RADIOACTIVITY IN NUCLEAR SPECTROSCOPY

Modern Techniques and Applications

VOLUME TWO

Copyright © 1972 by GORDON AND BREACH, Science Publishers, Inc.
440 Park Avenue South, New York, N.Y. 10016

Library of Congress Catalog Card Number: 76-110500

Editorial office for Great Britain:
Gordon and Breach, Science Publishers Ltd.
41-42 William IV Street
London W.C. 2, England

Editorial office for France:
Gordon & Breach
7-9 rue Emile Dubois
Paris 6e

Two volume set ISBN 0 677 14220 A
Volume One ISBN 0 677 12410 4
Volume Two ISBN 0 677 12420 1

All rights reserved. No part of this book may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without permission in writing from the Publishers.

Printed in the United States of America

Preface

After the 1965 conference on Internal Conversion Processes at Vanderbilt University, many expressed the thought that there should be another conference in a few years to follow up the ideas and suggestions in the field that grew out of that meeting. Thus the idea of the conference held at Vanderbilt University, August 11-15, 1969, was born.

At the earlier conference, J. M. Hollander talked about the impact of solid state detectors of lithium drifted silicon, Si (Li), and Germanium, Ge (Li), for electron and gamma-ray spectroscopy in nuclear physics. The rapid development of these detectors with large volumes and high resolution has undoubtedly surpassed expectation. Coupled with the development of these high resolution devices for gamma-ray spectroscopy has been the development of large sophisticated electronic systems with 4096 channel analyzers interfaced with computers and buffer tape or disk storage. These systems have made possible very precise gamma-ray energy measurements with accuracies that rival or better that of the best magnetic, electron spectrometers. The detection of gamma-ray intensities, especially of weak transitions, has taken on a whole new dimension so that in complex decays, accurate determination of branching ratios for comparison with nuclear models is now possible. Sophisticated coincidence experiments such as two parameter, 4096 $\times$ 4096, $\gamma - \gamma$ and $e - \gamma$ coincidence work with additional parameters of time or angular dependence of the coincidences have become feasible. Thus it has become possible to obtain very reliable information about the energies, spins and parities of levels in nuclei populated by radioactive decays that involve 100, 200 or more gamma-ray transitions. Many of us, who previously limited our research principally to electron spectroscopy, have been attracted by the precision of these new systems to gamma-ray spectroscopy as well.

The development of these sophisticated systems proceeded so rapidly that it was felt that the time had come for us to reflect on the quantity and quality of data being accumulated and the problems associated with the data acquisition. So a conference to provide a forum for discussions and critiques of the latest techniques in nuclear spectroscopy, with emphasis on the application of these techniques to studies of radioactive nuclei

was initiated. It was envisioned that the invited speakers would emphasize the power of the new techniques in the study of interesting and complex problems in nuclear physics and related fields.

Many people contributed to the successful completion of the conference and these proceedings. The other members of the planning committee, J. M. Hollander and J. O. Rasmussen are due a special word of thanks along with the foreign advisory committee of E. Matthias, M. Mladjenovic, B. Van Nooijen and A. H. Wapstra. We wish to thank the authors for their generous cooperation and hard work that made this book possible. Many of the authors graciously agreed to expand their papers to make the book more valuable as a reference guide in this field. All the conference participants are thanked for their contributions to the conference and their help in preparing the discussions. The cooperation of the Vanderbilt Physics and Astronomy Department and the University, particularly Chairman W. G. Holladay and Dean R. T. Lagemann is gratefully acknowledged. The work of the nuclear spectroscopy group at Vanderbilt was invaluable. These include A. C. Restor, Chief Assistant for the conference, A. V. Ramayya and D. Krmpotic and students F. Coffman, E. Collins, N. Dyer, J. Ford, N. Johnson, A. Kluk, P. Little, W. La Casse and N. Singhal. Thanks go to Miss B. Chambers with the assistance of Mrs. W. Edwards for able secretarial help as well as to others in the Vanderbilt Physics departmental office including Mr. D. Shepard and Mr. W. Stevens who helped with many of the details. The equipment for recording the discussions was supplied by Mr. B. Higgs, Edison Voicewriter Co.

The absence from our midst of Professor M. E. Rose, deceased, who contributed so much to the field of internal conversion and to the 1965 Conference on Internal Conversion Processes was recognized with sadness. It was appropriate that the conference dedicated the Thursday session on Internal Conversion Processes to his memory.

