Herman F. Mark (1895–1992): Viennese Born 'Ambassador' of Macromolecular Research

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Many different aspects can be told about the life of Herman Francis Mark: The story of Austria's dealing with the legacy of "the most distinguished chemist"[1] of pre-war Austria, today; the story of not re-employing Mark in Austria or Germany after World War II, but of granting him awards for his academic achievements; or the story of the making of Mark's biography.

Studying the available biographical sources, memoirs and autobiographical notes, it is not easy to escape the narrative of tremendous success told of him by former students, colleagues and by himself. In honour of his birthdays late in life many highly sponsored international symposia were held. For his 85th birthday, for instance, seven major celebrations were held to commemorate Marks scientific achievements: one each in New York, Philadelphia, Chicago, Moscow and Germany, and two in Israel. Once, Mark said: "My birthday is like the Salzburg Festival".[2]

Many scientists, who later became world-famous, have been students of Mark, for instance: Edward Teller, Leo Szilard and Marx Perutz. The double Nobel Prize winner Linus Pauling declared himself repeatedly 'deeply indebted' to Mark,[3] "I think of him, with affection and admiration, as a pioneer in modern structural chemistry and an important early contributor to its development".[4] After Mark's death at the age of 97 his autobiography was published in the series "Profiles, Pathways and Dreams: Autobiographies of Eminent Chemists", under the (sub-) title *A Century of Progress*.[5] This book rounded off the many publications on his splendid biography. A memorial conference was organised that paid tribute 'to the greatness' of the celebrated researcher and academic teacher.[6] In fact, he had received more than a dozen honorary doctoral decrees. He was also an elected member of more than two dozen Academies of Sciences and he had received the highest awards world wide, with one exception, the Nobel Prize.

Decades ago, Mark –the chemist, physicist and inventor– was also honoured, but not celebrated, in Austria. However, compared to other Austrian refugee scholars

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(for example, Karl Popper, Erwin Schrödinger, and Sigmund Freud) the name of Austria's once most distinguished chemist is not now in the public eye of Vienna.

The undivided international acknowledgement in the world of science rests on Mark's important academic work and achievements. To put it briefly: Firstly, on his advancement of a new academic discipline and a new field of research. He was acknowledged as the 'father of Polymer Science'. However, Mark's approach to the study of polymers had much wider implications. The study of macromolecules made him not only a pioneer in polymer science, but also an initiator of the beginnings of structural chemistry. Max F. Perutz, who had been placed as a student with Desmond Bernal in Cambridge in 1936, would later use the method of his teacher Hermann Mark, x-ray crystallography –to solve the alpha helix structure of haemoglobin. Deciphering the alpha helix paved the way to solve the structure of more complex proteomic systems. Students of Perutz, Watson and Crick, elucidated the double helix of DNA. Thus, the methodological approach, the Viennese chemist Mark had applied to polymer science, paved the way to the study of proteins and to other advances in molecular biology.

Secondly, Mark was acknowledged both as an industrial chemist and as well as an academic. He had realised very early the importance and advancement of polymer chemistry as a new branch of the subject. In the interwar period, the research on synthetic polymers had not created much impression among the advocates of traditional organic and physical chemistry in the universities, although cellulose had been utilised on an industrial scale as early as 1900. However, Mark had recognised the mood of the times. Ambitious to solve relevant problems, he had started to investigate the structure of natural polymers, in order to elucidate its influence upon their technical properties, such as strength, elasticity, softening point etc. These investigations were crucial for the further development of synthetic fibres. Industry and non-university research institutions were the first to recognise the importance of fundamental and applied polymer research. The industrial research done during the war was primarily empirical. Thus it remained for Hermann Mark at IG-Farben-Industry in Ludwigshafen, and Wallace H. Carothers at DuPont Company in Wilmington, Delaware to take a step forward. The work associated with Mark and Carothers signalled a breakthrough. Mark's research advanced the change in the approach to polymers, that is to say, from an empirical practise to theoretical, science based approach.

In the 1930's the research group directed by Carothers was to announce the synthesis of a synthetic polymer which, for the first time in history, had properties superior to natural fibres. The polymer was called 'Nylon'. Just when the true magnitude of the discovery of nylon was becoming apparent in 1937, "worsening

bouts of depression" prompted Carothers' suicide[7]. However, within academic circles, Carothers' work was not considered as very serious science, as his position was that of an industrial chemist, in contrast to Mark, who had gained experience in both industrial and in academic research.

