

Chapter 1

Gustav Mie: From Electromagnetic Scattering to an Electromagnetic View of Matter

Wolfram Hergert

Abstract The year 2008 saw the 100th anniversary of the publication of Gustav Mie's work "Contributions to the optics of turbid media, particularly colloidal metal solutions" in *Annalen der Physik*. This event was an occasion to express appreciation for his contribution to the theory of scattering of electromagnetic waves. The achievements of Gustav Mie in the framework of the development of an unified field theory and his contributions to the discussion around the formulation of the theory of general relativity have been mentioned many times in other contexts. A detailed description of Gustav Mie's work has, until now, been unavailable. This contribution undertakes the task of presenting a comprehensive account of the life and scientific work of Gustav Mie.

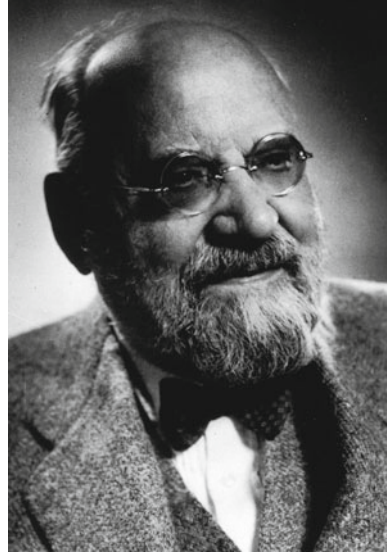
1.1 Introduction

It is generally perceived that the revolutions in physics at the beginning of the twentieth century are marked by the development of quantum physics and the special and general theories of relativity. Planck's introduction of the concept of quantum of action, regarded as the dawn of quantum physics, in December 1900 and Einstein's *annus mirabilis* 1905 mark this development. These milestones of progress in modern physics are often reflected as achievements of theoretical physics, although their starting points were experimental results and questions of those times. The best-known is the discovery of a new kind of radiation by W.C. Röntgen in the year 1895, based on experiments with cathode rays. In 1891,

W. Hergert (✉)

Department of Physics, Martin Luther University Halle-Wittenberg, Halle, Germany
e-mail: wolfram.hergert@physik.uni-halle.de

Fig. 1.1 Gustav Mie
(29.9.1868–13.2.1957).
[Archives University of
Freiburg (UAF)]



Gustav Mie (1868–1957) (Fig. 1.1), then a 23-year-old postdoctoral research fellow, stood at the beginning of his scientific career. Besides the development of modern physics, changes in the structure of the institutions occurred at that time. Cahan [1] discussed the institutional revolution in German physics in the years 1865–1914. The professional ethos of physicists at universities changed from pure teaching to research. The typical structure of a physical institute developed at German universities in the second half of the nineteenth century, accompanied by the construction of new and adequate buildings. Rostock and Heidelberg, where Mie studied, received new buildings for the physical institutes only after the turn of the century, whereas during 1890–1891, the buildings in Greifswald, Halle and Freiburg, where he later got a professorship, were ready for occupancy and operation. Gustav Mie's most creative years coincided with the time, when theoretical physics was established as an independent discipline [2].

Mie said of himself about his work:

As far as I can adjudicate on me, it became my occupation to establish the connection between theoretical and experimental physics, which stood at that time in danger, to diverge more and more. I believe that my most important achievement was the publication of a text book on electricity, in which I, above all, show Maxwell's differential equations, which to an outsider appear quite abstract, are nothing else as the shortest and most exact formulation of experimentally found laws, by which electrical and magnetic fields are linked with one another.¹

¹ [Mie81], p. 738f.

First, the stages of Mie's scientific career are reviewed. His scientific work is then highlighted in the second section. The connection between experimental and theoretical physics was very important for him. The following discussion will be concentrated on his theoretical work. Classical electrodynamics, field theory, theory of relativity and the quantum theory are his main fields of research. The work on the theory of matter and the contributions to the theory of the scattering of electromagnetic waves are particularly important. Gustav Mie's role as a lecturer along with a description of his disciples is the main theme of the next section. Mie's publications document also his desire, to present modern physical developments to a broader audience. These activities are treated together with his role as a lecturer.

The scientific achievements and conflicts of his long life were also overshadowed by two world wars and the time of the National Socialist movement. In this context, his reflections of social developments will also be discussed, as far as they can be concluded from his diaries, letters and secondary sources. I attempt to list a bibliography of the publications of Gustav Mie, as completely as possible. A bibliography of biographic notes on Mie is also provided.

Biographic details are specified in footnotes for persons who were important to Mie's scientific career and life; otherwise only biographical data is given. The origins of the figures and the photographs which did not originate from the author are explicitly cited.

1.2 Life and Scientific Career

1.2.1 *Childhood in Rostock*

Gustav Adolf Feodor Wilhelm Ludwig Mie was born on 29 September 1868 in Rostock (Fig. 1.2) to Hans Friedrich Ernst Amandus Mie (1828–1906), a salesman active in the insurance business and his wife Caroline, nee Ziegler (1834–1901). His parents were both children of Protestant pastors. Many of his Mecklenburgian relatives were Protestant pastors.² His uncle, Fedor Mie (1840–1905), worked as a Protestant pastor at St. Petri in Rostock.

Gustav Mie spent his childhood and youth in Rostock. He had three brothers and one sister. His brother Friedrich (1865–1911) became a high school professor in Berlin. His brother Johannes Mie worked as a merchant in Hamburg. His brother Amandus carried on with the family tradition and worked as a Protestant pastor in Scharnebeck.³ Gustav Mie attended High School at the Great City School (Große Stadtschule) in Rostock (Fig. 1.3), an educational institution rich in tradition, from

² The origins of the branched family can be followed up in [3].

³ H. Spehl, Mie, Gustav Adolf Feodor Wilhelm Ludwig in: [Bio6] p. 186ff., [4], [Mie81], p. 734.



Fig. 1.2 Mie's birthplace (house on the corner), Wokrenter Strasse 35 in Rostock. The house was all but destroyed in the war; however, it was carefully rebuilt in 1981–1982

1877 to 1886.⁴ The Christian Protestant family tradition instigated his desire for studies in theology after his Abitur. During high school, his interest shifted from theology to natural sciences. In his memoirs, he wrote about this change:

It was not until I was a sixth former that I got the idea of becoming a natural scientist and mathematician. Even today, I can recall the blessedness I felt when this idea came to mind and my parents agreed upon it. I have never been happier in my whole life than during those days and it felt like I was wandering around in paradise. The fact that I took the exam in Hebrew for my Abitur in 1886, typical of someone aiming at studying theology, proved how late I made my decision.⁵

However, it was not all plain sailing. Mie's brother Friedrich struggled to leave his career as a Protestant pastor imposed on him by his parents. In the year 1886, Mie received his school leaving certificate (Abitur). In the Abitur certificate (cf. Fig. 1.4), he was assessed to have a commendable behaviour. His diligence and attention was reported as, "in former times [as] insufficient, in the last terms good and very good". He finished the subject Mathematics with the grade "very good". "In Mathematics, he demonstrated ...good knowledge. Solving problems

⁴ The Great City School was installed in 1580 under the superintendence of the humanist Nathan Chyträus (1543–1598) in the former Dominican monastery St. Johannis. In the years 1864–1867 the new classicistic building was built by the Rostock architect Th.H. Klitzing. Between Easter 1860 and Michaelis 1901, 7 pupils named Mie completed the Great City School [5].

⁵ [Mie81], p. 734.



Fig. 1.3 The Great City School in Rostock

g. in der **Mathematik** zeigte er in allen Prüfungsarten, nicht nur
gute Kenntnisse. Die Lösung der Aufgaben war meist
einmalig und richtig. Die Preisbeurteilung war sehr gut.
Insbesondere die mündliche Prüfung war gut.
Sehr gut.

h. in der **Physik** hat er bei allen Prüfungen eine gute
Auffassung der Naturerscheinungen und seine Kenntnisse
war gut. Gut.

i. in der **Chemie** hat er bei allen Prüfungen eine gute
Auffassung der Naturerscheinungen und seine Kenntnisse
war gut. Gut.

Fig. 1.4 Part of Gustav Mie's Abitur certificate. (UAF, Nachlass Mie, C136/1—Zeugnisse)

never caused difficulties for him. The exam results were very good. Therefore, he was excused from the verbal examination”.⁶ He also achieved a good grade in Physics. The school leaving certificate states: “In Physics he always had keen interest, a good understanding of natural phenomena and acquired a good

⁶ Archives University of Freiburg (UAF), Nachlass Mie, C136/1—Zeugnisse.

knowledge of the physical laws”.⁷ In Chemistry, Hebrew, Greek and History he also achieved good grades, while he was not as successful in the foreign languages English and French, and neither was he very successful in his native German.

1.2.2 Study in Rostock and Heidelberg (1886–1890)

Mie completed his studies at the university in his hometown Rostock as well as in Heidelberg. He first enrolled in Rostock in the winter semester of 1886–1887. After three terms, he moved on to Heidelberg in the summer of 1888, “to become acquainted with something else” as he writes in his memories.⁸ It might be, that also the Rostock mathematician Martin Krause (1851–1920), a disciple of Leo Königsberger (1837–1921) the prominent mathematician in Heidelberg at that time, contributed to his decision. The summer term of 1889 saw him back in Rostock. He finished his studies in Heidelberg, where he spent the remaining time from the winter semester 1889–1890 up to the summer semester 1890.

Initially, he placed emphasis on chemistry, geology and mineralogy. In the winter semester of 1886–1887, 18 students were enrolled in chemistry at Rostock University.⁹ Chemistry was lectured by Oscar Jacobsen.¹⁰ Chemistry in Rostock had a good reputation at the time. Mie attended lectures on mineralogy and geology given by Eugen Geinitz.¹¹

Prior to the beginning of Mie’s studies in Rostock, mathematics, physics, geology and astronomy were represented by Hermann Karsten,¹² born into an old Mecklenburgian family, which produced a number of scholars. Karsten was, at the same time, director of the Navigation School. Only late, in contrast to other German universities, did an independent chair for physics become installed in Rostock. The first full professor was Heinrich Matthiessen¹³ who started at 1873.

Physics was housed in the same building as chemistry for a long time. As a result of considerable extensions to the university available in the years 1870–1890 a

⁷ *ibid.*

⁸ [Mie81] p. 735.

⁹ [6], p. 1003.

¹⁰ Oscar Jacobsen (1840–1889), study in Kiel, 1865 assistant at the Chemical Laboratory of the University of Kiel, 1868 graduation, 1871 private lecturer, 1873 professorship in Rostock, see also [7].

¹¹ Eugen Geinitz (1854–1925), study in Dresden and Leipzig, 1876 graduation Leipzig, 1877 habilitation Göttingen, private lecturer in Göttingen and Heidelberg, 1878 professorship in Rostock. Geinitz is the father of the geology of Mecklenburg (Book “Geologie Mecklenburgs”).

¹² Hermann Karsten (1809–1877), studies in Bonn, Berlin and in Königsberg with Bessel, 1830 private lecturer in mathematics and mineralogy in Rostock, 1832 extraordinary professor, 1836 professor.

¹³ Heinrich Friedrich Ludwig Matthiessen (1830–1906) studies of natural sciences in Kiel with G. Karsten, grammar school teacher in Jever and Husum, 1873 professor in Rostock.

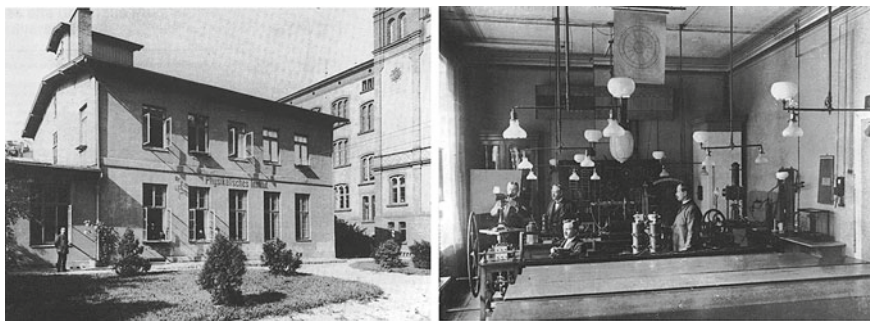


Fig. 1.5 *Left* View of the old Institute of Physics in the year 1885 (still without the front extension). On the back of the original photo Prof. Matthiessen noted the following in August 1885: “The Physical Institute—1885 photo taken by Dr. phil. Mönnich, Privatdozent, and given to the Institute. The persons presented on it, from left to the right, are: Institute servant Maass, cand. König, stud. Black (IInd assistant), cand. Karnatz (assistant) and teacher Klingberg”, *Right* Interior of the old Institute of Physics, persons from left to right Dr. Groesser, Prof. Matthiessen, Dr. Brüsck and Maass ([9], pp. 96 and 99.)

building within the yard of the main building became available for physics, which had already served as a chemical laboratory from 1834 to 1844 [8] (see Fig. 1.5). This was the situation the student Gustav Mie encountered at the physical institute.

In the year 1879, the mathematical–physical seminar was established; the first directors were physicist Hermann Matthiessen and mathematician and astronomer Johann Martin Krause.

Paragraph 1 of the statutes of this seminar reads as:

The mathematical–physical seminar has to give the students suggestions and guidance for independent investigations and free lectures in the field of abstract mathematics and in mathematical physics. Subject to further regulations, the control of this institute will be transferred to the professors of mathematics and physics under the superintendence of the Ministry, Department of Education. Independent from each other they offer topics for small and larger written work and free lectures and give suggestion and guidance to the members for execution of the tasks. The details of the contents and scheduling of the seminar-like exercises are left to the directors.¹⁴

The directors could nominate three students for one award per term. Mie was awarded in the year 1889.¹⁵ Chemistry and physics, however, quickly slipped into the background of Mie’s studies.

In the middle of the nineteenth century, Heidelberg was outstandingly represented in physics, chemistry and mathematics. Chemist Robert Bunsen (1811–1899) taught there from 1852 until retirement in the year 1889. Hermann von Helmholtz (1821–1894) a versatile physiologist and physicist, held the chair for physiology in Heidelberg from 1858 to 1870. Gustav Kirchhoff (1824–1887)

¹⁴ [10], p. 223.

¹⁵ [11], p. 828.



Fig. 1.6 *Left* Leo Königsberger (1837–1921), mathematician, *Right* Harry Rosenbusch (1836–1914), mineralogist and petrographer. (Courtesy of UAH)

was a full professor for physics in Heidelberg from 1854 to 1875. His successor was Georg Hermann Quincke (1834–1924). Mathematics was also outstandingly represented in Heidelberg. Following Ludwig Otto Hesse (1811–1874), Leo Königsberger¹⁶ taught for a short period between 1869 and 1874 (Fig. 1.6). Succeeding Immanuel Lazarus Fuchs (1833–1902), Königsberger taught from 1884 to 1914 for the second time in Heidelberg. In 1869, a mathematical–physical seminar was established at Heidelberg university, with Kirchhoff and Königsberger as the first directors.¹⁷ In the year 1890, the subjects physics, chemistry, botany, zoology, mineralogy, mathematics and agriculture were separated from the Philosophical Faculty and combined to form a new Scientific-mathematical Faculty. The physicist Quincke was the first dean and the mathematician Königsberger became his deputy.

In spite of Quincke and Bunsen being outstanding scholars in physics and chemistry, Mie continued to concentrate on mathematics and mineralogy.

¹⁶ Leo Königsberger (1837–1921) Professor in Greifswald, Dresden Vienna and Heidelberg, work on the theory of elliptical and hyperelliptical integrals and complex differential equations, Helmholtz biography, see also [12].

¹⁷ Statutes of the seminar in, Archives of University of Heidelberg (UAH), Fak. -Akte H-IV-102/71, Nr. 78, fol. 75–76, cf. [13]. Statutes of such seminars are regularly printed in “Zeitschrift für mathematischen und naturwissenschaftlichen Unterricht”, for example in vol. 5, 173 (1874) the statutes of the mathematical–physical seminar of Halle University can be found.

One reason for this choice may have been the absence of lectures in theoretical physics. Mie acquired his knowledge in theoretical physics mainly by self-instruction. It may be, due to his engagement in mineralogy, that Mie was not a regular member of the mathematical–physical seminar; only students having mathematics and physics as their main subjects could be regular members.

In Heidelberg, the mathematician Leo Königsberger and the mineralogist and petrographer Rosenbusch¹⁸ (Fig. 1.6) were his academic teachers. Königsberger was a excellent academic teacher. A student reported on his lectures:

Königsberger performed with virtuoso control of the material rapidly, clearly, dragging the listener along. His fresh, self-confident, strong nature, as well as his kindness and fairness secured him the affection of the academic youth.¹⁹

Mie completed the summer semester of 1889, once again in Rostock, and concluded his study in the summer of 1890 in Heidelberg. The emphasis of his study was mineralogy and mathematics. His preoccupation with mineralogy was so intense that Harry Rosenbusch, the founder of the systematic petrography, employed him as a junior research assistant. Mie's task was to organise and catalogue the hand piece and thin section collection consisting of 7,000 pieces.

Leo Königsberger remembers his student Mie in his memories. He writes:

My lecturer activity ... turned out well beyond all expectation, excellent young men, who later occupied many chairs of mathematics, physics, astronomy at German and foreign universities, like Ph. Lenard, M. Wolf, G. Mie, K. Boehm among others, whom I call my scholars.²⁰

Max Wolf (1863–1932) later was the director of the National Observatory of Baden in Heidelberg and Phillip Lenard (1862–1947), Nobel Laureate of the year 1905, occupied the physics chair in Heidelberg.

