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REVIEW

The Discovery of Magnetic Resonance in the Context of 20th Century Science: Biographies and Bibliography. IV: Selected Bibliography of Theoretical and Experimental Research on Magnetic Resonance and Its History

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Abstract—In this chapter, we provide a bibliography of research in the field of ESR, NMR and related phenomena, such as magneto-mechanical resonance, a technique used both to detect magnetic resonance and to confirm magnetic flux quantization; along with exotic atom-related resonances, muon spin resonance and the fine structure and Zeeman effect of positronium. For the reference list provided in this book, out of dozens of thousands of studies we selected several hundred works which we believe represent major lines of research and development in the field of magnetic resonance. The list of literature is structured into several sections: I. Historiography (including reminiscences); II. Monographs, Overviews, and Subject Collections; III. Internet (reference material); IV. Original Research Papers. The latter is further broken down into several subsections covering the development of magnetic resonance foundational ideas (subsection IV.1.), studies on paramagnetic and ferromagnetic absorption and dispersion (IV.2.), works on molecular-beam and atomic-beam magnetic resonance (IV.3.), and original research papers on different magnetic resonances in condensed matter and on their applications (IV.4.). The reference list is provided with brief commentary.

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INTRODUCTION

Magnetic (paramagnetic) spin resonance is the absorption and radiation of energy due to magnetic field-induced changes in spin orientation. Spin sublevel energies are quantized as a result of the interaction of electron and nuclear spin magnetic dipoles and (or) electric quadrupoles[1] with an external magnetic field and (or) an internal electric field, respectively. There are other spin interactions dependent

Deceased.

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[1] Particles with spin $S > 0$ have magnetic dipoles, with spin $S \geq 1$ – electric quadrupole, with spin $S \geq 2$ – magnetic octupole, etc. Octupole and other higher-order moments interaction, though, contribute very little to spin-lattice interactions and to the magnetic resonance frequency [II. 1960. Kopferman, H., Chapter 1, pp. 15-20].

on properties of substances that have their influence on magnetic resonance spectra too. Macroscopic magnetic resonance phenomena are associated with the net magnetic moment precession around the effective polarizing field and, as well, with the effects on this precession that are produced by an alternating magnetic field, local interactions, and thermal relaxation of spin magnetic moments. Multifaceted nature of this phenomenon providing for a wide range of experimental methods integral to the advancement of natural sciences (chemistry, biology, geology even), medicine and technology compels an exploratory interest in the milestones and hallmarks of its history. As do theoretical aspects of magnetic resonance inextricably linked to the entire system of methods in theoretical physics and chemistry. A survey of relevant research papers and overview materials allows to trace major turning points in the history of magnetic resonance as viewed from many different perspectives.

Historiographical at its core, this monograph called for at least some reasonable criteria to structure the bibliography in line with within broader groupings such as by nature, by subject, by scientific school, etc. The selected list of literature compiled for this book have thus been broken down by category and structured into several sections: I. Historiography (including reminiscences), II. Monographs, Overviews and Subject Collections, III. Internet (reference material), and IV. Original Research Papers. The latter was further broken down into several subsections. The first (IV.1.) is a relatively short list of papers on the development of magnetic resonance foundational ideas that began with J. Larmor and his works [IV.1. 1896. Larmor, J.]; the second (IV.2.) – a list of studies on paramagnetic and ferromagnetic absorption and dispersion, from works by V. K. Arkadiev [IV.2. 1913. Arkadiev, V. K.] and by R. Gans and R. Loyarte [IV.2. 1921, Gans, R.] onwards, the third (IV.3.) – a list of works on molecular-beam and atomic-beam magnetic resonance beginning with I. Rabi and his research [IV.3. 1938. Rabi, I. I.]. The final subsection (IV.4.) includes a list of original research papers on different magnetic resonances in condensed matter and on their applications, the longest of the four. The list starts with the pioneering works by E. K. Zavoisky [IV.4. 1945. Zavoisky, E. K. 2.], F. Bloch [IV.4. 1946. Bloch, F. 1.], and E. M. Purcell [IV.4. Purcell, E. M. 2.]. The section is provided with the alphabetical index of authors. The author index includes references to overviews and monographs (of section II) by the authors of the original research as well. References that do not fit into the structure but are instrumental in comprehending the history and, to some extent, methodology of magnetic resonance are for the most part listed in section IV.4. and only occasionally in sections I, II or III. Within each section, the list of literature is arranged by year of publication, reference lists for each year are arranged alphabetically by author names (or by titles in case of collections of works).

In the preliminary discussion, citations start with the section number (from I to IV.4.) followed by year of publication and by author. If several papers by the same author are listed, the citation ends with the publication's sequential number in the author's list of papers for the year. If there are many co-authors, the first in the list is cited. In case of a collection of works, its title is used instead, often abbreviated. Web sites are cited by key words and by general web address (Nobel Archive, http://almaz.com.nobel/; ISMAR, http://www.ismar.org; Physical Review etc., https://journals.aps.org/about/prola; Journal of Magnetic Resonance, https://www.sciencedirect.com/journal/journal-of-magnetic-resonance/issues; JETP Letters, http://www.jetpletters.ru/ps/archive.shtml etc.). Unfortunately, many of the web-pages cited in [I. 2006. Kessenikh, A. V.] are no longer available, while others have been changed. Stan's Library compiled and edited by Stanislav Sýkora [III. 2007. Sykora, S.], an open access resource published on the Internet, made a great contribution to the list of publications included in this book. If an original work is cited in one of the chapters of the book, it is most likely to be accordingly annotated This book was originally written with Russian speaking readers in mind. For the English translation, the list of publications was therefore slightly revised. Namely, Russian translations of the works originally written in other languages have been taken out of the list for their obvious redundancy. Works that were translated into and published in Russian are instead marked with (trR).

The reader might find it frustrating that references are annotated with no apparent uniform style. Unfortunately, the amount and the diversity of references and annotations comprising Chapter 4 hardly allow for any uniform style to be applied or need any, in the authors' opinion.

As was said earlier, papers that are pertinent to magnetic resonance studies contextually only are incorporated in the reference list as well. Such is Van Vleck's monograph on electric and magnetic susceptibilities [II. 1932. Van Vleck J. (+)], R. Noyes' work [IV.1. 1956. Noyes, R. (+)] integral to comprehending the diffusion mechanism of spin-state selection in chemical reactions in liquids, papers by Van Vleck and Weisskopf [IV.4. 1945. Van Vleck, J. H. (+)] and by Fröhlich [IV.4. 1946. Fröhlich. H. (+)] on general mechanisms of spectral line broadening, among others. Early papers by E. K. Zavoisky [IV.2. 1932. Zavoisky, E. K.; IV.2. 1936. Zavoisky, E. K. 1.; IV.2. 1936. Zavoisky, E. K. 2.; IV.4. 1945. Zavoisky, E. K. 1. (b)] relevant from historical and biographical perspective are another example of such publications. Related problems (*) include magneto-mechanical resonance, a technique used both to detect magnetic resonance and to confirm magnetic flux quantization; along with exotic atom-related resonances, muon spin resonance and the fine structure and Zeeman effect of positronium.

None of the contextual references are arranged independently, instead they are marked with special symbols. The symbols are:

- (+) – for additional literature,
- (b) – for biographical material,
- (hist) – for historical material,
- (histR) – for material important in the context of magnetic resonance development solely in Russia,
- (*) – for related problems.

In the in-text annotations the information is given in accordance with other, more comprehensive, sources on the history of magnetic resonance, if such are available. References independently selected both by S. Sýkora and by the authors are annotated with his comments anyway. Annotations are provided when the title alone does not reveal some curious, historiographically important, details.

In both physics and chemistry, some substances give a conditioned response just like a Pavlov's dog. With regard to proton magnetic resonance, such matter first and foremost includes water and ethanol. In the context of EPR and NMR, it's ruby (Cr^{3+} in Al_2O_3). In NMR in solids, it's fluorite (CaF_2), and in EPR – α,α-diphenyl-β-picrylhydrazyl (DPPH) free radical. In some instances, the substance is included in the title of the paper or at least in the abstract, in others – it is named in the in-text annotation. In this way the reference list provided in Chapter 4 may prove helpful in compiling a subject index, at some point in the future. As for the comprehensive list of Names in Magnetic Resonance Research, which we believe could be of historiographical interest, it has in part been comprised in the form of the Author Index of Part IV. Original Research Papers.

For the reference list provided in this book, out of dozens of thousands of studies we selected several hundred works which we believe represent major lines of research and development in the field of magnetic resonance. We hope our list to become a valuable contribution to any future collective effort to study the body of research on magnetic resonance and its history.

PRELIMINARY DISCUSSION OF THE SELECTED LIST OF LITERATURE

Historiography of magnetic resonance. Not that many serious historiographical studies on magnetic resonance and its applications have been published so far. Most of them were timed to coincide with big anniversaries in 1994, 1996[2], 2004, 2006 and so on, including the book by B. I. Kochelaev and Y. V. Yablokov [I. 1995. Kochelaev, B. I.] and the large article by E. Becker et al. [I. and II. 1996. Becker, E. D.] in Volume I of Encyclopedia of Nuclear Magnetic Resonance [I. 1996. ENMR]. In his monumental monograph, whether he liked it or not, [I. 1966. Jammer, M.] M. Jammer had to cover the development of magnetic resonance theoretical foundations, now an integral part of quantum mechanics and quantum statistics.

Anniversaries prompt upsurge in reminiscences published, including about personalities and breakthroughs that shaped the history of magnetic resonance. The *Historiography* section thus comprises all the works that were available and known of as of the time this monograph was finished. From them, stand out reminiscences about E. K. Zavoisky [I. 1993. Magician of Experiment; I. 1996. Zavoisky, V. K.; I. 1996. Supplemental Biographical Materials; I. 2007. Zavoiskaya, N. E. A History of One Discovery. IDT Publishers], S. A. Altshuler [I. 2001. S. A. Altshuler; I. 2004. S. A. Altshuler], and B. M. Kozyrev [I. 2004. B. M. Kozyrev]. A great contribution to the historiography of magnetic resonance was made by A. Abragam in his magnificent memoirs [I. 1991. Abragam, A.]. A remarkable collection of reminiscences that comprises Volume I of Encyclopedia of Nuclear Magnetic Resonance[3] [I. 1996. Goldman, M.; Lauterbur, P. C.; Proctor, W. G.; Waugh, J. S.] is another valuable historiographical resource. The Encyclopedia was inspired by E. Becker, a British physicist, who was already mentioned earlier. Both he and his team gave

[2] 1994 – 50th anniversary of EPR discovery; 1996 – 50th anniversary of NMR discovery, 1997 – the centenary of Larmor's theorem, etc.

[3] In 1996, to mark 50 years of NMR discovery, Encyclopedia of Nuclear Magnetic Resonance (an eight-volume set edited by E. Becker) was published in Great Britain. Historical overviews and reminiscences comprise Volume I named Historical Perspectives [I. 1996. ENMR. Vol.1]. The book turned out to be very expensive ($3500 for an eight-volume set). Still, one complete set found its way to Russia and is now the property of the Institute of Organic Chemistry, Russian Academy of Sciences, with the assistance of one of the Encyclopedia's contributors – N. M. Sergeyev, professor, Chemical Department, Moscow State University, and president of the Russian Association of NMR Spectroscopists. Along with review articles on NMR, Volume I contains NMR investigators' biographical information and chronicles major turning points in the history of NMR development.

credit to Soviet scientists for their contribution to the discovery and development of NMR, its theoretical foundations and numerous applications. Soviet NMR investigators, though, missed their opportunity to properly contribute to the Encyclopedia. Their belated articles – on the role the Soviet science played in the development of NMR or, to be precise, on the history of how it integrated into the world's NMR community – were eventually published in [I. 2001. Kessenikh, A. V. 2; 2008. Kessenikh, A. V.; 2009. Kessenikh, A. V. 1, 2]. The only Russian contributors to the Encyclopedia were B. I. Kochelaev with his articles on how E. K. Zavoisky discovered EPR in 1944 (and how, back in 1941, he had to stop his NMR experiments on the verge of observing the phenomenon) and N. M. Sergeyev, a prominent Russian NMR researcher, who submitted an article on the history of NMR and isotope effects studies [I. 1996. (ENMR). Sergeev, N. M.]. Plentitude of reminiscences, essays and overview articles (see for example [I. 1996. Fedin, E. I.; I. 1997. Khachaturov, A. S.; Borodin, P. M.; I. 1998. Scherbakov, V. A.; I. 2008. Fedin, E. I.]) published in the Russian NMR Newsletter[4] further broadened historiographical perspective on magnetic resonance research in the USSR. Proceedings of anniversary conferences on magnetic resonance are in part included in the *Historiography* section as well. Such is the Conference held in Kazan in 1969 [I. 1971. Paramagnetic Resonance] to mark the 25th anniversary of the discovery of EPR in condensed matter. It was at the Conference in Kazan that Altshuler and Kozyrev [I. 1971. Altshuler, S. A.] first unveiled the dramatic circumstances that thwarted Zavoisky's efforts to observe NMR, C. Gorter shared the story of his bad luck with the search for NMR and EPR [I. 1971. Gorter, C.], and A. Kastler, a Nobel Prize winner, delivered his brilliant introductory speech [I. 1971. Kastler, A.] paying tribute to the pioneer of EPR research, his predecessors and his successors. Another example of such an event is the 10th Anniversary Conference held by the Groupement AMPERE [I. 1961. 10e Colloque Ampère: Leipzig, 13-17 Septembre, 1961], a European association of scientists active in the field of magnetic resonance and related phenomena. Please, note, that many of the conference proceedings, akin to many of the articles in the Encyclopedia of NMR, contain both historiographical information and, to a greater extent, overview material (and hence are categorized as (or duplicated in) II. Monographs, Overviews and Subject Collections), along with original papers (some of them are included in the Original Research section).

