Lise Meitner. 1878-1968
Author(s): O. R. Frisch
Source: *Biographical Memoirs of Fellows of the Royal Society*, Vol. 16 (Nov., 1970), pp. 405-420
Published by: Royal Society
Stable URL: https://www.jstor.org/stable/769597
Accessed: 18-11-2019 16:15 UTC

LISE MEITNER

1878-1968

Elected For. Mem. R.S. 1955

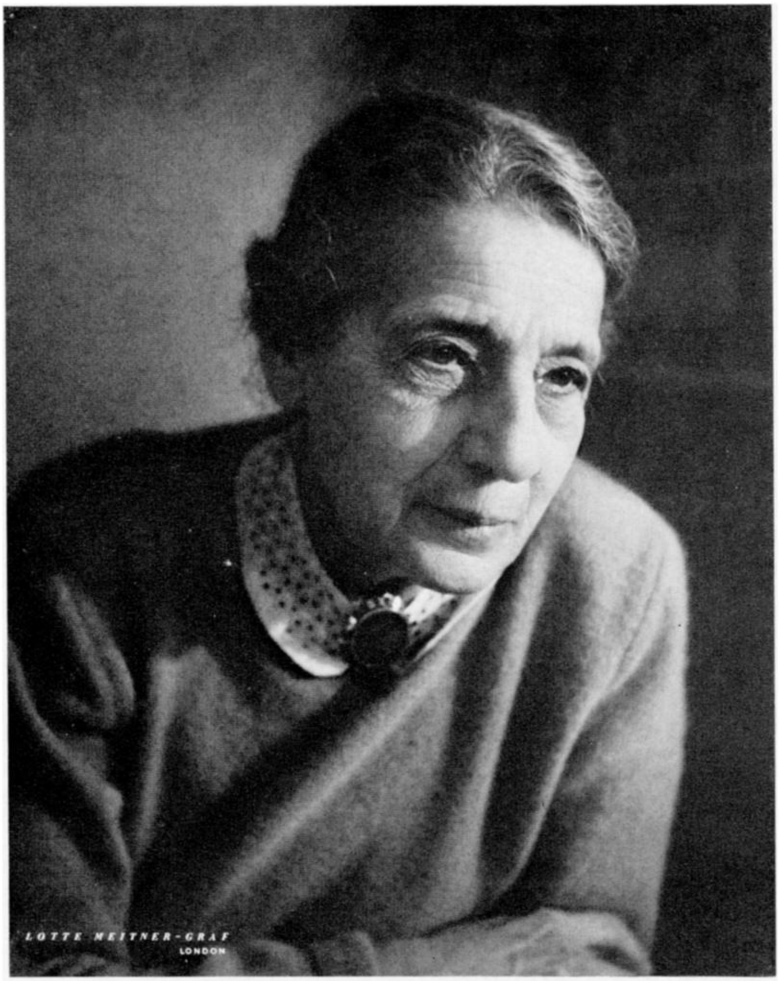
Lise Meitner's name has become widely known for her part in the discovery of nuclear fission, which made atomic power possible, as well as atomic weapons. But among physicists she had been known for many years as one of the early pioneers in the study of radioactivity. Einstein nicknamed her 'the German Madame Curie'; but though most of her work was done in Berlin she came from Austria and retained her nationality through her life, even after she became a Swedish citizen about eight years before her death.

She was born on 7 November 1878 in Vienna where she spent the first third of her life, a town to which she always remained very attached. Another third she worked in Germany. When Austria was occupied by the Nazis she found refuge in Sweden where she stayed for over 20 years. It was only at the age of 81 that she gave up scientific research and retired to England to live out the rest of her days in Cambridge, close to her eldest nephew (the author of this memoir).

Her father was Dr Philipp Meitner, a respected lawyer and keen chess player. She was the third among eight children; thus she was used both to being ruled by her two older sisters and ruling over the younger children. Although her parents came from Jewish stock, her father was a freethinker, and the Jewish religion played no role in her education. Indeed, all the children were baptized, and Lise Meitner grew up as a protestant; in later years her views were very tolerant though she would not accept complete atheism.

Lise Meitner became a physicist because of a burning desire to understand the working of nature, a desire that appears to go back to her childhood. But she had first to pass the state examination in French so that she might support herself as a teacher if the need arose; only then did she get permission to sit for the 'Matura', the examination that qualified her to enter the University of Vienna in 1901. For two years she worked very hard to prepare herself, coached by Dr Arthur Szarvasy, later professor of physics in Brno (Slovakia). Her sisters used to tease her, predicting she would fail because she had just walked across the room without studying! But she was one of the four girls that passed, out of fourteen.

From her university days she remembered occasional rudeness on the part of the students (a female student was regarded as a freak) but also much



Lise Meitner

encouragement from her teachers. In particular she often spoke of the contagiously enthusiastic lectures of Ludwig Boltzmann; it was probably he who gave her the vision of physics as a battle for ultimate truth, a vision she never lost. When she became Doctor Philosophiae in 1905 she was the second woman in Vienna to obtain a doctorate in physics. Her dissertation on heat conduction in inhomogeneous materials (measurements on mercury ointments, to test a formula by Maxwell) was based on work done under the supervision of Franz Exner and Hans Benndorf.

For another year or so she remained in Vienna; when she succeeded in clearing up a point concerning optical reflexion which had puzzled Lord Rayleigh she was encouraged to think of a career in theoretical physics and to ask her father's permission and financial support for going to Berlin—for a year or two as she thought—to study under Planck. She had met Planck briefly when after Boltzmann's death (in response to an invitation to become his successor) he had visited Vienna.

But before going to Berlin she had made her first contact with the new subject of radioactivity, to which she was introduced by Stefan Meyer and which was to become the topic of her life's work. In 1905 it was not yet known for sure whether α rays were deflected in passing through matter, and Lise Meitner designed and performed one of the first experiments which showed that some deflexion did indeed occur. But at that time she had no intention of specializing in that field.

On arriving in Berlin in 1907 she arranged to attend the lectures of Planck, but had some difficulty in finding a place to do experimental work. While she hesitated whether to accept an offer by Heinrich Rubens to work in his own laboratory—with her shyness, she felt, she would never dare ask that great man any questions—she met the young chemist Otto Hahn who said he was looking for a physicist to help him with his work on radioactivity. Here was a frank and informal man of her own age from whom—she felt—she could learn a great deal. There was the difficulty that Hahn was to work at the Chemical Institute under Emil Fischer who did not allow women in his laboratory. But they equipped an old carpenter's workshop for doing radiation measurements, and in this 'Holzwerkstatt' Lise Meitner was allowed to work. Two years later, when women's education became regularized, Emil Fischer dropped the ban and supported her in a fatherly manner.

