Chapter 6

Otto Stern—With Einstein in Prague and in Zürich

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Abstract The two years that Otto Stern spent with Albert Einstein in Prague and Zürich, between the spring of 1912 and the spring of 1914, can be viewed as his apprenticeship in theoretical physics. This chapter describes that formative phase in Stern's scientific career, prior to his emergence as one of the greatest innovators in experimental physics.

1 One Semester in Prague

Otto Stern completed his studies in physical chemistry and worked under the supervision of Otto Sackur on his doctoral dissertation on the kinetic theory of the osmotic pressure of concentrated solutions. Stern chose the problem himself and Sackur suggested that the theoretical work be accompanied by measurements on solutions of dissolved carbon dioxide. In the spring of 1912 Stern submitted his thesis under the rather long title “On the Osmotic Pressure of Condensed Solutions and the Validity of the Henry Law for Condensed Solutions of Carbon di-Oxide in Organic Solvents at Low Temperatures.”

In May 1912, Stern joined Einstein at the German part of Charles University in Prague. This was Einstein's first academic appointment as full professor and Stern was his first post-doctoral student. When asked, years later, why he preferred to go to Einstein, rather than, what seemed to be a more natural choice, to join Walther Nernst or Fritz Haber, Stern did not have a clear answer other than his wish to meet the great man that Einstein was. He acknowledged that this wish may have been an impudence, but Einstein agreed right away. The “matchmaker” between Stern and Einstein was Haber, who was friendly with both Sackur and Einstein.

The description of the relations between Stern and Einstein presented in this paper is based, to a large extent, on Stern's recollections expressed in two interviews from the early 1960s, with Res Jost in 1961 [1] and with Thomas S. Kuhn in 1962 [2].

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Stern vividly remembered his first impression of Einstein:

I expected to meet a very learned scholar with a large beard, but found nobody of that kind. Instead, sitting behind a desk was a guy without a tie who looked like an Italian road-mender. This was Einstein. He was terribly nice. In the afternoon he was wearing a suit and was shaven. I had hardly recognized him.

Einstein's time in Prague is best known as a formative chapter in his journey towards the General Theory of Relativity. In Prague he wrote 11 papers, 6 of which were devoted to relativity. Yet, he kept an open eye on the growing interest in the applications of quantum theory in solid state physics and in physical chemistry. He pioneered this development in 1907 with his paper on the specific heat of solids [3]. Although there were four local academic institutions with full physics professors, they were all doing classical work and Einstein had no one to talk to about the contemporary issues on the agenda of physics. Thus, there could not have been a better time for Stern to join Einstein. Despite the difference in background and experience they had a lot to talk about. They were both interested in molecular theory, both understood and appreciated the work of Boltzmann and both believed in the reality of atoms and molecules, which was not so common in those days.

Stern recalled that already then he realized that Einstein was one of the few contemporary physicists who insisted that thermodynamics was absolutely fundamental, one of the few parts of physics that could never be changed. This observation is in accord with Einstein's own recollection about his fascination with thermodynamics in the early stage of his scientific career. In his *Autobiographical Notes*, we find a special reference to this domain of classical physics [4]:

A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Hence the deep impressions it made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts.

Stern's sojourn with Einstein in Prague lasted one semester. In August 1912, Einstein accepted an appointment at the Swiss Federal Institute of Technology (ETH) in Zurich. He invited Stern to join him there as his scientific assistant. About fifty years later, Stern summarized his first post-doctoral experience:

With Einstein in Prague – this was a decisive element in my scientific development. I was then introduced to the real problems of those times.

2 Interacting with the Stars at ETH

In 1911, the mathematician Marcel Grossmann was appointed dean of the mathematics-physics department of ETH. One of the first initiatives as dean was to ask Einstein if he would be interested to return to Zürich, where he already held an academic position before going to Prague. At that time Einstein had already understood that in order to make progress in his effort to formulate a general theory of

relativity, he needed mathematical methods which he did not know then. In Zürich, Grossmann became his mentor on tensor calculus and Riemannian geometry, and his partner and coauthor of a preliminary version of the general theory of relativity.

In spite of working almost exclusively on the general theory of relativity, Einstein was always willing to discuss issues and questions that Stern brought to his attention. The close relationship between them, which started in Prague, continued in Zürich. Stern would occasionally retreat into Einstein's office, because that was the only place in the institute where one was allowed to smoke and Einstein used to visit him in his laboratory. On such occasions they had lively discussions on the unsolved problems of quantum theory. They even wrote a paper together (see Chap. 5).