Gustav Mie registered for the state examination of the higher teaching profession in 1890. He had to take the exam at the Technical University of Karlsruhe. He requested the examination in mathematics and physics as major subjects, and took mineralogy and chemistry as minor subjects. He also took an exam in religion through his own volition. His topic in physics was “to deduce, from the laws of induction, the basic principles necessary for the construction of dynamo-electric machines, as well as it's mode of action in a mathematical way”. He worked on this topic with such enthusiasm and interest, leaving himself only 24 h to write his report on the mathematical topic. The situation was reflected in the assessment on his mathematical work:

The written examination in mathematics “On the geodetic lines on the surfaces of second order”, even if the developments in the individual points could be more detailed and more

¹⁸ Karl Heinrich Rosenbusch (1836–1914), professor for petrography and mineralogy at the universities of Strasbourg and Heidelberg, 1903 Wollaston medal, cf. also [14, 15].

¹⁹ Report of the student O. Rausenberger in [16], p. 179.

²⁰ [12] p. 187.

clearly expressed and also, the order and care of elaboration could be better, but overall, the contents and conception of the task can probably be rated sufficient.²¹

This is in contrast to the judgement of Otto Lehmann (1855–1922) with respect to the written examination in physics:

The treatment of the topic: “Mathematical deduction of the the basic principles of construction of dynamo-electric machines from the laws of induction” proves that the candidate applied himself to a level of excellence in particularly difficult theories of electricity and is able to move and independently proceed with full certainty in this area. It is acknowledged that the resulting work is be rated as excellent”.²²

In the summer of 1891, Mie attained a doctorate with the thesis “On the Fundamental Principle of the Existence of Integrals of Partial Differential Equations”. In the personal record for the thesis he wrote:

During his study time he [the author] visited the lectures of the following Mr. professors and associate professors: Krause, Matthiessen, Geinitz, Jacobsen, Königsberger, Cantor, Schapira, Rosenbusch, Osann, Goldschmidt, Andrae. To all his admired teachers, most of all Mr. Geh. Rat Königsberger and Mr. Geh. Bergrat Rosenbusch, the author expresses devoted thanks [Mie1].

1.2.3 Karlsruhe: Beginning of the Scientific Career (1892–1902)

After graduation, the pursuit of a scientific career seemed unlikely. Mie found an employment in Dresden at a private school in summer 1892.²³ Anyway, Mie sent a copy of his thesis to Otto Lehmann, his examiner in physics in the state examination, and was offered an assistantship at the Technical University of Karlsruhe. Otto Lehmann²⁴ was the successor of Heinrich Hertz (1857–1894), who was active from 1885–1889 at the TH Karlsruhe (Fig. 1.7). Hertz had accomplished his innovative experiments on the propagation of electromagnetic waves at that time. His successor Lehmann became famous for the investigation of liquid crystals.

Gustav Mie had to lead the physical practical course²⁵ and used this in order to gain appropriate knowledge in experimental physics. Furthermore, he had to

²¹ UAF, Nachlass Mie, C136/1 Zeugnisse.

²² *ibid.*

²³ From the copy of testimonials existing in the archives, it was revealed that this refers to the Müller Gelinek Six-form High School. This school had a long tradition and before the transformation into a private school on the 26 April 1819, it was the urban Friedrich August School.

²⁴ Otto Lehmann (1855–1922), Study Strasbourg, Teacher for Physics, Mathematics and Chemistry in Mulhouse (Alsace), 1883 Lecturer in Physics TH Aachen, 1888 Professor for Electrotechnology at the Polytechnic Institute Dresden, 1889 Ordinarius at Karlsruhe Technical University Fridericiana with teaching assignment for Physics and Electrotechnology.

²⁵ see Lehmann’s report in [17], p. 84.

support Lehmann with the experiment lectures. The large number of students in Karlsruhe and the impression of the lectures of Kundt (1839–1894) during his study in Strasbourg brought Lehmann to dedicate himself to the intensive development of experiment lectures.²⁶ Regarding the experiments shown in the lectures of Lehmann it is said:

Also today most experimental physicists prefer the demonstration of physical experiments in the large-scale setups, which could be noticed from all places of the lecture room. This style was consequently pursued by Lehmann. The enormous size of his experimental assemblies and the spryness of the experimental presentation led to largest acceptance and concentration among his students. To demonstrate the forces that could be produced by electric currents, Lehmann, according to the verbal report of a student, catapulted a lab assistant to the lecture room ceiling using current power. Although such experimental setups could not become completely accepted, they surely remained not without influence on the modern presentation of physical experiments. They have been certainly treasured by his students, who reported after the lecture grinning due to “Circus Lehmann”.²⁷

Lehmann’s appointment to an extraordinary professorship of electrotechnology at the Polytechnic Institute in Dresden took place with himself quoted as saying, “without any intention of dedicating myself permanently to electrotechnology”.²⁸ In the year 1895 in Karlsruhe the Electrotechnical Department was created and thus electrotechnology was separated from physics. At this time the technical universities Darmstadt and Hannover were prominent in the training of electrical engineers. Karlsruhe, although one of the latecomers with regard to the institutionalisation of electrotechnology, ascended in 1910 to become the prominent training centre for electrical engineers.²⁹ In the year 1892, an electrotechnical extraordinary professorship was awarded to August Schleiermacher (1857–1953), a former assistant of H. Hertz. Over three decades, from 1896 to 1927, he represented theoretical electrotechnics as professor ordinarius.³⁰ There was a friendly and collegial contact between Hertz and his assistant of only a year younger, Schleiermacher, recorded in Hertz’s diaries.³¹ Schleiermacher, as the first professor at a German technical university, conducted his lectures on theoretical electrotechnics based on Maxwell’s theory. However, the appointment of Engelbert Arnold³² in the year 1894 was considerably more important to the

²⁶ see [17], p. 88f., see also [18].

²⁷ [19], p. 108, private communication K.A. Turban 1881.

²⁸ see [17], p. 72.

²⁹ see: W. König, *Gewinner und Verlierer. Der Stellenwert der einzelnen Hochschulen im Institutionalisiertungsprozess der Elektrotechnik in Deutschland 1882 bis 1914*, in [20], p. 171ff.

³⁰ In 1892 he was appointed as first budgetary professor for electrotechnics in Karlsruhe. On 11 July 1896 Schleiermacher became regular professor for theoretical physics in the electrotechnical department of Engelbert Arnold. In 1926 the chair was rededicated to theoretical electrotechnics after Schleiermacher’s retirement. cf. [21].

³¹ cf. [21], p. 25.

³² Engelbert Arnold (1856–1911), 1874–1878 studies in Zürich, 1880–1891 Polytechnic Institute Riga, joint founder of the Russian-Baltic Electrotechnical Factory 1888, 1891 chief electrician of Maschinenfabrik Oerlikon, from 1894 Karlsruhe, see also [22].

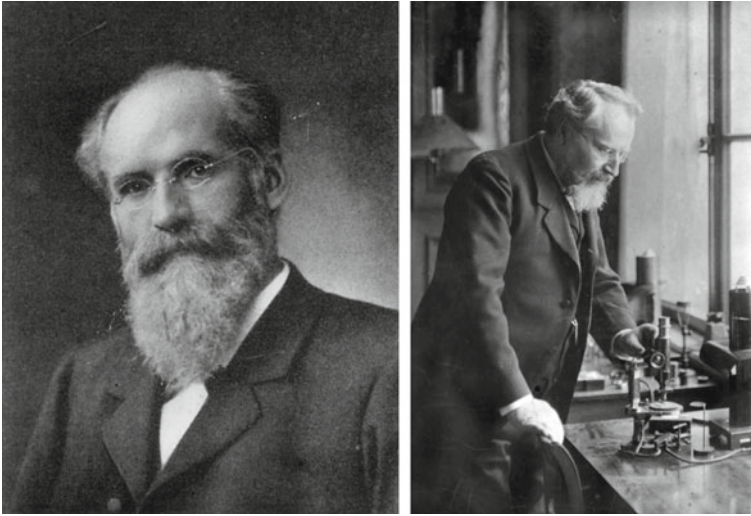


Fig. 1.7 Engelbert Arnold (1856–1911), Otto Lehmann (1855–1922). (Archives Karlsruhe Institute of Technology, Karlsruhe)

success of electrotechnology in Karlsruhe (Fig. 1.7). Arnold focussed his work in the area of the construction of high performance, high-speed d.c. machines. This was the area which was treated by Mie in his state examination work. All in all, Mie found a scientific environment in Karlsruhe strongly influenced by the ideas and scientific work of J.C. Maxwell and H. Hertz. He did not follow Lehmann's work on liquid crystals; however, an exchange of letters with Lehmann continued until much later.

In the first Karlsruhe years, Gustav Mie trained himself increasingly in physics, where electrodynamics and their technical application became his preferred field, both in practical experiments and theoretical treatment. Suggestions on how to deal with the problems with the systems of units put forward by Lehmann who was himself preoccupied with such questions at the time.³³ Electrotechnical problems were permanently present due to Arnold's work. Mie also worked on electro-technical problems in Greifswald, the next institution of his academic career. Interestingly, Mie published work on d.c. machines together with Arnold [Mie8].

With the work "Draft of a general Theory of the Energy Transmission" Gustav Mie attained habilitation on 29 July 1897.³⁴

³³ O. Lehmann, *Das absolute Maßsystem*, Verh. des Naturwiss. Vereins zu Karlsruhe **12**, 365 (1897), excerpts in: Zeitschr. für den physikal. und chem. Unterricht **10**, 77 (1897).

³⁴ University and regional Library (ULB) Halle: Dissertationes polytechn. Karlsruhanæ 1896–1899, No. 11, *Entwurf einer allgemeinen Theorie der Energieübertragung* von Dr. Gustav Mie, Habilitationsschrift zur Erlangung der *venia legendi* für mathematische Physik an der Großherzoglichen Technischen Hochschule in Karlsruhe. (Sonderdruck aus den Sitzungsberichten der K. Akad. der Wiss. Wien [Mie6]).

In the year 1900 Mie was appointed professor with the teaching assignment “Modern Trends and Opinions on Electricity and the Science of the Electrical Waves”.³⁵

In the scientific life of the university town Karlsruhe scientific associations were very important. Such an association was already created in 1840 by Alexander Braun (1805–1877), the director of the Naturalienkabinett at that time. Starting from 1862, the association arose as “Naturwissenschaftlicher Verein in Karlsruhe” with new statute. The “Naturwissenschaftlicher Verein Karlsruhe e.V.” has presently been active for 150 years. The report on the meetings of the years 1888–1895 proves that 12 to 15 meetings per year took place. The mean number of listeners was approximately 30. In average, physical topics have been discussed five times a year. The professors and members of the Physical Institute participated actively in this association since its inception. Heinrich Hertz presented his experiments for the first time to the public during one of the meetings of this association. From 1885 to 1889 Hertz presented eight times. Thus, he lectured on 24 June 1887 on “New Relationship between Light and Electricity”³⁶ and on 22 February 1889 he gave a lecture on “Relations between Light and Electricity”.³⁷ The original apparatuses used by Hertz were still present in the institute with Lehmann’s assumption of office. Lehmann wrote:

I came into possession of the physical cabinet which belonged to Hertz that contained several intrinsically worthless items, however, amongst them were, from a historical perspective, very precious apparatuses. There are in particular items, which in occasion of the International Electrotechnical Exhibition in Frankfurt a. M. in 1891 occupied an important place ... and will be later relinquished to the German Museum in Munich on its strong request ...³⁸

Otto Lehmann spoke regularly at the association meetings. Lehmann met with the other members for meetings mostly in the physics lecture hall, in order to be able to demonstrate experiments. The “Experimental Lecture on Röntgen’s X-rays” presentation by Lehmann was held on 7 February 1896.³⁹ While Hertz and Lehmann participated regularly and actively in the meetings of the scientific association, Engelbert Arnold, a member of the association too, hardly contributed.

Gustav Mie became a member during the 432th meeting on 16 December 1892. He gave his first lecture on 5 January 1894, entitled “On the Nature of Heat”. During his time in Karlsruhe Mie gave seven additional lectures in the meetings of

³⁵ [17], p. 84.

³⁶ Verh. des Naturwiss. Vereins zu Karlsruhe **10**, pp. 150–51 (1883–1889).

³⁷ ibid. **11**, pp. 41–43 (1883–1895).

³⁸ cf. [17], p. 71, in 1913 the Karlsruhe devices were inventoried in the German Museum in Munich. For the history of the devices see also: J.H. Bryant, *Heinrich Hertz’s Experiments and Experimental Apparatus: His Discovery of Radio Waves and his Delineation of their Properties*, in [23], p. 39 ff.

³⁹ Verh. des Naturwiss. Vereins zu Karlsruhe **13**, p. 37 (1895–1900), “The lecture, which was given by the speaker, over 3 weeks on five occasions, for different corporations and associations, is printed in the papers”, see also [Mie4].

the scientific association of Karlsruhe. He spoke in the 488th meeting on 15 May 1896 on the topic of “On the Meaning of Hertz’ Mechanics” [Mie10].

The replication of the Hertz experiments with the original equipments still existing in the institute at the time made a lasting impression on Mie. He also used parts of the original Hertz equipment in the meeting of the scientific association on 16 July 1897 to report on “Telegraphing without Wires, with Experiments”.⁴⁰ The work crucial for Gustav Mie’s further career was his publication on the Lecher problem [Mie9]. From this work he was noticed, for the first time, as a theoretical physicist, and not as an electrical engineer.

On 14 March 1901, Gustav Mie and Berta Hess, daughter of Friedrich Hess, district surveyor in Heidelberg, got married. It turned out to be a childless marriage. However, Gustav and Berta Mie spent a long and fulfilled life together. On 3 January 1916 he wrote about himself and his wife:

For an outsider, it is difficult to understand, how an inherently pedantic and quite scientific person, as I am, can be compatible with a person with an artistic nature and infused with fantasy, such as, like my wife.⁴¹

1.2.4 Greifswald: The productive Period (1902–1917)

From his theoretical work in Karlsruhe, in particular by the investigation of electrical waves on parallel wire systems [Mie9], Mie had already acquired a certain reputation. The attainment of an extraordinary professorship was thus the next logical step.

At the beginning of the twentieth century, Greifswald was a small Prussian university town at the Baltic Sea, not far away from Rostock, Mie’s native city. The university in Greifswald was founded way back in 1456.⁴² In the years 1888–1891 the Physical Institute acquired a new building under the auspices of Professor Anton Oberbeck (1846–1900), well adapted to the needs of physical research of that time (Fig. 1.8). Prior to his full professorship in Greifswald, Oberbeck held a chair for theoretical physics in Halle. The University of Halle was one of the first German universities, establishing such a chair.⁴³

The successor of Oberbeck in Greifswald was Franz Richarz (1860–1920). Richarz accepted a professorship at Marburg in 1901. The subsequent regulation paved the way for Mie to Greifswald. Carl König (1859–1936), who did not have a large impact in physics, was a professor extraordinarius in Greifswald since 1899. In the proposal by the faculty for Richarz’s successor, Hallwachs (1859–1922) (Dresden) and Dietrici (1858–1929) (Hannover) have been mentioned, but the

⁴⁰ Verh. des Naturwiss. Vereins zu Karlsruhe **13**, S. 98–103 (1895–1900).

⁴¹ UAF, Nachlass Mie, E12/69.

⁴² For the history of physics in Greifswald see [25–28].

⁴³ cf. [2] vol. 2, chapter 15, p. 33 ff.

faculty insisted in transferring the chair to König. In the course of this personnel decision the replacement of the professor extraordinarius should be settled at the same time.⁴⁴ The proposal list for the occupation of the extraordinary professorship covered Pringsheim (1881–1963) (Berlin), Elster (1854–1920) (Wolfenbüttel), Wiechert (1861–1928) (Göttingen), Mie (Karlsruhe) and Straubel (1864–1943) (Jena). Mie was set only on fourth place and the judgement over him was however farsighted and lead the Minister to entrust the position to a “coming man”:

Mie’s work shows the fact that his mathematical skill is linked also with the ability of physical opinion and important achievements for the future are to be expected from him. His publications are however up to now purely theoretical in nature.⁴⁵

The years in Greifswald were Mie’s most scientifically fruitful time. To a considerable degree it fulfilled the expectation that accompanied his appointment. In the year 1905, König was relocated to Gießen. During the Richartz follow-up discussion the budgetary professor extraordinarius was still favoured by the faculty, but now the situation took a different turn. The philosophical faculty reacted to the transfer of König with a three person proposal: Rubens (1865–1922) (Charlottenburg), Dieterici (Hannover), Pringsheim (Berlin). Concerning Mie the faculty explicated:

The present professor extraordinarius, Professor Mie has, by his scientific achievements and his personal integrity, acquired a respectable position and we would not hesitate to suggest him for the full professorship. However, it is our desire to put more emphasis on the experimental aspects of physics and a more fundamental form of presentation than we expect them to be given by Prof. Mie with his predominantly theoretical capabilities.⁴⁶

The ministry insisted on a more detailed rationale, and in the long run Mie got the position. Both appointment procedures show that theoretical physics began to be established that time. On 17 September 1905, Mie became a full professor under the condition that he represented physics in its entire extent. At the same time he was appointed the director of the Physical Institute and the Astronomical–mathematical Institute. From winter semester 1836–1837 until 1887 the Astronomical–mathematical Institute belonged to the Mathematics department. The Astronomical–mathematical Institute was moved to Physics department during the directorship of A. Oberbeck in the winter semester 1887–1888. Lectures in astronomy were given by W. Ebert (1871–1916) from 1903 till 1905.⁴⁷ During Mie’s directorship astronomy was abandoned. It was reactivated in 1922.⁴⁸ Gustav

⁴⁴ Archive of the University of Greifswald (UAG), Phil.Fak I290.

⁴⁵ *ibid.*

⁴⁶ UAG Phil. Fak. I 298.

⁴⁷ cf. A. Schnell, Gestrandet in Wien: Wilhelm Ebert (1871–1916), *Acta Hist. Astr.* **43**, 318 (2011).