In 1907 the subject of radioactivity was still very young. The nature of α, β and γ rays was known, and the spontaneous transformation of radioactive elements had been put forward by Rutherford and Soddy. But the discovery of the atomic nucleus (Rutherford 1911) was still to come, and it was the concept of isotopes (Soddy 1913) that finally brought order into the chaos of radioactive substances. During those years before the First World War, Hahn and Meitner published a large number of papers most of which are no longer of interest. But some of them should be mentioned, and certain trends were beginning to take shape.

To Hahn, the chemist, the discovery of new elements and the study of their chemical properties was the most exciting part of the work; Lise Meitner was more interested in disentangling their radiations. With α rays, their well-defined range made it easy to measure their energy quite accurately. For β rays no such simple method existed. In passing through matter they are attenuated in a much more gradual way, often following approximately an exponential absorption law, as do γ rays.

In a new field it is often good strategy to make simple assumptions even when there is no clear support for them. Hahn and Meitner adopted the assumption (Heinrich Willy Schmidt 1906) that β rays of defined energy followed an exponential absorption law, and that each pure radioactive substance emitted electrons with defined energy. Thus a deviation from exponential absorption sometimes misled them into thinking that a preparation was a mixture when it was not; but on the whole those assumptions, wrong though they were, served them surprisingly well.

All the same it soon became clear that a better method for analysing β rays was needed. Study of their magnetic deflexion was a possible way, and collaboration with Otto von Baeyer at the physics department of the university gave access to a suitable magnet. This was a fertile collaboration, but the resolution of the method was not sufficient to shake seriously the belief in the exponential absorption of monoenergetic β rays. However, the rule that each element sends out only one group of electrons was found to have many exceptions and it became clear that β rays were more complex than had been thought.

In 1914 the World War caused the work to be interrupted; Hahn was called up and Lise Meitner volunteered as an X-ray nurse with the Austrian army. It was a harrowing time for her, working up to twenty hours a day with inadequate equipment and coping with large numbers of Polish soldiers with every kind of injury, without knowing their language. But there was periodic leave when Lise Meitner went back to Berlin to carry out a few measurements each time, and Hahn sometimes succeeded in synchronizing his leave with hers. In the study of radioactive substances, measurements at fairly long intervals may be needed to let activities build up or unwanted ones decay. The search for the unknown precursor of actinium could be pursued in that way and was successful; by the end of the war the discovery of protactinium (not protoactinium; the t had been inserted to avoid just such a clash of vowels in proactinium, the name first considered) was ready to be published.

At that time they were no longer working in the carpentry shop. The ban that kept Lise Meitner out of the chemical laboratories had been lifted in 1909 when women came to be admitted to academic studies in Germany. In 1912 the Kaiser-Wilhelm Institut für Chemie was opened on a (then!) rural site in Berlin-Dahlem; there Lise Meitner worked for 25 years, first as a 'guest' and from 1918 as head of a growing physics department. This was the first of a number of scientific institutes within the framework of the Kaiser-Wilhelm-Gesellschaft, financed at first by German industry, later with increasing support from the State. The name was kept even after Germany became a republic in 1919, but was changed to Max-Planck-Gesellschaft after the Second World War.

Her connexions with the University of Berlin were slight. She was Assistant to Max Planck from 1912 to 1915, and after the war she received the venia legendi (Dozentur) in 1922; the subject, cosmic physics, of her inaugural lecture was reported as 'cosmetic physics' in the press (more plausible with a female Dozent!). In 1926 she was made extraordinary (i.e. titular) professor, but never gave any courses of lectures. But she went regularly to the weekly colloquium where new papers were discussed before an impressive front bench of Nobel Prize winners, among them Max Planck, Albert Einstein, Walther Nernst, Gustav Hertz and Erwin Schroedinger.

After the defeat of Germany the political confusion and the revolution that overthrew the monarchy made work difficult for a while, and there was still some work to be done on the properties of protactinium. So it was only in 1922 that Lise Meitner once more began to publish results of her own work, aimed at clarifying the relations of β- and γ-rays. By then it had become clear that some radioactive substances emitted an electron from the nucleus, while others—the α-emitters—did not, so that what electrons they did emit had to come from the outer shell and had to be regarded as secondary. So presumably were some of the electrons emitted by the true electron emitters; but which of the electron lines—of which a great many had by then been identified—were the primary electrons that came from the nucleus? (Sir) Charles D. Ellis in Cambridge thought it was none of them; that the primary electrons formed that continuous spectrum which (Sir) James Chadwick had found as early as 1914. Lise Meitner was doubtful of that result; she said that Chadwick's method of counting electrons deflected by a fixed angle in a variable magnetic field had not enough resolution to distinguish a continuous spectrum from a number of separate lines. On the other hand the better resolution of her photographic measurements, further improved when in 1922 she published measurements done with Danysz's method of focusing the electrons by deflexion through 180°, tended to emphasize the narrow lines while the continuous spectrum looked very faint and was attributed to secondary effects.

But the fundamental reason of her scepticism was her conviction that the primary electrons, just like α-particles, must form a group of well-defined energy, in the spirit of the quantum theory whose application to nuclei was becoming established, in the middle 1920s, mainly by papers of George Gamow. Even when the existence of a continuous spectrum became more firmly established she still felt that this must be a secondary effect; that the primary electrons left the nucleus with a fixed energy, a varying part of which they then lost, in the form of a continuous spectrum of γ-radiation, on their way through the strong electric field around the nucleus, and perhaps by collisions with the atomic electrons.

So it was a great shock to her when C. D. Ellis and W. A. Wooster showed in 1927, with a micro-calorimeter, that the average energy each electron lost in their apparatus was not—as her views would demand—equal to or above the upper limit of the continuous spectrum, but equal to the mean energy calculated from that spectrum. She immediately set out, with Wilhelm Orthmann, to check that result by a somewhat improved method, and found very good agreement; their joint paper was sent to press late in 1929.

That growing evidence for the continuous energy distribution of the primary electrons emitted in β-decay became a topic 'best not talked about, like the new taxes' (Peter Debye). But it led Wolfgang Pauli to write his famous letter to Lise Meitner and Hans Geiger in which he proposed a new neutral particle, later to be called neutrino, which was to be emitted together with the electron and to share the available energy at random with it while being too elusive to be detected by the available means. It proved even more elusive than Pauli had thought: effects due to free neutrinos were not established until 1956. Today a great deal of effort is devoted to their study.

