STUDIES OF NUCLEAR DECAYS AND APPLICATIONS OF COINCIDENCE TECHNIQUES

Properties of excited levels
Some features of electron capture decays

BY

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AKADEMISK AVHANDLING

SOM MED TILLSTÅND AV MATEMATISK-NATURVETENSKAPLIGA FAKULTETEN VID STOCKHOLMS UNIVERSITET FÖR VINNANDE AV FILOSOFISK DOKTORSGRAD FRAMSTÄLLES TILL OFFENTLIG GRANSKNING Å FÖRELÄSNINGSSALEN FÖR FYSIK LÖRDAGEN DEN 7 MARS 1964 KL. 10

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Preface

D. R. Inglis (Revs. Modern Phys., *25* (1953) 390) pointed out more than ten years ago that "*nuclear spectroscopy aims on the one hand to help to develop, on the other hand to get along without, a detailed knowledge of the nature of nuclear 'forces'* ". The paradox arises from the fact that a simultaneous discovery of all the laws governing the behaviour and explaining the structure of atomic nuclei seems improbable, but it is reasonable to suppose that one can advance in a "*stepwise fashion*".

In the absence of an exact theory of nuclear forces, a number of models have been used, each accounting for only a part of the empirical facts. Two current approaches are: individual-particle systems where one or very few nucleons are allowed to move in the average central potential of the other nucleons, and collective systems where the behaviour of the whole nucleus considered as a fluid is predicted on a hydrodynamical basis. Both views are relatively successful in the calculation of mechanical and electromagnetical momenta of nuclear levels. The prediction of half-lives as well as of excitation and decay energies is somewhat less accurate.

It would often seem desirable for groups or individual investigators to devise a series of related experiments within a limited field, with the intention of establishing the degree of validity of some well defined features of present theories and models. One of the main purposes of the author's stay in Sweden has been to get acquainted with different types of instruments and techniques in the field of nuclear spectroscopy. Thus several subjects which were not always connected have been taken up. In particular, coincidence techniques have been applied frequently in this work to the determination of properties of excited levels.

In the case of excited nuclear states the study of emitted gamma rays and particles (most often conversion electrons) is practically the only way through which information can be acquired on the properties of these levels. The last two decades have seen a tremendous development of the techniques used for the detection of such radiations. One would like in particular to mention four major items which have been used all through the present work: magnetic spectrometers, scintillation detectors, multichannel analyzers and in particular, coincidence techniques. The latter yield invaluable information in establishing decay schemes. The recent introduction of bidimensional multichannel analyzers broadens even more the scope of applicability of this technique.

In this work special attention has been devoted to some problems connected with electron capture, in particular to the determination of decay energies by means of the relative proportion of capture in the K and L shells. It may be pointed out that electron capture decaying isotopes have been often used in other works (e.g. testing of the oscilloscope method). This is associated with the presence of X-rays, following immediately after a great percentage of the decays, which can be used to trigger diverse coincidence systems.

The following papers are included in this thesis:

I. I. Bergström, E. C. O. Bonacalza, A. Jech, M. Pérez and P. Thieberger, The oscilloscope method of measuring nuclear half-lives. *Nucl. Instr. and Methods 8* (1960) 151–172.

II. P. Thieberger, E. C. O. Bonacalza and H. Ryde, Experimental study of the influence of non-proportional response of NaI(Tl) scintillation crystals upon the energy resolution for gamma rays. *Nucl. Instr. and Methods 14* (1961) 225–230.

III. E. C. O. Bonacalza and G. B. Holm, Measurement of the g-factor of the 247 keV state in Cd^{111} with the differential method. *Physics Letters, 4* (1963) 343–344.

IV. I. Bergström, E. C. O. Bonacalza and P. Thieberger, Evidence for octupole and quadrupole vibrational states in Pb^{205}. *Arkiv Fysik 22* (1962) 95–110.

V. E. C. O. Bonacalza, Search for vibrational levels in Br^{79}. *Arkiv Fysik 26* (1964) 141–152.

VI. E. C. O. Bonacalza, P. Thieberger and I. Bergström, The decay energy of Bi^{205}. *Arkiv Fysik 22* (1962) 111–125.

VII. P. Erman, E. C. O. Bonacalza and J. Rossi, The K Auger effect in Br^{79}. *Arkiv Fysik 26* (1964) 135–140.

VIII. P. Erman, J. Rossi, E. C. O. Bonacalza and J. Miskel, The K Auger group intensities in Cl^{37}. *Arkiv Fysik 26* (1964) 35–44.

A short review of these papers is presented below:

I. In this work the half-lives of several nuclear levels have been determined with the oscilloscope method. This method has been modified and is applied in different ways. It is shown that it covers a large part of the region where delayed coincidence techniques are applicable. The oscilloscope is used not only as a conventional delayed coincidence circuit but also in some cases as a multicoincidence unit (multichannel time analyzer). Some well known cases were taken up to test the method. Furthermore a new half-life was discovered and a recently reported one was confirmed (Pb^{203} – 55 ns – and Pb^{205} – 4.1 ms–). The half-lives measured are in the range 10^{-2} s to 10^{-8} s.

II. The use of fast-slow coincidence techniques and a summing circuit allowed a check of the unfavourable influence of the non-proportionality of the response of NaI(Tl) scintillators upon the energy resolution. It was also possible to compare with theoretical predictions and good agreement was found with them.

III. The differential method for studying nuclear momenta and their interactions is a good example of combination of different techniques, in this case angular correlations, delayed coincidences and multichannel analysis of events. Together they allow the detailed time dependence of the interaction (which is smoothed out with the integral methods) to be observed. In the present work the magnetic moment of the 247 keV level in Cd^{111} is determined as having a value of (0.794 ± 0.006) nm thus showing a marked improvement in the accuracy, as is often the case with this method.

IV and V. In these works, singles electron and gamma spectra and coincidences, as well as angular correlations are measured and several points of the level schemes of Pb^{205} and Br^{79} are cleared up. Particular attention is devoted to the existence of quadrupole and octupole excitations. In the nearly spheric Pb^{205} it is found that the 703 keV level might be due to one phonon excitation whereas one of the levels at about 2.6 MeV excitation energy seems to arise from octupole vibration. In Br^{79} only one level can be clearly ascribed to quadrupole excitation (307 keV).

VI, VII and VIII. In paper VI the decay energy of Bi^{205} is determined by measuring coincidences with the K and L X-rays which follow electron capture. In this way K to L and K to total capture ratios were found. The method is able of giving accurate results in favourable conditions (namely small decay energy and relatively large Z value). A serious limitation arises from the large errors in the experimentally determined values of the mean fluorescence yield for the L shell, $\bar{\omega}_L$, and for the mean number of vacancies producted in the L shell for each vacancy in the K shell, η_{KL}. Particularly for the extension of the method to lower Z values the situation is rather bad due to the large discrepancies in the experimental K Auger group intensities, which are needed to establish η_{KL}. Thus a special investigation was undertaken to cover two cases of low Z, namely Br^{79} ($Z = 35$) and Cl^{37} ($Z = 17$). Special pre- and post-acceleration techniques were used in the beta spectrometer and source thickness effects were eliminated by the use of samples that were isotope separated with very low ion deposition energies.

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