⁴⁸ The building of the physical institute also contained an observatory. A modern astrodome on the tower can be seen on Fig. 1.8, cf. H. Kersten, *Astronomie in Greifswald* in [25], p. 51ff.



Fig. 1.8 The Physical Institute in Greifswald (built 1889–1891). A commemorative plaque is posted on the wall of the building. The text reads: “Professor Dr. Gustav Mie (1868–1957) cofounder of a uniform theory of particles and field, Greifswald 1902–1917”, see also [24]

Mie was Dean of the Philosophical Faculty in Greifswald in the year 1912–1913, and was elected rector of the university on 15 May 1916 for a one-year period. He began his rectorship with the lecture “Law of Nature and Spirit” [Mie39].

In the year 1916, Mie received an offer to be the successor of Ernst Dorn in Halle. After some hesitation and repeated negotiations with the ministry he accepted the offer in December 1916. As candidates for his successor, he brought Johannes Stark (1874–1957) (Aachen), as well as in second place, *pari loco* Johannes Königsberger (1874–1946) (Freiburg) and Clemens Schäfer (1878–1968) (Breslau) to discussion. Mie had already become acquainted with Stark during his time in Greifswald where Stark was serving as a substitute professor, in the years 1907–1908, for professor extraordinarius Starke (1874–1960), who was later an ordinarius at the RWTH Aachen from 1917 to 1940. The faculty at the end followed Mie’s proposal.

Inferred from his diaries, it was a happy time for Mie personally in Greifswald, despite difficulties due to the World War. During one evening on a sailing yacht Stark reported:

He [Mie] had an assistant named Falkenberg, who possessed a beautiful large sailing yacht with a habitable space. It lay on the Ryck opposite Wieck. Once we spent an amusing evening on it. It had already become dark, when we rose to the deck, in order to go ashore. It followed Guschen, as he was referred to by Mrs. Mie, deep in thought as usual, he continued to rise when he fell into the water which was, fortunately, only as deep as his

height. Despite the unfortunate accident we had to laugh at the sudden disappearance of the great philosopher. We pulled him out rapidly and he laughed, too.⁴⁹

1.2.5 Halle: Intermediate Station (1917–1924)

In 1890, at practically the same time as the Physical Institute in Greifswald, the Physical Institute of Halle University also got a new modern functional building. Also in Halle, special care was taken to set up a building that meets all the requirements of the physical research at this time [30]. Here, Ernst Dorn⁵⁰ acquired special merits. As successor of Oberbeck in Halle, he was considerably involved in the construction of the new institute.

After 1870, theoretical physics itself began to be institutionalised in Halle.⁵¹ With Anton Oberbeck, Halle had a professor extraordinarius for theoretical physics starting from 1878. In 1884, Oberbeck received an offer to Karlsruhe, his position was subsequently converted to a personal chair in order to maintain a position for him in Halle. The vacant chair in Karlsruhe was occupied by Heinrich Hertz. Hertz had an offer from Greifswald, but preferred Karlsruhe due to the excellent conditions in comparison to those at the institute in Greifswald. Oberbeck's personal professorship was occupied by Ernst Dorn later on. After the death of the full professor of experimental physics, Carl Hermann Knoblauch,⁵² Dorn took over his chair for experimental physics and became the director of the institute. The second position was downgraded to an extraordinary professorship for theoretical physics and transferred to Karl Schmidt.⁵³ This decision was unfortunate, to that extent, since Schmidt's field of interests had been more technical and applied physics than theoretical physics.

The institute in Halle was larger than the institute in Greifswald, had a higher reputation and even a higher remuneration. Theoretical physics, which was Mie's main focus, at least formally, was already institutionalised in Halle. Advancing this institute must have appeared as an appealing task to Mie, so much so that he accepted the offer from Halle. However, the hearings of the appeal were

⁴⁹ [29], p. 35.

⁵⁰ Ernst Dorn (1848–1916), studies in Königsberg, teacher in Königsberg and Berlin, 1873 habilitation in mathematics Greifswald, 1873 extraordinarius for physics in Breslau, 1881 professor in Darmstadt, 1886 professor in Halle as a successor of Oberbeck, 1895 director of the physical institute, see also [30].

⁵¹ see [2] vol. 2, p. 33ff.

⁵² Carl Hermann Knoblauch (1820–1895), studies in Berlin, 1845 cofounder of the Berlin Physical Society, 1848 habilitation in Berlin, 1849 professor in Marburg, 1853 professor in Halle, 1886–1871 rector of the University of Halle, 1878 President of the Leopoldina, see also [30, 31].

⁵³ Karl Schmidt (1862–1946), studies in Göttingen and Berlin, assistant in Strasbourg and Königsberg, 1889 habilitation Halle, 1895 extraordinary professorship for theoretical physics, 1912 personal tenured professorship.

complicated. The special position held by Schmidt, being the cause for conflicts over the next years, was a contributing factor.

During the regulation of the successor to Dorn, the faculty first mentioned Peter Debye (1884–1966), then Max von Laue (1879–1960) and in third place, Gustav Mie. As criteria for the selection the faculty stated:

Conserving the existing ordinaries is of outmost importance for the faculty. In addition, we would like to engage a scientific personality capable of arranging the academic instruction together with the present full professor in a harmonic and versatile manner. Another decisive aspect is that the former contrast between experimental and theoretical research has vanished and the present full professor's effort has developed in the more experimental direction. Therefore the faculty agreed on personalities with focus on theoretical aspects without excluding experimental work.⁵⁴

Debye and Laue were not to be attracted for Halle. Corresponding to the qualities of Mie the faculty noted:

As a distant third choice following these two researchers we propose Gustav Mie, Greifswald. ...The number of the Mie's papers is not as large as those of the two physicists selected first, nevertheless the treated problems and the kind of their solution marks Mie as a researcher of outstanding gift, deep thoroughness and great originality.⁵⁵

A large portion of the documents in the archive of Halle University from Mie's time in Halle reveals his conflicts with Karl Schmidt. Schmidt, who had large support within the faculty and from the chancellor, steadily tried to increase his influence in the institute. Mie's plans for the modernisation of the institute in Halle were thwarted by Schmidt.

During his time in Halle, Mie actively participated in the sessions of the so-called "Naturforschende Gesellschaft". This society was founded already in 1779. On 20 June 1918 he spoke about "The study of the physics of the inner atom by X-rays" and on 8 July 1919 about "The decay of atoms during radioactive processes".⁵⁶ Other scientific societies were also active in Halle. In 1917 the so-called "Hallescher Verband für die Erforschung der Mitteldeutschen Bodenschätze und Ihrer Verwertung" was founded. Mie was also interested in such activities. He was a member of this society until his departure to Freiburg. On 28 September 1917 he wrote:

On Wednesday, there was a great occasion: Foundation of Halle's Federation for the Study of the Mineral Resources. I hope that this will result in my increased contact with the industrial circles, because I want to gain much knowledge of the technology. That's my largest desire.⁵⁷

On 7 February 1917 Mie became member of the German Academy of the Natural Scientists Leopoldina. The photo (cf. Fig. 1.9) was filed along with his member documents.

⁵⁴ Archive of Halle University (UAH), PA11453: Peronalakte Mie 1916–1918.

⁵⁵ *ibid.*

⁵⁶ cf. *Mitteilungen der Naturforschenden Gesellschaft zu Halle* 5, 53f. (1920), [32].

⁵⁷ UAF, Nachlass Mie, E12/71.

Fig. 1.9 Gustav Mie in 1917, when he became a member of the Leopoldina. (Courtesy of Archive of the Leopoldina, member documents Gustav Mie, member number 3412)



Although his theory of matter was conceived in Greifswald, the discussion and exchange of letters about field theory and general relativity with Einstein mainly occurred during his time in Halle. Mie's time in Halle was scientifically fruitful, although he could not realize all his ideas for the development of the institute. On the other hand, Halle was intellectually exciting for him. Mie and his wife regularly visited the theatre and concerts. He visited the art gallery near the institute building, but did not get acquainted with expressionism, a main collection area of the gallery. He met also "old Rostock guys" like the philologist K. Brockmann (1868–1956) and the botanist G.H. Karsten (1863–1937). Both professors also received their Abiturs from the Great City School in Rostock. While in Freiburg, on 26 October 1924, Mie wrote about that time in Halle:

I think back at Halle, as a time of my highest mental stimulation, in contrast to the enormously rich industries and crowds of dissatisfied workers living in darkness, to the mental contrasts of men of the industry, completely oriented on power and will, and the religious powers, before with which I had never become acquainted. It was the most interesting, spirited interplay of brightness and darkness, although somewhat though on

the nerves at the time. Now, I withdrew myself here into peace, because I still want to muster my strength, in order to produce something.⁵⁸

1.2.6 Freiburg: Ordinarius and Retirement in Baden (1924–1957)

Gustav Mie did not fully assimilate with Halle, probably due to the conflicts with K. Schmidt. The political riots at the beginning of the 1920s in central Germany surely was another reason for him to look for a position at a respected university. His positive memories of the first years of his scientific career in Karlsruhe and his wife's family ties made a return to Baden seemed reasonable. In a letter to Sommerfeld he wrote:

I have to say that I am looking forward not only to leaving here, but also to being at the beautiful Freiburg institute and returning to the beautiful Baden country, with which I am so familiar.⁵⁹

In 1895, Franz Himstedt⁶⁰ became a full professor in Freiburg succeeding Emil Warburg,⁶¹ who went to Berlin. Wolfgang Gaede's⁶² development of pumps was of crucial importance to Himstedt's work on channel rays, alpha-rays and X-rays. As with the appellate procedures in Greifswald and Halle, Mie was not the faculty's favoured applicant, however, the reasons in this case were different. In the report of the selection to the Faculty of Sciences of the University of Freiburg from 25 April 1923 J. Zenneck (1871–1959) (Munich), Chr. Füchtbauer (1877–1959) (Rostock), Cl. Schäfer (Marburg) and W. Gaede (Karlsruhe) have been mentioned.⁶³ The list finally handed to the ministry included: Zenneck, Schäfer and Füchtbauer. Zenneck rejected the offer, and thus the ministry allowed the faculty to supplement the list. In a letter of the faculty to the rector and senate for submission to the ministry, now Mie was mentioned *primo loco*. It was written:

We make use of the opportunity granted by the ministry, because it came to our attention, that Professor Gustav Mie (Halle), one of our most prominent physicists, may be inclined

⁵⁸ UAF, Nachlass Mie, E12/72.

⁵⁹ UAF, Nachlass Mie, E12/37 Nr.18.

⁶⁰ Franz Himstedt (1852–1933), studies in Göttingen, graduation and habilitation University of Göttingen, 1878 private lecturer Göttingen, 1880 private lecturer Freiburg, 1889 successor of Röntgen in Gießen, 1895 professor in Freiburg.

⁶¹ Emil Warburg (1846–1931), studies in Heidelberg and Berlin, 1867 graduation, 1870 habilitation, 1872 Strasbourg, 1876 professor in Freiburg, 1894 professor in Berlin, 1905 director of the Physikalisch-Technische Reichsanstalt.

⁶² Wolfgang Gaede (1878–1945), studies in Freiburg, 1901 graduation, 1909 habilitation in Freiburg, 1913 professor in Freiburg, 1919 professor in Karlsruhe.

⁶³ UAF, Generalakten, Bestand B1/1287.

to accept the offer from Freiburg. We did not mention him before, because we considered it unlikely that he might be willing to accept our offer, however, it seems like he did not get assimilated in Halle and would like to come to South Germany. Prof. M. Wien, Jena, writes about him: “Among the living German physicists, I consider him among those of highest rank, not only as a theoretician, but also as an experimentalist”. Not only is he an outstanding researcher, but also a very successful teacher, as proven by numerous experimental and theoretical theses accomplished under his supervision. His style of presentation is plain and clear. Mie is a subtle, highly educated man and a pleasant, kind colleague.^{64,65}

Wilhelm Kast (1898–1980), Mie’s assistant in Halle followed him to Freiburg.

Mie’s years in Freiburg were associated with a number of honours. In 1925, his first station in his scientific career celebrated the 100th anniversary of the foundation. On this occasion Schleiermacher initiated the award of the honorary title “Doctor Engineer” to Mie. Schleiermacher pointed out in his report: “...his habilitation about the general validity of Poynting’s theorem of energy flux, prepared in Karlsruhe, showed the direction of research, pointing to general and basic questions”.⁶⁶ Gaede added in his report: “This outstanding and profound scientist stands out from other physicists by having a lot of sympathy for technical issues and proven this on several occasions”.⁶⁷ On his 70th birthday the issue 3 of volume 425 of “Annalen der Physik” (1938) was dedicated to Mie; it also contained papers by his disciples. In 1938, G. Mie and A. Sommerfeld became honorary members of the German Physical Society.

Mie was awarded with the Goethe-Medal for Art and Science on his 75th birthday in November 1943. The medal was given to artists, scientists and others as authorised by Hindenburg. In 1934, Adolf Hitler, in his position as German Head of State, took over the authority for awarding this medal. Kast, Mie’s former assistant in Halle and Freiburg started the activities to effect this award.⁶⁸ One of the main arguments of the referees is the seminal influence of Mie’s textbook [Mie37].

The building of the Physical Institute in Freiburg was destroyed during the Second World War. In honour of the eminent physicist, the new building was named “Gustav Mie Haus”.⁶⁹

Apart from the obligations at the institute, Mie took part in the scientific life of the university town Freiburg, as he usually did. As in Karlsruhe and Halle, Freiburg also had a lively scientific society, so-called the “Naturforschende

⁶⁴ *ibid.*

⁶⁵ Dissertations with purely theoretical content supervised by Mie could not be found.

⁶⁶ UAK, Best. 27059, Sig. 1, 385.

⁶⁷ *ibid.*

⁶⁸ cf. UAF, B24/2448.

⁶⁹ In honour of Mie’s time in Halle the new main physics lecture hall of Halle University was named “Gustav-Mie-Hörsaal”. Also, a so-called Mie prize is awarded to excellent students of physics in Halle.

Gesellschaft zu Freiburg im Breisgau”, founded 1821. On 16 December 1925 Mie spoke about fundamentals of the quantum theory [Mie62].

Mie was active right to his very last semester. He retired in June 1935. On 1 February 1935, Mie wrote to Sommerfeld:

...In this winter semester I gave lectures for the gentlemen of my institute and of the physical-chemical institute about your handbook article about “Electron Theory of Metals”. Eventually I will continue in the next semester, to speak also about the further development of the theory corresponding to the article of Bethe. I guess, we spoke about that in Pyrmont. I have had a lot of fun with this matter.⁷⁰

After retirement, epistemological and theological questions became the focus of his attention. He published several papers on these subjects.⁷¹ [Mie78, Mie80, Mie83] In honour of Mie’s 85th birthday, a colloquium was organised by his former students and assistants on the 1 November 1953. Berta Mie died in 1954 and Gustav Mie passed away on 13 February 1957 at the ripe old age of 89.

1.3 Scientific Fields of Activity

The name of Gustav Mie is surely most frequently mentioned in connection with the term “Mie scattering” and “Mie effect”. His contributions to the development of field theory and general theory of relativity are acknowledged in many reviews [33, 34]. Other scientific contributions of Gustav Mie are still of great interest.

In a certain manner, Mie’s scientific papers are standard examples in the framework of the sociology of scientific knowledge. Corresponding to R.K. Merton the following thesis holds: “all scientific discoveries are, in principle, multiples, including those that, on the surface, appear to be singletons”.⁷² Stigler’s law of eponymy states that the naming of an effect, a law, an equation rarely follows the name of the discoverer.⁷³ The scientific community has to be prepared also for the breakthrough of a new theory. “If an early valid statement of a theory falls on deaf ears, and a later restatement is accepted by the science, this is surely proof that the science accepts ideas only when they fit into the then-current state of science”.⁷⁴ Mie scattering can be discussed in such a context. In the *Dictionary of the named Effects and Laws in Chemistry, Physics und Mathematics*, Mie does not appear as associated with Mie scattering, instead, the “Mie-Grüneisen equation of state” is cited.⁷⁵

⁷⁰ Letter of Mie to Sommerfeld from 1 Februaray 1935, UAF, E12/37, Nr.23.

⁷¹ The value of those articles should not be discussed here. It was a subject of controversy among the editors of the planned Mie edition Höhnle and Plötze. cf. UAF, Nachlass Hönl E14/2, see also review to Mie’s “Naturwissenschaften und Theologie”, *Die Naturwissenschaften* **20**, 566 (1932).

⁷² [35], p. 298.

⁷³ Stigler’s law of eponymy. [36], cf. also [37].

⁷⁴ [38], p. 146.

⁷⁵ [39], p. 212.

Table 1.1 Distribution of Gustav Mie's publications on the stations of his scientific career and on his scientific fields of activity

| Period | Station | Publications |
|---|------------|--------------|
| 1892–1902 | Karlsruhe | 12 |
| 1903–1918 | Greifswald | 33 |
| 1919–1924 | Halle | 14 |
| 1925–1936 | Freiburg | 21 |
| 1937–1950 | Retirement | 7 |
| Field of activity | | Publications |
| Field theory, theory of relativity | | 17 |
| Electrodynamics, electrotechnics | | 10 |
| X-rays | | 8 |
| Thermodynamics, statistics | | 7 |
| Quantum physics | | 6 |
| Mathematics | | 4 |
| Scattering theory, optics | | 3 |
| Textbook /textbook contributions | | 4 |
| Philosophy, religion | | 7 |
| Popular science | | 8 |
| Biographic contributions | | 4 |
| Miscellanea | | 9 |

A list of Mie's publications is given as completely as possible in the appendix. Table 1.1 gives an overview of the distribution of his publications at the institutions of his scientific career. Furthermore, the attempt was made to sort his publications corresponding to the subject. Table 1.1 clearly shows that the Greifswald years have been the most successful period. The papers concerning scattering theory [Mie25] as well as the three publications concerning the theory of matter [Mie32, Mie33, Mie36] were written in Greifswald. Also, the beginning of the discussion with Einstein about the basics of the theory of general relativity dates back to that time [34].

