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A TALE OF OBLIVION: IDA NODDACK AND THE 'UNIVERSAL ABUNDANCE' OF MATTER

by

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Ida Noddack was a German chemist who in 1925, with her husband Walter Noddack, discovered element 75 (rhenium) and possibly element 43 (technetium). She is also known to have anticipated, by nine years, the possibility of nuclear fission. This article focuses on Ida's hypothesis that all elements are present in any mineral. Ida related the relative abundance of the elements in the Universe to hypothetical properties of the atomic nuclei. This allowed her to speculate about a different Periodic Table in which isotopes might be the cause of unexpected features of periodicity. Ida Noddack faced many professional obstacles because of her scientific nonconformity and gender, the resentment of physicists against intrusion in their field, and the overall difficulty of research under and after the Nazi regime.

Keywords: Ida Noddack; chemical element abundance; German science

INTRODUCTION

Ida Noddack (*née* Tacke, 1896–1978) and her husband, Walter Noddack (1893–1960), excelled in analytical chemistry, demonstrated notably in their discovery of element 75 of the Periodic Table (rhenium) in 1925. The couple is also associated with a recently resurrected, and possibly still unresolved, dispute in the history of science concerning the discovery of element 43 (masurium, later renamed technetium).[1]

Ida made it clear that she was never an assistant to Walter; they were co-workers. Their joint career has been treated by Brigitte van Tiggelen and Annette Lykknes as a true *Arbeitsgemeinschaft* (work partnership), and it remains difficult to ascertain what can be attributed to Ida's participation as an independent scientist in the broader context of the couple's scientific production; by any standards her competence as a scientist is beyond doubt.[2] According to van Tiggelen & Lykknes, Walter published, with Ida or alone, work that was considered to be relatively uncontroversial in the field because he held a high-ranking academic position, whereas Ida (who had much less to lose) published alone when the material was unconventional.

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In this study, even though the Noddacks' work was so closely interwoven and was for the most part collaborative, it is Ida who will be the main focus, given her greater difficulties in the scientific arena and the unorthodoxy of some of her ideas. The debate on the existence of nuclear fission, as well as Ida's activities as an element hunter, has been discussed in the secondary literature.[3] However, a less studied aspect of Ida's work is her hypothesis about the distribution of matter in the Universe, a subject rich in implications, not only from a historical viewpoint but also for its epistemological interest. Questions that help us to understand how her research was received in the scientific community include the following.

(i) How did Ida's correct interpretation, in 1934, of Fermi's experimental results as nuclear fission help to detract from the acceptance of her work on the distribution of chemical elements?
(ii) Did the ensuing controversy with Otto Hahn and Fritz Strassmann on the possible fission of uranium, later made even more bitter by the dispute with Emilio Segrè and Carlo Perrier over the discovery of masurium, affect the evaluation of the universal element frequency hypothesis?
(iii) Given the international prestige of German chemistry, especially before World War II, why was the reception of the distribution hypothesis so muted?

The present article is cast with these questions in view.

Biographical sketch

Ida Tacke was born in 1896 in Lackhausen, in the northern Rhine region, the daughter of a varnish manufacturer. In 1918 she graduated in chemical and metallurgical engineering at the Technische Hochschule in Berlin, where she immediately started research on the organic chemistry of fatty acids, obtaining the degree of Dr. Eng. in chemistry in 1921. Her first job was in the chemistry laboratory of the Berlin turbine factory of AEG (a company affiliated to General Electric in the USA). There she worked in a world-famous building designed by the architect Peter Behrens to resemble the shape of a turbine.

Ida had been in touch with Walter Noddack, a researcher in the University of Berlin's Physical Chemistry Department, since 1922. Walter had been a brilliant doctoral student of the Nobel laureate Walther Nernst, who in 1922 was invited to direct the prestigious German PTR (Physikalisch–Technische Reichsanstalt; Imperial Physical Technical Bureau). As a consequence, Walter followed Nernst and went to work in the PTR's Chemistry Division, where his project was to search for the remaining missing elements of the Periodic Table. In 1924 Ida decided to resign her job and to work full time as an unpaid collaborator at the PTR, helping Walter's research. Walter's PTR group concentrated on elements 43 and 75, predicted in the Periodic Table by Mendeleev in the same column as manganese. Walter and Ida had the insight that the new elements should be looked for not in the more obvious manganese ores, but rather in the minerals of manganese's horizontal neighbours in the Periodic Table.

Ida had good connections in the chemical laboratory of Siemens & Halske's lamp factory in Berlin, and there she had access to new X-ray spectroscopy equipment in the group led by Otto Berg. After very demanding analytical work, in 1925 Walter and Ida were able to announce the discovery of elements 75 (Berg was also a co-author) and 43, respectively

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named rhenium, in homage to Ida's birthplace, and masurium, honouring Walter's background in eastern Germany. In 1926 Walter Noddack and Ida Tacke were married.

Their discoveries of elements 43 and 75 were soon disputed by other scientists in search of the same elements. This forced the Noddacks to engage in the enormous task of surveying some 1800 ores (and meteorites) to obtain weighable quantities of the new elements. In this task they succeeded only in the case of rhenium, because masurium proved extremely hard to obtain by analytical means. However, they secured the sponsorship of Siemens for a few years in a laboratory specially built for their research as a result of Siemens's interest in the possible use of rhenium instead of tungsten in the filaments of electric lamps.

In 1929, Walter and Ida were granted a German patent for the rhenium coating of lamp filaments, and a British patent for the use of rhenium as a catalyst for oxidation processes. During 1931 and 1932 they secured three patents in the USA for, respectively, filaments for incandescent lamps and vacuum tubes; rhenium concentrates; and the use of metallic rhenium as an electric glower for incandescent lamps. These achievements culminated in 1931 with the joint award of the German Chemical Society's prestigious Liebig Medal. For their discovery of rhenium and masurium, the Noddacks were repeatedly nominated for the Nobel Prize (in 1932, 1933, 1935 and 1937). In 1934 they received the coveted Scheele Medal of the Swedish Chemical Society and in the same year secured another German patent, this time for rhenium concentrates.

