UNIVERSITÄT
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Faculty of Physics
and Earth Sciences

Felix Bloch (1905-1983) in Leipzig

Universitätsarchiv Leipzig

Felix Bloch studied physics in Zurich with H. Weyl, E. Schrödinger and P. Debye and also attended lectures on mathematics, chemistry and crystallography. After Zurich Felix Bloch followed his teacher Debye who had been appointed professor at Universität Leipzig in 1927. Bloch remembers: „Debye told me that Heisenberg was coming to Leipzig, and said, ‚If I were you, I would work with Heisenberg.'" [1]. Peter Debye directed the Physikalische Institut and Werner Heisenberg, who had also been recently appointed, directed the Institut für Theoretische Physik. Bloch described his first day in Leipzig October 1927 as follows: „As soon as I had completed the simple formality of registering as a student of the University in the center of the city I went to the Physics Institute, which was located near the outskirts. It was an old building opposite a cemetery on one side and adjoining the garden of a mental institution on the other, but occupied by people who were far from being either dead or crazy." [2].

His time in Leipzig as well as the dawn of quantum mechanics were the major influences on Bloch's scientific life. His first publication, rooted in preliminary work from Zurich, deals with the coupling of atomic oscillators to the radiation field. [3]. He was Heisenberg's first PhD student and in his 1928 thesis „Über die Quantenmechanik der Elektronen in Kristallgittern" (On the quantum mechanics of electrons in crystal lattices) [4] he laid the groundwork for band structure theory in solids [5]. This work updated the 30 year old theory of electrons in metals of P. Drude from Leipzig [6] to the level of quantum mechanics. The electron waves from his thesis are now termed *Bloch states*. Subsequent work [7] in Leipzig by R. Peierls [8, 9], A. Wilson [10] and W. Heisenberg [11] lead to the understanding of metals, insulators, band gaps, semiconductors and holes (defect electrons). Bloch remembers: „The greatest effort in my thesis was spent on calculating the resistivity. Since a perfectly periodic lattice had been understood to present no impediment to the current, it was clear that a finite resistance could arise only from irregularities and that its temperature-dependence would have to be explained by the thermal motion of ions." [12]. Bloch hints here at what is now called *Bloch oscillation*, the periodic and coherent motion of electrons in real and $\boldsymbol{k}$-space and establishes the microscopic theory of carrier scattering.

Afterwards Bloch worked with Pauli in Zürich and in the Netherlands on ferromagnetism. In Utrecht he formulated the first theory of spin waves [13]. 1930 Bloch returned to Leipzig as Heisenberg's assistent for theoretical physics. Part of his habilitation thesis „Zur Theorie des Austauschproblems und der Remanenzerscheinung der Ferromagnetika" (Theory of the exchange problem and remanence effects in ferromagnetics) dealt with *Bloch walls*, the transition region between domains with different magnetization. On January 30 1932, after delivering a final lecture on „Probleme des Atomkernbaus" (Problems of the nuclear structure) he was awarded the *venia legendi* (teaching permission). Two publications on ferromagnetism stem from this period [14, 15]. Despite the rise of anti-Semitism and related problems Bloch says about this time: „Nevertheless, I was happy at that time. I had a very close relationship to Heisenberg, and I was happy to do my first teaching at the University of Leipzig" [16]. We note Arnold Siegert whos 1934 thesis „Der Einfluss der Bindung auf den Wirkungsquerschnitt für Stöße sehr schneller Elektronen" (The influence of bonds on the cross-section of the impact of very fast electrons) [17, 18] was supervised by Bloch.

Bloch, due to his Jewish faith, was deemed „Nichtarier" by the government of that time and the continuation of his position as assistant became impossible. As such, the loss of his teaching permission in Germany was foreseeable. At that point he emigrated from Germany to Kopenhagen and worked with N. Bohr, later in Zurich and in Rom with E. Fermi. In March 1934 Bloch moved to Stanford, CA where he became professor in 1936.

Bloch's research lead to many more notable and defining results: the *Bethe-Bloch formula* for the stopping of particles in matter, the *Bloch equations* for the dynamics of two-level systems, and the *Bloch-Siegert shift* in a strongly driven two-level system. This shift was developed together with A. Siegert who had also arrived at Stanford [16, 18]. This period also witnessed the development of the *Bloch sphere* for the description of the state of a two-level system, nowadays also termed qubit. Bloch's probably most important scientific discoveries concern nuclear magnetic resonance („nuclear induction") [19, 20] or NMR. This method is the basis for the well-known magnetic resonance imaging methods in medicine. For this Felix Bloch and Edward M. Purcell were jointly awarded the 1952 Nobel prize in physics [21].