While in that respect Lise Meitner had been led astray by her firm belief in the simplicity of nature she was right in another respect: by accurately measuring the electron lines of actinium she showed (*Z. Phys.* **34**, 807, 1925) that they were knocked out from the electron shells, not of the decaying nucleus but of the nucleus formed; thus she showed that the γ-ray followed the radioactive transformation rather than (as Ellis had suggested) triggering it off. She also observed and correctly interpreted the radiationless transitions in which an electron from an outer shell jumps into a vacancy in an inner shell, its energy not being radiated away as a characteristic X-ray quantum but used in ejecting another electron. This phenomenon is usually named after Pierre Auger who described it independently and more clearly about two years later.

Lise Meitner was not very interested in instrumental development and never invented a method or instrument of her own; but she was quick in introducing any method developed elsewhere, if she could see a use for it. A rather original idea was to use Millikan's droplet method to study the ionization density of α-particles in air along their path, which was done by her student Gerhard Schmidt (*Z. Phys.* **72**, 275, 1931). She also introduced C. T. R. Wilson's cloud chamber, which had been hardly used since its invention in 1911, to Berlin and used it in many researches, together with her students and with her assistant Kurt Philipp, and introduced innovations such as its use at greatly reduced pressure, for the study of slow electrons. She was one of the first (in a paper with Philipp, dated 25 March 1933) to observe positrons formed from γ-rays.

In fact she had observed another manifestation of the production of electron-positron pairs even earlier, namely, its contribution to the attenuation of hard γ-rays in their passage through matter. In 1926 Hans Geiger and W. Mueller developed their wire counter, later to become known as the Geiger-Mueller counter, the most widely used instrument in nuclear physics; and Lise Meitner got a student to try it out. When the student complained about trouble from a γ-ray source next door she immediately saw that the great sensitivity of this new instrument would make it possible to measure the attenuation of well-collimated, narrow beams of γ-rays. Here was an opportunity to test a recently published formula by Oskar Klein and Y. Nishina relating to the Compton effect, the collisions of high-energy photons with the loosely bound electrons in matter.

With light elements, up to magnesium, the results agreed well with the Klein-Nishina formula, but with aluminium the attenuation was distinctly higher and kept rising with increasing atomic number. The seeming discontinuity between magnesium and aluminium hinted at some effect of nuclear structure, perhaps a resonance, which would presumably cause scattering of γ-rays with unchanged wavelength, in contrast to Compton scattering which increases the wavelength. Much effort was wasted by Lise Meitner and her students in searching for that unchanged scattered component, which was not there. The excess attenuation was not due to scattering at all but to the formation of electron-positron pairs, which was not discovered until later, in 1933.

The discovery of the neutron in 1932, the positron in 1933 and artificial radioactivity in 1934 caused a turmoil in nuclear physics, reflected in a number of short papers in which Lise Meitner with her collaborators tried to keep pace with those rapid developments in physics. The political developments in Germany did not help. Hitler had come to power early in 1933, and the ensuing anti-semitic laws caused many 'non-aryan' scientists to lose their university posts and to go abroad. The Kaiser-Wilhelm-Gesellschaft was less vulnerable, being partly controlled by industrialists; but the Nazis tried to enforce party loyalty by various forms of infiltration, and Hahn and Meitner had to be increasingly cautious to avoid an open conflict, and to be able to keep those of their people who were partly Jewish or who refused to join the Nazi party.

The situation became critical when Austria was occupied by German troops in March 1938. From then on, Lise Meitner was no longer a foreigner protected by her Austrian nationality, but subject to the racial laws of Nazi Germany. Her honesty did not allow her to conceal her Jewish descent (as some people did), and her dismissal could only be a question of time. Her position looked even more sinister when her friend and colleague, Max von Laue, said he had heard of an order, issued by Heinrich Himmler (head of the secret police), that no university teachers—whether Jewish or not—should in future be allowed to leave Germany. An attempt by the influential industrialist, Fritz Bosch, then President of the Kaiser-Wilhelm Gesellschaft, to obtain permission for her to leave the country was unsuccessful. There appeared to be a very real danger that she might lose her job and then be prevented from seeking a new position abroad. Peter Debye, a physicist of Dutch origin, was consulted and agreed to write to his colleague, Dirk Coster, at the University of Groningen. As a result Coster came to Berlin to fetch Lise Meitner, having arranged (with the help of his colleagues Adriaan

Fokker and W. J. de Haas) that the Dutch immigration officer should let her enter even though she had only her (now meaningless) Austrian passport and no visa. Lise Meitner had one and a half hours in which to pack her most necessary belongings—and in the laboratory no one but Hahn knew that she was leaving Germany for good.

Holland had a distinguished tradition in physics but did not at that time possess very good facilities for nuclear research, and after a short stay she moved on to Denmark where for some weeks she enjoyed the hospitality of her good friend Niels Bohr and his wife Margrethe. The facilities for nuclear research were good, and there were a number of young and active physicists at work, including the present writer. It was probably her wish not to compete with those younger people that led to her decision not to remain in Copenhagen. Instead she accepted the invitation of Manne Siegbahn, head of the newly-built Nobel Institute for Physics in Stockholm. Siegbahn had made his name in the field of X-ray spectroscopy, chiefly through his superb skill in devising instruments of high accuracy; he and his pupils had created a Swedish tradition of precision physics. His institute possessed a cyclotron under construction, the first to be built on the mainland of Europe (about the same time as the cyclotrons at Cambridge, Copenhagen and Liverpool). For making the best use of that new atom-splitting machine and for training students in the required ancillary techniques the presence of Lise Meitner was valuable.

For 22 years Lise Meitner remained in Sweden. Although on arrival she was about 60 she acquired a good command of the language; she built up a small research group and published a number of short papers, mostly describing the properties of some new radioactive species formed with the help of the cyclotron. But she felt isolated at the Nobel Institute as Sweden as a country was isolated during the war; she had few students and lacked the help and stimulus that Hahn had given her during her years in Berlin. Perhaps she also suffered under the impression that Siegbahn was more interested in his precision physics than in the comparatively crude measurements that were possible in the study of radioactive isotopes.

