# Ernst Ising 1900-1998

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The Ising model is one of the standard models in statistical physics. Since 1969 more than 16,000 publications appeared using this model. The model was introduced by Ernst Ising in his doctor dissertation. His life covers most of the past century and was interwoven with striking events in science and politics. It was characterized as a "walk on a tightrope". In this paper some biographical notes and milestones of the early development of the Ising model are given.

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Ernst Ising was born on May 10, 1900 in Köln (Cologne, Germany), the son of the merchant Gustav Ising and his wife Thekla, nee Löwe. Two years later the family moved to Bochum (Westphalia), where Ernst spent his childhood. In easter 1907 he entered the school there and 1918 he completed the Gymnasium. Shortly after that he had to do a brief military training, but fortunately World War I was finished before he could be sent for mission. So in easter 1919 Ising started studying mathematics and physics at the University of Göttingen and continued his studies in Bonn and Hamburg.

In Hamburg Wilhelm Lenz (1888 - 1957) suggested to Ising to turn to theoretical physics. Under his guidance he began in 1922 studies on a model of ferromagnetism, which were completed by a dissertation [1]. It was accepted by the faculty of mathematics and natural sciences of the Hamburg University in July 1924 (Figs. 1 and 2). During his stay in Hamburg Ising became acquainted with his contemporary Wolfgang Pauli (1900 - 1958) who has just accepted a job in the same institute. At the same time Otto Stern (1888 - 1969) was working there who has done together with Walther Gerlach (1889 - 1979) the famous experiments with atomic beam in an inhomogeneous magnetic field.

After receiving his doctor's degree Ising went to Berlin and worked from 1925 to 1926 in the patent office of the Allgemeine Elektrizitätsgesellschaft (AEG). Not being satisfied with this job he decided to become a teacher. For a year he worked at the famous boarding school in Salem in South-Baden (near the lake Constance). In 1928 he returned to Berlin University to study philosophy and pedagogy. In 1930 he passed the state examinations before the school board in higher education. In the same year he married Johanna Ehmer, a doctor of economy whom he met in Berlin. The couple went to Strausberg near Berlin, where Ernst Ising got a teaching position at a high school as "Studienassessor" (in Germany a holder of a higher civil service post, who has passed the necessary examinations but has not yet completed his probationary period). Later he was tranferred to Crossen on the river Oder (now: Krosno Odrzańskie in Poland) to fill in for an ill colleague.

Hitler came to power in January 1933 and almost immediately Jewish citizens were being dismissed from their jobs as civil servants. Ernst Ising lost his position. For one year he was unemployed, except for a short stay in Paris at a school for emigrant children. In 1934 he found a new job as a teacher at a boarding school for Jewish children in Caputh near Potsdam. This school was founded by the progressive social educationalist Gertrud Feiertag (1890 - 1943?), next door was Albert Einstein's summer house. When Einstein went to U.S.A. in 1932, this house was rented from him for additional classes (cf. [2]). The number of students increased in the following years, because Jewish children had been expelled from public schools. In 1937 Ising became the headmaster of the school. As part of the "Kristallnacht" on November 10, 1938 he experienced the devastation of his school building by incited inhabitants and children of the village as part of that great pogrom against the Jewish population in Germany (Fig. 3).

In the early morning on January 27, 1939 Ernst Ising was taken by the Gestapo and interrogated for four hours. He was dismissed after he had promised to leave Germany. He and his wife traveled to Luxembourg with the plan to emigrate to the United States of America. But at that time the quota for immigration to the U.S.A. forced them to remain in Luxembourg. On Ising's fortieth birthday the German army occupied Luxembourg forcing the closing the U.S. consulates. Thus, the couple had to work at menial jobs, struggling to survive.

