Chapter 8
Walther Gerlach (1889–1979): Precision Physicist, Educator and Research Organizer, Historian of Science

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Abstract Walther Gerlach's numerous contributions to physics include precision measurements related to the black-body radiation (1912–1916) as well as the first-ever quantitative measurement of the radiation pressure (1923), apart from his key role in the epochal Stern-Gerlach experiment (1921–1922). His wide-ranging research programs at the Universities of Tübingen, Frankfurt, and Munich entailed spectroscopy and spectral analysis, the study of the magnetic properties of matter, and radioactivity. An important player in the physics community already in his 20s and in the German academia in his later years, Gerlach was appointed, on Werner Heisenberg's recommendation, Plenipotentiary for nuclear research for the last sixteen months of the existence of the Third Reich. He supported the effort of the German physicists to achieve a controlled chain reaction in a uranium reactor until the last moments before the effort was halted by the Allied *Alsos Mission*. The reader can find additional discussion of Gerlach's role in the supplementary material provided with the online version of the chapter on SpringerLink. After returning from his detention at Farm Hall, he redirected his boundless elan and determination to the reconstruction of German academia. Among his high-ranking appointments in the Federal Republic were the presidency of the University of Munich (1948–1951) and of the Fraunhofer Society (1948–1951) as well as the vice-presidency of the German Science Foundation (1949–1961) and the German Physical Society (1956–1957). As a member of *Göttinger Achtzehn*, he signed the Göttingen Declaration (1957) against arming the *Bundeswehr* with nuclear weapons. Having made history *in* physics, Gerlach

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became a prolific writer *on* the history of physics. Johannes Kepler was his favorite subject and personal hero—as both a scientist and humanist.

1 Introduction

What Walther Gerlach said about his academic mentor, Friedrich Paschen (1865–1947), could also be said about Gerlach himself (Gerlach 1935):

> The physicists saw him as a master of experimental physical research who carried on the great tradition of precision physics …With his unusual manual dexterity, he built the finest [scientific instruments], tirelessly trying to get the last out of them, in the conviction that every instrumental advance in physical research opens up new possibilities—and will enable new insights. And the fact that he succeeded in this …made him love his [scientific instruments] almost tenderly.

By the time he earned his Ph.D. in Paschen's Tübingen laboratory in 1912 at age 23, Gerlach was a major player in the research area of black-body radiation. He would pursue a related topic, that of light pressure, after an interruption due to World War One and his crucial involvement in the epochal Stern-Gerlach experiment during 1921–1922. In 1925, Gerlach would assume the chair of his mentor and in 1929 move on to Munich as the successor of Wilhelm (Willy) Wien (1864–1928), thereby receiving the accolade due to a leading experimental physicist. Gerlach's tenure at Munich, which lasted until his retirement in 1957, would only be interrupted by his detention at Farm Hall (1945–1946) and a stint at the University of Bonn (1946–1948), then in the British Zone of Occupation.

In 1944, upon consulting Werner Heisenberg (1901–1976), Otto Hahn (1879–1968), and Paul Rosbaud (1896–1963), Gerlach became the head of the Physics Section at the Reich Research Council and *Reichsmarschall's* Plenipotentiary for nuclear physics responsible for the German *Uranprojekt*. Thereby, Gerlach entered higher echelons of Third Reich's establishment (Walker 1995). As available testimonials, including his own, suggest, in this capacity, Gerlach saved many young physicists from the service on the front—and, unbeknownst to him, likely kept the Allies abreast of the German nuclear research via Paul Rosbaud (1896–1963), a scientist and publisher who had become a British agent (Kramisch 1986). In his character testimonial about Gerlach, Rosbaud stated (Rosbaud 1945):

> Gerlach hated the Nazis, he had to suffer under their denunciations …he loved his country and wished the best to her and did not want her to perish …. During the last period of the war he only was interested in advancing pure research work and in saving the lives of scientists. He exceeded many times his competencies to save people …In contrast to many others, he was absolutely incorruptible and in consequence, despite [receiving] 2 or 3 Führerpakete,[1] sometimes half starved.

[1] A food allocation provided during WWII once a year to the military and other choice personnel on behalf of Adolf Hitler.

In the aftermath of World War Two and beyond, Gerlach directed his boundless elan and determination to the reconstruction of German academia. He built up anew the Institute of Physics at Munich's *Ludwig-Maximilans-Universität* and served as the university's Rector (1948–1951); during the same period he served as the founding President of the *Fraunhofer-Gesellschaft* for applied research; was Vice-President of the *Deutsche Forschungsgemeinschaft* (1949–1961) and of the *Deutsche Physikalische Gesellschaft* (1956–1957). "Making friends and cultivating friendships was one of his greatest talents" (Gentner 1980), which Gerlach amply deployed throughout these years.

Gerlach was also engaged in attempts to limit the spread of nuclear weapons and signed as a member of *Göttinger Achtzehn* the Göttingen Declaration opposing the move by the West-German government to arm the *Bundeswehr* with tactical nuclear weapons (12 April 1957).

Since the late 1940s, Walther Gerlach's interest turned increasingly to the history of science. He would write about 500 didactic, biographical, and memorial articles—apart from about 320 research papers and monographs (Nida-Rümelin 1982). His essay on Max Planck (Gerlach 1948) or book on Johannes Kepler (Gerlach 1980) belong to his most acclaimed history works.

Gerlach was co-nominated, with Otto Stern, thirty-one times for the Nobel Prize in Physics for the Stern-Gerlach experiment, Fig. 1. Gerlach's contributions to the fields of black body radiation, light pressure, magnetism, and spectroscopy were no less demanding but remain much less known. In this chapter, we revisit Gerlach's seminal works in an attempt to do justice to his scientific legacy. We conclude by showcasing his work in the history of science.

2 Walther Gerlach's Social Background, Upbringing, and Education

Walther Gerlach was born on 1 August 1889 in Wiesbaden-Biebrich (Huber 2015). His father, Valentin Gerlach (1858–1957), came from a family of craftsmen based in Frankfurt and became a doctor. However, he only practiced medicine for a short time and soon turned to experimental chemistry. His mother, Maria, neeé Niederhaeuser (1868–1941), also came from a family of craftsmen, from the nearby Wiesbaden area. Figure 2 shows Walther Gerlach in the first year of his life. When he turned two, his twin brothers Werner and Wolfgang were born.

Formal upbringing in the family was primarily set by the father and took place within the framework of the conservative value system of the time. Figure 3 shows Gerlach as a school child. However, more strongly yet, it was shaped by the Enlightenment ideas of the Freemasons, of whose order the father was a member. Freedom, Equality, Brotherhood, Tolerance, and Humanity were at the foundation of their creed. The father, Figs. 4 and 5, was also an admirer and connoisseur of Johann Wolfgang Goethe, whose understanding of education played an important role in the

Nomination	Year	Nominator	Country
1	1924	Albert Einstein	Germany
2	1925	Ernst Wagner	Germany
3	1927	Max Born	Germany
4	1927	James Franck	Germany
5	1927	Heinrich Rausch von Traubenberg	Czechoslovakia
6	1928	James Franck	Germany
7	1928	Max Reich	Germany
8	1928	Pierre Weiss	France
9	1928	Julius Wagner-Jauregg	Austria
10	1929	Eduard Haschek	Austria
11	1929	Gustav Jäger	Austria
12	1929	Stefan Meyer	Austria
13	1929	Karl Przibram	Austria
14	1929	Johannes Stark	Germany
15	1929	William Campbell	U.S.A.
16	1930	William Campbell	U.S.A.
17	1931	Max von Laue	Germany
18	1932	Friedrich Hund	Germany
19	1932	Erwin Meyer	Switzerland
20	1934	Gustav Jäger	Austria
21	1934	Stefan Meyer	Austria
22	1934	Egon von Schweidler	Austria
23	1934	Hans Thirring	Austria
24	1934	Dirk Coster	Netherlands
25	1936	Pierre Weiss	France
26	1937	Anton von Eiselsberg	Austria
27	1937	Stefan Meyer	Austria
28	1937	Egon von Schweidler	Austria
29	1937	Hans Thirring	Austria
30	1940	Dirk Coster	Netherlands
31	1944	Manne Kai Siegbahn	Sweden

Fig. 1 Walther Gerlach's nominations for a Nobel prize in Physics. The compilation is based on the information available at the nomination archive https://www.nobelprize.org/nomination/archive/. The 1924 nomination by Albert Einstein was not a valid one, as Einstein nominated additional candidates apart from Stern and Gerlach that year

Gerlach family as well. Not to forget Valentin Gerlach's membership in a student association *Corps Alemannia* to whose events he would often take his children along.

The upbringing in the Gerlach family was both highly demanding and encouraging, characterized by rigor and devotion. The father himself had learned that one can only achieve something in life through determined work and self-discipline and wanted to pass on this realization to his children. The parents set at first narrow boundaries but gradually expanded them as the children grew older and could increasingly take responsibility for their own actions. Walther Gerlach's first diary tells of extensive hikes, preoccupation with flora, fauna and minerals, visits to the theater, literary, artistic and musical activities as well as photography and much more. He played the piano and organ and tried his hand at drawing and poetry.

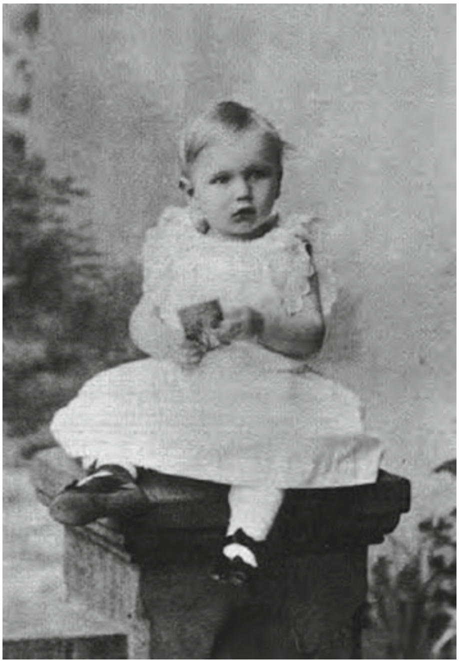

Fig. 2 Walther Gerlach in 1889 (Heinrich and Bachmann 1989)

Fig. 3 Walther Gerlach as a pupil (Heinrich and Bachmann 1989)

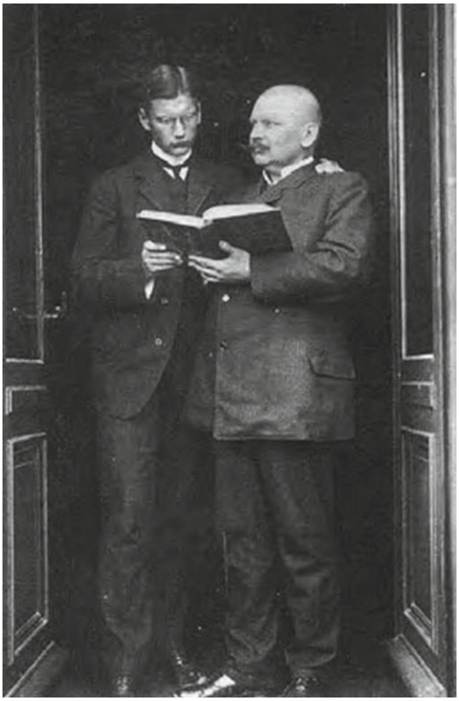

Fig. 4 Walther Gerlach with his father in 1909. Courtesy of Werner Kittel, Hamburg

Walther Gerlach later found the term “aimless determination” for his own understanding of how education works. What he meant was that, for instance, at high school, one should not pursue subjects with an eye on their utility for a future profession but rather give free rein to one’s inclinations and interests “without a plan” but “with determination.”

