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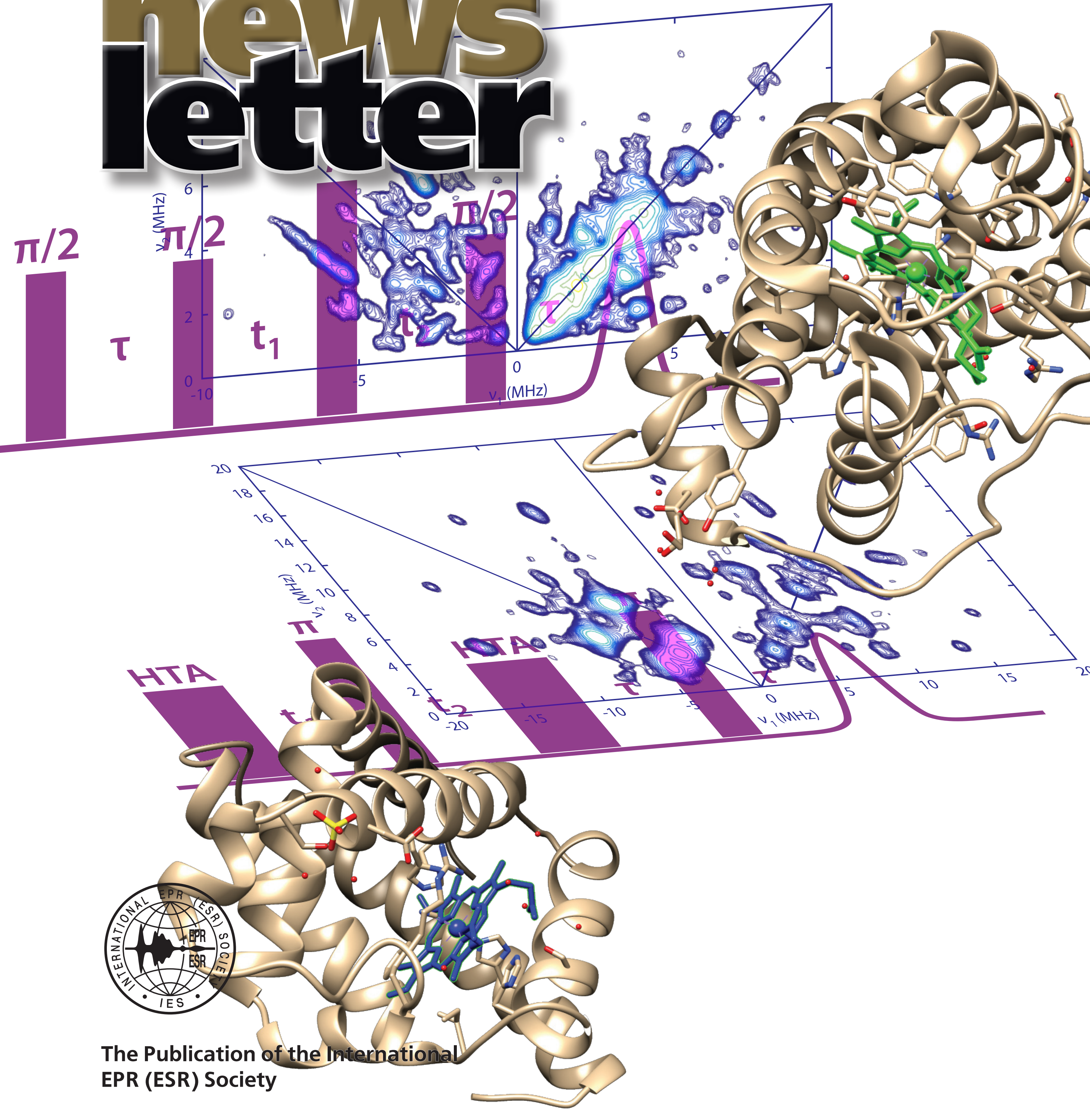

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Please feel free to contact us with items (news, notices, technical notes, and comments) or ideas for the *EPR newsletter*.

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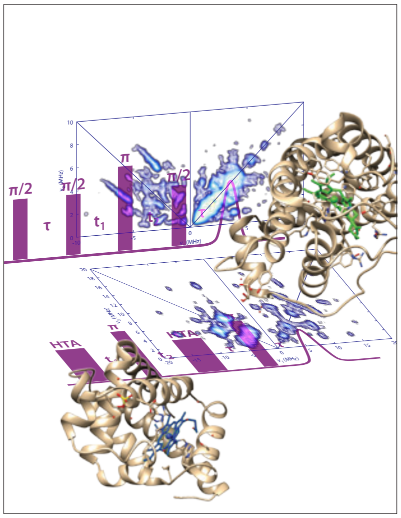


The cover picture illustrates aspects of research carried out by Sabine Van Doorslaer, recipient of the Bruker Prize 2018. It shows how the ruffling of the heme group in ferric protoglobin (shown in green) is reflected in the appearance of extended double-quantum ridges in the ^{14}N HYSCORE spectrum due to the magnetic inequivalence of the heme ^{14}N nuclei. The SMART HYSCORE spectrum of ferric myoglobin reveals narrow double-quantum cross peaks in line with its more relaxed flat heme group (indicated in blue).

epr newsletter

The Publication of the International EPR (ESR) Society

volume 28 number 3 2018

Editorial

Dear colleagues,

By now all of us must have visited the IES website (www.ieprs.org) and with deep sorrow learned about the demise of Yuri Tsvetkov, IES President in the period of 2002–2005 and Fellow of IES. The condolences letter sent by Thomas Prisner, current IES President, gives a concise but comprehensive overview of Yuri Tsvetkov's scientific achievements and pioneering contributions to the development of magnetic resonance. A detailed In Memoriam column devoted to Yuri Tsvetkov will be published in the forthcoming issue of the *EPR newsletter*.

With great sadness we added the dates of Yuri's birth and passing away in parentheses in the list of Fellows of IES on the second cover page, as we did for other fathers of our field Charles P. Poole, J. Michael Baker, Kalman Hideg and Charles P. Slichter in the previous issue (for the relevant In Memoriam, see 28/1-2, pp. 20–28). In this issue we bid farewell to George Feher, pioneer of electron nuclear double resonance. Wolfgang Lubitz and Klaus Moebius prepared a collection of contributions from authors of the international magnetic resonance and molecular structure communities "…honoring him as an exceptional scientist, a wise man with a proverbial sense of humor, a Mensch who mastered the difficult stages of his life without losing his empathy for the people around him. …" (pp. 10–29).

Our recent losses prompt me to quote from an email message of Timothy Baker, son of Michael Baker : "… Mark Newton's obituary and John Pilbrow's appreciation are wonderful tributes. My father would have been proud, since I know that he regarded his fellowship of IES as a great honour. We treasure his medal and citation in the family archive. It is sad but I suppose inevitable to see such a cluster of obituaries of pioneers of EPR in the newsletter. I gather that George Feher and Roger Elliott have died recently, too. We are fortunate to have the likes of Mark Newton and others of my father's graduate students to carry the torch forward. …"

How true! We bid farewell to the fathers of magnetic resonance but at the same time we are optimistic about the future of EPR. The torch is being carried forward! To name a few: in their interviews, IES Fellows 2017 Jack Freed (18/2-3, p.23) and Wolfgang Lubitz (pp. 5, 6); Sabine Van Doorslaer (Bruker Award 2018) (pp. 3, 4); and Daniella Goldfarb (IES Gold 2017) (pp. 4, 5) share their experience and enthusiasm concerning the potentials of EPR in different fields of research. The younger EPR generation, in this issue represented by Fazhan Shi (IES Young Investigator Award 2017) (p. 6) and new EPR faculty John Franck (p. 32), together with many other winners of diverse magnetic resonance awards for young researchers featured in other issues, clearly demonstrate that the enthusiasm and optimism of the pioneers of EPR is being fully sustained.

It this respect, it was a brilliant idea of Sabine van Doorslaer, Associate Editor of the *EPR newsletter*, to introduce the Present meets Future column, in which she confronts the views and experiences of an early stage researcher in EPR with those of one of his/her mentors. It was instructive and entertaining to meet with Jennifer Mathies and Edgar Groenen (24/3, pp. 10, 11), Daniel Klose and Heinz-Juergen Steinhoff (25/1-2, pp. 16–18), Olesya Krumkacheva and Elena Bagryanskaya (26/1, pp. 4–7), and Matthew Krzyaniak and John McCracken (28/1-2, pp. 9–11). We are looking forward to meeting with other heroes of Sabine's column.

The fathers of EPR may rest in peace. The torch is being carried forward!

Laila Mosina

Interview with Professor Sabine Van Doorslaer on the Occasion of Her Bruker Award 2018

EPR newsletter: *Dear Professor Van Doorslaer, on behalf of the readers of the EPR newsletter we congratulate you on your Bruker Award 2018. We are most appreciative that you agreed to answer the questions of this interview. Why did you start towards your career in science?*

Although there are multiple parameters that determine decisions in life, there are two factors that definitely played a major role in my choice for science: growing up next door to an engineer and going to a girls-only high school. My next door neighbor was set on having his son – my best friend at the time – follow in his footsteps. Hence, he was constantly explaining his son all kinds of technical things and was very much into learning by doing. Since I was always roaming around their house, I got included in the 'how stuff works' experiments and explanations. As it turned out, my friend never became an engineer – he is too much of an out-door farming-type guy, but his father got me hooked on science and technology.

This interest in science was further cultivated in my (girls-only) high school. Although separate schools for girls and boys were in Belgium almost standard up till the late 1970s, they started to get more gender mixed in the 80s. In my high school all divisions for professional and technical secondary degree programs were already open for boys and girls, but that was not the case for the general secondary school division (ASO[1]) that I followed. Although I can name and experienced many downsides of gender separation in primary and secondary schools, it had the good effect that I never had to compete with boys in fields that were (and to an extent still are) claimed to be a male playground, namely the 'hard' sciences physics, chemistry and mathematics. I only realized much later, being a mother of two daughters with interests in science, that I have been very fortunate in that way. I have learnt by now that the mechanisms of gender biasing are very subtle and unfortunately very effective in a negative way.

Already in high school, I was intrigued by both physics and chemistry. Physics was the field in which you could actually "talk" in that wonderful language of mathematics, and I fell in love with molecular structures and their reactions from my very first lesson of chemistry.

From left to right: Eric McInnes, Sabine Van Doorslaer and Peter Höfer.

Although I long considered becoming an engineer (following the example of our neighbor), a visit to the engineering department in Ghent University in the last year of high school made me realize that this was not what I wanted. I finally decided to go for Chemistry, but my disappointed Physics teacher planted a seed in my head that grew during my first year at University. At my high school graduation, she bluntly asked me 'Why don't you study both chemistry and physics? I think you can do that.' I laughed this off at the time, but combined with my interest in quantum mechanics that was arisen by my first year quantum chemistry course, it was this remark that made me decide to study Physics and Chemistry in parallel.

Who introduced you into magnetic resonance?

Although I learned about NMR as an analytical tool in organic chemistry during my Chemistry degree lessons, I did not immediately fall in love with magnetic resonance. I majored in inorganic chemistry and quantum chemistry and did my Chemistry master thesis in the latter field. It was only when I got introduced to EPR in my Physics degree program that my attention was caught. Prof. Freddy Callens (Ghent University) introduced me to EPR in one of the student projects in the 3rd year of Physics. Because of my dual interest (and indecisiveness) in chemistry and physics, I was very much on the look-out for study fields that would allow me to combine both interests. Quantum chemistry is one of them, but magnetic resonance turned out to be even more so. I once heard Edgar Groenen say that EPR is the technique that brings you closest to the electron wave function, and this probably sums up why I like EPR so much. I therefore did my master thesis in Physics under the guidance of Etienne Boesman and continued to do a PhD in the same lab under the guidance of Freddy Callens doing ENDOR on paramagnetic centers (such as O_2^-, O_3^-, S_2^-, Se_2^-) in various materials, ranging from alkali halides to hydroxyl apatite and even plant material. Although I sometimes wondered about the relevance of these studies during my PhD, I know now that it was a fantastic learning school and formed the basis of many of the things I did since then. I cannot thank Freddy and Etienne enough for that.

What part of your research is most dear to your heart and why?

That is a very hard question. I have always very much enjoyed doing EPR (or science in general). Every topic is as a puzzle. It gets into my head and I can't stop thinking about it till it is solved, even if the answer may only come many, many years after the question. What I enjoy the most is not only satisfying my own curiosity and learning new things, it is also the pleasure of thinking out loud together with other scientists. Certainly now, at a point in my career where many administrative and

[1] In the Belgian ASO scheme, pupils are prepared for higher education.

management tasks are eating away at my time, I can get a lot of positive energy from sitting behind a spectrometer and discussing EPR and science.

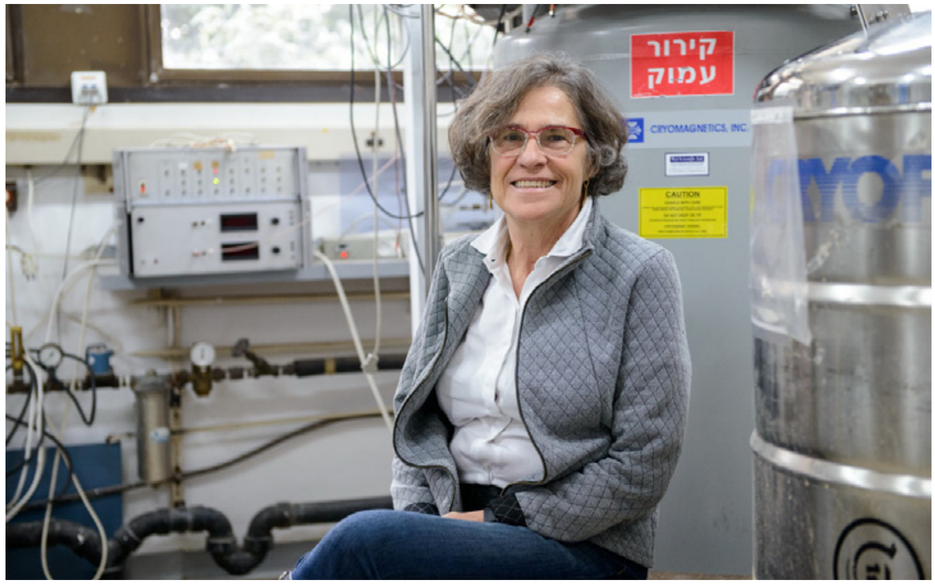
I am probably best known for EPR studies on heme proteins, metallo porphyrins and related systems, and although there have been moments that I have thought it was time to move on to other topics, there is always that next question that intrigues me. So, if you ask for research that is close to my heart, this (and in extension EPR applied to inorganic chemistry problems) is probably it. I really treasure the past and present joint work on (bio)inorganic problems with Mario Chiesa, Maria Fittipaldi, Ines García-Rubio, Damien Murphy and many others.

What is your message to the young generation of magnetic resonance researchers?

The current neo-liberal climate have brought (apparent) direct measurements of achievements and the related strong competition into science. Although it is in the current setting impossible for young researchers to ignore the boundaries for career advancement, they should safeguard not to get drawn too much in this rat-race. Research should remain curiosity-driven, rather than being opportunistic. To use the words of Goethe "*Wer nicht neugierig ist, erfährt nichts.*" [If you're not curious, you won't find out anything.] Although the former is almost too obvious to put into words, I see more and more young scientists that forget to enjoy the pleasure of finding out things. So my message would be to always look for the joy in science. And rest assured, we all have doubts and moments where we want to pack it all in. Don't be fooled by the 'everything is great' fronts that some scientists put on. It is nothing but a survival strategy.

EPR has always been an area where we are more collaborators than competitors and I hope that this will remain the case also in the future. This is in the hands of the young magnetic resonance researchers. There are far more problems that can be tackled by EPR than there are EPR scientists to tackle them. We are still fishing in a sea instead of a pond. The big challenges for the young generation lie in explaining to non-EPR scientists what exactly you can learn from EPR and to get them interested; to go fishing in the open sea and not only along the shore. It is something that will not happen on its own account, but will need some effort. I think that those who put in that effort, will get many rewards. Magnetic resonance is a great field to work in.

Interview with Professor Daniella Goldfarb on the Occasion of Her IES Gold 2017



EPR newsletter: *Dear Professor Goldfarb, on behalf of the readers of the EPR newsletter we congratulate you on your IES Gold 2017. We are most appreciative that you agreed to answer the questions of this interview.*

Why did you start towards your career in science?

I loved Physics and Chemistry at high school, I particularly enjoyed the chemistry labs and was fascinated by the idea that I could find out the content of a series of transparent and colorless solutions and which discover the ions were 'hiding' in an unknown sample. This driving force of 'discovering what is there that cannot be seen' has been a central motto of my work since then. In addition, I liked the challenge of solving problems in math and physics. So eventually I ended up in Physical Chemistry that combines all this. I was also lucky to have excellent Physics and Chemistry high school teachers who managed to inspire some of us with the beauty of these subjects and the challenges they pose, beyond just being difficult subjects.

Who introduced you into magnetic resonance?

I did my undergraduate studies in Chemistry, with an emphasis in Physics at Hebrew University in Jerusalem. I was a good student and as such was given the opportunity to choose a lab for a summer project after my second year. I choose the laboratory of the late Prof. Haim Levanon, who just stated his own lab and was already a known expert in EPR spectroscopy. My role was limited to extracting and purifying chlorophyll samples for a graduate students in the lab, who was studying their photo-physics using EPR spectroscopy. I was not allowed to "touch" the spectrometer but was permitted to watch how experiments were performed. I continued working in this lab also throughout my third and last year of my B.Sc. studies. While purifying the chlorophylls was tedious and not terribly exciting, I was very impressed with the power of spectroscopy. Since then the excitement of solving and obtaining molecular information from a spectrum has become a motivating force throughout my scientific work.

After graduation I followed my husband Arnon to the US and completed my M.Sc. degree, this time in IR and Raman spectroscopy as there were no labs focusing on magnetic resonance. So I started to do real serious research in magnetic resonance only for my Ph.D. at the Weizmann Institute after coming back to Israel I first considered pursuing a project related to NMR on biological systems, and my prospective supervisor Prof. Hadassah Degani suggested that I take a few months to learn NMR theory with the well known pioneer in NMR, Prof. Zeev Luz; as it turned out, a few months turned into a full and productive Ph.D. program on NMR of liquid crystals with Prof. Luz.