A revision of Mie's publications shows that he appeared as the coauthor of an article only on a few occasions. In Karlsruhe, he published a paper with E. Arnold [Mie8] and in Halle with J. Hergweg [Mie53]. Two papers in Freiburg were about roentgenographic investigations of polymeric formaldehyde. The investigations were conducted in collaboration with Hermann Staudinger (1881–1965), later a Nobel Laureate in Chemistry [Mie68, Mie69]. The subject of the investigation was the proof of existence of the fibroid structure. This verification was fundamental for later work of Carothers (1896–1937) to develop fully synthetic fibres. In 1931, he published a paper with E. Frankenberger about the measurement of refractive indices [Mie73].

Some of Mie's areas of scientific interest will be discussed in more detail now. At the beginning, some of his early and nowadays somewhat unknown publications will be considered. His work on electrotechnics and electrodynamics, field theory and the theory of relativity and of course on scattering theory will be discussed in more detail.

1.3.1 Transport of Energy and Thermodynamics

Two publications will be mentioned at first, dealing with problems of fundamental nature. The findings of those papers became common property during the development of physics. Therefore the papers are rarely cited nowadays.

Gustav Mie's paper, produced during his habilitation, "Draft of a General Theory of the Energy Transmission" [Mie6] is one of his less known publications. The development of Maxwell's theory and especially Poynting's work had shown that the transport of energy is not restricted to electric conductors. This changed point of view led to the reconsideration of the term energy. In particular H. Hertz (1857–1894) called for additional investigations in this field.⁷⁶ Mie's habilitation was one step in this direction. Max Jammer (1905–2010) writes about this work:

Mie showed, in this publication, whose importance for the development of modern physics can hardly be overestimated, that not only a fluid under pressure transports energy, transferring it in relation to pressure and velocity, but that every deformation of an elastic body causes a current of energy, that can be exactly determined. ...However, Mie was not able to draw the final conclusion. Matter and energy were still two different aspects of physical reality for him.⁷⁷

It should be mentioned that this work is recently discussed in the framework of problems of scientific education in schools [41].

Methods for a direct investigation of the interaction of atoms were still a long way from being feasible at the beginning of the twentieth century. Therefore, the influence of interatomic interactions on macroscopic properties was studied starting from a number of assumptions. This is also the way of thinking presented by Gustav Mie in his paper "On the kinetic gas theory of single atomic bodies" [Mie13]. This paper is a fundamental contribution to the microscopic theory of solids. Eduard Grüneisen (1877–1949) wrote in his article "State of Solids"⁷⁸ for the "Handbuch der Physik":

In his fundamental work about the kinetic theory of single atomic bodies G. Mie introduced the assumption, that the potential of attractive as well as repulsive forces between two atoms, is inversely proportional to the distance of the atoms. Hence, the potential energy of two atoms at distance ρ is given by

$$\phi = -\frac{a}{\rho^m} + \frac{b}{\rho^n}, \quad (1.1)$$

⁷⁶ H. Hertz, *Untersuchungen über die Ausbreitung der elektrischen Kraft*, Gesammelte Werke, Leipzig 1894, Bd. 2, S. 234 und S. 294 and G. Helm, *Die Energetik nach ihrer geschichtlichen Entwicklung*, Leipzig 1898.

⁷⁷ [40], p. 187f.

⁷⁸ [42], E. Grüneisen: Zustand des festen Körpers, p. 1 ff.

where the first term represents the attractive and the second term the repulsive force. a and b are constants.⁷⁹

Mie considered [Mie13] mainly single atomic gases, but Grüneisen [43] extended the field of application of the potential to solids. Both authors did not speculate about the origin of the forces. Experimental results for the coefficients m and n are given for example by Fürth [44]. Usually the Mie potential is written in the form

$$V(r) = D_0 \left\{ \frac{n}{m-n} \left(\frac{\sigma}{r} \right)^m - \frac{m}{m-n} \left(\frac{\sigma}{r} \right)^n \right\}. \quad (1.2)$$

The Mie potential is a precursor of the Lennard–Jones potential, which fixes the exponents to $m = 12, n = 6$. The Lennard–Jones potential is written as

$$V = 4\varepsilon \left\{ \left(\frac{\sigma}{r} \right)^{12} - \left(\frac{\sigma}{r} \right)^6 \right\} = \varepsilon \left\{ \left(\frac{r_m}{r} \right)^{12} - 2 \left(\frac{r_m}{r} \right)^6 \right\}. \quad (1.3)$$

The 12–6 form was introduced by Lennard–Jones (1894–1954) in 1924 [45–47]. The Mie potential witnessed a renaissance as a model potential during the last years. The solution of the Schrödinger equation with a Mie potential was discussed [48–52]. The potential (1.2) was used in [53] to describe the interaction of He with a Cu (110) surface, in relation to He scattering. Thermoelastic properties have also been investigated using such a potential [54, 55]. Barakat et al. [56] used the Mie potential to calculate the binding energy of metallic nanoparticles. Potentials of the form (1.2, 1.3) are named sporadically also Mie–Lennard–Jones potentials.⁸⁰ The Mie–Grüneisen equation of state follows from the assumptions of the power function form of the interaction and the corresponding potential.⁸¹

1.3.2 Electrotechnics and Electrodynamics

Electrotechnics and electrodynamics were Mie’s preferred areas of interest during his time in Karlsruhe as well as at the beginning of his Greifswald years. His investigation of electromagnetic waves along a wire are connected to the work of Heinrich Hertz. The impression Hertz’s work had on the young Gustav Mie whilst in Karlsruhe was very significant.

Ernst Lecher (1856–1926) published his paper on the investigation of a system of parallel wires in 1890 [58]. Arnold Sommerfeld (1868–1951) published his theoretical investigation about the propagation of electromagnetic waves along a

⁷⁹ *ibid.*, p. 11. Grüneisen refers in the discussion on Mie’s paper [Mie13] and his own article published considerably later [43].

⁸⁰ z.B. W.C. de Markus, *Planetary Interiors*, S. 441 in [57].

⁸¹ s. [42], p. 22, [Mie13], [43].

wire in 1899 [59]. In the year 1900, Mie's article containing the complete theoretical solution of the Lecher problem appeared [Mie9]. Mie gave a complete mathematical analysis, a style we encounter later in his treatment of the scattering problem.

Sommerfeld answered on the consignment of the article on the parallel wire system by Mie:

Dear colleague, Many thanks for the consignment of your treatise. It was, as you can imagine, exceptionally interesting for me. I am personally not only glad about the scientific progress, but also that my wire waves got such a competent and thorough reader. ...You have done an ample piece of work!⁸²

Mie answered immediately:

Dear Professor, I have been very glad about your friendly letter and your appreciative words. In fact, I finished the laborious task, because I was almost completely preoccupied by the task for 3/4 of a year, insofar as when lectures or practical course work did not require my attention. Hence, it is in a certain manner a bit regrettable, that the Fourier series as a result of complex calculations can be truncated in case of air wires almost always after the first term....⁸³

This particular investigation established Mie's reputation as a theoretical physicist. During the years 1900 and 1901, Mie exchanged ideas on wire waves with Sommerfeld several times. Soon after, there was to be a further development in this area. Mie's solution was rigorous and was based on Maxwell's theory, but due to the series expansions used by Mie, the results appeared in the form of confusing formulas. Sommerfeld wrote: "But—if you want to open a lock, you have to use a key and not a hatchet. The power series expansion [in Mie's paper] appears in this case as a hatchet, not as a proper key" [60]. D. Hondros, a Ph.D student of Sommerfeld's, investigated in his theses a further development of the theory, starting from considerations of G. Gentile (1875–1944) about diffraction by a pair of parallel wires [61, 62]. Mie did not come back to his investigations of 1900. It seems that he was not very interested in following the development in this field.

Motivation by Engelbert Arnold played an important role for Mie in Karlsruhe and at the beginning of his time in Greifswald by way of occupying himself with practical electrotechnical problems. Arnold contributed substantially to the development of direct current machines. The commutation was one of the main problems in the development of more effective direct current machines. The question came into the focus of several researchers and a couple of publications appeared practically at the same time. Concerning the value of their own publication, written together with Gustav Mie, Arnold explicated:

Due to the thankworthy cooperation of Dr. Mie the complicated solution of differential equation (3) was successfully presented in a neat manner. The graphical representation of the conversion of energy during the short circuit period leads to results, different from the

⁸² Letter of Sommerfeld to Mie from 1 July 1900, UAF, E12/37 Nr.1.

⁸³ Letter of Mie to Sommerfeld from 9 July 1900, UAF, E12/37 Nr.2.

conceptions used so far for the processes during the short circuit. Therefore the publication of this work is still of interest.⁸⁴

Apart from the development and construction of generators and motors, the rating and improvement of distribution networks was an important issue of that time.⁸⁵ Mie studied heat conduction in stranded cables, a problem important for the dimensioning of such cables [Mie17, Mie19].

1.3.3 Scattering Theory

Mie's article "Contributions to the optics of turbid media, particularly colloidal metal solutions" [Mie25], published in the year 1908, belongs to the so-called "Sleeping beauties and wallflowers", i.e. papers that received much-delayed appreciation [64, 65]. It was not until 1945 that this investigation received a broad appreciation and application. The development of computer engineering, especially, advanced the application of Mie's theory. This seminal work is not only important with respect to its scientific content. The commonly used terminology, Mie scattering, does not accommodate the history of Mie's investigation.⁸⁶ This work of Gustav Mie seems to be a singular point in his scientific opus. Most of the biographical notes about Mie do not keep track of the genesis and context of this paper on scattering theory. Both points of view will be discussed here in more detail.

The young professor extraordinarius Mie had to represent theoretical physics. The Ph.D students at the institute Karl Degen, Erich Lischner and later also Walter Steubing⁸⁷ visited the lectures of Mie. Under supervision of the ordinarius König, experimental investigations on colloidal metal solutions were performed. Degen and Lischner defended their theses connected to such investigations in May 1903 [66–68]. The topic of Degen's Ph.D was the experimental investigation of the dielectric properties of a magnesium sol. Lischner investigated the elliptical polarisation of light, reflected from pigment solutions. One special example of his investigation was fuchsin, a triphenylmethane pigment dissolved in alcohol. Mie was familiar with those investigations of course. At the same time, H. Siedentopf (1872–1940) and R. Zsigmondy (1865–1929) developed the so called ultramicroscopy, a version of dark field microscopy, to uncover submicroscopic particles with a size of a few nanometer by means of their scattered light [69]. Zsigmondy's interest in colloids was motivated by his work on coloured glasses with the glass

⁸⁴ cf. [Mie8], p. 97.

⁸⁵ cf. [63], p. 132ff.

⁸⁶ Instead of Mie theory, occasionally the terms Lorenz-Mie theory or Lorenz-Mie-Debye theory are used.

⁸⁷ Walter Steubing (1885–1965), Ph.D 1908 Greifswald, TH Aachen (Stark), 1927 professor for applied physics Breslau, 1948 professor in Hamburg.

factory Schott und Genossen in Jena. It was possible to correlate colour changes with particle sizes and particle forms by means of ultramicroscopy. In 1905, Zsigmondy published a review on the ultramicroscopic investigations on colloids [70]. Zsigmondy wrote:

A series of examples should be used to demonstrate, how by an incremental fragmentation of a solid—the metallic gold—the properties of the same will change. The fragmentation of the solid should be continued as far as possible; if possible down to molecular dimensions. On the other hand, size and properties of the single particles, obtained as a result of the fragmentation, should be determined exactly.⁸⁸

Chapters 10 and 11 of Zsigmondy's book discuss the connection between particle size and colour, and also the colour change of colloidal gold. Zsigmondy sums up:

Based on this fact, also supported by investigations of gold ruby glass, we have to denote every attempt to calculate the particle size in case of metal hydrosols from the light absorption as untimely.⁸⁹

In 1906, the journal “Zeitschrift für Chemie und Industrie der Kolloide” was founded.⁹⁰ The introduction pointed to Zsigmondy's book [70] and stated, “...that we are at the doorstep of a new great area, where science has to develop and industry to exploit—this is the colloids”.⁹¹ In 1902, Mie studied Planck's dispersion theory [71, 72]. This can be concluded from the exchange of letters with Max Planck (1858–1947).⁹² The reasons that motivate the investigations of Steubing were revealed clearly in the report “The optical properties of colloidal gold solutions” [Mie23] published in “Zeitschrift für Chemie und Industrie der Kolloide” in November 1907. The topic of Steubing's and Mie's investigation was perfectly suitable for the new journal. Part of the reason why this journal was chosen was probably due to its fast publication turnaround time. This article was a report on a talk given by Mie on 18 September 1907 on the 79th “Versammlung Deutscher Naturforscher und Ärzte” in Dresden.⁹³ During the discussion of the talk Siedentopf pointed out a paper by J. C. Maxwell Garnett (1880–1958) [73] unknown to Mie that time. Siedentopf also discussed the possibility extending the calculations to elliptical particles.⁹⁴ Walter Steubing defended his thesis on 16 December 1907 in Greifswald [74]. In 1908, a corresponding publication appeared in “Annalen der Physik” [74]. Steubing himself did not come back to the topic of his Ph.D work in his future work. He started his scientific career with Johannes

⁸⁸ [70], preface.

⁸⁹ *ibid.*, p. 112.

⁹⁰ vol. 1 (1906)–vol. 12 (1913) *Zeitschrift für Chemie und Industrie der Kolloide*, vol. 13 (1913)–vol. 179 (1961) *Kolloid-Zeitschrift*, vol. 180 (1962)–vol. 251 (1973) *Kolloid-Zeitschrift & Zeitschrift für Polymere*, than *Colloid & Polymer Science*.

⁹¹ *Zeitschrift für Chemie und Industrie der Kolloide*, 1 (1906).

⁹² UAF: E012/38, exchange of letters Mie-Planck, Nachlass Gustav Mie.

⁹³ see also the publication in “Berichte der Dt. Physikal. Gesellschaft” [Mie24].

⁹⁴ see also “Verhandlungen der Gesellschaft Deutscher Naturforscher und Ärzte”, 79, 40 (1907).

Stark (1874–1957) in Aachen and published three papers with him on canal rays from 1908 to 1910.

The first communications on the work done in Greifswald appeared at the end of the year 1907. Mie sent his complete paper to Wilhelm Wien, editor of “Annalen der Physik”, in January 1908. Mie wrote:

Dear colleague,

I have enclosed within an article of theoretical work on the optics of turbid media, to request publication in the Annalen. Perhaps, I will send more soon, but hopefully with less voluminous amount of material. ...Eventually it will be possible to meet you at Easter. Maybe I intend to start with some kind of snow sport, because I see that I need some physical fitness. If it is not possible to meet you in Würzburg, I would go to the Bavarian mountains for a few days.⁹⁵

Wilhelm Wien responded:

Dear colleague,

I confirm the receipt of your work on optics of turbid media, which discusses a really relevant topic. I would be very happy to welcome you here and to discuss a number of things. At the end of the winter semester I have to go to Mittenwald immediately to stay there for several weeks. I have to advise you strongly to start skiing. ...Because, as always, when a number of theoreticians gather together, it is also a time for scientific conversation.⁹⁶

The submission of the paper was practically also the starting point for Mie's participation in the winter sports meetings in Mittenwald.

The publication of the article [Mie25] marked the conclusion of Mie's work on this topic. This was often considered as exceptional in retrospect. It is not uncommon for a scientist to keep working on the same topic for years or decades to become a specialist in a narrow field. Mie's behaviour can be understood from his style of work and the development of physics till that time. In his work on the Lecher problem, a complete mathematical solution of a certain physical problem was given. Also, in case of the seminal contribution to scattering theory, a complete mathematical solution for spherical particles was given. An extension to spheroids, when the expected difficulties in the numerical evaluation were taken into consideration, did not look very promising. Mie was also busy with his “Lehrbuch der Elektrizität und des Magnetismus”, which appeared 1910. His book was dedicated to the electromagnetic program and in its intention exceeded the solution of a single problem. Mie himself wrote in the preface:

It is without any doubt, that the actual foundation of the whole physics is electricity. Electricity fills the place, that was occupied 100 years ago by mechanics. Mechanics itself as well as optics becomes more and more a part of electricity.⁹⁷

⁹⁵ UAF: E01248, 16, exchange of letters Mie-Wien, Nachlass Gustav Mie.

⁹⁶ UAF: E01248, 13, exchange of letters Mie-Wien, Nachlass Gustav Mie.

⁹⁷ [Mie27], Vorwort, S. VII.

Table 1.2 Summarizing timetable to the development of scattering theory, based on [77]

| Year | Author | Ref. | Achievement, Remark |
|-----------|----------------------|----------|-------------------------------------|
| 1863 | A. Clebsch | [78] | Elastic wave equation |
| 1871 | Lord Rayleigh | [79] | “Rayleigh” scattering |
| 1872 | Lord Rayleigh | [80] | Scattering of sound by a sphere |
| 1881 | Lord Rayleigh | [81] | Scattering by a dielectric cylinder |
| 1881 | H. Lamb | [82] | Elastic waves |
| 1890 | L.V. Lorenz | [83] | Results analogous to [Mie25, 84] |
| 1893 | J.J. Thomson | [85] | Scattering by a conducting sphere |
| 1899/1900 | G.W. Walker | [86, 87] | Scattering by a sphere |
| 1908 | G. Mie | [Mie25] | Complete <i>reference solution</i> |
| 1909 | P. Debye | [84] | Debye potentials |
| 1910 | J.W.N. Nicholson | [88] | Scattering by a sphere |
| 1915 | H. Bateman | [89] | Complete review |
| 1917 | A.J. Proudman et al. | [90] | Numerical results to [91] |
| 1920 | G.N. Watson | [92] | Theory of Bessel functions |
| 1920 | T.J. Bromwich | [91] | Complete solution (started in 1899) |

Einstein's *annus mirabilis* was three years prior in 1908. The theory of special relativity was intensively discussed and Mie found more excitement thinking about a new foundation of a theory of matter instead of puzzling over details of a special problem. A sign of such an attitude was his participation in the congress of natural scientists in Salzburg in 1909. Einstein took part in such a large congress for the first time. Mie participated in the discussions on talks about basic questions in electromagnetism and the theory of special relativity. Contributions to the discussions on other topics are not documented.⁹⁸ This demonstrated that his main interest was already focussed on topics other than scattering theory.