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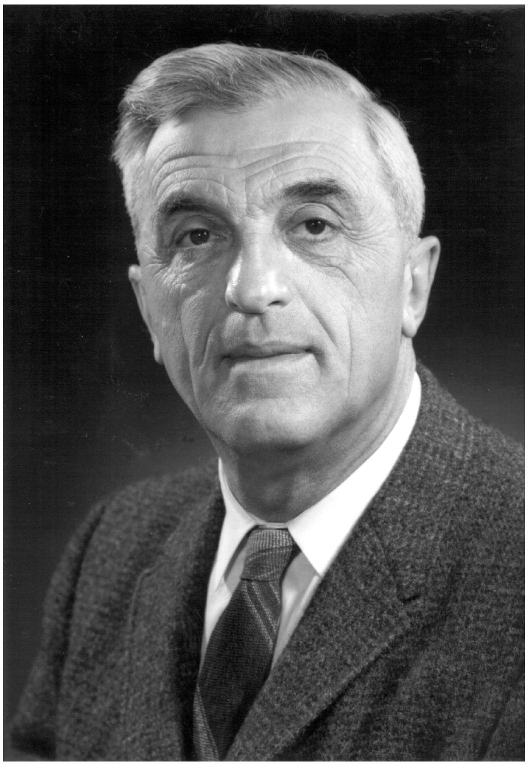
M. Grundmann, February 2017

Universitätsarchiv Leipzig   (left: W. Heisenberg)



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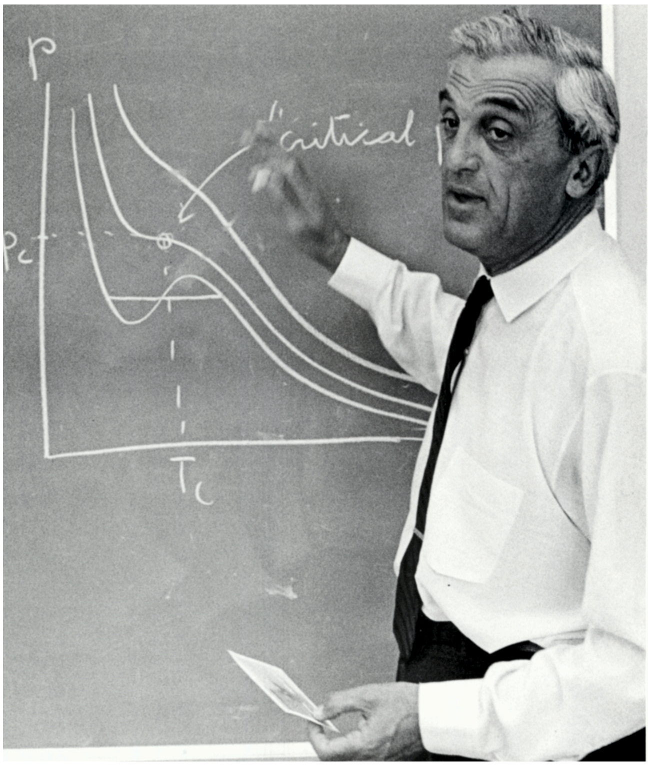

Stanford University [22]

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[2] F. Bloch, *Heisenberg and the early days of quantum mechanics*, Phys. Today ***29***, 23-27 (1976).

[3] F. Bloch, *Zur Strahlungsdämpfung in der Quantenmechanik*, Physikal. Zeitschrift ***29***, 58-66 (1928).

[4] F. Bloch, *Über die Quantenmechanik der Elektronen in Kristallgittern*, Z. Phys. ***52***, 555-560 (1928).

[5] R. Hofstadter in: „Felix Bloch – A Biographical Memoir" (National Academy of Sciences, Washington D.C., 1994). *„The importance of this paper can hardly be overstated for it provided the basis for the band theory of condensed matter.".*

[6] P. Drude, *Zur Ionentheorie der Metalle*, Z. Phys. ***1***, 161-165 (1900).

[7] In [1] Bloch remembers: *„The fact that there were bands, several bands, and there were gaps was to me totally trivial. I mean, that, I said, so what? I understand that. But what I missed was that this makes a difference, the difference between an insulator and a metal — incredibly stupid. And also, and then, how semiconductors, all that sort of thing, that by excitation, you can create electrons. I just didn't think of it. But as I say, the existence of bands and the gaps between the bands, that was, I wasn't moved by that, not at all.".*

[8] R. Peierls in: Interview of Rudolf Peierls by Lillian Hoddeson and Gordon Baym on 1977 May 20, Niels Bohr Library & Archives, American Institute of Physics, College Park, MD, USA. *„But, then, Heisenberg suggested that I should look at the problem of the wrong sign of the Hall Effect, which sometimes is positive and we understand why today, but at the time — Well, it was clear that from the Bloch's results you could sometimes get an acceleration, in the opposite sense to the wave vector. You had to convince yourself that this was real, and you had to convince yourself that that did not mean that there would be a negative conductivity, and so on."*.

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[21] F. Bloch, *The principle of nuclear induction*, Nobel lecture, December 11 1952.

[22] Stanford University, courtesy AIP Emilio Segrè Visual Archives, with permission.