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In honor of Sir Peter Mansfield

The advent of NMR in the light of Sir Peter Mansfield's innovations

Richard R. Ernst

Laboratorium für Physikalische Chemie, ETH-Zentrum, 8092 Zurich, Switzerland

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Dear Sir Peter, Ladies and Gentlemen,

I have to admit that I admire you, Peter, ever since the mid 1960s for your ingenious contributions to science which were always much ahead of the crowd, some of which are still not properly exploited even today. It is indeed a great pleasure for me to say a few words on the occasion of this celebration.

Sir Peter Mansfield has, among others, three important qualities: solid, lively, magnetic, and he combined them during his career in an exceedingly fruitful manner. He was born in the same year as me. But considering the eternal solidity of his achievements, I always considered him as being much ahead of me. On the other hand, his lively, energetic approach to science, his fighter's spirit gave me and gives me the impression of a very young, unspoiled man. And he is certainly magnetic, attracting many clever and themselves ingenious coworkers. But you know that these three adjectives equally well characterize the fields in which Sir Peter was active, and this is what I would like to talk about. There may be some duplication in what I have to say with the following lectures. But I think that his great achievements cannot be properly appreciated by hearing about them only once.

Sir Peter Mansfield started out in solid-state physics. He belongs to a generation where each graduate student had still to build his own instrument before he could make relevant measurements under the direction of Jack Powles [1,2]. While my instrument which I built during my thesis never worked, he made creative contributions with it almost on the first day.

The surprising discovery of echoes in solids in the presence of strong dipolar couplings was not expected, even by experts. Of course, spin echoes were well known to occur under different circumstances, the Hahn echoes having been observed more than a decade earlier [3]. All previous echoes have been observed in inhomogeneously broadened systems where localized interactions are responsible for the linewidth. The elimination of splittings caused by an intricate network of dipolar couplings was far less obvious. There was at that time already a hint in literature on the observation of solid echoes by I.J. Lowe [4]. But details were missing and Peter Mansfield was not aware of this reference at the time of his discoveries. His thorough analysis of solid echoes [5] induced by a $90^\circ_0-90^\circ_{90^\circ}$ pulse pair formed the basis for the later explosive development of multiple pulse dipolar decoupling techniques.

The next innovation in the field of dipolar decoupling came from Ostroff and Waugh [6], and initiated a period of lively competition between the groups of MIT and the University of Nottingham. The American authors extended in their paper Powles' and Mansfield's solid echo sequence [1] into a pulse train, leading to a series of solid echoes and to a much extended free induction decay. The publication was followed within a few days by a paper by Mansfield describing the same, independently conceived, idea [7]. Soon afterwards, Waugh and Huber [8] proposed the next innovation, a phase alternation of the pulses which allowed chemical shifts to be retained. Again, there were parallel developments in Mansfield's group leading to the same proposal [9]. The proposed pulse sequence was truly the first to allow high resolution solid state NMR. It is not astonishing that the competitive situation led to some friction between the two worldwide leading research groups and to two bellicose papers [10,11]. But it was not the. The next innovation, again from Waugh's group was the proposal of the famous WAHUHA sequence [12] which leads to an efficient error correction. The symmetry principles, exploited in a very simple form already in the WAHUHA sequence, were then generalized by Mansfield in another seminal paper [13]. It contained among others already the highly efficient MREV-8 pulse sequence which was, 2 years later, reinvented by Rhim, Elleman and Vaughan [14]. Even more extended pulse sequences were conceived in the following years by other authors. But in essence, the basic development in multiple pulse homonuclear dipolar decoupling, or in 'spin alchemy' was thereby concluded.

Before Peter Mansfield turned his major interest towards magnetic resonance imaging, a very clever scheme for the indirect detection of rare, low-gamma spin resonance was published [15]. It took advantage of polarization destruction spectra which allowed him to trace out the free induction decay of the rare spins point by point with a spectral resolution that was not attainable before.

