RADIOACTIVITY IN NUCLEAR SPECTROSCOPY

Modern Techniques and Applications

VOLUME ONE

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IN NUCLEAR SPECTROSCOPY

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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

International Conference on Radioactivity in Nuclear Spectroscopy
Vanderbilt University, Nashville, Tenn.

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I: Opening Session

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WELCOME BY PROFESSOR W. G. HOLLADAY, CHAIRMAN

DEPARTMENT OF PHYSICS AND ASTRONOMY, VANDERBILT UNIVERSITY

Professor Hamilton, distinguished delegates to this Conference:

Since the last International Conference on Nuclear Radioactivity held on this campus in 1965, Vanderbilt University has looked forward to this return engagement. A meeting such as this is a time for renewal – renewal of acquaintances, renewal of the zest and spirit to do science, renewal of inspiration and dedication to the continuation of your scientific work. This University is honored to have this opportunity to participate in this process of renewal as the host of the Conference. In these times of campus turmoil throughout the planet, perhaps the best that we can offer here is some intellectual stimulation in an atmosphere of relative peace and tranquility. While the most certain guarantee of trouble is to assume we won't have any, yet, thus far, we have managed to escape the worst that has occurred elsewhere, and I am hopeful that this happy state of affairs will continue, at least, through this week.

While you are on this campus, we wish to do all in our power to make your stay as pleasant as possible. If you need a duplicating machine, or a transparency producer, or the telephone, or have any other special needs, I invite you most cordially to call on us for help.

While I have your ear, I wish to make one other point. I don't know how it is in your part of the world, but in this one region of it, despite the astounding and unprecedented triumphs of recent weeks, the entire scientific enterprise is paradoxically under some cloud of suspicion. Scientists, in general, and physicists in particular have not been very successful in interpreting effectively their work beyond the confines of their own discipline. Nuclear physics, which deals with the system whose stability accounts for the very existence of all ordinary matter, a subject which has transformed relations among nations, which has provided enormous new sources of energy and which has found fruitful applications in a diversity of other activities - Nuclear physics should provide an especially powerful vehicle to convey the value and meaning of science to a larger audience. Accordingly, as you consider the importance to science of the technical developments on the program of this meeting, I commend to your attention the importance as well of contemplating and articulating these developments in the larger perspective of how they can uplift the minds and lives of people everywhere.

In this spirit, then, let this Conference begin.

THE INTERFACE OF THEORY AND EXPERIMENT IN NUCLEAR SPECTROSCOPY — JOHN RASMUSSEN

YALE UNIVERSITY, NEW HAVEN, CONNECTICUT, USA

An examination of contributions to this and similar recent nuclear conferences shows that the exploration of nuclear levels by radioactivity has entered a new dimension. The tremendous developments in solid-state detectors and computers are in a short timespan having an impact on nuclear spectroscopy comparable to that of Galileo's telescope on the science of astronomy. To be sure, much knowledge had been accumulated about stars and planets without the telescope. Tycho Brahe's careful observations and Kepler's calculations had laid foundations for Isaac Newton's fundamental new insights. An impetus to these studies in astronomy in the 17th century was provided by the revolutionary sun-centered astronomical "shell model" of Copernicus. In part Tycho Brahe was trying to measure some motion of the fixed stars, in order to prove the heliocentric Copernican theory. For this task he simply had insufficient resolution, but the by-products, the precise observations of planetary motion made great contributions. Galileo's telescope increased resolving power and the precision of position measurement. The increased light-gathering power showed vast numbers of hitherto - unseen stars and revealed a substructure of some objects, such as, the phases of Venus, a powerful support of the Copernican theory. Likewise, for two decades of nuclear spectroscopy the great impetus for research has come from the shell models of Mayer and Jensen and the Bohr-Mottelson extensions. These models predated even our sodium-iodide gamma ray spectroscopy. And much of subsequent nuclear spectroscopy has aimed at testing various consequences of the nuclear shell model theories.

Most of us here today have shared a Galilean excitement with the advent of the germanium gamma spectrometers with their high resolution, multi-channel capabilities. It did not take long to realize that this order-of-magnitude gain in resolution in the solid-state detector created an unbalance and problems at another stage. Preamplifier noise became limiting, and the typical 256-channel analyzers (or luxurious 400-channel models) and hand-plotting practices became wholly inadequate. It was fortunate that technological developements such as field effect transistors, integrated circuitry, and so on came to fruition in time. Fortunately, too, great improvements in both small and large digital computers have come to offer a rescue from being overwhelmed at this earliest stage by solid-state detector information. The extraction of state-of-the-art energies and intensities from the spectroscopic measurements can be done. We shall hear at this conference reports of these marvelous computerized systems to take 4000 to 8000 channels of information in single or multi-dimensional analysis. But I fear that the basic problem is only being pushed one step further. Suppose we have for some radioactive isotope measured and analyzed some two hundred separate gamma rays, and this is not an unusual number, and suppose even that we have checked out the 4×10^4 coincidence possibilities and have conversion electron measurements and some angular distributions. Then what? How are these marvelous measurements to have any influence on or stimulate the imaginations of modern-day Keplers or Newtons among our nuclear scientists?

What I say now is not meant as criticism of others but mainly as self-criticism and expression of frustration at the inability to adequately communicate the results from much exciting new data. In groups with which I've been associated, we've been tempted by the high resolution of germanium detectors into ever more complicated situations. At the predecessor Nashville conference I proudly showed colored slides of gamma rays accompanying spontaneous fission, gathered in three-dimensional analysis and sorted according to fission asymmetry. Sad to say, very little of this work is yet in print. We felt, too, that a new study of gamma rays following beta emitting fission products would reveal some gamma rays in common with those measured in prompt fission conincidence. Jerry Wihelmy, working in Berkeley with Stan Thompson and me, undertook the task of measuring gammas of unseparated fission fragments on a tape conveyor belt. Jerry's thesis, now nearly complete, will document this wok, in which some 20,000 gamma rays have been processed in the computer for energy and half life information. I would repeat the question, "Then, what?"

Our thinking and that of referees and editors of journals regarding publication is still geared to the earlier simpler nuclear world of low resolution data. It is felt not proper to publish results until one has established level schemes and fitted many of the gamma rays into such schemes. Thus, we continue to pile up mountains of data, always awaiting that next improved experiment at a little bit higher resolution or with a new coincidence technique or something that will resolve enough questions to satisfy us sufficiently for writing up the work. If the nuclear spectroscopy community is not to be doomed to endlessly repeating each other's experiments and reliving each other's experiences, we must do some very hard thinking about new modes of communicating results, of interfacing to theory, and of interfacing between experimental groups. Especially in the complicated in-beam gamma spectroscopy, I'm very much impressed with the importance of cross bombardments by all possible means of making a given nucleus, of measuring its levels by radioactivity studies, too. Also it is very desirable to have overlapping information from heavy-particle spectroscopy and to put all these measurements together. One good example is U^{234} where levels are produced by β^-, E.C., and α decay, plus (d,p) and (d,t) reactions. There have been other notable cooperative efforts where several