The historical development of scattering theory will be now summarised.⁹⁹

Table 1.2 lists a few milestones in the development of the scattering theory, that were mainly, as it were, precursors to Mie's paper. Clebsch (1833–1872) [78] investigated boundary value problems in elastic media, especially of sound waves impinging on spherical surfaces. Clebsch's work is fundamental from several points of view. It had already contained work on potentials that were later named Debye potentials. Clebsch's treatise was published before Maxwell's theory. It presented the theory in component form as opposed to the modern notation of vector analysis. This might be the reason why the work of Clebsch is only rarely cited. The work of Lord Rayleigh (1842–1919) on the exact solution of the scattering problem of a dielectric cylinder [81], published in 1881, is based on Maxwell's theory. Lamb (1849–1934) [82] solved the vectorial wave equation with methods, used also by Clebsch, and provided a basis for a series of further publications.

⁹⁸ see Verhandlungen der Gesellschaft Deutscher Naturforscher und Ärzte, **80** (1908), **81** (1909).

⁹⁹ The remarks are based on the the reviews of Kerker [75] and Logan [76, 77]. For a detailed discussion see especially [77].

Fig. 1.10 Ludvig Lorenz (1829–1891). (Portrait from [93])



Ludvig Lorenz¹⁰⁰ (Fig. 1.10) is mainly known as the “second Lorenz” from the Lorentz-Lorenz formula and, incidentally, the so-called Lorenz gauge is often erroneously attributed to H.A. Lorentz.¹⁰¹ Lorenz’s work from 1890 [83] is based on the work of Clebsch and contains the exact solution of the scattering problem for the sphere. The Lorenz theory is not based on Maxwell’s theory, but based on the exact solution of the same boundary problem. This work has remained practically unknown. As already mentioned, Mie was pointed to a paper by Maxwell Garnett at the conference of natural scientists in Dresden 1907. Mie cites Maxwell Garnett [73] in his paper, but also an older publication of L. Lorenz [96]. In contrast to Mie, to Maxwell Garnett, the work of Lorenz from 1890 was known. He cited the Lorenz paper [83] together with publications of Lord Rayleigh and H. Hertz in the first part of his own publication. Therefore, Mie could have found a hint to the work by Lorenz. However, Lorenz’s original work in the Danish language was most likely not known to him. Nicholson (1881–1955) [88] investigated

¹⁰⁰ Ludvig Lorenz (1829–1891), studies in Copenhagen, 1852 diploma as chemical engineer, September 1858- Juli 1859 studies in Paris, 1866 teacher at the academy of military sciences in Copenhagen, 1887 working as a free scientist, funded by Carlsberg, 1876 professor, 1887 doctor honoris causa of Uppsala University (see also [94, 95]).

¹⁰¹ see for instance H. Klingbeil, *Elektromagnetische Feldtheorie*, Teubner-Verlag Stuttgart, 2003; W. Nolting, *Grundkurs Theoretische Physik 3—Elektrodynamik*, Springer-Verlag, Berlin 2002.

the light scattering from a metallic sphere and compared the results with those from geometrical optics. He also developed a series of asymptotic formulae for Bessel functions, necessary for the discussion of the scattering on large spheres. The same formulae have been developed earlier by Lorenz and were part of his 1890 work. The publications of Mie [Mie25] and Debye [97] remained largely unknown in England as exemplified by the Nicholson paper [88]. This lack of knowledge of the work of others is in strong contrast to the complete overview, given by Bateman for the first time [89]. The bilateral appreciation and knowledge of scientific work disembodyed at the beginning of World War I in appeals, that depressed the atmosphere in the international scientific community for a long time (see also Chap. 5). Finally, the work of Bromwich (1875–1929) and his co-workers Proudman, Dodson and Kennedy should be mentioned. Bromwich published his paper in 1920 [91], but the exact solution was already known to him in 1899. Proudman et al. [90] performed detailed numerical calculations, published in 1917.

Logan summarised the distinctive feature of Mie's contribution, which resulted in the paper to be generally accepted as a reference, in an apposite manner:

What Mie did that was different from the work of previous writers was to set out on an ambitious computing program. He made calculations which involved summing the first several partial waves, in order to be able to obtain numerical results for spheres, which were too large to qualify for the criterion to be small enough for only the first partial wave (Rayleigh scattering) to be important. Mie's paper is complete in itself, and it served as the basis for much of the work which has been done in this field since its publication. ...Mie's paper caught the attention of his and later generations because he employed the results of his very *thorough* paper to study a very interesting practical problem, and others, who came after him, found that his paper provided them with a *good* and a *complete*, guide to follow in their applied work in light scattering.¹⁰²

In 1904 Mie's booklet "Molecules, Atoms, World Ether" appeared [Mie18]. It was a result of lectures from a summer school in Greifswald in 1903. He discussed the properties of turbid media, using atmosphere, milk and also gold colloids as examples. Further editions appeared in 1907 and 1911. The final sentences of the part about turbid media are identical in the first two editions:

The small oscillators in the two colloidal gold specimen, that I have shown, have the special property of the absorption of certain types of light strongly, especially the green color. Therefore the red color prevails in the passing light.¹⁰³

In the third edition from 1911 his intensive study of the subject is reflected in the following reformulation of that passage:

That the colloidal metal solutions show totally different colors than the usual turbid media is related to the special optical properties of metals. They show with respect to the different types of light a very strong selective behavior, certain colors are strongly absorbed, whereas other colors are strongly reflected. In the red gold solutions, for example, a very strong absorption of green light by the gold particles occurs, but for blue solutions one obtains mostly an abnormally strong lateral emission of yellow-red light.

¹⁰² Logan [77], p. 9 and footnote 16.

¹⁰³ [Mie18], p. 57 1st edition, p. 61 2nd edition.

The theory of Lord Rayleigh, which we have already discussed, is valid only for particles of such substances, which do not strongly absorb or reflect, that means substances which would appear as a form of a coarse powder that is white or only weakly colored. Most substances belong to this class.¹⁰⁴

1.3.4 Theory of Matter and Theory of Relativity

Even today, Gustav Mie's publication "Contributions to the optics of turbid media, particularly colloidal metal solutions" is the basis of many practical applications, but his contributions to the theory of matter are interesting only in a historical context. His three publications "Grundlagen einer Theorie der Materie" [Mie32, Mie33, Mie36] have had strong influence on the development of field theory at that time. Mie's contributions in this area are appreciated and discussed in-depth in a series of reviews and books.¹⁰⁵

Up to his contribution to scattering theory, Mie's scientific work was much influenced by Maxwell's theory. He contributed to the extension of the theory and, propagation by way of his textbook [Mie29]. Therefore it is not surprising, that Mie is seen, from a historical point of view, as a proponent of the electromagnetic field program. The unified description of electric, magnetic and optic phenomena based on Maxwell's theory as well as the success of electron theory of H.A. Lorentz (1853–1928) provided the electromagnetic field program a dominant role. The program was formulated mainly by E. Wiechert (1861–1928) and J. Larmor (1857–1942) in the 1890s and was at the turn of the century the dominant concept. Significant contributions made by, to name only a few, M. Abraham (1875–1922), W. Wien (1864–1928), A. Sommerfeld (1868–1951), J.J. Thomson (1856–1940), H.A. Lorentz (1853–1928) and H. Poincaré (1854–1912). Vizgin states:

The radical form of the electromagnetic program advanced by Wiechert in 1894 and somewhat later by Larmor declared the ether to be primary reality; its excited states gave the charged particles (electrons), and the origin of their mass was explained on the basis of the concept of electromagnetic mass developed in the 1880s and 1890s, primarily by British scientists (J.J. Thompson, Heaviside, and also, somewhat later, Searle and Morton). It was assumed that the laws of Newtonian mechanics could be deduced from the equations of the electromagnetic field.¹⁰⁶

The persistent result of this effort was the introduction of the field concept and the attempt to unify physical phenomena on this basis. Mie's substantial work with the field concept and the attempt to develop a new theory of matter in the framework of the electromagnetic program is rather connected with the end of this development. Late highlights in this sense are the unified theories of Hilbert

¹⁰⁴ [Mie18], p. 66 3rd edition.

¹⁰⁵ see Vizgin [98], Kohl [33], Renn (Ed.) [99, 100], Corry [101].

¹⁰⁶ [98], p. 7.

(1862–1943) in 1915 and Weyl (1885–1955) in 1917. They tried to develop a unified theory of the electromagnetic field and the gravitational field based on the theory of general relativity. Mie's work stimulated the attempts of Hilbert and Weyl and also later work on nonlinear field theories of Born (1882–1970) and Infeld (1898–1968) [102]. The dawn of the 1920s was characterised by the boom of the quantum mechanical program. Most of the physicists preferred to work in this framework, because it was easier to relate the theoretical developments to the real physical processes.

Mie published his theory of matter in three articles in the years 1912 and 1913 [Mie32, Mie33, Mie36]. It was a very ambitious program to unify electromagnetism, gravitation and the first ideas of quantum mechanics. Mie's aim was to finally get a theory which describes the existence and properties of the electron and later on also of atoms and molecules, which produces the atomic spectra and also delivers the field equations of gravitation.

Mie's work was connected with the discussion around the theory of general relativity. Einstein emphasised, that the extensions he aimed for should be independent of any assumptions about the constitution of matter. In contrast to this point of view, Mie was searching for a theory of matter based on an electromagnetic field concept. He wanted to start from a set of equations describing the state and dynamical evolution of the ether. Elementary particles, as an inherent part of the theory, should manifest themselves as so-called knots of the ether. To explain a stable electron in electromagnetic terms (charged sphere) an additional attractive force, the so called Poincaré stress, is necessary. Mie made a different choice. He considered nonlinear field equations. Maxwell's equations are expected to be the weak field limit of the nonlinear field equations. He started from a world function and got the field equations by means of Hamilton's variational principle. In contrast to Einstein, the solution of the gravitational problem would have been a bonus of his unified field theory.

A series of notes in his diary reflect his struggle with mathematical problems but also his pleasure in thinking about the solution of physical problems.

In the last week I was submerged in a fog of mathematical formulae and calculations. They concerned the effect of the gravitational field on the internal structure of an electron. I believed that I had found a beautiful entry into the dark region by the Born transformation and with the introduction of bipolar coordinates and I hoped to head for a light soon. However, I immediately came into a sea of fog, drove around in it wildly back and forth, because I thought, once I could get to the border of the fog by chance, I could then slip free.¹⁰⁷

At the end Mie missed his grandiose goal, but his formalism has had a large influence on the further development of unified field theories. A sign of the importance of Mie's work is that Weyl discusses the theory in his famous book "Raum-Zeit-Materie".¹⁰⁸

¹⁰⁷ UAF, Nachlass Mie, E12/68, diary note from 28 October 1915.

¹⁰⁸ See [103] and also [104].

Hilbert included Mies's work in his field theory and mentioned this in his publication at the very beginning. Hilbert wrote:

The tremendous problems stated by Einstein and his subtle methods conceived to their solution as well as the profound ideas and original conceptualisations whereby Mie formulates his electrodynamics, opened new routes for the investigation of the foundations of physics. I want in the following—in terms of the axiomatic method—essentially starting from two simple axioms, to develop a new system of fundamental equations of physics, which are of ideal beauty. I believe that the equation contains the solution of the problems of Einstein and Mie simultaneously.¹⁰⁹

Mie was very excited about the progress made by Hilbert. After the receipt of Hilbert's publication he noted:

Yesterday a separate print of Hilbert's paper "The Fundamentals of Physics" arrived. In this essay he combines my theory of matter with the principle of general relativity, which Einstein aims at, but only Hilbert really fulfils. It is a completely wonderful work! With what a strong fist this Mathematician strikes hard! He smashes the largest obstacles to smithereens. My boldest dreams are exceeded. I believe that it will not take long, before we really get the true world function and will be able to create matter like god in a mathematical way. I just wrote a letter to Hilbert. I am extremely excited about this event.¹¹⁰

Mie was also invited to the Wolfskehl lectures¹¹¹ in 1917. In 1915, Einstein was invited to give Wolfskehl lectures and M.v. Smoluchowski was the invitee in 1916. Other renowned invitees have been Poincaré, Lorentz, Sommerfeld, Planck, Debye, Born and others. Mie's Wolfskehl lectures appeared in print in 1917 [Mie43, Mie44, Mie45]. After finishing the corrections in the proof sheets, Mie commented:

I have now completed the last proof-sheet of my *Einsteiniade* and soon, the third and final lecture will also be printed. I cannot help myself, I found it enormously interesting reading.¹¹²

An important place for discussion and controversy was the regular meeting of the "Gesellschaft deutscher Naturforscher und Ärzte". Mie and Einstein visited the meetings regularly. They presented their own contributions or commented on contributions from others during the discussion. A conflict between Mie and Einstein appeared at the meeting in Vienna in 1913 (see Fig. 1.11). Einstein presented an overview, "To the state of the art of the gravitational problem". Einstein discussed his theory, developed together with Marcel Großmann, and also

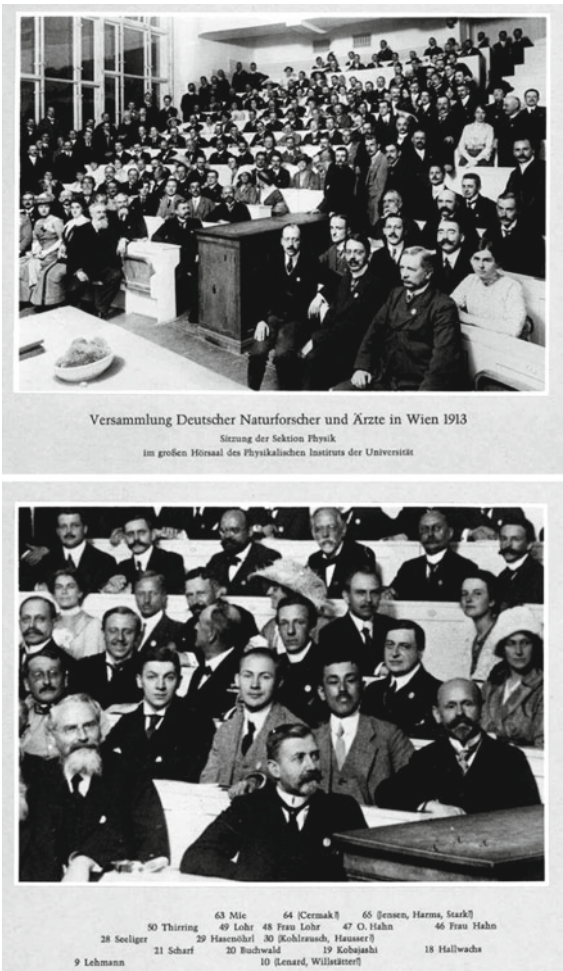
¹⁰⁹ D. Hilbert, *Die Grundlagen der Physik. Erste Mitteilung. Vorgelegt in der Sitzung vom 20. November 1915.* in "Nachrichten von der Königlichen Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse", Heft 5, 395–407 (1915).

¹¹⁰ UAF, Nachlass Mie, E12/69, diary note from 13 February 1916.

¹¹¹ Paul Wolfskehl (1856–1906) was an industrialist with mathematical interest. He bequeathed 100000 Mark to the Royal Academy of Sciences of Göttingen to be given to that person, who will proof Fermat's Theorem during the next 100 years. (Wolfskehl prize) The interest of the prize money was used to organize the Wolfskehl lectures.

¹¹² UAF, Nachlass Mie, E12/71, diary note from 8 December 1917.

Fig. 1.11 “Naturforscherversammlung” in Vienna, 21 to 28 September 1913. (Courtesy of Techniseum Mannheim)



included attempts, especially Nordström’s theory, in his talk. The discussion was led mainly by Mie and Einstein. Mie was angry that Einstein failed to mention his theory. A controversy documented in the *Physikalische Zeitschrift* was the result. In an exchange of letters from 1917 to 1919 both scientists discussed their different points of view. Illy summarised the exchange of letters and discussion between Mie and Einstein:

The case of Einstein and Mie underlines a rather sceptical thesis: there is no perfect understanding of each other. Theories change in the hands of scientists, taking part in a relay race called science with each member of the team leaving the fingerprints of his commitments and beliefs on it. These fingerprints are often nonrational and incomprehensible to others. But this is the way science always grows...¹¹³

¹¹³ [105], p. 256.

The “Naturforscherversammlung” in 1920 took place in Bad Nauheim and was dominated by controversies about Einstein’s theory of relativity and the dispute between Einstein and Lenard (1862–1947). Mie spoke about “The electrical field of a charged particle rotating around a center of gravitation”. Mie appeared in the discussion as a critical promoter of the theory of general relativity.¹¹⁴

1.4 Gustav Mie as University Teacher

1.4.1 Lectures

Gustav Mie was full professor for experimental physics and director of the institutes in Greifswald, Halle and Freiburg. The obligation which accompanied with these positions was to cover teaching in experimental physics. A check of the university calendars of the corresponding years demonstrates that Mie did not regard teaching as an annoying obligation. On 2 November 1915, he wrote in his diaries with reference to the beginning of the practical course of the students of medicine and the difficult times during World War I:

In such a situation one is automatically kind and attentive to the young people and immediately forgets to play the role of the schoolmaster, which is often, for me, so inexpressibly distasteful. Yesterday, I took to being a teacher with great pleasure, and by the way, there were also three ladies sprucing up the otherwise so martial audience. ...Then, I had my first lecture in this term ...and it was a great pleasure for me to tell the young people, as an introduction to electricity, a little bit about my old friend, the world ether to teach them respect.¹¹⁵

As an example, the canon of the courses that Mie lectured in Freiburg from winter semester of 1925–1926 until the winter semester of 1934–1935 is given in Table 1.3. The courses remained almost unchanged during the whole period. Starting from the summer semester 1930 the half-day courses *Advanced Practical Course I and II*, where Mie lectured the first part together with Kast (1896–1980), replaced *Physical Exercises for advanced Students*. The workload from the lectures was high and, apart from the large experimental physics lecture, also included the work in practical courses.