In Zurich, Stern also benefited greatly from interactions with other physicists, who were familiar with problems and debates at the forefront of research in physics. He enjoyed discussions with Paul Ehrenfest who spent an extensive visit at ETH with his wife Tatjana around the fall of 1913. Ehrenfest was also interested in the Nernst heat theorem, a topic that was on Stern's mind then and for years to come. It seems that they thought well of each other and Ehrenfest sent him a reprint of his volume on Statistical Mechanics with an inscription.

In Zürich, Stern met Max Laue (not yet von Laue) who had just made his monumental discovery of X-ray diffraction from crystals. Their acquaintance evolved into a lifelong friendship. Stern and Laue shared the same opinion on Bohr's model of the atom published in 1913. They were shocked by the departure from everything they learned in physics, implied by that model. To express their dismay, they vowed that "if this nonsense of Bohr should prove to be right in the end, we will quit physics." Stern recalled that Einstein had a better insight and foresight than they had: "Einstein mentioned to me that he had thought about something like Bohr's atom himself."

Stern's formal education in physics was a standard general physics course. This was greatly enriched by faithfully attending Einstein's lectures in Prague and in Zürich. Einstein's teaching in Zürich was mainly done in the colloquium, which was attended at various times also by Laue and Ehrenfest. Einstein did not prepare his lectures, but just talked at the board, sometimes getting lost in the argument or even making mistakes. The lectures were not good for ordinary students but were very stimulating for the better students who could see Einstein's mind at work. What Stern learned from those lectures was not to be ashamed of making mistakes and to be always ready to admit them. The other feature that he then learned from Einstein, which served him throughout his scientific life was "Querdenken" ("lateral thinking")—a kind of creative approach to solving problems via reasoning that is not immediately obvious. Today, one would refer to it as "thinking out of the box."

3 The "Zero-Point Energy" Paper

In 1911 Walter Nernst initiated a program of measuring the specific heat of solids. Results of measurements at sufficiently low temperatures showed a tendency of the specific heat to vanish as the absolute temperature approached zero. This was in

accord with Einstein's specific heat formula, derived by applying Planck's quantum theory to atomic oscillations in a solid. This formula predicts that the specific heat of all solids vanishes at zero absolute temperature.

At sufficiently high temperatures, the specific heat of all elements in the solid state is the same—expressed by the classical Dulong-Petit law. Nernst wanted to extend these results to account for the contribution of rotational degrees of freedom to specific heat. To this end, Arnold Eucken, working in his laboratory, measured the specific heat of hydrogen [5].

Einstein was interested in Eucken's results, thinking that they might help to clarify another issue of basic importance. In 1911 Max Planck modified his black-body radiation theory [6], assuming a system of oscillators of frequency ν , which absorb energy continuously but emit energy in discrete energy units of $h\nu$. In Planck's original theory, the average energy of an oscillator, at temperature T , was:

$$E = \frac{h\nu}{\exp(h\nu/kT) - 1}.$$

In what is known as Planck's "second quantum theory," the radiation distribution is unchanged, but there is an additional energy term at all temperatures and particularly at zero temperature, which is referred to as "zero-point energy":

$$E = \frac{h\nu}{\exp(h\nu/kT) - 1} + \frac{h\nu}{2}$$

Einstein was looking for ways of detecting the existence of zero-point energy in physical phenomena. He believed that it may be reflected in Eucken's results on the specific heat of hydrogen. He engaged his assistant, Otto Stern, in this effort and shortly after arriving in Zürich, they published a joint paper [7].

The paper begins with the assumption that the mean kinetic energy of rotation acquired by the molecules under the influence of radiation must be equal to the mean kinetic energy acquired by collisions with other molecules. Hence, the question is for what mean value of rotational energy will a diatomic molecule be at equilibrium with radiation at a given temperature. Making the simplifying assumption that all molecules rotate at the same frequency ν , their rotational energy $E = J(2\pi\nu)^2/2$ has to be equal to Planck's expression for the radiation energy. As a result, the rotational frequency becomes temperature dependent and the specific heat will depend on the presence of the zero-point energy term. Einstein and Stern concluded that the specific heat calculated with the zero-point energy term agrees quite well with Eucken's measurements. When this term was omitted the result was very different from the measured curve.