Overviews and monographs. A concise historical overview of the evolution of magnetic resonance basic concepts is presented in [I. 2009. Kessenikh, A. V. 2] which came out in the period in-between the publication of the first edition of *Magnetic Resonance Historiography and Bibliography* [I. 2005. Kessenikh, A. V.] and the time work on the present book was started. The overview covers major methodological aspects of magnetic resonance theory and experimental research. One of its sections begins with a reference to H. Kopfermann's fundamental monograph [II. 1956. Kopfermann, H.]

In the overview, competing notations for magnetic resonance condition are discussed – $\omega=\gamma H$ vs $\omega=\gamma B$ (in which H is magnetic field intensity and B is magnetic field induction) – with Kopfermann's monograph and Purcell's textbook [II. 1965. E. Purcell] as a reference source. After the Berkley Course introductory textbook on electricity and magnetism, authored by Purcell, had been published, nearly all physicists, in particular of Anglo-Saxon origin, adopted the $\omega=\gamma B$ notation, as opposed to the $\omega=\gamma H$ that had been previously in use. Two alternative notations for the same phenomenon stemmed from there being different systems of units preferred by different scientists in different historical periods, a problem covered in brief in [I. 2009. Kessenikh, A. V. 2]. Purcell was the first to include magnetic resonance in a textbook on electricity and magnetism.

Early monographs and overview papers on NMR, EPR and other magnetic resonances (published before 1961, for the most part) are in themselves historical "artifacts" tracing magnetic resonance experimental, theoretical and methodological development. In this respect, invaluable is *Microwave Spectroscopy*, a monograph by V. Gordy [II. 1955. Gordy, V.] which has a comprehensive bibliography included, arranged by subject and by year. About one third of it covers magnetic resonance spectroscopy. Likewise, one cannot overestimate the importance of E. Andrew's *Nuclear Magnetic Resonance* [II. 1957. Andrew, E. R.] boasting a bibliography of 508 references – one of the first ever monographs on nuclear magnetic resonance, and an early monograph on EPR by Altshuler and Kozyrev [II. 1961. Altshuler, S. A.]. Lösche's praised *Nuclear Induction* [II. 1957. Lösche, A. (Kernindukzion)] also offers a solid, chronologically arranged (yet with no thematic structure) reference list. It must be noted, that for the Russian edition [II. 1963. Lösche, A.] its bibliographical chapter was revised and expanded by the author and by the team of translators led by P. M. Borodin. In Russian, the book was published

[4] An unofficial bulletin issued by the Russian Association of NMR Spectroscopists in 1990-2011. Since 1998, the bulletin had been edited by A. V. Aganov, the Kazan State University. Its publication frequency varied from 1 to 4 times per year. In part, the issues of the Russian NMR Newsletter have been archived by Aganov and his assistant N. Galiullina.

nearly 7 years after the German language original (at the time, 7 years accounted for 35% of the entire history of publications on magnetic resonance in condensed matter!).

Generally, monographs that were published in later years and those that are subject-specific are still of interest from historical perspective. Jeffries' *Dynamic Nuclear Orientation* [II. 1963. Jeffries, C. D.[(trR)]] is one such example. Another one is an overview paper by A. Abragam and M. Borghini [II. 1964. Jeffries, C. D.[(trR)]], along with monographs by F. Mehring and U. Haeberlen [II. 1976. Mehring, F. [(trR)]; II. 1976. Haeberlen, U.[(trR)]]. The list of examples continues with *Magnetic and Spin Effects in Chemical Reactions*, a monograph by A. L. Buchachenko, R. Z. Sagdeev and K. M. Salikhov [II. 1978. Buchachenko, A. L.], along with the famous *Principles of Nuclear Magnetic Resonance in One and Two Dimensions* by R. Ernst, G. Bodenhousen and A. Wokaun [II. 1987. Ernst, R.].

Classic monographs by A. Abragam [II. 1961. Abragam, A.] and by A. Abragam and B. Bleaney [II. 1970. Abragam, A.], widely known as the Bible of NMR and the Bible of EPR, respectively, both give a panoramic view of the contribution made by world's leading scientists. Both are also important in terms of historical and scientific perspective they gave that is central to understanding how basic ideas and methods of magnetic resonance had been developing over time. For an attentive reader, *Electron Paramagnetic Resonance of Transition Ions* by Abragam and Bleaney helps uncover the origin of many of the now accepted approaches to the theory and methods of magnetic resonance. The monograph refers to fundamental works that laid the theoretical foundations of EPR of transition element compounds, like papers by F. Hund [IV.1. 1927. Hund, F.], H. Bethe [IV.1. 1929. Bethe, H.], H. Kramers [IV.1. 1930. Kramers, H. A.], J. Van Vleck [IV.1. 1932. Van Vleck, J. H.], H. Jahn and E. Teller [IV.1. 1937. Jahn, H. A.], and others.

In terms of their contribution to the study of the history of science, all the monographs can be ultimately divided into two categories. The first one provides an exhaustive reference list (Altshuler and Kozyrev seem to have set the record in the 2nd edition of their *Electron Paramagnetic Resonance* [II. 1972. Altshuler, S. A.] with its 2499 references). Indeed, reference lists supplied in the foundational monographs on magnetic resonance formed the backbone of the present book. The other category is vividly exemplified by A. Abragam's *Nuclear Magnetism* [II. 1961. Abragam, A.]. Although it had come out in print 11 years before the record-breaking monograph by Altshuler and Kozyrev, in 1961, it was not the amount of research he missed out[5] that led to a more modest reference section in Abragam's monograph, rather it was the principle he used for citation. What makes *Nuclear Magnetism* an invaluable historiographical source is the historical perspective on the development of dynamic NMR spectroscopy it gives, to say nothing about it in itself being a historical document that reflects the state of paramagnetic (nuclear magnetic for the most part) resonance research and applications early in the 1960s.

Essentially, any decent monograph is of at least some value to a historian. The mere emergence of books that use "energetic, imperatively prescribing tone"[6] to describe how to use a technique to get the ultimate result says that a certain stage in its practical application has been reached. The difficulty is only with modern fields of study as the scientists behind them are usually the ones who chronicle their fields' history in the making, preferably a well-organized team of scientists. Of particular mention are those who arranged for major works in other languages to be translated into Russian (in many cases they edited the translations as well, which is clear from the corresponding references). Generally, in Russian, monographs were published 2 to 4 years after the original had come out in print. In this regard, stand out G. V. Skrotsky, S. V. Vonsovsky, V. F. Bystrov and A. N. Sheinker, and K. M. Salikhov. Some of the most important translated works were edited by S. A. Altshuler and E. Lipmaa, among others.

Of great value, in terms of retrospective historical study, are proceedings of conferences on magnetic resonance (no matter the title, be it colloquium, seminar, workshop or other). Worth noticing are the proceedings of one of the first ever international conferences on radio spectroscopy (magnetic resonance, mostly) that took place in Amsterdam, in September, 1950 [II. 1951. Proceedings of International Conference…], and were published in Volume 17 of *Physica*. F. Bloch and E. M. Purcell, future Nobel Prize winners for their discovery of NMR, both spoke at this even. A. Kastler shared his findings for which, 16 year later, he would be given a Nobel Prize, for the first time. H. Kopfermann, a renowned German scientist, who had emigrated to the United States before the Word War II broke out, took the trouble of sharing the works by his young colleagues from the University of Göttingen. The young colleagues were H. Dehmelt and H. Kruger, discoverers of nuclear

[5] The 1st edition of *Electron Paramagnetic Resonance* [II. 1961. Altshuler, S. A.] published in 1961 already contained 1066 references!

[6] The citation belongs to E. I. Fedin and comes from his foreword to the Russian translation of [II. 1965, Bible, R.] he edited.

quadrupole resonance [II. 1951. Kopfermann, H.]. At the very same event, Oxford scientists of Bleaney's school reported rapid development of the EPR method that had only been discovered by E. K. Zavoisky 6 years before. For them, it was the second occasion, though, the first being at the Meeting of the Physical Society of London [II. 1948. Proceeding of the Physical Society]. There were two papers delivered by Japan scientists, despite it being only 5 years after the World War II ended leaving Japan defeated and all but destroyed. Contrastingly, not one Soviet scientist was able to attend the Conference. Zavoisky's discovery was referred to by many of the speakers [II. 1951. Kastler, A.; Gorter, C. J.; Bleaney, B.], while he himself at the time was working for the Soviet nuclear project at Arzamas-16 [I. 1998. Zavoiskaya, N. E. [(b)]]. His worthy successors, S. A. Altshuler and B. M. Kozyrev, struggled to get their works published for some bogus reasons of secrecy, but mostly because Soviet bureaucrats were deathly afraid of any contact between Soviet scientists and their international counterparts, or, to be more precise, it was strictly forbidden. M. A. Bloch, in his book [I. 2001. Bloch, M. A., pp. 260-261], reported that a group of Soviet physicists, including A. M. Prokhorov, on 30 August, 1950, was denied a trip to Amsterdam to the Conference. Presidium of the USSR Academy of Sciences submitted a request (Ref. No.-5621s) to the Central Committee of the Communist Party of the Soviet Union to send a delegation consisting of academician Andronov A. A., Prokhorov A. M., Vladimirskii K. V., and Oraevsky P. S. (member of the Presidium) to take part in the 2nd International Conference on Spectroscopy at Radiofrequencies to be held in Amsterdam, on 18-23 September, 1950. The request was denied (in a note signed by M. A. Suslov and V. Grigoryan, Ref. No. 25-s-1633, dated 14 Sep 1950). The note referred to Prokhorov and Vladimirskii alone and stated as reason "the composition of the delegation not meeting the requirements set." The "requirements" were obviously bogus. The document A. M. Bloch cited is now at the Russian State Archive of Social and Political History, fond 1, inventory 17, item 65, lists 59-61. This incident is a perfect illustration of why a Soviet scientist (E. K. Zavoisky) was hardly expected to be nominated for the Nobel Prize at the time. Meanwhile, if one compares proceedings of the Conference [II. 1951. Proceedings of International Conference…] with publications in Soviet scientific journals of the same period (1944-1950), one can see that USSR scientists had a lot to share, only they were not allowed to. For example, see [IV.4. 1947. Zavoisky, E. K. 1.; Altshuler, S. A.; Vladimirskii, K. V.; Kozyrev, B. M.]. For the first time soviet scientists, B. M. Kozyrev and A. M. Prokhorov, attended an important international conference in 1955. It was held at Cambridge University, on 4-5 April, 1955 [II. 1955. Microwave and Radiofrequency Spectroscopy].

Historiography of magnetic resonance gained a lot from overview articles included in the proceedings of the anniversary conference held in Kazan, in 1969 [II. 1971. Paramagnetic Resonance], of Varian's Third Annual Workshop on Nuclear Magnetic Resonance [II. 1960. Papers Presented at the…] and of other events. Very useful in this regard are feature overviews that were published by *Analytical Chemistry* biennially, the first of them being [II. 1972. Corio, P. K.]. Also worth noting are the *Advances in Magnetic Resonance* (edited by J. S. Waugh) and *NMR Basic Principles and Progress* (edited by P. Diehl et al.) book series that published overview works like [II. 1976. Haeberlen, U.]. Those two series are of undeniable historiographical value and are well worth to be incorporated into wider practice.

There are also collections of selected overviews, for example a volume of selected works published in memory of B. M. Kozyrev, each of the articles containing bibliography of great value [II. 1990. Radio Spectroscopy…].

Finally, one cannot overestimate the contribution of the true annals of Soviet and Russian physics in the 20th century – *Advances in Physical Sciences*[7] – and of *Russian Chemical Reviews*[8] that published an overwhelming amount of materials providing a retrospective outlook on the evolution of magnetic resonance.

To cover related fields the authors are not well acquainted with (such as muon spin resonance, positron emission tomography, magnetic resonance spectroscopy of exotic atoms, and the like), The Physical Encyclopedia [II. 1992. Gurevich, I. I.; Ponomarev, L. I. 1, 2.; Faustov, R. N.; etc.] was of great help.

To wind up the discussion of *Monographs*, *Overviews and Subject Collections*, it must be noted that magnetic resonance spectroscopy, that was born as a single whole, today should not be irrevocably divided into NMR, EPR and NQR, from historical (and to some extent methodological) viewpoint. To this speak, for instance, the history of the Overhauser effect, of the Provotorov theory, and of spin polarization and magnetic field effects in chemical reactions [II. 1978. Buchachenko, A. L.]. Magnetic resonance spectroscopy

[7] See, for example, [II. 1959. Blumenfeld, L. A.; II. 1960. Khutsishvili, G. R.; II. 1965. Khutsishvili, G. R.; II. 1972. Atsarkin, V. A.; II. 1973. Valiev, K. A.; II. 1976. Pokazaniev, V. G.; II. 1978. Atsarkin, V. A.; Korst, N. N.; II. 1981. Atsarkin, V. A.; II. 1987. Borovik-Romanov, S. A.], and other.

[8] See, for example [II. 1973. Slonim, I. Y.; II. 1977. Sagdeev, R. Z.], and other.