Theoretical physics was lectured by Emil Cohn¹¹⁶ and Johann Georg Königsberger.¹¹⁷ Courses in theoretical physics were only rarely given by Mie.

¹¹⁴ For a summary see of the meeting see Weyl [106].

¹¹⁵ UAF, Nachlass Mie, E12/69, diary note from 2 November 1915.

¹¹⁶ Emil Cohn (1854–1944), 1879 Dr. phil. in Strassburg, assistant of A. Kundt, 1884 habilitation in theoretical physics, 1919 honorary professor in Rostock, 1920–1935 honorary professor in Freiburg, 1938 together with Gans, Graetz, Jaffé, Kaufmann and other physicists of Jewish descent withdrew out of DPG, 1939 emigrating to Switzerland.

¹¹⁷ J.G. Königsberger (1874–1946), 1904–1936 professor of physics at the University of Freiburg, pioneer of semiconductor physics, coined 1911 together with Weiss the term “semiconductor” (son of the mathematician Leo Königsberger).

Table 1.3 Courses of Gustav Mie at the University of Freiburg from the WS 25/26 up to the WS 34/35

| | Lecture | Amount |
|----|--|-----------|
| SS | Experimental Physics I (Mechanics, Acoustics, Thermodynamics) | 5 h/week |
| | Mathematical Additions to Experimental Physics | 2 h/week |
| | Physical Exercises for Students of Natural Sciences | 6 h/Wweek |
| | Small Physical Practical Course for Physicians and Pharmacists | 3 h/week |
| | Physical Exercises for advanced students | Daily |
| | Guidance for independent work | Daily |
| | Physical Colloquium | 2 h/week |
| WS | Experimental Physics II (Electricity and Optics) | 5 h/week |
| | Mathematical Additions to Experimental Physics | 2h/week |
| | Physical Exercises for Students the Natural Sciences | 6 h/week |
| | Small Physical Practical Course for Physicians and Pharmacists | 3 h/week |
| | Physical Exercises for advanced students | Daily |
| | Guidance for independent work | Daily |
| | Physical Colloquium | 2 h/week |

see university calendars on-line in FREIMORE - FREIburger Multimedia Object REpository
<http://freimore.uni-freiburg.de>

Occasionally, instead of the *the Mathematical Additions to Experimental Physics*, lectures on quantum mechanics were offered. In the summer semester of 1927 *The Schrödinger Mechanics*¹¹⁸ was taught and *Quantum Mechanics* was offered in the summer semesters of 1929 and 1931. The lecture of the summer semester 1927 continued into the winter term of 1927–1928 with the lecture *The Schrödinger Mechanics II*. This was followed by the lecture *The Dirac Theory of the Electron* in the winter semester of 1929–1930.

The courses in Greifswald and Halle mainly followed the structure in Table 1.3. From 1911 to 1914, Mie also offered theoretical lectures in Greifswald, for example *Theory of Relativity* (WS12/13) and *Theory of the Quantum of Action* (SS13). Due to the difficulties with K.E.F. Schmidt, Mie did not offer lectures in theoretical physics in Halle.

Regarding the structure and effect of Mie's lectures, Kast wrote:

It had always been his concern that the field representation should be introduced at high school level, not only to university students. Just as he did not place the topic of electric forces but electric field pattern at the beginning of the 2nd part of his basic lecture, he did not begin the first part with the laws of motion but with the weight of bodies as a consequence of the gravitational field of earth, taking his audience as far as the theory of relativity. Therefore, his lectures were not easy, particularly as he did not allow simplification that would have affected the rigour in the content of the presentation. By this however, the lectures attained a degree of coherence that deeply impressed those who were willing to follow.¹¹⁹

¹¹⁸ Königsberger lectured in the same term *Elements of the Quantum Theory*.

¹¹⁹ [Bio10], p. 130.

1.4.2 *Disciples*

Within the institute, Mie predominantly appeared as an experimental physicist. During his activity as a professor in Greifswald, Halle and Freiburg he did not supervise purely theoretical theses.¹²⁰ In this sense, Mie, concerning his theoretical work, did not form a school in the way Sommerfeld did. Nevertheless, he promoted several young physicists in their career systematically. As an example, August Julius Herweg¹²¹ came from W. Wien (1864–1928) (Würzburg) to Greifswald. After Herweg's habilitation Mie requested the title professor on his behalf and tried to obtain him a teaching appointment for spectroscopy.¹²² This request for the teaching appointment was declined by the minister for religious and educational affairs. Herweg followed Mie to Halle. In Halle however, a teaching appointment for “Research Methods of latest Physics” was then obtained for Herweg. In 1923 Herweg accepted an offer as a regular extraordinary professor for high-frequency engineering, outlines of physics and photography to the Technical University Hannover. The vacant assistantship was occupied by Wilhelm Kast,¹²³ who later also followed Mie, as assistant, to Freiburg and in 1937 became full professor and director of the Physical Institute in Halle.

1.4.3 *Textbooks and Popular Scientific Brochures*

Gustav Mie wrote a series of popular scientific brochures and papers on actual problems of physics for the general public. The brochures “Ions and Electrons” [Mie14] and “Molecules, Atoms, World Ether” [Mie18] are two examples. Mie also published a popular description of Einstein's theory in 1921 [Mie50]. His final treatise “Foundations of Mechanics” dates back to 1950 [Mie86]. His book entitled, “Textbook on Electricity and Magnetism. An Experimental Physics of the World Ether for Physicists, Chemists and Electrotechnicians”. [Mie29] is highly

¹²⁰ See: Jahresverzeichnis der an den deutschen Universitäten erschienenen Schriften (1887–1913), Jahresverzeichnis der an den deutschen Universitäten und Technischen Hochschulen erschienenen Schriften (1914–1925), Jahresverzeichnis der an den deutschen Universitäten und Hochschulen erschienenen Schriften (1926–1936). Purly theoretical Ph.D thesis supervised by Mie could not be found.

¹²¹ August Julius Herweg (1879–1936), studies in Würzburg, scholar of W. Wien, graduation Würzburg 1905, habilitation Greifswald 1907, 1913 professor, 1914–1918 army service, 1921 extraordinary professor in Halle, from 1923, extraordinary professor at TH Hannover.

¹²² UAG, Acta of the Phil.Fak. of the Königl. Univ. Greifswald I 324 (Dekanat Mie), J.Nr. 1245.

¹²³ Wilhelm Kast (1898–1980), studies in Halle, 1922 graduation, 1924 Freiburg, 1927 habilitation, 1933 appointment as extraordinary Professor, 1937 full professor and director of institute in Halle, 1947 Bayer AG Leverkusen, 1954 honorary professor University Cologne, 1957 honorary professor university Freiburg.

regarded, was printed in three editions 1910, 1941 and 1948, Mie was 80-years old when he finished working on the final edition of his textbook.

Mie's book was the first to contain a consequent classification of the field quantities in quantities of intensity and quantities of quality. He also developed an electromagnetic system of units, based on Volt, Coulomb, Centimeter and Second, which is no longer relevant. The first edition starts from the physical phenomenon rather than the mathematical approach.

Mie's textbook, dedicated to Engelbert Arnold and Otto Lehmann in memory of his Karlsruhe years of apprenticeship, appeared in the publishing house of Ferdinand Enke, Stuttgart. Mie kept connections with this publisher for over 40 years. The exchange of letters between Enke and Mie highlights the relationship, which was not entirely frictionless at times, between a scientist and the publisher, who also had economic interests.¹²⁴ Enke visited Mie in Halle at the beginning of 1924, to discuss details of a second edition after the success of the first edition. They reached an agreement and settled on the deadline of April 1925. This deadline was exceeded by more than 15 years in the end. Mie wrote in a letter to Enke on 29 November 1925:

I started to rewrite my book to get a shorter version after your visit to Halle, but I cannot do this without completely changing the character of the book. Therefore I finally decided to follow the second possible way, namely to adapt it to a truly complete textbook which includes all elements of the mathematical theory. ...I assume, that I will need nearly three years to get it done. It will be a totally new book.¹²⁵

Schäfer quoted in his recension of the second edition regarding the relevance of Mie's textbook as follows:

The first edition of Mie's "Textbook of Electricity and Magnetism" appeared in 1910. This was the first experimental textbook which took the introduction and realisation of the field concept seriously into account, introducing the reader in the mindscape of Faraday and Maxwell following a thoroughly thought out plan. Mie did not go back to ideas and concepts of the theory of remote action. To the expert it is unquestionable that this book has had a profound impact to the textbook literature after 1910, even if the authors did not mention their source explicitly.¹²⁶

The following remark of Schäfer about the style in Mie's textbook seems to be characteristic of Mie's mode of practice: "The diction is sober, objective, clear, and empathic. The formulation of the important theorems is presented in almost pedantic accuracy to avoid any misunderstanding about the meaning of the material: The learner cannot expect a better leader".¹²⁷

¹²⁴ vergl. UAF—Nachlass Mie, Bestand E12/30 Verlagsverhandlungen 1912–1946.

¹²⁵ *ibid.*

¹²⁶ Mie, Gustav: *Lehrbuch der Elektrizität und des Magnetismus*, Stuttgart 1941, Besprechung durch Cl. Schaefer, *Die Naturwissenschaften* H. 17/18, S. 267f (1942).

¹²⁷ *ibid.*, S. 268.

1.5 Scientific Community and Society

Gustav Mie was strongly affected by the events of his times, in particular in his work as a university teacher. His time in Greifswald coincides with World War I. In these awkward times, he also officiated as rector of Greifswald University. The time in Halle was accompanied by the revolution of 1918–1919, the Kapp Putsch of 1920, the Central-German rebellion in March 1921 and the effects of hyperinflation in 1922–1923. During his last years at Freiburg University, Mie felt the seizure of power of National Socialists and their increasing influence on the University. Mie's retirement was marked by the experience of the horrors of World War II, as well as the beginning of the democratic reconstruction of Western Germany. It is beyond the scope of this text to give a complete analysis of the development of the academic, political and ideological opinions of Mie. In addition, among other things, a detailed evaluation of the diaries would be necessary.¹²⁸

Gustav Mie was fully integrated into the network of theoretical physicists at that time. He came into contact with Arnold Sommerfeld over his work on the parallel wire system [Mie9]. At almost the same time, Mie began an exchange of letters with W. Wien in 1900.¹²⁹ Soon, Mie belonged to the community of prominent German theoretical physicists, who met for skiing holidays, often in Mittenwald. Mie was friends with W. Wien, A. Sommerfeld, M. von Laue and P. Debye. The appreciation of his work was also expressed in the fact that his colleagues recommended him for full professorships several times. He was suggested for the post of the full professor in Frankfurt/Main by Sommerfeld along with Laue and Debye in 1913, Wien suggested Mie for a full professor in Tübingen as the second choice after Stark in 1916.

Mie's extensive scientific exchange of letters as well as the numerous letters of appraisal in appointment procedures¹³⁰ show that Mie was strongly integrated into the physics community of that time. S.L. Wolff places Mie in a network of reactionary physicists during the time of the Weimar Republic [107, 108]. Gustav Mie's basic political orientation can be regarded as national conservative.¹³¹

Gustav Mie's mainly conservative and somewhat nationalistic point of view can be deduced, for example, from his publication "Werner Siemens as a Physicist" [Mie40] from 1916. At the end of the essay he characterised Siemens as a person. Mie wrote:

If we consider Siemens as a person, as we can see him from the memoirs of his life, one can conclude that he possess to a large degree the typical characteristics of a German. It is

¹²⁸ UAF, inventory E012/68-E012/72 (copies), Nachlass Gustav Mie.

¹²⁹ UAF, E012/48, Briefwechsel Mie-Wien, see also Archives Deutsches Museum Munich, Nachlass Wilhelm Wien, Briefwechsel.

¹³⁰ see UAF: E012/33, E012/34, Nachlass Gustav Mie, Berufungen.

¹³¹ Diary entries to current events prove Mie's political point of view, UAF, inventory E012/68-E012/72.

definitely impossible to conceive this man to have grown up anywhere else but in Germany. Also the peculiar connection of the desire for clear, scientific and objective insight with a strong compulsion to influence the environment in an active and creative way has to be counted as the typical properties which, in the end, makes the difference between the German technology in general and that of other peoples. This unification of energy and spirit of research in Germans, which allowed Siemens, with ingenious peculiarity, to pace through his life as a hero, faced by the largest difficulties, which will hopefully also contribute such that our native country will overcome the actual ordeal.¹³²

World War I, involving all industrial nations, also gave rise to industrial conflicts, in which scientists were professionally mobilised [109]. At the beginning of the war, scientists tried to justify the points of view of the respective belligerent parties with invocations and corresponding replies. This development is characterised by the term “War of the Spirit”.¹³³ After an article by Sir J.J. Thompson in The Times on the 1 August 1914 on the 4 October 1914 the appeal “An die Kulturwelt! Ein Aufruf” followed as a reply.

In this time also the *Aufforderung*, initiated by Wilhelm Wien appeared, polemising against the “Ausländerei” and in particular the strong English influence. Finally it led to a politically motivated regimentation of the citations of scientific work. Mie was one of the 16 signatories of the *Aufforderung*, 700 copies of which were sent to all Universities in Germany and Austria.

To evaluate Mie’s attitude at the time of the National Socialism, one must consider that he had already reached his retirement age in 1933 [110]. In the conflict centred around “German Physics” the article “German and Jewish Physics” by W. Menzel was published in the “Völkischer Beobachter” on 29 January 1936. Heisenberg answered in the same journal on the 28 February followed by another reply by Stark. Thereupon, Heisenberg prepared a memorandum to the Reichserziehungsminister Rust, which pointed out the difficulties of physics, and in particular the importance of theoretical education and the cooperation between theoretical and experimental physics. The memorandum was signed by 75 experimental and theoretical professors in the summer of 1936. Being asked by Werner Heisenberg to sign the memorandum on 11 May 1936, Mie replied, that he would do it with “great pleasure”.¹³⁴ In addition to the examples specified by Heisenberg, Mie pointed out another example of fruitful collaboration between theory and experiment:

A more impressive example, albeit from older times, ...is the discovery of the electromagnetic waves propagating freely in air by Heinrich Hertz. It is safe to state that without Maxwell’s theory no one would ever have got the idea of performing such experiments. H. Hertz considered them as an explicit verification of Maxwell’s theory. As I know from a trustworthy source in Karlsruhe, any practical applications were far from his

¹³² [Mie40], p. 776.

¹³³ After the title of the book “Krieg der Geister” from Hermann Kellermann, Dresden, 1915. In this book corresponding calls and signatory lists are printed.

¹³⁴ UAF, inventory E012/41, exchange of letters Mie-Heisenberg, 1a, letter Heisenberg at Mie of 11 1936, 1b, letter Mie at Heisenberg 15 May 1936, 2b text of the memorandum Leipzig, 30 May 1936.

considerations. What was more amazing is to see the world being reshaped by the electromagnetic waves.¹³⁵

Besides physics and mathematics, philosophy (interest in Kant's philosophy) and theology played an important role in Mie's life. His talk at the beginning of his rectorate in Greifswald in 1916, entitled "Law of Nature and Spirit" [Mie41], dealing with questions of causality, received, to Mie's surprise, much attention amongst the members of the theological faculty. After 1930, he published a series of writings of religious and ideological content [Mie76, Mie78, Mie82, Mie84, Mie87]. In Freiburg, Mie, along with the philosopher Jonas Cohn (1869–1947) and the zoologist Spemann (1869–1941) founded a scientific society called "Pentathlon", which met monthly for lectures and discussions. The society ceased to exist in 1933, when Cohn was forced to leave Germany.

During the November pogroms on the night from 10 to 11 November 1938, amongst many others, the synagogue of Freiburg was set on fire by the SS. These events led to the establishment of the "Freiburger Kreis", a resistance group, to which Mie and his wife belonged [111–113]. The Group organised monthly discussions, in private dwellings, of persons involved until September 1944.

1.6 Concluding Remarks

Single aspects of Mie's scientific work have been illuminated in the past, often in the context of different contributions to the history of physics, especially larger historical studies about field theory and the theory of relativity [33, 98, 114]. Parts of his extensive correspondence can be found in the edited correspondence of Arnold Sommerfeld [115] as well as in the "Collected Papers of Albert Einstein" [116]. Gustav Mie's archives¹³⁶ are, to a large extent, unexplored.

In the 1970s an initiative existed to publish parts of scientific legacy, in particular the correspondence of Gustav Mie.¹³⁷ This project was driven in particular by Helmut Hönl¹³⁸ in collaboration with Herbert Fröhlich¹³⁹ and Ernst Plötze. The Mie edition should have been published with the support of the Leopoldina. The correspondence between Helmut Hönl and Heinz Bethge (1919–2001), president of the Leopoldina in Halle at that time, documents this attempt. In the

¹³⁵ *ibid.*, 1b.

¹³⁶ UAF, E0012, Nachlass Gustav Mie.

¹³⁷ see UAF: C136, materials for the edition Gustav Mie, worked on by Rolf Steinmann 2001; E14, Nachlass Helmut Hönl, worked on by David Geiger, 2003.