In 1946 she spent half a year in the U.S.A. as visiting professor at the Catholic University, Washington, D.C., and was nominated 'Woman of the Year' by the American Press. In 1947 she retired from the Nobel Institute and accepted an offer from the Swedish Atomic Energy Committee to set up a small laboratory for her at the Royal Institute for Technology. Later she moved to a Laboratory of the Royal Academy for Engineering Sciences where an experimental nuclear reactor was being built deep down in a hall blasted out of the solid granite on which Stockholm stands, and the director of that enterprise, Sigvard Eklund (later Director-General of the International Atomic Energy Agency in Vienna) became Lise Meitner's lifelong friend. Here she stayed for the rest of her time in Sweden, first directing the work of a research assistant, later mainly engaged in reading, attending colloquia and discussing problems with other physicists. Her mind was still active when in 1960 she retired to England in order to be nearer to her relatives of whom several lived in London and Cambridge.

It was shortly after her arrival in Sweden that she made her most widely known contribution to science: the interpretation of an observation by Hahn and Strassmann as 'nuclear fission' (the phrase coined in her joint paper (*Nature, Lond.* **143**, 239) with Frisch). She had been invited to spend her first Swedish Christmas with friends in Kungälv, a small town on the West coast of Sweden, and had invited Frisch to come over from Copenhagen to join her. At their first breakfast she was preoccupied with a letter from Hahn which contained the incomprehensible result that radioactive barium isotopes were formed from uranium under neutron bombardment. Here it may be well to go back a bit.

In 1934, after several years of pursuing separate lines of research, Hahn and Meitner had joined forces again to follow up a result by Enrico Fermi in Rome. Fermi had bombarded a great variety of elements with neutrons and had found that usually—and invariably with heavy elements—the neutron was absorbed to form a heavier isotope—usually β-radioactive—of the bombarded nucleus. In the case of uranium, several substances with different decay periods and different chemical properties were found, some of which were presumably transuranic elements, with an atomic number above 92.

In order to isolate such elements, Hahn and Meitner used a particular chemical technique (roughly speaking, precipitation of the irradiated and acidified uranium salt solution with hydrogen sulphide) which left in solution all elements between polonium ($Z = 84$) and uranium ($Z = 92$); in that way they felt sure that their precipitate contained only transuranic elements. Admittedly a German chemist, Ida Noddack, had said that in her opinion the formation of transuranic elements could not be regarded as proven until their identity with any element between hydrogen and uranium was excluded; but her paper, published in a journal little read by pure scientists, had been dismissed as mere pedantry by those who did read it, and had no influence on later events. Fermi had found that it was only in light nuclei that the impact of a neutron could cause the emission of a charged particle (a proton or helium nucleus) and thus lead to the formation of a nucleus with lower atomic number; just what one would expect from the theory of atomic nuclei.

It was thus with considerable surprise that Hahn and Meitner read a note by Irene Curie who reported from Paris (1937) that the irradiation of uranium with neutrons produced—among many others—a substance with penetrating β-rays and a half-life of $3\frac{1}{2}$ hours which behaved chemically rather like thorium. This would imply that a uranium nucleus on being hit by a neutron could emit an α-particle (a helium nucleus), which seemed very unlikely. No such α-particles were observed in a search by one of Lise Meitner's students, Gottfried von Droste. Yet the formation of the $3\frac{1}{2}$-hour substance was confirmed though Hahn thought it behaved more like actinium (three, not two, nuclear charge units below uranium!); moreover, Hahn and

Fritz Strassmann who had joined the team in 1935 found more products with those chemical properties, as well as three with the properties of radium, no less than four places below uranium.

Those results were so hard to reconcile with nuclear theory that Lise Meitner wrote a letter to Hahn expressing great doubt and asking for irrefutable evidence. As a consequence, Hahn and Strassmann decided to embark on a series of careful tests designed to prove without doubt that those last-mentioned products were chemically identical with radium. They could indeed be precipitated with barium, as radium can; but then they could not be separated from the barium! Hahn and Strassmann concluded, with great reluctance and in very cautious language, that those substances were indeed isotopes not of radium but of barium.

That was the news in the letter which Lise Meitner discussed with Frisch after their breakfast in Kungälv. It soon became clear that Niels Bohr's 'droplet model' of the nucleus was the clue to understanding how barium nuclei could be formed from uranium nuclei which were nearly twice as heavy; that the division ('fission') into two smaller nuclei was made possible by the mutual repulsion of its many protons which made a uranium nucleus behave like a droplet with its surface tension greatly reduced by its electric charge. Moreover, the estimated difference between the mass of a uranium nucleus (plus an extra neutron) and the slightly smaller joint mass of the two fragment nuclei meant (because of Einstein's mass-energy equivalence) the liberation of a large amount of energy; and the mutual repulsion of the two fragments would make them fly apart with just that amount of energy.

The joint paper was composed a few days later over the telephone since Lise Meitner and Frisch had returned to Stockholm and Copenhagen, respectively. Clearly the whole evidence for transuranic elements was now in doubt since it rested on the sulphide precipitation which did not exclude elements lighter than polonium. A few months later Lise Meitner joined Frisch in Copenhagen to show experimentally, in the first place that radioactive fission fragments could be collected on a receiver (a water surface) close to a uranium layer under neutron irradiation, and also that the decay curve of the sulphide precipitate from the material so obtained had the same shape as that from the precipitate obtained directly from irradiated uranium. It was concluded that no observable amounts of real transuranic elements (which would have stayed in the uranium rather than being projected on to the water surface) were produced. Today we know that transuranic elements (neptunium and plutonium) are indeed formed.

Actually one of the products of slow-neutron irradiation of uranium was unambiguously shown to be a uranium isotope of 24 minutes half-life (*Z. Phys.* **106**, 249); moreover, by measuring the resonance cross section Lise Meitner could show that it must be ^{239}U, formed by neutron capture from the abundant ^{238}U. Its observed β-decay was bound to lead to the formation of a transuranic element, but no radioactive daughter substance was observed. Later that daughter substance was found by Edwin Macmillan (1939) and named neptunium; its β-rays were too soft to have been recorded by the rather thick-walled counters used in Berlin and Copenhagen. Its daughter substance in turn was named plutonium; this long-lived α-emitter ^{239}Pu was the explosive in the first atomic bomb, tested at Alamogordo on 16 July 1945.