Fig. 1. The AMPERE Society today supports a diverse range of activities – from conferences to schools – on manifold magnetic resonance-related topics. Reproduced from: B. Blümich and B. Maraviglia "65 Years Ago: The Birth of the AMPERE Society", https://www.ampere-society.org/pdf/65years.pdf. The figure was kindly provided by the AMPERE Society.

in magnetically ordered materials is, to a certain extent, a separate case, yet they all still share some common approaches in both theory and experiment [II. 1952. Ferromagnetic Resonance; II. 1961. Ferromagnetic Resonance; II. 1969. Turov, E. A.].

Magnetic resonance phenomena and, in particular, applications have nevertheless become highly differentiated. High resolution NMR "in one and two dimensions" is now the method for studying chemical compounds, from simple ones to complex compounds such as biopolymers [II. 1996. Wütrich, K.; II. 1998. Doreleijers, J. E.; I. 1998. Ananikov, V. P.]. EPR and chemically induced dynamic nuclear polarization (CIDNP) merged to become a method for studying photosynthesis. EPR and NMR are used together to investigate the mechanism of high-temperature superconductivity [II. 1994. Berthier, C.; II. 1996. Brinkmann, D.]. In clinical practice, magnetic resonance tomography (or imaging) techniques, that are of undeniable benefit to the humankind [II. 1981. Atsarkin, V. A.; II. 1993. Magnetic Resonance in Medicine], emerged and firmly established. Magnetic resonance force microscopy is now gaining momentum as a research method. Dynamic nuclear polarization has evolved to become an independent technique, disrupting the traditional way high-resolution NMR and NMR in solids are applied.

Reference material on the internet. Internet material is nowadays as common as any other source of information for exploring the history of science. Alas, it often has limited lifetime on the Internet and there comes a point in time when only a recollection of it can be referred to. Such is the case with historical information on major players on the world market of magnetic resonance instrumentation, for example. In most instances, companies prefer to publish information on their current businesses which are not always the same as half a century ago. Varian Associates, US, is one such example – it quit the market of magnetic resonance instrumentation after its founders, Varian brothers, had passed away. A comprehensive study on how NMR instruments development was organized at Varian Associates, an article by T. Lenoir and C. Lécuyer (Stanford. NMR at Varian), used to be published on the web-site of Stanford University to mark 25th anniversary of NMR discovery, at https://www.stanford.edu, but is no longer available (however, the article [I. 1995. Lenoir, T.] is available). Contribution to the advancement of magnetic resonance instruments made by Swiss-German Bruker-Physik AG, now Bruker Corporation, is extensively covered in [I. 1996. Eichhoff, U.] and in a historical essay that was kindly provided by Dr. Uwe Eichhoff, a German physicist and an employee of Bruker BioSpin GmbH. Yet, no other source of similar information seems to be present on the world wide web. For a historian of the 20th century science, the role that research and development units of private and state corporations play in the development of entire fields of science is of particular interest. And it must be said, that magnetic resonance methods owe explosive development of their research and analytical applications precisely to the efforts of Varian Associated, now no longer on the market, of Bruker Corporation, present day market leader, and, in part, of JEOL Ltd., a Japan manufacturer.

Biographical information on Nobel Prize laureates is available on the official website of the Nobel Prize [III. The Nobel Prize], as well as on the The Nobel Prize Internet Archive web site [III. The Nobel Prize Internet Archive]. Web sites of international associations on magnetic resonance, such as the International EPR (ESR) Society [III. IEPRS], the International Society of Magnetic Resonance [III. ISMAR] or Le Groupement AMPÉRE [III. AMPERE] provide information on other scientists who played an important role in the advancement of magnetic resonance theory and applications. The latter is often referred to as AMPERE after, on its web site, the original name of this organization since its foundation in 1951 [I. 1996. ENMR] – *Atomes et Molecules Par Étude Resonance Electromagnétique*, an elegant echo of the name of the great French physicist – was Americanized, for the sake of predominantly English-speaking scientific community, to the formal *Association of Microwave Power in Europe for Research and Education* [III. AMPERE]. AMPERE has a subdivision, Euromar, that organizes high-profile international events in Europe on the subject of magnetic resonance – annual meetings covering all aspects of the phenomenon (see Fig. 1).

The study of the list of experimenters who received prestigious awards or prizes from IES, ISMAR or other magnetic resonance international organizations, generally available on their web sites, helps understand whose works are to be added to the far from complete reference list in this book in the future. On a side note, among prestigious international awards in the field of EPR one bears the name of E. K. Zavoisky – the International Zavoisky Award established by the Kazan State University (no other Soviet or Russian scientist gave his name to a similar award in the field of NMR, though). Among the scientists who were given awards by the IES, there are such Soviet authorities on EPR as L. A. Blumenfeld, A. I. Vanin, Y. S. Lebedev, Y. N. Molin, K. M. Salikhov, Y. D. Tsvetkov, and T. Sanadze. For advances in the field of NMR, the Ampere Prize, in 1994, went to Estonian physical chemist E. Lipmaa, a pioneer of heteronuclear and solid-state NMR[9] spectroscopy in chemistry research, who was held in high esteem both in the Soviet and in the world scientific NMR communities. Among those awarded the ISMAR Prize, there was E. K. Zavoisky, for his works on EPR, although the Prize was conferred to him posthumously, in 1977.

All the above speaks to the fact that in the field of ERP Soviet science ranked higher, if compared to NMR.

When exploring the paradoxical history of how the Overhauser effect was predicted and studied, and of its applications development [I. 2004. Kessenikh, A. V. 2.], the authors came across a number of web sites devoted to and providing useful information on the prominent American physicist the effect is named after, on his true contribution to science and the circumstances of him becoming one of the most esteemed experts on magnetic resonance in the world, for example [III. Physics. Purdue; III. News. Uns. Purdue]. Overall, it appears that development of a systematized register of relevant web sites could be of help for studying the history of magnetic resonance. So far, no such register seems to exist. Stanislav Sýkora's web site listing NRM bibliography [III. Stan Sykora], mentioned earlier, is a good example to follow in compiling the register. The web-site was widely consulted to compile the bibliographical part of the present book.

Internet, nowadays, is also an easily accessible source of images, historical and others, often rare and unique.

Original research papers. *Magnetic resonance foundational works.* In his book [II. 1962. Abragam, A., Chapter 1], Abragam, drawing on the example of NMR, thus outlines the general trajectory of magnetic resonance theory evolution: magnetization (different magnetic states) in particle beams [IV.1. 1933. Frisch, R.; Esterman, I.], nuclear spin magnetization in condensed matter [IV.1. 1937. Lasarew, B. G.],

[9] Heteronuclear NMR spectroscopy uses interactions between different types of NMR-active nuclei. Generally, it requires higher sensitivity and specific observation methods. Solid-state NMR requires specific methods for cancelling interactions that result in magnetic resonance line broadening (magnetic dipole and electric quadrupole interactions).

particle beam magnetic resonance [IV.1. 1938. Rabi, I. I. 1.], magnetic resonance in condensed matter [IV.4. 1945. Zavoisky, E. K. 2.]. To this impeccable system only a few milestones from the prior period can be added: the hypothesis of the existence of elementary charges – the Ampére molecular currents – that André-Marie Ampère first presented to the French Academy of Sciences, Paris (see [I. 1968. Bel'kind, L. D.]); Larmor's theorem on gyromagnetic properties of "electrified" particles [IV.1. 1896. Larmor, J.]; Zeeman's experiment in optical spectra [IV.1. 1897. Zeeman, P.]; the establishment of spin hypothesis [IV.1. 1924. Pauli, W.; IV.1. 1926. Uhlenbeck, G. E.]; and the adoption of quantum [IV.1. 1927. Pauli, W.] and quantum-statistical approaches [IV.1. 1927. Dennison, D. M.] to interpreting magnetic phenomena. In this way, the broader context of magnetic resonance development is represented. Also, the *Foundational Works* section includes some fundamental works on electron spin hyperfine interactions [IV.1. 1930. Fermi, E.], on nuclear magnetic moment [IV.1. 1934. Landé, A.; Tamm, I. E.], on magnetic properties of atoms, molecules and crystals (see references in [II. 1972. Abragam, A.] earlier), on spin temperature [IV.1. 1939. Casimir, H. B. G.], on magnetic resonance in different coordinate systems [IV.1. 1938. Rabi, I.; IV.1. 1940. Bloch, F.], and other papers. It must be said, that some of the studies by P. Curie and P. Weiss, P. Langevin and A. Sommerfeld would be appropriate in this section as well. Likewise, much more of the research by O. Stern, A. Landé and some other scientists could have been included (this book, however, incorporates only a selected list of their works). Generally, the *Foundational Works* section contains papers that we consider to be milestones in the history of magnetic resonance.

Magnetic absorption and dispersion. Recognition and rapid adoption of quantum paradigm put the theory of magnetic resonance into the mainstream of scientific advancement. Meanwhile, classical physicists searched, not unsuccessfully, for anomalous absorption and dispersion of electromagnetic waves in ferromagnets. The first to explore this avenue was the Russian physicist V. A. Arkadyev [IV.2. 1913. Arkadyev, V. A.] who was later joined by the Argentinian R. Loyarte and his German colleague R. Gans [IV.2. 1921. Gans, R.]. J. D. Dorfman [IV.2. 1923. Dorfman, J.], in the Soviet Union, endeavored to fit their empiric approach into then embryonic quantum paradigm, drawing on their findings and on Einstein and Ehrenfest's work [IV.1. 1922. Einstein, A.] he was strongly impressed by. At times partial towards the scientific advances of Soviet origin, regardless of their objective importance, some of Soviet science historians tend to overrate Dorfman's paper on "photomagnetic effect", otherwise a work of undeniable value. On the other hand, Arkadyev's part in the advancement of radiofrequency spectroscopy of ferromagnets must not be underrated. It turns out in 1940s-1950s his successors in the Soviet Union observed magnetic resonance of ferromagnetic (ferrimagnetic) substances (see [IV.4. 1951. Fomenko, L. A.], a work by an employee of the Central Laboratory to Counter Man-Made Radio Frequency Interference).

With time, experimental methods were gaining in sensitivity. By the 1930s, instruments had become sensitive enough for the scientists to embark on magnetic absorption and dispersion studies in paramagnetic substances, in addition to ferromagnets. In this regard, of foremost importance are the works by C. J. Gorter and his co-workers [IV.4. 1936. Gorter, C. J. 1-3.]. In 1936, the focus shifted to the search for nuclear magnetic resonance[10]. The publications included in the *Magnetic Resonance Foundational Works* subsection for the most part was not turning points in the history of science, but they do mark the transition from the calorimetric method to measuring electromagnetic energy absorption [IV.2. 1936. Gorter, C. J. 2.] and then to the method of oscillator response [IV.2. 1942. Gorter, C. J.] similar to Zavoisky's grid-current technique [IV.2. 1932. Zavoisky, E. K.]. They are more like period features, some of them contributing modestly to the development of the method but at the time being the talk of the town. There was time, for example, when almost all works on NMR began in the same manner: authors paid tribute to Gorter's first unsuccessful attempt to detect NMR [IV.2. 1936. Gorter, C. J. 2.] and continued by lamenting his unwillingness to listen to Heitler and Teller [IV.1. 1936. Heitler, W.] who had already proved that at low temperatures in diamagnetic substances nuclear spin relaxation times were too long to observe NMR.

Molecular and atomic beams. In its way, this subsection is crucial. Indeed, nuclear magnetic resonance [IV.3 1938. Rabi, I. I. 1, 2.] and electron paramagnetic resonance [IV.3. 1940. Kush, P. 1, 2.], both of critical importance in terms of magnetic resonance methods development, were first observed in particle beams. Likewise, nuclear spin quadrupole interactions were investigated through molecular beam experiment. While the first experiments in which a molecular beam technique was used to detect NMR are commonly referred to in literature, the first EPR studies using atomic alkali-metal beams are rarely cited in papers on EPR.

[10] Two works by Gorter, both reporting negative results [IV.2. 1936. Gorter, C. J. 2.; IV.2. 1942, Gorter, C. J.], E. K. Zavoisky's interrupted experiment, recounted in [I. 1971. Altshuler, S. A.].

Some works published after 1944, for instance [IV.3. 1947. Nierenberg, W. A.], are included in this subsection as well, as after NMR and EPR in continuous media had been discovered the beam method as such did not lose its relevance. To this speaks the Nobel Prize awarded to N. F. Ramsey in 1989 for the development of the hydrogen maser that uses the atomic beam method to produce nonequilibrium populations.

Magnetic resonance and magnetic relaxation. In 1944, original research papers on magnetic resonance and relaxation in condensed matter began to come out. In the first three years there were only a few, then – dozens, by 1950 there had been hundreds of works published, and by mid-1950s – thousands of them.