I was introduced to EPR spectroscopy only during my post-doctoral training. I had my heart set on a position in the Griffin group at MIT to do solid state NMR, which at the time was highly challenging. I was accepted and the family started to make the necessary plans (I had two little girls at the time) but then my husband landed an exciting job in distant Houston, and the sky seemed to fall upon me. Things, however, are not always as bad as they seem. I started to look for labs in NMR in the Houston area and found none. But, during my literature searches I came across the lab of the late Prof. Larry Kevan, well known pioneer of pulsed EPR. At the time this was a new exciting direction, highly under developed as compared to NMR, and commercial spectrometers were non-existent. I decided that this will be my new direction in science. Larry accepted me to his lab and the smile came back to my face. In Houston I got used to derivative CW EPR spectra (this is hard for an NMR spectroscopist who does not know how a CW spectrum looks like) and learnt how build a pulsed EPR spectrometer.

What part of your research is most dear to your heart and why?

The instrumental and methodological development part. Working with homebuilt spectrometers, although frustrating at times, is highly rewarding and is lot of fun because it allows you to implement new ideas and new experiments, independent on the manufacturer assistance and cost. Our home built W-band pulse spectrometer is constantly changing and improving; it is a dynamic spectrometer. Eventually, this also leads to new knowledge and new applications. One of the reasons I am so fond of magnetic resonance is the great variety of experimental techniques it offers and a "dynamic" spectrometer allows us to realize this as much as possible.

What is your message to the young generation of magnetic resonance researchers?

You are in a wonderful and exciting field that keeps reinventing itself since its discovery in the mid 40th of the pervious century. It never stays sill and keep venturing into new areas a decade ago seemed impossible. It has endless applications and faces, so keep enjoying its versatility and diversity and pushing it forward.

Interview with Professor Wolfgang Lubitz on the Occasion of His IES Fellowship 2017

EPR newsletter: *Dear Professor Lubitz, on behalf of the readers of the EPR newsletter we congratulate you on your IES Fellowship 2017. We are most appreciative that you agreed to answer the questions of this interview.*

Why did you start towards your career in science?

As a young boy I was very interested in science, both physics and chemistry, and used to do experiments in school – and also at home to the displeasure of my parents. I had some very good teachers in high school who fostered my interest early on. In 1969 I finally decided to study chemistry at the Freie Universität Berlin. My curiosity, excitement and dedication continued through my student years and doctoral work. It was a fantastic time...

Who introduced you into magnetic resonance?

This was first Professor Harry Kurreck, a physical organic chemist at the FU Berlin, who gave brilliant lectures at the Chemistry Department on the chemistry of radicals and EPR spectroscopy and Professor Klaus Möbius (Molecular Physics, FU Berlin), whom I met later in his memorable courses on advanced magnetic resonance spectroscopy. During my diploma and doctoral work I had the pleasure to be tutored by Peter Dinse and Reinhard Biehl at the Möbius lab, and also by Martin Plato from whom I learned a lot about the theory of magnetic resonance. During my postdoctoral time I added expertise in the laboratory of George Feher at UC San Diego, learning new things in particular from Roger Isaacson and naturally from many discussions with George.

What part of your research is most dear to your heart and why?

This is a difficult question to answer. During my career I worked on many aspects of magnetic resonance that I liked very much. During my initial work I tried to apply ENDOR to several non-proton nuclei in organic radicals, later I used this knowledge to study chlorophyll radicals and triplet states and also other cofactors in photosynthetic reaction centers (e.g. quinone radicals) in solution and in the protein, and finally moved to the exciting field of transition metal complexes and metalloenzymes. One of the most challenging and interesting problems in my career was the elucidation of the function of the tetranuclear manganese cluster that is catalyzing the light-driven oxidation of water in oxygenic photosynthesis. This Mn_4CaO_x-complex is paramagnetic in practically all states of the water splitting cycle and can be studied by advanced EPR techniques. Such experiments were indispensable for determining the electronic structure of the intermediate catalytic states, the water binding events and finally the O_2 release. Of comparable importance for me was the elucidation of the structure and function of the enzyme hydrogenase which converts dihydrogen to protons and *vice versa*. A profound understanding of both enzymes, water oxidase and hydrogenase, is crucial for the development of a future bioinspired catalytic production of solar fuels from water and sun light. Several generations of students and postdocs during the last 3 decades have greatly contributed to this work in my laboratory. I very much hope that they have all profited from their work on these interesting scientific projects.

What is your message to the young generation of magnetic resonance researchers?

First find out what you really like to do, what gives you most pleasure and where you are able to really contribute – and then go for it! Look for the best place and laboratory to work on the chosen subject and pick a good mentor. I believe that the field of magnetic resonance with all its facets is very interesting and highly attractive – both for people interested in either instrumentation or method development or in various applications in chemistry, physics, biology and medical research. You will frequently work in an interdisciplinary environment; learn about modern spectroscopy, data analysis and interpretation – often including quantum mechanical calculations and molecular modeling. To me this is an ideal field to work in.

Important is to pick a topic where for example EPR can really contribute. Choose a field that is not overcrowded yet; otherwise your competitors will be faster and you will lose out. Think hard about the best way to do your experiment using the strength of the available instrumentation and your own imagination. An important point is the sample. Try to get the best preparation and remember that the quality (and concentration) of the sample can save a lot of measurement time or even rescue the whole project. Therefore, try to keep good contact to synthetic chemists or biochemists and have them around when samples are made and joint experiments are performed. And have brain storming sessions on new compounds and new techniques (e.g. pulse sequences) and the development of new instrumentation (e.g. probe heads).

Perform from time to time unusual experiments off the beaten path that might have little chance to succeed but would provide important new insight or could even lead to a scientific breakthrough – if they work. Follow up unusual and unexpected results – don't give up too quickly, they often contain important new information. Always discuss your results thoroughly with your coworkers or fellow scientists and get their opinions – science is not a one-way street. Talk about your science – both within your community and the general public. We do not work in an ivory tower any more. And finally publish your results in good journals that people from your community read. And don't forget "bad science cannot be saved by good writing – but good science can be wrecked by bad writing" as one of my mentors, George Feher, has put it once in a letter to one of his students.

And most of all retain your curiosity – and have fun in the lab!

IES Young Investigator Award 2017

Fazhan Shi:

First of all, I would like to thank the International EPR Society. It is my great honor to be awarded such a high level prize. I have attended the IES conference twice. Each time was impressive and I gained a lot. Besides the honor, I feel responsible for the future and hope to contribute further in the field of single-molecule EPR.

As one of the most important techniques, EPR finds broad application in a wide range of disciplines, such as studying basic molecular mechanisms in biology and chemistry. However, conventional EPR spectrometers need macroscale amount of molecules to accumulate a large enough signal-to-noise ratio. The nitrogen-vacancy (NV) center in diamond was proposed as an ultra-sensitive magnetic sensor to realize microscale magnetic resonance spectroscopy and imaging. My research is focused on the single-molecule/nanoscale magnetic resonance spectroscopy and imaging. Since I was a graduate student, I have performed systematic studies along this line and have done a series of researches to push forward single-molecule/nanoscale magnetic resonance technology, including home-built setups, quantum control of NV centers, detection of protons in nanoscale samples/single molecule, and so on.

At the very beginning, supervised by Prof. Jiangfeng Du at University of Science and Technology of China (USTC), I succeeded in building a single spin magnetic resonance spectrometer, and then realized quantum control of NV center and quantum computation based on the system. These efforts are the basis for research to come. Secondly, I joined the quantum sensing team lead by Prof. Jörg Wrachtrup in Stuttgart and succeeded in recording the nuclear magnetic resonance spectra on a $(5\text{-nm})^3$ sample volume [*Science* 339, 561 (2013)]. This work, together with the other similar study [*Science* 339, 557 (2013)], opened a new way toward nanoscale nuclear magnetic resonance and was evaluated by Science as "a first step toward such a machine by demonstrating detection of protein-sized volumes of nuclear spins under ambient conditions". Then, we detected the interaction within a nuclear spin dimer in diamond and realized the atomic-scale structure analysis [*Nature Physics* 10, 21 (2014)]. This work was reported at the impressive APES-IES-SEST 2014 conference in Nara, Japan. Then, the single-protein magnetic resonance spectroscopy under ambient conditions was achieved [*Science* 347, 1135 (2015)]. We used the NV center to detect a nitroxide labeled protein and gained the first magnetic resonance spectrum of a single protein through EPR under ambient conditions. This work was evaluated by Science writing: "The solution is to image individual proteins in living cells in real time as they go about their business of sustaining life. An important milestone toward this goal is reported by Shi et al. on page 1135 of this issue." Now, I am unceasingly working in the field of EPR and trying to improve single-molecule EPR technology step-by-step.

All of the above work, including other works that are not listed here, cannot be done without great favors from my collaborators. I would like to give my sincere thanks to all of my collaborators. Specially, I want to acknowledge my mentor, Prof. Jiangfeng Du, who guided me into this amazing research field and gave me great support throughout my graduate career until now. As the director of a large group, Prof. Du keeps keen interest on science and works very hard. His passion encourages me and others in our lab. I also give thanks to Prof. Jörg Wrachtrup. I visited Prof. Wrachtrup's group in University of Stuttgart and stayed there for one year. I learned a lot and my horizons were broadened there.

Transmit and Receive Systems Covering the 70GHz-3THz Spectrum

VDI offers a wide variety of transmit and receive systems covering the 70GHz-3THz spectrum. These systems incorporate VDI's frequency extension and mixer components coupled with commercially available microwave oscillators and amplifiers.

For transmit systems, VDI can configure them with or without a drive oscillator. A VDI Amplifier / Multiplier Chain (AMC) requires a customer supplied low frequency source (typically <20GHz, 10dBm nominal). A VDI Transmitter (Tx) integrates a source (oscillator or synthesizer) with the VDI AMC. A VDI Mixer / Amplifier / Multiplier Chain (MixAMC) requires a customer low frequency local oscillator. A VDI Receiver (Rx) integrates the LO drive oscillator with the Mixer and LO Chain for turn-key operation.

Standard AMCs and MixAMCs have been developed to provide high performance RF drive multiplication and downconversion for full waveguide band coverage. These systems can be used to extend traditional spectrum analyzers and signal generators into the THz and mm-wave ranges. VDI's standard AMC and MixAMCs offer various modes of operation. VDI AMCs can be operated in standard frequency mode (<20GHz, 10dBm nominal) or high frequency RF drive mode (<45GHz, 0dBm nominal). VDI MixAMCs can also operate in standard and high frequency LO drive modes. Customers also have the option to operate MixAMCs for block-downconversion (<20GHz IF) or as a spectrum analyzer extender. Standard AMCs and MixAMCs are available from WR15 (50-75GHz) to WR1.0 (750-1,100GHz).

VDI offers both narrow-band high-power and broadband low-power systems. High power systems use VDI's D-series X2 multipliers to achieve maximum multiplier efficiency and power handling. VDI has developed many high power systems for special customer applications, such as a novel multiplier based source with output power of 160mW at 200GHz.

Reconfigurable / modular AMCs are also available upon request.

George Feher (1924–2017)

On November 28, 2017 George Feher passed away at the age of 93 in his home in La Jolla, California (USA), where he has lived for more than 50 years, very close to the University of California San Diego (UCSD). He has been one of the first Professors at the Physics Department of the newly founded campus in the early sixties and helped to make UCSD one of the leading research schools in the country.

George Feher was born (29 May 1924) into a Jewish family in Bratislava, Czechoslovakia. In 1938 he was expelled from high school as a Jew – a year before the Nazi occupation. With a group of teenage friends from the local Zionist movement he finally left the country in 1941 over land to Palestine that was under British Mandate at this time. There he first worked in a kibbutz for about one year before he moved to Haifa, where his elder sister Erika lived and where he found a job as radio repairman, which was nicely fitting his technical interests. In Haifa he also took technical courses at a trade school, and in 1943 he became a lab assistant with Franz Ollendorf, then professor at the Technion. During this time he also intensively worked on a descrambling device for the Haganah, the Jewish paramilitary organization in the British Mandate. His device was then successfully used by the Haganah to tap into the encoded communication between the British Commissioner in Jerusalem and the Prime Minister in London. It was five decades later that George learned about the positive outcome of his highly confidential work at the Technion before the foundation of the state of Israel in 1948.

In 1944 George Feher applied to study at the Technion but failed to be accepted as a student since he was not well-versed in the bible. Subsequently, he applied at a large number of universities in USA – and only two (Harvard and UC Berkeley) were willing to accept him without high school diploma. It took almost two years before he had acquired sufficient money to travel to California, where he took up his studies at UC Berkeley in 1947 under difficult financial circumstances – and finally obtained his B.S. (1950) in engineering physics, his M.S. (1951) in electrical engineering, and his Ph.D. (1954) in physics with Arthur F. Kip and Charles Kittel as supervisors. During his graduate studies he built an EPR spectrometer and applied the at this time rather new technique to study conduction electrons in metals. During these early years he furtively looked also at some biological systems using EPR in the Berkeley laboratory and found signals in blood and illuminated plant material, topics that he later picked up again in his research as biophysicist.

After his Ph.D. he joined Bell Laboratories at Murray Hill (New Jersey) where he had the freedom to develop and explore his own technical ideas. Using his expertise in EPR spectroscopy, he decided to work on semiconductors, which resulted in a series of exciting publications. A seminal paper on sensitivity considerations of EPR (G. Feher, *Bell Sys. Tech. J.*, 36, 449, 1957) laid the groundwork for the theory and design principles of EPR spectrometers. This was before commercial spectrometers became available. His ideas were subsequently used by Varian and others to design their instruments. In 1956 George Feher designed an entirely new, history-making experiment in the field of magnetic resonance. He combined EPR and NMR spectroscopy (G. Feher, *Phys. Rev.* 103, 834, 1956) and actually performed the first double resonance experiment – that paved the way for many more to come in magnetic resonance and other spectroscopies. He called it ENDOR (Electron Nuclear DOuble Resonance) – with reminiscence to the witch of Endor, a village in Israel, where a story of prophecy happened that is told in the Bible (1 Samuel 28:3 - 25). ENDOR combines the high sensitivity of EPR and the high spectral resolution of NMR in an elegant way and allows measuring nuclear magnetic moments and the interactions of the unpaired electron with the magnetic nuclei, the hyperfine couplings, even in complex systems for which the EPR spectrum is completely unresolved. The technique, first applied in solid-state physics, was later extended to study radicals in solution (J. Hyde and A. Maki, 1964), to triple resonance (K. Möbius, 1974/75) and to versions with pulsed microwave and radiofrequency excitations (W. Mims, 1965). ENDOR is now one of the most employed methods in the suite of EPR techniques and applied to answer questions in physics, chemistry and biology alike. During his time at Bell Labs, George Feher performed several other novel experiments that should be mentioned, e.g. the generation of nuclear polarization via "hot" conduction electrons by D.C. electric fields (1959), the formation and detection of short-lived muonium atoms μ^+e^- as donors in silicon (1960), and the construction of the first solid-state MASER (1957), the forerunner of the LASER. This MASER was used on the first US satellite. In later years George continued his strong interest in developing new techniques resulting in such fascinating methods as paraelectric resonance (1965/66) and fluctuation spectroscopy (1973/75).

In 1959/60 George Feher accepted a position as visiting associate professor at Columbia University (New York) as successor of Charles H. Townes. There he met Elsa, his later wife (marriage 1961) who worked in the lab as a PhD student from Argentina. The joint appointment at Bell Labs and Columbia did not last long, and in 1960 he followed the call of Roger Revelle, who was establishing the new campus of UC San Diego in La Jolla. George became one of the first professors at the physics department, where he was given the opportunity to expand his research activities into the field of biophysics that he had always dreamed of. After a transition period of several years, many discussions with biologists and biochemists, and after a sabbatical he spend in a biology lab at MIT and Cold Spring Harbor he decided to work on the primary processes of bacterial photosynthesis. At this time very little was known about the structure and function of the photosynthetic unit and only a few scientists worked in this field. The idea of studying the initial steps of light-induced charge separation in photosynthesis was an obvious extension of his earlier work on electrons in silicon, the material used in solar cells. EPR and ENDOR could be used to follow the electron-transfer reactions in the reaction center (RC) of photosynthetic organisms, i.e. to study and characterize the nature of the primary reaction products which all contain unpaired electrons from the transfer of a single electron from the primary donor to a series of acceptor molecules.

At UCSD George Feher started to grow purple bacteria (*Rhodobacter sphaeroides*, carotenoid-less strain R-26) and soon, using a new detergent (LDAO), succeeded to isolate the RC in highest possible quality as minimal unit capable of light-induced charge separation (G. Feher, *Photochem. Photobiol.*, 1971). This key development allowed the determination of the cofactors: 4 bacteriochlorophylls (BChl), 2 bacteriopheophytins (BPh), 2 ubiquinones (UQ) and one non-heme Fe^{2+} and the characterization of the 3 protein subunits (L, M and H). Using EPR and ENDOR he was able to help identify the primary electron donor as a BChl dimer (1975), which was proposed earlier by J. Norris (1971), and identified an iron-bound quinone as subsequent acceptor (1971/72). To detect broad EPR signals he used light-modulation, and for better Zeeman resolution and assignments he expanded his repertoire from X- (9 GHz) to Q-band (35 GHz) EPR. An important step was the manipulation of the RC, i.e. to remove and exchange the quinones and also the high-spin Fe^{2+} and exchange it with other metal ions, e.g. diamagnetic Zn^{2+} (R. Debus et al., *Biochemistry* 1986). This opened the possibility to study the radical anions of both ubiquinones by EPR and ENDOR in great detail (W. Lubitz and G. Feher, 1999; M. Flores et al., 2007). As intermediate acceptor the BPh radical anion could be stabilized and studied. Furthermore the magnetic exchange interaction between the paramagnets was investigated and gave information on the electronic tunneling mechanism between these species. In this endeavor EPR/ENDOR was also performed on RC single crystals, the ultimate experiment to obtain the full information on the g, hyperfine and quadrupole tensors (F. Lendzian et al., 1993; R. Isaacson et al., 1995). In the following this finally led to a comprehensive characterization of the electronic structure of all the reactants of light-induced charge separation and helped enormously to better understand the functional details of the RC. These results have been obtained with a large number of students, postdocs and collaborators at UCSD (see G. Feher, *Photosyn. Res.* 55, 1-40, 1998). In the EPR laboratory Roger Isaacson's expertise was indispensable who worked with George Feher at UCSD since the early sixties. Of equal importance were the excellent biological preparations (Edward Abresch) und the expert help of Melvin Okamura.