The second part of the paper is a new derivation of Planck's radiation formula, including zero-point energy, based on a method used previously by Einstein and Hopf [8] to derive the classical Rayleigh-Jeans radiation law. This part of the paper was assigned to Stern. He recalled this episode as an unpleasant confrontation with Einstein. Stern concluded that the zero-point energy term was $h\nu$ and not $h\nu/2$.

Einstein thought that this was impossible and instructed him to redo the calculation. When he got the second time the same answer, Einstein was annoyed and decided to do the calculation himself and got the same result. In the paper there is a footnote stating that this discrepancy should be resolved in a more rigorous calculation.

The paper by Einstein and Stern generated broad interest and stimulated theoretical and experimental work. However, a short time after its publication Einstein announced that he and Stern encountered contradictions in their treatment of the specific heat of hydrogen and that their results are untenable. At the second Solvay Conference in October 1913 he even denounced the notion of zero point energy. In the interview with Res Jost, Stern refers to this paper as nonsense. I do not know how many “wrong” papers had Stern published in his scientific career. For Einstein, this was neither the first one, nor the last.

There was no way to treat correctly the specific heat of hydrogen before the distinct features of ortho-hydrogen and para-hydrogen were known.

It should be noted that the concept of zero-point energy remains a rigorous consequence of quantum mechanics.

In spite of its obvious discrepancies, it is appropriate to remember this paper in the present context because it played a role in the lively debates of those days and contributed to the experience of the young Stern as a novice in the international scientific arena.

4 The Habilitation Process

In German-speaking countries the habilitation process is required to be entitled to lecture at a university and to be eligible for appointment as a professor. The candidate for habilitation has to submit a summary of an original research. With his habilitation application, Stern submitted his paper “On the Kinetic Theory of Vapor Pressure of one-atomic solids”, published under a broader title [9].

In this paper Stern calculated the change in entropy from zero temperature to temperatures where the classical molecular theory is valid. The expression of the entropy of a monoatomic gas contains a constant that affects the vapor pressure of the solid phase. This constant plays a fundamental role in the formulation of Nernst’s theorem (the third law of thermodynamics). In his calculation, Stern used Nernst’s theorem and Einstein’s theory of the specific heat of solids. The change of entropy at vaporization was derived applying the classical statistical mechanics of gases, valid at the high temperature of vapor. He finally derived the entropy constant and obtained the same results as have been previously derived by Sackur [10] and Tetrode [11]. But, unlike their derivation, Stern’s method was unquestionable. Stern remembered well, in the interview with R. Jost, this first physical-theoretical discovery—the derivation of vapor pressure using molecular theory. He was very proud of this result. Einstein liked this work and urged Stern to submit the habilitation application.

The Habilitation committee was composed of two physicists, Albert Einstein and Pierre Weiss, and a chemist, Emil Baur. In his recommendation to approve Stern’s

Habilitation petition [12], Einstein refers to this paper as an entirely independent work. He is quite specific in his evaluation:

The theoretical determination of the vapor pressure of solids is a problem that acquired great importance on account of Nernst's heat theorem and that many of today's ablest physicists have tackled, though these efforts have not achieved the desired goal. In the past year, Sackur finally found a formula that agreed with experience to within the margins of error, but Sackur's attempt to provide a theoretical foundation for this formula must be considered unsuccessful, because in order to carry out the derivation Sackur had to invoke hypotheses about molecular motion of gases that lacked any justification. Mr. Stern has now succeeded in deriving this formula using the methods of the kinetic theory of gases, without having to resort to any special hypotheses whatsoever.

Einstein concludes:

This derivation is of lasting value. The method devised by Mr. Stern, which permitted him to achieve his goal in an astonishingly simple way, demonstrates unusual talent.

Emil Baur's opinion [13] is also worth quoting. He concurs with Einstein that the paper submitted by Stern, without any doubt, attests to great talent. He regrets that Stern summarized his work in a short paper rather than presenting his discovery in a monograph summarizing the whole phenomenon of vapor pressure. Baur believes that Stern did not do it because the physicists on the committee wanted to speed up the process so that Stern could join the teaching staff as soon as possible. With this goal he agrees. Baur describes the revival of interest in the classical problems of physical chemistry, basically due to Planck's radiation theory. Baur would like to see a lecture course on this new area of research at ETH and he thinks that Stern satisfies all the conditions to fulfill this task.