Thirdly, Mark's greatest accomplishment was, as his son Hans put it, as a pioneer in applying modern physics to chemistry.[8] Hermann Mark became one of the leading investigators in the field of the use of an infant analytical technique, x-ray diffraction, which provided irrefutable proof for the macromolecular structure of colloidal substances, like cellulose, rubber and silk. Mark's experience in x-ray work deepened the understanding of the polymer structure, which had been crucial for the further development of synthetic fibres, such as nylon, acrylic and polyester.

However, it remained for Mark to finally contribute decisively to the acceptance of polymer chemistry as a truly scientific discipline, which deserved to be promoted and incorporated in the academic curricula. Mark, who had been forced to escape the Nazi terror in Austria, became an "agent of change", as Norbert M. Bikales of the National Science Foundation (Washington) put it in a lecture at the Memorial Symposium for Herman Mark in 1992: "He was future oriented until the end. More than any other person he was responsible for spreading the gospel of macromolecules" in the United States, where serious academic research in polymers had not existed before he arrived, and beyond.[9] The only polymer scientist working in an academic position was Carl S. Marvel at Illinois University. Marvel had done work in synthesizing polymers but had not been interested in how they behaved. It was Mark who became the "ambassador" for polymer chemistry and education.[10]

The achievements ascribed to Mark are impressive. They cannot be understood fully without considering the historical circumstances of the advancement of Mark's scientific career. In 1932, when Hermann Mark was appointed professor and director of the so called "First [I.] Chemical Laboratory" of the University of Vienna[11], he brought a formidable scientific career in industry to a satisfactory but temporary end. After having finished studies in organic chemistry in Vienna in 1921, he changed to the University of Berlin as a post-doctoral instructor. Soon Fritz Haber recommended him to move to the Kaiser Wilhelm Institut für Faserstoffchemie, the newly established fibre Research Institute. This institute had been the first to study the structure of high-molecular-weight natural substances by the application of x-ray techniques. The ultimate goal of studying "Faserstoffe" was the establishment of quantitative values in the structure of organic molecules. At the Institute for Chemistry of Fibrous Material Mark esta-

blished himself as an expert crystallographer, who managed to decipher structures of inorganic and of organic substances.

In 1927 Mark accepted the position of a research manager in the laboratories of I.G. Farben Industries, Germany's largest chemical corporation at that time. There, work was conducted by a group of physicists, chemists, and engineers. The x-ray studies led to the determination of the structure of cellulose, silk, rubber and other natural high polymers. Their work concentrated on the investigation of organic structures for correlation with their technical properties, such as strength, elasticity, water retention, etc. The purpose of research at Ludwigshafen was clear, the goal of developing synthetic substitutes for natural fibres. For this purpose, Mark coordinated and organised research on macromolecules in three sections, synthesis, characterisation and application. Since this model had proved to be of value, he would later organise research on this manner in Vienna and New York. The collaborative research was published in the famous book *Der Aufbau der hochpolymeren organischen Naturstoffe,*[12] edited by Mark and by the head of the research laboratory, Kurt H. Meyer.

When the political climate worsened in Germany in 1932, the son of a Protestant father with Jewish descent was warned not to continue to hold the position at Ludwigshafen. Mark was prompted to accept a chair at Vienna University, where he was appointed Professor of Chemistry in 1932. Mark succeeded Professor Rudolf Wegscheider, and he re-organized the "First [I.] Chemical Laboratory". At that time structural chemistry was an unusual, one might say, a marginal field of academic research. Structural chemistry was at the time an industrial domain; academically it was not yet considered a serious discipline. Nevertheless, Mark introduced x-ray analysis, and concentrated on the design of the first academic curriculum for polymer technology. Thus he founded the first comprehensive polymer research and teaching institute.[13]

In the 1930s the Viennese academic system was in a bad condition. Anti-Semitism was at least as strong as in Germany. Young Jewish scholars and scientists were prevented from following academic careers. Thus, much of the academic discourse took place outside of the university. In interwar Austria, many new approaches to scholarship and science were developed at a non-university level. Thus, most of today's renowned intellectuals were not part of the academic system rather they belonged to private research groups and academic circles. In fact, third party encouraged or financed research projects turned out to be most innovative. Some of the then marginalised Viennese scientists and scholars went on to significantly transform science and scholarship.[14]

The Viennese School of high-polymer research, developed on both a university and on a non-university level: The "First [I.] Chemical Laboratory", which was directed by Hermann Mark, was part of the Vienna University. The "Second [II.] Chemical Laboratory" was headed by Professor Dr. Ernst Späth until his death in 1946. As a Professor, Mark was supposed to educate people. However, apart from producing chemists, Mark carried out research that was financially supported by IG Farben. Doing research in the new field of polymers seemed to be attractive for young scientists. The younger generation was attracted by the ongoing controversies in the age of the foundation of polymer science. Thus Mark's research programme attracted a number of scientifically ambitious doctoral students in chemistry, physics and mathematics, who were considered to be Jews. After World War I they rarely had a chance to obtain a post in Austria because of Anti-Semitic discrimination.