Walther received Protestant baptism shortly before starting school. In keeping with liberal attitudes, the family members were not practicing Christians, but rather sought the divine in natural phenomena.

Walther entered elementary school in 1896 and switched to the *Königliches Gymnasium zu Wiesbaden* (now *Diltheyschule-Wiesbaden*) in 1899, where he took the Abitur exam in 1908. Walther Gerlach’s school performance was unspectacular. He was a good student, but not an outstanding one. In his *Abitur* certificate, Mathematics and Philosophy were noted as the desired courses of study. Upon his admission to the University of Tübingen at Easter 1908, Gerlach indeed began studying these two subjects. However, when he attended a lecture and laboratory course by the physicist Friedrich Paschen, Fig. 6, he was so impressed by Paschen’s experiments that he gave up philosophy in favor of physics.

Fig. 5 Walther Gerlach (left) with his brothers Werner (2nd from left) and Wolfgang (right) and their father (seated). Courtesy of Werner Kittel, Hamburg

Fig. 6 Friedrich Paschen. Creative Commons

Fig. 7 Walther Gerlach in Frankfurt, early 1920s. Courtesy of the Archive of the University of Frankfurt

At the outset of his studies in Tübingen, Gerlach joined the student association *Corps Borussia*, a fencing fraternity like his father's *Corps Alemannia*—and another formative influence. Figure 7 shows Gerlach in his early thirties with a fencing wound on his left cheek. Gerlach would leave the fraternity as late as 1954, likely to indicate his view that German universities should foster international spirit rather than parochial student associations.

Gerlach's physics studies progressed at a rapid pace: In the 5th semester he started work on his doctoral thesis, in the 6th semester he became Paschen's assistant, and at the end of the 8th semester, on 29 February 1912, he took his doctoral examination.

There was strict discipline at Paschen's institute but also an open international atmosphere. Gerlach's time at the institute proved formative for both his personality and his experimental abilities. Either became a key prerequisite for later success in performing the Stern-Gerlach experiment and other precision measurements where Gerlach pushed the limits of the possible. Paschen requested from his assistants to be almost permanently present at the institute and to work hard all the time, quipping "How's the crap going?" Paschen's manner earned him the epithet "Institute Tyrant" (Gerlach 1908–1950). Nevertheless, Gerlach remained grateful to and respectful of Paschen. Apparently, the mentoring by Paschen was for Gerlach just a continuation of his father's upbringing.

Gerlach stayed at Paschen's institute for two more years despite the hard time he was having. He greatly valued the stimulating discussions at the institute of all the exciting developments that were taking place in physics and remained highly productive throughout. In spite of his heavy workload, Gerlach maintained numerous contacts with researchers from a wide variety of disciplines, which rhymed well with his curiosity and fostered his versatility.

After the outbreak of World War One, Gerlach worked in the X-ray laboratory of the gynecological clinic at the University of Tübingen, whose director was a close friend. There he developed an astonishingly simple X-ray device for locating projectiles and metal splinters in soldiers' bodies that was, moreover, well suited for the rough field conditions.

On 24 August 1915, Gerlach was drafted into military service in Ulm as a *Landsturm* recruit, but released again in December because of rheumatoid arthritis.

In May 1916 he was called up again, this time to *Technische Abteilung der Funkertruppen*, abbreviated as *Tafunk*, with which he stayed until the end of the war. Its head was Max Wien, Willy Wien's cousin. The task of Gerlach's department was to develop and test radio equipment based on the new technology of tube amplifiers. His stay at *Tafunk* was interrupted twice by illness (appendicitis and the "Spanish flu"). While on sick leave in May 1916, he completed his *Habilitation*.

In the Fall of 1916, he took part in the fighting of the VIth Army in Flanders and Artois and directly experienced the horrors of war. After a dispute with Paschen, who wanted his assistant back at his institute in Tübingen, Gerlach did an *Umhabilitation*, in 1917, in Göttingen. He continued his scientific work and even managed to publish several papers based on his previous research. Most importantly, at *Tafunk*, Gerlach met other physicists, among them Max Born (1882–1970), James Franck (1882–1964), Wilhelm Westphal (1882–1978), but also Richard W. Pohl (1884–1976) and Peter Debye (1884–1976), who helped with his move to Göttingen. He also worked for an extended period with Gustav Hertz (1887–1975), Fig. 8, Heinrich Hertz's

Fig. 8 Walther Gerlach with Gustav Hertz (left) working at *Tafunk* in Jena, May 1917. The hand-written note by Gerlach reads: "Hertz und ich am Schreibemfänger [Hertz and I at the telegraph], Jena-May 1917" (Heinrich and Bachmann 1989)

Fig. 9 Richard Wachsmuth. Courtesy of the Archive of the University of Frankfurt

nephew and future Physics Nobel laureate, jointly with James Franck, for 1925. From September 1917 to March 1918 he was on an inspection tour in Belgium and northern France. Upon his return, Gerlach married Wilhelmine Mezger and in 1918 their daughter Ursula was born. On January 27, 1919, he was released from the military as chief engineer. In order to be able to provide for his family, Gerlach opted for an industrial rather than an academic job and landed a managerial position at the physical laboratory of the Elberfeld paint factory. However, he soon realized that industrial research was not his cup of tea and returned to academia once the University of Frankfurt offered him a position. As of 1 October 1920, Gerlach became the first assistant to the director of Frankfurt's Institute of Experimental Physics, Richard Wachsmuth (1868–1941), Fig. 9.

Frankfurt was the first station on Gerlach's academic path at which he had his own position. Three more would follow. A detailed timeline of Gerlach's life and career is given in Appendix A.

3 Precision Physics

In his first book, written in Frankfurt, Gerlach provided the following definition of "precision measurement" (Gerlach 1921):

> By 'precision measurement' we mean an investigation in which all sources of error are taken into account and all observed phenomena are clarified: It is also characteristic of [a precision] measurement that each individual step is theoretically and numerically justified, its influence on the course of the experiments thoroughly tested, spelled out, and presented in all detail; in short, the reader must be able to form a judgment from the description of the experiments about the evidential value and the [degree of] certainty of the results.

What Gerlach meant was best exemplified by his own work, which became a standard of precision physics.

3.1 Black-Body Radiation

There is a record of what Gerlach thought about the state of Physics in about 1910 when he entered the 5th semester at Tübingen and started working on his dissertation under Paschen (Gerlach 1978a), p. 200:

> [There] were special fields of general interest such as long-wave infrared, gas discharge, spectroscopy, radioactivity, canal rays, which had been worked on at various institutes; the theoretical foundations were thermodynamics, kinetic theory of gases, electromagnetism, electron theory of the electrical and optical properties of matter. But there was probably no such thing as central questions; these were certainly not relativity or quantum physics.

The dissertation topic that Paschen assigned to Gerlach had nothing to do with any of the above but rather entailed revisiting one of the major themes that Paschen had worked on a decade earlier, namely black body radiation. Paschen's interest was revived by a discrepancy between the "canonical" value of the constant σ in Stefan-Boltzmann's law as determined in 1898 by Ferdinand Kurlbaum (1857–1927) (Kurlbaum 1898) and a new value published in 1909 by the reputable Ch. Féry (Féry 1909). Strangely enough, Max Planck's 1900 law (Planck 1900) governing the spectral distribution of black-body radiation—and the first salvo of the quantum revolution—was neither mentioned nor cited in Gerlach's thesis completed in 1912 (Gerlach 1912). This in spite of the fact that Planck's law not only allowed to derive the Stefan-Boltzmann law but also to express the constant σ in terms of fundamental constants. Had Gerlach made this connection, it would have lent his effort a fundamental character as well, at least from a more recent perspective. At the time, however, only few—among them Albert Einstein (1879–1955)—regarded Planck's law (and Planck's constant) as fundamental (Frisch 1963), i.e., as more than a mathematical representation of empirical data.

The Stefan-Boltzmann law obtains by integrating Planck's spectral intensity, $I(\lambda, T)$, of black body radiation

$$I(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \left[\exp\left(\frac{hc}{\lambda kT} \right) - 1 \right]^{-1} \tag{1}$$

over the wavelenght λ at temperature T

$$I(T) \equiv \int_0^\infty I(\lambda, T) d\lambda = \sigma T^4, \tag{2}$$

yielding

$$\sigma = \frac{2\pi^5 k^4}{15c^2 h^3} \tag{3}$$

with k Boltzmann's constant, h Planck's constant, and c the speed of light. This derivation of the Stefan-Boltzmann law was carried out for the first time by Planck himself (Planck 1901).

In his dissertation, Gerlach set out to clarify the discrepancy between Kurlbaum's and Féry's values of σ—however without resorting to the ultimate arbiter, namely Eq. 3. This would not have been feasible at the time anyway, as Planck's constant was not known accurately enough at the time.

While Kurlbaum obtained a value of 5.32×10^{-12} W cm^2 K^{-4} (Kurlbaum 1898) using the bolometer method, Féry obtained a significantly larger value, of 6.30×10^{-12} W cm^2 K^{-4} (Féry 1909), using a thermocouple. Upon a thorough inspection of Féry's paper, Paschen concluded that Kurlbaum's method was likely the less accurate one and tasked Gerlach with recreating Kurlbaum's apparatus while avoiding possible sources of error, such as replacing a bolometer with a thermopile (i.e., an array of thermocouples) to measure the temperature.

Gerlach's apparatus is shown in Fig. 10. A *Hohlraum* realization of a black body (Valentiner 1910), produces black-body radiation at 0° or 100 °C, defined, respectively, by the freezing and boiling points of water at atmospheric pressure. Upon passage through a diaphragm, the radiation is absorbed by detection stripes made of manganin (an alloy of copper, manganese, and nickel with a low thermal expansion coefficient) electroplated with platinum black (in order to suppress selective absorption). The detection stripes were held at a distance of half a millimeter from a thermopile, with an insulating layer of ambient air in between. The thermopile was of the type developed earlier by Paschen for his spectroscopic investigations (Gerlach 1912). The current produced by the thermopile was measured by a sensitive galvanometer. The measurement procedure was as follows: (a) the black body at 100 °C irradiates the detection stripes for as long as the galvanometer reading increases, reaching a steady-state value of, say, i_0; (b) the black body at 100 °C is replaced with a black body at 0 °C and the detection stripes are electrically heated up until the galvanometer reading becomes equal to i_0; (c) The measured Joule heat (electric power) equals the difference of the radiant power carried by the black-body radiation at 100 and 0 °C. In order to achieve good statistics, the black bodies were swapped every minute or two and the galvanometer read every 15 s. The value that came out of Gerlach's measurements was $\sigma = (5.9 \pm 0.057) \times 10^{-12}$ W cm^2 K^{-4} (after a correction for reflected radiation). Gerlach's detection scheme is sometimes referred to as Ångström-type pyrheliometer (Coblentz 1913).

Paschen lavished the highest praise on Gerlach's achievement (Paschen 1912b):

> [Gerlach] was able to justify *ab ovo* every single aspect of the new method, which is one of the most difficult tasks of physics altogether.