After the war an enormous amount of chemical research was published which showed clearly that the fission of a uranium nucleus could occur in many different ways and was predominantly unsymmetrical, the two fragments differing by about 30 per cent in mass. (Physical evidence for that had been published before the war.) Various explanations of that asymmetry were proposed. Lise Meitner pointed out (1950) that the observed asymmetry was such as to allow in each fragment a maximum of its nucleons to be arranged in closed shells. Actually that idea had been briefly mentioned (unknown to her) in the paper by Goeppert-Mayer, one of the papers in which (1948) the shell theory of nuclei had been first proposed. Apart from that short note she never worked on problems of nuclear fission again; she refused, when invited, to take part in developing the atomic bomb and hoped till the end that it would prove impossible, though all the time she feared she would be wrong in that hope.

Lise Meitner took great delight in music, as did all her brothers and sisters (one sister became a concert pianist). She occasionally played piano duets with her nephew though hardly anybody else knew that she could play the piano. In her old age she still fondly remembered the musical evenings once a week at the house of Max Planck, himself a fine pianist. She went to concerts as long as she could walk, and never ceased to try following contemporary trends in music.

In spite of her close friendship with Max Planck and other great physicists like Niels Bohr, James Franck and Max von Laue, she never quite lost the shyness of her young days. But among friends she could be lively and cheerful, and an excellent story-teller. She was interested in almost everything; always ready to learn and ready to admit her ignorance of things outside her own field of study. But within that field she moved with great assurance and was convinced of the power of the human mind to arrive at correct conclusions from the great laws of nature. When that conviction misled her (as in the belief that β-rays must be monoenergetic, or that certain substances she studied must be transuranic) the recognition that she had been wrong was a shock as if nature had been unfair to her devoted work. But the advance of knowledge was always her first concern, and she felt the delight of every good scientist in a good piece of work done by someone else.

Slight in figure and shy by nature, she learnt assurance from success, and she seemed to draw ever new strength from the wonder and the beauty of the physical universe and its laws. To elucidate those laws was her main desire, and her only ambition was for her work to be recognized among her colleagues; publicity in any form she disliked very much. Practical applications of science did not concern her, and it was a source of deep distress in her later years that her work should have led to the horror of the atom bomb.

In her institute she kept strict discipline, and it was her (justified) pride that in a quarter of a century it never became contaminated with radioactivity, despite the large amounts of radio-elements that were handled in the same building. But while her students feared her strictness they came to her with their personal problems, and her warm, practical humanity is still remembered with fondness. In her early days in Berlin she had found cheerful informal company and good music at the house of Max Planck to whom she remained for ever attached in deep gratitude and whose advice she often sought and heeded in subsequent years. Her friendship with James Franck meant a great deal to her, and so did that with Niels Bohr, and with her contemporary, the plant physiologist, Elisabeth Schiemann. The rightful place of women, and in particular of women scientists, was a lively concern of hers on which she has spoken and written repeatedly.

After retiring to Cambridge in 1960, Lise Meitner led a more quiet life. She still travelled a good deal, to meet friends and give lectures, but growing deafness made it gradually more difficult for her to attend lectures and discussions. In 1963 she went to Vienna to speak before a large audience at the Urania Volksbildungsanstalt about '50 years of physics', a talk that was later printed in English as 'Looking back'. After a strenuous visit to the U.S.A. at Christmas 1964 she suffered a heart attack which caused her to spend some months in a nursing home, and from which she returned to her flat much enfeebled. Yet her strength failed only slowly, and in 1967 she made a good recovery after a fall in which she broke her hip bone. But she did not travel any more and gradually gave up all other activity. For the last two months she was in a nursing home in Cambridge where her life slowly ebbed away. She died on 27 October 1968, a few days before her ninetieth birthday, having outlived all her brothers and sisters, and was buried in a country churchyard, where her youngest brother had been buried some years previously.

A list of Lise Meitner's distinctions includes membership of the Academies of Berlin, Copenhagen, Gothenburg, Göttingen, Halle, Oslo, Stockholm, and Vienna, as well as honorary doctorates from Adelphi College, University of Rochester, Rutgers University and Smith College (U.S.A.), and from the University of Stockholm (Sweden). She was awarded
The Leibniz Medal (1924) by the Berlin Academy of Sciences,
The Lieben Prize (1925) by the Vienna Academy of Sciences,
The Ellen Richards Prize (1928), from U.S.A.; shared with Ramart Lucas (Paris),
The Prize for Science and Art (1947) by the City of Vienna,
The Planck Medal by the German Physical Society (1949), jointly with Otto Hahn,
The Otto Hahn Prize (W. Germany 1954),
The Schlozer Medal (1962) by the University of Göttingen,

The Enrico Fermi Prize (1965) shared with Otto Hahn and Fritz Strassmann) by the U.S. Atomic Energy Commission.

In 1957 she became a Member of the Ordre pour le Mérite, Civilian Class (W. Germany).

O. R. Frisch

BIBLIOGRAPHY

1906. Wärmeleitung in inhomogenen Körpern. II. *Phys. Inst. Wien,* Bd. **115**, Abt. IIa, 125. (Dissertation, Dr. phil.)

1906. Über einige Folgerungen, die sich aus den Fresnel'schen Reflexions formeln ergeben. *S. Ber. preuss Akad. Wiss.; Math. Natur-Klasse* **115**, Abt. IIa, June 1906.

1906. Über die Absorption der α- und β-Strahlen. *Phys. Z.* **7**, 588.

1907. Über die Zerstreuung der α-Strahlen. *Phys. Z.* **8**, 489.

1908. (With O. Hahn.) Über die Absorption der β-Strahlen einiger Radioelemente. *Phys. Z.* **9**, 321.

1908. (With O. Hahn.) Actinium C, ein neues kurzlebiges Produkt des Actiniums. *Phys. Z.* **9**, 649.

1908. (With O. Hahn.) Über die β-Strahlen des Actiniums. *Phys. Z.* **9**, 697.

1909. (With O. Hahn.) Eine neue Methode zur Herstellung radioaktiver Zerfallsprodukte; Thorium D, ein kurzlebiges Produkt des Thoriums. *Verh. dt. phys. Ges.* **11**, 55.

1909. Strahlen und Zerfallsprodukte des Radiums. *Verh. dt. phys. Ges.* **11**, 648.

1909. (With O. Hahn.) Die Ausstossung radioaktiver Materie bei den Umwandlungen des Radiums. *Phys. Z.* **10**, 422.

1909. (With O. Hahn.) Nachweis der komplexen Natur von Radium C. *Phys. Z.* **10**, 697.