Today, one knows of many young Jewish scientists, excluded from academic careers, who have moved into cognitively underdeveloped academic fields, so-called 'border sciences.' In Germany, they were not allowed to compete scientifically with the Professors, who occupied the centre of the discipline; thus, they moved to peripheral universities.[15] In Austria, marginalised scholars remained located in a geographical sense in the centre, in Vienna. However, they organised themselves informally outside of the universities, setting up, as already mentioned, a second "scholarly culture".[16]

When Mark was appointed professor, he switched over to basic research, since the synthesis of new monomers and polymers could be better performed in Ludwigshafen. He concentrated upon the mechanisms of polymerisation. Hermann Mark hired a number of doctoral students and young assistants, among them were Johann Wolfgang Breitenbach, Eugene Guth, Friedrich Eirich, Robert Simha, Engelbert Broda and Max Perutz. They were set to determine the relationship between molecular weight and viscosity. Mark initiated the statistical treatment of macromolecular substances. The most important achievement was the formulation of a statistical theory of the elasticity of rubber-like molecules and the mechanical properties of rubber. Many of Mark's collaborators were Jewish by origin, as Mark would soon become himself, according to the Nuremberg laws.

In 1937, when the Nazis were ready to take over Austria, the manager of the large Canadian International Paper Company, Dr. C. B. Thorne, submitted an offer to Mark to take over the position of a research manager in the central laboratory in Hawkesbury, Ontario, Canada. In April 1938, after having been dismissed and arrested for interrogation, Mark accepted the Canadian offer. The visa-problem was solved by the Canadian ambassador. Mark handled the money-transfer pro-

blem scientifically: He bought platinum/iridium wire from a number of Viennese suppliers, and bent the wire into coat hangers. Hermann Mark knew he had to leave Austria, and he took his wife, their children and a Jewish niece in an adventurous trip by car. They mounted a Nazi flag on the radiator of their car, strapped ski equipment to the roof, and drove from Vienna into Switzerland on May 10th, 1938.[17] As Mark himself, most of his Jewish scientific collaborators also had to leave Austria. Though with one consequence, on February 7th, 1939 the Manchester Guardian had to report of the "break up of the School of Chemistry which Professor Mark had organised in Vienna".

Concerning the careers of Austrian academic refugees one important fact may be noticed, namely, the significant correlation between, what might be called, the 'paradigmatic youth' of a field of scientific research and the proportion of refugee scholars from it. In other words, the more the scientists shifted away from the dominant paradigm, the higher the probability of their becoming émigrés during the rule of National Socialism, and also the higher the probability of their fitting in culturally more successfully overseas and of their continuing academic careers in the Anglo-American world. To put it briefly, there was an obvious relation between social marginality, innovation and the continuation of academic careers in the countries of refuge. This fact can be confirmed in many disciplines, from which scholars and scientists emigrated after 1933 and 1938 respectively; among them those in the fields of economics, the social sciences, humanities and the natural sciences[18], in chemistry in particular. As to the members of the research group of Hermann Mark, their expulsion turned out to be the springboard for successful academic and professional careers in the Anglo-American world.

By the time Mark had to leave Austria in 1938, he had made important contributions to the field of polymer science. First, he had initiated a theory of the mechanisms of polymerisation processes. Second, he had experimentally proofed the influence of the structure of natural and synthetic polymers upon properties, and third, his systematic investigations on the relationship between structure and properties of macromolecular systems provided the knowledge for the design of new polymers with certain desired and required properties.

In 1936, the Rockefeller Foundation complained about the relative weakness of those fields of chemistry in the U.S., which were meant to contribute most directly to organic structural chemistry, a field of research notably developed in Europe. Thus, Mark's qualifications gradually gained in importance. He was already then recognised as one of the world's most important high polymer researchers. Since there had not yet been any organised academic research in high polymer chemistry in North America, Mark soon acted as intermediary in this new discipline,

transferring the European style of physically based research in polymer chemistry to Canada and the United States of America.