In 1934 Ida published a paper criticizing Enrico Fermi's supposed discovery of element 93 as the product of nuclear fusion by the bombardment of uranium with neutrons. She suggested instead that Fermi's experiments pointed to nuclear fission. Leading German scientists, among them Otto Hahn, considered Ida's suggestion inadmissible, even ridiculous. This criticism may have contributed to the opposition that still existed to the Noddacks' recognition as discoverers of masurium, which intensified after 1937, when Carlo Perrier and Emilio Segrè artificially produced element 43 in a nuclear reaction.

Owing to the high levels of unemployment that followed the 1929 Wall Street crash, a new German law of 1932 had forced married employed women to abandon their positions in favour of men, so forcibly becoming housewives, a fate that Ida escaped because she still had the status of an unpaid collaborator. The Nazi takeover of 1933, however, had a profound impact on the couple's life and their scientific careers. One of the first consequences was their move in 1935 to Freiburg University (figure 1), where Walter was appointed Full Professor of Physical Chemistry, a position formerly occupied by a Jewish scientist, Georg Hevesy.

In 1941 the Noddacks moved again, this time to the University of Strasbourg. France's defeat by Prussia in 1871 had resulted in the annexation of Alsace and encouraged the Germans to make the university a jewel in the German crown. Germany successfully transformed Strasbourg into an elite institution, which was then lost to the French after the country's defeat in World War I. Once the university was recovered after Germany had reoccupied Alsace, the Nazi government invested heavily to make Strasbourg a showpiece for the supposedly superior qualities of Aryanism. Walter was appointed director of two institutes at the university, where most professors were members of the National Socialist Party, although Walter himself never was. Ironically, in this new situation Ida obtained for the first time a paid academic position as a professor.

As the war raged, Germany faltered after the D-day invasion, forcing the Noddacks to be evacuated in 1944 to a small village along with their laboratory research equipment. In the following year, during the so-called denazification process, the Allied Forces exonerated

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Figure 1. Ida Noddack in her laboratory at the University of Freiburg, where she and Walter Noddack worked from 1935 to 1941. She is standing in front of her X-ray spectrograph. (Date and photographer unknown; courtesy of University Archives, KU Leuven, Archive Walter and Ida Noddack-Tacke, nr. 51.)

Walter of accusations of Nazism. This was confirmed by the permission that was granted for Walter and 'Professor' Ida to resume their research, but Walter found no job in the major universities. In 1946 he finally obtained a modest position in a technical college, the Philosophisch-Theologische Hochschule in Bamberg. Still in possession of their old equipment from Strasbourg, Walter independently founded a private Geochemical Institute in Bamberg, where Ida became an (again) unpaid member of the staff, engaging in geochemical and physiological research. The institute was recognized and nationalized as part of the Federal Republic of Germany's network in 1956, and not long afterwards, in 1960, Walter died. Ida, however, continued her research there until 1968, when she moved to a retirement home, finally dying in 1978.

Ida, the element hunter?

One of the remarkable features about the Noddacks is the conspicuously little attention that historians of science have given to their research, a silence especially pronounced in the case of Ida. More recently their work has begun to attract new attention, notably with regard to the controversy over element 43 and the early recognition of nuclear fission by Ida. However, it appears that Ida's scientific ideas were far more penetrating than has generally been recognized, and what she wrote about geochemistry and cosmochemistry should certainly be re-examined.

The Noddacks' element discoveries have been portrayed as a story of success in the case of rhenium and as a failure for masurium, these different outcomes being attributed to their having been unaware that times had changed.[4] The chemical analytical processes of ore refining that proved useful in isolating rhenium between 1925 and 1929 were supposedly no longer valid 10 years later, by which time physics had provided chemistry with nuclear tools capable of either breaking up or fusing elements, and forming new ones. According to this view, such short-sightedness was enough to discredit the Noddacks, to the point that the name masurium was never to become widespread in either the German or the international literature. A definitive demonstration that the Noddacks' views were

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outmoded would then be exemplified by Ida's lecture of 1934 addressing the gaps in the Periodic Table, where she stubbornly clung to the old definition of the elements based on atomic weight, rather than atomic numbers, thus giving priority to isotopes, not to elements.[5]

My reading of the ensemble of Ida's original articles does not square with these standard interpretations. The discovery of rhenium was duly recognized as an achievement of the Noddacks, as various references in the literature confirm.[6] However, in the USA the *Journal of Chemical Education* gave them early credit for the discovery of masurium as well as rhenium. The chemist Mary Elvira Weeks, who wrote regularly about historical matters for that journal, assembled her contributions in a volume that first appeared in 1933 as *The discovery of the elements*. According to Weeks, the Noddacks' discovery of masurium and rhenium

> ... was not accidental, but the result of a long search in platinum ores and in the mineral columbite .... The difficult concentration processes were carried out by Dr. Noddack and Dr. Tacke alone, but Berg assisted in making the observations with the X-ray spectroscope.
>
> On September 5, 1925, Fräulein Tacke lectured on the new elements before the Verein Deutscher Chemiker in Nuremberg. After thanking her for the address, the president mentioned that this was a historic occasion, for it was the first time that a woman had ever spoken before the Verein. He also expressed the hope that other 'Chemikerinnen' might soon follow her example. Fräulein Tacke and Dr. Noddack have since been united in marriage and have continued their joint researches ....[7]

Weeks's book was widely read, with several editions (the fifth in 1945) reproducing the same account as above. Along the same lines, during the 1930s the cover of several issues of the *Journal of Chemical Education* featured a representation of the Periodic Table, with masurium (Ma) and rhenium (Re) always shown in column VII, under manganese.[8]

More recently Roberto Zingales has reviewed the dispute about the priority that never came the Noddacks' way for their discovery of element 43.[9] Even though Zingales subsequently revised his opinion (in the face of criticism of his views on many fronts), the controversy does not seem to have been satisfactorily settled.[10] The problems generally associated with experimental work, especially those related to measurement and replication, also have a role in this story. Attention should be given to the interpretative biases of scientists both in favour and in opposition to results that contradict prevailing scientific theories, and by now there is a growing critique of the inexorability and unquestionability of a self-justifying 'scientific method'.[11] I believe that this characteristic of science to arouse controversies is pertinent to this case.

In the literature related to this particular controversy, it is commonly stated that the name 'technetium' was officially adopted in 1947, after an article published by the chemist Fritz Paneth in *Nature*.[12] There Paneth acknowledged and lamented that

> The names 'masurium' and 'illirium' are so firmly rooted in text-books and tables that recent work on artificial isotopes of the elements 43 and 61 is sometimes referred to as the production of species of masurium and illirium.