Apart from the papers that first reported the observation (discovery) of magnetic resonance phenomena[11], the reference list in subsection IV.4. includes works reporting the discovery of double resonance phenomena [IV.4. 1950. Kastler, A.; Pound, R. V.], of hyperfine structure in EPR spectra [IV.4. 1950. Abragam, A.], of NMR chemical shifts [IV.4. 1950. Dickinson, W. C.; Proctor, W. G.; IV.4. 1951. Gutowsky, H. S. 1.] and NMR Knight shifts [IV.1. 1949. Knight, W. D.], of indirect spin-spin interactions in NMR [IV.4. 1951. Gutowsky, H. S. 2, 3.], etc. They all are undoubtedly milestones in science development. Likewise, the list contains early papers providing theoretical interpretation of the nature of those phenomena [IV.4. 1950. Ramsey, N. F.; IV.4. 1953. Ramsey, N. F.]. Some of the works are included in the list to trace the origin of some of the name-bearing apparatuses, such as the Pound circuit [IV.4. 1947. Pound, R. V.] or the Rollin scheme [IV.4. 1946. Rollin, B. J.], or effects, like, first and foremost, the Overhauser effect (for instance, [IV.1. 1954. Beljers, H. G. L.] was the first to use it in the title). Papers like those can sometimes be considered period features. Outstanding researchers in the field can be broadly divided into forerunners, pioneers, classics of magnetic resonance and inventors. The study of history of magnetic resonance from the perspective of its most important names can be paraphrased as the study of “paradoxes in magnetic resonance history”[12], something that history of science has in abundance. Some paradoxical situations repeat themselves over and over again from generation of scientists to generation, from one knowledge area to another. One of the most common paradoxes in science is what can be called “*casus* Columbus”, that is to search for one thing and to discover another. It happens to experimenters and theoreticians alike. Zavoisky was searching for NMR but discovered EPR. Overhauser was searching for the most efficient theoretical mechanism for electron spin relaxation in metals [IV.1. 1953. Overhauser, A. 1.], but to no avail (compare to [IV.4. 1954. Elliot, R. J.]). Instead, he predicted what is now known as the nuclear Overhauser effect – one of the manifestations of electron-nuclear double resonance and of dynamic nuclear polarization, namely the transfer of nuclear spin polarization from one type of nuclear spin to another on saturation and resonance excitation. The effect is universal and occurs in any substance with specific mechanisms and correlation time values of spin-spin interactions between two different types of spins. Notably, those can as well be interactions between two different nuclear spins (spin groups) [IV.4. 1955. Solomon, I.] or between an electron spin and a nuclear spin. To a historian, scientific errors and scientific breakthroughs are of equal interest, as both are period features. Therefore, some of “erroneous” findings have been added to the reference list, including those from Sýkora’s bibliography (he marked them with “wrong interpretation”).

Some of original researches offer comprehensive overview chapters. Such are, for example, early papers by E. T. Lippmaa [IV.4. 1962. Lippmaa, E. T. 1, 3.]. In his fist publications on his original design of a high-resolution NMR spectrometer he compared its characteristics to those of other laboratory and manufactured spectrometers. He is a good example for young researchers to follow, as only few of them now bother to put their findings in the context of advances made by their predecessors and peers.

We do not claim to offer a substantial comparative analysis of different sources according to their “importance” (or, at the very least, according to their citation frequency). But we can positively state, that before 1933, for instance, the overwhelming majority of commonly cited papers had been written in German[13], while after 1944 the greater part of works was originally in English, more than a half of magnetic resonance research, up until mid-1960s, being published in the American *Physical Review*. With time, the growing number of papers could have been found in chemical journals (in particular, in the *Journal of Chemical Physics*), in journals on biology and medicine, and in some specialized journals (since 1969, in the *Journal of Magnetic Resonance* and in *Organic Magnetic Resonance,* now *Magnetic Resonance in Chemistry*). In one of our previous papers

[11] EPR: [IV.4. 1945. Zavoisky, E. K. 1.], NMR: [IV.4. 1946. Bloch, F.; IV.4. 1946. Purcell, E. M.], FMR: [IV.4. 1946. Griffiths, J. H. E.], NQR: [IV.4. 1950. Dehmelt, H. G. 1, 2.].

[12] Compare [I. 2004. Kessenikh, A. V. 2.] and [I. 2004. Kessenikh, A. V.]

[13] In H. Bethe’s classical work [IV.1. 1929. Bethe, H.], itself in German, not a single work in any other language is referred to!

[II. 1999. Kessenikh, A. V.], it was noted that the exhaustive 1972 review of literature on NMR [II. 1972. Corio, P. L.] contained only 128 papers by Soviet scientists in both Russian and non-Russian journals (17 altogether) out of the total of 2088 references (for the period of 1969-1971). Such, objectively, was the contribution of the Soviet science to NMR research (6% of the total number of publications). In the present book this contribution is magnified, to say the least, to lay the foundations for the historiography of magnetic resonance research in the USSR, the task our previous works were not up to.

CONCLUSION

We do hope that some of the approaches offered in this book will continue to be used in future works on the subject. We recommend starting the list of references for every stage in magnetic resonance development with monographs and overviews that are in a way concluding the period. Once the most important references in those works have been reviewed, one can proceed to other papers by frequently cited authors. Those works can often be found in reference material available on the Internet or are cited in the monographs under review. Next, one can make a list of scientists (award-winning in most cases) without whose works the bibliography would not be complete. In this endeavor, material published on the Internet is usually of great help. Another important source for author selection at this stage are journals' author indexes and citation indexes. Armed with such a list one can proceed to another round of bibliography examination paying attention to the papers by award-winning or commonly cited authors among references provided in "concluding" works. Inevitably, it takes more than one study of available bibliographies to compile a comprehensive reference list on a particular subject, as they commonly list hundreds of references. We hope that the reference list included in this book, however incomplete it may be, lays a strong foundation for our effort to be continued by others. To that end, subsection IV.4. of *Original Research Papers* is supplied with author index that, among other things, reflects the contribution of the authors of original research to overview literature and monographs. It must be said, though, that, for this book, the list of sources available to the authors was limited by technical reasons (namely, by the availability of literature in libraries[14]).

Originally, the idea was to limit the detailed review of original research by the period ending in 1969-1971. However, we could not help including later works by the Nobel Prize and the International Zavoisky Award winners and papers reporting discoveries of new magnetic resonance phenomena that we know of, as well as articles on latest developments at Russia's biggest centers of magnetic resonance research (Kazan, Novosibirsk, the Institute of Chemical Physics of Russian Academy of Sciences and its daughter organizations, Lomonosov Moscow State University, etc.). Obviously, with regard to the latter two categories, our judgement is more subjective, for which we apologize to the scientists whose works are missing from our reference list. To select later works to be included in the magnetic resonance bibliography we widely consulted A. V. Arutyunyan, V. A. Atsarkin, P. G. Baranov, V. A. Zabrodin, V. E. Zobov, A. V. Ilyasov, S. V. Kapelnitsky, G. E. Karnaukh, A. A. Kokin, G. B. Lagodzinskaya, Y. N. Molin, I. V. Ovchinnikov, K. M. Salikhov, N. M. Sergeev, Y. I. Talanov, E. B. Feldman and other colleagues, to each of whom we are deeply grateful.

Our first attempt at compiling a comprehensive bibliography on magnetic resonance [I. 2005. Kessenikh] inadvertently missed (or barely included) entire layers of literature that may not be crucial for magnetic resonance development, but are of significance in terms of its historiography. In terms of subject matter, missing were publications on EPR studies of clusters and biradicals, NMR spectroscopy of nuclei with large quadrupole moment, NMR in magnetically ordered materials, FMR, AFMR, etc. In terms of sources, largely missing was the body of original research that had been published in the Journal of Magnetic Resonance since 1969. To correct the flaws in the original bibliography would take a totally revamped publication, four times thicker at the very least. The present monograph includes a partially revamped reference list, some several hundred references added and revised with the help of sources available at the libraries at the Physical Institute and the Institute of Chemical Physics of Russian Academy of Science, and on the Internet. Once again, we encourage our colleagues to continue our endeavor to compile a comprehensive bibliography on magnetic resonance and the history of its development.

[14] Unavailability of lots of Soviet scientific journals (still not digitized) has a sharply negative impact on studying the history of science in the USSR. In recent years, this abnormal situation has slowly begun to change — some journals were digitized, fully or partially (vivid examples are Biochemistry (Moscow) and the Reports of the USSR Academy of Sciences). Paradoxically, this critical problem is still being tackled only by enthusiasts, but not by journal founder, publishers, scientific and government leadership. Fortunately, large collections of printed versions of old Soviet journals are stored in some unique libraries (public or institutional, e.g., the library of N. N. Semenov Institute of Chemical Physics), but the prospects for further long-term preservation of these collections are not encouraging.

Appendix 1. Selected annotated bibliography on the history of magnetic resonance

Legend:

- (*) – publications on magnetic resonance related problems (magneto-mechanical resonance, muon spin resonance, the fine structure and Zeeman effect of positronium);
- (+) – additional literature;
- (b) – biographical material;
- (hist) – historical material;
- (histR) – material important in the context of magnetic resonance development in Russia;
- (trR) – Russian translation is available.

When the title of the work does not reveal some important detail of the experiment, the reference is supplied with an annotation. Some of the annotations come from the Collection of References edited by Stanislav Sýkora [III. 2007. Sykora, S.] and are marked with (S. S.).

I. HISTORICAL STUDIES AND MATERIALS (HISTORIOGRAPHY)

1957

(1957) Interview with E. K. Zavoisky [in Russian], *Soviet Union*, **11**, 22.

1961

(1961) 10e Colloque Ampère: Leipzig, 13-17 Septembre, 1961 [in French], *Archives des Sciences, éditées par la SPHN. Fascicule Spécial*, **14**, 1-531.

(1961) Le Groupement Ampère de 1952 à 1962 [in French], *Archives des Sciences, éditées par la SPHN. Fascicule Spécial*, **14**, 3-5.

1963

Nesmeyanov, A. N., and Fedin, E. I. (1963, October 29) Eagerly awaiting [in Russian], *Literaturnaia Gazeta (Literature Newspaper).* (histR)

1966

Jammer, M. (1966) *The Conceptual Development of Quantum Mechanics First Edition*, McGraw-Hill, New York. (trR)

1968

Bel'kind, L. D. (1968) *André-Marie Ampère. 1775-1836* [in Russian], Nauka, Moscow.

1971

Altshuler, S. A., and Kozyrev, B. M. (1971) Regarding the history of electron paramagnetic resonance discovery in *Paramagnetic Resonance 1944-1969. The All-Union Anniversary Conference (Kazan, 24-29 June, 1969) [in Russian]*, pp. 25-31, Nauka, Moscow.

Reprinted in (1993) *Magician of Experiment: Reminiscences about Academician E. K. Zavoisky* [in Russian], pp. 12-17, Nauka, Moscow.

Gorter, C. J. (1971) Concerning the electron magnetic relaxation and resonance in *Paramagnetic Resonance 1944-1969. The All-Union Anniversary Conference (Kazan, 24-29 June, 1969)* [in Russian], pp. 15-25, Nauka, Moscow.

Listed in II. Reviews and Monographs as well.

Kastler, A. (1971) Regarding the history prior to the discovery of electron paramagnetic resonance in *Paramagnetic Resonance 1944-1969. The All-Union Anniversary Conference (Kazan, 24-29 June, 1969) [in Russian]*, pp. 9-15, Nauka, Moscow.

Reprinted abridged in (1993) *Magician of Experiment: Reminiscences about Academician E. K. Zavoisky* [in Russian], pp. 18-21, Nauka, Moscow.

(1971) *Paramagnetic Resonance 1944-1969. The All-Union Anniversary Conference (Kazan, 24-29 June, 1969)* [in Russian].

Listed in II. Reviews and Monographs as well.

1974

Dunskaya, I. M. (1974) *The Emergence on Quantum Electronics* [in Russian], Nauka, Moscow.

1975

(1975) Acoustic paramagnetic resonance: the discovery made by S. A. Altshuler. Concerning the discovery of paramagnetic resonance [in Russian], *Herald of the Academy of Science of the USSR*, 149.

1980

Borovik-Romanov, A. S. (1980) Concerning the discovery of paramagnetic resonance [in Russian], *Studies in the History of Science and Technology*, no. 3, 126.

1989

Abragam, A. (1989) *Time Reversal: An Autobiography*, Oxford University Press, Oxford, New York. (trR)

1990

Frenkel, V. Y., and Yavelov, B. E. (1990) Einstein: Inventions and Experimentation [in Russian] 2nd ed., Nauka, Moscow. (*)

Among other things, the work by Einstein and de Haas on the magnetomechanical effect is discussed. The accuracy of measurements was not high enough providing for the wrong solution for the problem of electron g-factor.

1993

Altshuler, S. A., and Kozyrev, B. M. (1993) Regarding the history of electron paramagnetic resonance discovery in *Magician of Experiment: Reminiscences About Academician E. K. Zavoisky* [in Russian], pp. 12-17, Nauka, Moscow.

Reprinted from in (1971) Paramagnetic Resonance 1944-1969. The All-Union Anniversary Conference (Kazan, 24-29 June, 1969) [in Russian], pp. 25-31, Nauka, Moscow.

Kastler, A. (1993) Regarding the history prior to the discovery of electron paramagnetic resonance in *Magician of Experiment: Reminiscences About Academician E. K. Zavoisky* [in Russian], pp. 18-21, Nauka, Moscow.

For the full, illustrated text of the conference paper, see (1971) Paramagnetic Resonance 1944-1969. The All-Union Anniversary Conference (Kazan, 24-29 June, 1969) [in Russian], pp. 9-15, Nauka, Moscow.

Listed in II. Reviews and Monographs as well.

Shushakov, O. A., and Legchenko, A. V. (1993) Non-drilling NMR in Earth's magnetic field [in Russian], *NMR Newsletter*, 13-15.

Silkin, I. I., and Trofanchuk, L. A. (1993) Concerning the history of the ERP discovery (Archive materials and lost-and-found-again apparatuses) in *Magician of Experiment: Reminiscences About Academician E. K. Zavoisky* [in Russian], pp. 114-118, Nauka, Moscow.

Vonsovsky, S. V. (1993) Reminiscences about academician E. K. Zavoisky in *Magician of Experiment: Reminiscences About Academician E. K. Zavoisky* [in Russian], pp. 21-27, Nauka, Moscow.