However, when Gerlach's result, accompanied back-to-back by Paschen's endorsement, was published (Gerlach 1912), see also Fig. 11, the competitors, Ferdinand Kurlbaum and Siegfried Valentiner (1876–1971)—both from the *Physikalsch-Technische Reichsanstalt* (PTR) in Berlin—disagreed. A rather acrimonious public debate ensued that called for more work on Gerlach's and Paschen's part and led to two more investigations by Paschen and nine more by Gerlach, including Gerlach's *Habilitation* thesis.

Developing into a "war of attrition," the exchanges slowed down after the outbreak of World War One and ceased in 1916 (Gerlach 1916)—without resolving the issue. Throughout, Gerlach was troubled by the realization that a physics problem could not be brought to a closure, if possible in his favor. He would devise and implement new experimental schemes with a great persistence—but to no avail. In the end, the PTR made plans for resuming the measurements of σ—using Gerlach's method. Gerlach would demonstrate both his persistence and inventiveness in his later work

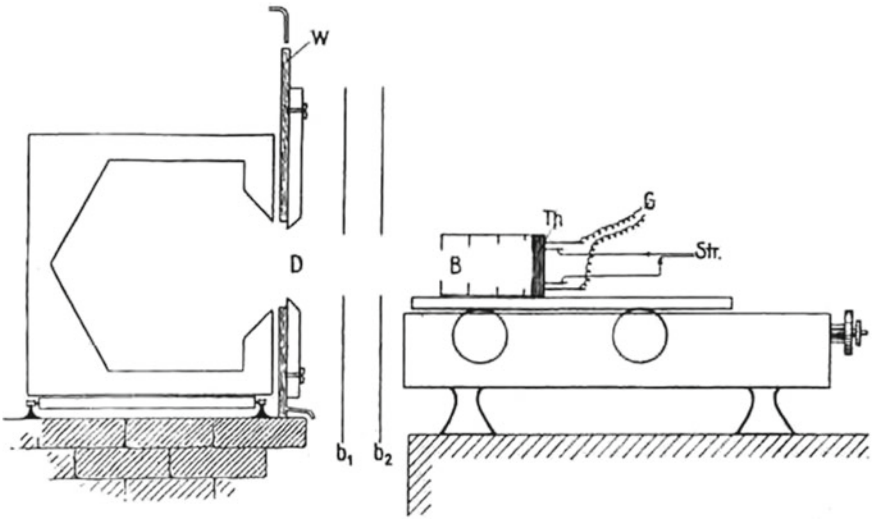

Fig. 10 Schematic of the apparatus Gerlach built in Paschen's laboratory in Tübingen to perform precision measurements of the proportionality constant σ in the Stefan-Boltzmann law (Gerlach 1912). Gerlach's realization of the black body together with a diaphragm (D) and slits (b_1 and b_2) is shown on the left. The right-hand side shows the detector with the detection strips and thermopile (Th), the galvanometer (G), and apertures (B). The detector assembly is mounted on a dividing engine whose position can be accurately controlled

1912. № 6.

ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 38.

1. *Eine Methode zur Bestimmung der Strahlung in absolutem Maß und die Konstante des Stefan-Boltzmannschen Strahlungsgesetzes; von Walther Gerlach.*

M. Ch. Féry[1]) veröffentlichte 1909 eine neue Methode zur absoluten Strahlungsmessung und fand mit dieser einen um 18,4 Proz. höheren Wert für die Konstante des Strahlungsgesetzes

$$S = \sigma (t + 273)^4,$$

als nach den Messungen von F. Kurlbaum[2]) angenommen wurde. An Stelle des Kurlbaumschen Wertes

$$\sigma = 5{,}32 \times 10^{-12} \,\text{watt}\,\text{cm}^{-2}\,\text{grad}^{-4}$$

erhielt er aus einer großen Reihe allerdings nicht sehr gut übereinstimmender Resultate das Mittel

$$\sigma = 6{,}30 \times 10^{-12} \,\text{watt}\,\text{cm}^{-2}\,\text{grad}^{-4}.$$

Während sich in der Féryschen Methode bisher kein prinzipieller Fehler nachweisen ließ, konnte Hr. Prof. Paschen[3]) zeigen, daß eine absolute Messung nach dem Kurlbaumschen Bolometerprinzip bei Verwendung eines ungleichmäßig dicken Bolometers[4]) einen zu kleinen Wert geben muß. Ich habe daher auf Anregung von Hrn. Prof. Paschen nach einer von ihm angegebenen Methode, bei welcher die der Kurlbaumschen Messung nach Paschen anhaftende Unsicherheit vermieden ist, welche aber in jeder anderen Beziehung (bestrahlte Oberfläche, Strahlung von 100° zu 0°) der Kurlbaumschen Messung entspricht, die Konstante σ neu bestimmt.

1) Ch. Féry, Bull. Soc. Franc. d. Phys. (2) **4.** 1909; Ann. de chim. et phys. (VIII) **17.** p. 267. 1909; Compt. rend. **148.** p. 515. 1909.
2) F. Kurlbaum, Wied. Ann. **65.** p. 746. 1898.
3) F. Paschen, Ann. d. Phys. **38.** p. 30. 1912.
4) F. Kurlbaum, Ann. d. Phys. **2.** p. 552 oben. 1900.

Fig. 11 Publication that came out of Walther Gerlach's Ph.D. thesis (Gerlach 1912) as well, most conspicuously in the Stern-Gerlach experiment. Apparently, when he got something into his head, it was difficult to dissuade him from it.

Interestingly, as part of the debates between Gerlach and Paschen on the one side and the PTR scientists on the other, Paschen pointed out, (Paschen 1912a), that the new value of σ would be of consequence for the values of the fundamental constants it was made out of according to Planck's law, cf. Eq. 3. Let us note that the currently accepted value of the Stefan-Boltzmann constant is (CODATA 2020)

$$\sigma = 5.670374419 \times 10^{-12}\,\mathrm{W\,cm^{-2}\,K^{-4}} \tag{4}$$

i.e., like Gerlach's value, between Kurlbaum's and Féry's values.

3.2 *Walther Gerlach and the Stern-Gerlach Experiment*

A detailed account of the purpose, outcome, and significance of the Stern-Gerlach experiment (SGE) can be found in Chap. 5 of this volume. Herein we emphasize Gerlach's contribution to the realization of the SGE and glean what the relationship between Stern and Gerlach was like from their mutual correspondence as well as from their correspondence with others.

As noted, in October 1920 Gerlach landed an assistantship at Wachsmuth's Institute for Experimental Physics at Frankfurt. The Frankfurt university recognized his *Habilitation* and, in addition, promoted him to the rank of *Extraordinarius* a month later. Max Born's adjacent Institute for Theoretical Physics was a more congenial environment for the curious and enterprising Gerlach than Wachsmuth's operation. All the more so that Born, with his assistants Otto Stern, Elisabeth Bormann, and Alfred Landé, was engaged in experiments as much as in theory and encouraged Gerlach to partake in their discussions as well as to give them a hand with their experiments. Born would even publish with Gerlach—on electron affinity (Gerlach and Born 1921a) and on light scattering (Gerlach and Born 1921b). However, Gerlach would also pursue his own agenda: it was at Frankfurt that he launched his investigations into the magnetic properties of materials that would bring him together with Stern and later take center stage in his research at Frankfurt and his subsequent stations. In particular, Gerlach was interested in the relationship between magnetization and structure (Bachmann and Rechenberg 1989), p. 10. In connection with his investigation of the magnetic properties of a bismuth alloy, the question arose as to whether atomic bismuth was para- or diamagnetic. Gerlach set out to answer this question in a molecular beam experiment, in which the deflection of a beam of bismuth atoms by an inhomogeneous magnetic field would be examined (Mehra and Rechenberg 1982), p. 436. Born tried to dissuade Gerlach from what seemed to be a hopelessly difficult undertaking. Whereupon Gerlach invoked a quip he heard from Edgar Meyer (1879–1960), his professor of theoretical physics at Tübingen: "No experiment is so dumb that it should not be tried" (Estermann 1975) and continued setting up his bismuth beam experiment and thus collecting experience in much of

Fig. 12 Otto Stern (2nd from left), Edgar Meyer (5th from left), Walther Gerlach (6th from left) in Tübingen in about 1926. Courtesy of the Otto Stern Collection, Berkeley

what was needed for the SGE. Let us add that Edgar Meyer, Fig. 12, with whom Gerlach had worked on the photo-effect, contested the separation of physics into theoretical and experimental. Max Born was apparently of the same persuasion in this respect. In February 1921, he reported to Einstein (Born 1969), p. 82:

> We have now Gerlach here with us, who is awesome: energetic, knowledgeable, skillful, ready to help.

In his 1977 talk, Gerlach told the story of his recruitment by Otto Stern for the SGE as follows (Gerlach 1977):

> One day Stern would come to me and say: 'Do you know what space quantization is?' I would say: 'No, I have no idea.' 'But you should actually know that. Recently Debye and Sommerfeld published [papers] suggesting that the [anomalous] Zeeman effect can be explained by a quantum effect, by the so-called space quantization. That is, [the magnetic dipole of] a silver or sodium atom can only have two settings [orientations] in a magnetic field, it cannot adjust itself at will or precess, but can only have two very specific settings [orientations], or actually even three, namely perpendicular to the magnetic field or in ... the direction or against the direction [of the magnetic field] ...
>
> Repeated discussions with Stern during our daily visits at *Café Rühl* finally led to a plan to make the experiment in such a way that there was hope of seeing space quantization.

Gerlach perhaps thought that he would just have to modify his current experiment on the magnetic properties of bismuth. Finally, he agreed: "Yes, I want to try it" (Gerlach 1977). But then

> [Stern] would come back again: 'It isn't worth it, I've miscalculated, power of ten too little.' And then, it went back and forth a couple of times for a week or a fortnight and one day he would come back and say: 'Yes, now I've done [the calculations] properly and the thing only works if you get fields with an inhomogeneity of about ten or fifty thousand Oersted per centimeter—and that's not possible.' And then I said to him: 'Yes, I am almost there, I already have ten thousand [Oersted per centimeter], namely for my planned bismuth experiment'. 'So,' he said, 'let's try it.'

And they did. Stern first published the concept of what was to become the SGE, accompanied by feasibility calculations (Stern 1921), prompted to "patent" the idea by seeing the page proofs of a paper by Harmut Kallmann and Fritz Reiche on an electric analog of the SGE, see also Chaps. 5 and 20. The collaboration that ensued between Stern and Gerlach was in part so successful because of the complementarity of their skills and perhaps even working habits: while Stern had gained experience with molecular beams, Gerlach developed expertise in designing strong inhomogeneous magnetic fields. While Stern preferred to call it a day around 6 p.m. at that time, have dinner and go to the cinema, Gerlach liked to work at night, often doing with just three hours of sleep.