Paneth went on to explain that the slowness of chemists to abandon the names was due to the failure of the name-givers to withdraw their claims. He added that in the case of masurium Walter Noddack (he systematically ignored Ida) even went so far as to complain in 1930 to the 'convener of a chemical meeting in Königsberg' (Paneth himself) that he should have been invited to speak on this element, and he was not. In support of his case, Paneth stated that

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during the war Walter had been appointed professor of inorganic chemistry in Strasbourg by the 'occupying power' (he again chose to ignore Ida), and that after the war 'when the French chemists returned, they found the symbol Ma painted on the wall of the main chemistry lecture theatre in a large representation of the Periodic System.'

He finished his article with a compelling call:

> So far no names for elements 43, 61 and 85 have officially been put forward by their discoverers Perrier and Segrè, Coryell and his group, and Corson, Mackenzie and Segrè, respectively. Every chemist concerned with the task of teaching systematic inorganic chemistry and of knowing his up-to-date table of the Periodic System will be grateful if they will publish soon the names which they consider suitable.

There was no need for serious concern on Paneth's part, for in an obviously calculated manoeuvre, page 24 of the same issue of *Nature* carried a letter signed by Perrier and Segrè naming element 43 as technetium, and another letter signed by Corson, Mackenzie and Segrè naming element 85 as astatine (promethium, element 61, was omitted).

However, these names were not immediately imposed. After the end of World War II, the work of the International Union of Pure and Applied Chemistry (IUPAC) continued for some years to embrace problems of nomenclature, including those elements. In these years, Paneth attended IUPAC's international conferences, in which despite its scientific prominence Germany was not allowed to participate because it was an occupied, non-independent land after 1945. The IUPAC records show that several postwar congresses left the name of element 43 blank.[13] Finally the IUPAC group on the Nomenclature of Inorganic Chemistry prepared its 1957 Report, which was published in 1959. It now officially gave the name technetium to the former masurium.[14]

Segrè's later version of this story in an interview given in 1967 is also interesting.[15] He said that on the technetium question the Noddacks 'had been plain dishonest', basing this serious charge on a visit and talks he had had with the Noddacks. I believe that the fact that Paneth and Segrè were exiled Jews, whereas the Noddacks were now and then still mistakenly characterized as Nazi supporters, had a significant role in this evaluation, a subject to which I return below.

The distribution of chemical elements in the Universe

All of the previous controversies are historically interesting in themselves, but Ida's approach to the elements was part of a broader world-view that has not been sufficiently discussed, with the result that what was perhaps her most original contribution within the team she formed with Walter has been neglected. In her 1934 article Ida held the periodic system to be capable of providing new discoveries beyond the chemical elements, revealing more about the structure of matter. She spoke of a possible new natural system of classification that would be based on a table of isotopes, not only of elements.

As early as 1930, Ida and Walter published tables with the existing values for the composition of the Earth's crust, introducing corrections relative to the scarcer elements, for which they found a higher percentage than had been reported in similar studies. They also gave values for the composition of meteoric rocks very similar to that of the Earth's crust.[16] Their distribution curves showed an increase in frequency starting with lighter elements up to oxygen, followed by a slow decline thereafter. They also confirmed

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alternating higher and lower intensities between odd and even element numbers, as well as peaks at silicon, tin and lead, with lows at scandium, gallium, indium, tellurium, chlorine, masurium and rhenium. This led Ida to the hypothesis that the nucleus formed shells with increasing atomic numbers, somewhat similar to the system of electronic shells.[17]

Instead of disregarding the importance of the atomic numbers, Ida suggested that research should be concentrated on the composition of the nuclei of the individual isotopes. What was at stake was an attempt to understand a higher-order arrangement that would account for the formation of isotopes in accordance with such properties of the nucleus. It was for this reason that the Noddacks boldly stated in their 1930 paper that the 'distribution of the elements in the universe is a well-defined property of the nucleus'. Another strong statement was 'that meteorites surely were not to be regarded as debris of a big cosmic body . . . they were condensed during the formation of the solar system'.

It is not within the scope of the present article to examine how far Ida's provocative thoughts reflected broader historical and philosophical issues related to the foundations of the Periodic Table.[18] However, the extensive bibliography on the subject gives ample evidence of a still open debate, which highlights Ida's remark on the appropriateness of founding the periodic system on the isotopes rather than on the elements, an issue at the heart of her disagreement with Paneth and Hevesy in the first half of the century.[19] The question implied by considering either elements as basic (not simple) substances or, on the contrary, isotopes as basic for the periodic system, is whether there exists a 'natural' classification, even if this had not yet been discovered. Are electronic configurations sufficient for this classification, or do we need to probe still deeper into the configuration of the nucleus to discover such a 'natural' system?[20]

This last question was at the core of Ida's 1934 paper on the periodic system, in which she enlarged on an idea present in the couple's article of 1930 about the distribution of the elements. The 1934 paper reproduced a lecture that Ida gave to commemorate the hundredth birthday of Mendeleev, in which she stated that the periodic system was incomplete, and not only because of the missing elements 61, 85, 87 and the transuranic ones. She insisted on 'the possibility of also making interesting discoveries in the fundamentals of the periodic system, that might influence our ideas about the structure of the material world above the realm of chemistry'.

Most chemical elements, Ida continued, comprised isotopes, which could not be separated by chemical means. The progress of physics then taught that chemical properties depended on the outer electronic shells; this by itself would lead to the chemical identity of an element's isotopes. At this point Ida made a radical statement: this was a dogma, and as such it needed to follow the fate of all dogmas; that is, it would one day be contradicted, as had happened with the hydrogen isotope. It was for this reason that she concluded that isotopes increased the units of the periodic system from the 92 elements to around 280, so that a new natural system should be sought.

In 1942, in the only book that she authored alone, devoted to an account of the development and constitution of chemistry, Ida returned to similar questions.[21] Although the book was written for a broad audience, Ida used it to defend her strongly held position: science must constantly rid itself of dogmas, because they are always a sign of human incompleteness and retard the development of science.

In 1936 Ida published another highly significant article, based on the continuation of intense laboratory work on the chemical analysis of element concentrations in mineral ores.[22] After analysing many samples, she was convinced that 'most of the best known

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elements were to be found in this material, the still missing ones were not sufficiently looked for. One has the general impression that these elements would also be found after enough work and time were spent on them'.

