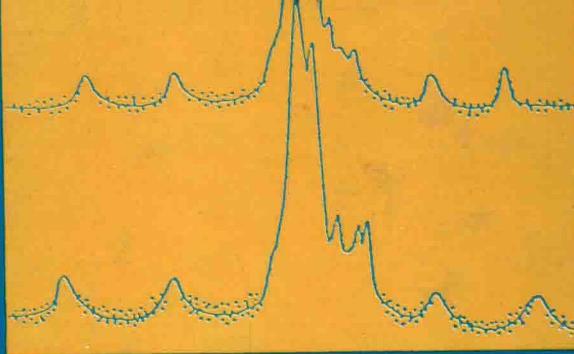

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APPLICATIONS OF NUCLEAR GAMMA RESONANCE SPECTROSCOPY
(Mössbauer Spectroscopy)

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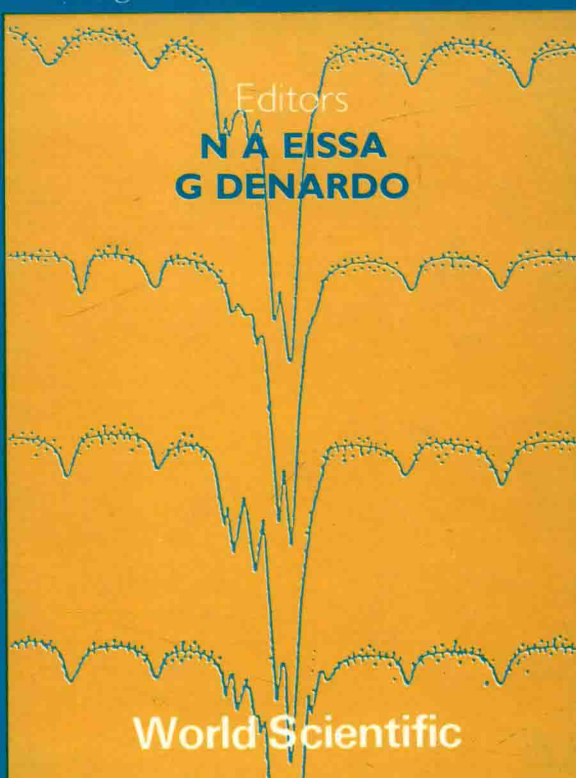

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PROCEEDINGS OF THE SCHOOL ON APPLICATIONS OF NUCLEAR GAMMA RESONANCE SPECTROSCOPY (MOSSBAUER SPECTROSCOPY)

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APPLICATIONS OF NUCLEAR GAMMA RESONANCE SPECTROSCOPY (Mössbauer Spectroscopy)

PREFACE

Nuclear Gamma Ray Resonance had been discovered by R. L. Mössbauer in 1958, and later named after him as Mössbauer Spectroscopy. Since then this field has spread to cover many branches of science and technology. It was decided to organize the first Mössbauer School for scientists from the Third World countries, within the frame of activities of the International Centre for Theoretical Physics (ICTP). These proceedings include the lectures of this school in the basic theory of Mössbauer effect, spectrometers and some applications in different fields.

Our thanks go to: Prof. Abdus Salam, ICTP Director, Prof. L. Bertocchi, ICTP Deputy Director, Dr. A. Hamende, Head, Administration Office, Prof. M. H. A. Hassan, TWAS Executive Secretary and Mrs. M. T. Mahdavi, secretary of the School.

The School was partially supported by the Kuwait Foundation for the Advancement of Sciences (KFAS) through Prof. A. Hamoui, SARF President.

N. A. Eissa and G. Denardo


School on Nuclear Gamma Resonance Spectroscopy
I.C.T.P. Trieste
11 - 16 August 1986

INAUGURATION SPEECH

by

Prof. N. A. Eissa
Director of the School

Mössbauer Spectroscopy has proven to be one of the most effective experimental methods for the scientific investigation in a large variety of problems covering many branches in science and technology. It is an ideal technique for both educational and research purposes in even an environment with a poorly developed scientific infrastructure. The popularity of the method is due to the fact that it allows one to carry out experiments with the highest energy resolution by making use of a relatively simple experimental apparatus.

In general, while one was interested in the earliest times of Mössbauer spectroscopy in qualitative interpretations, nowadays one uses it for quantitative measurements, including technical and industrial. This method can be used in any Third World laboratory and therefore it can promote transfer of technology effectively in the Third World. The present school is organized for scientists from the Third World countries to explain the basis and applications of this technique.

I would like to express my thanks, also on behalf of all the participants, to Prof. Abdus Salam, the Director of the ICTP and to Prof. A. Hamoui, the President of the SARF for their enthusiasm and financial support.