It is a pleasure to thank the following who provided the funds which made the conference possible: The Aerospace Research Laboratories of the Office of Aerospace Research U.S. Air Force, The International Union of Pure and Applied Physics, and Vanderbilt University. The cooperation of Gordon and Breach in the publication of this book is most appreciated. The cooperation of the publishers of *Arkiv. f. Fysik, Nuclear Instruments and Methods, Nuclear Physics, The Physical Review, Physical Review Letters* and *Physics Letters* to allow the inclusion in various papers of materials previously published in these journals is gratefully acknowledged.

JOSEPH H. HAMILTON

Nashville, Tennessee

JOSE C. MANTHURUTHIL

CONTENTS

此为试读，需要完整PDF请访问：www.ertongbook.com

VOLUME TWO

VIII. HYPERFINE FIELDS

Chairman: L. Keszthelyi, Budapest, Hungary

IX. CONCLUDING SESSION

Chairman: B. van Nooijen, Delft

CONTRIBUTED PAPERS

A table of contents immediately following page 1206 contains a listing of all Contributed Pages which have been printed as pages 1207 to 1498.

RECENT DEVELOPMENT OF HIGH RESOLUTION BETA-RAY MAGNETIC SPECTROMETERS–

MILORAD S. MLADJENOVIC

B. KIDRIC INSTITUTE OF NUCLEAR SCIENCES
BELGRADE, YUGOSLAVIA

The high resolution electron spectroscopy faces two tasks, one unfinished in nuclear spectroscopy and another just beginning in the virtually infinite field of molecular spectroscopy.

1. Precise informations on nuclear excited states obtained from L-subshells ratios measurements have been so far mainly confined to lower energies (< 300 keV). Only a small number of precise measurements were reported in the region beyond 500 keV. There are thousands of transitions for which L-subshells were not precisely determined;

Besides "anomalous" conversion, some nuclear information might perhaps be obtained at higher energies, higher Z and M1 transitions.* The conversion near the nucleus compared to conversion further away increases with energy, while the influence of nuclear geometry is greater at high Z and for magnetic transitions. It will be interesting to see whether it will be possible to differentiate between models of the nucleus, beginning with the presently used surface current approximation.

Since the line width of 0.01% permits to separate the L-lines of 1 MeV at Z = 50, the limit increasing to 3 MeV at Z=100, it can be seen that much work can be done with resolutions, not

*This was discussed by Dr. L. M. Band in her lectures on the computation of ICC's, delivered in Belgrade, September, 1967.

better than 0.01%. On the other hand, ICC's decrease by 2-3 orders of magnitude when the transition energy increases from 200 keV to 1-2 MeV. The intensity is therefore by far the most important limitation. High luminosities are needed, which means the elimination of abberations and increase of source size. Another possibility is the extended focus which would increase the information number.

2. Any perturbation of electron cloud due to chemical binding, ionization, any inner or outer field causes level energy shifts, which are easier to detect at lower energies and in outer shells. Both, inner and outer conversion offer the possibilities to study these effects. The most beautiful and promising example is the ESCA work, initiated by Kai Siegbahn and his collaborators in Uppsala.

Most of the effects connected with the atom environment are confined to low energies. Very high resolution is always needed and much work can be done with line widths of 0.01%. When an external excitation is used, it is convenient to have an extended focal plane.

The above brief discussion of spectrometer requirements is summarized in the following table.

TABLE I

Main type of information		Nuclear	Atom and Environment
Main energy region		Medium and higher E	low E ($<$ 100 keV)
Spectrometer Characteristics	Resolution	0.01%	0.01%
	Luminosity	very high L critically needed	good L welcomed
	Extended focal plane	Useful to compensate lack of L	Convenient for external excitation
	Use of iron	Iron-free (or iron)	Ironfree

It would perhaps not be wise to try designing a single spectrometer to meet all the above requirements. An all-round instrument is often a sign of a lack of money or experience. One spectrometer

此为试读,需要完整PDF请访问: www.ertongbook.com

could be made to cover low energies, up to 100 keV. Temperature and cooling would not then be a problem. One would like to have an extended focal plane with an array of detectors or a large position sensitive detector.

Another spectrometer covering higher energies could be made either ironfree, or iron-covered.One would need a large source and a large transmission, all that at routine 0.01% resolution.

Of course, many other combinations are possible, and we have only given two illustrations of what might be of interest to build in the future.

The review of recent developments of high resolution spectrometers will not include material covered by Lee-Whiting at the 1965 Herceg-Novi Meeting (1) and low energy spectrometers described by K. Siegbahn and collaborators in the ESCA book (2). Some of the expressed opinions will be based on the discussions held at the meeting on Design of Beta-ray Spectrometers which took place in Bled (Yugoslavia), from the 15th to 18th of January 1968.

