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FOREWORD

I am most pleased and, in a way, I feel honored to write the Foreword for the book *The Hanle Effect and Level-Crossing Spectroscopy*, which covers such a very wide range of applications not only in the initial areas of atomic and molecular physics, but also in solid state physics, solar physics, laser physics, and gravitational metrology. To link these fields together in a *coherent* way has been the merit of the editors of the book, who attracted most distinguished authors for writing the chapters.

In retrospect to Hanle's discovery of *quantum mechanical coherence* between two quantum states about 65 years ago, this book demonstrates the enormous impact and central importance the effect has had, and most vividly still has, on modern physics. On the other hand, the concept of quantum mechanical coherence, which is an outgrowth of the linear superposition principle of quantum states, has been evident through a considerable number of experimental methods beyond the original Hanle effect; some of these methods were only recently discovered or applied and they have indeed revolutionized research fields such as atomic collision physics. For example, measurements of interfering magnetic sublevel scattering amplitudes in impact excitation of atoms opened up a new area of research in which so-called *complete* or *perfect atomic collision experiments* are applied. The famous Franck-Hertz experiment of electron impact excitation of atoms which proved energy conservation between colliding atoms and electrons and the emitted photons has been extended by the electron-photon coincidence technique during the last two decades. The analysis of such modern Franck-Hertz experiments in which the electron, having excited the atom, and the photon are detected in coincidence is based upon coherence effects for the excitation amplitudes of magnetic sublevels. Allow me just to mention that these "dynamical coherence effects" of impact excitation of atoms link a considerable part of my own research to that initiated through Professor Hanle in the Institute of James Franck at Göttingen. I am using the word *dynamics* because the coherence effects in impact excitation of atoms depend both on the energy of the incoming electrons and on the angle of the inelastically scattered electrons. Only very recently have quantum chromodynamical coherence effects been discovered in jets of high-energy particle reactions.

Hanle's life was not free from dramatic experiences which were, particularly in connection with the discovery of the Hanle effect itself, highly exciting. When he was a student in his fifth semester at Heidelberg and 21 years old, he presented a seminar on the energy–mass equivalence and the deflection of light from the sun that had just been detected by a British research group. This seminar led to a massive conflict with Noble prize winner Professor Lenard, who did not accept Einstein's theory of relativity. As a consequence of this severe clash with Lenard, Hanle was advised to leave Heidelberg so he went to James Franck and Max Born at Göttingen, where he encountered a completely different, humane attitude and a highly stimulating scientific environment. Göttingen was developing into a world center of research in physics and Hanle's investigation on fluorescence polarization was very highly regarded. However, distinguished theoretical physicists did not initially agree with Hanle on the interpretation of his effect. Max Planck personally said to Hanle, "your interpretation cannot be correct, it contradicts quantum theory." Of course, modern quantum mechanics was not yet born and most theoreticians considered his effect as a kind of Faraday effect. However, the decisive breakthrough came after Arnold Sommerfeld's visit to Göttingen when the great master of atomic theory asked him for an explanation of the magnetic effects on the polarization of resonance fluorescence detected by Wood and Ellet and Hanle himself. Next day, after having worked the whole night in the laboratory and checking experimental data, he presented his classical explanation and the suggestion of coherence of the two σ-components of the resonance light.

After gaining his PhD in Göttingen in 1924 Hanle stayed on as a research assistant for one year, and went then to Gerlach in Tübingen for half a year. J. Franck subsequently recommended Hanle to Gustav Hertz in Halle; there Hanle pioneered another piece of work, namely, the measurement of optical excitation functions of atoms by electron impact. Again, this work opened up a whole new field of research leading to cross-section measurements and, in the 1970s, to angular correlation experiments of coincident electrons and photons in impact excitations of atoms. Two and a half years after his PhD, Hanle received his Habilitation and was promoted to "Privatdozent," the first step toward a successful University career in Germany. In 1929 Hanle became "ausserplanmässiger Professor" in the Institute of Geheimrat Max Wien in Jena/Thuringia; at that time he was the youngest professor of experimental physics in Germany. During his stay at Jena University, Hanle was also asked to administer the chair of the distinguished Professor P. Debye and also another extraordinary chair of radiation physics. However, owing to clashes with the Nazis, Hanle lost his appointment in Jena in 1937. His friend, Professor Joos, saved Hanle's

University career by appointing him as an assistant back at Göttingen University subject to the special condition that he should refrain from any political statement. In 1939 Hanle was drafted for military service with responsibility as head of the weather station for a military airport. Afterward he was delegated to research on important war activities, such as radar and infrared technologies. In 1941 Hanle succeeded Professor Gerthsen of Giessen University. Of course research and scientific work was almost impossible during the war and in 1944 the building of his Physics Institute was bombed and destroyed to a large degree.

Immediately after the war, Hanle and his colleagues were responsible for traffic and the allocation of the needs of the population in the region. Convinced of the importance of science and physics, Hanle put an enormous effort into rebuilding Giessen University, the science faculty, and the Physics Institute. In 1953 Hanle was offered the distinguished chair of Ramsauer at the Technical University in Berlin. He was tempted to accept the offer and to help the City of West Berlin in its fight for survival and to reestablish Berlin once again as a world center of scientific research. As a diploma student of Professor Hanle in Giessen, I remember his many journeys between Berlin and Giessen and his concern for promoting what he had built up at the Justus-von-Liebig-University in Giessen. He finally decided to remain in Giessen and also turned down a chair at Saarbrücken University in 1957.