George Feher was always aware of the power of X-ray crystallography; consequently he started a program to understand the crystallization process of proteins – namely nucleation, growth and cessation - by using lysozyme as simple model (Z. Kham et al., 1978; S. Durbin et al., 1996). In the seventies it was still considered impossible to crystallize integral membrane proteins like the RC. This was proven incorrect in the early eighties, when bacteriorhodopsin was crystallized (H. Michel and D. Oesterhelt, 1980) and soon after a bacterial RC could be crystallized from the purple bacterium *Rhodopseudomonas viridis* (H. Michel, 1982) and the structure solved by J. Deisenhofer, H. Michel, R. Huber (J. Deisenhofer et al., *JMB*, 1984) who received the 1988 Nobel Prize in Chemistry for this achievement. Stimulated by this success Feher's group tried to crystallize the RC of *Rb. sphaeroides* and a first paper was published soon (J. Allen and G. Feher, *PNAS*, 1984) followed by a series of six publications in the same journal (1987/88) in collaboration with the crystallographer D. Rees (CalTech) detailing the cofactors, the protein subunits, the membrane-protein interactions, the carotenoids, the specific iron side and a species comparison. A summary of this comprehensive work appeared in Nature (G. Feher et al., *Nature*, 1989). This was all made possible by the excellent RC preparations, the choice of the right crystallization conditions and a careful biochemical characterization, including the determination of the amino acid sequences of the protein subunits, a difficult time consuming task in the early eighties (J. Williams et al., *Proteins* 1986). In later years several other important papers were published by the Feher group, including an attempt to detect light-induced structural changes (M. Stowell et al., *Science*, 1997) that were earlier proposed (D. Kleinfeld et al., *Biochemistry*, 1984) – and a first co-crystallization structure of the bacterial RC

George Feher (right) and Wolfgang Lubitz (left) (August 1987 at the International Biophysical Congress in Jerusalem) with its natural electron donor cytochrome c_2 (H. Axelrod et al., *JMB*, 2002).

Through his work George Feher has greatly contributed to an understanding of electron transfer in the photosynthetic RC, a topic of great general interest. These results have also been important for the much more complex plant reaction centers and for the development of theoretical concept like the Marcus theory employed to biological ET. Even more so, George and his group contributed to an understanding of the protonation of the RC (M. Okamura et al. *BBA*, 2000), from a biochemical point of view the more important process since it drives the formation of ATP. Many of these results were obtained on genetically modified RCs – a system for mutagenesis of the *Rb. sphaeroides* RC was developed and extensively used in the Feher laboratory (M. Paddock et al., *FEBS Lett.*, 2003).

George Feher has been a pioneer not only in the development of EPR and ENDOR techniques but also in biological electron and proton transfer, the understanding of membrane proteins and the primary processes of bacterial photosynthesis – radiating into many other fields of biophysics. He recognized early on that a single technique can rarely solve a complex problem in biology and started to develop and employ numerous methods appropriate to solve the relevant questions in his laboratory. He was also convinced that it is necessary to produce all samples whenever possible in your own laboratory, which required a massive but worthwhile effort moving into different fields of microbiology, molecular biology and biochemistry. To work in such an environment was a great challenge for all his students and postdocs – but the benefits were enormous. I personally owe George a lot for the opportunity to work and learn in such an interdisciplinary environment, which was crucial for my later career.

George Feher was honored by many prizes and awards that are too numerous to be all mentioned here. In particular for his development of EPR and the invention of ENDOR he received the American Physical Society Award (1960), the O. E. Buckley Solid State Physics Prize (1975), the Gold Medal of the International EPR Society (1992), the Bruker Prize (1992), the Zavoisky Award (1996) and became Fellow of the International Society of Magnetic Resonance (ISMAR) and Fellow of the International EPR Society (IES). He has been a member of the National Academy of Sciences, USA, the American Academy of Arts and Sciences and the American Association for the Advancement of Science.

All his life George retained an intimate relationship with Israel and often went to visit family and friends and to serve on several committees. His original idea to return to Israel was abandoned already quite early – but he never made peace with not living in Israel. His 70th birthday was celebrated at the Hebrew University of Jerusalem, the university from which he also received an honorary doctorate in 1994. In 2006 he was awarded the prestigious Wolf Prize at the Knesset in Jerusalem together with Ada Yonath for his life achievements.

Since his early childhood George Feher loved tinkering and later continued to do things with his own hands. At UCSD he kept a small laboratory – that nobody was allowed to enter – where he performed experiments, often off the beaten path, which led to new ideas and the development of novel techniques, e.g. "fluctuation spectroscopy" (G. Feher and M. Weissman, *PNAS* 1973; M. Weissman et al., *PNAS* 1976). Discussions with his students and postdocs about problems and progress in the lab were on his daily agenda. In the department he successfully avoided committee work and found more time to plan new experiments, write successful grants and excellent publications. Many of his papers became citation classics – not only for their scientific content but also for the excellent and clear style of writing. Many of his students profited a lot from his insistence of clear writing and explaining the results as simple as possible (but not simpler).

In his private life George Feher was a great sportsman. Since his childhood he liked swimming and even was member of a swimming club in Bratislava. In discussions he vividly remembered the 1936 Olympics in Berlin and the film about it by Leni Riefenstahl, but this event happened at a place that became the center of evil for many Jews. During his whole life George was haunted by the holocaust that affected his family and many of his friends. He wrote a book about it during the last years of his life (G. Feher, Thoughts on the Holocaust, 2017) with fairly dark and negative conclusions about the human nature.

During later years he often visited the UCSD swimming pool together with me providing ample opportunities for scientific and personal exchange afterwards in the sauna or Jacuzzi. Until recent years he was still playing tennis with his colleagues and friends in La Jolla. Dating back to his time as a student in Berkeley, he developed a passion for poker playing – and actually became a dedicated world class poker player who even participated in the world championships in Las Vegas. He also regularly played poker with colleagues at UCSD – and usually won. He had a wonderful sense of humor and was a great story teller – many of the best jokes I know came from him. His "after dinner speeches" are legend – some have even been published, e.g. in the Proceedings of the three Symposia on Photosynthetic Reaction Centers in Cadarache, France, 1987, 1992 and 1997 ("Light Reflections I, II, III").

George is leaving behind his wife Elsa and his two daughters Shoshanah and Paola and three grandchildren. We have lost an outstanding scientist, a great person and a dear friend. With his family we share the mourning for him. George will be sorely missed; he will remain on our memory!

Wolfgang Lubitz
Max Planck Institute for Chemical Energy Conversion, Mülheim/Ruhr, Germany

Thoughts on George Feher

Under this common headline 21 contributions from authors of the international magnetic resonance and molecular structure communities have been collected by Wolfgang Lubitz and myself for this Memorial Column. The authors had been asked to communicate some of the experiences they had when encountering, scientifically or personally, with George Feher, who sadly passed away on November 28, 2017, at the age of 93.

The contributions turned out to be very diverse, both in format and content, their authors ranging from "decades-long co-workers" to "never-met-him-personally" scientists. But all of them expressed their thoughts on George Feher with high estimation of – and even devotion to – him, honoring him as an exceptional scientist, a wise man with a proverbial sense of humor, a *Mensch* who mastered the difficult stages of his life without losing his empathy for the people around him. Who loved his growing family and hold faith with his friends around the world.

George Feher was born May 29, 1924 in Bratislava, Czechoslovakia. At the age of 17 he succeeded to escape, together with a few of his Zionist friends from the local swimming club *Bar Kochba*, from his hometown with the aim to reach Palestine (at the time a British Mandate). Their daring escape from Bratislava was almost too late because since March 1939 Slovakia had declared independence from Czechoslovakia to become a puppet state of Nazi Germany. The deportation of Jews from Slovakia started in March 1942. After a dangerous journey with many frightening incidents they were lucky to arrive in Palestine, where they joined a Kibbutz.

Feher left the Kibbutz after a year and a half to move to Haifa where he, the passionate radio amateur, could earn his living as an electronic repairman at the Israeli Institute of Technology (the Technion). The challenging task he was first assigned to was an oscilloscope to be built from captured German and Italian surplus equipment. Sure enough, he accomplished the task and assembled the first functioning oscilloscope in the Technion, probably in the whole of Palestine. It gained quite some publicity in the local press as the "Hebrew oscilloscope". More than 50 years later he told us, with a smile, that, being a patriot, he had the time axis in this oscilloscope running from right to left in accord with Hebrew writing.

While at the Technion, Feher worked as an electronics expert also for the *Haganah*, the Jewish military underground organization. His classified work was focused on constructing an electronic device to decipher the coded telecommunication of the British Mandate troops in Palestine, specifically tapping into the direct telephone line between the British High Commissioner in Jerusalem and 10 Downing Street in London and making their conversations intelligible. It was in early 1945 when he was told to accomplish this work, with the code name X-25, within three to four weeks. Well, he mastered also this problem within the abhorrently short deadline. But only by taking lots of amphetamine pills to stay awake despite a huge sleep deficit. To his disappointment, however, he was never made privy to the apparent secret whether his decoding equipment actually worked in the field. In fact, Feher had to wait 47 years until he learned that his X-25 story was publicly declassified in an article of an Israeli daily newspaper, the *Yediot Achronot*, featuring *The Best Kept Secret*. And, on May 29, 1994, Rachel Nechushtai, a Hebrew University Professor of Botany with focus on photosynthesis – and a friend of the Feher family (see her contribution at the end of this Column) – arranged the 70th birthday party for George Feher at the Mount Scopus campus of the Hebrew University of Jerusalem. Many people who crossed his life at the various stages of the past 60 years were invited to participate. Among those who came were most of his boy friends from the *Bar Kochba* swimming club – those who had escaped with him from Bratislava in 1941 while those who stayed perished in the Holocaust. And Rachel Nechushtai read the story of his X-25 decoder from the *Yediot Achronot* in English – and not only George Feher was deeply moved. But hard to believe: An official acknowledgment of the working of his decoding equipment Feher received from the Ministry of Defense of the State of Israel only much later – in February 2000, fifty two years after the British Mandate troops withdrew from Palestine.

George Feher left Palestine in 1946 to study in the United States. This was not his first choice, rather he wanted very much to stay in Haifa and study at the Technion. Formally he could not get accepted into the Technion without a high school diploma which, of course, as a school boy refugee from Bratislava, he could not present. His high school education had been interrupted in 1939 by the expulsion of Jews from the Slovak schools. His boss at the Technion, Professor Ollendorff, arranged with the Rector to take a special entrance examination for him. The examination was in English, Mathematics, Physics, History – and the Old Testament. Feher passed everything with distinction – except for the Bible examination and, therefore, was not accepted. Ollendorff felt very bad about it. But all his pleading with the administration did no good. The Rector and his admission committee conclusively declared: "A Jewish engineer has to know the Bible". Period.

There was nothing left for young George Feher but to try to get accepted as a student at a university abroad that had less strict admission requirements concerning formal high-school graduation – and concerning Bible familiarity. On the advice of Felix Bloch he opted for the US, and by summer 1946 he had earned enough money, from starting a small production line for microphones with piezoelectric crystals, to embark on the transatlantic trip. Almost 50 years later, when he was awarded a doctorate honoris causa by the Hebrew University of Jerusalem, he could not resist to point out how much easier it was to obtain that honorary degree than to get accepted to the Technion.

The main stages of his academic education and career in the US are well covered in various contributions of this Memorial Column, and shall not be repeated or forestalled here. Except for summarizing that the University of California, at Berkeley, was unique in that it was willing to admit him without a high school diploma (and without asking for excessive tuition fees); there he received a BS and MS in engineering and, in 1954, a PhD in physics. From 1954 to 1960, Feher worked at the Bell Telephone Research Labs in New Jersey, probably the foremost research institution in solid state physics at the time in the US. In that period at Bell, he developed the Electron-Nuclear Double Resonance technique (ENDOR) that still finds wide applications. When, in 1960, he became professor at the University of California at San Diego (La Jolla) he would set-up the experimental programs in the new Physics department. Later he would go on to pursue exciting new problems using the tools of physics in molecular biology. In the meantime, Feher took a part-time position teaching in the physics department at Columbia University. There, he met a graduate student from Argentina, Elsa Rosenvasser. They fell in love with each other and happily married; their symbiotic relation lasted for almost 60 years until his death.

From the many distinctions and awards George Feher received during his academic career I think he liked the 2007 Wolf Foundation Prize in Chemistry most. According to the Wolf Prize jury, "Feher's impressive work in research on photosynthesis rests on his extraordinarily vivid imagination and on the sustained discipline with which he forced himself to master the underlying biochemistry in a brilliant and systematic manner. His work is seminal for the construction of synthetic and semi-synthetic molecular energy converters, which may have profound implications in an energy-demanding world." Photosynthesis, the conversion of light into chemical energy, is considered the most important biochemical process on Earth. It provides the basic source of food, it has produced all fossil fuels, has created the oxygen-rich atmosphere and the protective ozone layer of our planet. Feher shared the Wolf Prize in Chemistry with Ada Yonath from the Weizmann Institute of Science. She pioneered the solution of the three-dimensional structure of the ribosome. She received the 2009 Nobel Prize in Chemistry for this work. Ada Yonath became the first Israeli woman – in fact the first woman from the Middle East – to win a Nobel Prize in the sciences. The 2007 Wolf Prizes were presented to the laureates at the Knesset in Jerusalem by Dalia Itzik, the then acting President of Israel. She casually read the laudatio texts of the official Prize certificates, and then handed over small personal presents to the laureates. George Feher received a copy of the Bible. In a short *ad hoc* statement of thanks he made the unforeseeable remark that he left Palestine 1946 for the US because he failed the entrance examination for the Technion because of insufficient knowledge of the Bible.

The day after the Knesset presentation a magnificent Minisymposium at the Weizmann Institute in Rehovot was organized to honor the new Wolf Prize recipients in Chemistry. Maibi Michel-Beyerle (Munich) and Klaus Möbius (Berlin) gave invited lectures in reference to Feher's – and their own – work on the photosynthetic reaction center. During his lecture, Klaus stepped down from the podium to present George with the *Festschrift* in *Applied Magnetic Resonance* (Volume 31, 2007) on the occasion of his 80th birthday – and the 50th anniversary of his invention of ENDOR. Klaus Möbius and Martina Huber were the Guest Editors of this special issue, which actually was a complete special volume of the journal! George Feher was pleased – despite the additional 1.5 kilogram of excess baggage to be shipped home. In addition to the heavyweight Bible he had received in the Knesset.

The 2007 *Applied Magnetic Resonance* special issue was well timed considering decimal anniversaries of important events in George Feher's life:

– 50 years ago, in 1956, George Feher had invented the ingenious combination of NMR and EPR to observe nuclear magnetic resonances via the electron spin resonance line. Naturally, he named it ENDOR, a technique that turned out to revolutionize the field of EPR spectroscopy of complex systems. With this acronym George Feher gave reference also to the "Witch of Endor" in the Old Testament (in the Hebrew Bible, in the First Book of Samuel, the Witch of Endor was an augur who summoned the prophet Samuel's spirit, at the demand of King Saul of the Kingdom of Israel). This, however, is another story and will be told by several authors of this Column.

– 40 years ago, in 1968, George Feher decided to focus his research work on the primary processes in bacterial photosynthesis, a field where his seminal contributions span a wide range: from setting the standard for reproducible protein preparations to the understanding of the functional role of reaction centers in light-initiated electron and proton transfer processes.

– 30 years ago, in 1975, George Feher published a seminal ENDOR paper together with his postdoc Arnold Hoff which proved the "special pair" hypothesis of the primary donor of photosynthetic bacteria. The special pair had been postulated earlier by Jim Norris and co-workers at Argonne on the basis of EPR linewidth studies.

– 20 years ago, in 1987, George Feher and co-workers in collaboration with Douglas Rees's group at UCLA succeeded in solving the X-ray crystallographic structure of the reaction center (RC) from the photosynthetic bacterium *Rb. sphaeroides*. This was only five years after a great advance of the bacterial photosynthesis field had been made by Hartmut Michel, Johann Deisenhofer and Robert Huber who crystallized the RC from *Rps. viridis* and determined its 3D structure (1988 Nobel Prize in Chemistry).

– 10 years ago, in 1997, the crystallographic work of George Feher and co-workers on illuminated RC single crystals from *Rb. sphaeroides* marked the first X-ray structure of a membrane protein in its transient charge-separated working state of primary photosynthesis.

An outstanding co-worker of George Feher in the time of combining ENDOR and photosynthetic reaction center was Arnold Hoff, then a postdoc from Leiden University. Of course, there had been also other players in the game from competing groups, as is often happening in many areas of frontier research when "something hot" is in the air. Those competitors were adequately referenced by George Feher in the literature (see his Bruker Lecture: George Feher, "Identification and Characterization of the Primary Donor in Bacterial Photosynthesis: a Chronological Account of an EPR/ENDOR Investigation", J. Chem. Soc. Perkin Trans. 2 (1992) 1861-1874).

Arnold Hoff and Johann Deisenhofer wrote a keynote review on "Photophysics of photosynthesis. Structure and spectroscopy of reaction centers of purple bacteria" (Phys. Reports 287 (1997) l-247) in which they competently covered also the complex story of EPR, ENDOR and TRIPLE resonance investigations of the special-pair primary donor cation radical D^+ in frozen and liquid solution as well as in single crystals. From this we quote:

"Experiments carried out in solution are designed to do away with the dipolar interaction. Yet, this interaction provides valuable information on the electronic structure of the radical studied and is important for the unambiguous assignment of the ENDOR lines.

It is best studied in single crystals, which also allows to measure accurately the g-anisotropy, another source of valuable information on the structure of the primary donor.

Three groups, of Feher in San Diego and of Möbius and of Lubitz in Berlin, are presently engaged in carrying out single-crystal EPR and ENDOR/TRIPLE experiments.