INAUGURATION SPEECH

by

DR. Adnan Hamoui
President of the ICTP Arab Friends Society

at the

School
on
Applications of Nuclear Gamma Resonance Spectroscopy
(Mössbauer Spectroscopy)

Trieste, 11 August 1986

Professor Abdus Salam, Distinguished Scientists, Fellow Colleagues, Ladies and Gentlemen

I am honoured for this opportunity given to me to inaugurate this School on "Applications of Nuclear Gamma Resonance Spectroscopy" and to extend a warm welcome to this gathering of distinguished scientists in the field of Mössbauer Spectroscopy.

This School is co-sponsored by SARF, The ICTP Arab Friends Society, which was founded three years ago with membership that stands now to about three hundred members.

SARF's main mission is to help the ICTP in achieving its objectives and to promote contacts and cooperation among Arab scientists.

With this aim, SARF organized here last year a symposium on "The Status of the Physical and Mathematical Sciences in the Arab World".

Also, SARF is co-sponsoring the

"Egypt Workshop on Photovoltaic Conversion"

which will be held in Cairo this year from 16 to 20 November and will be directed by Prof. M. K. El Mously, SARF's Secretary.

Ladies and Gentlemen,

Our interest in the present School springs from the fact that the Mössbauer Spectroscopy has proven to be one of the most effective experimental methods for investigating a quite large number of problems ranging from Nuclear Physics to Medicine. Besides, it is an ideal technique even with modest scientific infrastructure.

Ladies and Gentlemen,

This School – as nearly all SARF's activities – would not be possible without the generous support of the ICTP, and for that we are grateful to its Director Professor Abdus Salam and to its administrative body, particularly to the local organizer of this School Professor G. Denardo.

We are also very thankful to the lecturers of this School, Professors M. Abd-Elmeguid, G. Alonzo, G. Balestrino, A. Deriu, U. Gonser, I. Ortalli, G. Principi and particularly to Professor N. A. Eissa, the Director of the School, for his invaluable efforts for its success.

We are also grateful to the "Kuwait Foundation for the Advancement of Sciences" for its partial support to this School.

Fellow participants and Colleagues,

We sincerely hope that during this School you will be able to establish some regional cooperation or partnerships between your Mössbauer laboratories and groups that enable bilateral visits and technical assistance, which are often needed.

Also we hope, that you would have an enjoyable time in this hospitable city: Trieste.

Ladies and Gentlemen,

Let me thank once again Professor Abdus Salam who has so kindly consented to grace this occasion and to declare this School open.

Thank you for your attention.

CONTENTS

BASIS OF MOSSBAUER SPECTROSCOPY

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ABSTRACT

The method to be discussed here can be described in two ways:- either as Recoil-Free Gamma Resonance Absorption (RGRA) or as Mossbauer Spectroscopy. The latter term is the one now generally accepted. The reason for the use of the name of a particular person is the fact that this method has a unique history. It is to be hoped that the wonderful and even romantic story of its discovery will one day be told in full detail in a book which could, of course, only be written by that person himself. Rudolf Mossbauer.

1. HISTORY

Chance, skill and ingenuity are ingredients of great discoveries. For Mossbauer, the chance was provided by the isotope ^{191}Ir. In his search for nuclear-resonance fluorescence in this isotope he stumbled over an unexpected phenomenon, actually only a peculiar irregularity in his gamma counting device. He demonstrated his experimental skill but not simply ignoring this minor effect, but by proceeding to find its origin consistently and systematically. The right solution was an ingenious idea which developed into one of the great methods of modern science.

The development of the underlying concepts of the discovery can be divided into three stages, as shown schematically in Fig. 1.

In the pre-Mossbauer period nuclear reactions-for instance, the emission and absorption of gamma radiation-were treated in a classical fashion by the equations of motion which govern the movement of bodies. Thus, in a nuclear transition with energy E_0, a recoil of the nucleus with energy E_R occurs and the energy of the emitted gamma ray E_γ is reduced by the recoil according to the conservation of energy

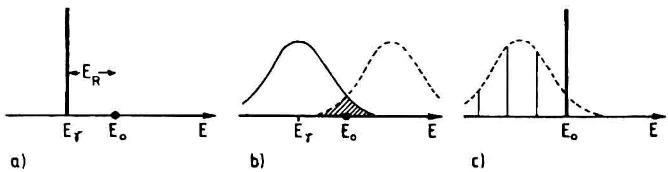

Fig. 1. Energy relationship relevant to the Mossbauer effect.