¹³⁸ Helmut Hönl (1903–1981), Studies in Heidelberg, Göttingen and Munich, 1926 graduation with A. Sommerfeld, 1933 habilitation in Stuttgart, 1940 extraordinary Professor in Erlangen, 1943 professor in Freiburg, 1971 emeritus.

¹³⁹ Herbert Fröhlich (1905–1991), graduation 1930 with Sommerfeld, private lecturer in Freiburg, as Jew forced to leave Germany, 1935 University of Bristol, 1948 University of Liverpool.

end, the project could not be realised. A detailed investigation of the life and scientific work of Gustav Mie is thus still pending.

Acknowledgments I appreciate the support of the staff members of the university archives of the Universities of Greifswald, Halle, Heidelberg and Freiburg, the archives of Karlsruhe Institute of Technology as well as the archives of the National Academy of the Sciences Leopoldina during my search. My special gratitude applies to Vincent Loke, Thomas Wriedt and Christian Matyssek for the critical reading of the manuscript and Thomas Wriedt for suggestions and references.

Publications of Gustav Mie

- [Mie1] G. Mie, Zum Fundamentalsatz über die Existenz von Integralen partieller Differentialgleichungen, Dissertationes Philosoph. Heidelbergensis 1892, Dresden, Druck von B.G. Teubner, 1892
- [Mie2] G. Mie, Fundamentalsatz über die Existenz von Integralen partieller Differentialgleichungen, Zeitschrift für Mathematik 37, 151–170 (1892)
- [Mie3] G. Mie, Fundamentalsatz über die Existenz von Integralen partieller Differentialgleichungen, Zeitschrift für Mathematik 37, 193–211 (1892)
- [Mie4] G. Mie Die Röntgen'sche Strahlung, S. V-IX, Sonderdruck aus: Beilage zur Nr. 7 der Zeitschrift des Vereins für Finanzassistenten, 1896
- [Mie5] G. Mie, Beweis der Integrirbarkeit gewöhnlicher Differentialgleichungen nach Peano, Mathemat. Annalen 43, 553–568 (1893)
- [Mie6] G. Mie, Entwurf einer allgemeinen Theorie der Energieübertragung, Sitzungsber. d. K. Akad. d. Wiss. Wien, Math.-nat. Klasse 107 Abt. Ila, 1113–1180 (1898) (Habilitationsschrift)
- [Mie7] G. Mie, Über mögliche Ätherbewegungen, Ann. der Physik 68, 129–134 (1899)
- [Mie8] G. Mie und E. Arnold, Über den Kurzschluß der Spulen und die Commutation des Stromes eines Gleichstromankers, Elektrotechn. Zeitschrift 20, 97–101, 136–138, 150–152 (1899)
- [Mie9] G. Mie, Elektrische Wellen an zwei parallelen Drähten, Ann. der Physik 2, 201–249 (1900)
- [Mie10] G. Mie, Die mechanische Erklärbarkeit der Naturerscheinungen: Maxwell-Helmholtz-Hertz, Nat. Ver. Verh. (Karlsruhe) 13, 402–420 (1900)
- [Mie11] G. Mie, Ein Beispiel für Poyntings Theorem, Zeitschrift für physikal. Chemie 34, 522–526 (1900)
- [Mie12] G. Mie, Über die Bewegung eines als flüssig angenommenen Äthers, Physikal. Zeitschrift 2, 319–325 (1901)
- [Mie13] G. Mie, Zur kinetischen Gastheorie der einatomigen Körper, Ann. der Physik 11, 657–697 (1903)
- [Mie14] G. Mie, Die neueren Forschungen über Ionen und Elektronen, Sonderausgabe aus der Sammlung elektrotechnischer Vorträge Bd. 4, Enke Stuttgart, 1903, 40 S. (2. Aufl. 1906)
- [Mie15] G. Mie, Der elektrische Strom in ionisierter Luft in einem ebenen Kondensator, Ann. der Physik 13, 857–889 (1904)
- [Mie16] G. Mie, Über eine Methode, das spezifische Gewicht sehr verdünnter Lösungen zu bestimmen, Festschrift Ludwig Boltzmann gewidmet zum 60. Geburtstag, Ambrosius Barth, Leipzig 1904, 326–332
- [Mie17] G. Mie, Das Problem der Wärmeleitung in einem verseilten elektrischen Kabel, Neu-Vorpommern u. Rügen, Nat.-Ver. Mitteil. 36, 155–188 (1904)
- [Mie18] G. Mie, Moleküle, Atome, Weltäther, Verlag von B.G. Teubner, Leipzig, 1. Auflage 1904, *Aus Natur und Geisteswelt* Sammlung wissenschaftlich-gemeinverständlicher Darstellungen 58. Bändchen (2. Aufl. 1907, 3. Aufl. 1911, 4. Aufl. 1919)

- [Mie19] G. Mie, Das Problem der Wärmeleitung in einem verseilten elektrischen Kabel, *Elektrotechn. Zeitschrift* 137, 137–143 (1905)
- [Mie20] G. Mie, Über die Kurzschlußstromkurve eines Gleichstromankers, *Zeitschrift Math. Phys.* 53, 37–60 (1906)
- [Mie21] G. Mie, Experimentelle Darstellung elektrischer Kraftlinien, *Zeitschrift für d. phys. u. chem. Unterricht* 19, 154–156 (1906)
- [Mie22] G. Mie, Erwiderung auf Riebesells Abhandlung: Kommutation des Stromes in Gleichstromgeneratoren, *Zeitschrift Math. Phys.* 55, 143–146 (1907)
- [Mie23] G. Mie, Die optischen Eigenschaften kolloidaler Goldlösungen, *Zeitschrift für Chemie und Industrie der Kolloide* 2, H. 5, 129–133 (1907)
- [Mie24] G. Mie, Die optischen Eigenschaften kolloidaler Goldlösungen, *Berichte der dt. phys. Ges.* 5, 492–500 (1907)
- [Mie25] G. Mie, Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen, *Ann. der Physik* 25, 377–445 (1908)
- [Mie26] G. Mie, Sättigungsstrom und Stromkurve einer schlecht leitenden Flüssigkeit, *Ann. der Physik* 25, 597–614 (1908)
- [Mie27] G. Mie, Eine bequeme Methode zur Erzeugung ganz schwach gedämpfter elektrischer Schwingungen von kleiner Wellenlänge, *Verh. der dt. phys. Ges.* 12, 860–866 (1910)
- [Mie28] G. Mie, Hydratisierung und Molekularwärme der Ionen in sehr verdünnten wässrigen Lösungen, *Ann. der Physik* 33, 381–399 (1910)
- [Mie29] G. Mie, Lehrbuch der Elektrizität und des Magnetismus. Eine Experimentalphysik des Weltäthers für Physiker, Chemiker und Elektrotechniker, 736 S., Stuttgart 1910, 2. vollständig umgearbeitete Aufl. 1941, 3. Aufl. 1948, span. Ausgabe Barcelona 1944
- [Mie30] G. Mie, Antwort auf die Bemerkung des Hrn. Seibt zu der Arbeit des Hrn. K. Settnik: Entstehung von sehr wenig gedämpften Wellen usw., *Ann. der Physik* 36, 207–208 (1911)
- [Mie31] G. Mie, Die Materie, 32 S., Verlag von Ferdinand Enke, Stuttgart 1912 (Vortrag gehalten am 27. Januar 1912 (Kaisers Geburtstag) in der Aula der Universität Greifswald)
- [Mie32] G. Mie, Grundlagen einer Theorie der Materie I, *Ann. der Physik* 37, 511–534 (1912)
- [Mie33] G. Mie, Grundlagen einer Theorie der Materie II, *Ann. der Physik* 39, 1–40 (1912)
- [Mie34] G. Mie, Bemerkungen zu der Arbeit des Herrn W. Sorkau über Turbulenzreibung, *Physikal. Zeitschrift* 14, 93–95 (1913)
- [Mie35] G. Mie, Bemerkungen zu der Arbeit des Herren Gotthelf Leimbach: Energieaufnahme elektrischer Sender von kleiner Wellenlänge, *Physikal. Zeitschrift* 14, 723–725 (1913)
- [Mie36] G. Mie, Grundlagen einer Theorie der Materie III, *Ann. der Physik* 40, 1–66 (1913)
- [Mie37] G. Mie, Bemerkungen zu Einsteins Gravitationstheorie I, *Physikal. Zeitschrift* 15, 115–122 (1914)
- [Mie38] G. Mie, Bemerkungen zu Einsteins Gravitationstheorie II, *Physikal. Zeitschrift* 15, 169–176 (1914)
- [Mie39] G. Mie, Prinzip von der Relativität des Gravitationspotentials, *Festschrift für J. Elster und H. Geitel* (1915), S. 251–268
- [Mie40] G. Mie, Werner Siemens als Physiker, *Die Naturwissenschaften* 4, 771–775 (1916)
- [Mie41] G. Mie, Naturgesetz und Geist, *Deutsche Revue* 41, 150–163 (1916)
- [Mie42] Bilder aus Greifswalds Vergangenheit, Gewidmet von der Universität Greifswald ihren Kriegsstudenten (Vorwort G. Mie), Verlag Bruckner & Co. Greifswald, 1917
- [Mie43] G. Mie, Die Einsteinsche Gravitationstheorie und das Problem der Materie, *Physikal. Zeitschrift* 18, 551–555 (1917)
- [Mie44] G. Mie, Die Einsteinsche Gravitationstheorie und das Problem der Materie, *Physikal. Zeitschrift* 18, 574–580 (1917)
- [Mie45] G. Mie, Die Einsteinsche Gravitationstheorie und das Problem der Materie, *Physikal. Zeitschrift* 18, 596–602 (1917)
- [Mie46] G. Mie, Einführung eines vernunftgemäßen Koordinatensystems in die Einsteinsche Gravitationstheorie und das Gravitationsfeld einer schweren Kugel, *Ann. der Physik* 62, 46–74 (1920)
- [Mie47] G. Mie, Die Gesetzmäßigkeit des Naturgeschehens, Bertelsmann, Gütersloh, 1920

- [Mie48] G. Mie, Das elektrische Feld eines um ein Gravitationszentrum rotierenden geladenen Partikelchens, *Physikal. Zeitschrift* 21, 651–658 (1920)
- [Mie49] G. Mie, Über die Abklingung der Lichtemission eines Atoms, *Ann. der Physik* 66, 237–260 (1921)
- [Mie50] Die Einsteinsche Gravitationstheorie. Versuch einer allgemeinverständlichen Darstellung der Theorie, 4+69 S., Leipzig, Hirzel 1921 (2. verbesserte Aufl. 1923)
- [Mie51] Die Relativitätstheorie von Einstein. *Zeitschrift des Vereins Deutscher Ingenieure* 65, 26. Februar, S. 236 (1921)
- [Mie52] Die Einsteinsche Gravitationstheorie, *Deutsche Rundschau*, 187, 171–184, 310–342 (1921)
- [Mie53] G. Mie und J. Herweg, Die Zahl der von sehr schwachen Röntgenstrahlen ausgelösten Elektronen, *Ann. der Physik* 68, 120–126 (1922)
- [Mie54] G. Mie, Träge und schwere Masse, *Ann. der Physik* 69, 1–51 (1922)
- [Mie55] G. Mie, *Théorie Einsteinienne de la Gravitation. Essai de vulgarisat. de la théorie*, Hermann, Paris 1922
- [Mie56] G. Mie, Echte optische Resonanz bei Röntgenstrahlen, *Zeitschrift für Physik* 15, 56–57 (1923)
- [Mie57] G. Mie, Echte optische Resonanz bei Röntgenstrahlen, *Zeitschrift für Physik* 18, 105–108 (1923)
- [Mie58] G. Mie, Das elektrische Feld eines schweren elektrisch geladenen Kügelchens, das um ein Gravitationszentrum kreist, *Ann. der Physik* 70, 489–558 (1923)
- [Mie59] G. Mie, Abklingzeit und Verweilzeit angeregter Atome, *Ann. der Physik* 73, 195–208 (1924)
- [Mie60] G. Mie, Theorie der Bremsstrahlung und der Comptonschen Streustrahlung (Vortrag auf dem III. Dt. Physikertag, Danzig, 10.-16.9.1925) *Physikal. Zeitschrift* 26, 665–669 (1925)
- [Mie61] G. Mie, Bremsstrahlung und Comptonsche Streustrahlung, *Zeitschrift für Physik* 33, 33–41 (1925)
- [Mie62] G. Mie, Theorie der Bremsstrahlung und der Comptonschen Streustrahlung, *Physikal. Zeitschrift*, 26, 665–669 (1925)
- [Mie63] G. Mie, Das Problem der Materie und die Relativitätstheorie, *Scientia (Mailand)* 37, 149–156 (1925)
- [Mie64] G. Mie, Das Problem der Materie und die Relativitätstheorie, *Scientia (Mailand)* 37, 225–234 (1925)
- [Mie65] G. Mie, Das Problem der Materie (Öffentliche Antrittsrede, gehalten am 26. Januar 1925), Speyer & Kärner, Freiburg i. Br., 1925
- [Mie66] G. Mie, Die Grundlagen der Quantentheorie (Vortrag in der Freiburger Naturforschenden Gesellschaft), 38 S., Speyer & Kärner, Freiburg i. Br., 1925
- [Mie67] G. Mie, Ein Linienspektrum bei Wellenlängen von mehreren Dezimetern (nach Messungen von E. Frankenberger), *Physikal. Zeitschrift* 27, 792–795 (1926)
- [Mie68] G. Mie, H. Staudinger, R. Signer, H. Johner und J. Hengstenberg, Der polymere Formaldehyd, ein Modell der Zellulose, *Zeitschrift für physikal. Chemie* 126, 425–448 (1927)
- [Mie69] G. Mie und J. Hengstenberg, Zur Arbeit: E. Ott, Röntgenometrische Untersuchungen an hochpolymeren organischen Substanzen, *Helvet. chim. Acta* 11, 1052 (1928)
- [Mie70] G. Mie, Probleme der Quantenelektrik, *Ann. der Physik* 85, 711–729 (1928)
- [Mie71] G. Mie, Einleitung in die Physik, in: A. Eucken, O. Lummer, E. Waetzmann (Hrsg.) *Müller-Pouillet's Lehrbuch der Physik*, 11. Auflage, Erster Band, Erster Teil, 1–70, Friedr. Vieweg und Sohn, Braunschweig 1929
- [Mie72] G. Mie, Quantentheorie und Elektrodynamik, *Verh. Dt. Phys. Ges.* 12, 46 (1931)
- [Mie73] G. Mie und E. Frankenberger, Über Präzisionsmessungen von elektrischen Brechungs-exponenten nach der 2. Drudeschen Methode, *Festschrift zur 10-j. Tätigkeit des magnetischen Labors. Moskau* (1931) S. 13–20
- [Mie74] G. Mie, Elektrodynamik, in: W. Wien und F. Harms (Hrsg.) *Handbuch der Experimentalphysik* Bd. 11, Teil 1, XII u. 502 S., Akad. Verlagsges. Leipzig 1932

- [Mie75] G. Mie, Elektron, Bd. 2 S. 500–512, Materie, Bd. 6 S. 786–790, Weltäther, Bd. 10 S. 649–655, in: R. Dittler, G. Joos, E. Korschelt, G. Link, F. Oltmanns, K. Schaum (Hrsg.) Handbuch der Naturwissenschaften, 2. Auflage, Jena, Gustav Fischer 1932–1935
- [Mie76] G. Mie, Naturwissenschaft und Theologie, Akad. Verlagsgesellschaft, Leipzig 1932, 40S., Sonderdruck aus der Zeitschrift *Die christliche Welt*, Nr. 22 und 23 (Leopold Klotz Verlag, Gotha)
- [Mie77] G. Mie, Geometrie der Spinoren, Ann. der Physik 17, 465–500 (1933)
- [Mie78] G. Mie, Die geistige Struktur der Physik, Studien des apologetischen Seminars Bd. 38, 36 S., Bertelsmann, Gütersloh 1934
- [Mie79] G. Mie, Zur Erinnerung an Ch.A. Coulomb und A.M. Ampère, Die Naturwissenschaften 24, 369 (1936)
- [Mie80] G. Mie, Julius Herweg †, Zeitschrift für techn. Physik 17, 321–323 (1936)
- [Mie81] G. Mie, Raum und Zeit in der Physik, Festschrift til Professor Dr. Anathon Aall (1937)
- [Mie82] G. Mie, Die Denkweise der Physik und ihr Einfluß auf die geistige Stellung des heutigen Menschen, 37 S., Stuttgart 1937
- [Mie83] G. Mie, Der Trägheitsfaktor, Zeitschrift für d. phys. u. chem. Unterricht 51, 90 (1938)
- [Mie84] G. Mie, Die göttliche Ordnung in der Natur, 3 Aufsätze, 31 S., Tübingen 1946
- [Mie85] G. Mie, Aus meinem Leben, Zeitenwende 19, 733–743 (1948)
- [Mie86] G. Mie, Die Grundlagen der Mechanik, VI u. 80 S., Ferdinand Enke Verlag, Stuttgart 1950
- [Mie87] G. Mie, Gott in der Natur, in: Wunder der Gnade Gottes in unserem Leben - Gesammelte Zeugnisse, Verlagsbuchhandlung Bethel, Hamburg 1952, S. 94–97