As described in Chap. 5, it took a tremendous effort to make the experiment work. Stern, who did not believe in the reality of space quantization to begin with, left on 1 October 1921 to assume a professorship at Rostock. Gerlach continued improving their apparatus and during the night of 4 November 1921 observed for the first time a broadening of a silver beam sent through an inhomogeneous magnetic field. This provided evidence that silver atoms carried a magnetic dipole moment—but did not suffice to demonstrate the existence of space quantization. During the Christmas recess, Gerlach and Stern reconfigured their apparatus again, but Gerlach's subsequent attempts to see space quantization had failed. At their meeting in Göttingen in early February 1922, Gerlach and Stern decided to try the experiment one more time. On the train back to Frankfurt, Gerlach remembered a modification he made earlier when examining crystals by X rays using the Debye-Scherrer method, namely to use a *slit* instead of a pinhole to boost both flux and spatial resolution. Gerlach had even reported on the improvement he thereby achieved at the German Physics Day in Jena in September 1921 (Huber 2015). Upon arrival in Frankfurt, Gerlach replaced the pinhole (of 0.05 mm diameter) defining the silver beam at the entrance into the inhomogeneous magnetic field by a rectangular $0.03 \times 0.8\ \mathrm{mm}^2$ slit with its longer side perpendicular to the field direction (Gerlach and Stern 1922)—and during the night of 7 February 1922 achieved the ultimate success.

Wilhelm Schütz (1900–1972), who was in 1922 Gerlach's Ph.D. student, described the difficulties of the SGE as well as the final triumph as follows (Schütz 1969):

> The old apparatus had only yielded a broadening of the silver beam [deposit on the glass plate] of the expected magnitude …due to the inhomogeneous magnetic field. A major improvement of the apparatus with the aim to further increase its resolution was [therefore] necessary. During this rebuilding period, Stern moved to Rostock to assume a Professorship

for Theoretical Physics there. He would show up in Frankfurt every now and then (during Christmas 1921 and Easter 1922) for discussions and to measure the inhomogeneity of the magnetic field …Soon came the time when I was able to enter the holy premises of the laboratory and take a look at the pumps, when [the technician Mr.] Schmidt was not on duty and Prof. Gerlach had to sleep once in a while …Anyone who has not been through it cannot at all imagine how great were the difficulties with an oven to heat the silver up to about 1300°K within an apparatus which could not be heated in its entirety [the seals would melt] and where a vacuum of 10^{-5} Torr had to be produced and maintained for several hours. The cooling was done with solid carbon dioxide and acetone or with liquid air. The pumping speed of the Gaede mercury backing pumps and the Volmer mercury diffusion pumps was ridiculously low compared with the performance of modern pumps. And then their fragility; the pumps were made of glass and quite often they broke, either from the thrust of boiling mercury …or from the dripping of condensed water vapor. In that case the effort of several days of pumping, required during the warming up and heating of the oven, was lost. Also, one could be by no means certain that the oven would not burn through during the four- to eight-hour exposure time. Then both the pumping and the heating of the oven had to be started from scratch. It was Sisyphus-like labor and the main load of responsibility lay on the broad shoulders of Prof. Gerlach. In particular, W. Gerlach would take over the night shifts. He would get in at about 9 p.m. equipped with a pile of reprints and books. During the night he then read the proofs and reviews, wrote papers, prepared lectures, drank plenty of cocoa or tea and smoked a lot. When I arrived the next day at the institute, heard the intimately familiar noise of the running pumps, and found Gerlach still in the lab, it was a good sign: nothing broke during the night.

Then I arrived at the institute one morning in February 1922; it was a wonderful morning: with cool air and fresh snow! W. Gerlach was once again at it, developing the deposit of an atomic beam that had been passing through an inhomogeneous magnetic field for eight hours. Full of expectation, we applied the development process, whereupon we experienced the success of several months of effort: The first splitting of a silver beam in an inhomogeneous magnetic field. After Master Schmidt and, if I remember correctly, E. Madelung had seen the splitting [the deposit was about 1.1 mm long and the splitting only about 0.06 to 0.1 mm], we went to Mr Nacken to the Mineralogical Institute to have the finding recorded on a microphotograph. Then I was tasked with sending a telegram to Professor Stern in Rostock, with the text: "Bohr is right after all!"

The consequences and impact of the stroke of luck for the emerging quantum physics that the collaboration between Otto Stern and Walther Gerlach at Frankfurt was are described in Chap. 5. We note that Albert Einstein and Paul Ehrenfest coined the term Stern-Gerlach experiment, in recognition of the fact that it was Stern who conceived it, although Gerlach largely carried it out (Einstein and Ehrenfest 1922). Moreover, Otto Stern was the pioneer of *quantitative* experiments with molecular beams.

In 1924, Einstein nominated, alongside with others, both Stern and Gerlach for the Nobel Prize in Physics (Schmidt-Böcking et al. 2019). By 1944, Gerlach and Stern had been nominated together thirty-one times for the Nobel Prize, cf. Fig. 1. Stern received fifty-two additional nominations for his other experiments with the molecular beam method and was awarded the Nobel Prize in Physics in 1944 for the year 1943. Gerlach ended up empty-handed, although Manne Siegbahn (1886–1978), then chairman of the Nobel Committee for Physics, proposed Stern, together with Gerlach, in 1944 as the sole candidates. And Eric Hulthén (1891–1972) in his broadcast on Swedish Radio on 10 December 1944 honoring the award of the Nobel prize to Stern extolled almost exclusively the SGE. In the documents and reports of the Nobel Archives there is no indication as to why Gerlach was left out. The reason may have been Gerlach's high-level involvement in the Nazi research establishment, especially in the management of the nuclear program, see Sects. 1 and 4.

The personalities of Stern and Gerlach were quite different: while Gerlach enjoyed being in the driver's seat, Stern preferred the back seat. Only a few letters exchanged between them have been preserved. The following one, from 16 January 1924, concerns the last (Gerlach and Stern 1924) of their four joint publications, all of which dealt with the SGE (Schmidt-Böcking et al. 2019), p. 125:

> Dear Gerlach, many thanks for your messages. I thought our paper had arrived at the *Annalen* [der Physik] a long time ago. In any case, I totally vote for the *Annalen*, and you do too, for such long claptrap is nothing for the [Zeitschrift für Physik]. I couldn't come in during the week, not to [Frankfurt], because I had to go to Breslau, and [going to] both [places] was a little too much for me. For [molecular beams] I invent ever more ingenious apparatus that only keeps working worse, z.[um] K.[otzen]! In contrast, the [electric molecular beams] are quite endurable. But it all goes so terribly slowly!
>
> I hear that Schaefer got a call from Freiburg. He has to go there! Cordial greetings to all friends, your family, and yourself. Yours Otto Stern

When Gerlach succeeded Paschen at Tübingen, Stern sent him, on 16 November 1925, the following telegram (Schmidt-Böcking et al. 2019), p. 125:

> = Cordial congratulations to the *Grossbonzen* [big shot] from Stern +

Whereupon Gerlach replied (Schmidt-Böcking et al. 2019), p. 126:

> Dear Stern, it is Sunday, 22 November, and I just got your telegram. As I started writing the above, the furniture trucks have arrived ... So I begin my rant in the hope that my wife will leave me alone for a moment.
>
> ... Mr. S. made statements about the evaluation of our magneton experiments which—as we noticed from his multiple inquiries—give rise to the impression that our calculation could be 100% wrong; and furthermore that the evaluation did not take into account possible sources of error and uncertainties, and that, in particular, we missed out on taking the width of the slit into account. Although Mr S.'s reasoning is correct, his note is indeed likely to lead to misunderstandings.
>
> Mr. S. namely always speaks about the distance between the locus of maximum intensity on the deflected strip and the locus of the ... narrow undeflected strip, for which case the formula we use would indeed give an almost 100% error. However, our measurements always refer to the center of the deflected strip, which Mr. S. only discusses at the end of his note; for this case, Mr. S. himself calculates a deviation of at most 20%.
>
> Furthermore, Mr. S. seems to assume that we were not aware of the influence of the distance of the slit. [In our paper] we refer to the work of Stern where this influence was discussed and the corresponding formula ... that takes into account the Coriolis force was derived. Mr S. could have easily figured that out from the literature. At the time we just remarked as much ... and stated a possible error on the order of magnitude of ±10%. We insist that Mr. S.'s note doesn't bring forth any new thoughts and that its content pretty much coincides with our presentation. We only object to the manner of his attack.
>
> Dear Stern, how are you health-wise? It's a pity that you weren't in Göttingen. Here [in Tübingen], there's a terrible mess [due to Gerlach's move]. Hopefully, it will sort itself out soon. I will then write to you about the atomic beam experiments. Please do publish

> something with [Immanuel] Estermann again! Cordial greetings, also from my wife, Yours W. Gerlach

Next in the chronology of the preserved letters that bear upon the relationship between Stern and Gerlach is a note written by Stern from Zurich to Lise Meitner (1878–1968) in 1957:

> Dear Lise Meitner, ... So let's meet in Munich. However, I can only come for 1-2 days, for two reasons: (1) [I cannot be away from Zurich for more than 1–2 days, because I expect a visitor]; (2) I don't care about seeing the Munich physicist Mr. Gerlach. Therefore, I leave it entirely up to you when you and I will meet. Please just let me know as soon as possible. It was very nice to see [Otto Robert] Frisch again and to get to know his wife; they seem to fit very well together.
>
> The two of us, the old ones, will have a lot to chat about and I'm hugely looking forward to seeing you again. Most cordially, Yours Otto Stern

Then there is a postcard to Stern penned jointly by Walther Gerlach, Otto Robert Frisch (1904–1979), Immanuel Estermann (1900–1973), William Nierenberg (1919–2020), Hans Kopfermann (1895–1963), and Peter Toschek (1933–2020) from the Brookhaven Molecular Beam Conference that was organized by Hans Kopfermann and held at Heidelberg in 1959 (Schmidt-Böcking et al. 2019), p. 245:

> Lichtstrahlen sind zum Brechen, Atomstrahlen z. K.! [zum Kotzen]. [This is a kind of affectionate "secret code" between Stern and Gerlach from their Frankfurt time—a pun expressing their occasional disgust with their difficult atomic/molecular beam experiments. "Brechen" means refraction as well as vomiting; "Kotzen" is a vulgar word for vomiting. A free translation, without the pun, would be: Light beams refract, atomic beams disgust.] Too bad that you aren't here, but we think of you warmly! Yours Walther Gerlach
>
> Remarkably, I got to know Mr. Gerlach only here. But molecular beams have become awfully complicated! With cordial greetings, yours OR Frisch
>
> Cordial greetings, Estermann
>
> Best regards will see you soon! Nierenberg
>
> We were very sorry not to have you here. Yours Hans Kopfermann
>
> Cordial Greetings from yours P. Toschek

It can be gleaned from many letters held at Otto Stern's Estate (Schmidt-Böcking et al. 2019) that he had quite a friendly relationship with all his correspondents. The above-quoted letter to Lise Meitner from 22 April 1957 suggests that Stern's feelings towards Gerlach were/became less than cordial, at least at the time. Conversely, Walther Gerlach wrote and spoke about Stern with the highest respect and much affection. This transpires in particular in the obituary of Stern that Gerlach wrote for the *Physikalische Blätter* (Gerlach 1969):

> Those who knew him appreciated his open-mindedness—he was a grand seigneur!—his unconditional reliability, the fruitful and—due to his fast thinking—difficult discussions, and—for those ho had a sense for it—his often nearly sarcastic but well-conceived assessments of things and people; bossing people or poor manners were anathema to him.
>
> Although a theoretician by nature, Stern was full of experimental ideas, never at a loss for a new proposal if the implementation of the previous one failed. At our farewell from Frankfurt, I gave him, in memory of the months of hopeless striving to see space quantization, an ashtray

with the inscription [Stern's and Gerlach's "secret code" in our translation] "Light beams refract, atomic beams disgust;" this ashtray endured all those years till Berkeley—but our experimental apparatus, lab books, and the originals of our results had burned during the Second World War.