$$E_0 = E_R + E \quad .$$

This situation is shown in Fig. 1a. However, in the pre-Mossbauer period it was possible to perform gamma resonance fluorescence experiments. This was accomplished by using prior nuclear reactions, fast rotating devices or high temperatures in order to provide large Doppler effects to compensate for the recoil loss. In such experiments the absorber line and/or the emission line can be broadened and in the overlap region resonances are possible (shaded area in Fig. 1b). Thus, it was expected that absorption would increase with higher temperatures. Mossbauer's thesis work proceeded along this line to find nuclear resonance fluorescence. Unexpectedly he observed an increase in absorption at lower temperatures, and in a careful analysis he was able to deduce the physical principle of this phenomenon[1,2]. He showed that an earlier paper by Lamb[3] on neutrons was applicable to his problem. He realized that the emission and absorption of gamma radiation can occur in a recoilfree fashion. Without recoil the gamma ray carries the full energy of the transition ($E_\gamma = E_0$) and in the schematic representation (Fig. 1c) a line appears at E_0: the Mossbauer line. The personal accomplishment of discovering recoilfree gamma ray resonance absorption justifies the name Mossbauer Effect. If the method had been found by theoretical predictions, experimental observations and engineering skill-a combination sometimes leading to new methods we would probably speak of Recoil-Free Gamma Resonance Absorption (RGRA). Instead, we take the name Mossbauer and use it in connection with the method, isotopes, lines, spectrometer, etc.

The early history of the Mossbauer effect has been well described by Lipkin[4]: in the prehistoric period (before 1958) the effect might have been discovered, but was not. In the early iridium age (1958) the effect was discovered, but taken no notice of. During the middle of the iridium age the effect was noticed, but not believed. In the latter part of the iridium age the effect was believed, but aroused no interest. And then nature helped by providing the iron isotope ^{57}Fe. Actually Mossbauer himself had already realized the favorable properties of this isotope, but at that time an appropriate source was not available to him. With the iron age (after 1959) the effect experienced a breakthrough of dramatic proportions. All previous doubts were dismissed and the wonderful applications such as hyperfine interactions and relativistic effects were demonstrated. Particularly in the United States a fierce fight began in an effort to obtain some priority in the remaining glamour of the new effect. In the editorial of Phys. Rev. Lett. (April 1960) we read: "We believe that the time has come to put a damper on the influx of Letters on the Mossbauer effect". As early as 1961, just three years after the discovery, Mossbauer was awarded the Nobel Prize[5]. It is virtually unique for someone to achieve this distinction de facto by his first publication.

In retrospect we have to ask ourselves why the Mossbauer effect was not found much earlier. Theoretically, the general concept was already provided in the twenties. It seems surprising that we are genuinely so wrapped up in our macroscopic environment, where we experience recoil everywhere, that it took the analysis of an accidental observation to open our eyes to this microscopic recoil-free quantum effect.

The Mossbauer effect entered with ease all disciplines of natural science: physics, chemistry, biology, metallurgy, engineering, geology, and even such fields as archaeology, art, medicine and others. The Mossbauer Effect Data Index (MEDI)[6] compiles all the work done with this method. Several books on the Mossbauer effect have been published, the emphasis being mainly on certain aspects and applications [7-19]. Unfortunately, the effect is still considered exotic by many and it is only with reluctance that text books and field conferences take note of the effect. The people using the Mossbauer effect form a kind of close community with regular conferences and news letters. It is very rare for a community to exist on the basis of a scientific method alone. Perhaps the special terminology of the method has some psychological effect-could it be that the constant references to resonances and hyperfine interactions help to create a friendly atmosphere? It is also encouraging that the man who started it all is still actively engaged in the method which has been given his name.

2. PRINCIPLES

Mossbauer's discovery was substantially the realization that a certain probability for recoil-free events exists in the gamma ray emission and absorption processes. When there is no energy loss in the transition from the excited nuclear state to the ground state the gamma ray carries the total energy of the nuclear transition. When this gamma ray strikes, on its path, an isotope with the same nuclear transition there is a certain probability that excitation will take place. The phenomenon of resonance involves two bodies. Resonance between the two nuclei of source and absorber is achieved by the gamma rays, as indicated schematically by the bold arrows in Fig. 2. In this figure

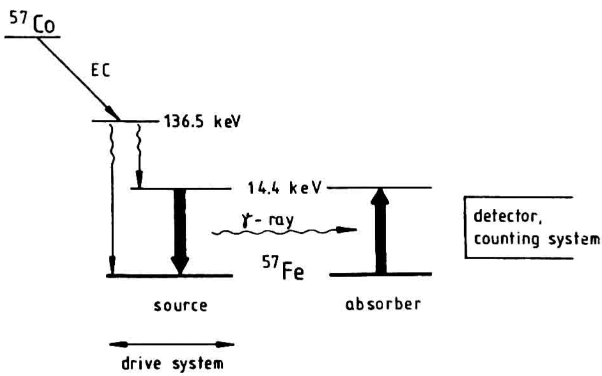

Fig. 2. Schematic representation of the components in a Mossbauer setup: source and absorber (^{57}Co, ^{57}Fe) with their nuclear transitions (the bold arrow indicates the resonance transitions), drive system (in the case applied to the source), gamma ray detector and counting system.

the situation for the isotope ^{57}Fe is shown including the transitions occurring in the source of ^{57}Co. Information regarding all Mossbauer parameters and effects is summarized in Table 1.