Zavoisky, E. K. (1993) A historical sketch of EPR in *Magician of Experiment: Reminiscences About Academician E. K. Zavoisky* [in Russian], pp. 222-225, Nauka, Moscow.

(1993) *Magician of Experiment: Reminiscences About Academician E. K. Zavoisky* [in Russian], Nauka, Moscow.

1995

Aganov, A. V. (1995) Y. Y. Samitov and his scientific path. Proceedings of the 2nd All-Russia Seminar "NMR Latest Advancements in Structural Studies" [in Russian], *NMR Newsletter (Special Issue)*, 5-15.

Lenoir, T., and Lécuyer, C. (1995) Instrument makers and discipline builders: The case of nuclear magnetic resonance, *Perspect. Sci.*, **3**, 276-345, https://doi.org/10.1162/posc_a_00485.

Zavoiskaya, N. E. (1995) [in Russian], *Kurchatovets*.

Kochelaev, B. I., and Yablokov, Y. V. (1995) *The Beginning of Paramagnetic Resonance*, WORLD SCIENTIFIC, https://doi.org/10.1142/2610.

1996

Becker, E. D., Fisk, C. L., and Khetrapal, C. L. (1996) The development of NMR in *Encyclopedia of Nuclear Magnetic Resonance*, pp. 1-158, John Wiley & Sons, Chichester.

Eichhoff, U. (1996) Bruker Analytishe Meestechnik GmbH [in Russian], *Journal of General Chemistry*, **XL**, 26.

Fedin, E. I. (1996) The golden stamp of failure (reminiscences) [in Russian], *NMR Newsletter*, 336-344.

Goldman, M. (1996) The time when spin temperature was hot stuff in *Encyclopedia of Nuclear Magnetic Resonance*, pp. 338-341, John Wiley & Sons, Chichester.

Grant, D. M., and Harris, R. K. (Eds.). (1996) Encyclopedia of Nuclear Magnetic Resonance 1st edition., John Wiley & Sons, Chichester.

Listed in II. Reviews and Monographs as well.

Lauterbur, P. C. (1996) One path out of many - how MRI actually began in *Encyclopedia of Nuclear Magnetic Resonance*, pp. 445-449, John Wiley & Sons, Chichester.

Proctor, W. G. (1996) When you and I were young, Magnet in *Encyclopedia of Nuclear Magnetic Resonance*, pp. 548-551, John Wiley & Sons, Chichester.

Sergeyev, N. M. (1996) Isotope effects on spin-spin coupling constants in *Encyclopedia of Nuclear Magnetic Resonance*, p. ??, John Wiley & Sons, Chichester.

Slighter, C. P., Coreyf, R. L., Curro, N. J., Desoto, S. M., O'hara, K., Imai, T., Kini, A. M., Wang, H. H., Geiser, U., Williams, J. M., Yoshimura, K., Katoh, M., and Kosuge, K. (1996) Nuclear magnetic resonance and electron spins: Some history, ancient and in the making, *Philosophical Magazine B*, **74**, 545-561, https://doi.org/10.1080/01418639608240356.

Ustynyuk, Y. A., and Gurevich, A. Z. (1996) Varian [in Russian], *Journal of General Chemistry*, **XL**, 40.

Waugh, J. S. (1996) Alchemy of nuclear spins in *Encyclopedia of Nuclear Magnetic Resonance*, pp. 683-688, John Wiley & Sons, Chichester.

Zavoisky, V. K. (1996) The Past [in Russian], Tatpoligraf, Kazan.

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Web site: "Groupement AMPERE": https://www.ampere-society.org/

Web site: "ISMAR" (International Society of Magnetic Resonance): http://www.weizmann.ac.il/ISMAR/

Web site: "IES" (the International EPR (ESR) Society): http://www.ieprs.org/

Web site: International Society for Magnetic Resonance in Medicine: https://www.ismrm.org/

Web site: NMR monographs. Collection of References edited by Stanislav Sýkora: http://www.ebyte.it/library/refs/Refs_NMR_Books.html, https://doi.org/10.3247/SL1Refs05.003.

Journals' official web sites:

Web site: EUROMAR: http://www.euromar.org/about.html

Web site: European Federation of EPR groups (EFEPR): http://efepr.uantwerpen.be/efepr/

Web site: The Journal of Magnetic Resonance (the official journal of the ISMAR) https://www.journals.elsevier.com/journal-of-magnetic-resonance

Web site: Solid State Nuclear Magnetic Resonance: https://www.journals.elsevier.com/solid-state-nuclear-magnetic-resonance

Web site: Progress in Nuclear Magnetic Resonance Spectroscopy: https://www.journals.elsevier.com/

progress-in-nuclear-magnetic-resonance-spectroscopy

Web site: Journal of Magnetic Resonance Imaging (the official journal of the International Society for Magnetic Resonance in Medicine): https://onlinelibrary.wiley.com/journal/15222586

Web site: Magnetic Resonance in Medicine (the official journal of the International Society for Magnetic Resonance in Medicine): https://onlinelibrary.wiley.com/journal/15222594

Web site: Journal of Biomolecular NMR: https://link.springer.com/journal/10858

Web site: Applied Magnetic Resonance: https://link.springer.com/journal/723

Web site: Magnetic Resonance Materials in Physics, Biology and Medicine: https://link.springer.com/journal/10334

Web site: http://www.euromar.com/

IV. ORIGINAL RESEARCH PAPERS

IV.1. BEFORE 1944: MAGNETIC RESONANCE FOUNDATIONAL WORKS

1897

Larmor, J. (1897) The influence of a magnetic field on radiation frequency, *Proc. R. Soc. Lond.*, **60**, 514-515, https://doi.org/10.1098/rspl.1896.0080.
Larmor's theorem, Larmor precession.

Zeeman, P. (1897) On the influence of magnetism on the nature of the light emitted by a substance, *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, **43**, 226-239, https://doi.org/10.1080/14786449708620985.
The Zeeman effect, splitting of optical lines in a magnetic field.

1921

Landé, A. (1921) Über den anomalen Zeemaneffekt (Teil I) [in German], *Zeitschrift für Physik*, **5**, 231-241, https://doi.org/10.1007/BF01335014.

Landé, A. (1921) Über den anomalen Zeemaneflekt (II. Teil) [in German], *Zeitschrift für Physik*, **7**, 398-405, https://doi.org/10.1007/BF01332807.

1922

Einstein, A., and Ehrenfest, P. (1922) Quantentheoretische Bemerkungen zum Experiment von Stern und Gerlach [in German], *Zeitschrift für Physik*, **11**, 31-34, https://doi.org/10.1007/BF01328398. [trR]
The idea of magnetic resonance existence proposed for the first time.

Gerlach, W., and Stern, O. (1922) Der experimentelle Nachweis des magnetischen Moments des Silberatoms [in German], *Zeitschrift für Physik*, **8**, 110-111, https://doi.org/10.1007/BF01329580.

1923

Landé, A. (1923) Termstruktur und Zeemaneffekt der Multipletts [in German], *Zeitschrift für Physik*, **15**, 189-205, https://doi.org/10.1007/BF01330473.

1924

Pauli, W. (1924) Zur Frage der theoretischen Deutung der Satelliten einiger Spektrallinien und ihrer Beeinflussung durch magnetische Felder [in German], *Naturwissenschaften*, **12**, 741-743, https://doi.org/10.1007/BF01504828.
The idea of some nuclei having a magnetic moment presented.

1925

Hund, F. (1925) Zur Deutung verwickelter Spektren, insbesondere der Elemente Scandium bis Nickel [in German], *Z. Physik*, **33**, 345-371, https://doi.org/10.1007/BF01328319.

1926

Uhlenbeck, G. E., and Goudsmit, S. (1926) Spinning electrons and the structure of spectra, *Nature*, **117**, 264-265, https://doi.org/10.1038/117264a0.
Hypothesis of the existence of electron spin justified.

1927

Dennison, D. M., and Fowler, R. H. (1927) A note on the specific heat of the hydrogen molecule, *Proc. R. Soc. Lond. A*, **115**, 483-486, https://doi.org/10.1098/rspa.1927.0105.
The role of nuclear spins in the statistical mechanics of molecules.

Hund, F. (1927) Zur Deutung der Molekelspektren. II [in German], *Z. Physik*, **42**, 93-120, https://doi.org/10.1007/BF01397124.

Pauli, W. (1927) Zur Quantenmechanik des magnetischen Elektrons [in German], *Z. Physik*, **43**, 601-623, https://doi.org/10.1007/BF01397326.
Pauli's famous equations.

1929

Bethe, H. (1929) Termaufspaltung in Kristallen [in German], *Ann. Phys.*, **395**, 133-208, https://doi.org/10.1002/andp.19293950202.

Kramers, H. A. (1929) La rotation paramagnétique du plan de polarisation dans les cristaux uniaxes de terres rares, *Proceedings of the Section of Sciences*, **32**, 1176-1189.

1930

Dorfiman, J. (1930) Zur Frage über die magnetischen Momente der Atomkerne [in German], *Z. Physik*, **62**, 90-94, https://doi.org/10.1007/BF01340406.
Relies on the erroneous hypothesis that nuclear structure includes electrons.

Fermi, E. (1930) Über die magnetischen Momente der Atomkerne [in German], *Z. Physik*, **60**, 320-333, https://doi.org/10.1007/BF01339933.
The theory of hyperfine (contact) electron-nuclear spin-spin interaction.

Kramers, H. A. (1930) Théorie Générale de la Rotation Paramagnétique dans les Cristaux, *Proc. Amst. Acad.*, **33**, 959-972

Weisskopf, V., and Wigner, E. (1930) Über die natürliche Linienbreite in der Strahlung des harmonischen Oszillators [in German], *Z. Physik*, **65**, 18-29, https://doi.org/10.1007/BF01397406. (+)
General theory of the linewidths at radiation emission.

1932

Van Vleck, J. H. (1932) Theory of the variations in paramagnetic anisotropy among different salts of the iron group, *Phys. Rev.*, **41**, 208-215, https://doi.org/10.1103/PhysRev.41.208.

Waller, I. (1932) Über die Magnetisierung von paramagnetischen Kristallen in Wechselfeldern [in German], *Z. Physik*, **79**, 370-388, https://doi.org/10.1007/BF01349398.

1933

Estermann, I., and Stern, O. (1933) Über die magnetische Ablenkung von Wasserstoffmolekülen und das magnetische Moment des Protons. II, *Z. Physik*, **85**, 17-24, https://doi.org/10.1007/BF01330774.
One of the two papers that won O. Stern the Nobel Prize for the discovery of the magnetic moment of the proton.

Frisch, R., and Stern, O. (1933) Über die magnetische Ablenkung von Wasserstoffmolekülen und das magnetische Moment des Protons. I, *Zeitschrift für Physik*, **85**, 4-16, https://doi.org/10.1007/BF01330773.
One of the two papers that won O. Stern the Nobel Prize for the discovery of the magnetic moment of the proton.

1934

Landé, A. (1934) Nuclear magnetic moments and their origin, *Phys. Rev.*, **46**, 477-480, https://doi.org/10.1103/PhysRev.46.477.

Tamm, I. E., and Altshuler, S. A. (1934) Magnetic moment of the neutron [in Russian], *Dokl. Akad. Nauk SSSR*, **1**, 455-460. (+)
The backbone of the theory is the comparison between deuteron and proton magnetic moments and mass.

1935

Dorfiman, J. (1935) Magnetic properties and nuclear magnetic [in German], *Physikalische Zeitschrift der Sowjetunion*, **7**, 126-127.

Landau, L. D., and Lifschitz, E. M. (1935) On the Theory of the Dispersion of Magnetic Permeability in Ferromagnetic Bodies [in German: Zur Theorie der Dispersion der magnetische Permeabilität der ferromagnetische Körpern], *Physikalische Zeitschrift der Sowjetunion*, **8**, 153-166. (trR)

1936

Gorter, C. J. (1936) Paramagnetic relaxation in a transversal magnetic field [in French], *Physica*, **3**, 1006-1008, https://doi.org/10.1016/S0031-8914(36)80326-7.

Heitler, W., and Teller, E. (1936) Time effects in the magnetic cooling method-I, *Proc. R. Soc. Lond. A*, **155**, 629-639, https://doi.org/10.1098/rspa.1936.0124.
Calculation of the relaxation time of the nuclear magnetic moment in diamagnetic crystals absolutely free from paramagnetic impurities and in the absence of diffusion processes proved that observation of NMR in such “sterile” conditions is practically impossible.

1937

Jahn, H. A., and Teller, E. (1937) Stability of polyatomic molecules in degenerate electronic states - I–Orbital degeneracy, *Proc. R. Soc. Lond. A*, **161**, 220-235, https://doi.org/10.1098/rspa.1937.0142.

Lasarew, B. G., and Schubnikow, L. W. (1937) Das Magnetische Moment des Protons [in German], *Physikalische Zeitschrift der Sowjetunion*, **11**, 445-457.
Direct measurement of the magnetic moment of solid hydrogen.

Rabi, I. I. (1937) Space Quantization in a Gyrating Magnetic Field, *Phys. Rev.*, **51**, 652-654, https://doi.org/10.1103/PhysRev.51.652.
(S. S.) Magnetic resonance in molecular beams proposed to measure angular moments.

1938

Casimir, H. B. G., and du Pré, F. K. (1938) Note on the thermodynamic interpretation of paramagnetic relaxation phenomena, *Physica*, **5**, 507-511, https://doi.org/10.1016/S0031-8914(38)80164-6.