According a secret letter of Adolf Eichmann from January 1942 the deportation of Jews was prepared, "... except for Jewish spouses of German-Jewish married-couple." [3]. Because of this regulation Ising could stay with his family. But he and all other 36 Jewish husbands of non-Jewish wives left in Luxembourg were forced to work for the Germany army. From May 1943 until the liberation in autumn 1944, they were ordered to dismantle the Maginot Line railroad in Lorraine.

Two years after the end of the war Ising and his family left Europe on board the freighter "Lipscomb Lykes" and arrived in New York in April 1947. For one year he was a teacher at the State Teacher's College in Minot (N.D.). In 1948 he got a position as Professor of Physics at the Bradley University Peoria (IL), where he taught until his retirement in 1976. In 1953 he obtained the U.S.A. citizenship and the name Ernest.

After the World War II Wolfgang Pauli requested his coworker Valentin Telegdi to inquire for surviving physicist. Ising's address was found and Pauli wrote in February 1951 [4]: "Lieber Herr Ising, Haben Sie vielen Dank für Ihren Brief, ich bin sehr froh zu wissen, daß Sie die die Hitlerei lebend überstanden haben und eine Stelle haben... (Dear Mister Ising, many thanks for your letter, I am very happy to know that you have overcome the 'Hitlerei' alive and that you have a job...)" (Fig. 4).

Ising's great passion in the postwar years was for teaching. His students remember his elaborate classroom experiments and his fine humor. He said that a class had not gone well unless the students laughed at least once during the hour. He liked fine arts and poetry and could, e.g., recite from memory poems by Goethe and other German classics up to the old age. This seems to be also reflected in Ising's second scientific publication "Goethe as a Physicist" [5].

Ernst Ising enjoyed sporting activities, especially hiking and swimming. In 1980 he and his wife took part an ice show of Dorothey Hamill, an Olympic Gold Medal Winner. They skated a waltz together. He was also an avid photographer. Before and after his retirement he traveled a lot and visited all states of the U.S.A. and many countries all over the world.

Dr. Ernest Ising died May 11, 1998, at his home in Peoria, just one day after his 98th birthday.

The concept of a microscopic magnetic model consisting of elementary magnetic moments, which are only able to take two positions "up" and "down" are created by Wilhelm Lenz. First he has applied this model to explain paramagnetic properties of solids [6]. At the end this paper he developed the idea of interaction by the following sentences: "Nimmt man an, daß im ferromagnetischen Körper die potentielle Energie eines Atoms (Elementarmagnets) gegenüber seinen Nachbarn in der Nullage eine andere ist als in der $\pi$-Lage, so entsteht eine natürliche zum Kristallzustand gehörige Gerichtetheit der Atome und daher spontane Magnetisierung... Es ist zu hoffen, daß es gelingt, auf dem angedeuteten Weg die Eigenschaften der Ferromagnetika zu erklären. (Assuming that in a ferromagnetic solid the potential energy of an atom (elementary magnet) with respect to its neighbors is another one in the zero position than in the $\pi$ position, then a natural orientation of the atoms and thence spontaneous magnetization arise... It is to hope that it succeeds to explain the properties of ferromagnetics this suggested way.) " In his dissertation [1] Ising studied the special case of a linear chain of magnetic moments, which are coupled by interactions between nearest neighbors. He showed that spontaneous magnetization cannot be explained using this model in its one-dimensional version but erroneously he applied this result also to the three-dimensional case [7].

Ising became aware of the first and the only contemporary citation of his paper by Heisenberg [8], who introduced the quantum mechanical exchange interaction to describe ferromagnetism. Heisenberg wrote: "Andere Schwierigkeiten wurden noch ausführlich von Lenz [6] diskutiert, und es gelang Ising [7], zu zeigen, daß auch die Annahme richtender, hinreichend großer Kräfte zwischen je zwei Nachbaratomen einer Kette nicht genügt, um Ferromagnetismus zu erzeugen. (Other difficulties are discussed in detail by Lenz, and Ising succeeded in showing that also the assumption of aligning sufficiently great forces between each of two neighboring atoms of a chain is not sufficient to create ferromagnetism.)"