A special tribute to the *"Stern-Stunden"* in Frankfurt and their importance for the development of quantum physics was given by Walther Gerlach in his lecture on 2 March 1960—still during Stern's life—at the *Physikalischer Verein Frankfurt* (Gerlach 1960):

> Around 1910, the French physicist Dunoyer developed the method of the so-called atomic or molecular beams. These are atoms that fly along straight lines from an oven through a small orifice into a highly evacuated chamber. Here at this institute, Max Born, Elisabeth Bormann, and, foremost, Otto Stern took up this idea in 1920 and experimentally developed the atomic beam method. That was a risky undertaking as at the time the means to produce high vacuum were still extremely limited ... Stern succeeded in measuring the mean velocity of the atoms, Born and Bormann measured their mean free path, and in later years Stern also succeeded in measuring the velocity distribution in an atomic beam. In the meantime, this method has been so refined by [Immanuel] Estermann, who is now at Chicago, that it affords the best temperature measurement of gases or vapors at 2000 degrees or more. Finally, Stern was able to demonstrate that free-flying atoms follow a free-fall parabola like a projectile. Moreover, at this institute, the reality of space quantization was successfully demonstrated in an experiment that provided direct access to an atomic state predicted by quantum theory.

Upon finishing the SGE, Gerlach would return to what he called his "hobby," namely his research on radiation pressure that he had started already in 1913 in Tübingen (Huber 2015). The pursuit of this "hobby" was deemed to be about as difficult as the SGE (Rollwagen 1980). Gerlach's interest was likely triggered by the inherent connection between radiation pressure and the Stefan-Boltzmann law.

3.3 Radiation Pressure

Ludwig Boltzmann (1844–1906) succeeded in 1884 to derive the law, $I(T) \propto T^4$, cf. Eq. 2, that his teacher, Josef Stefan (1835–1893), found in 1879 empirically (Boltzmann 1884). In his derivation, Boltzmann invoked Maxwell's theory of electromagnetism and the second law of thermodynamics, prompted by an earlier attempt by Adolfo Bartoli (1851–1896) to arrive at Stefan's law by the same route. Boltzmann was able to show that substitution of the pressure $p = I(T)/(3c)$ exerted by black-body radiation of energy density $I(T)/c$ into the second law of thermodynamics in the form $Tdp - pdT = [I(T)/c]dT$ yields

$$\frac{dI(T)}{4I(T)} = \frac{dT}{T} \tag{5}$$

which upon integration indeed gives Stefan's law—since then also known as the Stefan-Boltzmann law.

During his detention at Farm Hall (see below), Gerlach reminisced (Gerlach 1945) about his early attempts to come to terms with the effects he observed with a Crookes radiometer (light mill), a contraption invented by William Crookes (1832–1919) in 1873:

> In Tübingen in 1913/14, I tried to enhance the sensitivity of the radiometer [consisting of vanes mounted on a spindle in a partially evacuated bulb] by implementing alternative shapes of the vanes. This is when I observed a "negative" rotation of the vanes, i.e., in the direction opposite to that of the incident light.

Gerlach's original idea that he could measure radiation pressure with a Crookes radiometer turned out to be overly optimistic, as the processes involved in the radiometer physics are all but simple. It would take Gerlach and his coworkers two decades (1913–1932) to clarify the "positive" and "negative" radiometer effects and to carry out an absolute measurement of radiation pressure. Was it worth the effort? For sure it was, as those who were (and, in some quarters, still are) credited with first measurements of radiation pressure—Pyotr Lebedev (1866–1912), Ernst Nichols (1869–1924), and Gordon Hull (1870–1956)—did not and could not have measured anything else than spurious radiometer effects. As Gerlach and coworkers would show in their work, these only disappear at a vacuum better than 10^{-6} torr, which was not attainable during the period 1901–1903 when Lebedev, Nichols, and Hull published their radiation pressure studies.

Gerlach reentered the fray in 1919 when he published, jointly with Wilhelm Westphal, a theory of the radiometer (Gerlach and Westphal 1919) that, however, had to be quickly retracted (Westphal 1919):

> More detailed considerations have shown ... that the theory is untenable, despite a very good agreement with experiment. In particular, Mr [Albert] Einstein gave me a friendly hint that [our theory] contradicts momentum conservation.

At the 1920 meeting of the German Physical Society in Berlin, Westphal noted (Westphal 1920):

> The goal of the investigations [of the radiometer effects] is to collect a complete set of experimental data needed for a theory of the radiometer.

Gerlach answered the challenge implied by Westphal's talk with a series of four papers entitled *Untersuchungen an Radiometern I–IV* [Investigations of the Radiometer I–IV] published between 1923 and 1932. The first paper of the series opens with the bold statement (Gerlach and Albach 1923):

> As is well known, there is no complete theory of the radiometer available.

The paper then describes a compensation radiometer consisting of a single vane with thermally insulated sides enclosed in a bulb filled with gas of variable pressure (in the range of 10^{-1}–10^{-4} torr). One side of the vane is a receptor of radiation, the other is an electrically heatable bolometer. Like in his pyrheliometer, see Sect. 3.1, the carefully controlled electric heating of the bolometer side made it possible to compensate for the heating of the other side by the incident radiation. The compensation was carried

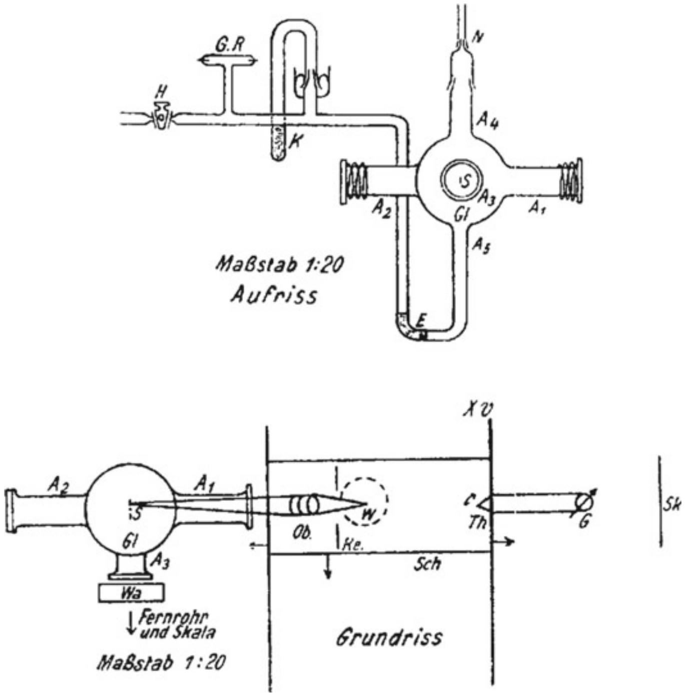

Fig. 13 The torsional radiometer of Gerlach and Golsen in side-view (top) and top-view (bottom) (Golsen 1924). The vane (not shown) used in the first quantitative measurement of radiation pressure was made of platinum foil (1.45×1.05 cm^2 and 7 μm thick). Its weight was balanced out by a platinum wire. The radiometer was housed in a glass ball (*Gl*) equipped with arms (A_1–A_5) for pumping and access and to allow to bring the radiation in and to take it out. It was evacuated by a Volmer diffusion pump combined with a cryo- and sorption pump (a *Volmeraggregat*) separated by a valve (H). The pressure was measured using a McLeod gauge and below 10^{-5} torr inferred from the damping of the torsional oscillations of the radiometer suspended on a 11 cm long quartz filament. A mirror (S) was attached to the filament to facilitate the read-out of the amplitude of the torsional oscillations. The radiation source was a tungsten arc lamp (W) whose output was focused on the vane by a camera lens (*Ob*). The power of the lamp was calibrated using a Hefner lamp and monitored during the measurements by a thermopile (*Th*) connected to a galvanometer (G). Except for the windows, the glass ball was shielded by a cotton-wool wrapping

out as a function of pressure for various absorption and thermal isolation materials. The instrument proved to be capable of sensitively measuring small changes of intense radiation.

However, Gerlach's goal was to directly measure light pressure rather than to investigate radiometer effects. To that end, he teamed up with Alice Golsen (Gerlach 1945):

> With Ms. Alice Golsen from Wiesbaden—who, as it turned out, was my classmate in 1896—I did the first measurement of radiation [pressure] as a precision measurement—with absolutely measured radiation energy. It was arduous but beautiful, clean work, a recuperation

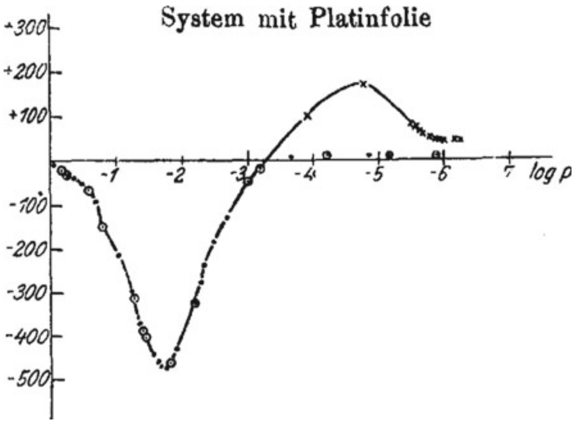

Fig. 14 The dependence of the vane amplitude (ordinate) on the logarithm of gas pressure, log p (abscissa). The negative and positive amplitudes of the platinum vane refer, respectively, to deflections against and along the direction of the incident light beam. The various series of data points (•, ×, and ⊙) correspond to different irradiances and are all found to follow the same curve (Golsen 1924)

of sorts from the perpetual failures of the space-quantization experiments. In Ms. Golsen I found a wonderful collaborator, both scientifically and as a person.

Their collaboration resulted in the second paper (Gerlach and Golsen 1923) of the series as well as a detailed summary written by Alice Golsen (Golsen 1924). The aim of the experiment was to provide an unequivocal measurement of radiation pressure, free of radiometer effects and any disturbances. That meant that the radiometer measurements had to be done as a function of gas pressure all the way down to 10^{-6} or even 10^{-7} torr where a pressure dependence would vanish. A new apparatus was built, Fig. 13, that amounted to a torsion balance with a platinum vane attached to a quartz filament suspended in a glass ball. Its "rest-amplitude" observed at pressures below 10^{-6} torr was then attributed to radiation pressure. The measurements proceeded as follows: after several days of pumping, the dependence of the amplitude of the vane would be measured as a function of gas pressure at constant irradiation by a tungsten arc lamp, see caption to Fig. 13. The power of the lamp was monitored [normalized] by a thermopile. Achieving a steady-state amplitude lasted often for hours and was perturbed by outgassing as well as by the vibrations of the institute building. A typical dependence of the amplitude on gas pressure is shown in Fig. 14; it would take on the order of 100 h to acquire the data points shown. As one can see, at gas pressures between 1 torr and 10^{-4} torr, the amplitude is "negative," meaning that, upon irradiation, the vane moves against the incoming light beam. Only at pressures below 10^{-3} torr would the amplitude become "positive" (i.e., along the light beam direction), inching towards the pressure-independent "rest-amplitude" at pressures below 10^{-6} torr. In order to access the requisite pressure range, sorption pumping with charcoal and cryo-pumping with liquid oxygen (!) had to be applied—for days ... As stated by Gerlach and Golsen, cryo-pumping with dry ice had not sufficed to reach the "rest-amplitude" regime. The radiation pressure was then evaluated from the observed "rest-amplitude" and the measured properties of the torsion balance, such as its force constant. The measured light pressure (light force per illuminated surface area of the vane), p, and the calibrated irradiance, I^*, were then compared and found to obey the relationship

$$p = \frac{I^*}{c} \tag{6}$$

with an accuracy of about 2%. This was the first-ever quantitative measurement of radiation pressure.