We shall start with cylindrically symmetric flat instruments to continue with non-symmetrical types and end with less conventional trochoidal and optical analogy spectrometers.

1. *Computer improvements of* $\pi\sqrt{2}$ spectrometers.– Recent work in Uppsala (3) shows how very wise it is to test with the computer a given magnet design by finding the iso-abberation curves. An optimum theoretical field given by the coefficients of the field in median plane is practically never produced by a real magnet. Some of the higher order coefficients often differ from the theoretical values. One then usually accepts the magnet geometry which seems to give the field in median plane closest to the theoretical optimum. The Uppsala group proceeded in a different way. They calculated the field in the whole volume containing orbits and then for slightly different core dimensions, calculated iso-abberation curves. It turned out that the best geometry was not the one giving the field in median

plane closest to the theoretical optimum. The most reliable optimization of a given magnet design is achieved by computing large numbers of orbits for a closely lying range of parameters.

2. Large Radial Angle Spectrometers: $\pi\sqrt{10}$, $(\pi/2)\sqrt{13}$ and Winding Field Spectrometers.

The dispersion of a flat spectrometer with cylindrically symmetric field can be increased by increasing the radial focusing angle. The beam is then axially focused n times. The radial focusing angle θ_r and dispersion D can be expressed as function of n by

$$\theta_r = (1 + n^2)^{1/2} \qquad D = 2\,(1 + n^2)$$

For n = 1 and 3 one obtains

$$n = 1 \qquad \theta_r = \pi\sqrt{2} = 255^\circ \qquad D = 4$$

$$n = 3 \qquad \theta_r = \pi\sqrt{10} = 569^\circ \qquad D = 20$$

The case of n = 1 corresponds to classical $\pi\sqrt{2}$ spectrometer. For n= 3 dispersion increases by a factor of 5, but the beam describes an angle larger than 2π, which means that a part of the beam will be hitting the source and the detector before being focused.

Lee-Whiting was first to discuss in detail the properties of $n > 1$ fields (4). He has shown that the abberation coefficients do not increase appreciably with n. We summarize briefly below some of his results:

–The focus is further away from the source (approximately 180°) for odd values of n, which are therefore preferable.

–The problem of premature encounters of the beam with the source and the detector is less severe for n = 3.

–For n = 3 the scattereng problems would be less serious if a wide aperture is used, the high aperture being inconvenient because the radial foci are close to source and detector.

–Lee-Whiting recommends that the source and the detector should be moved in opposite directions from the optic circle, and placed at some distance from it. This case was considered later in more detail by Daniel and Laslett (5).

A spectrometer of $\pi\sqrt{10}$ type was built in Moscow (6). We shall describe it further below.

Another approach to $n \geq 1$ spectrometer was developed by Daniel and collaborators (7). [illegible] gives up the axial focus so that at the position of the radial focus, the beam has the maximum axial extension. The exit slit is high and has to be curved. This introduces new degrees of freedom, allowing a reduction of abberations. The resolution is made independent of various higher order terms in the following way.

–The remaining second order term in angular opening is eliminated by curving the exit slit in the radial plane. It can be simply shown that electrons emitted from a point source at a given axial angle hit the focal plane at a given height. The equation of the focal line is then parabolical.

–Another degree of freedom is offered by the possibility of azimuthally curving the focus. This can be used to eliminate the third order cross term (first order radial, times second order axial opening).

–The remaining fourth order cross term (second order axial times second order radial opening) can be made less important by making a diamond shaped entrance baffle.

One should add that high sources can be used because the equation of the exit slit does not contain the axial coordinate of the point source, to the first order.

Theoretically, such a type of spectrometer should give a high

transmission with a very high resolution, as shown below by two sets of theoretical parameters.

Resolution	Transmission
7.3×10^{-6}	1.3×10^{-2}
4.0×10^{-4}	2.7×10^{-2}

for point source and $\theta_f = 324° \equiv (\pi/2)\sqrt{13}$

The luminosity is expected to be good due to the possibility of using a high source. We shall describe below the spectrometer constructed in Heidelberg.

Heidelberg $(\pi/2)\sqrt{13}$ *spectrometer.* (Fig. 1) The basic parameters of the spectrometer are the following.

Field shape: $B = B_0 (1 - 0.692308\eta + 0.461538\eta^2 - 0.31656\eta^3 + 0.22965\eta^4)$

Radial focusing angle: 342.5°

Dispersion D = 6.5

Radius of equilibrium orbit: $r_0 = 30$ cm

The magnet is iron-free, the field being produced by ten coils. The field was first found using current loops approximation, and then corrections for finite size were made. The coils were made with a mechanical precision of 0.1 mm. In the symmetry plane the deviations of the real field from the theoretical are $1\text{-}2.10^{-4}$.