S.G. Brush gave the following impressive characterization [9]: "Thus Heisenberg used the supposed failure of the Lenz-Ising model to explain ferromagnetism as one justification for developing his own theory based on a more complicated interaction between spins. In this way the natural order of development of theories of ferromagnetism was inverted; the more sophisticated Heisenberg model was exploited first, and only later did theoreticians return to investigate the properties of the simpler Lenz-Ising model."

The name "Ising model" seems to have been coined in a publication in 1936 by R. Peierls "On Ising's Model of Ferromagnetism" [10]. He has considered boundary lines which separate "up" and "down" spin regions in a two-dimensional square Ising lattice. By estimation of an upper limit for the total length of closed boundaries he could show that, at sufficiently low temperatures, only a small fraction of all spins are enclosed by boundary lines. Consequently, the majority of spins must have the opposite sign leading to spontaneous magnetization of the system. N.G. van Kampen, M.E. Fisher, S. Sherman and others have found later, that in [10] summations over the lengths of boundaries were incorrectly extented to infinity for finite systems, cf. [9], [11]. Finally, Griffiths has remedied this defect in 1964 by a modification of Peierls' proof [11]. Peierls has pointed out in 1966 that his original argument is not influenced by the found error, because it only leads to an overestimation of the length of boundary lines and the rest remains valid [12].

The most striking success of the model is accompanied by the search for the phase transition between the ferromagnetic and the paramagnetic state, cf. [9]. The actual breakthrough came from the findings of various authors [13] - [15] which say that a matrix representation of the problem can be introduced in such a way that the partition function can be related to the largest eigenvalue of this matrix. Kramers and Wannier [13] have calculated the numerical value for the Curie temperature of the two-dimensional Ising model, whereas the exact and complete solution was first given by Onsager [16], cf. also [17].

Ising was completely shut off from scientific life and communication for a long time and so it was not until 1949 that he found out from the scientific literature that his paper had become widely known (Fig. 6).

Ising himself was overwhelmed whenever the reaction of the community to the Ising model was mentioned (Fig. 7), but in his modesty he everytime appreciated the contribution of his supervisor. In a letter to the author he wrote [18]: "Ich weise gern darauf hin, daß das Modell eigentlich Lenz-Ising-Modell heißen sollte. Mein Lehrer, Dr. Wilhem Lenz, hatte die Idee und schlug vor, daß ich als meine Doktorarbeit eine mathematische Ausarbeit mache, ... (I like to point out that the model really should be called Lenz-Ising model. My supervisor, Dr. Wilhelm Lenz, had the idea and proposed that I make a mathematical workout as my dissertation, ...)".

I am deeply indebted to Jane Ising for letting me have and use her unpublished memoirs [19]. I thank Thomas Ising for critical reading the manuscipt.

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Caption of figures:

Fig. 1. Ernst Ising, approx. 1925.

Fig. 2. Front page of Ising's dissertation, 1924.

Fig. 3. Letter from Ising to the school administration in Potsdam, Nov. 15, 1938. ("Since November 11, the Jewish boarding school in Caputh is closed. A resumption of classes is out of the question in the foreseeable future. I am afraid that all papers and documents are lost. My address is at present Berlin-Wilmersdorf, Paretzerstr. 10 IV c/o Berger. Ising.").

Fig. 4. Beginning of a letter from Wolfgang Pauli to Ernst Ising, Feb. 23, 1951.

Fig. 5. Ernest and Jane Ising in Peoria (IL), March 1996.

Fig. 6. Citation remark on Ising model in Ising's notebook.

Fig. 7. Number of publications on Ising model (above) and relative number (below) according the database INSPEC which contains literature in physics, electrical engineering, electronics and computing. The database contains 6.5 million records, 15.994 Ising citations are among them.