Gerlach and Golsen summarized their results thus (Gerlach and Golsen 1923):

1. In a vacuum from about 10^{-6} to 10^{-7} torr a constant amplitude ["rest-amplitude"] of the radiometer was found that is interpreted as purely due to radiation pressure.
2. This amplitude is proportional to the incident energy [power] and independent of the wavelength of the radiation.
3. The radiation pressure calculated from the constant amplitude agrees with the theoretical value.

In the third paper of the radiometer series (Gerlach and Madelung 1923), Gerlach and Erwin Madelung (1881–1972) debunk the radiometer theory published in 1922 by Edith Einstein. Finally, in 1932 Gerlach and Wilhelm Schütz publish the final, fourth sequel of the series (Gerlach and Schütz 1932) that deals with the radiometer effects at "high pressures" and corroborates the recent model put forward by Paul Epstein (Epstein 1929).

In 1975, Gerlach wrote a rebuttal (Gerlach 1975) to an article published in *Physik in unserer Zeit* whose author repeated the claim that radiation pressure was measured for the first time in the experiments of Lebedev, Nichols, and Hull. We note that Gerlach provided an impetus in 1970 for the founding of *Physik in unserer Zeit*.

It is mind-boggling that Gerlach's work on radiation pressure is still not widely known and that most textbooks keep attributing the first measurements of radiation pressure to experiments in which it could have not been observed.

After completion of the radiation pressure work at Frankfurt, Gerlach moved to his second academic station—his alma mater—as *Ordinarius*. His appointment at Tübingen received a strong push from Albert Einstein (Rechenberg 1979). Figure 15 shows Gerlach during the Tübingen period. Figure 16 shows his extended family during that time.

In addition to his time-consuming research projects at Frankfurt, Gerlach wrote two books: *Experimentelle Grundlagen der Quantentheorie* (Gerlach 1921) and the acclaimed *Materie, Elektrizität, Energie* (Gerlach 1923), a survey of the development of atomism over the previous decade.

We note that among Gerlach's students at Frankfurt was Hans Bethe (1906–2005), who began his physics studies in 1924. In his reminiscence (Bernstein 1979), Bethe acknowledged that Gerlach's stimulating lectures on atomic physics became a decisive influence on his further work in physics.

Fig. 15 Walther Gerlach as director of the Physics Institute in Tübingen. Courtesy of Werner Kittel, Hamburg

4 Gerlach's Involvement in the *Uranprojekt*

The German *Uranprojekt* was no precision physics. Launched in reaction to the discovery of nuclear fission by Otto Hahn, Lise Meitner, Fritz Strassmann, and Otto Robert Frisch and in the wake of subsequent theoretical work by Niels Bohr and John Wheeler, the project started taking shape already several months before the outbreak of World War Two. Paul Harteck, the successor at Hamburg of the exiled Otto Stern, had written in April 1939 to the *Reichswehrministerium* [Ministry of Defence] about the promise of both a nuclear reactor and a nuclear weapon, amply described in the publications by the above. Harteck's letter ended up at the *Heereswaffenamt* [Army Ordnance Bureau]. In September 1939, the Bureau's Kurt Diebner (1905–1964) and former Heisenberg student Erich Bagge (1912–1996) enlisted leading German physicists—Walther Bothe (1891–1957), Hans Geiger (1882–1945), Heisenberg, Hahn, Harteck, and Carl Friedrich von Weizsäcker (1912–2007)—in a wide-ranging war-time nuclear program. This received additional support through an initiative by Göttingen's Wilhelm Hanle (1901–1993) and Georg Joos (1894–1959) from the Ministry of Education. The members of the group, also known as the *Uranverein*, got promptly down to work. Heisenberg produced a secret report in which he described a uranium nuclear reactor (*Uranmaschine*) and urged the Bureau's leadership to support isotope separation not only as the surest path to a functional reactor but also

Fig. 16 The Gerlach family in Weimar in about 1927. From left: Walther Gerlach, Wolfgang Gerlach (brother of Walther Gerlach), Ruth Gerlach, neé Probst (2nd wife of Walther Gerlach), Valentin Gerlach (Walther Gerlach's father), Ingeborg Gerlach (elder daughter of Werner Gerlach and his wife Henriette "Henny" Syffert, who in 1943 married Wolfgang Kittel; they had two sons: Werner Kittel, born in 1945, and Gerd Kittel, born in 1948), Marie Gerlach, neé Niederhaeuser (mother of Walther Gerlach), Henny Gerlach, neé Syffert (wife of Werner Gerlach), and Werner Gerlach (brother of Walther Gerlach). Courtesy of Werner Kittel, Hamburg

to a nuclear bomb, without specifying the critical mass of U-235 needed (Cassidy 2017), p. 49. Based on the flawed research by Bothe on neutron capture by carbon, the *Heereswaffenamt* introduced the fatal mistake into the German nuclear program by branding graphite as an unsuitable moderator and relying on heavy water instead (Walker 1995), p. 225. Enrico Fermi's reactor at Chicago went critical in December 1942 using highly-purified graphite as a moderator. The loss of the heavy-water plant Norsk Hydro in Nazi-occupied Norway in early 1943 would then in effect upend the German nuclear program that relied on heavy water as a moderator. The *Uranprojekt* would continue, however, until the seizure of the German nuclear equipment by the American-led *Alsos Mission* in April-May 1945.

In 1941, several centers of German nuclear research emerged, all at first coordinated by Diebner and Bagge and concerned with aspects of the nuclear reactor as outlined by Heisenberg in his report. The most significant among them were Heisenberg's own institute at Leipzig and the Kaiser Wilhelm Institute (KWI) for Physics in Berlin, which fell under military command with Diebner installed as its acting director. Further reorganization saw Heisenberg appointed director of the KWI and Diebner relegated to an army research station in Gottow near Berlin. In August, Fritz Houtermans (1903–1966) and, independently, von Weizsäcker, demonstrated theoretically that Pu (plutonium) 239, produced in a uranium reactor from U-238 by neutron capture and subsequent β-decay, was at least as fissionable as U-235. As a result, an atom bomb suddenly appeared feasible. A controversial trip of Heisenberg and von Weizsäcker to see Bohr in Copenhagen followed. With the *Wehrmacht* defeated at Moscow and stuck at Leningrad, and the consequent mobilization of the German economy, the Army Ordnance Bureau approved funding, in February 1942, essentially only for Diebner's operation in Gottow (Cassidy 2017), p. 54. Heisenberg's KWI, however, had a sponsor in Abraham Esau of the Reich Research Council of the Ministry of Education and eventually of the *Reichsminister* Bernhard Rust himself. After a tantalizing conference, in February 1942, chaired by Rust on the prospects of a nuclear reactor, including its ability to breed fissionable plutonium, Esau was appointed, in December 1942, *Reichsbevollmächtigter* [Reich Plenipotentiary] for nuclear physics. But then the new Minister of Armaments, Albert Speer, induced Hitler to appoint Hermann Göring as head of the Reich Research Council whereby Esau became Göring's representative for nuclear issues. Already in July 1942, Heisenberg received a dual appointment in Berlin—as director of the KWI for Physics and professor of physics at the Berlin University. Heisenberg would use his expanded influence to push for Esau's replacement by a kindred spirit—Walther Gerlach. And indeed, as of 1 January 1944, Gerlach would become *Reichsmarschall's* Plenipotentiary for nuclear physics and remain in this position for sixteen months until his capture by the *Alsos Mission*.

Gerlach moved to his third academic station, *Ludwig-Maximilians-Universität* in Munich, on 1 October 1929 as the successor of Willy Wien. In 1935, a battle with the proponents of the so-called *Deutsche Physik*—Johannes Stark, Philipp Lenard, and their followers (Walker 1995)—flared up for the succession of the recently retired Arnold Sommerfeld (1868–1951), who held Munich's chair in theoretical physics. Gerlach headed the university's hiring committee, which chose Sommerfeld's former pupil, Werner Heisenberg—then already a Nobel laureate—to fill the vacant chair. The battle, which went through several stages and included public Nazi denunciations of the "White Jew" Heisenberg as well as an intervention by Heinrich Himmler (1900–1945) on Heisenberg's behalf, raged until September 1939 when Heisenberg was finally exonerated after an extensive SS investigation. However, in the meantime, the Munich chair went to a Nazi, Wilhelm Müller (1880–1968), an applied physicist. Whereupon Gerlach declared physics "dead" in Munich ... Heisenberg stayed put in Leipzig, until he received the call from Berlin.

Heisenberg and his *Uranverein* would hold additional presentations for both Speer and Göring and their staffs, carefully tailored to secure an autonomy of the physicists

Fig. 17 From left: Otto Hahn, Walther Gerlach, and Carl Friedrich von Weizsäcker in Göttingen, late 1950s. All three were members of Göttinger Achtzehn. Creative Commons

in setting the goals for the nuclear program and avoiding being "ordered to build the bomb; since failure to do so at the height of war would surely have meant execution" (Cassidy 2017), p. 55. We note that Heisenberg's understanding of the functioning of the bomb was inadequate all the way down to Farm Hall, as his recorded lecture to and conversations with his detained colleagues attest. As a result, his estimate of the critical mass of U-235 was orders of magnitude too high and so was the time needed to accumulate it by isotope separation (Bernstein 2001), pp. 129–131. Figure 17 shows Gerlach later on with two of his Farm Hall fellow detainees and interlocutors, Hahn and von Weizsäcker.

In June 1942, a heavy non-nuclear accident damaged the nuclear research laboratory at Leipzig. Afterwards, significant reactor research continued at two locations only—Heisenberg's KWI in Berlin and Diebner's facility in Gottow. Based on his calculations, Heisenberg concluded that about three tons of cast uranium and one and half tons of heavy water were needed in order to achieve a chain reaction in a cylindrical arrangement with rolled uranium plates interspersed with heavy water, a reactor design Heisenberg started building in a bunker at his KWI. Diebner, on the other hand, bet on using cast uranium in the form of cubes suspended on chains and immersed in frozen heavy water. When the ordered amounts of uranium finally arrived from the *Auergesellschaft*, Diebner's design produced a much higher neutron multiplication than Heisenberg's. Once Gerlach took over as Plenipotentiary for nuclear research, he diverted resources toward Diebner's facility, but enabled Heisenberg's operation to run in parallel, thereby thinning key resources, especially the wanting heavy water. By then, the Allied aerial bombing raids on Berlin became heavy enough for the city to start evacuating. On Speer's order, a large part of the personnel of Heisenberg's

KWI was moved to Hechingen, a rural place in Württemberg, not far from Tübingen. When Otto Hahn's KWI, a stone's throw from Heisenberg's, was destroyed in a targeted air raid, its personnel was moved to Tailfingen, not far from Hechingen. However, Heisenberg, his close associate Karl Wirtz (1910–1994) and their coworkers would stay on at the KWI for Physics in Dahlem and continue their attempts to get their reactor going. But at the end of 1944, with the Soviet Army reaching the left bank of the Oder river, Gerlach ordered both Heisenberg's and Diebner's groups to load their research equipment on trucks and move along with it to Hechingen. Once the convoy reached the experimental station of the *Reichsforschungsrat* in Stadtilm, about halfway, Gerlach pressed Diebner to stay there and make a final attempt to achieve chain reaction. Heisenberg's group, upon reaching Hechingen, set up a reactor in a cave—in fact a wine cellar—in a nearby village called Haigerloch. Their attempts, joined by von Weizsäcker, ended when the Haigerloch reactor was seized by the *Alsos Mission*. Gerlach's decision to enable Diebner his last-ditch effort is somewhat reminiscent of Gerlach's stubbornness in his own research that had so often paid off ...