1909. (With O. Hahn.) Über eine typische β-Strahlung des eigentlichen Radiums. *Phys. Z.* **10**, 741.

1909. (With O. Hahn.) Über das Absorptionsgesetz der β-Strahlen. *Phys. Z.* **10**, 948.

1910. (With O. Hahn.) Eine neue β-Strahlung beim Thorium X; Analogien in der Uran- und Thoriumreihe. *Phys. Z.* **11**, 493.

1911. Vorträge aus dem Gebiet der Radioaktivität. *Phys. Z.* **12**, 147.

1911. (With O. v. Baeyer & O. Hahn.) Über die β-Strahlen des aktiven Niederschlags des Thoriums. *Phys. Z.* **12**, 273.

1911. (With O. v. Baeyer & O. Hahn.) Nachweis von β-Strahlen bei Radium D. *Phys. Z.* **12**, 378.

1911. Über einige einfache Herstellungsmethoden radioaktiver Zerfallsprodukte. *Phys. Z.* **12**, 1094.

1911. (With O. v. Baeyer & O. Hahn.) Magnetische Spektren der β-Strahlen des Radiums. *Phys. Z.* **12**, 1099.

1911. (With J. Franck.) Über radioaktive Ionen. *Verh. dt. phys. Ges.* **13**, 671.

1912. (With O. v. Baeyer & O. Hahn.) Das magnetische Spektrum der β-Strahlen des Thoriums. *Phys. Z.* **13**, 264.

1912. (With O. Hahn.) Über die Verteilung der β-Strahlen auf die einzelnen Produkte des aktiven Niederschlags des Thoriums. *Phys. Z.* **13**, 390.

1912. Über das Zerfallsschema des aktiven Niederschlags des Thoriums. *Phys. Z.* **13**, 623.

1913. (With O. v. Baeyer & O. Hahn.) Das magnetische Spektrum der β-Strahlen des Radioactiniums und seiner Zerfallsprodukte. *Phys. Z.* **14**, 321.

1913. (With O. Hahn.) Zur Frage nach der komplexen Natur des Radioactiniums und der Stellung des Actiniums im Periodischen System. *Phys. Z.* **14**, 752.

1913. (With O. Hahn.) Über das Uran X_2. *Phys. Z.* **14**, 758.

1913. (With O. HAHN.) Über die Verteilung der γ-Strahlen auf die einzelnen Produkte der Thoriumreihe. *Phys. Z.* **14**, 873.

1914. (With O. HAHN.) Über das Uran Y. *Phys. Z.* **15**, 236.

1914. (With O. v. BAEYER & O. HAHN.) Das magnetische Spektrum der β-Strahlen des Uran X. *Phys. Z.* **15**, 649.

1915. Über die α-Strahlung des Wismuts aus Pechblende. *Phys. Z.* **16**, 4.

1915. (With O. v. BAEYER & O. HAHN.) Das magnetische Spektrum der β-Strahlen von Radiothor und Thorium X. *Phys. Z.* **16**, 6.

1915. Über die β-Strahlen von Ra D und das Absorptionsgesetz der β-Strahlen. *Phys. Z.* **16**, 272.

1918. (With O. HAHN.) Die Muttersubstanz des Actiniums, ein neues radioaktives Element von langer Lebensdauer. *Phys. Z.* **19**, 208.

1918. Ueber das Protactinium. *Naturwissenschaften*, **6**, 324.

1918. Die Lebensdauer von Radiothor, Mesothor und Thorium. *Phys. Z.* **19**, 257.

1919. (With O. HAHN.) Über das Protactinium und die Lebensdauer des Actiniums. *Phys. Z.* **20**, 127.

1919. (With O. HAHN.) Der Ursprung des Actiniums. *Phys. Z.* **20**, 529.

1919. (With O. HAHN.) Über die chemischen Eigenschaften des Protactiniums. *Ber. dt. chem. Ges.* **52**, 1812.

1920. (With O. HAHN.) Über die Anwendung der Verschiebungsregel auf gleichzeitig α- und β-Strahlen aussendende Substanzen. *Z. Phys.* **2**, 260.

1920. (With O. HAHN.) Über die Eigenschaften des Protactiniums. *Ber. dt. chem. Ges.* **54**, Heft 1.

1921. Über die verschiedenen Arten des radioaktiven Zerfalls und die Möglichkeit ihrer Deutung aus der Kernstruktur. *Z. Phys.* **4**, 146.

1921. Radioaktivität und Atomkonstitution. *Festschrift, Kaiser Wilhelm Ges.* p. 154.

1922. (With O. HAHN.) Notiz über den Protactiniumgehalt in Pechblenderückständen und das Abzweigungsverhältnis der Actiniumreihe. *Z. Phys.* **8**, 202.

1922. Über die Entstehung der β-Strahl-Spektren radioaktiver Substanzen. *Z. Phys.* **9**, 131.

1922. Ueber den Zusammenhang zwischen β- und γ-Strahlen. *Z. Phys.* **9**, 145.

1922. Über die β-Strahl-Spektra und ihren Zusammenhang mit der γ-Strahlung. *Z. Phys.* **11**, 35.

1922. Über die Wellenlänge der γ-Strahlen. *Naturwissenschaften*, **16**, 1.

1923. Das β-Strahlspektrum von UX_I und seine Deutung. *Z. Phys.* **17**, 54.

1923. (With O. HAHN.) Die γ-Strahlen von Uran X und ihre Zuordnung zu Uran X_I und Uran X_2. *Z. Phys.* **17**, 157.

1923. Über eine mögliche Deutung des kontinuierlichen β-Strahlenspektrums. *Z. Phys.* **19**, 307.

1923. (With O. HAHN.) Über die Eigenschaften des Protactiniums. II. Mitteilung: seine Lebensdauer und sein Gehalt in Uranmineralien. *Ber. dt. chem. Ges.* **54**, 69.

1924. Über eine notwendige Folgerung aus dem Comptoneffekt und ihre Bestätigung. *Z. Phys.* **22**, 334.

1924. (With O. HAHN.) Das β-Strahlenspektrum von Radium und seine Deutung. *Z. Phys.* **26**, 161.

1924. Über die Rolle der γ-Strahlen beim Atomzerfall. *Z. Phys.* **26**, 169.

1924. Der Zusammenhang zwischen β- und γ-Strahlen. *Ergebn. Exakt. Naturwiss.* **3**, 160.

1924. (With K. FREITAG.) Photographischer Nachweis von α-Strahlen langer Reichweite nach der Wilsonschen Nebelmethode. *Naturwissenschaften*, **12**, 634.