As a first result the principal values of the g-tensor (g_{xx} = 2.00329, g_{yy} = 2.00239, g_{zz} = 2.00203) and its position in the crystal axes frame were determined for D^+ in RC of *Rb. sphaeroides* R-26 at 95 GHz [R. Klette, J. T. Törring, M. Plato, K. Möbius, B. Bönigk, W. Lubitz, Determination of the g Tensor of the Primary Donor Cation Radical in Single Crystals of *Rhodobacter sphaeroides* R 26 Reaction Centers by 3-mm High-Field EPR, J. Phys. Chem. 1993, 97, 2015-2020].

Single-crystal proton ENDOR and TRIPLE experiments at X-band on D^+ in RCs of *Rb. sphaeroides* R-26 at 281–288 K allowed the unambiguous assignment of all methyl α and β proton and two β-proton hyperfine tensors [F. Lendzian, M. Huber, R. A. Isaacson, B. Endeward, M. Plato, B. Bönigk, K. Möbius, W. Lubitz, G. Feher, The Electronic Structure of the Primary Donor Cation Radical in *Rhodobacter Sphaeroides* R-26 – ENDOR and TRIPLE-Resonance Studies in Single Crystals of Reaction Centers, Biochim. Biophys. Acta 1993, 1183, 139-160]. This work represents the culmination of two decades of ENDOR on the primary donor in bacterial RCs, and the fact that it was carried out independently in three laboratories and published in a joint paper makes it even more noteworthy.

For the first time it was possible to distinguish ENDOR lines due to the D_A and D_B dimer-halves, and to determine the asymmetry ratio for individual protons.

The angular dependence of the hyperfine-couplings in all three crystal planes was measured ... and compared with MO calculations of the hyperfine-tensors ...

This allowed the authors to assign unambiguously the lines due to the methyl groups, and to determine the precise location of a number of hydrogens with respect to the BChl macrocycles of D_A and D_B. (This information is not obtained from X-ray diffraction studies, where the H-atoms are placed according to standard molecular structures).

An important aid in the assignment of the ENDOR lines was the comparison of the experimental hyperfine-tensors with tensors calculated with the RHF-INDO/SP method using X-ray data, especially comparing the directions of the principal axes. (The calculated isotropic splittings were found to be less useful, as they are too sensitive to details of the X-ray structure).

The experimental isotropic hyperfine-splittings determined from the single-crystal data agreed well with those obtained with liquid solution ENDOR, showing that there is no change in the three-dimensional structure of the dimer D^+ and its amino acid environment upon crystallization."

Aside from the esteemed and prize-winning results, the Feher laboratory at UCSD excelled in promoting openness, honest and careful thinking, attention to detail, no tolerance to sloppiness in mind or in deed, nurturing of ideas, especially unconventional ones. George Feher's students and postdocs partook of an ethos of science and humanity, and took it with them on their future professional life.

Now that we lost George Feher, we are very sad. But try to get some comfort in recalling a wise saying he had often quoted: "The only ones dead are those who are forgotten".

We will not forget George Feher.

Klaus Möbius
Free University Berlin, Berlin, Germany

* * *

My original project as a postdoctoral fellow in George's laboratory was a subject dear to his heart, the mechanism of crystallization in proteins, which very few scientists studied at that time. He had begun this work with Zvi Kam, with whom I worked when I first arrived at UCSD. Zvi and George had examined the distribution of protein states, as monomers, dimers, trimers, etc., using light scattering spectroscopy and found that differences in this distribution between proteins undergoing crystallization and those undergoing simple precipitation.

The field was wide open and we decided to try multiple approaches. For example, one goal was to determine the distribution for different crystallization conditions and test their model using light scattering. In addition to that project, another direction of my research was the examination of crystals of the protein myoglobin using EPR. Myoglobin has a heme that is the site for oxygen binding as it serves to transport oxygen in the circulatory system. The heme has a very distinctive EPR spectrum that is sensitive to the local environment. Previous EPR studies had focused on how changes in the coordination of the central Fe of the heme were related to functional aspects such as oxygen binding. When the EPR studies had been performed on crystals of myoglobin, the spectrum was unusually broad, indicating an unidentified disorder. Our goal was to perform single crystal studies under different conditions to identify whether the disorder arose due to inhomogeneity of the packing of the proteins in the crystal. With Roger Isaacson, we designed a Teflon pedestal that had a ledge pitched at a specific angle so that a mounted crystal would have the crystallographic axes aligned with the magnetic field axis, allowing the spectrum to be measured with the magnetic field at different angles relative to the hemes. I grew the crystals of myoglobin and we began the measurements. This proved to be a fun project as our meetings would often diverge with George telling humorous stories about various scientists in the EPR field.

As these projects proceeded, we also began a new project on the crystallization of the reaction center from *Rhodobacter sphaeroides*, following the approaches pioneered by Deisenhofer, Huber, and Michel for the crystallization of reaction centers from the related bacterium, *Blastochloris viridis*. We quickly found suitable conditions for the crystallization of our reaction centers, leading to changing my goal from studying crystallization to being focused on the determination of the three-dimensional structure, which was completed as described in a series of papers. While this meant that we discontinued the EPR studies of myoglobin that work proved to be useful in the design of mounts for measurement of the EPR spectra of single crystals of reaction centers that was later perform by Roger and George with Friedhelm Lendzian and Wolfgang Lubitz.

James P. Allen
Arizona State University, Tempe, AZ, USA

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I first met George Feher when I was a Physics Ph.D student in Berkeley working under the direction of Melvin Klein. Mel and George had known each other since the late 40s, having met in the Microwave Laboratory in Berkeley's Electrical Engineering Department. It was exciting to meet George for the first time, particularly as a student who had decided to focus on EPR studies targeting photosynthesis. George visited with us in the Melvin Calvin Laboratory where we worked, and I got to join in with him and Mel for an hour chat, very exciting! This was a time just before the photosynthesis bacterial reaction center structures were revealed, so most of what we knew about the cofactors and the electron transfer reactions came from spectroscopy, with the Feher lab EPR/ENDOR efforts leading the way. Mel sent me off to read the elegant 1975 ENDOR paper by George, Roger Isaacson, and Arnold Hoff showing the halving of the proton hyperfine couplings in the RC electron donor compared to that of a monomeric bacteriochlorophyll cation, cementing the dimeric "special pair" model that Jim Norris had proposed based on the narrow linewidth of the RC radical EPR signal. Other exciting work included the EPR studies of the very broad coupled Fe(II)-Q_A- signal, based on the light-modulated method by Isaacson and Jim McElroy, and completed using Mel Okamura's ability to remove and replace the native ubiquinone. This was all great stuff, and it convinced me that EPR was a great way to go in figuring out how manganese is involved in photosystem II water oxidation. I was also moved by a statement George made, paraphrased here, that determining a hyperfine interaction is one of the most definitive measurements that can be made in science. Well that goal certainly seemed well worth pursuing and helped cement my plan to apply the relatively new pulse EPR methods to study the PSII oxygen evolving complex.

Mel was kind enough to send me as a graduate student to Photosynthesis Gordon Conferences, and it was at these exciting meetings that I had most of my exposure to George. The 80s were an exciting time in the bacterial reaction center world, with many state of the art spectroscopic methods converging with biochemistry and theory, and of course with the new reaction center crystal structures, including the *Rb. sphaeroides* that George and Jim Allen obtained along with Doug Rees. It was really great as a student to see the exciting progress that George and Mel Okamura and many other reaction center investigators were making in characterizing the fundamental geometrical and electronic structure of the RC cofactors and how this allows efficient unidirectional electron transfer over long distances. The science was great, but it was also fascinating and inspiring to watch the interplay between all the superbly talented investigators moving this field along so rapidly. The conflicts were of course as interesting as the agreements, and over time that is how a field moves along (we PSII people have certainly seen this occur!). Some of us still talk about the time after the *Rb. sphaeroides* structure was revealed that one (unnamed here) researcher decided to publicly challenge George to something that could best be thought of as a "battle of wits". This was VERY unwise, and the outcome of the skirmish was quickly and decidedly determined!

Around this era I started to learn more about George's amazing life story, including his childhood in Czechoslovakia and his escape as a young man into Palestine, his activities there in electronic espionage, and his subsequent travel to study in Berkeley, famously supported in part by a low wage summer fruit harvesting stent in the great Central Valley of California. He went over much of this in a fascinating "Thursday night talk" at the GRC, and also published details in a couple of personal accounts, such as Feher, *Photosynthesis Research* 55: 1–40, 1998. (or www.life.illinois.

edu/govindjee/history/FeherGeorgePP.pdf). This is fascinating reading on multiple levels!

As I got my own independent career going at Davis, I was fortunate to visit UCSD several times before George retired, which was great fun. I was mostly working on PSII EPR, which of course built up on what George and others had taught us about the bacterial RCs (the electron acceptor side is very similar, for example) but of course the real interest was on the manganese containing "oxygen evolving complex" unique to PSII. At one point I was asked to interview for an experimental biophysics position in the department, which was great until I learned that the department was calling it the "George Feher replacement" position. I certainly couldn't live up to that, and the department had the wisdom to hire in a different area of biophysics! Links between our groups continued, one highlight being a very nice pulse EPR study with George's long-time associate Mark Paddock on histidine coordination to the "mitoNEET" 4Fe-4S cluster (Dicus et al., JACS 2010). And of course my excellent PSII collaborator Rick Debus trained with George (removing and exchanging the acceptor side non-heme Fe) and then brought his great skills to the PSII world to the great benefit of us all.

It was also nice being in the same state as George, as visitors to his laboratory (including the coauthors of this memorial, Wolfgang Lubitz and Klaus Möbius) would visit us connected to trips to UCSD (particularly in the early years when Gus Maki was still with us at UCD).

We were unfortunate to lose Mel Klein in 2000. Alex Pines arranged a lovely memorial for Mel on the Berkeley campus, and I'll never forget the lovely tribute George gave to his longtime friend on that occasion. This was greatly appreciated by us all.

My last trip to the Feher lab was a bittersweet one. The Physics Department had decided they needed to repurpose the EPR lab space for other uses, and Mel Okamura said I should come down and see if there was anything we could put to good use going forward. This was very sad to see firsthand the end of George's EPR lab, but on the positive we were able to take the amazing Roger Isaacson Q-band ENDOR probe, and with some modification by Dr. William Myers we got this working in our Bruker pulse Q-band instrument where it is still being used almost daily. THAT makes me happy.

R. David Britt
University of California Davis, Davis, CA, USA

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The inventor of ENDOR (Electron Nuclear Double Resonance), George Feher, passed away in November 2017 at the age 93. With his ground breaking ENDOR experiment on phosphorus doped in Silicon he paved the way for generations of scientists using ENDOR for structural analysis. In addition, numerous variants were developed over time, such as special and general Triple, ENDOR induced EPR, and pulse-ENDOR.

He was born in Bratislava, Czechoslovakia in 1924. As a teenager he made his way to Israel via an overland route with several other teenagers in 1941. While in Haifa he worked as an electronics technician at the Technion. He was also active with the Haganah (the Jewish underground) and succeeded in tapping into and decoding the private telephone line between the British High Commissioner in Jerusalem and the British Prime Minister at 10 Downing Street in London. Unable to study at the Technion because "a Jewish engineer must know the Bible", he made his way to University of California, Berkeley in 1946 where he earned his bachelor's degree in engineering physics (1950), his master's degree in Electrical Engineering (1951), and a Ph.D. (1954) in physics. What is unusual is that he was accepted at the university without having a high school diploma.

He then worked as a physicist at Bell Laboratories and Columbia University. His skill in electrical engineering really shines in his 1957 Bell Technical Journal article titled "Sensitivity Considerations in Microwave Paramagnetic Resonance Absorption Techniques". It is still the best reference for students to learn how an EPR spectrometer functions. He was involved in the development of the three-level maser that rode in the first US satellite put in orbit in 1958, Explorer 1. During his tenure at Bell, he invented the ENDOR technique. He became a professor at University of California, San Diego in 1960.

George Feher started his career in solid state physics and later moved to biophysics. While still in Israel, he had read Erwin Schrödinger's book "What is Life?" and this sparked his interest in the field. Interestingly, this also reflects the changes of the fields where ENDOR is used. It started in solid state physics and then over the years the focus moved to chemistry and then on to structural biology.

His work also laid out the foundation for commercial ENDOR instruments, first at Varian and then at Bruker. In 1978 Bruker introduced a commercial broadband CW-ENDOR/Triple system which became a cornerstone for the success of our EPR instrument lines. Many generations of instruments later, ENDOR, especially the pulse version, is an eminent tool for structural analysis in many fields where EPR is used.

Over his career George Feher was honored with many prestigious awards. In 1976 he won the Oliver E. Buckley Prize Condensed Matter Prize for the development of ENDOR. He shared a Max Delbruck Prize with Roderick K. Clayton in 1982 for his contributions to the field of photosynthesis. As recipient of the 7th Bruker Prize of the Royal Society of Chemistry in 1992 he presented a lecture with the title "EPR and ENDOR Investigations of the Primary Reactions in Bacterial Photosynthesis". He was recipient of the 1996 Zavoisky Award. Ada Yonath and he received the 2006/7 Wolf Prize in Chemistry for ingenious structural discoveries of the ribosomal machinery of peptide-bond formation and the light-driven primary processes in photosynthesis.

Professor Feher promoted openness, honest and careful thinking, attention to detail, as well as the nurturing of ideas in his laboratory. His many students and postdocs benefitted from this attention and took these values with them in their later professional lives.

He is survived by his wife Elsa, daughters Shoshanah and Paola, and three grandchildren. A very nice obituary can be found at www.legacy.com/obituaries/carmelvalleyleader/obituary.aspx?n=george-feher&pid=187592684

Ralph Weber, Art Heiss, Peter Höfer
Bruker BioSpin, Germany and USA

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George Feher may be best known to the scientific community for his seminal contributions to ENDOR and to the understanding of primary processes of bacterial photosynthesis. He made many other extremely important contributions to our understanding of the behavior of electron spins. His semiquinone and trityl T_1 measurements at temperatures as low as 1.2 K define the low temperature extrema for organic radical relaxation. Feher's studies of phosphorus-doped silicon demonstrated many relaxation phenomena, especially for ENDOR. Current EPR users will find it well worth their time to read his papers on the use of adiabatic passage, observation of spontaneous emission, nuclear polarization schemes, line shapes of conducting metal samples, and observation of EPR lines by temperature modulation instead of magnetic field modulation. One of these papers might stimulate new ways to solve new problems.

George Feher and his colleague Roger Isaacson presented memorable lectures and posters at the International EPR Symposium in Denver.

George Feher received the Bruker Prize and the Gold Medal of the International EPR Society in 1992 and the Zavoisky Award in 1996. He is one of a small group of people who was awarded all three prizes.

George Feher will be greatly missed by the magnetic resonance community.

Gareth and Sandra Eaton
University of Denver, CO, USA

* * *

The first time I heard about George Feher was during my graduate studies in Rio de Janeiro (Brazil). My PhD adviser (George Bemski), who was a dear friend of him, told me many stories about the achievements of George Feher including the invention of the ENDOR technique at Bell Labs (New Jersey, USA) and the pioneering work on bacterial photosynthesis carried out at the University of California, San Diego (UCSD). I also learned about his strong personality and his systematic manner of doing research. A few years later, when George Feher decided to hire me as a Postdoctoral Fellow in his research group, I was thrilled and afraid at the same time but convinced that I was about to meet a great man. So, I moved to San Diego in the year 2000 and took over a project that was started by Wolfgang Lubitz in the early 80's, dealing with the electronic structure of the primary acceptor (a quinone molecule, Q_A) in reaction centers (RCs) of photosynthetic purple bacteria. It took me a few weeks to adapt to the Feher lab since bacterial photosynthesis was a completely new subject for me and my English at that time was deficient. Communicating with George Feher was never a problem because he was fluent in Spanish but I needed to interact also with the other members of the group. Thus, George was nice and offered to pay an intensive (30-day) English course at UCSD for me. After I registered in the course, he told me: "There are two kinds of immigrants in the United States, those that study English for 30 days and learn and those that study English all their life and never learn". Later, I told this story to Mark Paddock (a research scientist in the Feher group) and he told me that George's statement probably applied to US citizens born in the USA, too.

The goal of my project was to investigate the physical properties defining the specific function of Q_A, using ENDOR spectroscopy. We wanted to prove that two hydrogen bonds would be fine-tuning the electronic structure of $Q_A^{\bullet -}$ and therefore defining its function as one-electron transfer gate. At the beginning, my work in the lab was focused on sample preparations. I was well trained by Ed Abresch (a research specialist in the Feher group) on these matters, so very quickly I was capable of isolating, purifying and crystallizing RCs of photosynthetic purple bacteria – of course under the close supervision of George Feher. Once a week, I had a meeting with George to discuss the progress of my project. After the meetings, we used to have non-scientific conversations on different topics. For instance, he told me about his trip to Argentina in 1965 and how he had learned Spanish, and about his trip to Perú, in which he enjoyed very much visiting Machu Picchu. I told him about Peruvian history and one time I spent a couple of hours telling him about my origins. At that occasion, he suggested I should write a book on that story.

We knew from previous experiments that the two protons hydrogen bonded to $Q_A^{\bullet -}$ exchange, with deuterons, with different exchange times but the rates were unknown. Thus, our first task was to determine the values of the exchange times. This was accomplished by preparing $Q_A^{\bullet -}$ samples with different times of incubation in D_2O while concomitantly monitoring the changes in the amplitudes of the ^1H ENDOR signals. With the values of the exchange times in hand, we were able to prepare two additional samples in which each hydrogen bonded proton was preferentially deuterated. The preferential deuteration was fundamental for the identification and assignment of the ENDOR signals corresponding to each hydrogen bond. The assignments finally allowed a full characterization of the two hydrogen bonds by magnetic field selection. I enjoyed a lot all these experiments, they were well planned and had definitely the touch of George. It was a good training for me on planning experiments and predicting their results. Furthermore, they gave me a clear idea on how tedious some ENDOR experiments can be since it took me two months to collect the ^2H ENDOR data corresponding to the hydrogen bonds to $Q_A^{\bullet -}$. My efforts paid back because the results made George very happy about my project. On the day that I finished the ^2H ENDOR experiments, he came to my office to congratulate me and told me: "Marco, we have finally done it". Yes, I was about to finish a project that Wolfgang Lubitz started almost twenty years earlier. Another special occasion was when George and I went to Rio de Janeiro to celebrate the 80th anniversary of George Bemski in May of 2003. We surprised Bemski by showing up unexpectedly at the party that was held on a nice ranch outside Rio. It was a pleasant trip and I had the chance to get to know George from a different perspective.