Apparently, Heisenberg and Gerlach—and most others involved—struggled until the last moment not only out of scientific interest but also to salvage their scientific reputation. As David Cassidy put it (Cassidy 2017), p. 58:

> For Heisenberg, success would have demonstrated the survival of decent German physics, and, perhaps equally [importantly], would have made German physicists influential figures in the postwar reconstruction of Germany.

In his conversation with Otto Hahn at Farm Hall secretly recorded after the atomic bombing of Hiroshima, Gerlach made a similar point but added yet another dimension to it (Hoffmann 1993), p. 157:

> When I took [the *Uranprojekt*] over, I talked it over with Heisenberg and Hahn, and I said to my wife: "The war is lost and the result will be that as soon as the enemy enters the country I will be arrested and taken away." I only did it because, I said to myself, that [fission] is a German affair and we must see [to it] that German physics be preserved. I never thought for a moment of a bomb but I said to myself: "If Hahn has made this discovery, let us at least be the first to make use of it." When we get back to Germany we will have a hard time. We will be looked upon as the ones who have sabotaged everything. We will not remain alive [for] long there. You can be certain that there [will be] many people in Germany who [will] say that it is our fault. Now please leave me alone.

Gerlach withdrew from Haigerloch to Munich, "where he quietly resumed his pre-war work in his university laboratory" and was captured there on 20 April 1945 (Cassidy 2017), p. 75. He was first interned with a group of high-ranking Nazis and only on 15 June reunited with a group of detained German nuclear physicists. From 3 July 1945 until 2 January 1946, he was "detained as guest of His Majesty" (Gerlach 1978b) at Farm Hall in Cambridgeshire (Operation Epsilon), together with Erich Bagge, Kurt Diebner, Otto Hahn, Paul Harteck, Werner Heisenberg, Horst Korsching, Max von Laue, Carl Friedrich von Weizsäcker, and Karl Wirtz. The daily life at Farm Hall was described by Gerlach as follows (Gerlach 1978b):

> Five prisoners of war were taking care of cooking, house cleaning, and service. There were no interrogations or tasks so that we could use most of our time for work, for which the necessary literature was provided; radio, a good library, and a large park were all at our disposal; there were occasional trips to London or Middle-England. Hahn was the "doyen," who would smooth out occasional disagreements with the American and British officers. The rapport with the two British attending officers, who would also partake in common lunches and dinners, was amicable to the point of being personal. The good atmosphere would be only seldom disturbed by a visit by a high inspector of the secret service.

In the Farm Hall Protocols, Gerlach was characterized as "cheerful" and "cooperative" but, "based on the recorded conversations," under suspicion of "having had connections to the Gestapo" (Hoffmann 1993), p. 64. We have not found evidence in support of this suspicion, but Gerlach's involvement with the Nazi regime still remains an open question. However, as for instance Paul Rosbaud's testimonial suggests, see Sect. 1, Gerlach harboured a strong anti-Nazi sentiment. And he apparently never joined the NSDAP. But his brother Werner Gerlach (1891–1963), a professor of pathology, was an early NSDAP member and held a high honorary rank in the SS (Simon 2002). Werner would have a falling out over his NSDAP membership with his principled father, Valentin Gerlach. We hope that ongoing research will provide more clarity.

Ironically, the Farm Hall Protocols recorded the following conversation (Hoffmann 1993), p. 100:

> Diebner: I wonder whether there are microphones installed here?
>
> Heisenberg: Microphones installed? (laughing) Oh no, they are not that cunning. I don't think they know the real Gestapo methods; they're a little old fashioned in this respect.

Upon his release from Farm Hall, Gerlach, along with his fellow detainees, was confined to the British Zone of Occupation. Nevertheless, within the British Zone, he was free to accept a professorship at the University of Bonn. In April 1948 he would be free to return to Munich, in the American Zone of Occupation. In post-war Munich, Gerlach dedicated much of his time and effort to the restoration of the German academia in general and the *Ludwig-Maximilians-Univerität* in particular, including the resurrection of its Institute of Physics. Figure 18 shows Gerlach at the General Assembly of the Max-Planck-Gesellschaft, on whose Senate he served since 1951. His success in helping to raise the country from the ashes would earn him the highest honours in the Federal Republic, such as the Order *Pour le Mérite für Wissenschaften und Künste* awarded to him in 1970 by the President of Germany. In the context of this volume we note that, in 1988, the Stern-Gerlach Prize (since 1993 the Stern-Gerlach Medal) was established as the most prestigious German award for work in experimental physics, cf. Chap. 5. As a further example of Gerlach's stature we show a recently recovered silver plate, Fig. 19, that Gerlach received on his 70th birthday from the Senate of the Max-Planck-Gesellschaft in recognition of the services he provided as a member of the body over several decades.

Fig. 18 Walther Gerlach at the general assembly of the Max-Planck-Gesellschaft in Stuttgart in 1956. Courtesy of the Archiv der Max-Planck-Gesellschaft

Fig. 19 Silver Plate presented to Walther Gerlach on the occasion of his 70th birthday by the Senate of the Max-Planck-Gesellschaft. Long after Gerlach's death it was passed on by his second wife Ruth, see Fig. 16, to her nephew, Werner Kittel. From him it was acquired in 2020 by Horst Schmidt-Böcking for the *Physikalischer Verein Frankfurt*. Photo H. Schmidt-Böcking, 2020

5 Gerlach's Work in the History of Science

From early on, Walther Gerlach cultivated a sense for the history of physics, perhaps in keeping with Goethe's maxim that "the history of a science is that science itself." Gerlach's first piece in the history *of* physics (Gerlach 1924) appeared at a time when he himself was making history *in* physics. As Gerlach's bibliography compiled by Margret Nida-Rümelin reveals (Nida-Rümelin 1982), this would be followed by about 500 additional publications on the history of physics/science, including about 60 scientific biographies, as well as outreach articles. During his distinguished career, Gerlach gave numerous talks on issues ranging from scientific funding to epistemological considerations, some of which would later be published. These are also included in the above number of 500.

Gerlach's sense for the history of science would also come to the fore in his capacity as educator. Like his academic mentor, Friedrich Paschen, Gerlach indulged his students in the spectacle of well-prepared experiments, some of which recapitulated chapters from the history of physics. The demonstration of Otto von Gericke's hemispheres, refuting the *horror vacui* theory, evacuated by Gerlach, a pioneer of high-vacuum technology, must surely have been a treat! Gerlach would also ask his students history questions during exams (Bachmann and Rechenberg 1989, p. 145). As Bachmann and Rechenberg report (Bachmann and Rechenberg 1989, p. 146):

> When [Gerlach] realized *how* Newton brought out certain optical phenomena or Goethe observed phenomena that seemingly disproved them, he would be perhaps more pleased than if he discovered an altogether new physical effect.

Gerlach's writings on the history of science are based on his detailed knowledge of the subject—and its literature. He would have likely concurred with Steven Weinberg when he remarked (Weinberg 1998): "By assuming that scientists of the past thought about things the way we do, we make mistakes; what is worse, we lose appreciation for the difficulties, for the intellectual challenges, that they faced."

One of Gerlach's personal heroes was Johannes Kepler (1571–1630), whom he extolled not only as the first physicist in history worthy of the name, but also as a forerunner of humanism—"a priest of the book of Nature" (Gerlach 1972):

> It was an unbearable thought ... for Kepler that, on the one hand, human reason enables insight into the wonders of Nature (and "only science reveals wonders"), into the *harmonic* order of the world, but, on the other, that human life generally passes in *disharmony*, driven by quarrel, conflict, hate, and war.

Gerlach also details Kepler's relationship with Galileo (1564–1642), who kept snubbing Kepler, whether about celestial mechanics or optics. But it was Kepler, Gerlach points out, who provided, through his third law (published in 1619) relating quantitative properties of the orbits of different planets, the most irrefutable evidence for the heliocentric system. Galileo would, however, never use it in his defense during the 1633 trial by the Inquisition. The lack of appreciation for Kepler in some quarters may have aroused special sympathy in Gerlach, as he too had not always received due recognition, see Sects. 1 and 3.3. However, there's no trace of complaint

Fig. 20 Plaque at the entrance of the former *Physikalisches Institut* of the University of Frankfurt, Robert-Mayer Str. 2–4. Photo H. Schmidt-Böcking, 2002

about it in Gerlach's correspondence or any other source available to us. Secondly, Tycho de Brahe's measurements and their interpretation and analysis by Kepler of the eccentricity (0.0934) of Mars' orbit were revolutionary (in this case, also literally) precision measurements! And finally, Gerlach and Kepler were connected by the vicissitudes of their religious identity: they were both Protestants living in Catholic environments.

History of science was Gerlach's main preoccupation during the last twenty years of his life. His wide-ranging erudite historical writings deserve to be better known.

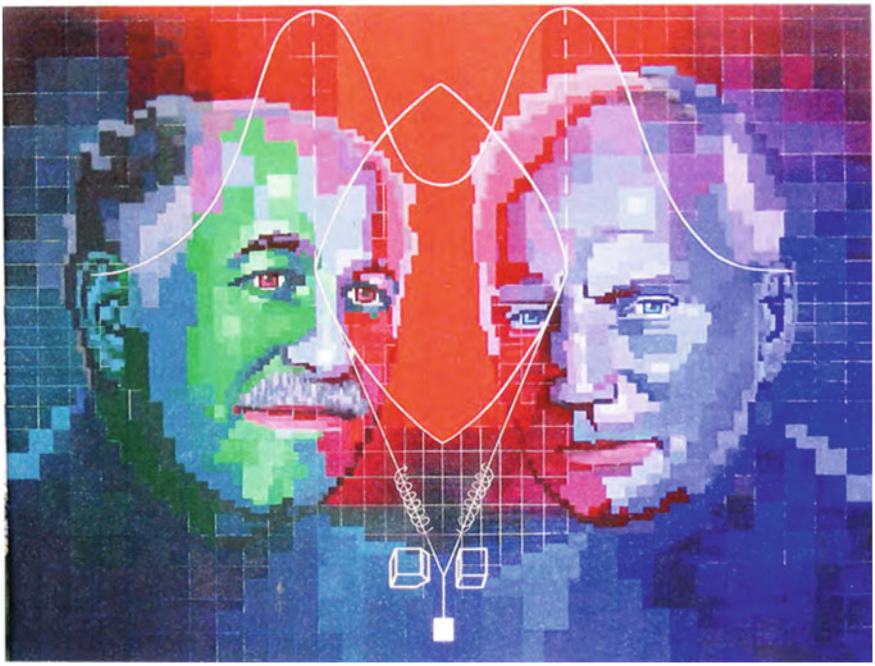

Fig. 21 Double-portrait of Otto Stern and Walther Gerlach by Jürgen Jaumann. The schematic of the Stern-Gerlach experiment and its outcome was drawn by Theodor Hänsch. Photo H. Schmidt-Böcking, 2020

6 In Conclusion

Walther Gerlach lives on through his enduring legacy in physics, higher learning, and history of science. His estate, held at the Deutsches Museum in Munich, is comprised of sixteen thousand items. Walther Gerlach also lives on in a number of public depictions, among them the memorial plaque, Fig. 20, designating *Die Alte Physik* building in Frankfurt as the site where the Stern-Gerlach experiment was carried out. The Physics Department at Frankfurt also features a double-portrait of Stern and Gerlach, Fig. 21.