Two counters are used, one 10 cm high for transmission up to 0.7%, and another 20 cm high for transmissions up to 1.5%.

The actual performance of the spectrometer can be judged from experimentally found parameters given below.

Table II

	Resolution	Transmission	Source area, mm^2	L
Normal Source	$4.8.10^{-4}$	1.0%	0.2 x 10 = 2	0.02 mm^2
	$3.0.10^{-4}$	0.6%	0.2 x 10 = 2	0.012 mm^2
	$2.2.10^{-4}$	0.6%	0.2 x 2.5 = 0.5	$3.10^{-3} mm^2$
	$1.3.10^{-4}$	0.15%	0.2 x 2.5 = 0.5	$7.5\ 10^{-4}$
Extended Source	$6.8.10^{-4}$	0.67%	250	167 mm^2

An inspection of the above table shows that the theoretically predicted performances were not attained, probably the main reasons being the field imperfections. But, the results are very good such as they are. It could be expected that with more computer work the field and performance could be improved.

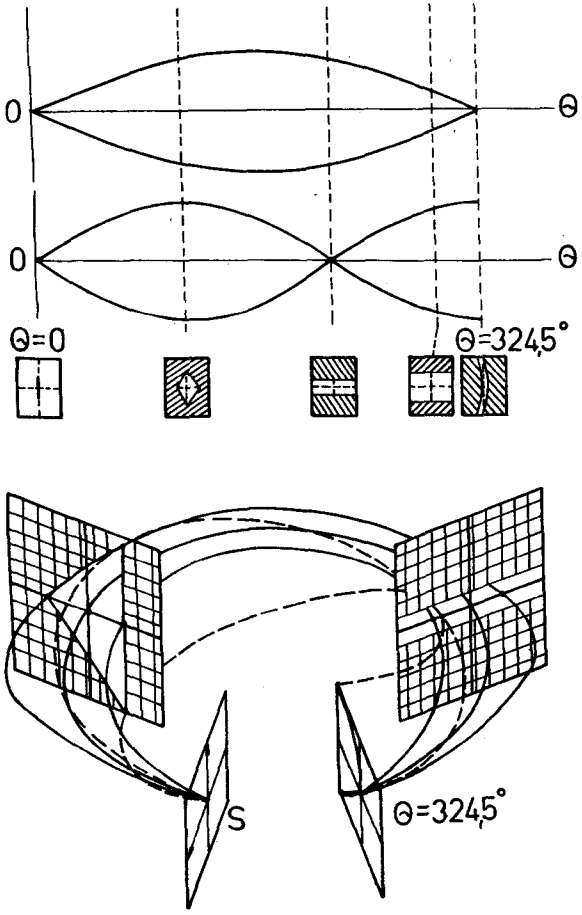

Fig. 1. Beam geometry of Heidelberg $(\pi/2)\sqrt{13}$ spectrometer.

Another advantage of this type of spectrometer are that the use of extended source is possible, while the corrector is hardly

needed.

The disadvantages are:

–large detector, very serious drawback

–multiple counter array difficult

–small distance source-counter, which becomes less critical for larger spectrometers

Moscow $\pi\sqrt{10}$ *spectrometer.* S. A. Baranov and collaborators (6) described very briefly a $\pi\sqrt{10}$ spectrometer. The basic parameters of the spectrometer are the following:

Field shape: $B = Bo\ (1-0.9\eta + 0.825\eta^2 - 0.767\eta^3)$

Radius of equilibrium orbit: $r_o = 40$ cm

Dispersion: $D = 20$

Radial focusing angle: 570°

The authors do not mention what kind of magnet is used and one gathers that it is probably of an iron-yoke type, from the last sentence in the paper: "It has to be mentioned however, that the requirements of magnetic field shape fitting are much more stringent in the given case and, probably, full use of the advantages of this type of instrument is only possible in an iron-free spectrometer."

The beam is prevented to enter the detector before completing 570° by two diaphragmes. One of them placed at 285° cuts the central part of the beam, and another, placed in front of the source, limits its radial angular opening angle. In such a way 2/3 of the horizontal opening of the beam is lost.

The authors give the following performances measrred with a ^{137}Cs source:

Source dimensions: 1.5×40 mm^2

Counter slit diam.: 2×50 mm^2

Solid angle: 3×10^{-4}%

Half width: 0.038%

Luminosity: 1.8×10^{-2} mm^2

此为试读,需要完整PDF请访问: www.ertongbook.com