The next task of my project was to fit the ^1H and ^2H ENDOR data, which I did with the help of Rafael Calvo, a long term collaborator of George Feher. The geometry of the two hydrogen bonds to $Q_A^{\bullet -}$ was obtained from the fit. This showed asymmetric hydrogen bonds with different directions and different bond lengths which affect the spin density distribution in the quinone radical and its electronic structure. By this time, George Feher had celebrated his 80th birthday in May of 2004 – many scientists came to La Jolla and I had the opportunity to meet several of George's former students and post-docs – and I had accepted a job offer from Wolfgang Lubitz to work at the Max-Planck Institute in Mülheim an der Ruhr (Germany). Before I left to Germany, it was decided that our experimental results would be published in a series of two papers. Thus, I wrote the manuscripts when I was already in Germany. The preparation of the first manuscript – a short one – was smooth and got ready after a few rounds with George. However, the second one did not follow the same fate. George wrote to me after reading the first draft: "Marco, I do not want written on my tombstone: He was a great scientist but his last paper was a disaster". Only then I realized that I was going to be the last post-doc of George. Incidentally, I was also the last PhD student of George Bemski. Anyway, the second manuscript was very much improved mainly with the help of Wolfgang Lubitz and both papers were finally published in the Biophysical Journal. A few weeks after the publication of the second one, Wolfgang and I received – in Mülheim – a package with a very good bottle of Champagne specially delivered from Barcelona (Spain). It was a present from George to celebrate the conclusion of our project – and his last scientific paper.

In 2008, I was recruited by Arizona State University (Tempe, USA) to serve as the Lead Research Scientist of the EPR facility at the university. This position was very convenient for me because it allowed me to frequently visit San Diego – where my long-time girlfriend Shawn used to live. It gave me also the opportunity to visit George in La Jolla. We had our informal chats until recent years. I am convinced that George Feher, during his long lifespan, has greatly impacted the life of many scientists – including mine. Working with George was educational for me. He was very gifted on designing the proper experiments. He was demanding but at the same time very supportive and loyal to his people. I am glad that I have known him and his family. George, I am going to miss visiting you in La Jolla!!!

Marco Flores
Arizona State University, Tempe, AZ, USA

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My first knowledge of George Feher and his work came early in my graduate student career at Columbia University with George Fraenkel. Feher had invented the double resonance technique of ENDOR published in 1956–1957 which he applied to solids containing paramagnetic species studied at low temperatures. Two years later in 1959 one of my first grad student projects was to develop ENDOR for stable radicals in fluid samples at room temperature. Fraenkel's lab was renowned for his ESR studies of organic free radicals such as semiquinones, both their electronic structure and their spin relaxation in various solvents. The question was what new information could we get from ENDOR in these systems. First I carefully studied Feher's groundbreaking ENDOR and related papers. Feher operated at low temperatures on systems with long relaxation times, so he could use techniques such as rapid passage through the nuclear spin resonance to effect changes in spin state populations, leading to stepwise use of the electron spin resonance source and that for nuclear spin resonance. By such stepwise procedures he could induce spin population changes such that the NMR spectrum could be obtained using the more intense ESR signal. However, in the liquid state the spin relaxation is much too fast, and at that time one had to perform the ESR experiment in the steady state. Thus liquid state ENDOR would require simultaneous steady state saturation of both an ESR and an NMR transition. So to address this challenge I bought a Heathkit FM radio set, and proceeded to construct it to supply the rf needed to generate the NMR, whereas the ESR existed in a state-of-the-art spectrometer. Concurrently I worked on a theory for liquid state ENDOR, first learning the ideas of spin relaxation being developed in Fraenkel's lab. I was actually excited with the possibility of developing a new technique to use to study molecular motions in liquids. However before I finished the experimental setup I demonstrated theoretically that the experiment was not feasible, because only about a couple of percent enhancement of the saturated ESR signal was possible, and this would be difficult to measure. So George Fraenkel took me off the project. But the fact remains that the early part of my graduate research was strongly motivated by George Feher's great accomplishment in solid-state ENDOR, although I had not at the time met him.

Soon after I started my career at Cornell as an assistant professor, Hyde and Maki in 1964 demonstrated a successful liquid state ENDOR experiment. I began a serious theoretical search for how it was possible. What emerged was a very extensive theory of saturation and double resonance, which however confirmed my graduate work: only very weak enhancements of the saturated ESR signal were possible in steady-state liquid ENDOR unlike Feher's low temperature ENDOR.

Fortunately Jim Hyde came to Cornell early in 1965 and confirmed the fact that in their successful experiment only weak enhancements were observed. They could isolate these enhancements by modulating the NMR signal and then passing the affected ESR signal through a second phase-sensitive detector at the NMR frequency! I, as a beginning grad student did not think of this, nor did my very capable advisor George Fraenkel. But since my extensive theoretical analysis was confirmed as essentially correct in my predictions, I did publish it. Thus there was a positive outcome arising from my earlier motivation by Feher's revolutionary papers on ENDOR.

Needless to say, it was a great pleasure to actually meet George Feher many years later in a workshop on ESR/Photosynthesis at the Advanced Study Institute at the Hebrew University in Jerusalem. Although I was the only guest at this five month workshop who was not professionally active in the field of photosynthesis, it was a pleasure to have an occasion to spend time with ESR colleagues from different countries. George Feher attended for six weeks. He proved to be a very friendly person with many interesting stories from his past extensive experiences. And I felt we developed a pleasant friendship during that time. One story in particular sticks with me. George had lived in Israel before coming to the US. So given that and his great accomplishments in solid state and biophysics, it is not surprising that he served on the advisory board of the Weizmann Institute of Science. Once, after serving at a meeting of that advisory board, and at the security at the airport on his departure from Israel, he spoke to the security agent in perfect Israeli Hebrew after handing him a US passport. Suddenly the security agent became alarmed, could he be a spy, and took him into a special room where he was interrogated for several hours, before a phone call to the Weizmann Institute cleared him. Here a great scientist who was aiding a major Israeli institution should be so mistaken by security is an odd and perhaps amusing event. Maybe I remember this story because of an odd and perhaps amusing experience I once had with border security upon entering Israel.

The next time I saw George was a couple of years later, again in Israel at a reunion of our Advanced Study Institute. I came with a very bad case of laryngitis and had asked the organizer, Haim Levanon, to not have me speak on the first day. Well for him it meant that he did not have me give the first lecture but the second instead. I whispered into a microphone to deliver my lecture, but had virtually no voice left at the end. Later there was a friendly and noisy reception of all the participants. When George and I saw each other we naturally said hello. But George could not hear my whisper in the noisy gathering. So he said to me "I'm George, remember me", and held his name tag up to me. It took some effort for me to convince him that I had not forgotten him, did say hello, but I was suffering from a bad case of laryngitis. Although George and I were in communication in the following years, we did not meet again in person, for which I am very sorry.

Jack Freed
Cornell University, NY, USA

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Unfortunately, I did not have the chance to work with George Feher, though, of course I knew of him and his scientific work, which included a most significant contribution to magnetic resonance – ENDOR spectroscopy. ENDOR spectroscopy, was and is one of the major methods applied in my lab and me and my lab members had lots of satisfaction and fun using it, and this is thanks to George's breakthrough invention. Finally, I was fortunate enough to get a chance to meet George Feher when he was awarded the prestigious Wolf prize in Israel in 2007. He shared the prize with Ada Yonath, a prominent Weizmann Institute scientist who later

George Feher (left), Michael Sela (former president of the Weizmann Institute) and Daniella Goldfarb.

received the Nobel Prize in Chemistry. The Weizmann Institute held a beautiful dinner in honor of Ada and George and as a member of the Weizmann Institute who is working in the field of EPR/ENDOR I was invited to the dinner as well. This was a lovely and memorable event and I was delighted to be given the chance to meet George and have a short glance to his modesty, charm, sense of humor and wittiness.

Daniella Goldfarb;
Weizmann Institute of Science; Rehovot, Israel

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Typically, a reminiscence such as these mixes remembrances of the subject with tales of the teller, and this will be no exception. George was a friend of my PhD advisor, Harden McConnell, who recommended me to him as a postdoctoral fellow. However, at that time George was dabbling in electric dipole spectroscopy and I made what was probably the wiser choice to decline. Fast forward to when I was on the faculty at Northwestern and beginning to 'reinvent' ENDOR (having never had the training I would certainly have acquired with George). One of my first plans was to look at hemes, which I had been working on in other ways. But Charlie Scholes who worked as a postdoc with George, didn't need to reinvent anything, and ran away with the problem. That in turn was a blessing in disguise, as it forced me to look at other, and ultimately richer, systems, and led to the development of orientation-selective ENDOR to analyze results from their frozen solutions. So the moral there was captured by John Lennon: "life is what happens while you're busy making other plans".

Although never having worked with George, I can nonetheless claim to be one of the few, if not the only, true descendant of his actual ENDOR discovery. George implemented the concept of monitoring an electron spin as the 'detector' for a NMR transition by a hyperfine-coupled nucleus. His implementation of this brilliant idea involved the introduction of an RF coil for exciting the nuclei into the EPR cavity of a field-modulated CW EPR spectrometer. The world has largely abandoned George's approach, and turned to time-domain methods, which offer multiple means of precisely controlling electron and nuclear spins, and do not suffer from the nuclear relaxation problems that can distort the CW ENDOR line. Indeed, we employ time-domain approaches routinely, and helped the push to higher microwave frequencies by constructing the first high-performance 35 GHz pulsed EPR/ENDOR bridge. *But*, we start every new project by taking measurements using the Feher-style 'CW' ENDOR (at 35 GHz)! The simple reason, it has sensitivity that surpasses that of every pulsed method: when working with weak samples, sensitivity (and George Feher) rules! So in our laboratory, we think about and emulate George on a daily basis, while working to strengthen his approach for the modern world.

But I do have one tale about George, which I think captures a remarkable element of his personality. He was the after-dinner speaker at the 'banquet' on the last night of a conference (Rocky Mountain?), and told an elaborate tale that in other hands would have been a tragic one, but to him was a joke upon himself. As he described in his memoir (Annu. Rev. Biophys. Biomol. Struct. 2002, 31:1-44), in 1956 testing one of the fundamental conservation laws in physics, conservation of parity, was a burning issue, and George had devised a way to make this test. But first, there were ENDOR and MASER experiments, and a planned ski trip! On the way back from that month-long ski trip he learned that parity non-conservation had been experimentally demonstrated in the interim. What astounded me at that dinner, and now, is that George told this tale of his 'missed Nobel prize' with the greatest good humor and no trace of the bitter regret that ordinary folk might harbor. His offhand remarks exactly took the tone of his memoir.

"So much for a bad choice of priorities and poor judgment: By not having jumped at the opportunity, I missed participating in one of the major upheavals in modern physics. I do not regret the skiing, but the maser? Who remembers that now? I am glad to see that ENDOR at least is still being used."

As George spoke one got the feeling that this was to him, truly would have been no more than a casual one-off, and if it fell through, then 'the joke's on me', and he was just on to the rest of his science with undiminished enthusiasm. *And* with the continued outstanding success we are celebrating here. And yes, there is no doubt about it: "ENDOR at least is still being used."

Brian Hoffman
Northwestern University, Evanston, Ill, USA

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In 1989 the Feher lab was in its full swing. With George at the helm, and Roger Isaacson, and Ed Abresch as the specialists, research on the reaction centers of bacterial and plant photosynthesis was running smoothly. At the usual retirement age George had acquired a new grant so no need to stop. As a beginning postdoc in the group it was impressive to see how George was always a few steps ahead: of the research going on, and how to proceed in the project. Characteristic was his deep understanding of all factors that can influence experimental outcomes. It was fascinating to see him analyze my experiment, and I was particularly struck when he applied his method to an experiment that confirmed an hypothesis we had: The outcome was what we had predicted, so why scrutinize this particular experiment for possible flaws? Because, indeed, finding the expected outcome can be a subtle nudge to be less careful, and the driving force behind George's research was the clearly evident desire to get to the bottom of science, to truly understand how things work.

An important component was his approach to publishing the results. Except for abstracts to demonstrate priority, full papers were the norm and those would cover the subject to completion and end up so clearly written that they could be used for teaching students. Many of those have become classics, such as the one on "Sensitivity considerations in microwave paramagnetic resonance absorption techniques" (Bell labs technical Journal Volume 36, 449–484 (1957)).

Beyond the lab, George's broad interests and perspectives on life were an inspiration. The one controversy that remained unresolved was the question whether a cabriolet would be superior to a motorbike as a means of transportation in Southern California. Here opinions were too fixed, on both sides, of course.

Martina Huber
Leiden University, The Netherlands

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Although I have never met him personally, George Feher has had, I think, an impact on my scientific development for which I am grateful. This is, in short, due to what I felt was the very specific way he approached scientific problems. My only indirect encounter with him was in 1972. This was at a meeting of the New York Academy of Sciences in New York at the end of the year. The topic was "Electron spin resonance and nuclear magnetic resonance in Biology and Medicine and Magnetic resonance in biological systems." The lectures were published in the Annals of the New York Academy 222, 1-1124 (1973). One can see from the roughly 1100 pages of this volume, that this was really a big meeting. The organizers had packed an enormous program into one single event, with topics ranging from I. Structure and Function of Hemoglobin via II. Structure and Function of Enzymes, III. Nucleic Acids Histones, Repressors, IV. Radiation Effects on DNA, V. Biological Membranes and Model Membranes, IX. Non Heme Iron Proteins and XI. Potential Clinical Applications of Magnetic Resonance. And, the list of the invited lecturers read much like the "Who is Who" of the EPR and NMR communities. I felt extremely privileged to be able, as a very young scientist, to talk about EPR studies of free radical structures in x-irradiated single crystals of DNA constituents. In those days, I had just started at the newly founded University of Regensburg, after a post-doctoral time (1969–1970) in Radiation Chemistry at UCLA, to build-up "our" new EPR Laboratory. And, I had planned to expand our technical possibilities by constructing an ENDOR device. I felt, it was indispensable for exploring free radical structures in molecules more complex than single nucleic acid bases, nucleosides or -tides. I had analyzed for roughly two years the available literature on ENDOR instruments and had begun, together with an electronic engineer, Dieter Weymann, as well as with my technician Gunnar Schmidt, to develop an apparatus which followed the main concepts of Horst Seidel (Stuttgart) in his work with color centers in alkali halides (Zeitschrift für Physik 165, 218 (1961). We got our first experimental data in about 1973/74 but it still took time before a published story could be told (Journal of Magnetic Resonance 21, 221 (1976)). Of course, during my literature work I had already become acquainted with George Feher's work, but it was really different to hear him give a talk, on the first day of the 1972 meeting, on Electron Nuclear Double Resonance on Myoglobin and Hemoglobin (Feher, Isaacson, Scholes and Nagel, page 86). It was just impressive, how he explained in a very straight-forward, seemingly simple way the highly complicated results concerning proton, nitrogen (^{14}N) and iron (^{57}Fe) interactions. For example, he used mutants and isotopically enriched samples as if it were self-understanding to have them on the lab-shelf. Temperatures of 2 Kelvin as well as a range of ENDOR frequencies, very rare in those days, were also employed. So, the impression I have taken home was, that scientific problems might become "solvable", if experiments were well planned ahead and everything necessary was made available. No abundance but everything necessary. The precise deconstruction of the scientific question into an experimental layout map seemed to be the clue. I cannot remember why I did not talk to him on this occasion. In retrospect, I wish I had done it.

There is another example that reflects this typical approach. I am not certain about when exactly George Feher started to tackle the topic of photosynthesis but his work on the "special pair" proven by ENDOR had become a fixed part of my lectures on Biophysics at Saarland University since about 1987. Again, it was the straightforwardness that impressed me. I wanted to show the students that one can find the correct solution to a highly complex problem with the precisely adapted experimental approach. This is what I connect with George Feher and I am sure, his outstanding contributions to the biophysical EPR/ENDOR topics will be remembered for a very long time by the community.

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In my senior year (1959-60) at Pomona College, California, I had hopes of entering graduate school in the new field of radio astronomy but was turned down by several universities due to low grades. I did not do well in classes, spending too much time as the technical director of the campus radio station, helping it upgrade its carrier current transmitters and eventually upgrading to a high power FM station. I gave up thinking about graduate school and started looking for jobs in industry.

My physics professor told me that a graduate school in physics had just opened up in La Jolla and I should apply, in spite of my grades. Maybe being such a new grad school, there would not be too much competition.

Fortunately, George Feher noticed my resume, with electronics experience and a hobby as an amateur radio (ham) operator (since age 12). He contacted me saying he could hire me as an electronic technician, but said I should spend an extra year at Pomona, retaking several physics classes such as E & M and optics. I could then enter as a graduate student, but only on probation, and would be paid as technician.

What George did for me, going out of his way to jump start my career, was typical of what he did over the years for so many people. He encouraged me to spend the extra year taking classes at Pomona and his support was the only reason I was accepted as a physics graduate student at UCSD. After getting an MS in physics in 1964, George hired me as a Research Specialist, a non-PhD academic position.

Newly arrived at UC San Diego, George was just starting solid state physics research projects in NMR and EPR, methods completely unfamiliar to me. I still recall my pleasant surprise on how closely related both NMR and EPR were to my hobby involving radio transmitters and microwave equipment. In particular my skills building homemade radio transmitters that would not interfere with neighbors' TV reception really helped. At Pomona College, I had taken a microwave laboratory course that applied directly to building our own X-band EPR spectrometer, patterned after the one George used at Bell Telephone Labs in his classic ENDOR papers in 1956 and 1957. It was very fortunate that I had the opportunity to work with designs George had developed at Bell, such as wide gap (10 cm) magnets, immersion dewars for (very) low temperature work, and various EPR/ENDOR cavities. Eventually, when working on protein single crystals, we found dielectric resonators to be ideal at X-band for high sensitivity ENDOR (CW) angular studies. A Q-band ENDOR cavity resonator was built, modeled after one from the Charles Scholes lab [1]. These systems were our work horses until George retired in 2004. EPR and ENDOR were instrumental in elucidating the electronic structure of the radical ions created in the charge separation processes in RCs (reaction centers).