Kronig, R. de L. (1938) On the theory of absorption and dispersion in paramagnetic crystals under

alternating magnetic fields, *Physica*, **5**, 65-80, https://doi.org/10.1016/S0031-8914(38)80110-5. (+)
On the theory of absorption and dispersion in paramagnetic and dielectric media.

Kronig, R. de L., and Bouwkamp, C. J. (1938) On the time of relaxation due to spin-spin interaction in paramagnetic crystals, *Physica*, **5**, 521-528, https://doi.org/10.1016/S0031-8914(38)80166-X.

1939

Casimir, H. B. G. (1939) On the equilibrium between spin and lattice, *Physica*, **6**, 156-160, https://doi.org/10.1016/S0031-8914(39)80006-4.

Casimir, H. B. G., de Haas, W. J., and de Klerk, D. (1939) A new method for determining specific heats at extremely low temperatures, *Physica*, **6**, 255-261, https://doi.org/10.1016/S0031-8914(39)90796-2.

1940

Bloch, F., and Siegert, A. (1940) Magnetic Resonance for Nonrotating Fields, *Phys. Rev.*, **57**, 522-527, https://doi.org/10.1103/PhysRev.57.522.
At the core of the paper lies the representation of a linearly polarized magnetic field as a sum of two fields rotating in opposite directions. The resonance frequency shift phenomenon (the Bloch-Siegert shift) is introduced.

1941

Van Vleck, J. H. (1941) Paramagnetic Relaxation and the Equilibrium of Lattice Oscillators, *Phys. Rev.*, **59**, 724-729, https://doi.org/10.1103/PhysRev.59.724.

IV.2. BEFORE 1944: STUDIES ON MAGNETIC AND FERROMAGNETIC ABSORPTION AND DISPERSION, AND OTHER MAGNETIC FIELD EFFECTS ON SUBSTANCES (MAGNETIC DISPERSION)

1913

Arkadiev, V. K. (1913) The theory of electromagnetic field in ferromagnetic metals [in Russian], *Journal of Russian Physical and Chemical Society*, **45**, 312-345
German translation published in 1919, in Arkadiew, W. (1919) Über die Absorption elektromagnetischer Wellen an zwei parallelen Drähten, *Ann. Phys.*, **363**, 105-138, https://doi.org/10.1002/andp.19193630202.

1919

Arkadiew, W. (1919) Über die Absorption elektromagnetischer Wellen an zwei parallelen Drähten, *Ann. Phys.*, **363**, 105-138, https://doi.org/10.1002/andp.19193630202.
Originally published in Russian, in 1913, in Arkadiev, V. K. (1913) The theory of electromagnetic field in ferromagnetic metals [in Russian], *Journal of Russian Physical and Chemical Society*, **45**, 312-345.

1921

Gans, R. (1921) Die Permeabilität des Nickels für kurze Hertzsche Wellen und die Messungen von Arkadiew, *Annalen der Physik*, **369**, 250-252, https://doi.org/10.1002/andp.19213690303.

Gans, R., and Loyarte, R. G. (1921) Die Permeabilität des Nickels für schnelle elektrische Schwingungen, *Ann. Phys.*, **369**, 209-249, https://doi.org/10.1002/andp.19213690302.

1923

Dorfmann, J. (1923) Einige Bemerkungen zur Kenntnis des Mechanismus magnetischer Erscheinungen [in German], *Z. Physik*, **17**, 98-111, https://doi.org/10.1007/BF01328670.
For a long time had been considered by the author and by some of Soviet historians of science a theoretical prediction (discovery) of magnetic resonance (photomagnetic effect). De facto, the paper offers a rough interpretation of the works by V. K. Arkadiev and R. Loyarte, on the grounds of magnetic resonance phenomenon prediction made by A. Einstein and P. Ehrenfest [IV. A. Einstein 1922].

1932

Zavoisky, E. K., and Vinnik, P. M. (1932) Apparatus for the Reception and Detection of Electrical Oscillations # 99471, USSR Author's Certificate 28546, filed 1931, issued in 1932 [in Russian]. (b)

1936

Gorter, C. J. (1936) Negative result of an attempt to detect nuclear magnetic spins [in French], *Physica*, **3**, 995-998, https://doi.org/10.1016/S0031-8914(36)80324-3.
A failed attempt at observing NMR, with the use of the calorimetric method.

Gorter, C. J. (1936) Paramagnetic relaxation in a transversal magnetic field, *Physica*, **3**, 1006-1008, https://doi.org/10.1016/S0031-8914(36)80326-7.

Zavoisky, E. K. (1936) Method for measuring atomic and molecular excitation potentials, *J. Exp. Theor. Phys.*, **6**, 37-51. (b)

Zavoisky, E. K., Kozyrev, B. M., and Salikhov, S. G. (1936) Measurements of high-frequency weak electric field absorption in some substances,

according to field strength [in Russian], *Dokl. Akad. Nauk SSSR*, **1**, 214-216. (b)
Wrong interpretation of resulting measurements in this paper gave grounds for M. A. Leontovich to doubt, eight years later, Zavoisky's discovery of EPR.

1939

De Haas, W. J., and Du Pre, F. K. (1939) Paramagnetic relaxation in gadolinium sulphate, *Physica*, **6**, 705-716, https://doi.org/10.1016/S0031-8914(39)90073-X.

1942

Gorter, C. J., and Broer, L. J. F. (1942) Negative result of an attempt to observe nuclear magnetic resonance in solids, *Physica*, **9**, 591-596, https://doi.org/10.1016/S0031-8914(42)80073-7.
A failed attempt at observing NMR with the use of the marginal oscillator method.

1943

Broer, L. J. F., Dijkstra, L. J., and Gorter, C. J. (1943) Paramagnetic relaxation in two hydrated nickel salts, *Physica*, **10**, 324-330, https://doi.org/10.1016/S0031-8914(43)90018-7.

Dijkstra, L. J., Gorter, C. J., and Volger, J. (1943) Further researches on paramagnetic absorption in iron ammonium alum, *Physica*, **10**, 337-347, https://doi.org/10.1016/S0031-8914(43)90020-5.

IV.3. BEFORE 1944 AND BEYOND: MAGNETIC RESONANCE IN MOLECULAR BEAMS

1938

Rabi, I. I., Zacharias, J. R., Millman, S., and Kusch, P. (1938) A new method of measuring nuclear magnetic moment, *Phys. Rev.*, **53**, 318-318, https://doi.org/10.1103/PhysRev.53.318.
Nuclear magnetic resonance detected in molecular beams, for the first time.

Rabi, I. I., Millman, S., Kusch, P., and Zacharias, J. R. (1938) The magnetic moments of $_3Li^6$, $_3Li^7$ and $_9F^{19}$, *Phys. Rev.*, **53**, 495, https://doi.org/10.1103/PhysRev.53.495.

1939

Rabi, I. I., Millman, S., Kusch, P., and Zacharias, J. R. (1939) The molecular beam resonance method for measuring nuclear magnetic moments. the magnetic moments of $_3Li^6$, $_3Li^7$ and $_9F1^9$, *Phys. Rev.*, **55**, 526-535, https://doi.org/10.1103/PhysRev.55.526.

1940

Alvarez, L. W., and Bloch, F. (1940) A quantitative determination of the neutron moment in absolute nuclear magnetons, *Phys. Rev.*, **57**, 111-122, https://doi.org/10.1103/PhysRev.57.111.
Magnetic resonance in a neutron beam.

Kush, P., Millman, S., and Rabi, I. I. (1940) Radiofrequency spectra of atoms. Minutes of the Columbus, Ohio, Meeting, December 28-30, 1939, *Phys. Rev.*, **57**, 344-361, https://doi.org/10.1103/PhysRev.57.344.
EPR study of alkali metal atoms in atomic beams.

Kusch, P., Millman, S., and Rabi, I. I. (1940) The radiofrequency spectra of atoms hyperfine structure and Zeeman effect in the ground state of Li^6, Li^7, K^{39} and K^{41}, *Phys. Rev.*, **57**, 765-780, https://doi.org/10.1103/PhysRev.57.765.
EPR study of alkali metal atoms in atomic beams.

Kellogg, J. M. B., Rabi, I. I., Ramsey, N. F., and Zacharias, J. R. (1940) An electrical quadrupole moment of the deuteron the radiofrequency spectra of HD and D_2 molecules in a magnetic field, *Phys. Rev.*, **57**, 677-695, https://doi.org/10.1103/PhysRev.57.677.
EPR study of alkali metal atoms in atomic beams.

Kusch, P., and Millman, S. (1940) On the radiofrequency spectra of sodium, rubidium and caesium, *Phys. Rev.*, **58**, 438-445, https://doi.org/10.1103/PhysRev.58.438.
EPR study of alkali metal atoms in atomic beams.

1947

Nierenberg, W. A., and Ramsey, N. F. (1947) The radiofrequency spectra of the sodium halides, *Phys. Rev.*, **72**, 1075-1089, https://doi.org/10.1103/PhysRev.72.1075.

1948

Bardeen, J., and Townes, C. H. (1948) Calculation of nuclear quadrupole effects in molecules, *Phys. Rev.*, **73**, 97-105, https://doi.org/10.1103/PhysRev.73.97.
(S. S.) Done for molecular beam experiments, this paper very accurately handles NQR effects.

1949

Kusch, P., and Mann, A. K. (1949) A precision measurement of the ratio of the nuclear g-values of Li^7 and Li^6, *Phys. Rev.*, **76**, 707-709, https://doi.org/10.1103/PhysRev.76.707.

Taub, H., and Kusch, P. (1949) The magnetic moment of the proton, *Phys. Rev.*, **75**, 1481-1492, https://doi.org/10.1103/PhysRev.75.1481.

1956

Ramsey, N. F. (1956) *Molecular Beams*, Oxford University Press, Oxford. (+)
Listed in II. Monographs and Overviews as well.

IV.4. AFTER 1944: MAGNETIC RESONANCE AND MAGNETIC RELAXATION IN CONDENSED MATTER

1944

Zavoisky, E. K. (1944) The paramagnetic absorption of a solution in parallel fields, *J. Phys. USSR*, **8**, 337-380

Zavoisky, E. K., and Altshuler, S. A. (1944) A new method for the study of paramagnetic absorption [in Russian], *J. Exp. Theor. Phys.*, **14**, 407-409.
In particular, Zavoisky reports observing EPR, recognizing the role of his colleagues he performed the experiment with.

1945

Frenkel, Y. I. (1945) Concerning the theory of relaxation losses due to magnetic resonance in solids [in Russian], *J. Exp. Theor. Phys.*, **15**, 409-416. (histR)
Does not specify the EPR line broadening mechanisms, phenomenologically implying their dissipative nature.

Van Vleck, J. H., and Weisskopf, V. F. (1945) On the shape of collision-broadened lines, *Rev. Mod. Phys.*, **17**, 227-236, https://doi.org/10.1103/RevModPhys.17.227. (+)
Concerning the theory of spectral line shapes broadened due to dissipation mechanisms.

Zavoisky, E. K. (1945) Paramagnetic relaxation of liquid solution for perpendicular fields, *J. Phys. USSR*, **9**, 211-216.

Zavoisky, E. K. (1945) Spin magnetic resonance in paramagnetics, *J. Phys. USSR*, **9**, 245.
The article firmly establishes Zavoisky's priority in the discovery of EPR.

Zavoisky, E. K. (1945) On the absence of anisotropy for spin-magnetic resonance, *J. Phys. USSR*, **9**, 447-448.
The conclusion applies only to dense paramagnets investigated in earlier papers.

Zavoisky, E. K. (1945) Paramagnetic absorption in solutions under parallel fields [in Russian], *J. Exp. Theor. Phys.*, **15**, 253-257. (b)

Zavoisky, E. K. (1945) Paramagnetic relaxation in liquid solutions under perpendicular fields [in Russian], *J. Exp. Theor. Phys.*, **15**, 344-350.

1946

Bloch, F., Hansen, W. W., and Packard, M. (1946) Nuclear induction, *Phys. Rev.*, **69**, 127-127, https://doi.org/10.1103/PhysRev.69.127.
Discovery of proton NMR in aqueous solutions of paramagnetic substances. The paper was submitted to the editorial office after the similar work by Purcell.

Bloch, F. (1946) Nuclear induction, *Phys. Rev.*, **70**, 460-474, https://doi.org/10.1103/PhysRev.70.460.
Bloch equations are suggested for describing NMR.

Bloch, F., Hansen, W. W., and Packard, M. (1946) The nuclear induction experiment, *Phys. Rev.*, **70**, 474-485, https://doi.org/10.1103/PhysRev.70.474.

Cummerow, R. L., and Halliday, D. (1946) Paramagnetic losses in two manganous salts, *Phys. Rev.*, **70**, 433-433, https://doi.org/10.1103/PhysRev.70.433.
The first work on EPR in the West. Refers to Zavoisky's discovery of EPR.

Fröhlich, H. (1946) Shape of collision-broadened spectral lines, *Nature*, **157**, 478-478, https://doi.org/10.1038/157478a0. (+)
General theory of the dissipation mechanism of spectral line broadening.

Griffiths, J. H. E. (1946) Anomalous high-frequency resistance of ferromagnetic metals, *Nature*, **158**, 670-671, https://doi.org/10.1038/158670a0. trR, S. V. Vonsovsky, ed.)
Ferromagnetic resonance observed independently of E. K. Zavoisky.

Pound, R. V., Purcell, E. M., and Torrey, H. C. (1946) Measurements of magnetic resonance absorption by nuclear moments in solids. Proceedings of the American Physical Society, *Phys. Rev.*, **69**, 681, https://doi.org/10.1103/PhysRev.69.674.2.
(S. S.) Comm. to the Am. Phys. Soc.

