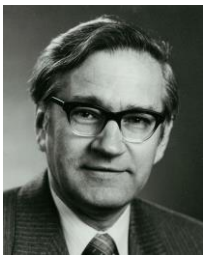

Richard R. Ernst – A scientist who added wings and dimensions to NMR spectroscopy (1933 – 2021)

This article is in tribute to Prof. Richard Robert Ernst who passed away on 4th June 2021. Prof. Ernst was a distinguished chemical physicist who was awarded Nobel Prize in 1991 for "his contributions to the development of the methodology of high resolution nuclear magnetic resonance (NMR) spectroscopy". His work laid the foundation of application of NMR in biology and medicine, including development of Magnetic Resonance Imaging. In the later part of his life, he had set up a modified Raman spectrometer at his home and developed method for identification of pigments in *Thangka* paintings in a non-destructive manner.

Introduction

It was the year 2012, Prof. Richard R. Ernst was speaking at an annual meeting of National Magnetic Resonance Society of India. He presented a nice slide showing how NMR spectroscopy integrates different streams of science. Then, a young undergraduate student asked him where is Mathematics? He had a slide in his stock to answer, which showed Mathematics at the root of the tree of knowledge of science (Figure 1). The slide also depicted the application of NMR spectroscopy in all the streams.

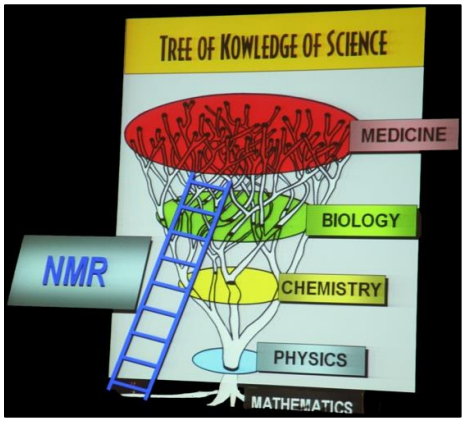

Figure 1: *Tree of knowledge of science. © Richard R. Ernst.*

Fourier-Transform NMR (FT-NMR)

NMR spectroscopy was developed in the 1940s by Felix Bloch and Edward Purcell to study the magnetic properties [1, 2]. But due to its inherent insensitive nature, NMR spectroscopy did not find much practical applications for a long time. People at that time jokingly started calling NMR as *No More Research*. Things changed in the year 1966 when Richard Ernst, while working at Varian Associates, discovered that the use of short and intense radiofrequency pulses instead of the traditional approaches of radiofrequency or magnetic field sweep could dramatically enhance the speed of data acquisition. He applied Fourier transformation to interpret the NMR signal measured as a function of time (called FID-free induction decay) by converting it to the signal intensity as a function of frequency (Figure 2) [3].

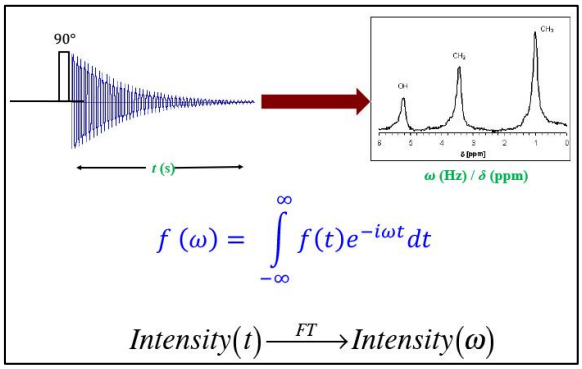

Figure 2: *Conversion of the time-domain data acquired after application of short radiofrequency pulse to the frequency-domain data by Fourier transformation.*

Ernst took forward the idea presented by Jean Jeener, at the Ampere summer school in 1971 and described a scheme to perform "two-dimensional" (2D) NMR experiments [4]. Later, taking cue from his work, researchers developed multi-dimensional and multi-resonance NMR spectroscopy. Dimensions in NMR spectroscopy mean number of frequency axes. These developments made it amenable to study small quantities of both organic and inorganic materials, biological macromolecules as well as less naturally abundant isotopes like ^{13}C, ^{15}N. Thus, the development of Fourier Transform NMR (FT-NMR) spectroscopy by Ernst not only made NMR spectroscopy fly but also added *dimensions* to it. Soon, a team comprising him, Kurt Wüthrich and Anil Kumar developed a three-pulse experiment called Nuclear Overhauser Effect Spectroscopy (NOESY) that could provide information on relative spatial orientation of atoms [5]. This established NMR spectroscopy as a method for atomic-resolution structure determination of proteins and nucleic acids in solution. Currently NMR spectroscopy is the only available method for obtaining three-dimensional structure of proteins inside the living cell [6].

Ernst also proposed a method for obtaining NMR-tomographic images. This laid the foundation for development of Magnetic Resonance Imaging (MRI) [7]. MRI is routinely used in hospitals to visualize the interior of the human body including lungs in a safe and non-invasive manner. It finds

applications in functional and psychological studies as well. The importance of his path-breaking discoveries that revolutionized the field and helped other researchers to develop new techniques can be gauged from the fact that he was the sole winner of the Nobel Prize in Chemistry in 1991. Later, researchers working on NMR and MRI were awarded Nobel Prize in Chemistry in 2002 [7] and in Medicine in 2003 [8], respectively.

Thangka paintings and spectroscopy

Apart from his excellence in NMR spectroscopy, he had an irresistible attraction for Tibetan philosophy, art and culture. He had started collecting *Thangka* paintings in the 1960s which developed into one of the richest collections. At his home, he had set up a mobile Raman microscope attached to a gantry on wheels (Figure 3) to characterise the pigments used in the paintings in a non-destructive manner and understand their geographical origin and age [9,10].

Figure 3: *Prof. Richard R. Ernst at his Raman laboratory set up in the basement of his home at Winterthur, Switzerland (picture by author).*

Ernst and India

Ernst had special love for Indian science. He was a regular visitor at NMR meetings and other conferences in India. As a member of advisory committee, he had helped NMR centres at TIFR, Mumbai and IISc, Bengaluru to grow. He laid the foundation of the School of Biotechnology at KIIT, Bhubaneswar and kept taking interest in its growth.

Biography

Richard R. Ernst was born in Winterthur, Switzerland on 14th August 1933. He studied at ETH Zürich where he received "Diplomierter Ingenieur Chemiker" in 1957 and Ph.D. in Physical Chemistry in 1962. Later, he worked at Varian Associates as a scientist where he invented Fourier transform NMR, noise decoupling, and a number of other methods. After that, he joined as a lecturer at ETH Zürich in 1968 and became a Full Professor of Physical Chemistry in 1976. He retired in 1998.

Figure 4: *Prof. Richard R. Ernst and his wife Mrs. Magdalena Ernst with the NMR book at their home (picture by author).*

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