From these findings, Ida drew a first very general conclusion: that every chemical element could be found in any mineral ore. The property, however, was not limited to minerals: 'also substances from living organisms and artificial products exhibit the same picture.'

This led to her second conclusion, that all chemical elements probably exist in all earthly substances (*Allgegenwartshäufigkeit*—all-present, or universal, abundance). This hypothesis was valid only for macroscopic conditions, obviously, because the refinement process could reach *in extremis* just a single atom. This would also explain why every type of soil and rock on the Earth's surface was to a certain extent radioactive.

The hypothesis that all elements are present in any mineral was derived from Ida's exhaustive trial-and-error experiments. It followed that by taking any sufficiently large natural material system, one arrived approximately at the same frequency distribution for all the elements of the Periodic Table. From this, she developed further speculations about the genesis of the elements in the Universe, the departure point being the formation and internal stability of atomic nuclei.[23] The minimal concentration at which a given element was present in any mineral was called by Ida the mineral's 'universal concentration' (*Allgegenwartskonzentration*). Her examination of the Earth's ores, Solar System meteorites and star spectra indicated a first approximation to this concentration. For example, no mineral that she examined was found to contain less than 0.02% of oxygen or 0.025% of iron.

It followed that the creation and distribution of elements in the Universe, stars and Earth were not a random process; rather, they followed certain rules, related to the properties of the atomic nucleus. Ida, in fact, seemed to be searching for meaning in the building blocks of matter. Contrary to her supposedly old-fashioned approach with regard to nuclear energy, the whole concept of searching for a higher-order system of the elements based on their isotopes seems today to hold out more promise than it did in the 1930s.[24]

After the difficult years of postwar reconstruction, and despite the loss of her residual prestige from before the war, Ida continued her research in Bamberg, even though her publications now looked more routine. In this period she published nothing more on her own, but only as part of a team, working either with Walter or with other collaborators.[25] After Walter's death, however, she resumed her individual authorship when she was invited to contribute to a magazine more directed at a general readership, *Vitalstoffe, Zivilisationskrankheiten*.[26]

This gave Ida a chance to return to her work of 30 years earlier. She did so in writing a series of three articles about the theory of the universal distribution of the chemical elements. In the first of them,[27] she recalled that the previously observed material had been enlarged in the meantime to cover 2400 samples of 800 mineral types, and that new, more sensitive methods had been applied, especially activation analysis with artificial radioactive isotopes, and photographic trace determination (an invention she claimed as hers). Since 1936, the universally present minimum concentration had become of more than merely academic interest: in transistors one worked with traces of impurity of 10^{-8} to 10^{-9}, and in biology the effectiveness of traces less than 10^{-10} had been demonstrated. When the Earth was formed, all elements were present, and their distribution equalled their universal concentrations; moreover, the composition of the terrestrial elements must have been roughly the same as that found in iron meteorites. Subsequently the distribution values changed, and the diffusion of atoms or ions played a large role, something she had first studied in Bamberg. The article ended with a fascinating account of the distribution of elements in sea animals, woods,

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plants, coals and graphites, for which she explained differences as being due to their temporal sequential formation and the role of organic substances in element filtering.

In her next article Ida discussed rhenium in the context of the universal concentration of chemical elements.[28] She stated again that all earthly substances may contain all of the chemical elements (her 1936 hypothesis). Now, however, she added the speculation that a particular concentration often allowed the material's origin to be determined and that this property could be applied to ancient historical materials as an indication of their original territory and even the mine from which they were extracted. Another application was that all living organisms directly or indirectly assimilated substances from their environment. Hence by comparing the traces of elements in sea animals with the ambient seawater she was able to predict in 1939 that they would contain heavy metals in very minute concentrations that had some vital function, as was duly demonstrated for cobalt through the discovery of vitamin B_{12}. In conclusion, following this and other examples of applications of her theory, Ida insisted on the hypothesis that all living beings, as well as all minerals, contain all of the elements of the Periodic Table.

Her last article discussed three factors related to the distribution of the elements: their migration, the carbon cycle, and the interplanetary dust that falls permanently on the Earth.[29] Element migration was a geological process, involving rivers and oceans and their changing conditions (for example the evaporation resulting in salt deposits). This transformation had possible commercial consequences: in the future, ocean floors might be mined to obtain any desired metal, provided that the recovery was economically viable. Discussing the well-known carbon cycle involving plants, animals, waters and the atmosphere, Ida concluded that the CO_2 content of the air and the sea, and even the mass of living substances, had been approximately constant for many millions of years. Finally, she examined the influence of interplanetary dust on the universal distribution of the elements on the Earth's crust. According to her calculations, in the past 4.5 billion years this extraterrestrial dust had settled, forming a floor layer at least 36 cm high and weighing about 124 g cm^{-2}. Because this dust, as well as the meteorites and the 'star showers', contained practically all the chemical elements, they contributed to intensifying the universal distribution of elements on the Earth, so adding to the nourishment of plants and animals.

These highly original ideas seem to have had no impact in the geological sciences. None of the books on geochemistry published since Ida's retirement that I have consulted refer to her.[30] One reason for this could be that neither Walter nor Ida belonged to an extensive scientific network, and that they consequently had no supporting institution to back up their views.[31] Did their relative isolation fully account for the virtual disappearance of their work in physical chemistry and geochemistry? Was the nature of such ideas so speculative that they were ignored? Even though Ida's ideas incorporated a significant amount of speculation, she always carefully tested her daring hypotheses against her experimental data, as did many other notable scientists.[32] My suggestion is therefore that there must be other reasons why the Noddacks, and Ida in particular, were neglected.

History and recognition

In a biography of Victor Goldschmidt (1888–1947) by Brian Mason, in which Goldschmidt is portrayed as the 'father of geochemistry', it is stated that after producing charts of the elements' relative terrestrial abundances, Goldschmidt speculated in 1938 on the possible 'nuclear origins'

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of these features. This was in a publication entitled *Die Mengenverhältnisse der Elemente und der Atomarten*, the ninth part of his research on the laws governing the geochemical distribution of the elements. Goldschmidt referred to this as his 'Ninth Symphony', containing data on the abundances of the elements in igneous rocks, meteorites and the solar atmosphere.[33] Mason observes that the idea was to influence the work of future 1963 Nobel laureates Maria Goeppert-Mayer and Jensen. Yet he makes no mention of the Noddacks, even though they and Goldschmidt had met at congresses and Ida had published her paper also on the subject previously, in 1936.[34] Mason, though, stresses how Nazi Germany hampered Goldschmidt's scientific work and almost sent him to a concentration camp.