This is a remarkable accolade coming from two professionally mature scientists to their younger colleague, only about one year after completion of his doctoral thesis. Stern's application was approved on July 22nd, 1913, and he was awarded the title of *Privatdozent* in early August.

5 Concluding Remarks

In July 1913, Max Planck and Walter Nernst came to Zürich to present to Einstein a tempting proposal—election to the Prussian Academy with generous financial support, directorship of the Kaiser Wilhelm Institute of Physics and professorship at the University of Berlin. Einstein arrived in Berlin in March 1914 to complete his masterwork—The General Theory of Relativity. Stern remained for a short time at ETH and then embarked on his independent scientific odyssey, described in the other contributions to this volume. As a corollary to the Einstein and Stern collaboration, it is worth mentioning their correspondence in 1916, which is a direct extension of their discussions in Zürich. This correspondence ended in a disagreement on the validity of Nernst's heat theorem for solid solution of mixed crystals [14]. Einstein

Fig. 1 Albert Einstein (left) and Otto Stern during a meeting in the mid-1920s

thought that the theorem applies only to pure substances, but he changed his mind when he saw Stern's paper on this issue [15].

This may have been the last serious scientific exchange between Stern and Einstein, but their relation evolved into a lasting friendship. Their paths crossed occasionally in Berlin, see Fig. 1, and in the U.S. Both shared the common fate of many of their peers who became homeless in their homeland when the Nazis came to power and had to rebuild their personal lives and scientific career in a foreign land.

References¹

1. ETH-Bibliothek Zürich, Archive, <http://www.sr.ethbib.ethz.ch/>, Otto Stern tape-recording Folder »ST-Misc.«, 1961 at E.T.H. Zürich by Res Jost; AEA, doc. 78-994
2. T. S. Kuhn (ed.), AIP oral history interviews. *Otto Stern Interviewed* (1962)
3. A. Einstein, Die Plancksche Theorie der Strahlung und die Theorie der spezifischen Theorie der Wärme, *Annalen der Physik*, **22**, 180 (1907); reprinted in CPAE, vol. 2, doc. 38
4. A. Einstein, in *Autobiographical Notes*, ed. by P.A. Schilpp. Albert Einstein: Philosopher-Scientist (Tudor Publishing Co., 1949), p. 33
5. A. Eucken, Die Molekulerwärme des Wasserstoffs bei tiefen Temperaturen (Berliner Berichte, 1912), p. 14
6. M. Planck, Eine Neue Strahlung Hypothese, Deutsche Physikalische Gesellschaft. Verhandlungen **13**, p. 138, 1911; for a historical discussion of Planck's second theory see Thomas

¹AEA—Albert Einstein Archives

CPAE—Collected papers of Albert Einstein

- S. Kuhn, *Black-Body Theory and the Quantum Discontinuity, 1894–1912*, ch. 10 (Oxford University Press, 1978)
7. A. Einstein, O. Stern, Einige Argumente für die Annahme einer molekularen Agitation beim absoluten Nullpunkt, *Ann. Phys.* **40**, 551 (1913); this paper is reprinted with an editorial introduction in CPAE, vol. 4, doc. 11
 8. A. Einstein, L. Hopf, Statistische Untersuchung der Bewegung eines Resonators in einem Strahlungsfeld. *Annalen der Physik*, **33**, 1105 (1910); reprinted in CPAE, vol. 3, doc. 8
 9. O. Stern, Zur kinetischen Theorie des Dampfdrucks einatomiger festen Stoffe und über die Entropie-konstante einatomiger Gase, *Physik. Zeitschr.* **XIV**, 629 (1913)
 10. O. Sackur, *Ann. Phys.* **40**, 67 (1913)
 11. H. Tetrode, *Ann. Phys.* **38**, 434 (1912)
 12. A. Einstein, *Expert Opinion on the Habilitation Petition of Otto Stern*, CPAE, vol. 5 doc 452
 13. E. Baur, Zu dem Habilitationsgesuch der Herrn Dr. O. Stern, AEA, doc. 70-020
 14. CPAE, vol. 8, doc. 191, 192, 198, 205
 15. O. Stern, Die Entropie fester Lösungen. *Ann. Phys.* **49**, 823 (1916)

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