Early on, even at Bell Labs in the fifties, George realized how computers (main frames then) could become non-productive time wasters. The slide rule was a different story. He was enamored with the HP 35 pocket calculator when it was introduced in 1972, and we immediately incorporated it into the EPR lab to calculate g-values. However, he made sure we still kept a conveniently located slide rule in every room in the lab and were not distracted by inappropriate "new technologies". For years (when we still made graphs on paper) he would proudly show how much quicker he could reduce and plot data with a slide rule. Furthermore, you immediately had an, inherently rounded off, answer that was closer to the actual accuracy of the experiment instead of the misleading 8-digit readout.

For 40 years, I had the most fulfilling job I could have asked for. I had the opportunity to work with students and post docs from around the world in fields of material science, chemistry, and biology.

George's legendary skills in grant writing supported all of us continuously for decades.

George positively affected the careers of so many with his ground-breaking and imaginative scientific work. We all miss George and I am grateful to him for teaching us the value of striving for the highest scientific and personal standards.

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As a post doc in 1966/1967 with Jim Hyde at Varian Associates, I had the opportunity to use the kW ENDOR instrument in his laboratory to carry out solution ENDOR studies on phenoxyl radicals derived from substituted, diphenylmethanes related to the galvinoxyl radical. These measurements resulted in a JACS publication [1]. Further use of the ENDOR instrument to examine some low-symmetry triphenylmethyl derivatives resulted in another publication [2]. An inspiration for all these measurements was George Feher's previously published ENDOR spectra of radicals in solids. It encouraged me to spend the time and effort to record high quality solution ENDOR spectra with the goal of interesting others, especially chemists, to use this important technique to examine the structure of radicals in solution. We implied 'typical' spectra were obtained – although, no mention was made of the great effort spent on obtaining the solution spectra.

In the past 10 to 15 years, the ENDOR technique has been used extensively at the University of Alabama [3–5] to characterize and detect various carotenoid radical cations and the carotenoid proton loss neutral radicals [6]. These carotenoid species are responsible for photo-protection in plants on a clear sunny day. The absence of this protection would cause destruction. These radical species [7] occur for 150 picoseconds or less in the presence of such sun light intensity in the plant, detected optically, short enough to avoid reaction with millisecond cellular diffusing oxygen but too short for direct detection by EPR/ENDOR. Fortunately, these carotenoid radicals can be formed and stabilized for long term ENDOR measurements in artificial matrices such as SiAl or MCM-41 (SiO system). These carotenoid radicals both exhibit the same unresolved EPR line and width (13–15 Gauss). Thus, an EPR measurement cannot distinguish nor identify these radicals. However, ENDOR measurements exhibit quite different resolved spectra for these radicals, allowing their detection, characterization and identification. The promotion by George Feher in the use of ENDOR measurements has enabled extensive insight into these photo-protection processes.

ENDOR measurements coupled with optical and electrochemical studies [8] have also provided insight into the mechanism why the carotenoid astaxanthin photo-protects the microalgae in open pond systems and artificial ponds specially designed for cultivation of alga to feed livestock and fish and deliver biofuels. This photo-protection is related to the ability of astaxanthin to form chelate complexes with metals and to be esterified, its inability to aggregate in the ester form, its high oxidation potential and the ability to form proton loss neutral radicals under high illumination in the presence of metals. The neutral radical species can be a very effective quencher of the excited states of chlorophyll under high light irradiation.

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George Feher is known for his ingenious contributions to science. He pioneered the structure/function relations of the simplest reaction center in photosynthesis, revealing the basic principles of light energy conversion in photosynthesis. Before stepping into biology, he made major contributions to the field of solid state physics.

Among the novel and, at the time in the nineteen fifties, revolutionary inventions by Feher is ENDOR, the first double-frequency method in spectroscopy that continues to be widely applied in a broad range of fields. ENDOR was initially developed to access structural features of crystalline and amorphous materials before he, and the entire EPR community, used it later for the study of biological systems with paramagnetic centers. ENDOR is the acronym for Electron-Nuclear Double Resonance. However, Feher chose the name also in the memory of the Witch of Endor in the First Book of Samuel. We mention this detail because it is ironic that fifteen years before, he was not accepted to the Technion – one of the reasons was a lack of knowledge of the Bible.

Among the many honors and awards he received in the course of his career the Wolf Prize in Chemistry in 2007 is the latest one. According to the laudatio of the Wolf Prize jury (which is no less true today than it was then) "*his impressive work in research on photosynthesis rests on his extraordinarily vivid imagination and on the sustained discipline with which he forced himself to master the underlying biochemistry in a brilliant and systematic manner. These qualities allowed him to view the complex problems related to the primary steps of photosynthetic energy conversion in their entirety, whereas many specialists tended to concentrate on individual pieces of the puzzle. It was Feher who was the first to identify the amino acid sequence of a membrane protein and who paved essential steps of the developments that led to the present detailed understanding of the reaction center, including its structure. Since insight into the structure and the charge separation mechanism of the reaction center has provided the principles of optimised light energy conversion in biology, Feher's work is seminal for the construction of synthetic and semisynthetic molecular energy converters, which may have profound implications in an energy-demanding world.*"

In his later years, George who was haunted all his life by the horrors of WWII and the question: *How could it have happened*? found the inner fortitude to condense his memories in "Thoughts on the Holocaust". For us it is perfectly understandable that the Wolf Prize awarded at the Knesset in Jerusalem had a very special meaning for him.

In admiration of his overwhelming life history as well as his seminal contributions to biology and physics, we have seen the passing of a great personality and of a giant in the world of science.

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George Feher, the inventor of ENDOR (electron-nuclear double resonance spectroscopy), an IES Gold Medal Laureate and IES Fellow, passed away in November, 2017. It is a great loss for our community, we would like to send our sympathies and condolences.

His research on photosynthetic systems using ENDOR gave a great impact to both EPR and biological communities. He also influenced the photosynthesis researchers using EPR in Japan, such as Asako Kawamori and others. I heard that Kawamori visited Feher's lab during her sabbatical and changed her EPR research drastically from the material science to photosynthetic systems. I am sure that George Feher has influenced many other scientists.

We lost a great pioneer in our field. I would like to express my heartfelt condolences to his family and his colleagues.

Hitoshi Ohta
Kobe University, Kobe, Japan

* * *

I had the great fortune of being associated with George Feher for over 30 years. This started out with a common interest in magnetic resonance but over the years dealt with many other approaches to unraveling the workings of the photosynthetic reaction center. George had a keen instinct for asking important questions and finding the best ways to answer them. He was trained as a physicist but when he switched to biophysics he realized that biological approaches were important. He was enthusiastic about learning biology, first hand in the lab. I remember doing experiments in the lab with him, testing for the presence of an iron-sulfur cluster in the reaction center protein by using our noses to test for hydrogen sulfide released after acidification, and cutting polyacrylamide gels to obtain subunit samples to send to Lisa Steiner (MIT) for amino acid analysis. This openness to new ideas would be evident in his work in science.

George was very interested in probabilities and random processes. I remember sitting at the EPR spectrometer with George and Roger Isaacson as noisy EPR traces were being accumulated on the CAT (computer of average transients). George would bet whether a small blip would show up again on the next trace, showing that it was a signal peak instead of a noise burst. He developed a technique, fluctuation spectroscopy, whereby kinetic parameters of a dynamic system could be determined by the fluctuations (noise) in the value of an equilibrium property. He was an ardent poker player and knew the probabilities of filling every hand of cards. Later in life, as his health problems increased he could tell you the probability of success for each course of treatment. He said his physician jokingly accused him of practicing medicine without a license.

The best lessons I learned from George were by playing tennis with him. I was his doubles partner for many years in a weekly match we had at noon at UCSD. He did not have a polished style but would run for every ball. Whenever I would cry "Oh no" when I couldn't reach a ball he would scold me saying "don't say that, don't give up". His dogged determination, (and his lob) won him many points. One afternoon we were scheduled to play during a time after the serious wild-fires in San Diego had produced soot that blackened the tennis courts making the ball difficult to see. This was a problem for George since he was having problems with macular degeneracy. When we arrived at the courts we found that George had brought a hose and cleaned the all soot off the court. He discovered the way to improve the signal to noise ratio. He was a remarkable person with so many amazing accomplishments. I will miss his wisdom and humor which meant so much to me.

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I did not know George Feher personally very well, just met him a few times on conferences and celebrations of significant birthdays of Klaus Möbius and Wolfgang Lubitz. Of course, I know him very well from his seminal papers in the field of magnetic resonance spectroscopy. His paper *Sensitivity Considerations in Microwave Paramagnetic Resonance Absorption Techniques*, published in Bell System Technical Journal from 1957 (actually the year I was born!) is for me still the gold standard for any technical description of spectrometer performance! What a beautiful paper! How well and clearly written! I have read this article so many times that my copy of this article, printed within my PhD time, not only became very yellow and washed-out, but also totally crumpled. By reading this article, I always had the feeling, that I know George Feher; as you think about a poet by reading his novels. Of course, it is not only this one paper, which was seminal from his time at Bell Laboratories! His work and ideas on spontaneous emission and masers, as well as his original experimental work on polarization transfer of coupled nuclear-electron spin systems are landmarks. They demonstrate very nicely the close relationship between dynamic nuclear polarization and electron-nuclear double resonance; two sides of the same coin. ENDOR spectroscopy is the basis for a detailed structural understanding of the ligand sphere geometry of paramagnetic centers. DNP recently became very popular again. A 1956 Physical Review Letter to the Editor from George Feher, describing nuclear polarization by selective adiabatic passage of resolved hyperfine lines, highlights this close relation referring to experimental work and private communications with Charlie Slichter; another outstanding scientist who unfortunately also passed away very recently. The bandwidth of George Feher's work is phenomenal, ranging from microwave technology and methods development, from physics to biology, from material sciences to bacterial photosynthesis. This broad range of scientific work and interest is mirrored by the many and diverse places, he stayed within his scientific and personal life. I enjoyed very much reading his personal accounts that he wrote from time to time on his career, his decision to step into molecular biology and his other passions. I use them very often in discussion with students as positive and exciting examples: always being open for new directions and ideas! I also like very much the fine humor, which gives his accounts a very special taste. I am very sorry, that there will be no further editions of such articles from him, but I am sure that his papers, beautiful from the scientific content as well as the style of writing, will further stimulate and excite many scientists.

Thomas Prisner
Goethe University, Frankfurt am Main, Germany

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For many years I knew George Feher as a pioneer in the creation and development of electron-nuclear double resonance (ENDOR). He established a method for recording the effect of nuclear paramagnetic resonance (NMR) by means of electron paramagnetic resonance (EPR) spectroscopy. This indirect method of recording the NMR effect makes it possible to increase the sensitivity of observing the NMR effect by several orders of magnitude. ENDOR methods have found very wide application in the study of the weak hyperfine interactions of electrons with magnetic nuclei.

It so happened that I met George Feher rather late, in 1996, on the eve of my 60th birthday. Of course, I knew him for about 30 years from his scientific publications. Moreover, I heard a lot about him from Dietmar Stehlik, Klaus Möbius, Wolfgang Lubitz and other colleagues who knew George personally, and some even worked for a while in his group. I learned from them many fascinating stories of George Feher's scientific and personal life during his stay in Palestine until 1946 after his escape from Nazi Slovakia and, subsequently, at various places in the USA.

In 1996, George Feher was awarded the International Zavoisky Prize for his outstanding contributions to the development and application of spin magnetic resonance in solid state physics and in the study of photosynthesis. The winners of the Zavoisky Award William B. Mims (1991), Brebis Bleaney (1992), Arthur Schweiger (1993), James R. Norris, Klaus Möbius, Yakov S. Lebedev (1994), James S. Hyde (1995) and George Feher (1996) composed a wonderful cohort of scientists! Their scientific creativity and that of other Zavoisky Award laureates (www.kfti.knc.ru/eng/zavoisky/Award_Holders) greatly contributed to the fact that today EPR spectroscopy is flourishing and finds continuously growing applications in many fields of science and technology. Since then I enjoyed my collaboration with George on the Zavoisky Award Selection Committee for about twenty years. It was always very helpful to have his wise advice.

George's visit to Kazan gave me and many other Kazan scientists the opportunity to personally meet and communicate with him. It turned out that George has a very interesting personality, very witty. He accompanied his stories with appropriate anecdotes. I got the impression that his life and scientific creativity were something inseparable. It was so easy to communicate with him! I remember an episode of our trip to the Volga river, the legendary river in Russia. Kazan is located completely on its East bank. We moved across the bridge to the West bank and admired its beauty. Then we had a picnic in the forest. It was fun. Of course, on such a picnic in the woods the service is very different from the service in restaurants but George was spiritually at ease. I think he liked the absolutely informal atmosphere. George was not just cheerful on his own. He was contagiously cheerful for those with whom he communicated. It was his main lesson for me.

Kev M. Salikhov
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It was one of the few rainy days in La Jolla when my wife and I arrived in Dec. 1970. The clouds cleared as we walked in from the Revelle parking lot. I was coming from a previous year's postdoctoral stay at an internationally known lab in the UK. That UK lab had been in the forefront of EPR research in the 1950's but by 1970 was living off its reputation. What a contrast the Feher lab was!

Foremost there was the EPR-ENDOR lab conceived by George Feher. It held one-of-a-kind apparatus expertly designed and kept in repair by super-engineer Roger Isaacson. That lab was evolving into a world-leading lab in EPR applications to photosynthesis and in EPR applications to heme systems. The biochemistry lab, conceived by George Feher in collaboration with physical biochemist Mel Okamura, would also project the Feher lab into the forefront of photosynthetic research. The entire Feher lab smacked of professionalism; even graduate student Jim McElroy was a trained electrical engineer. It was clear that George's lab was dedicated to rigorous scientific productivity, and *rigorous scientific productivity was what George expected from the people who worked there*.

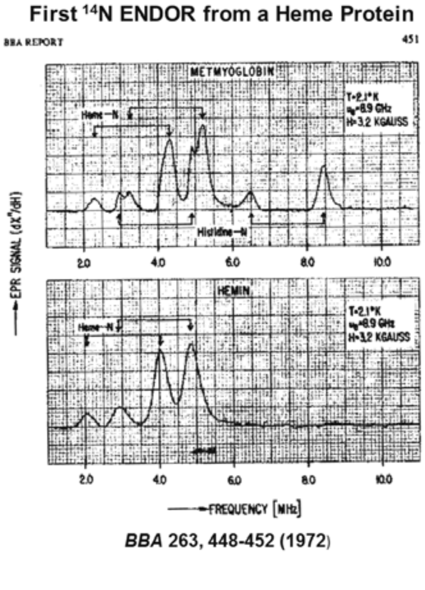
The rain cleared. There was productive work to be done. Our consensus goal was to obtain ENDOR from the heme and its surrounding ligands in heme proteins. Heme is a critically important prosthetic group in numerous proteins, serving functions as diverse as the catalytic active site and oxygen transporter. We were to elucidate the fundamental electronic structure at the heme; that meant finding ligand hyperfine couplings, underlying spin densities, and ultimately the wave function. We started with the monomeric heme protein metmyoglobin, the first protein ever to have its crystal structure determined. I brought useful prior knowledge from my Ph.D. work, where I had developed a heme-doped organic crystal. Single crystal helium temperature EPR of these heme-doped crystals directly gave heme nitrogen hyperfine couplings [1]. However, ENDOR was definitely the general method of choice to probe heme electronic structure from the broad EPR features of heme proteins.

George Feher understood how essential it is to have electron spin relaxation times sufficiently long that spin relaxation does not compete with RF (radio frequency)-induced ENDOR transitions. In his systematic way, before doing ENDOR he decided to investigate by saturation recovery EPR the temperature dependence of the spin lattice relaxation rate

$[1/(T_1)]$ of high spin ferric metmyoglobin. There was a strong $\exp(-\Delta/kT)$ temperature dependence from the electronic spin-lattice relaxation rate. The temperature behavior was from an Orbach process [2] that depended on the energy $\Delta \approx 10\ \mathrm{cm}^{-1}$ of the first zero-field-split excited state of high spin $(S = 5/2)$ ferric heme [3]. Besides providing a novel way of determining the zero-field splitting for heme proteins, these measurements pointed to using a temperature for ENDOR of about 2 K where $T_1 \approx 10$ ms. It must also be mentioned that spin-spin interactions between ferric hemes provided undesirable competition with ENDOR transitions, and so it was necessary to enhance the magnetic dilution of the samples, initially by glycerol cryoprotectant to prevent protein aggregation on freezing.

The microwave cavity, a *sine qua non* for doing ENDOR, was an Isaacson masterpiece of silvered quartz. The ENDOR signal itself was derived from the 100 kHz field-modulated EPR signal (dispersion, rapid passage conditions worked best) as perturbed by repetitively swept RF. The convergence of proper sample conditions, a highly functional ENDOR apparatus, the right temperature, and a certain amount of luck occurred in Nov. 1971 when the first ENDOR signal from metmyoglobin was detected. Interestingly, this finding happened while George Feher was away! Shown on the figure are the 1972 graph paper ENDOR traces of nitrogen ^{14}N ligand hyperfine structure from the heme nitrogens and the proximal histidine nitrogen of metmyoglobin [4]. Soon there was proton ENDOR from the heme itself and from its aquo ligand. ^{57}Fe ENDOR was attainable, even from ^{57}Fe in 2% natural abundance [5].

First ^{14}N ENDOR from a Heme Protein



***BBA* 263, 448-452 (1972)**

George wanted to assure that ENDOR was used not just to determine electronic structural parameters of the heme, but to find evidence that these parameters changed in response to biologically significant protein conformational changes. In the 1970's quaternary interactions between interacting hemoglobin subunits were the subject of major investigation. We found that a heme ligation change originating at α-subunits of $\mathrm{Hemoglobin}_{\mathrm{Milwaukee}}$ conformationally propagated into an ENDOR-detectable change of the proximal histidine nitrogen of the β-chain heme, tens of Angstroms removed from the α-chain heme [6]. A biological conformational change had indeed led to a biologically relevant, ENDOR-detectable electronic change.