Biographic and Bibliographic Communications about Gustav Mie

- [Bio1] Poggendorffs biographisch-literarisches Handwörterbuch 4 (1904) S. 1009; 5 (1926) S. 852; 6,3 (1938) S. 1728; 7a,3 (1958) S. 304
- [Bio2] Reichshandbuch der Deutschen Gesellschaft 2 Wirtschaftsverlag, Berlin 1931, S. 1252 (m. Bildn.)
- [Bio3] O. Eberhard, Zeugnisse deutscher Frömmigkeit, Leipzig 1938, S. 224–226
- [Bio4] um 70. Geburtstag, anonym, Annalen der Physik (5) 33 (1938) S. 185 (m. Bildn. u. Faks.)
- [Bio5] F. Emde, Gustav Mie 80 Jahre, Physikalische Blätter, 4, 349–50 (1948)
- [Bio6] K.H. Wagner Archiv der elektrischen Übertragung 3 (1949) S. 112
- [Bio7] Anonym, Naturwissenschaftliche Rundschau 2 (1949) S. 42–43
- [Bio8] H. Hönl, Gustav Mie 85 Jahre, Physikalische Blätter, 9, 508–510 (1953)
- [Bio9] Anonym, Naturwissenschaftliche Rundschau 6 (1953) S. 523
- [Bio10] W. Kast, Gustav Mie †, Physikalische Blätter, 13, 129–131 (1957)
- [Bio11] Anonym, Naturwissenschaftliche Rundschau 10 (1957) S. 161
- [Bio12] Anonym, Pharmazeutische Zeitung 102 (1957) S. 201
- [Bio13] H. Hönl, Gustav Mie zum Gedächtnis, Gedenkrede auf dem 22. Deutschen Physikertag in Heidelberg 1957, ...
- [Bio14] Gerhard Neumann, Naturwissenschaftler und Christ - Gustav Mie, in: Der Sonntag, Gemeindeblatt der Ev.-Luth. Landeskirche Sachsens 20 (1965) Nr. 47 S. 4
- [Bio15] H. Hönl, Intensitäts- und Quantitätsgrößen, In memoriam Gustav Mie zu seinem hundertsten Geburtstag, Physikalische Blätter, 24, 498–502 (1968)
- [Bio16] H. Spehl, Mie, Gustav Adolf Feodor Wilhelm Ludwig, in: B. Ottnad (Hrsg.) Badische Biographien, Neue Folge Bd. III, W. Kohlhammer Verlag Stuttgart, 1990
- [Bio17] P. Lilienfeld, Gustav Mie: The Person, Appl. Optics 30, 4696–98 (1991).
- [Bio18] H. Rechenberg, Mie, Gustav in: Neue Deutsche Biographie XVII München, 1994

- [Bio19] Berühmter unbekannter Rostocker: Gustav Mie-in der Heimat vergessen, an der Uni Freiburg und in Nachschlagwerken geehrt, Mecklenburg-Magazin: Regionalbeilage der Schweriner Volkszeitung, Band 44, 22 (2005)
- [Bio20] U. Kreibitz, Optische Eigenschaften von Nanopartikeln: 100 Jahre Mie-Theorie, Phys. in unserer Zeit 39 H. 6 (2008), S. 281–287
- [Bio21] M.I. Mishchenko und L.D. Travis, Gustav Mie and the evolving discipline of electromagnetic scattering by particles, Bull. Am. Met. Soc., 89, 1853–1861 (2008)
- [Bio22] M.I. Mishchenko, Gustav Mie and the fundamental concept of electromagnetic scattering by particles: A perspective, J. Quant. Spec. and Rad. Trans. 110, 1210–1222 (2009)

References

1. D. Cahan, Hist. Stud. Phy. Sci. **15**, 1 (1985)
2. C. Jungnickel, R. McCormach, *Intellectual Mastery of Nature—Theoretical Physics from Ohm to Einstein*, Vol. 2 The Now Mighty Theoretical Physics 187–1925 (University of Chicago Press, Chicago and London, 1986).
3. G. Willgeroth, *Die Mecklenburg-Schwerinischen Pfarren seit dem Dreißigjährigen Kriege* (Im Selbstverlag des Verfassers, Wismar, 1924)
4. S. Grimme (ed.), *Scharnebeck- gestern und heute* (Verein für Heimatkunde im Raum Scharnebeck e.V., 2002).
5. W. Neumann, *Die Große Stadtschule zu Rostock in 3 1/2 Jahrhunderten* (Rostock, 1930).
6. G. Schott, Wissenschaftliche Zeitschrift der Universität Rostock **18**, 981 (1969)
7. W. Sarich, Beiträge zur Geschichte der Wilhelm-Pieck-Universität Rostock **13**, 49 (1989)
8. K. Uhle, Wissenschaftliche Zeitschrift der Wilhelm-Pieck-Universität Rostock **34**, 12 (1985)
9. R. Mahnke, Beiträge zur Geschichte der Universität Rostock **17**, 92 (1991)
10. Rektor der Universität Rostock (ed.), *Mögen viele Lehrmeinungen um die eine Wahrheit ringen-575 Jahre Universität Rostock* (Konrad Reich Verlag, Rostock, 1994).
11. G. Becherer, Wiss. Zeitschr. der Univ. Rostock **16**, 825 (1967)
12. L. Königsberger, *Mein Leben* (Carl Winters Universitätsbuchhandlung, Heidelberg, 1919)
13. G. Kern, *Die Entwicklung des Fachs Mathematik an der Universität Heidelberg 1835–1914* (Universität Heidelberg, Staatsexamensarbeit, 1992)
14. O.H. Erdmannsdorff, Sitzungsberichte der Heidelberger Akademie der Wissenschaften: Math.-naturwiss. Klasse (1936). 3. Abhandlung.
15. E. Wülfing, Sitzungsberichte der Heidelberger Akademie der Wissenschaften: Math.-naturwiss. Klasse (1914). 8. Abhandlung.
16. W. Lorey, *Das Studium der Mathematik an den Deutschen Universitäten seit Anfang des 19. Jahrhunderts* (B.G. Teubner, Leipzig und Berlin, 1916).
17. O. Lehmann, *Geschichte des Physikalischen Instituts der Technischen Hochschule Karlsruhe* (G. Braunsche Hofbuchdruckerei und Verlag, Karlsruhe i. B., 1911)
18. J. Fricks, *Physikalische Technik oder Anleitung zu Experimentalvorträgen sowie zur Selbsterstellung einfacher Demonstrationsapparate*, (Vieweg, Braunschweig, 1904–1909).
19. P. Knoll, H. Kelker, *Otto Lehmann, Erforscher der Flüssigen Kristalle* (Ettlingen und Frankfurt, 1988)
20. H. Wessel (ed.), *Energie-Information-Innovation: 100 Jahre Verband Deutscher Elektrotechniker*, Geschichte der Elektrotechnik 12 (VDE Verlag GmbH Berlin, 1993).
21. D. Mlynski, *Fridericiana* **52**, 24 (1996)
22. M. Meyer, *Fridericiana* **52**, 19 (1996)
23. D. Baird, R. Hughes, A. Nordmann, *Heinrich Hertz: Classical Physicist, Modern Philosopher* (Kluwer Academic Publishers, Dordrecht/Boston/London, 1998)
24. A. Beu, G. Sokoll, *Greifswalder Tafelrunde* (Schelzky & Jeep, Greifswald, 1996)
25. K. Fesser (ed.), *Festschrift aus Anlaß des Jubiläums "150 Jahre Physik in Greifswald"* (Universität Greifswald, Greifswald, Institut für Physik, 1998)

26. D. Alvermann, K.H. Spiess, *Universität und Gesellschaft–Festschrift zur 550-Jahrfeier der Universität Greifswald*, Band I: Die Geschichte der Fakultäten im 19. Und 20. Jahrhundert (Hinstorff, Rostock, 2006).
27. Festschrift zur 500-Jahrfeier der Universität Greifswald, Band II (Universität Greifswald, Greifswald, 1956).
28. F. Schubel, *Universität Greifswald* (Wolfgang Weidlich, Frankfurt am Main, 1960)
29. A. Kleinert, *Johannes Stark: Erinnerungen eines Deutschen Naturforschers* (Bionomica-Verlag, Mannheim, 1987)
30. W. Hergert, Martin-Luther-Universität Wissenschaftliche Beiträge 1990/33 (O32) (1990).
31. W. Hergert, scientia halensis (3), 37 (1995).
32. C. Stephan, Die Naturforschende Gesellschaft in Halle: eine lokale Gesellschaft und das Engagement ihrer Mitglieder insbesondere auf den Gebieten der Physik und Chemie. Ph.D. Thesis, Universität Marburg, Marburg (2006).
33. G. Kohl, Relativität in der Schwebe: Die Rolle von Gustav Mie. No. 209 in Preprint Series (Max Planck Institut for the History of Science, Berlin, 2002).
34. W. Hergert, Scientia halensis (3), 13 (2005).
35. R.K. Merton, *The Sociology of Science: Theoretical and Empirical Investigations* (The University of Chicago Press, Chicago and London, 1973)
36. S. Stigler, Trans. New York Acad. Sci. **39**, 147 (1980)
37. J. Jackson, Am. J. Phys. **76**, 704 (2008)
38. G. Stigler, Transactions of the New York Academy of Sciences **39**, 143 (1980)
39. D. Ballentyne, D. Lovett, *A Dictionary of Named Effects and Laws in Chemistry, Physics and Mathematics* (Chapmann and Hall, London, 1980)
40. M. Jammer, *Der Begriff der Masse in der Physik* (Wissenschaftliche Buchgesellschaft, Darmstadt, 1981)
41. D. Plappert, Praxis der Naturwissenschaften-Physik in der Schule **57**, 22 (2008)
42. H. Geiger, K. Scheel (eds.), *Handbuch der Physik, Band X: Thermische Eigenschaften der Stoffe* (Springer, Heidelberg, 1926)
43. E. Grüneisen, Annalen der Physik **39**, 257 (1912)
44. R. Furth, Proc. R. Soc. Lond. **183**, 87 (1944)
45. J. Jones, Proc. R. Soc. London A **106**, 441 (1924)
46. J. Jones, proc. R. Soc. London A **106**, 463 (1924)
47. J. Jones, Proc. R. Soc. London A **106**, 709 (1924)
48. S. Erkoç, R. Sever, Phys. Rev. D **33**, 588 (1986)
49. S. Erkoç, R. Sever, Phys. Rev. D **30**, 2117 (1984)
50. E. Kasap, B. Gönül, M. Simsek, Chem. Phys. Lett. **172**, 499 (1990)
51. R. Sever, C. Tezcan, M. Bucurgat, Ö. Yesiltas, J. Math. Chem. **43**, 749 (2007).
52. R.S.S. Ikhdair, J. Mol. Struc. (Theochem) **855**, 13 (2008)
53. S.Ö.A. Erkoç, E. Iltan, Chem. Phys. Lett. **135**, 582 (1987).
54. H. Ledbetter, M. Lei, R. Rao, Physica B **159**, 265 (1989)
55. K. Jayachandran, C. Menon, J. Phys. Chem. Sol. **60**, 267 (1999)
56. T. Barakat, O. Al-Dossary, A. Alharbi, Int. J. Nanosci. **6**, 461 (2007)
57. S. Flüge (ed.), *Handbuch der Physik, Astrophysik III, Das Sonnensystem* (Springer, Berlin, 1959)
58. E. Lecher, Annalen der Physik **41**, 850 (1890)
59. A. Sommerfeld, Ann. der Physik und Chemie **67**, 233 (1899)
60. A. Sommerfeld, Nuovo Cimento **9**, 151 (1943)
61. D. Hondros, Über elektromagnetische Drahtwellen. Ph.D. Thesis, Ludwig-Maximilians-Universität München (1909).
62. D. Hondros, Annalen der Physik **335**, 905 (1909)
63. K. Jäger, *Die Entwicklung der Starkstromtechnik in Deutschland*, Teil 2: Von 1890 bis 1920 (VDE-verlag Berlin, 1991).
64. M. Cardona, W. Marx, Physik Journal **3**(11), 27 (2004)
65. W. Marx, Phys. in unserer Zeit **38**(1), 34 (2007)

66. K. Degen, *Beiträge zur Kenntnis kolloidaler Metalllösungen* (Julius Abel, Greifswald, 1903)
67. E. Lischner, *Über die elliptische Polarisierung des Lichtes bei der Reflexion an Lösungen anomal dispergierender Substanzen* (Greifswald, 1903).
68. E. Lischner, *Ann. der Physik* **317**, 964 (1903)
69. H. Siedentopf, R. Zsigmondy, *Ann. der Physik Journal* **10**, 1 (1903)
70. R. Zsigmondy, *Zur Erkenntnis der Kolloide* (Verlag von Gustav Fischer, Jena, 1905)
71. M. Planck, *Ann. d. Physik* **306**, 69 (1900)
72. M. Planck, *Ann. der Physik* **311**, 818 (1901)
73. J.M. Garnett, *Trans. Roy. Soc. CCIII A-370*, 385 (1904).
74. W. Steubing, *Über die optischen Eigenschaften kolloidaler Goldlösungen* (Johann Ambrosius Barth, Leipzig, 1908)
75. M. Kerker, *Appl. Optics* **30**, 4699 (1991)
76. N. Logan, *J. Opt. Soc. Am.* **52**, 342 (1962)
77. N. Logan, *Proceedings of the IEEE* **53**, 773 (1965)
78. A. Clebsch, *J. für Mathematik* **61**, 195 (1863)
79. L. Rayleigh, *Phil. Mag.* **41**, 447 (1871)
80. L. Rayleigh, *Proc. Math. Soc. (London)* **4**, 253 (1872)
81. L. Rayleigh, *Phil. Mag.* **12**, 81 (1881)
82. H. Lamb, *Proc. Math. Soc. (London)* **13**, 51 (1881)
83. L. Lorenz, *Vidensk. Selsk. Skrifter* **6**, 1 (1890)
84. P. Debye, *Ann. d. Physik* **30**, 57 (1909)
85. J. Thomson, *Recent Researches in Electricity and Magnetism* (University Press, Oxford, 1893)
86. G.W. Walker, *Quart. J. Math.* **30**, 204 (1899)
87. G. Walker, *Quart. J. Math.* **31**, 36 (1900)
88. J.W. Nicholson, *Proc. Math. Soc. (London)* **9**, 67 (1910)
89. H. Bateman, *The Mathematical Analysis of Electrical and Optical Wave Motion on the Basis of Maxwell's Equations* (University Press, Cambridge, 1915)
90. A.J. Proudman, A. Doodson, G. Kennedy, *Phil. Trans. Roy. Soc.* **217**, 279 (1917)
91. T.J. Bromwich, *Phil. Trans. Roy. Soc.* **220**, 189 (1920)
92. G.N. Watson, *Phil. Trans. Roy. Soc.* **220**, 189 (1920)
93. L. Lorenz, *Oeuvres Scientifiques de L. Lorenz* (Librairie Lehmann, Copenhagen, 1896)
94. H. Kragh, *Applied Optics* **30**, 4688 (1991)
95. M. Pihl, *Der Physiker L.V. Lorenz-Eine kritische Untersuchung* (Einar Munksgaard, Kopenhagen, 1939).
96. L. Lorenz, *Wied. Ann. der Phys.* **11**, 70 (1880)
97. P. Debye, *Zeitschrift für Physik* **9**, 775 (1908)
98. V. Vizgin, *Unified Field Theories* (Birkhäuser Verlag, Basel, Boston, Berlin, 1994)
99. J. Renn (ed.), *The Genesis of General Relativity*, vol. 4 (Gravitation in the Twilight of Classical Physics, The Promise of Mathematics (Springer Verlag, Dordrecht, 2007)
100. J. Renn (ed.), *The Genesis of General Relativity* Vol. 3: Gravitation in the Twilight of Classical Physics: Between Mechanics, Field Theory and Astronomy (Springer, Dordrecht, 2007).
101. L. Corry, *Stud. Hist. Phil. Mod. Phys.* **30**, 159 (1999)
102. M. Born, L. Infeld, *Proc. R. Soc. A* **144**, 425 (1934)
103. H. Weyl, *Raum - Zeit - Materie*, 5th edn. (Springer, Dordrecht, 1923)
104. E. Scholz (ed.), *Hermann Weyl's Raum-Zeit-Materie and a General Introduction to His Scientific Work* (Birkhäuser Publishing Ltd, Switzerland, 2001)
105. J. Illy, in *Einstein Studies* Vol. 3, *Studies in the History of General Relativity*, ed. by J. Eisenstaedt, A. Knox (Birkhäuser Publishing Ltd, Switzerland 1992), pp. 244–259.
106. H. Weyl, *Jahresbericht der Dt. Mathematiker-Vereinigung* **31**, 51 (1922)
107. S. Wolff, *Ber. Wissenschaftsgesch.* **31**, 372 (2008)
108. S. Wolff, *Acta Historica Leopoldina* **48**, 41 (2007)
109. R. MacLeod, *J. War Culture Studies* **2**, 37 (2009)
110. W. Heisenberg, *Deutsche und Jüdische Physik* (Piper Verlag, München, 1992)

111. N. Goldschmidt, Historisch-politische Mitteilungen: Archiv für christlich-demokratische Politik **4**, 1 (1997)
112. U. Kluge, Freiburger Universitätsblätter **102**, 19 (1988)
113. D. Rübsam, H. Schadek (eds.), *Der Freiburger Kreis–Widerstand und Nachkriegsplanung 1933–1945* (Stadtarchiv Freiburg, Freiburg, 1989)
114. K. Hentschel, *Interpretationen und Fehlinterpretation der speziellen und allgemeinen Relativitätstheorie durch Zeitgenossen Albert Einsteins* (Birkhäuser Publishing Ltd, Switzerland, 1990)
115. M. Eckert, K. Märker (eds.), *Arnold Sommerfeld Wissenschaftlicher Briefwechsel* (Deutsches Museum Verlag für Geschichte der Naturwissenschaften und der Technik, Berlin Diepholz München, 2000)
116. A. Einstein, *The collected papers of Albert Einstein* (Princeton University Press, UK, 1987)



<http://www.springer.com/978-3-642-28737-4>

The Mie Theory

Basics and Applications

Hergert, W.; Wriedt, Th. (Eds.)

2012, XIV, 259 p., Hardcover

ISBN: 978-3-642-28737-4