Purcell, E. M. (1946) Spontaneous emission probabilities at radio frequencies. Proceedings of the American Physical Society, *Phys. Rev.*, **69**, 681, https://doi.org/10.1103/PhysRev.69.674.2.
(S. S.) Comm. to the Am. Phys. Soc. First estimate of radiation damping.

Purcell, E. M., Torrey, H. C., and Pound, R. V. (1946) Resonance absorption by nuclear magnetic moments in a solid, *Phys. Rev.*, **69**, 37-38, https://doi.org/10.1103/PhysRev.69.37.
The earliest paper on NMR observed in condensed matter (paraffin).

Purcell, E. M., Bloembergen, N., and Pound, R. V. (1946) Resonance absorption by nuclear magnetic moments in a single crystal of CaF2, *Phys. Rev.*, **70**, 988-988, https://doi.org/10.1103/PhysRev.70.988.
(S. S.) Observation and theory of orientation dependence in solids.

Purcell, E. M., Pound, R. V., and Bloembergen, N. (1946) Nuclear magnetic resonance absorption in hydrogen gas, *Phys. Rev.*, **70**, 986-987, https://doi.org/10.1103/PhysRev.70.986.

Rollin, B. V. (1946) Nuclear magnetic resonance and spin lattice equilibrium, *Nature*, **158**, 669-670, https://doi.org/10.1038/158669a0.
(S. S.) CaF_2. Clarendon lab. Oxford.

Torrey, H. C. (1946) Theory of magnetic resonance absorption by nuclear moments in solids. Proceedings of the American Physical Society, *Phys. Rev.*, **69**, 680.
(S. S.) Comm. to the Am. Phys. Soc.

Zavoisky, E. K. (1946) Paramagnetic absorption in some salts in perpendicular magnetic fields, *J. Phys. USSR*, **10**, 170-173.

Zavoisky, E. K. (1946) Paramagnetic absorption in some salts in perpendicular magnetic fields [in Russian], *J. Exp. Theor. Phys.*, **16**, 603-606.

Zavoisky, E. K. (1946) Spin-magnetic resonance in the decimeter wave region, *J. Phys. USSR*, **10**, 197-198.
Performed at the Institute of Physical Problems, assisted by A. I. Shalnikov.

1947

Altshuler, S. A., Zavoisky, E. K., and Kozyrev, B. M. (1947) Concerning the theory of paramagnetic relaxation in a perpendicular magnetic field [in Russian], *J. Exp. Theor. Phys.*, **17**, 1122-1123.

Anderson, H. L., and Novick, A. (1947) Magnetic moment of the triton, *Phys. Rev.*, **71**, 372-373, https://doi.org/10.1103/PhysRev.71.372.2.

Bloch, F., Graves, A. C., Packard, M., and Spence, R. W. (1947) Spin and magnetic moment of tritium, *Phys. Rev.*, **71**, 373-374, https://doi.org/10.1103/PhysRev.71.373.

Bloch, F., Levinthal, E. C., and Packard, M. E. (1947) Relative nuclear moments of H_1 and H_2, *Phys. Rev.*, **72**, 1125-1126, https://doi.org/10.1103/PhysRev.72.1125.2.

Cummerow, R. L., Halliday, D., and Moore, G. E. (1947) Paramagnetic resonance absorption in salts of the iron group, *Phys. Rev.*, **72**, 1233-1240, https://doi.org/10.1103/PhysRev.72.1233.

Gorter, C. J., and van Vleck, J. H. (1947) The role of exchange interaction in paramagnetic absorption, *Phys. Rev.*, **72**, 1128-1129, https://doi.org/10.1103/PhysRev.72.1128.2.
Van Vleck helped Gorter find out the reason why Zavoisky failed to observe EPR in dense paramagnetic substances. The role of electron exchange interactions is taken into account.

Kittel, C. (1947) Interpretation of anomalous larmor frequencies in ferromagnetic resonance experiment, *Phys. Rev.*, **71**, 270-271, https://doi.org/10.1103/PhysRev.71.270.2. (trR, S. V. Vonsovsky, ed.)

Kozyrev, B. M., and Salikhov, S. G. (1947) Paramagnetic relaxation in pentamethylcyclopentadiene [in Russian], *Dokl. Akad. Nauk SSSR*, **58**, 1023-1025.
EPR hyperfine structure first observed.

Pound, R. V. (1947) Radiofrequency spectrometer for the detection of resonance absorption by nuclear moments. Minutes of the Meeting at Montreal, June 19-21, 1947, *Phys. Rev.*, **72**, 527, https://doi.org/10.1103/PhysRev.72.523.
Am. Phys. Soc. 19-21 June 1947.

Roberts, A. (1947) Two new methods for detecting nuclear radiofrequency resonance absorption, *Rev. Sci. Instrum.*, **18**, 845-848, https://doi.org/10.1063/1.1740859.

Roberts, A. (1947) The magnetic moment of the deuteron, *Phys. Rev.*, **72**, 979-979, https://doi.org/10.1103/PhysRev.72.979.
(S. S.) First observation of “wiggles” he coined the term). The term “wiggles” is introduced for NMR spectrometer oscillations after a quick magnetic resonance event.

Vladimirskii, K. V. (1947) Concerning oscillation phenomena in nuclear paramagnetism [in Russian], *Dokl. Akad. Nauk SSSR*, **58**, 1625-1628. (histR)
The first paper on NMR in the Soviet Union.

Yager, W. A., and Bozorth, R. M. (1947) Ferromagnetic resonance at microwave frequencies, *Phys. Rev.*, **72**, 80-81, https://doi.org/10.1103/PhysRev.72.80. (trR, S. V. Vonsovsky, ed.)

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Zavoisky, E. K. (1947) Measurement of magnetic susceptibility of a paramagnet at decimeter wavelengths [in Russian], *J. Exp. Theor. Phys.*, **17**, 155-161.

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Bagguley, D. M. S., Bleaney, B., Griffiths, J. H. E., Penrose, R. P., and Plumpton, B. I. (1948) Paramagnetic resonance in salts of the iron group - a preliminary survey: I. Theoretical discussion, *Proc. Phys. Soc.*, **61**, 542, https://doi.org/10.1088/0959-5309/61/6/311.

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Bleaney, B., and Penrose, R. P. (1948) Paramagnetic resonance at low temperatures in chromic alum, *Proc. Phys. Soc.*, **60**, 395, https://doi.org/10.1088/0959-5309/60/4/110.

Bloch, F., Nicodemus, D., and Staub, H. H. (1948) A quantitative determination of the magnetic moment of the neutron in units of the proton moment, *Phys. Rev.*, **74**, 1025-1045, https://doi.org/10.1103/PhysRev.74.1025. (+)

Bloembergen, N., Purcell, E. M., and Pound, R. V. (1948) Relaxation effects in nuclear magnetic resonance absorption, *Phys. Rev.*, **73**, 679-712, https://doi.org/10.1103/PhysRev.73.679.

(S. S.) Introduction of the BPP relaxation formula, including a factor 2 error.

Gutowsky, H. S., and Pake, G. E. (1948) Nuclear magnetism in studies of molecular structure and rotation in solids: ammonium salts, *J. Chem. Phys.*, **16**, 1164-1165, https://doi.org/10.1063/1.1746756.

(S. S.) Line narrowing due to internal motions in solids.

Hewitt, W. H. (1948) Microwave resonance absorption in ferromagnetic semiconductors, *Phys. Rev.*, **73**, 1118-1119, https://doi.org/10.1103/PhysRev.73.1118.2. (trR, S. V. Vonsovsky, ed.)

Jacobsohn, B. A., and Wangsness, R. K. (1948) Shapes of nuclear induction signals, *Phys. Rev.*, **73**, 942-946, https://doi.org/10.1103/PhysRev.73.942.

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Karplus, R., and Schwinger, J. (1948) A note on saturation in microwave spectroscopy, *Phys. Rev.*, **73**, 1020-1026, https://doi.org/10.1103/PhysRev.73.1020. (+)

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(S. S.) First NMR lock. Field/frequency ratio stabilizer using NMR technique suggested.

Pake, G. E. (1948) Nuclear resonance absorption in hydrated crystals: fine structure of the proton line, *The Journal of Chemical Physics*, **16**, 327-336, https://doi.org/10.1063/1.1746878.

Pake doublet discovered, a lineshape that arises from dipolar coupling between two spin-1/2 protons of H2O hydrated molecule in rigid crystal lattice.

(S. S.) First applications in chemical physics. Introduction of the famous Pake doublet.

Pake, G. E., and Gutowsky, H. S. (1948) Nuclear relaxation in ice at - 180°C, *Phys. Rev.*, **74**, 979-980, https://doi.org/10.1103/PhysRev.74.979.2.

Pake, G. E., and Purcell, E. M. (1948) Line shapes in nuclear paramagnetism, *Phys. Rev.*, **74**, 1184-1188, https://doi.org/10.1103/PhysRev.74.1184.

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Rollin, B. V., and Hatton, J. (1948) Nuclear paramagnetism at low temperatures, *Phys. Rev.*, **74**, 346-346, https://doi.org/10.1103/PhysRev.74.346.

^{19}F in CaF_2.

Van Vleck, J. H. (1948) The dipolar broadening of magnetic resonance lines in crystals, *Phys. Rev.*, **74**, 1168-1183, https://doi.org/10.1103/PhysRev.74.1168. (trR, S. V. Vonsovsky, ed.)

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Anderson, H. L. (1949) Precise measurement of the gyromagnetic ratio of H3, *Phys. Rev.*, **76**, 1460-1470, https://doi.org/10.1103/PhysRev.76.1460.

Bloembergen, N. (1949) On the interaction of nuclear spins in a crystalline lattice, *Physica*, **15**, 386-426, https://doi.org/10.1016/0031-8914(49)90114-7.

In particular, the concept of spin diffusion due to dipole interactions between nuclear spins is introduced.

Broersma, S. (1949) The magnetic susceptibility of organic compounds, *The Journal of Chemical Physics*, **17**, 873-882, https://doi.org/10.1063/1.1747080. (+)

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Brown, W. F. (1949) Crystal interactions in ferromagnetic resonance, *Phys. Rev.*, **75**, 1959-1960, https://doi.org/10.1103/PhysRev.75.1959. (trR, S. V. Vonsovsky, ed.)

Dehmelt, H. G. (1949) Kernquadrupolfrequenzen in festen Dichloräthylen, *Z. Physik*, **126**, 728.

Nuclear quadrupole resonance (NQR) discovery.

Dickinson, W. C. (1949) Magnetic moment of La^{139}, *Phys. Rev.*, **76**, 1414-1415, https://doi.org/10.1103/PhysRev.76.1414.2.

Dickinson, W. C., and Wimett, T. F. (1949) The magnetic moment of Be^9, *Phys. Rev.*, **75**, 1769-1769, https://doi.org/10.1103/PhysRev.75.1769.

Drain, L. E. (1949) A direct method of measuring nuclear spin-lattice relaxation times, *Proc. Phys. Soc. A*, **62**, 301, https://doi.org/10.1088/0370-1298/62/5/306.

(S. S.) Proposal for measurements of relaxation in complex systems.

Gutowsky, H. S., Kistiakowsky, G. B., Pake, G. E., and Purcell, E. M. (1949) Structural investigations by means of nuclear magnetism. I. Rigid crystal lattices, *J. Chem. Phys.*, **17**, 972-981, https://doi.org/10.1063/1.1747097.

Analysis of NMR line shapes by means of the spectral moment method. (S. S.) Introduction of spectral moments.

Hatton, J., and Rollin, B. V. (1949) Nuclear magnetic resonance at low temperatures, *Proc. R. Soc. Lond. A*, **199**, 222-237, https://doi.org/10.1098/rspa.1949.0135.

(S. S.) Ionic crystals, metals, solid H2 (1-14°K).

Holden, A. N., Kittel, C., Merritt, F. R., and Yager, W. A. (1949) Microwave resonance absorption in a paramagnetic organic compound, *Phys. Rev.*, **75**, 1614-1614, https://doi.org/10.1103/PhysRev.75.1614.

Hopkins, N. J. (1949) A magnetic field strength meter using the proton magnetic moment, *Rev. Sci. Instrum.*, **20**, 401-402, https://doi.org/10.1063/1.1741554.

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(S. S.) NMR magnetic-field meters are still of great importance.

Hopkins, N. J. (1949) The demonstration of nuclear magnetic resonance, *Am. J. Phys.*, **17**, 518, https://doi.org/10.1119/1.1989676. (trR, S. V. Vonsovsky, ed.)

Hutchison, C. A. (1949) Paramagnetic resonance absorption in crystals colored by irradiation, *Phys. Rev.*, **75**, 1769-1770, https://doi.org/10.1103/PhysRev.75.1769.2.

Kip, A. F., and Arnold, R. D. (1949) Ferromagnetic resonance at microwave frequencies in an iron single crystal, *Phys. Rev.*, **75**, 1556-1560, https://doi.org/10.1103/PhysRev.75.1556.

Kittel, C., Yager, W. A., and Merritt, F. R. (1949) On the Gorter normal field ferromagnetic resonance experiment, *Physica*, **15**, 256-257, https://doi.org/10.1016/0031-8914(49)90052-X. (trR, S. V. Vonsovsky, ed.)

Kittel, C. (1949) On the gyromagnetic ratio and spectroscopic splitting factor of ferromagnetic substances, *Phys. Rev.*, **76**, 743-748, https://doi.org/10.1103/PhysRev.76.743. (trR, S. V. Vonsovsky, ed.)