Anti-Semitism and German guilt

The role of German chemists seems similar, but also different when we compare it with that of physicists. Ute Deichmann has shown that the two German associations of chemists aligned more readily with the National Socialist Party than did their counterparts in physics, and that they already expelled Jewish members soon after 1933.[35] This was in line with the government's goal of engaging academic organizations to provide technical support for the German economy. It has been noted, however, that the majority of scientists were more accommodating and, in particular, that attempts to fashion a 'German chemistry' comparable with 'German physics' had less impact in the chemical community.[36]

In the immediate postwar period, scientists worked hard to reconstruct their bombed campuses. Unlike exiled Germans, their perception was that Germany should not be considered guilty in any way for the war itself (although such a defence did not extend to the extermination camps): the country had done nothing wrong; it had simply lost the war. The result was that they felt hostility towards the Allies and their policies of dismantling German industry and provoking starvation.[37]

The negative weight of the Strasbourg years at the height of Nazi repression may have had consequences for the spread of the Noddacks' ideas, during and after the war. The Law for the Liberation from National Socialism and Militarism (1946) obliged every German citizen to complete a questionnaire concerning former membership of Nazi organizations. The matter then went to a public prosecutor, and the process ended with a formal notice classifying each person under one of five categories, from the gravest ('major offender') to innocence ('exonerated'). Pending investigation of the circumstances, public officers, including scientists, were dismissed from their positions and had their bank accounts frozen.[38] Only by documenting or producing witnesses to prove that their activities had been of a purely academic nature during the Nazi era could scientists secure work in postwar Germany. It is possible that there were instances of personal revenge as well. Although the Noddacks were considered 'exonerated', the denazification records show how profoundly relations between scientists, including Walter, were still coloured by internal politics dating from the Nazi period.[39]

In contrast with a thorough investigation, after the war, 'whitewash certificates' were commonly issued by scientists considered free from the Nazi ideology to other colleagues who needed denazification clearance. It sufficed to say that the person had more or less expressed opposition to National Socialism (even if just confidentially, and not openly), and had supported only pure, 'unsoiled' science.[40] Quite commonly, evidence of having somehow helped to protect Jewish people offered a measure of immunity from charges of Nazism, as happened for the Noddacks.[41]

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Despite the desire for suspicions to be eliminated as rapidly as possible, the scars remained for a long time. Paneth and Segrè, both Jewish refugees of Nazi fascism, persisted in asserting that the Noddacks should be regarded as suspects of collaboration with Nazism. Might this explain why Segrè even accused them of scientific 'dishonesty' in relation to the technetium–masurium controversy? For whatever reasons, the fact remains that many highly qualified scientists, Walter and Ida among them, had trouble in finding posts, and Ida must have felt she would do better to continue as an unpaid staff member. In particular, even before the war Ida had suffered additional prejudice against her ideas as a result of her being a woman and hence someone at odds with Nazi ideology, which rated women as intellectually inferior, suited mainly for domestic life. German statistics during the war showed that women made up about 40% of the total numbers in laboratories, but few were assistants and even fewer had a *Dozentur*.[42] Clearly Ida was exceptionally highly regarded, and it was precisely during this time that she was appointed to a professorship at the University of Strasbourg.

The fission affair clearly illustrates the imbalance between achievement and recognition. When Fermi concluded in 1934 that his Roman team had artificially produced new heavier-than-uranium elements by bombarding the last elements of the periodical table with neutrons, Ida resolutely disagreed. Because the products did not show the expected properties of periodicity, she correctly suggested that what the Fermi group had accomplished was nuclear fission of heavy elements into much lighter elements, a hitherto unknown reaction. This contradiction of Fermi's 1934 interpretation seems to have ignited a spark that was conveniently extinguished by extra-scientific considerations, especially after Fermi's results were confirmed by Otto Hahn's team in Berlin between 1935 and 1938.[43] In 1935 Walter complained to Hahn in a Berlin seminar that Ida's hypothesis of nuclear fission had not even been examined, to which Hahn responded that he had not wanted to embarrass Walter's wife.[44] Those who should subsequently have been embarrassed were Hahn and Fermi themselves (Fermi even receiving a Nobel Prize in 1938 for work related to the supposed production of element 93 by fusion[45]).

Ida may also have suffered because she had her own ideas in the field of physics, and there was a dispute in atomic theory between physicists and chemists. Mary Jo Nye points out that it might have been the powerful influence of Ostwald's lack of interest in contemporary advances in physics that led German chemists to ignore the new quantum physics.[46] The historiography of science has helped establish a supposed scientific priority for the discipline of physics over chemistry, despite historiographic evidence to the contrary, and Nye illustrates a long-standing tension between the disciplines.[47] This strain is still present in science today, and it fuels ongoing discussions.[48] It has been argued that physico-chemical theories are not logical extensions of theories in physics and accordingly that chemistry does not reduce to physics.[49] Although Ida constantly insisted on the fission hypothesis, her claim was ignored by many prominent nuclear physicists, although in the end her interpretation prevailed.[50]

Conclusion

It is apparent from Ida's sole-authored publications that not only did she work with practical objectives concerning chemical elements and isotope separation, but she was also ready to question the fundamentals of the periodic system and more directly to seek new insights

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into the structure and essence of matter. In doing so, she was frequently willing to contradict prevailing scientific theories, to the point of calling attention to their becoming 'dogmas'. Her emphasis, allied to a sharp tongue, might have made her unpopular among physicists, thus contributing to the difficulties that surfaced around the controversial element discoveries, in particular the 'false' discovery of masurium. It is to her credit that her profound knowledge of the Periodic Table made possible her criticism of the alleged nuclear fusion in 1934. Later accusations of Nazi collaboration directed at the Noddacks influenced the historical assessment of their scientific relevance and are still present in the accounts related to element 43. This has probably also had a role in the scant attention given to Ida's hypothesis concerning the relative abundance of the elements in the Universe.

In conclusion, I point out how suggestive the history of science can become in relation to scientific matters *per se*. Besides its primary function of providing a better comprehension of past events and their context, the history of science also has propaedeutic potential, allowing us to recover ways to a future re-evaluation of scientific issues that emerge as still open to discussion.

