Jorge Schaeffer (1927-), Alfred Marcel Schneider (1925-), Hans Schneider (1927-), Biyamin Schwarz (1919-2000), Josef Silberstein (1920-), Frank Spitzer (1926-1992), Theodor David Sterling (1923-), Erwin Trebitsch (1920-), Hans Felix Weinberger (1928-) und John (Hans) Wermer (1927-).

The following names belong to young Austrians born after 1920 who were expelled from their home country and got their academic training as physicists in Great Britain or the United States:

Fred Peter Adler (1925-), Erika Rivka Bauminger (1927-), Arthur Biermann (1925-), Frank Joachim Blatt (1924-), Henry Victor Bohm (1929-), Frederic de Hoffmann (1924-1989), Harold Paul Furth (1930-), Thomas Gold (1920-2004), Robert Gomer (1924-), Kurt Gottfried (1929-), Leopold E. Halpern (1925-2007), Erich Martin Hardt (1919-), Charles Maria Herfeld (1925-), Arvid Herzenberg (1925-), Charles M. Herzfeld (1925-), Walter F. Hitschfeld (1922-), Frederic Gerald Holton (1922-), Robert Karplus (1927-), Walter Kohn (1924-), Noémie Koller (1933-), Alfred Leitner (1921-), Peter Lindenfeld (1921-), Ernest M. Loebl (1923-), Georg M. Low (1926-1984), William Zeev Low (1922-), Harry Lustig (1925-), Hans Michael Mark (1929-), Peter Arnold Moldauer (1923-1985), Peter Wolfgang Neurath (1923-), Paul Michael Pfalzner (1923-), Dan Porat (1922-), Kurt Reibel (1926-), Frederic Reif (1927-), Wolfgang Rindler (1924-), Fritz Rohrlich (1921-), Norbert Rosenzweig (1925-), Baruch Rosner (1931-), John Ross (1926-), Edwin E. Salpeter (1924-), Erwin Robert Schmerling (1928-), Siegfried Fred Singer (1924-), Joseph Sucher (1930-), Robert Stratton (1928-), Gerald Erich Tauber (1922-), George Maxime Temmer (1922-1997), Kurt Toman (1921-), Arye Leo Weinreb (1921-), Werner Paul Wolf (1930-), Paul Zilsel (1923-2006).

These two lists of mathematicians and physicists impressively demonstrate the loss of intellectual potential Austria suffered in the aftermath of the year 1938.

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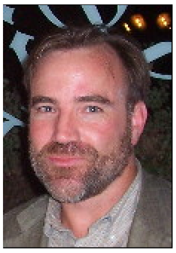
Hermann Minkowski and the Scandal of Spacetime

Scott Walter



When Hermann Minkowski's first paper on relativity theory[1] appeared in April 1908, it was met with an immediate, largely critical response. His paper purported to extend the reach of the principle of relativity to the electrodynamics of moving media, but one of the founders of relativity theory, the young Albert Einstein, along with his co-author Jakob Laub, found Minkowski's theory to be wanting on physical and formal grounds alike. The lesson in physics delivered by his two former students did not merit a rejoinder, but their summary dismissal of his sophisticated four-dimensional formalism for physics appears to have given Minkowski pause.

The necessity of such a formalism for physics was stressed by Minkowski in a lecture entitled "Raum und Zeit," delivered at the annual meeting of the German Association for Natural Scientists and Physicians in Cologne, on 21 September 1908. Minkowski argued famously in Cologne that certain circumstances required scientists to discard the view of physical space as a Euclidean three-space, in favour of a four-dimensional world with a geometry characterized by the invariance of a certain quadratic form. Delivered in grand style, Minkowski's lecture appears to have struck a chord, generating a reaction that was phenomenal in terms of sheer publication numbers and disciplinary breadth.

Historians have naturally sought to explain this burst of interest in relativity theory. According to one current of thought, Minkowski added nothing of substance to Einstein's theory of relativity, but expressed relativist ideas more forcefully and memorably than Einstein.[2] . It has also been suggested that Minkowski supplied a mathematical imprimatur to relativity theory, thereby reassuring those who had doubted its internal coherence.[3] A third explanation claims that Minkowski's explicit appeal to "pre-established harmony" between pure mathematics and physics resonated with Wilhelmine scientists and philosophers, just when such Leibnizian ideas were undergoing a revival in philosophical circles.[4]

The lack of historical consensus on the reasons for the sharp post-1908 upswing in the fortunes of special relativity reflects, to a certain extent, the varied, conflicting accounts provided by the historical actors themselves.[5] A focus on the disciplinary reception of Minkowski's theory, however, shows a common concern over the adequacy of Euclidean geometry for the foundations of physics. Much of the excitement generated by Minkowski's Cologne lecture among scientists and philosophers arose from an idea that was scandalous when announced on September 21, 1908, but which was soon assimilated, first by theorists and then by the scientific community at large: Euclidean geometry was no longer adequate to the task of describing physical reality, and had to be replaced by the geometry of a four-dimensional space Minkowski named the "world" (*Welt*).