A large number of publications have resulted from Hanle's work with many research associates and research students at Giessen. Polarization of fluorescence and phosphorescence radiation, in a way related to his famous PhD thesis at Göttingen, continued to be one of his favorite and beloved fields of research. Continuous studies of his well-known excitation and ionization functions of atomic, molecular, and polymer systems and the development and extension of the ultrasonic fluorescence meter by Hanle and Maercks (1938) showed his preference for research in light emission. The development of scintillation counters linked his studies on the production of light by energetic particles to nuclear physics.

In 1954 Hanle became chairman of the committee of radiation measurements of the atomic ministry with the Government at Bonn for a full decade. As a result of his duties at the ministry and his two offers of full professor at Berlin and Saarbrücken, Hanle's Institute at Giessen was provided with a generous new building and also a new Institute on Radiation Physics ("Strahlenzentrum") was provided as one of the first interfaculty institutions in the Federal Republic of Germany (FRG). Hanle was a member or chairman of many national and international committees, notably of the German-French-Rector Conference, chairman of the Röntgen Museum, chairman of the education committee on the diploma in physics, and editorial adviser of the *Physikalische Blätter*, which is the official journal of the German Physical Society. A series of honors were bestowed on Hanle: Dr. Ing. E.h (honorary doctor of the faculty of engineering) by the University of Stuttgart in 1970, the Grosses Verdienstkreuz (an important medal) of the FRG in 1973, the Röntgen prize of the Röntgen Museum in 1975, and, last but not least, in the same year, the University of Göttingen renewed his doctorate to commemorate the 50th anniversary of his famous PhD award in 1925.

When he became Professor Emeritus, Hanle continued to be active in research on level-crossing spectroscopy. He still takes a lively interest in this field of research and attempts to record every known and new activity of his effect. He also devoted much work to editing the first two volumes of *Progress in Atomic Spectroscopy*, which, together with the subsequent two volumes, have developed into a most comprehensive survey of the achievements in atomic physics research.

I was always highly impressed by Hanle's clear and direct approach in understanding and analyzing the fundamental physics of a given research problem. I highly treasure the many and fruitful discussions I had with Professor Hanle as my teacher and highly regarded mentor.

Not only the scientific community of physicists but also laymen and people of our generations will be in debt and grateful to Professor Hanle for his achievements.

H. Kleinpoppen
Stirling

PREFACE

The Hanle effect was presented by Wilhelm Hanle in *Zeitschrift für Physik* in 1924. During the following years, the efforts to provide a consistent interpretation of this effect played a dominant role in the development of quantum theory. Several works on this subject by N. Bohr, G. Breit, R. Oppenheimer, V. Weisskopf, and W. Hanle himself contributed to the definite supersession of the old theory, according to which quantum systems could exist only in what are now called stationary states, in favor of the present quantum theory, which regards the possible states of a system as vectors of a Hilbert space. Experimentally, the Hanle effect provided a method for measuring the natural linewidth, and thus the lifetime, of an excited level independently of the Doppler broadening.

In more recent years, since the revival of atomic and molecular spectroscopy which followed the introduction of double resonance spectroscopy by Bitter, Brossel, and Kastler in 1949, of optical pumping by A. Kastler in 1950, and of (nonzero field) level crossing by Colegrove, Franken, Lewis, and Sands in 1959, the Hanle effect has constantly found novel applications in pure and applied physics.

The aim of the present book is to provide a complete physical insight into the Hanle effect and level-crossing spectroscopy, and to present an overview, as complete as possible, of their applications in many different fields of physics. The introduction provides a brief historical survey, an English translation of Prof. Hanle's original paper, and a general discussion of the effect. In the subsequent chapters, appropriate authors present the applications of the Hanle effect and level crossing in several fields. These cover atomic, molecular, and solid state physics, where physical properties like, for instance, the quantum state lifetimes can be determined by measuring the Hanle effect at known external fields; solar physics where, conversely, the observation of the effect on states of known lifetime can lead to the determination of the field intensities; gravitation, where the Hanle laser is proposed as a possible gravitational probe; and laser physics and technology, where the nonlinear Hanle effect, apart from its theoretical interest, can lead to large enhancement in laser output power. The chapter dedicated to laser physics provides the first available extensive survey on the effects of an external field on the output power of gas lasers. Special emphasis is dedicated to far-infrared molecular lasers and to noble-gas ion lasers; the combined action of magnetic plasma confinement and the nonlinear Hanle effect in a noble-gas ion laser are also thoroughly discussed, in view of their important commercial applications. Several new results are presented for the first time in this book.

We hope that the scientific community will appreciate the efforts made by the authors, who have undertaken the difficult task of a clear and, as far as possible within the limits of the available space, complete description of the aspects of an exciting subject, which has played extremely important rôles in several branches of physics for more than 60 years since its discovery.

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