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Notes

1 The use of the word 'discovery', though quite routine, is generally misleading in the history of science. The search for new elements in the first half of the twentieth century involved fierce competition, and in the case of the isolation of the Periodic Table's element 43 an earlier claim had been made by the Japanese chemist Masataka Ogawa, who published his result in 1909 and named it nipponium. No replication of his results was successful, and the claim was forgotten. Recent re-examination of his data seems to indicate that he had instead isolated element 75; see Eric Scerri, *A tale of seven elements* (Oxford University Press, 2013), pp. 102–103 and 221.

2 Brigitte van Tiggelen and Annette Lykknes, 'Ida and Walter Noddack through better and worse: an Arbeitsgemeinschaft in chemistry', in *For better or for worse? Collaborative couples in the sciences* (Science Networks, Historical Studies no. 44) (ed. A. Lykknes *et al.*), pp. 103–147 (Springer, Basel, 2012). The assessment of individual authorship by van Tiggelen and Lykknes was based on manuscript laboratory notebooks, but it should be remarked how difficult it is to judge *ex post facto*, because it might happen that the main author was not always the one taking notes in joint research work. For example, the 1937 article, written for a Russian publication under Walter's name alone, was in fact by Ida, because Walter did not have time to prepare it.

3 Original research on this topic appears in Brigitte van Tiggelen, 'The discovery of new elements and the boundary between physics and chemistry in the 1920s and 1930s. The case of elements

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43 and 75', in *Chemical sciences in the 20th century* (ed. Carsten Reinhardt), pp. 131–144 (Wiley-VCH, Weinheim, 2001). An overview of the contributions of Ida and Walter, as well as their joint work, is presented by Van Tiggelen and Lykknes, *op. cit.* (note 2). The main biographical source on the Noddacks (very helpful, although laden with a laudatory tone) is by a former student of Walter's, Hans Georg Tilgner: *Forschen, Suche und Sucht. Kein Nobelpreis für das deutsche Forscherehepaar, das Rhenium entdeckt hat. Eine Biografie von Walter Noddack und Ida Noddack-Tacke* (Libri Books on Demand, Norderstedt, 1999). Also interesting are the notes of Fathi Habashi, *Ida Noddack (1896–1978). Personal recollections on the occasion of the 80th anniversary of the discovery of rhenium* (Métallurgie Extractive Québec, Québec, 2005). Fathi was personally acquainted with Ida, and studied in Germany under Friedrich August Henglein, another disciple of Walter's.

4 Van Tiggelen, *op. cit.* (note 3), pp. 133 and 136–140.

5 Ida Noddack, 'Das periodische System der Elemente und seine Lücken', *Angew. Chem.* **47**, 301–305 (1934).

6 Reviews and abstracts of papers written by the Noddacks appeared regularly in the USA. Examples are 'Rhenium', *Chem. Abstr.* **24**, 3959 (1930); 'Two new elements of the manganese group', *J. Chem. Educ.* **2**(10), 939 (1925); 'The element rhenium', *J. Chem. Educ.* **9**(1), 161–162 (1932). Ida and Walter published a book collecting data about the new element: *Das Rhenium* (Leopold Voss, Leipzig, 1933). The book was cited in the USA, for example in A. Gosse, 'The chemical properties of elements 93 and 94', *J. Am. Chem. Soc.* **57**, 440–441 (1935), at p. 440.

7 Mary Elvira Weeks, *The discovery of the elements* (Mack Primburg, Easton, PA, 1933), pp. 321–322.

8 An advertisement for a new Periodic Table (1941), compiled by Henry Hubbard (from the US Bureau of Standards), also showed masurium and rhenium. The advertisement was often displayed on the pages of the *Journal of Chemical Education* during the war years.

9 Pieter van Assche reopened this controversy in 1988. Accordingly, John T. Armstrong, of the US National Bureau of Standards, used modern equipment and spectral analysis to confirm that the spectral lines attributed to masurium by the Noddacks were consistent with element 43. He concluded from this that their equipment was sensitive enough to detect its traces in the 1920s; see P. van Assche & J. T. Armstrong, *J. Res. Natl Inst. Stand. and Tech.* **104**, 599 (1999). For a reappraisal of the possibility of the actual discovery of element 43 by the Noddacks, see the article by Roberto Zingales, 'From masurium to trinacrium: the troubled story of Element 43', *J. Chem. Educ.* **82**, 221–227 (2005), and the ensuing discussions by Fathi Habashi and others in the same journal.

10 For example, Eric Scerri wrote in 2007: 'The evidence marshaled by Van Assche is rather convincing and implies that the first isolation of element 43 involved a naturally occurring element'; see Scerri, *The Periodic Table. Its story and significance* (Oxford University Press, 2007), p. 174. In 2013 Scerri returned to the idea that element 43 could only be produced artificially, admitting that he had 'erroneously accepted this work as evidence for the validity of the discovery by Noddack *et al.* in 1925'; see Scerri, *A tale of seven elements* (Oxford University Press, 2013), p. 224, n. 17. Yet Scerri followed this change of opinion with the observation that the discovery of a natural fission reactor in Gabon, which was active 2 billion years ago, showed that several elements previously thought to be absent from the Earth did occur naturally; these elements included technetium (*ibid.*, pp. 138–139).

11 It is still useful to read the earlier presentation of this problem by Allan Franklin in *The neglect of experiment* (Cambridge University Press, 1986), as well as the more recent discussion by Harry Collins and Trevor Pinch in *The Golem. What you should know about science* (Cambridge University Press, 1998).

12 'The making of the missing chemical elements', *Nature* **159**, 8–10 (1947).

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13 The IUPAC records are held at the Chemical Heritage Foundation in Philadelphia, Pennsylvania. Gradually the prohibitions on German participation were lifted, as can be seen from a 'Report' on the Symposium on Geochemistry held in Zurich on 11–13 August 1953, at which Walter Noddack gave a lecture on energy storage in minerals (IUPAC Addenda, Box 214). The Federal Republic of Germany was fully reinstated in 1955.

14 *Nomenclature of Inorganic Chemistry* (*1957 Report*) (Butterworths Scientific Publications, London, 1959).

15 Also quoted in Scerri, *op. cit.* (note 1), pp. 136–137; the full transcription by the American Institute of Physics can be accessed at http://www.aip.org/history/ohilist/4876.html.