The scandalous nature of spacetime is brought into focus first by examining the situation of physical geometry at the time of Minkowski's first lecture on relativity in 1907, and then by following the evolution of his definition of the "world" in his writings on relativity. For the sake of concision, these preliminary observations are omitted here, in favour of a few examples of the reaction sustained by Minkowski's radical world view on the part of a few of his most capable readers in physics.[6]

The published version of “Raum und Zeit” sparked an explosion of publications in relativity theory, with the number of papers on relativity tripling between 1908 (32 papers) and 1910 (95 papers).[7] This sudden upswing in the interest is clearly a complex historical phenomenon requiring careful study, for the theory of relativity carried different meaning for different observers.[8] While Minkowski’s spacetime theory is conceptually and formally distinct from Einstein’s special relativity theory and the Lorentz-Poincaré relativity theory, the history of its reception is similarly polysemous. For example, a disciplinary analysis of the reception of Minkowski’s Cologne lecture reveals a overwhelmingly positive response on the part of mathematicians, and a decidedly mixed reaction on the part of physicists.[9] A close examination of the physicists’ response to Minkowski’s lecture shows that what they objected to above all in Minkowski’s view was the idea that Euclidean space was no longer adequate for understanding physical phenomena. The range of response among physicists to Minkowski’s attack on Euclidean space, we will see here, went fairly smoothly from cognitive shock and outright denial, on one end, to unreserved enthusiasm and collaborative extension on the other end.

Among the physicists shocked by Minkowski’s spacetime theory was Danzig’s Max Wien, an experimental physicist. In a letter to the Munich theoretical physicist Arnold Sommerfeld, Max Wien described his experience reading Minkowski’s Cologne lecture as provoking “a slight brain-shiver, now space and time appear conglomerated together in a gray, miserable chaos”.[10] His cousin Willy Wien, director of the Würzburg Physical Institute and co-editor of *Annalen der Physik*, was shocked, too, but it wasn’t the loss of Euclidean space that bothered him so much as Minkowski’s claim that circumstances forced spacetime geometry on physicists. The entire Minkowskian system, Wien said in a 1909 lecture, “evokes the conviction that the facts would have to join it as a fully internal consequence.” Wien would have none of this, as he felt that the touchstone of physics was experiment, not abstract mathematical deduction. “For the physicist,” Wien concluded his lecture, “Nature alone must make the final decision”.[11]

On the opposite end of the spectrum of response to Minkowski’s attack on Euclidean space, Max Born and Arnold Sommerfeld saw in Minkowski spacetime the future of theoretical physics. Both men had close ties to Minkowski, and upon the latter’s untimely death on 12 January 1909, each took up the cause of promoting a spacetime approach to physics. In a crucial contribution to Minkowski’s program, Sommerfeld transformed Minkowski’s unorthodox matrix calculus into a four-dimensional vector algebra and analysis,[12] based on the notational conventions he had introduced in 1904 as editor of the physics volumes of Felix Klein’s monumental *Encyclopedia of Mathematical Sciences Including Applications*. Sommerfeld’s streamlined spacetime formalism was taken over and extended by Max Laue, then working in Sommerfeld’s institute in Munich, for use in the first German textbook on relativity theory.[13] Laue’s textbook was hugely successful, and effectively established the Sommerfeld-Laue formalism as the standard for research in relativity physics.

Sommerfeld insisted upon the simplification afforded to calculation by the adoption of a spacetime approach, and left aside Minkowski’s philosophical interpretation of spacetime, with one exception. In the introduction to his 1910 reformulation of Minkowski’s matrix calculus, Sommerfeld echoed Minkowski’s belief that absolute space should vanish from physics, to be replaced by the “absolute world” of Minkowski spacetime.[14] This exchange of absolutes, Euclidean 3-space for Minkowski spacetime, was clearly designed to calm physicists shocked by Minkowski’s high-handed dismissal of Euclidean space as the frame adequate for understanding physical phenomena.

Between the extremes represented by the responses of Max Wien and Arnold Sommerfeld emerged the mainstream response to Minkowski’s interpretation. The latter is well represented by remarks expressed by Max Laue in his influential relativity textbook, mentioned above. Laue considered Minkowski spacetime as an “almost indispensable resource” for precise mathematical operations in relativity.[15] He expressed reservations, however, about Minkowski’s philosophy, in that the geometrical interpretation (or “analogy”) of the Lorentz transformation called upon a space of four dimensions. One could avail oneself of the new four-dimensional formalism, Laue assured his readers, even if one was not blessed with Minkowski’s spacetime-intuition, and without committing oneself to the existence of Minkowski’s four-dimensional world.