1924. Über die Energieentwicklung bei radioaktiven Zerfallprozessen. *Naturwissenschaften*, **12**, 1146.

1924. Die Sichtbarmachung der Atome. *Kaiser-Wilhelm Inst. Chem.*, Annual report.

1925. (With O. HAHN.) Die β-Strahlspektren von Radioactinium und seinen Zerfallsprodukten. *Z. Phys.* **34**, 795.

1925. Die γ-Strahlung der Actiniumreihe und der Nachweis, dass die γ-Strahlen erst nach erfolgtem Atomzerfall emittiert werden. *Z. Phys.* **34**, 807.
1926. (With K. Freitag.) Über die α-Strahlen des Th C+C′ und ihr Verhalten beim Durchgang durch verschiedene Gase. *Z. Phys.* **37**, 481. (Correction *Z. Phys.* **38**, 574.).
1926. Einige Bemerkungen zur Isotopie der Elemente. *Naturwissenschaften*, **14**, 719.
1926. Neue Arbeiten über die Streuung der α-Strahlen und den Aufbau der Atomkerne. *Naturwissenschaften*, **14**, 863.
1926. Experimentelle Bestimmung der Reichweite homogener β-Strahlen. *Naturwissen-, schaften*, **14**, 1199.
1926. Die Kernstruktur. *Handb. d. Phys.* **22**, 124.
1927. (With M. v. Laue.) Die Berechnung der Reichweitestreuung aus Wilson-Aufnahmen. *Z. Phys.* **41**, 397.
1928. Das β-Strahlenspektrum des Radiothors als Absorptionsspektrum seiner γ-Strahlen. *Z. Phys.* **52**, 637.
1928. Das γ-Strahlenspektrum des Radiothors in Emission. *Z. Phys.* **52**, 645.
1928. Das γ-Strahlenspektrum des Protactiniums und die Energie der γ-Strahlen bei α- und β-Strahlenumwandlungen. *Z. Phys.* **50**, 15.
1928. Über geeignete Dampf-Gasgemische für verschiedene Versuche nach der Wilsonschen Nebelmethode. *Z. phys. Chem.* **139**, 717.
1929. Energieverteilung der primaeren β-Strahlen und die daraus zu folgende γ-Strahlung. *Phys. Z.* **30**, 515.
1929. Das β-Strahlenspektrum des Radiothors in Emission. *Z. Phys.* **52**, 645.
1929. Die Höhenstrahlung und ihre Beziehung zu physikalischen und kosmischen Vorgängen. *Z. angew. Chem.* **42**, 345.
1929. *Die γ-Strahlen.* Müller-Pouillet II, 3, **11**, 132.
1930. (With W. Orthmann.) Über eine absolute Bestimmung der Energie der primären β-Strahlen von Radium E. *Z. Phys.* **60**, 143.
1930. (With H. H. Hupfeld.) Prüfung der Streuungsformel von Klein und Nishina an kurzwelliger γ-Strahlung. *Phys. Z.* **31**, 947.
1930. (With H. H. Hupfeld.) Über die Prüfung der Streuungsformel von Klein und Nishina an kurzwelliger γ-Strahlung. *Naturwissenschaften*, **18**, 534.
1931. (With H. H. Hupfeld.) Über das Absorptionsgesetz für kurzwellige γ-Strahlung. *Z. Phys.* **67**, 147.
1931. (Mitglieder: M. Curie, A. Debierne, A. S. Eve, H. Geiger, O. Hahn, S. C. Lind, St. Meyer, E. Rutherford, E. Schweidler.) (Experten: J. Chadwick, I. Joliot-Curie, K. W. F. Kohlrausch, A. F. Kovarik. L. W. Mc.Keehan, L. Meitner u. H. Schlundt.) Die radioaktiven Konstanten nach dem Stand von 1930. *Phys. Z.* **32**, 569.
1931. Die Bedeutung des Atomgewichtes in der modernen Physik. *Ber. dt. chem. Ges.* **64**, 149.
1931. Über Wechselbeziehungen zwischen Masse und Energie. *Z. Vereines dt. Ing.* **75**, 977.
1931. Über die Ionisierungswahrscheinlichkeit innerer Niveaus durch schnelle Korpuskularstrahlen und eine Methode zu ihrem Nachweis. *Naturwissenschaften*, **19**, 497.
1931. (With O. Hahn.) Lord Rutherford zum 60. Geburtstag. *Naturwissenschaften*, **19**, 729.
1931. (With O. Hahn.) Notiz über die Entdeckung des Protactiniums. *Naturwissenschaften*, **19**, 738.
1931. (With H. H. Hupfeld.) Über das Streugesetz kurzwelliger γ-Strahlen. *Naturwissenschaften*, **19**, 775.
1931. (With K. Philipp.) Das γ-Spektrum von Th C″ und die Gamowsche Theorie der α-Feinstruktur. *Naturwissenschaften*, **19**, 1007.
1932. (With O. Hahn.) Zu A. v. Grosse: Entdeckung und Isolierung der Elements 91. *Naturwissenschaften*, **20**, 363.
1932. (With H. H. Hupfeld.) Über die Streuung kurzwelliger γ-Strahlung an schweren Elementen. *Z. Phys.* **75**, 705.

1932. (With K. Philipp.) Über die Wechselwirkung zwischen Neutronen und Atomkernen. *Naturwissenschaften*, **20**, 929.

1932. Die Bedeutung der β- und γ-Strahlen für die Atomforschung. *Z. Elektrochem.* **38**, 490.

1933. (With K. Philipp.) Die γ-Strahlen von Th C und Th C″ und die Feinstruktur der α-Strahlen. *Z. Phys.* **80**, 277.

1933. (With H. Kösters.) Über die Streuung kurzwelliger γ-Strahlen. *Z. Phys.* **84**, 137.

1933. Streuung kurzwelliger γ-Strahlen. *Helvet. Phys. Acta*, **6**, 445.

1933. (With K. Philipp.) Weitere Versuche mit Neutronen. *Z. Phys.* **87**, 484.

1933. (With O. Hahn.) Zur Entstehungsgeschichte der Bleiarten. *Naturwissenschaften*, **21**, 237.

1933. (With K. Philipp.) Die bei Neutronenanregung auftretenden Elektronenbahnen. *Naturwissenschaften*, **21**, 286.

1933. (With K. Philipp.) Die Anregung positiver Elektronen durch γ-Strahlen von Th C″. *Naturwissenschaften*, **21**, 468.