16 The original work, 'Die Häufigkeit der chemischen Elemente', appeared in *Naturwissenschaften* **18**, 757–764 (1930) and was duly reviewed as 'The distribution of the chemical elements' in *Chem. Abstr.* **24**, 5546 (1930). Also related to this subject is their more focused article in *Zeitschrift für physikalische Chemie* of 1931, reviewed as 'Occurrence of the platinum metals in the earth's crust', *Chem. Abstr.* **26**, 672 (1931).

17 In 1917 William Harkins had studied the abundance of isotopes as a function of the atomic number, and Richard Sonder (whose works were known by Ida Noddack) suggested that these relationships reflected the structure of the nucleus. See Helge Kragh, 'An unlikely connection: geochemistry and nuclear structure', *Phys. Perspect.* **2**, 381–397 (2000). The idea of nuclear shells was later developed by Maria Goeppert-Mayer and Johannes Jensen (for which they were awarded the 1963 Nobel prize). As Kragh notes, Maria Goeppert-Mayer arrived at this conception while trying to understand primordial element formation.

18 I refer the interested reader to the comprehensive work of Eric Scerri, *Selected papers on the Periodic Table* (Imperial College Press, London, 2009). In it, Scerri argues that philosophical aspects continue to underwrite the periodic system and that its future is consequently open to scrutiny and debate. See also Michael Gordin, 'The short happy life of Mendeleev's Periodic Law', and Michael Laing, 'Patterns in the Periodic Table—old and new', in *The Periodic Table into the 21st Century* (ed. Dennis Rouvray and Bruce King), pp. 41–90 and 123–143, respectively (Research Studies Press, Baldock, 2004). An interesting and comprehensive survey of the then existing proposed structures for the Periodic System is Edward Mazurs, *Graphic representations of the Periodic System of chemical elements* (published by the author, 1957), and its revised edition *Graphic representations of the periodic system during one hundred years* (University of Alabama Press, Tuscaloosa, AL, 1974).

19 See Scerri, *op. cit.* (note 10), pp. 278–280.

20 For a provocative alternative proposal of a hitherto unchecked structure of the nucleus, see a description of Robert Moon's model accounting for the ordered growth of the nuclei with increasing atomic weight in Laurence Hecht, 'Mysterium Microcosmicum: the geometric basis for the periodicity of the elements', *Campaigner* **1**(2), 18–30 (1988). This goes beyond the idea of 'shells' in the nucleus, assuming that its constituents form internal well-ordered geometrical structures.

21 *Entwicklung und Aufbau der chemischen Wissenschaft* (Hans Ferdinand Schulz, Freiburg, 1942). This remains a very readable and elegantly written work. One of its highpoints is the down-to-earth yet rigorous definition and sharp distinction between scientific observation/experimentation, hypothesis, and theory. Ida and Walter were jointly the authors of another, earlier book for a general readership on the history and applications of geochemistry: *Aufgaben und Ziele der Geochemie* (Hans Ferdinand Schulz, Freiburg, 1936).

22 'Über die Allgegenwart der chemischen Elemente', *Angew. Chem.* **49**, 835–841 (1936); reviewed as 'The over-all occurrence of the chemical elements', *Chem. Abstr.* **31**, 586 (1936). The Noddacks had published a preliminary version in Sweden in 1934, reviewed as 'The geochemical distribution coefficient of the elements', *Chem. Abstr.* **29**, 707 (1934). Ida also drew on her research on rare earths of meteorites in 'Die Häufigkeit der Seltenen Erden in Meteoriten', *Z. Anorg. Allg. Chem.* **225**, 337 (1935).

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23 Ida's paper appeared before the publications of Carl von Weizsäcker about element transmutations inside the stars (1937, 1938), and George Gamow on the origin of elements (1946), as Kragh, *op. cit.* (note 17), points out.

24 The prospect of a new science of materials based on isotopes, including transuranic ones, was presented in Jonathan Tennenbaum, 'The isotope economy', *21st Century* (Fall–Winter), 8–37 (2006) (see http://www.21stcenturysciencetech.com/2006_articles/Isotope_Economy.pdf).

25 See I. and W. Noddack, 'Rhenium and its present technical uses', *Chem. Abstr.* **45**, 9441 (1951); I. Noddack and E. Wicht, 'Separation of rare earths in an inhomogeneous magnetic field', *Chem. Abstr.* **50**, 13–14 (1956); W. and I. Noddack and E. Wicht, 'Separation of rare earths in an inhomogeneous magnetic field', *Chem. Abstr.* **52**, 11642 (1958); W. and I. Noddack, 'Determination of traces of sulfur', *Chem. Abstr.* **53**, 12929 (1959); H. Thies, W. Oppelt, W. and I. Noddack, 'The anticoagulation effects of twelve rare-earth metals in animals', *Chem. Abstr.* **57**, 3083–3084 (1962).

26 This was the official organ of the International Society for Research on Nutrition and Vital Substances, with its headquarters in Hanover, West Germany. Ida was an honorary member, in the company of such well-known figures as Linus Pauling and Albert Schweitzer.

27 'Zur Allgegenwartstheorie der chemischen Elemente', *Vitalstoffe Zivilisationskrankh.* **6**, 15–19 (1961).

28 'Über das Rhenium und die Allgegenwart der chemischen Elemente', *Vitalstoffe Zivilisationskrankh.* **8**, 194–202 (1963). In the same edition (pp. 44–47) she published a more topical subject, an account of the procedures for the chemical dissolution of human kidney stones. The source of a chemical deduced from minute impurities present in the compound had been first investigated in 1934 by Ida and Walter; see 'Source studies', *J. Chem. Educ.* **12**, 98 (1935).

29 'Zur Allgegenwart der chemischen Elemente', *Vitalstoffe Zivilisationskrankh.* **10**, 83–86 (1965).

30 A. Vynogradov, *The geochemistry of rare and dispersed chemical elements in soils* (Consultants Bureau, New York, 1959), p. 136, corroborated Ida's idea (without mentioning her): 'It may be asserted that all elements occur in soils in a greater or lesser amount.'

31 Van Tiggelen, *op. cit.* (note 3), p. 200; Habashi, *op. cit.* (note 3), p. 79.

32 In relation to the formation of elements in the Universe, several speculations were imagined by Walther Nernst and James Jeans; see Helge Kragh, 'Superheavy elements and the upper limit of the periodic table: early speculations', *Eur. Phys. J.* H **38**, 411–431 (2013). Kragh notes that these and other scientists were willing to engage in speculations almost completely divorced from empirical data. I fully agree with Kragh that speculations are also an important part of the history of science.