By disengaging Minkowski’s spacetime ontology from the Sommerfeld-Laue spacetime calculus, Laue cleared the way for the acceptance by physicists of his tensor calculus, and of spacetime geometry in general. A detailed study of the reception of Minkowski’s ideas on relativity has yet to be realized, but anecdotal evidence points to a change in attitudes toward Minkowski’s spacetime view in the 1950s. For example, in the sixth edition of Laue’s textbook, celebrating the fiftieth anniversary of relativity theory, and marking the end of Einstein’s life, its author still felt the need to warn physicists away from Minkowski’s scandalous claim in Cologne that space and time form a unity. As if in defiance of Laue, this particular view of Minkowski’s (“Von Stund’ an . . . ”) was soon cited (in the original German) on the title page of a rival textbook on special relativity.[16] In Laue’s opinion, however, Minkowski’s most famous phrase remained an “exaggeration”.[17]

Minkowski’s carefully-crafted Cologne lecture shocked scientists’ sensibilities, in sharp contrast to all previous writings on relativity, including his own. The author of “Raum and Zeit” famously characterized his intuitions (*Anschauungen*) of space and time as grounded in experimental physics, and radical in nature. Predictably, his lecture created a scandal for physicists in its day, but unlike most scandals, it did not fade away with the next provocation. Instead, Minkowski focused attention on how mathematics structures our understanding of the physical universe, in a way no other writer had done since Riemann, or has managed to do since, paving the way for acceptance of even more visually-unintuitive theories to come in the early twentieth century, including general relativity and quantum mechanics. Minkowski’s provocation of physicists in Cologne, his rejection of existing referents of time, space, and geometry, and his appeal to subjective intuition to describe external reality may certainly be detached from Minkowski geometry, as Laue and others wished, but not if we want to understand the explosion of interest in relativity theory in 1909.

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Hyperbolic Dynamical Systems at the ESI in 2008

Domokos Szász

Depending on their fundamental behaviours, dynamical systems can be classified as 'stable' or 'unstable'. Basic examples of stable systems are the mathematical pendulum or the solar system with periodic or quasi-periodic motions (cf. KAM-theory). Unstable behaviour is strongly connected to non-vanishing of Lyapunov exponents, to sensitivity to initial conditions, and to stochastic or chaotic behaviour. Basic examples of unstable systems are particle systems (e. g. those of hard balls) giving rise to statistical mechanics, or hydrodynamic equations giving rise to turbulence.

Technically speaking, for the map which describes the transition of the system from time zero to time one, hyperbolicity means that the spectrum of the linearized map has no eigenvalue on the unit circle. Hyperbolicity is most easily detected if this condition also holds for all iterates of the map, i.e., for the transitions of the system from time zero to time n for every $n \geq 1$.

In 1996, Philippe Choquard, Carlangelo Liverani, Harald Posch and myself organized the semester *Hyperbolic Systems with Singularities* at the ESI. Though billiard systems, hard ball systems, etc. were among our top interests, the name of the semester was different and chosen with the following idea back in our minds. We intended to go beyond billiard-like systems, we wanted to understand them primarily as examples of hyperbolic systems with singularities. The hope was that this wider framework would help to better understand billiard-like systems. The semester was most successful, with many exciting results in the seminars, discussions and in subsequent preprints.

Let me point out here only one result, Lai Sang Young's tower construction, for two reasons. Firstly, the title of her paper — probably accidentally — was *Statistical Properties of Hyperbolic Systems with Singularities* thus containing the same 'terminus technicus' as the name of the semester. (Her paper was ESI preprint No. 445 and appeared in 1998 in Annals of Mathematics). The second reason is that the — in my view — most sensational result of that paper, the exponential decay of correlations for planar finite horizon Sinai billiards, was proved exactly by using the advantage of considering billiards from this broader perspective, as hyperbolic systems with singularities. In this way, part of her tools and ideas were borrowed from methods worked out for the Hénon map, for unimodal maps of the interval, etc. Since then billiard methods are getting better and better embedded into the theory of hyperbolic dynamical systems. It is worth pointing out that before Young's work, for the same class of billiards, stretched exponential decay had already been known (Bunimovich-Sinai, 1981, Bunimovich-Chernov-Sinai, 1991) and this weaker property was still sufficient to establish the CLT (central limit theorem), for instance. However, for the derivation of finer stochastic properties (e. g. the local version of CLT, Szász-Varjú, 2004) this weaker property was not sufficient and for obtaining them it seems to have been necessary to go down to the tower construction itself.

This time the name of the programme is not very original: *Hyperbolic Systems with Singularities*, organized by Harald Posch, Lai Sang Young and myself. The fact that physicists have been among the organizers (Harald Posch both times and Philippe Choquard in 1996) reflects the fact that the topic is central to both mathematics and physics. Furthermore the composition of a mixed audience has the absolute advantage that both mathematical and physical theories can gain a lot from the interaction of the communities involved.

The duration of the programme is rather short: six weeks altogether. By using the abbreviation $Wn, n = 1, 2, ..., 6$ for the 6 weeks of the programme, the structure of the semester is the following. W2 - W5 are the central parts of the program. During W2 and W5 there will be two workshops. W2 (June 2-6) will be focused on nonequilibrium systems and was organized essentially by Harald Posch with the assistance of the co-organizers. The talks and the discussions will concentrate on four major topics:

- Hamiltonian systems: low-dimensional particle systems
- Hamiltonian systems: anharmonic chains and coupled maps
- Stochastic systems
- Open quantum systems

In the last decade these problems have been in the focus of attention equally of mathematicians and physicists. To mention just one fundamental problem, to which the