We close with Gerlach's credo (Gerlach 1978):

> *Etwas Gutes kommt nie zu spät.* [It's never too late for something good to happen.]

Appendix: Timeline of Walther Gerlach's Life and Career

The timeline below has been translated and adapted from the catalogue of the 1989 centennial exhibition *Walther Gerlach—Physiker—Lehrer—Organisator* at the *Deutsches Museum* in Munich curated by Rudolf Heinrich und Hans-Reinhard Bachmann (Heinrich and Bachmann 1989).

- **August 1889–March 1908 Childhood, Youth**
- 1 August 1889 Walther Gerlach was born in Biebrich am Rhein near Wiesbaden at 8:15; his mother was Maria Wilhelmine, neé Niederhaeuser; his father Dr. med. Valentin Gerlach, physician and chemist, Freemason and Goethe-expert
- 4 September 1891 Birth of twin brothers Werner and Wolfgang, joint Protestant baptism of all three brothers on 26 April 1896 in Bergkirche Wiesbaden
- 1895–1896 Volksschule [elementary school]
- April 1896–March 1899 City Middle School Wiesbaden
- April 1899–March 1908 Royal Humanities High School [Königliches Humanistisches Gymnasium] in Wiesbaden
- 9 March 1908 Abitur [finals] at the Royal Humanities High School in Wiesbaden
- **April 1908–Juli 1915 University studies in Tübingen**
- April 1908–February 1911 Studies at the Eberhard-Karls-Universität Tübingen: Since the 1st semester prepares to major in philosophy and mathematics; since the 5th semester in physics and chemistry. Gerlach attends lectures on philosophy by Ernst Adickes, mathematics by Alexander von Brill, experimental physics by Friedrich Paschen, theoretical physics by Richard Gans and Edgar Meyer
- April 1908 Joins Corps Borussia
- 15 November 1910 Student-Assistant of F. Paschen at the Institute of Physics, University of Tübingen (received an annual stipend of 1850 RM)
- March 1911 Exmatriculation
- 29 February 1912 Graduated "magna cum laude" with a thesis entitled "Eine Methode zur Bestimmung der Strahlung in absolutem Mass und die Konstante des Stefan-Boltzmannschen Strahlungsgesetzes." Adviser: Friedrich Paschen
- **August 1915–October 1920 First World War and First Employment**
- August 1915 Drafted to serve with the Infantry Regiment 247 in Ulm
- December 1915 Dismissed due to illness
- 29 April 1916 *Habilitationskolloquium* in Tübingen
- May 1916 Named *Privatdozent* at the University of Tübingen
- 6 May 1916 Drafted by the Pioneer Battalion Berlin-Schöneberg, subordinated to the *Prüfungskommission* [Examining Board]; Military rank: *Pioniergefreiter* [pioneer private]

- 2 June 1916 Assigned by the Tübingen Faculty to give a lecture "Über die Existenz eines Elektrizitätsatoms" [On the existence of an atom of electricity]
- 22 July 1916 Submitted habilitation thesis entitled "Experimentelle Untersuchungen über die Messung und Grösse der Konstanten des Stefan Boltzmannschen Strahlungsgesetzes" (Adviser F. Paschen)
- Fall 1916 Promoted to the rank of *Oberingenieur* [chief engineer] at the Inspectorate of the Radio Units. Assigned to the technical Department of the Radio Units (Tafunk), deployed to the test stations and factories in Würzburg, Stuttgart (at Bosch), and Jena
- Fall 1916 Drafted by the VIth Army in Flanders and Artois
- Dezember 1916–January 1917 Hospitalized at the surgical clinic of *Lazarett* Jena
- January–September 1917 With Tafunk in Berlin and Jena
- August 1917 Habilitation in Göttingen co-sponsored by Waldemar Voigt and Peter Debye; appointed as *Privatdozent*
- 12 September 1917 Relinquished the right to teach at the University of Tübingen
- 5 March 1918 Assigned to the back-up radio company Döberitz; takes part in the campaign in Champagne and Flanders
- 20 June 1918 Contracted the "Spanish flu;" at the *Lazarett* Mannheim
- Oktober 1918 Relocated to Tafunk in Berlin-Stahnsdorf
- December 1918 Carried out demobilization tasks for the Ministry of War
- 27 January 1919 Dismissed from Tafunk Berlin
- **February 1919–October 1920 Head of the Physics Laboratory of the *Farbenfabriken* Elberfeld**
- **October 1920–December 1924 *Privatdozent* and *Extraordinarius* Professor at the University of Frankfurt**
- 1 October 1920 First Assistant and *Privatdozent* at Richard Wachsmuth's Institute for Experimental Physics at the University of Frankfurt
- 1 November 1920 Senior Assistant and *Privatdozent* with the title *Extraordinarius* at the University of Fankfurt
- 8 Februar 1922 Evidence for space quantization of silver atoms in a magnetic field (Stern- Gerlach effect)
- 1 March 1923 Reported the first quantitative measurement of radiation pressure (with Alice Golsen)
- **January 1925–September 1929 Professor in Tübingen**
- 1 January 1925 *Ordinarius* Professor and Director of the Institute of Physics of the University of Tübingen as successor of his mentor Friedrich Paschen (Paschen left to become the President of the Physikalisch-Technische Reichsanstalt in Berlin)
- 2 December 1926 Public inaugural lecture in Tübingen: "Über das Wesen physikalischer Erkenntnis und Gesetzmässigkeiten"
- 3 June–5 July 1927 On leave at the University of Zurich working with Edgar Meyer
- 1928 Dean of the Faculty of Mathematics and Physics of the University of Tübingen
- **October 1929–May 1945 Professor in Munich (1st tenure)**
- 1 October 1929 *Ordinarius* Professor at the Ludwig-Maximilians-Universität Munich as successor to the deceased Willy Wien
- 22 February 1930 Elected Member of the Bavarian Academy of Science

- 15 June 1931 Member for life of the [governing] Committee of the Deutsches Museum
- Fall 1933 Banned from lecturing and administering exams for being allegedly unsuited to educate German Youth
- Beginning of 1934 Lifting of the lecturing ban
- 31 January 1935 Elected to a three-year membership in the administrative committee of the Deutsches Museum
- 20 March 1936 Participation at a conference on gravitation in London
- 1936 Lifting of the ban to administer examinations
- 1937 Elected Senator of the Kaiser-Wilhelm-Gesellschaft (forerunner of Max-Planck-Gesellschaft)
- 18 August 1938 Attended the symposium “Modern Methods of Chemical Analysis” in London, organized by the British Association, Cambridge
- Beginning of 1939 Founding of the international journal “Spectrochimica Acta” with Paul Rosbaud
- May 1939 Lecture tour in Poland
- November 1939 Prof. Dr.-Ing. Ernst August Cornelius from the *Technische Hochschule Charlottenburg* in Berlin entrusted by the Supreme Command of the Navy to establish a work group named after him—Arbeitsgruppe Cornelius (AGC); Gerlach together with about fifteen additional scientists from industry and universities called upon to join AGC, which cooperated, among others, with Askania-Werke in Berlin—a manufacturer of torpedos
- 27 November 1939 Gerlach tasked, within the AGC, with the development of methods for demagnetization of ships and torpedos, defusing magnetic mines and the development of magnetic fuses
- 1 October 1943 AGC was dissolved
- 1 January 1944 Hermann Göring named Gerlach head of the Physics Section in the *Reichsforschungsrat* and Plenipotentiary for nuclear physics, as successor to Abraham Esau
- April 1944 Gerlach founded the journal “Reichsberichte für Physik” [Reich Reports on Physics] which is slated explicitly for internal use only
- 31 January 1945 Relocation of part of the nuclear program (Diebner’s group) to Stadtilm in Thuringia
- End of February 1945 Relocation of the rest of the nuclear program (Heisenberg’s group) to Hechingen and Haigerloch in Württemberg
- **May 1945–March 1948 Detention, Professorship in Bonn**
- 3 May 1945 Relocation to Heidelberg by U.S. Army officers; meeting with Samuel Goudsmit
- 10 May–15 Juni 1945 Detention in France and Belgium (Le Vésniet, Le Grand Chesnay, Faqueval)
- 3 July 1945–2 January 1946 Detention at Farm Hall in England
- January 1946 In Alswede near Hannover
- 5 February 1946 Arrival in Bonn; ordered not to leave the British Zone of Occupation

- February 1946–31 March 1948 Assumed the duties of the chair and director of the Institute of Physics of the University of Bonn
- Spring 1946 President of the *Notgemeinschaft der Deutschen Wissenschaft* [German Science Foundation] in North Rhine-Westphalia
- 11 September 1946 Founding Member of the Max-Planck-Gesellschaft (in the British Zone)
- **April 1948–September 1957 Professor in Munich (2nd tenure)**
- 1 April 1948 Resumption of the professorship at Munich after the lifting of the ban on leaving the British Zone (Gerlach's substitute since May 1945 was Eduard Rüchardt)
- 7 May 1948 Elected to a three-year membership in the administrative committee of the Deutsches Museum
- 1948–1951 Rector of the *Ludwig-Maximilians-Universität* in Munich
- January 1949–June 1961 Vice-President of the *Notgemeinschaft der Deutschen Wissenschaft* and its successor organization, the *Deutsche Forschungsgemeinschaft* (DFG)
- 7 May 1949 Elected to a three-year term in the Governing Board of the Deutsches Museum; in 1963 Gerlach would be elected again for a three-year term and finally, in 1968, for life
- 1949 Founding President of the Fraunhofer-Gesellschaft
- 1951–1969 Member of the Senate of the Max-Planck-Gesellschaft
- 1956 –1957 President of the Association of the German Physical Societies
- 12 April 1957 Involvement in the preparation and signing of the Declaration of the Göttingen Seven
- 1957 Member of the Kepler Committee of the Bavarian Academy of Sciences
- October 1957–August 1979 Emeritus in Munich
- 1959 Founding Member of the Vereinigung Deutscher Wissenschaftler (VDW)
- **1965–1979 Research Fellow at the Forschungsinstitut für die Geschichte der Naturwissenschaften und der Technik at the Deutsches Museum**
- 1970 awarded Order *Pour le Mérite für Wissenschaften und Künste* by the President of Germany
- 26–28 August 1971 Attended the International Congress on the History of Science in Leningrad; talk on Johannes Kepler
- 16 May 1979 Received an honorary degree from the Faculty of Physics of the University of Tübingen
- 10 August 1979 Walther Gerlach died in Munich shortly after his 90th birthday

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