The initial ENDOR studies were in frozen solutions at g-value extrema. However, complete elucidation of hyperfine and quadrupole couplings and of the underlying electronic structure required single crystal rotation studies. Again there was sophisticated biochemistry needed to make magnetically dilute single crystals (95% diamagnetic CO myoglobin and 5% paramagnetic ferric metmyoglobin) prepared with ^{14}N or ^{15}N heme. Then of course there was a clever Isaacson sample holder. The final publication of the metmyoglobin single crystal work in 1982 was the culmination of tour de force data gathering and data analysis, and it provided the hyperfine and quadrupole benchmarks that are still referenced [7].

There is more to tell about the Feher lab, circa 1970-73, than experimental results. Help was always forthcoming (Thank you, Roger!) when advice was needed on the subtleties of the EPR-ENDOR apparatus, on signal-to-noise enhancement, and on the engineering skills that would be necessary if one was ever going to create one's own ENDOR apparatus. The photosynthetic studies in the Okamura-Feher biochemistry lab were in many respects bioenergetic studies, and information on bioenergetics was useful for my own later work on mitochondrial proteins. I well remember the Friday afternoon group meetings, where frequently one was asked to provide an in-house seminar. That meant that if one didn't understand what one was doing or couldn't explain it so that others understood it, it could be painful. George Feher had an instinct for critically probing those painful areas where physical insight was lacking, and for my future teaching, thinking, and writing I now appreciate that. Of course cake and occasional champagne at a Friday afternoon group meeting tended to ease the pain.

George was a role model for what a good physicist, and in fact, a good scientist, should be doing. The Feher lab was one where you paid attention, listened, asked questions, and learned. His contributions to 20th century science were serious ones, and it was an absolute honor to be associated with him.

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Unfortunately I never had the privilege to meet George Feher personally. I learned about his invention of electron nuclear double resonance (ENDOR) when I joined the group of Horst Seidel at the 2. Physikalisches Institut of the then Technical University of Stuttgart in the fall of 1962 as a Ph.D. student. Solid state research was largely still in a phenomenological state and I was enthusiastic about the possibility of using ENDOR to study a solid on the atomic scale. Seidel had built the first ENDOR spectrometer in Germany. He used components of a Varian X-band EPR spectrometer and a cylindrical room temperature cavity with two pairs of rods in Helmholtz configuration to generate the rf field. In the middle of the cavity was a "cold finger" with the sample cooled by liquid N_2, H_2 or He.

ENDOR of a paramagnetic point defect was measured as a small desaturation of a saturated EPR transition by the simultaneous induction of an NMR transition of a superhyperfine (shf) coupled magnetic nucleus of the lattice (called ENDOR line). Seidel studied F-centers in alkali halides and showed unambiguously that an F-center consists of an unpaired electron on an anion vacancy. He resolved the shf interactions with many shells of lattice nuclei demonstrating the rather wide spread distribution of the unpaired F-center electron.

My topic was the investigation of interstitial atomic hydrogen centers in KCl which is the most simple impurity defect in an alkali halide, which as an almost pure ionic crystal is also a most "simple" solid. The shf interactions with 2 shells of K^+ and 3 shells of Cl^- neighbors could be resolved. The experimental shf interactions of this model defect could be explained rather well by orthogonalizing the atomic hydrogen 1s wave function with a Löwdin procedure to the ionic cores of the alkali and halide ions.

The signal intensity of the ENDOR lines in solids is at most about 1% of the EPR signal intensity, generally much less. Desirable is very low temperature and high microwave frequencies and power. A point defect can have many ENDOR lines for one crystal orientation with respect to the static magnetic field (B_0) depending on the electron spin state, the number of interacting nuclei and their magnetic/electric quadrupole interactions. There can be hundreds of lines for one orientation. To determine the defect structure in a single crystal of known symmetry one must measure the ENDOR spectra with B_0 orientations in two crystal planes in small angular steps. The measurement and analysis of the angular dependencies of such many line spectra can be quite cumbersome and difficult.

In 1974 I took up the first chair in experimental physics at the newly founded university of Paderborn. The challenge was to set up a new department of physics, a crystal growth laboratory and a new ENDOR laboratory with the aim to contribute to materials science. The spectrometers were built using commercial components and developing special He cryostats for the measurement at temperatures as low as about 1.4 Kelvin and sample rotation. They were built in our engineering workshop. The employment of computers allowed the "automatic" measurement of angular dependencies, determination of ENDOR line frequencies and their analysis. With this instrumentation apart from further ionic crystals a range of semiconductors was studied: Si as well as binary semiconductors such as GaP, GaAs, GaN and SiC. Paramagnetic dopants and in particular "antisite" defects were analysed such as As on a Ga site and others.

Often EPR spectra of several defects overlap strongly and cannot be separated in EPR. By measuring a kind of ENDOR excitation spectrum of one ENDOR line varying the magnet field intensity and automatic rf frequency tagging one can disentangle their EPR spectra (called ENDOR–induced EPR). Also ENDOR spectra contain lines of several defects for a setting of B_0 in the EPR overlap area. By setting the experiment to fulfill triple resonance conditions one can measure the ENDOR spectra of each defect separately (Double ENDOR).

Already a small concentration of point defects determines the optical and electrical properties of solids. Thus it was desirable to develop EPR and ENDOR detection schemes allowing a direct correlation of the defect structure to these properties which is important for the development of devices, i.e. to help "defect engineering".

Correlation with the optical absorption is achieved by detecting EPR and ENDOR via the change of the magnetic circular dichroism of the absorption (MCDA). The spectrometer consists basically of an optical spectrometer, where the sample is located in a special ENDOR cryostat with 2 optical windows and with B_0 generated by split coil superconducting magnets along the light path. The first ODEPR and ODENDOR measurements were performed on AsGa antisite defects in GaAs. Also in MCDA-EPR excitation spectra can be measured to disentangle several overlapping defects (EPR tagged by MCDA). In MCDA-EPR/ENDOR also a two-dimensional spatial resolution of the defect distribution has been realised. The detection of EPR in luminescence had been widely applied previously. However, attempts to measure ENDOR via luminescence were not successful, probably due to the long nuclear relaxation times compared to optical radiative transition times.

With thin layers like epitaxial semiconductor layers or devices like diodes EPR and ENDOR have a sensitivity problem. In semiconductors with electrical conductivity of excess carriers in a static magnetic field the spin dependent recombination (SDR) of donor-acceptor pairs can be used to detect EPR (EDEPR), a mechanism known for some time, but it only became successful when working at low temperature. EDEPR and EDENDOR were first detected in a P-doped Si-sample in the photoconductivity. The method is considered to be open to more development. It also allows the construction of low cost spectrometers since the effect does not depend on the microwave frequency.

In conclusion, as one example, it is mentioned that ENDOR measured with several methods was instrumental in analysing the fundamental mechanism of radiation damage in X ray storage phosphors. This helped to improve these compounds in cooperation with industrial firms opening broad ranges of applications, e.g. in generating X ray pictures of patients in every hospital.

The invention of ENDOR by George Feher did not only further fundamental and applied research in solids but also helped theory to develop ab initio calculations of the electronic structure of point defects by providing many experimental data to be explained.

Johann-Martin Spaeth
University of Paderborn, Germany

* * *

George Feher was a special man for all of us but special in an individual way for each of us. I met George for the first time when he came to Kazan to give the Zavoisky Award 1996 lecture. Before his arrival I exchanged email messages with Simone Powell, George's office secretary, who took care of his travel arrangements. His trip to Kazan was also special. On the day scheduled for his arrival Simone emailed me, that because of bad weather, the first leg of his long route, San Diego - Kazan, had to be cancelled and she had found a completely different route for George. Thanks to her email, we could pick George up at the airport in Kazan in due time. In addition, the weather here cheated us. Instead of sunshine and warmth, as I informed Simone, based on the long-term weather forecast, it was cold, windy and raining. And George's outfit was good for California but not for Kazan! Horrible! Nevertheless, George's poker face did not show any traces of displeasure. At this first encounter, George greatly impressed and charmed me by his unaffected manners and the shadow of a smile I could see on his lips. I also understood he liked to travel light when he asked that his Zavoisky Award Diploma to be taken out of its heavy oak frame and he rolled the diploma up to carry it under his arm. At the banquet in George's honor I was seated next to George. We exchanged a couple of words between toasts. In particular, he wondered about the etymology of my surname and I explained to him that it originated from the Bible name

From left to right: Laila Mosina, George Feher and Simone Powell (La Jolla, 2005)

Moses. His immediate reaction was to ask me if I was Jewish. However, he seemed to be quite happy with my clarification that I am Russian on my father's side and Tatar on my mother's side. George sent me a thank-you email when he was back in La Jolla and then we exchanged conventional Hanukkah and New Year's greetings.

My email correspondence with Simone continued and it was really fantastic, that with all the differences in our background and origin and citizenship, etc., we found so many things in common to speak about and to understand each other. We felt that we were friends. So it was quite natural that I sent Simone a hello from Tucson in 1999, when I had a common short-term research grant with Arnold Raitsimring at the University of Arizona. In her return email Simone told me that George is inviting me to give a talk at his lab's seminar. I accepted this invitation with gratitude. Simone and Jay, Simone's husband, met me in San Diego airport and the California fairy tale started. I enjoyed the creative atmosphere at the seminar and in the lab. It was nice to meet with George's colleagues and I immediately realized that if George was the brain and the driving force of the research carried out in his lab, Simone was its heart and soul filling it with warmth, care and positive emotions. George gave me a tour over the UCSD campus and told me the story of his first years there. He showed me his tennis club and then we walked on the beach. The sun was setting and the wind blowing from the ocean was strong, moist and cool. Our feet were buried in the sand as we walked. Talking with George was like breathing or swimming, as there was no tension at all. I had the feeling that I had known George for ages and we were tuned to the same wavelength. It is difficult to recollect exactly what we spoke about but I remember quite vividly that we jumped from one subject to another. In particular, I asked him if he thinks that there will be peace some day in the Middle East and I remember his sad face and answer, "I do not think so".

When I became editor of the *EPR newsletter* and we were working on our first issue (13/1-2, 2003), it was inspiring and heartwarming to have his help and support (he contributed the "Playing Poker" article to the Another Passion column, pp. 10-12). And his help and support continued for many years (please see his articles in the *EPR newsletter*).

What am I grateful to George Feher for? For the walk on the La Jolla beach, for the opportunity to make friends with Simone and Jay Powell, for the generosity with which he shared with the readers of the *EPR newsletter* the precious gems of his reminiscences, for his sense of humor and for the shadow of a smile on his poker face...

I am happy that within George's lifetime I was able to tell him many times about my gratitude, not only in my words, but also with special issues and columns of the *EPR newsletter* dedicated to him. And the star, George Feher, still shines in my universe.

Laila V. Mosina, Editor, *EPR newsletter* of the IES
Zavoisky Physical-Technical Institute, Russian Academy of Sciences, Kazan, Russia

* * *

As a biologist, I would like to state upfront that my knowledge and expertise in Electron Paramagnetic Resonance are very limited. However, I feel very lucky that whatever I did learn in this field my teacher was one of the greatest contributors to EPR and the developer of the ENDOR method, the late Prof. George Feher. George gave two courses on EPR in the Hebrew University and as his host I attended every lecture. Also in endless discussions he explained me the principles in such a clear way – that I have never heard from any other scientist!

I first met George as a graduate student in the Technion in the laboratory of Prof. Nathan Nelson. George who was a member of the Technion Board of Directors used to come every year for the annual meetings and to give a talk on the advancements in characterizing the bacterial reaction centers in his UCSD laboratory. As a graduate student I used to attend all these lectures and in one of these talks I told him that by chance I found out that he is the uncle of my best friend and classmate that was sitting next to me for our four years of high school – Dalia Zohar. What a small world – finding out that one of the leaders of RC research and EPR has family in Haifa – my home town, a family where I spent lots of time as a teenager.

We became very close colleagues after a conference held in 1983 in Zurich, Switzerland, on reaction centers. I attended the conference and gave a talk on my results on Photosystem I and George invited me to join him on a train journey from Zurich to Basel where he wanted to check on a possible collaboration for the crystallization of his RCs. It was on this trip that we discussed the possibility that I will join his laboratory as a post-doc (never happened because UCSD at those days did not have a good Ph.D. program in History for my husband) ...On this trip I also gained courage and asked George about a story I heard in the Technion that he was not admitted to the Technion as an engineering student. George confirmed the story saying that he got A+ in four tests (English, Mathematics, Biology and Physics) BUT he flunked the test in Bible... and that when he wrote a letter to object the decision he got an official answer that "A Jewish engineer should know the Bible..." So he went to get his degrees in Berkeley. Years later in one of our endless talks about his history in Israel (then Palestine, 1941–1945) I asked him where did he learn such a great English and he said he was given permission to learn

it from BBC early mornings one hour before he had to go to work in the Kibbutz...

In 1994 we celebrated in The Hebrew University of Jerusalem (where I became a Faculty member) the 70th birthday of George. For this event, among other things, I went to Berkeley and interviewed his Ph.D. advisor Prof. Kip and from the library received the copy of his Ph.D. thesis. His career in EPR started there with his Ph.D in Physics entitled: "Electron Spin Resonance Absorption in Metals". All the EPR community who knew George as a leader in the field – learnt about his passion to play POKER when he wrote his article about Poker in the *EPR Newsletter*. However, I am not sure that the EPR community knows that George learnt Poker in Berkeley when he was waiting for the Magnets to cool down (see figure).

I miss you George and your clear explanations... You were a role model to me and from you I learned that when there is no available methodology to answer a scientific question (GF: "remember the scientific question is always the MOST important one!") – you have to invent it! This you told me when we talked how the ENDOR innovation came...

Rachel Nechushtai
Hebrew University Jerusalem,
Israel

The impact of George Feher's five years at Bell Labs on my career

James S. Hyde

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Introduction

George Feher received his PhD degree in physics from the University of California at Berkeley in 1954, which is the year that I graduated from the Massachusetts Institute of Technology and began to work toward my own PhD in physics. Feher took a position at Bell Labs and wrote several papers during the five years I was in graduate school that had a profound effect on my own career. He wrote the seminal paper on EPR sensitivity considerations [1], and he discovered electron nuclear double resonance (ENDOR) [2–5], which I believe was the earliest double irradiation experiment across all branches of magnetic resonance, nuclear magnetic resonance (NMR) as well as EPR. He also made contributions to the understanding of passage effects in EPR. These contributions are distributed across his ENDOR papers, including an appendix to his definitive study on ENDOR of donors in silicon [4]. My intent in this letter is to focus on the impact of his work in the Bell Labs years of his scientific career on my own research.

Sensitivity Considerations in Microwave Paramagnetic Resonance Absorption Techniques

Feher's *Sensitivity Considerations in Microwave Paramagnetic Resonance Absorption Techniques* paper [1] became available as I was in the process of developing an EPR spectrometer at 24 GHz that made use of a transmission cavity with a bucking arm to reduce microwave levels in the transmitted signal. It was fantastic to see Feher's analyses for both reflection and transmission cavities. He had an undergraduate degree in electrical engineering, and this paper provided immediate technical information useful in spectrometer development.

One of the analyses that Feher carried out was of sensitivity in a spectrometer with a reflection cavity and a detector output proportional to input voltage. Equation (1) is taken from Ref. 1 for this case.

$$S = \chi\eta Q P_0^{1/2} \qquad (1)$$

Here, χ is the radio frequency (RF) susceptibility per unit volume and P_0 is the incident microwave power. The Q-value can be readily measured, but the filling factor η presents some problems. It is given by Eq. (2), which today we would handle by a finite-element computer program to obtain the integrals.

The filling factor η is given by

$$\eta = \int_s B_1^2 \sin^2\Phi dV_s / \int_c B_1^2 dV_c \qquad (2)$$

where the integrals are over the cavity (c) and sample (s) and Φ is the angle between the dc polarizing magnetic field and B_1.

I joined Varian Associates in 1959, about the time that Feher left Bell Labs. The Varian EPR spectrometers were designed in accordance with Eq. (1). I developed the first commercial Q-band system while at Varian. It had a cylindrical TE_{011} wire-wound cavity that was scaled from a similar X-band cavity. I was eager to compare sensitivities, and quickly learned a cruel lesson: the concentration sensitivity was about the same even though the sensitivity measured in number of spins detected had improved by a factor of about 100. If the number of spins per milliliter is fixed, the variables in Eq. (1) do not change very much on going from X- to Q-band, and some of the changes are offsetting. However, the volume of sample decreases tremendously.

Some years later, A. J. Hoff edited a book that was dedicated to Feher on the occasion of his 65th birthday. I contributed a chapter that had, as a starting point, Eq. (1) [6]. I defined the resonator efficiency parameter,

$$\Lambda = B_1/P_0^{1/2}, \qquad (3)$$

and reformulated Eq. (1) such that the filling factor no longer appeared. The use of the resonator efficiency parameter provides a statement of the finite-element contributions to the EPR signal from a point in space. The formulation can be thought of as a differential version of Feher's original integral formulation. We use it today in all computer-driven analyses of resonators. It is convenient, as an example, for modeling the effects of the dielectric properties of the sample or of the sample cuvette in loop-gap resonators (LGR).

The four variables in Eq. (1), P_0, Q, χ, and η, are independent in a certain range of conditions. However, as P_0 increases, microwave power saturation begins to occur and the RF susceptibility χ changes. I often prefer to readjust P_0 to hold H_1 at the sample constant when comparing two alternative microwave resonators.

The LGR introduced by Froncisz and Hyde (see Ref. 7) has certain advantages compared with cavity resonators that can be understood by studying Eq. (1). The advantages are a higher resonator efficiency parameter at a point in the sample compared with a cavity resonator, and better sensitivity for small difficult-to-prepare spin-labeled mutant proteins. A further advantage of the LGR is that the RF field is relatively homogeneous over the sample.

In the analyses of Ref. 1, microwave power saturation characteristics were neglected. The last section in Feher's paper briefly considers this issue. It led to another line of research in my own career – that of the uniform field resonator.

In a series of papers from my laboratory, we introduced the uniform field (UF) cavity as an approach to the problem of inhomogeneity of the RF field over the sample. The UF cavity has three sections: a central sample-containing section at cutoff where the RF field is uniform and end sections that satisfy boundary conditions at the end walls. That approach is reviewed in a recent publication [7].

As another example of loss of independence of the variables in Eq. (1), consider a sample dissolved in water. Both Q and η are affected and must be optimized in concert. Feher carried this analysis through for a cylindrical sample tube [1]. Early on, it was discovered that a large increase in filling factor for aqueous samples is achieved by using a flat cell rather than a capillary in the nodal plane of a rectangular TE_{102} cavity. The thickness of the cell must be adjusted for optimum Q-value. This specific example was not foreseen in Ref. 1, but the appropriate methodology was introduced.