33 Brian Mason, *Victor Goldschmidt: father of modern geochemistry* (Geochemical Society, San Antonio, TX, 1992), pp. 74–76. In his 'Ninth Symphony', Goldschmidt speculated on the possible existence of transuranic elements, as Ida had already done in 1934. It may be a coincidence, but Ida and Goldschmidt both attended a conference in Moscow in 1934 to commemorate the centenary of the birth of Mendeleev.

34 Apparently, the only historian of science who has paid attention to the Noddacks' pioneering work in geochemistry is Helge Kragh; see his 'From geochemistry to cosmochemistry: the origin of a scientific discipline, 1915–1955', in Reinhardt (ed.), *op. cit.* (note 3), pp. 160–190. Kragh notes that in 1901 the American geologist Oliver Farrington had hypothesized that the relative abundance of the chemical elements in meteorites and on the Earth were practically the same, a fact corroborated by the chemical analysis later undertaken by Ida.

35 Ute Deichmann, '"To the Duce, the Tenno and our Führer: a threefold Sieg Heil". The German Chemical Society and the Association of German Chemists during the Nazi Era', in *The German Physical Society in the Third Reich. Physicists between autonomy and accommodation* (ed. Dieter Hoffmann and Mark Walter), pp. 280–316 (Cambridge University Press, 2012). Walter Noddack expressed concern in a meeting of the Association of German Chemists in 1939

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because the government wanted to recognize chemical technicians as possessing the same status as academically trained chemistry doctors. This political move could be seen as a way of opening a door for party members wishing to enter the organization.

36 Jeffrey Allan Johnson, 'The case of the missing German quantum chemists: on molecular models, mobilization, and the paradoxes of modernizing chemistry in Nazi Germany', *Hist. Stud. Nat. Sci.* **43**, 391–452 (2013).

37 Klaus Hentschel, 'Distrust, bitterness, and sentimentality. On the mentality of German physicists in the immediate post-war period', in Hoffmann and Walter (eds), *op. cit.* (note 35), pp. 317–366.

38 Johnson, *op. cit.* (note 36).

39 Alan Beyerchen, *Scientists under Hitler. Politics and the physics community in the Third Reich* (Yale University Press, New Haven, CT, 1977), pp. 197–210. See also Andreas Karachalias, *Erich Hückel (1896–1980): from physics to quantum chemistry* (Boston Studies in the Philosophy of Science, vol. 283) (Springer, Dordrecht, 2010), pp. 171–175.

40 Klaus Hentschel and Ann Hentschel (eds), *Physics and National Socialism. An anthology of primary sources* (Birkhäuser, Basel, 1996). See the correspondence of Gustav Mie to Max von Laue of November 1934 (*ibid.*, pp. 87–91), citing the academic opposition to Walter Noddack's appointment to replace Georg Hevesy, who was Jewish and had been a partner of Fritz Paneth, before fleeing from Germany. The biographical profile of Ida Noddack presented in this same 1996 book still refers to her 'pro-Nazi involvement' (p. xl). In general, the rigour of denazification was gradually lessened, and by 1951 there was a tendency to cover up the past not only of the Germans but also of the Western Allies, who were anxious to draw on the technical expertise of German scientists.

41 Carola Sachse, "'Whitewash culture': how the Kaiser Wilhelm/Max Planck Society dealt with the Nazi past", in *The Kaiser Wilhelm Society under National Socialism* (ed. Suzanne Heim, Carola Sachse and Mark Walker), pp. 373–399 (Cambridge University Press, 2009), at p. 385.

42 Tilgner, *op. cit.* (note 3), pp. 132–138.

43 Johnson, *op. cit.* (note 36), p. 441.

44 Jonathan Tennenbaum, *Kernenergie, die weibliche Technik* (Dr. Böttiger Verlag, Wiesbaden 1994), pp. 211–227; Tilgner, *op. cit.* (note 3), p. 206. Ruth Lewin Sime, 'The search for artificial elements and the discovery of nuclear fission', in Reinhardt (ed.), *op. cit.* (note 3), pp. 146–159.

45 According to the Nobel Committee, the 1938 Nobel Prize in Physics was awarded to Fermi 'for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons'. However, Fermi had not discovered any 'new elements', as Ida argued, even though he maintained in his Nobel Lecture (12 December 1938) that he had produced elements 93 ('ausenium') and 94 ('hesperium'), precisely the mistake pointed out by Ida. It is interesting to note that Ida's 1934 article dismissed not only Fermi's assumption but also an earlier claim for element 93 made by the Czech chemical engineer Odolen Koblic (which he called 'bohemium'); see Kragh, *op. cit.* (note 32), p. 415.

46 Mary Jo Nye, *From chemical philosophy to theoretical chemistry. Dynamics of matter and dynamics of disciplines, 1800–1950* (University of California Press, Berkeley, CA, 1993), pp. 6–8.

47 *Ibid.*, pp. 32–55.

48 See Nikos Psarros, 'The lame and the blind, or how much physics does chemistry need?', *Found. Chem.* **3**, 241–249 (2001); also Ana Simões and Kostas Gavroglu, 'Issues in the history of theoretical and quantum chemistry, 1927–1960', in Reinhardt (ed.), *op. cit.* (note 3), pp. 51–74.

49 G. K. Vemulapalli, 'Physics in the crucible of chemistry. Ontological boundaries and epistemological blueprints', in *Philosophy of chemistry. Synthesis of a new discipline* (Boston

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Studies in the Philosophy of Science, vol. 242) (ed. Davis Baird, Eric Scerri and Lee McIntyre), pp. 191–204 (Springer, Dordrecht, 2006).

50 In a 1966 radio interview Otto Hahn finally confirmed, after a long silence on the matter, that Ida was right: '*die Ida hatte doch Recht*' (Tilgner, *op. cit.* (note 3), p. 216). According to Fathi Habashi, Hahn's refusal to acknowledge Ida's work, even after she wrote a note in *Die Naturwissenschaften* in 1939 observing that she had correctly identified fission in 1934, tarnished his image as a scientist (Habashi, *op. cit.* (note 3), p. 80). But it probably did far greater harm to Ida's contemporary reputation.

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