About the same time when Paul Lauterbur conceived his revolutionary concepts for magnetic resonance imaging [16], Peter Mansfield started to explore an entirely different approach to obtain geometric information based on a diffraction concept in the presence of a very strong magnetic field gradient [17]. While Lauterbur had the imaging of macroscopic objects in mind, Mansfield was more interested in exploring atomic structures. Mansfield's original concept has still not yet been implemented. But it initiated a very fruitful development in magnetic resonance imaging, contributing essential new concepts. For example, the insightful k-space description of imaging was implicitly already invoked in this visionary work. It was later reintroduced by Feiner and Locher [18] and by Ljunggren [19].

As usual for great achievments, the magnetic resonance imaging concept can be traced back much further into the dark history. It is often said that the first human NMR signal was seen by Felix Bloch when he inserted already in 1946 his finger into an NMR probe assembly (Unconfirmed rumors). Later, Ed Purcell and Norman Ramsey attempted, without success, to sense nuclear resonance in their heads exposed to a strong magnetic field and radio frequency irradiation (Letter of E.M. Purcell to H.Y. Carr, dated 28 November 1983). Robert Gabillard explored already in 1951 the influence of magnetic field gradients on the NMR lineshape [20]. Some rather odd experiments, placing rubber pieces in a magnetic field gradient, were performed by Herman Carr in the course of his thesis [21] in order to simulate the expected free induction decay of ethanol. With much imagination and goodwill, this could be interpreted as the very first one-dimensional imaging experiment although the experiment was not conceived for imaging purposes. Also the somewhat naïve but influential attempts of Raymond Damadian, described in a patent application of 1972 [22], did not lead to a world-shaking breakthrough as no working imaging concept was proposed. It was indeed Paul Lauterbur who broke the ice by the proposal of a projection-reconstruction technique [16].

Peter Mansfield's revolutionary contributions to magnetic resonance imaging concern a series of methodological inventions that step-wise improve the efficiency of the imaging process, leading ultimately to the optimum conceivable technique: echo planar imaging [23]. While others [24] attempted to simultaneously excite the entire object to be imaged for optimizing sensitivity, Mansfield's approach was focusing on selective irradiation of parts of the object, a concept [25] that turned out to be extremely fruitful. Selective pulses have become of vital importance in magnetic resonance imaging. Another approach of reaching selectivity by time-varying magnetic field gradients was worked out simultaneously by Hinshaw [26].

At first, the line scan method was proposed by Mansfield in which the object is scanned line by line [27]. The procedure was then extended to planar imaging [28] where an entire plane of volume elements was simultaneously observed. A further extension was multiplanar imaging [29]. These attempts invoked the principle of reduction of dimension where by a suitable magnetic field-gradient direction the two- or three-dimensional spin density was projected onto a single frequency axis. This allowed fast imaging but led to a considerable loss of sensitivity by the need of selecting narrow slices of excitation in the investigated object.

The mentioned disadvantage could finally be removed by the conception of echo planar imaging (EPI) [30]. Considering the data flow, EPI is the optimum conceivable technique that allows minimum measurement time without any sacrifice in sensitivity per unit time. It may be not the easiest technique to implement because of its enormous requirements regarding switched magnetic field gradients, but it is inherently the most of all techniques. It is very likely that its practical importance will significantly grow in the near future.

With EPI, it became possible to record real-time movies, for example of a cardiac cycle [30]. For the first time, also the time dimension could be adequately covered by magnetic resonance imaging.

The technical requirements for the implementation of EPI and related methods were staggering. But Sir Peter Mansfield provided clues to their solution. In particular the usage of screened gradient coils [31,32] and active acoustic screening [33] turned out to be beneficial in practical applications.

Sir Peter Mansfield has presented during his highly successful career an enormous gemmate bouquet of great ideas. Some of the buds still have to open to reveal their full beauty and usefulness. But it is clear already today that Sir Peter Mansfield will remain in the history of magnetic resonance, one of the most creative promoters with contributions in a very wide field ranging from solid state physics to clinical medicine. He has rendered the field of NMR even more exciting and considerably more useful than it ever was before. We as spectroscopists and as members of the human society are enormously grateful to him for his everlasting contributions.

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