs non-coinciding with parallelly placed transitions;

d_2) if the above rule does not determine the unambiguous transition order in the cascades (alternative initial decay scheme fragments are created), the fragment with the smallest number of unused coincidence is chosen as the initial one;

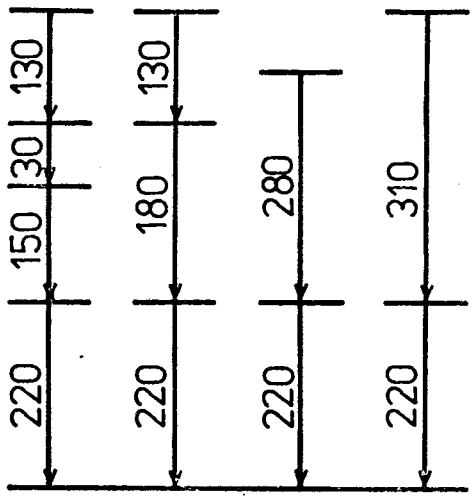

Fig. 2. Incorrect order of 150 and 30 transitions of the 220-150-130-30 cascade is the reason of incomplete utilization of Cp *coincidences; namely, 30-280 coincidence cannot be used, if the rules of the first step of the CCM and the initial rules are respected.*

d_3) even if the d_2 condition is not sufficient for the unambiguous selection of initial decay scheme fragment, the original c) condition is respected (in case of yes-no coincidences the more intensive transition is placed lower).

Now consider a case, when the ground state of the found initial decay scheme fragment is, as a matter of fact, the first excited state (e.g., it is an isomeric state). By applying the third step of the CCM, we obtain a level with negative energy, provided the real ground state is populated by a coinciding transition. Transition depopulating the first excited state must be also observed.

An analogous situation can occur, if a correct ground state position is found, but some excited levels are isomeric. Consequently, when cascades are attached under P′, their lowest transitions, if they feed those isomeric ones, may not hit the ground state, even they may not feed any till now established levels.

The rule modifying the third step of the CCM can be formulated as follows:

A relevant cascade will be attached under P′, if its lowest transition populates either the ground state or some of the earlier established states. If a new level or a new ground state is created, it is required to observe a corresponding non-coinciding transition which depopulates the new created level or the original ground state, respectively. In the opposite case, a cascade will be placed above P′ in accordance with the rules of the modified first step of the CCM.

To take into account the intensity balance of particular levels and with respect to coincidence incompleteness, it is necessary to divide transitions coinciding with P′, into two subsets: the first one contains more intensive transitions than P′, the second one contains the left transitions. The transitions of both subsets are processed separately. Call the CCM modified by the above rules the modified CCM/MCCM/. Note: if a decay scheme fragment is known before the construction begins, it can be used as an initial decay scheme fragment. It must contain at least one coinciding transition.

6. *PROBLEM OF TOTAL COINCIDENCE UTILIZATION*

The decay scheme found by the MCCM satisfies not only the fundamental rules declared at the beginning of the present paper, but shows one more property: every transition placed there has been completed on the basis of its coincidence with a transition already placed in the scheme (except the transitions not coinciding at all). Sometimes it is possible to distribute coinciding transitions into few sets so that transitions in one set do not coincide with those in another one. In such a case the construction procedure is repeated until all coincidences are exhausted. For every subset of coinciding transitions one decay scheme is obtained.

If we complete unplaced non-coinciding transitions, energies of which are equal to the difference of some level energies within the corresponding errors in particular decay scheme fragments, the same transitions, which occur in several fragments simultaneously, become a starting point for their fusion.

7. COMPUTER PROGRAMME

A computer programme based on the described method has been realized. The efficiency of the programme strongly depends on the completeness of coincidence information, especially when the initial decay scheme fragment is not involved in input data. The programme output allows to evaluate the correctness of the found decay scheme because intensity balance results and coincidence intensities derived from the scheme are presented. Possible modifications of the found decay scheme are also suggested. The programme is proposed for maximum 499 γ-transitions and maximum 79 coinciding ones. Typical running times vary around tens of seconds on the CDC 6500 computer.

8. CONCLUSION

Although the described procedure may not always affect a rich diversity of problems being connected with the decay scheme construction, the hitherto experience with processing of sixteen nuclei (e.g., [11-15]) is surprisingly good: 85-100% agreement in the transition placement and the found levels with the published ones has been obtained (only the parts of decay schemes confirmed by coincidences have been evaluated, of course). Therefore the programme could facilitate considerably the process of decay scheme building.

I would like to thank J.Adam, L.Hlavaty, M.Honusek and J.Liptak for numerous consultations and comments, that contributed to the solution of this problem.

REFERENCES

1. *Rikovska J., Zvolska V.., Hnatowitz V. Soubor programu pro zpracovani experimentalnich dat v jaderne spektroskopii, Report, Rez-leden-1976.*
2. *Kaupe A.F. Commun. Assoc. Comput. Machinary, 1963, 6, No. 6, p.313, algorithm 178.*
3. *Kalmykova L.A., Burmistrov V.R. JINR, 10-9808, Dubna, 1976.*
4. *Helmer R.G., Backlin A. Nucl.Instr. and Meth., 1968, 65, p.31.*
5. *Foster P.P., Camp D.C. CPC, 1971, 2, No. 5, p.288.*
6. *Hammermach B. et al. Ann.Phys., 1961, 13, p.284.*
7. *Sumbajev O.J.Izv. Akad. Nauk SSSR, 1965, 29,p.741.*
8. *Dzelepov B.S. Metody razrabotky slozhnych skhem raspada, Izd. Nauka, Leningrad, 1974.*
9. *Johnson L.V., Kenett T.J. Nucl.Instr. and Meth., 1970, 87, p.109.*
10. *Rester A.C. Nucl.Instr. and Megh., 1971, 96, p.269.*
11. *Basnat M.I. et al. JINR, E2-8303, Dubna, 1976.*
12. *Liptak J., Kristiak J., Kristiakova K. JINR, E6-11090, Dubna, 1977.*
13. *Adam J. et al. Nucl.Phys., 1975, A254, p.63.*
14. *Kracikova T.I. et al. Nucl. J.Phys., 1974, B24, p.852.*
15. *Abdurazakov A.A. et al. Izv. Akad. Nauk SSSR (ser. fiz.), 1976, 40, p.1976.*

Received by Publishing Department on August 2 1978.