1933. (With Kan Chang Wang.) Der innere Photoeffekt der γ-Strahlen. *Naturwissenschaften*, **21**, 594.

1934. (With K. Philipp.) Weitere Versuche mit Neutronen. *Z. Phys.* **87**, 484.

1934. Über die von I. Curie und F. Joliot entdeckte künstliche Radioaktivität. *Naturwissenschaften*, **22**, 172.

1934. Die Streuung harter γ-Strahlen. *Naturwissenschaften*, **22**, 174.

1934. Das Energiespektrum der positiven Elektronen aus Aluminium. *Naturwissenschaften*, **22**, 388.

1934. Über die Erregung künstlicher Radioaktivität in verschiedenen Elementen. *Naturwissenschaften*, **22**, 420.

1934. Atomkern und periodisches System der Elemente. *Naturwissenschaften*, **22**, 733.

1934. Über die Umwandlung der Elemente durch Neutronen. *Naturwissenschaften*, **22**, 759.

1934. Neuere Atomkernprozesse. (Forschung und Fortschritt.) *Kaiser Wilhelm Inst. Berl.* **10**, 246.

1935. (With O. Hahn.) Über die künstliche Umwandlung des Urans durch Neutronen. *Naturwissenschaften*, **23**, 37.

1935. (With O. Hahn.) Über die künstliche Umwandlung des Urans durch Neutronen. (II. Mitteil.) *Naturwissenschaften*, **23**, 230.

1935. (With O. Hahn.) Die künstliche Umwandlung des Thoriums durch Neutronen: Bildung der bisher fehlenden radioaktiven $4n+1$ Reihe. *Naturwissenschaften*, **23**, 320.

1935. (With O. Hahn & F. Strassmann.) Einige weitere Bemerkungen über die künstlichen Umwandlungsprodukte beim Uran. *Naturwissenschaften*. **23**, 544.

1936. (With O. Hahn.) Neue Umwandlungsprozesse bei Bestrahlung des Urans mit Neutronen. *Naturwissenschaften*, **24**, 158.

1936. *Kernphysikalische Vorträge am Physikalischen Institut der Eidgenössischen Technischen Hochschule*. Verlag Julius Springer.

1936. (With O. Hahn & F. Strassmann.) Neue Umwandlungsprozesse bei Neutronenbestrahlung des Urans; Elemente jenseits Uran. *Ber. dt. chem. Ges.* **69**, 905.

1936. (With O. Hahn.) Künstliche radioaktive Atomarten aus Uran und Thorium. (Dt. Chem. Ges. Berlin, Sitzung 13.1.36.) *Angew. Chem.* **49**, 127.

1937. (With O. Hahn & F. Strassmann.) Über die Umwandlungsreihen des Urans, die durch Neutronenbestrahlung erzeugt werden. *Z. Phys.* **106**, 249.

1937. β and γ rays of elements beyond uranium. *Annln Phys.* **29**, 246.

1937. (With O. Hahn & F. Strassmann.) Über die Trans-Urane und ihr chem. Verhalten. *Ber. dt. chem. Ges.* **70**, 1374.

1938. (With O. Hahn & F. Strassmann.) Künstliche Umwandlungsprozesse bei Bestrahlung des Thoriums mit Neutronen; Auftreten isomerer Reihen durch Abspaltung von α-Strahlen. *Z. Phys.* **109**, 538.

1938. (With O. Hahn & F. Strassmann.) Ein neues langlebiges Umwandlungsprodukt in den Trans-Uranreihen. *Naturwissenschaften*, **26**, 475.
1938. (With O. Hahn.) Trans-Urane als künstliche radioaktive Umwandlungsprodukte des Urans. *Scientia*, Jan. 1938.
1939. (With O. R. Frisch.) Disintegration of Uranium by Neutrons; a new type of Nuclear Reaction. *Nature, Lond.* **143**, 239.
1939. (With O. R. Frisch.) Products of the Fission of the Uranium Nucleus. *Nature, Lond.* **143**, 471.
1939. (With O. R. Frisch.) Products of the fission of uranium and thorium under neutron bombardment. *Kgl. Danske Vid. Selskab, mat.-fys. Medd.* **17**, 5.
1939. New Products of the Fission of the Thorium Nucleus. *Nature, Lond.* **143**, 637.
1940. Capture cross-sections for thermal neutrons in thorium, lead and uranium 238. *Nature, Lond.* **145**, 422.
1941. Resonance energy of the Th capture process. *Phys. Rev.* **60**, 58.
1941. Behaviour of rare earths under neutron bombardment. *Ark. Mat. Astr. Fys.* **27*A***, 3, No. 17 (18 pp.).
1942. Radiations emitted by Scandium 46. *Ark. Mat. Astr. Fys.* **28*B***, 4, No. 14 (6 pp.).
1943. A simple method for the investigation of secondary electrons excited by γ rays and the interference of these electrons with measurements of primary β-ray spectra. *Phys. Rev.* **63**, 73. *Phys. Rev.* **63**, 384: Erratum. Also *Ark. Mat. Astr. Fys.* **29*A***, No. 17 (14 pp.).
1945. Disintegration scheme of scandium 46. *Ark. Mat. Astr. Fys.* **32*A***, No. 6 (11 pp.).
1945. Attempt to single out some fission processes of uranium by using the differences in their energy release. *Rev. Mod. Phys.* **17**, 287.
1946. Radioactive nuclei produced by irradiation of copper with deuterons. *Ark. Mat. Astr. Fys.* **33*A***, 1, paper 3 (12 pp.).
1948. Einige Bemerkungen zu den Einfangsquerschnitten langsamer und schneller Neutronen bei schwereren Elementen. *Annln Phys.* **3**, 115.
1949. Otto Hahn zum 8. März 1949. *Z. f. Naturforschung*, **4a**, 81.
1950. Spaltung und Schalenmodell des Atomkerns. *Ark. Fys.* **4**, 383 (see *Nature, Lond.* 1950, **165**, 561).
1952. Die Anwendung des Ruckstosses bei Atomkernprozessen. *Z. Phys.* **133**, 141.
1954. Einige Erinnerungen an das Kaiser-Wilhelm-Institut für Chemie in Berlin-Dahlem. *Naturwissenschaften* **41**, 97.
1960. The status of women in the professions. *Physics Today*, **13**, August, p. 17.
1964. Looking back. *Bulletin Atomic Scientists*, November 1964, p. 2.