ENDOR

Two letters to the editor describe the first ENDOR experiments on donors in silicon as well as in F-centers of KCl crystals [2, 3]. The latter was of particular interest to me, since I was studying F-centers in LiF [8]. The quite wonderful acronym for electron-nuclear double resonance, ENDOR, was introduced in Feher's full length paper on donors in silicon that appeared in the *Physical Review* [4]. It did not take long for word to spread around the EPR community that there was a double meaning for "ENDOR". It is the name of a place in the Old Testament [9]. Briefly, King Saul had outlawed witches, but nevertheless he visited one, in disguise, in order to learn about the future. He was recognized and was told the truth: on the next day a pending battle would be lost and he would die. Rudyard Kipling wrote a poem with a stirring final stanza, "and nothing has changed of the sorrow in store for such as go down on the road to En-dor". I once asked Feher if he actually knew the bible this well. He told me that he really did, and that his idea was that the theoreticians at Bell Labs would, like Saul, fall on their faces in a faint when confronted with truth concerning the Si donor waveform. He went on to say that the first reference in the seminal *Physical Review* paper on ENDOR was the biblical citation. Feher told me that at the last possible moment Sam Goudsmit, the editor, discovered the citation and called Feher to tell him that the journal felt it was inappropriate and was going to remove it. I vaguely recall that Feher told me he threatened some kind of retribution if they made any mistakes in correcting the nearly 100 remaining citations.

A student who pores over the Feher ENDOR papers will never forget the distinction between inhomogenous and homogeneous broadening. Figure 1 from Ref. 4 is instructive. Fundamentally, ENDOR provides a way to increase spectral resolution by overcoming inhomogeneous broadening. In the decade from 1960 to 1970, I published 18 papers on ENDOR. They are briefly reviewed in Ref. 7. Basically, I found ways to obtain enhanced resolution in unordered solids as well as in liquids, recognizing that there were different categories of inhomogeneous broadening. I found myself, like Feher, increasingly interested in problems in biophysics. Specifically, Feher had originally focused on single crystals, and I found ways to carry out ENDOR studies on unordered solids including frozen solutions of proteins. I also introduced the field of ENDOR in fluids.

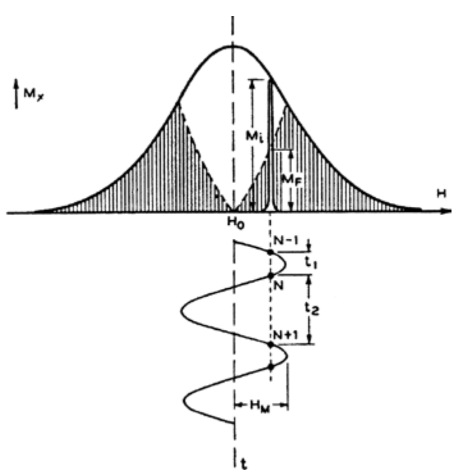

Fig. 1. The idealized behavior of an inhomogeneously broadened line when a sinusoidal field modulation is applied. The initial magnetization M_i decays to the steady-state magnetization M_F. The spin packets are traversed under adiabatic fast passage conditions. (Reprinted figure with permission from George Feher, Physical Review, 114, 1219-1244, 1959. Copyright 2018 by the American Physical Society.)

Adiabatic Rapid Passage

Feher's ENDOR experiments in the early years were based on the effect of an incident nuclear RF field on the EPR dispersion signal under conditions of rapid passage. The time-varying magnetic field inverted magnetization in the inhomogeneously broadened EPR signal in accordance with Fig. 1. The dispersion signal was orders of magnitude more intense than the adsorption signal. One might expect broadening of the NMR signal that is observed indirectly by change in the EPR signal in the presence of field modulation. However, the NMR gyromagnetic ratio was so low that this contribution to the ENDOR linewidth was negligible. All early Feher papers on ENDOR contain some discussion of adiabatic rapid passage, and the key *Physical Review* paper contains a lengthy appendix [4].

Feher played a role in the seminal theoretical and experimental work of M. Weger "Passage Effects in Paramagnetic Resonance Experiments", which appeared in *The Bell System Technical Journal* in July 1960 [10]. The paper contains the following acknowledgment: "This work was carried out under the supervision and with the constant help of G. Feher".

My own contributions to the field of passage spanned my career, including one of my PhD dissertation papers on F centers in LiF [8], the development of saturation transfer spectroscopy to observe very slow rotational diffusion of spin-labeled macromolecular assemblies, and observation of free induction decay signals from microwave frequency sweep at W-band. Access to these papers is provided in Ref. 7. My work was strongly influenced by the studies of Weger and Feher. Specifically, very slow rotational diffusion can be studied by first harmonic dispersion passage effects. Motional information arises from differing effects comparing turning-point regions with regions between turning points in near rigid limit spin label spectra. However, there can be excessive noise when detecting dispersion. Weger's analysis led me, working closely with D. T. Thomas, to use the second harmonic absorption display, which was found to be a practical solution to the noise problem. See Ref. 7 for more detail and access to the extensive literature from the Thomas laboratory on dynamics of musculo-proteins.

In an "upside down" line of reasoning, I introduced the technique of non-adiabatic rapid sweep (NARS) to observe pure absorption lines rather than the derivative-like output of a phase sensitive detector. We sought to avoid passage effects, although we intended to be "on the verge" of passage conditions. The zeroth harmonic of the response of the spin system to field modulation was calculated on a desktop computer. See Ref. 7 for access to the details.

Feher invented the idea of temperature modulation to overcome the complexities of passage effects and, at the same time, obtain pure absorption displays of EPR spectra. The original temperature modulation article [11] was reproduced in Hoff's book [6]. Hoff must have been as pleased with it as I was.

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The 51st Annual International Meeting of the RSC ESR Group
April, 2018, London, UK

The 51st Annual International Meeting of the ESR Group of the Royal Society of Chemistry has taken place in April 2018 in Queen Mary University of London. There were 120 participants from 16 countries. The organisers – Maxie Roessler and Enrico Salvadori – deserve a medal for their valiant victory over East London. The challenges, successfully overcome, had included a group of socialist student protesters who had occupied the conference dinner venue (in the true British capitalist spirit, a better venue was found quickly). Just a few days before the meeting, a child was born to Maxie and her husband. It does take a biologist to know the limits of human endurance, and to be present and in command nonetheless. Maxie received a standing ovation.

The unique atmosphere and architecture of East London were every bit as fascinating as the weather, and shared much of the colour palette with it. A particular highlight was the group of historic buildings, merchants and temples just outside the hotel. It was universally acknowledged that the charming place and its surroundings were still carrying the spirits of Charles Dickens and Edgar Allan Poe.

Bruker Prizes

Since 1986, Bruker Corporation has generously sponsored an annual lectureship and prize, given to a scientist who has made a major contribution to the application of ESR spectroscopy in chemical or biological systems. The Bruker Prize 2018 was awarded to Professor Sabine Van Doorslaer, University of Antwerp for her outstanding contributions to application-oriented method development and for cutting-edge studies of proteins, materials, and catalysts.

In his laudatory speech, Professor Gunnar Jeschke noted that Sabine van Doorslaer applied a broad arsenal of advanced pulsed ESR techniques at different frequencies, and analysed ESR spectra based on quantum-chemical computations in order to understand the spatial and electronic structure of paramagnetic systems. Thanks to her, it had become known how structurally diverse the heme centres are and how this structural diversity was related to function. Her collaborative work on asymmetric homogeneous catalysis stands out in this field. Prof van Doorslaer published a number of fine papers on the measurement of small hyperfine couplings, and on signal processing in ESEEM very early on in her career. Beyond her research achievements, she a great teacher who has strongly contributed to the cohesion of ESR community. She is a regular and well-liked lecturer at summer schools of the European Federation of EPR Groups, and has chaired the European COST Action on Advanced Paramagnetic Resonance Methods in Molecular Biophysics. Currently, she is the President of the European Federation of EPR Groups. The 2018 Bruker lecture titled "Hyperfine companions on a journey through the world of (bio)materials" was followed by the Bruker reception.

The other annual EPR prize sponsored by Bruker is the Thesis Prize, set up to recognise outstanding work by PhD students in the field of ESR Spectroscopy. The Committee received nine applications from the students who had submitted their thesis in the previous two years. By reading the summaries and the support letters from supervisors and examiners, the Committee narrowed the field down to three submissions and then went through the considerable job of reading each thesis in depth. It was abundantly clear that the extraordinary scientific work by Audrey Bienfait was the winner. The best way to illustrate the achievement is to quote from the reports by the selection committee:

"This is the first experimental observation of the Purcell effect. When the Nature paper reporting the work was published, I immediately recognized its importance and made it the focus of one of my weekly EPR tutorials. The thesis demonstrates deep scholarship and understanding of this striking new perspective on spin relaxation. The scholarship covers a wide range of topics relevant to the key experiments and the theoretical background. There is good assessment of the relative effects of various experimental parameters. A prize lecture on this topic will be the highlight of the meeting."

"Nearly everyone in Magnetic Resonance had so far treated radiofrequency and microwave irradiation as 'the B_1 field' – a one-way term in the spin Hamiltonian with a cosine in front and a tendency to complicate the mathematics. That is, of course, an approximation: in a good enough resonator the electromagnetic field is detectably quantised, and a two-way quantum mechanical interaction exists between the spins and the electromagnetic field – a generalisation of the Zeeman effect. However, extraordinary extents of miniaturisation, electronic engineering and cooling are required to make it visible. This work has accomplished the feat. It reports the first experimental observation of the Purcell effect – a two-way quantum mechanical interaction between the electromagnetic field of the resonator and the spins inside it. The effect is strong enough to be the dominant relaxation mechanism for the systems reported, meaning that spins can be re-set on demand by the instrument electronics. As well as being a fundamental achievement in spin physics, this work opens up entirely new research avenues in quantum systems engineering."

All attendees were very impressed and noted, with gratitude, that Bruker was again a major force behind making the Conference a success.

JEOL and IES prizes

In the long history of the RSC ESR Group, one of the best predictors of an excellent scientific career is the JEOL medal: many past winners are currently holding faculty posts at

Prof Prisner awarding Prof Lubitz the IES fellowship universities across the world. All student abstracts were considered for the short-list, the authors of the best six were invited to give a talk. It was very clear to the committee that the fine work by Leah R. Weiss on the dynamics of exchange coupled triplet excitons was the winner. The two runners-up were Katharina Keller and Melissa Van Landeghem. A representative of the JEOL Corporation presented the medal during the drinks reception, much appreciated by the attending students, that the company also sponsored.

The International EPR Society has traditionally presented two poster prizes during the Conference Dinner: Nino Wili was recognised for his work on chirped pulses in EPR, and Kaltum Abdiaziz was awarded the other prize for her poster on EPR electrochemistry.

Group photo at Queen Mary University of London by Regent's Canal

Committee

The following committee members have served their full term of office: Gunnar Jeschke, whose superhuman efficiency was commended; Chris Wedge, who was a brilliant Web Master; Andrew Gibbs, whose role in getting the Bruker Thesis Prize off the ground was noted with thanks; Fraser MacMillan ceased to be the Treasurer; Emma Richards was thanked for her role with a note that she will rotate back on the Committee soon as the Cardiff Conference organiser; Chris Timmel and Arzhang Ardavan received a standing ovation for the Oxford conference.

David Norman was elected to the Treasurer post; Olav Schiemann was elected International Representative; Chris Wedge was re-elected Web Master; Sylwia Kacprzak of Bruker Corporation was elected Industry Representative; Gavin Morley was elected Ordinary Committee Member.

Prof McInnes with JEOL Prize winner and runner ups (from left to right: Leah Weiss, Melissa Van Landeghem, Prof McInees and Katherina Keller)

Next conference

Stephen Sproules is organising the next conference in Glasgow between 7th and 11th April 2019. See www.esr-group.org/conferences/2019-conference-glasgow for further information.

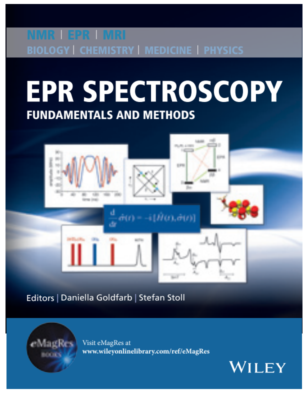
Prof Ilya Kuprov, Secretary
School of Chemistry
University of Southampton
UK

Prof McInnes with poster prize winners (from left to right: Ivan Timofeev (Springer prize), Edmund Little (Springer), Prof McInnes, Nino Wili (IES), Angeliki Giannoulis (Oxford University Press), Kaltum Abdiaziz (IES), Lucia Gigli (Oxford University Press)

new EPR Faculty

John Franck became an Assistant Professor of Chemistry at Syracuse University in August 2016. John received his BA in Chemistry from Northwestern University in 2003 and earned his PhD in Chemistry from Alex Pines' lab from the University of California at Berkeley in 2008. He studied with Songi Han as an Elings Prize Postdoctoral Fellow at the University of California at Santa Barbara, where John helped develop Overhauser Effect Dynamic Nuclear Polarization (ODNP), a magnetic resonance technique to characterize the properties of hydration water molecules that surround all biomacromolecules such as proteins and lipid bilayers. He continued his postdoctoral studies at Cornell University under Jack Freed. John's current research goals include studying materials and biological systems using ODNP as well as a variety of EPR and NMR spectroscopies.

new Books & Journals



EPR Spectroscopy. Fundamentals and Methods.
Editors: Daniella Goldfarb and Stefan Stoll
Publisher: Wiley
No. of pages: 648 pages
ISBN-13: 978-1-119-16299-5 (hard cover)
Price: USD 195 (hardcover)

This is a multi-author graduate-level textbook on modern EPR spectroscopy. It provides an introductory but fairly comprehensive overview of the current field of EPR. The 27 chapters of the book cover the theoretical principles, the common experimental techniques, and many important application areas of modern EPR spectroscopy. The book contains, in concise form, all the material needed to understand state-of-the-art EPR spectroscopy at the graduate school/research level.

The first part of the book gives the reader an introduction to basic continuous-wave (CW) EPR and an overview of the different magnetic interactions (Zeeman, hyperfine, spin-spin couplings, zero-field splitting, and nuclear quadrupole) that can be determined by EPR spectroscopy, their associated theoretical description, and their information content in terms of structure and dynamics. The second part provides the basics of the various EPR techniques, including pulse EPR and EPR imaging, along with the associated instrumentation. Parts C and D build on parts A and B and offer introductory accounts of a wide range of modern advanced EPR techniques, with examples of applications. The techniques in part C include FT-EPR, hyperfine spectroscopy, dipolar spectroscopy, and shaped pulses. Part D presents rapid-scan EPR, EPR microscopy, optically and electrically detected EPR, and very-high-frequency EPR.

The contributions are authored by Marina Bennati, Aharon Blank, Christoph Boehme, Peter Borbat, Enrica Bordignon, Alice Bowen, Michael Bowman, Hanjiao Chen, David Collison, Gareth Eaton, Sandra Eaton, Burkhard Endeward, Boris Epel, Akiva Feintuch, Jack Freed, Peter Gast, Daniella Goldfarb, Etienne Goovaerts, Edgar Groenen, Howard Halpern, Jeffrey Harmer, Gunnar Jeschke, Hans Malissa, Alexander Maryasov, Eric McInnes, John Morton, Frank Neese, Thomas Prisner, Edward Reijerse, Anton Savitzky, Philipp Schöps, Alexander Schnegg, Philipp Spindler, Stefan Stoll, Joshua Telser, Art van der Est, Sabine Van Doorslaer, Shimon Vega, Stefan Weber, and Gary Wolfowicz. The book was edited by Daniella Goldfarb (Weizmann Institute of Science) and Stefan Stoll (University of Washington).

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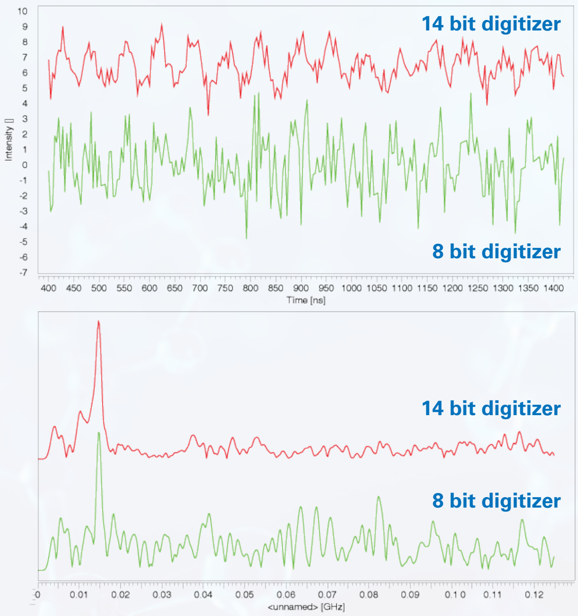

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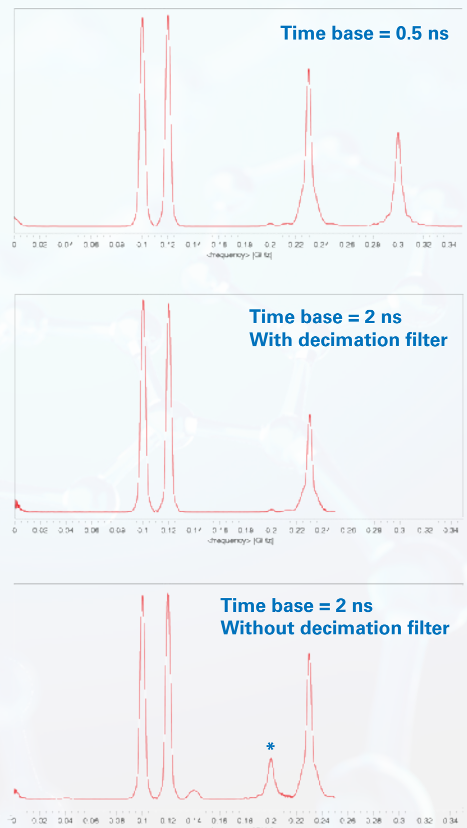

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