Knight, W. D. (1949) Nuclear magnetic resonance shift in metals, *Phys. Rev.*, **76**, 1259-1260, https://doi.org/10.1103/PhysRev.76.1259.2.

Discovery of the Knight shift - NMR frequency shift in metals, induced by the interactions between nuclear spins and conduction electrons.

(S. S.) Discovery of Knight shifts in metal.

Penrose, R. P., Gorter, C. J., and Abragam, A. (1949) Hyperfine structure in the solid state, *Nature*, **163**, 992-992, https://doi.org/10.1038/163992a0.

Polder, D. (1949) VIII. On the theory of ferromagnetic resonance, *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, **40**, 99-115, https://doi.org/10.1080/14786444908561215. (trR, S. V. Vonsovsky, ed.)

Proctor, W. G. (1949) The magnetic moment of ^{203}Tl, *Phys. Rev.*, **75**, 522-523, https://doi.org/10.1103/PhysRev.75.522.

Proctor, W. G. (1949) The magnetic moments of Sn^{117}, Sn^{119}, and Pb^{207}, *Phys. Rev.*, **76**, 684-684, https://doi.org/10.1103/PhysRev.76.684.

Proctor, W. G., and Yu, F. C. (1949) On the magnetic moments of ^{115}Sn, ^{111}Cd, ^{113}Cd, ^{195}Pt, and ^{199}Hg, *Phys. Rev.*, **76**, 1728-1729, https://doi.org/10.1103/PhysRev.76.1728.3.

Spooner, R. B., and Selwood, P. W. (1949) Nuclear induction and the structure of catalytically active solids, *J. Am. Chem. Soc.*, **71**, 2184-2187, https://doi.org/10.1021/ja01174a072.

Thomas, H. A., and Huntoon, R. D. (1949) Amplitude bridge for detection of nuclear resonance, *Rev. Sci. Instrum.*, **20**, 516-517, https://doi.org/10.1063/1.1741585.

Torrey, H. C. (1949) Transient nutations in nuclear magnetic resonance, *Phys. Rev.*, **76**, 1059-1068, https://doi.org/10.1103/PhysRev.76.1059.

(S. S.) Aims at measurements of relaxation in complex systems.

Wheatley, J., and Halliday, D. (1949) Paramagnetic absorption in single crystals of copper sulfate pentahydrate, *Phys. Rev.*, **75**, 1412-1415, https://doi.org/10.1103/PhysRev.75.1412.

Wright, A. (1949) Some aspects of paramagnetic relaxation, *Phys. Rev.*, **76**, 1826-1838, https://doi.org/10.1103/PhysRev.76.1826.

Williams, D., and Zimmerman, J. R. (1949) Determination of nuclear gyromagnetic ratios I, *Phys. Rev.*, **76**, 350-357, https://doi.org/10.1103/PhysRev.76.350.

γ NMR of 12 nuclei observed with 10^{-4} precision.

Williams, D., and Chambers, W. H. (1949) Nuclear gyromagnetic ratios II, *Phys. Rev.*, **76**, 638-640, https://doi.org/10.1103/PhysRev.76.638.

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Abragam, A., and Pryce, M. H. L. (1950) Theoretical interpretation of copper fluosilicate spectrum, *Proc. Phys. Soc. A*, **63**, 409, https://doi.org/10.1088/0370-1298/63/4/113.

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Andrew, E. R., and Bersohn, R. (1952) Erratum: Nuclear magnetic resonance line shape for a triangular configuration of nuclei, *J. Chem. Phys.*, **20**, 924, https://doi.org/10.1063/1.1700610.

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Birks, J. B. (1950) The properties of ferromagnetic compounds at centimetre wavelengths, *Proc. Phys. Soc. B*, **63**, 65, https://doi.org/10.1088/0370-1301/63/2/301. (*) (trR, S. V. Vonsovsky, ed.)

Bloembergen, N., and Dickinson, W. C. (1950) On the shift of the nuclear magnetic resonance in paramagnetic solutions, *Phys. Rev.*, **79**, 179-180, https://doi.org/10.1103/PhysRev.79.179.

Brown, R. M. (1950) Nuclear magnetic resonance in weak fields, *Phys. Rev.*, **78**, 530-532, https://doi.org/10.1103/PhysRev.78.530.

(S. S.) Description of a low-frequency probehead.

Collins, T. L. (1950) Nuclear magnetic resonance for K39, *Phys. Rev.*, **80**, 103-103, https://doi.org/10.1103/PhysRev.80.103.

Un. of British Columbia, Vancouver.

Dehmelt, H.-G. (1950) Kernquadrupolfrequenzen in kristallinen Jodverbindungen [in German], *Naturwissenschaften*, **37**, 398-398, https://doi.org/10.1007/BF00738365.

NQR of ^{127}I reported.

Dehmelt, H.-G., and Krüger, H. (1950) Kernquadrupolfrequenzen in festem Dichloräthylen [in German], *Naturwissenschaften*, **37**, 111-112, https://doi.org/10.1007/BF00623717.

NQR of CI isotopes reported.

Dickinson, W. C. (1950) Dependence of the F^{19} nuclear resonance position on chemical compound, *Phys. Rev.*, **77**, 736-737, https://doi.org/10.1103/PhysRev.77.736.2.

(S. S.) Parallel discovery of chemical shifts. F^{19}.

Dickinson, W. C. (1950) Hartree computation of the internal diamagnetic field for atoms, *Phys. Rev.*, **80**, 563-566, https://doi.org/10.1103/PhysRev.80.563.

(S. S.) First explanations of chemical shifts.

Griswold, T. W., Kip, A. F., and Kittel, C. (1952) Microwave spin resonance absorption by conduction electrons in metallic sodium, *Phys. Rev.*, **88**, 951-952, https://doi.org/10.1103/PhysRev.88.951.

Guillaud, C., Yager, W. A., Merritt, F. R., and Kittel, C. (1950) Ferromagnetic resonance in manganese ferrite and the theory of the ferrites, *Phys. Rev.*, **79**, 181-181, https://doi.org/10.1103/PhysRev.79.181.

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Gvozdover, S. D., and Magazanik, A. A. (1950) Magneto-spin resonance studies of atomic nuclear paramagnetism [in Russian], *J. Exp. Theor. Phys.*, **20**, 701-705. (histR)

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(S. S.) Hahn echo, stimulated echo, 2- and 3-pulse sequences.

Hahn, E. L. (1950) Spin echoes, *Phys. Rev.*, **80**, 580-594, https://doi.org/10.1103/PhysRev.80.580.

Holden, A. N., Kittel, C., Merritt, F. R., and Yager, W. A. (1950) Determination of *g*-values in paramagnetic organic compounds by microwave resonance, *Phys. Rev.*, **77**, 147-148, https://doi.org/10.1103/PhysRev.77.147.

Kastler, A. (1950) Quelques suggestions concernant la production optique et la détection optique d'une inégalité de population des niveaux de quantifigation spatiale des atomes. Application à l'expérience de Stern et Gerlach et à la résonance magnétique [in French], *J. Phys. Radium*, **11**, 255-265, https://doi.org/10.1051/jphysrad:01950001106025500.

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Kittel, C., Galt, J. K., and Campbell, W. E. (1950) Crucial experiment demonstrating single domain property of fine ferromagnetic powders, *Phys. Rev.*, **77**, 725-725, https://doi.org/10.1103/PhysRev.77.725.

Kittel, C., and Herring, C. (1950) Effect of exchange interaction on ferromagnetic microwave resonance absorption, *Phys. Rev.*, **77**, 725-726, https://doi.org/10.1103/PhysRev.77.725.2. (trR, S. V. Vonsovsky, ed.)

Korringa, J. (1950) Nuclear magnetic relaxation and resonnance line shift in metals, *Physica*, **16**, 601-610, https://doi.org/10.1016/0031-8914(50)90105-4.

Lindström, G. (1950) An experimental investigation of the nuclear magnetic moments of D2 and H1, *Phys. Rev.*, **78**, 817-818, https://doi.org/10.1103/PhysRev.78.817.

(S. S.) First report of 1H chemical shifts.

Newman, R. (1950) Proton nuclear magnetic resonance studies in KH_2PO_4, KH_2AsO_4, $NH_4H_2PO_4$, and $NH_4H_2AsO_4$, *J. Chem. Phys.*, **18**, 669-678, https://doi.org/10.1063/1.1747723.

Pound, R. V. (1950) Nuclear electric quadrupole interactions in crystals, *Phys. Rev.*, **79**, 685-702, https://doi.org/10.1103/PhysRev.79.685.

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(S. S.) technical description of the "Pound" NMR instrument.

Proctor, W. G. (1950) On the magnetic moments of Tl^{203}, Tl^{205}, Sn^{115}, Sn^{117}, Sn^{119}, Cd^{111}, Cd^{113}, and Pb^{207}, *Phys. Rev.*, **79**, 35-44, https://doi.org/10.1103/PhysRev.79.35.

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(S. S.) Technical description of the "Proctor" NMR instrument.

Proctor, W. G., and Yu, F. C. (1950) On the magnetic moments of Mn^{55}, Co^{59}, C^{l37}, N^{15}, and N^{14}, *Phys. Rev.*, **77**, 716-717, https://doi.org/10.1103/PhysRev.77.716.

Proctor, W. G., and Yu, F. C. (1950) The dependence of a nuclear magnetic resonance frequency upon chemical compound, *Phys. Rev.*, **77**, 717-717, https://doi.org/10.1103/PhysRev.77.717.

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(S. S.) Discovery of chemical shifts 14N.

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Ramsey, N. F. (1950) The internal diamagnetic field correction in measurements of the proton magnetic moment, *Phys. Rev.*, **77**, 567-567, https://doi.org/10.1103/PhysRev.77.567.

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Shielding of nuclear magnetic moments with electronic shells results in the chemical shift in NMR frequency.

(S. S.) Theory of chemical shifts.

Shaw, T. M., and Elsken, R. H. (1950) Nuclear magnetic resonance absorption in hygroscopic materials, *The Journal of Chemical Physics*, **18**, 1113-1114, https://doi.org/10.1063/1.1747875.

(S. S.) Water absorption and moisture studies will be an NMR evergreen.

Sternheimer, R. (1950) On nuclear quadrupole moments, *Phys. Rev.*, **80**, 102-103, https://doi.org/10.1103/PhysRev.80.102.2.

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Thomas, J. T., Alpert, N. L., and Torrey, H. C. (1950) Nuclear magnetic resonance in methane, *J. Chem. Phys.*, **18**, 1511, https://doi.org/10.1063/1.1747522.

Townes, C. H., Herring, C., and Knight, W. D. (1950) The effect of electronic paramagnetism on nuclear magnetic resonance frequencies in metals, *Phys. Rev.*, **77**, 852-853, https://doi.org/10.1103/PhysRev.77.852.

Townes, C. H., and Turkevich, J. (1950) Hyperfine structure and exchange narrowing of paramagnetic resonance, *Phys. Rev.*, **77**, 148-148, https://doi.org/10.1103/PhysRev.77.148.

Trounson, E. P., Bleil, D. F., Wangsness, R. K., and Maxwell, L. R. (1950) Magnetic resonance in antiferromagnetic materials near the Curie temperature, *Phys. Rev.*, **79**, 542-543, https://doi.org/10.1103/PhysRev.79.542.2. (trR, S. V. Vonsovsky, ed.)

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Abragam, A., Pryce, M. H. L., and Simon, F. E. (1951) Theory of the nuclear hyperfine structure of paramagnetic resonance spectra in crystals, *Proc. R. Soc. Lond. A*, **205**, 135-153, https://doi.org/10.1098/rspa.1951.0022.

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Abragam, A., and Pryce, M. H. L. (1951) The theory of paramagnetic resonance in hydrated cobalt salts, *Proc. R. Soc. Lond. A*, **206**, 173-191, https://doi.org/10.1098/rspa.1951.0063.

Andrew, E. R. (1951) Nuclear magnetic resonance absorption in NaSbF6, *Phys. Rev.*, **82**, 443-444, https://doi.org/10.1103/PhysRev.82.443.

Arnold, J. T., Dharmatti, S. S., and Packard, M. E. (1951) Chemical effects on nuclear induction signals from organic compounds, *J. Chem. Phys.*, **19**, 507, https://doi.org/10.1063/1.1748264.

Highly-resolved proton NMR spectrum of ethanol comprising three proton line shapes with different chemical shifts obtained for the first time.

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Arnold, J. T., and Packard, M. E. (1951) Variations in Absolute Chemical Shift of Nuclear Induction Signals of Hydroxyl Groups of Methyl and Ethyl Alcohol, *J. Chem. Phys.*, **19**, 1608-1609, https://doi.org/10.1063/1.1748134.

(S. S.) First report on variability in chemical shift of mobile hydrogens.

Bloch, F. (1951) Nuclear relaxation in gases by surface catalysis, *Phys. Rev.*, **83**, 1062-1063, https://doi.org/10.1103/PhysRev.83.1062.

Bradford, R., Clay, C., and Strick, E. (1951) A steady-state transient technique in nuclear induction, *Phys. Rev.*, **84**, 157-158, https://doi.org/10.1103/PhysRev.84.157.

(S. S.) Introduction of SSFP (Steady-State Free Precession).

Clay, C. S., Bradford, R. S., and Strick, E. (1951) A possible relation between the nuclear relaxation time, T2, and molecular structure, *J. Chem. Phys.*, **19**, 1429, https://doi.org/10.1063/1.1748086.

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Ethics approval and consent to participate

This work does not contain any studies involving human and animal subjects.

Conflict of interest

The authors of this work declare that they have no conflicts of interest.

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