In the autumn of 1938, after his arrival in Canada, Herman Francis Mark, as he now called himself, was appointed research manager for the Paper Company in Hawkesbury. He immediately set about modernising the world's biggest paper plant and supplier of cellulose, introducing new theories and methods, for instance, in the areas of the influence of molecular weights on the mechanical properties of organic and synthetic fibres. The Canadian International Paper Company was the main supplier of cellulose for the DuPont Company. At that time the DuPont Company was the largest producer of rayon in America. They were interested in the characterisation of cellulose. Since none of the American universities had departments of polymer science at that time, DuPont placed Mark as an Adjunct Professor at the Polytechnic Institute of Brooklyn (New York) in 1940. After the war he was appointed to the first created Professorship in Polymer Science and established polymer chemistry as a part of the general chemistry curriculum.

The archival sources do not verify Mark's official story of straight away emigration from Austria to North America. After Hitler's occupation of Austria, the 'Anschluss', the London Society for Academic Refugees tried to rescue Mark and seven other eminent Austrian scientists for British industry or universities. Among them, were three Austrian Nobel Prize winners (Franz Viktor Hess, Otto Loewi and Erwin Schrödinger). Outstanding British scientists (Joseph Needham, Eric K. Rideal and Robert Robinson) and industrial tycoons had described Mark as "one of the best researchers living in the field of x-ray analysis of solid bodies, such as biological structures and polymers".[19] They organised a research fellowship at Balliol College, Oxford and assured Mark, that he and his family "would not starve", if he decided for England. Mark declined the offer which had been delivered by the British intelligence service in Vienna. England seemed to him not to be the right place to go. However, after having spend one year in Hawkesbury, Mark felt isolated there. He was then even ready to come to England as a 'voluntary' and to put his abilities at the disposal of war chemistry. Mark's unique knowledge was much appreciated by his British colleagues. W. Lawrence Bragg offered him a fellowship at Cavendish laboratory, and other academic and industrial offers were made. However, the permission to go was rendered valueless as the academic appointment in New York prevented Mark from leaving America. Soon, Mark was to become involved in a number of military projects but only a few of them had to do with polymers.

The so-called Shellac Bureau, whose function was the testing and chemical characterisation of shellac, was based in Brooklyn. Brooklyn was the major port of entry for shellac. Shellac, a natural polymer, was used in the optical industry, dental technology, and for phonograph records, pressed from shellac compounds. Since shellac needed to be imported from Asia, the war stimulated a search for a synthetic substitute. In respect to this, Mark's research and consulting experience at I.G. Farben was most valuable. He was well informed about synthetic resins with properties even superior to those of shellac. Mark was assigned to the Shellac Bureau, and in 1941 he was named director.

During the war, the United States lost access to natural rubber. The impact of the developing rubber shortage stimulated the government to sponsor a synthetic rubber research program. Soon about 2500 to 3000 chemists and engineers were occupied with research into synthetic rubber. Mark was familiar with the know-how, since he had worked in a synthetic rubber plant. Buna S and Buna N had been developed at I.G. Farben laboratories. Mark was assigned to a committee that tried to help the industry develop synthetic rubber technology. With Mark's collaboration, the American rubber industry was able to develop synthetic rubber and to produce the necessary quantities of rubber needed during World War II.

Simultaneously with his war work engagements, Mark was working to strengthen polymer research and education at 'Brooklyn Poly.' When Mark had joined the school, Polymer science was not as yet very prestigious. However, during the war it became a new interdisciplinary and academic branch of chemistry. Industry had sensed its novelty and utility. In effect, the Polymer Research Institute was established and Brooklyn Polytechnic became the first institute in the United States dedicated to polymers. Mark used the experiences he had collected in Berlin, Ludwigshafen and Vienna. He designed the first post-graduate program of polymer studies in America in a similar way to that which he had done at the University of Vienna a decade earlier, though on a much larger scale.[20]

After World War II Mark became one of the most important exponents of principles of polymer science: firstly, in regard to interdisciplinarity. Mark created the Polymer Research Institute in Brooklyn based on his experience-based conviction that systematic progress could only be expected, if organic chemists, physical chemists and at least one physicist were assembled into a team to conduct research. According to this he organised the Institute in three sections following the Viennese model, synthesis, characterisation and application of high polymers. Secondly, by establishing co-operations between industry and fundamental academic research. Thirdly, as the interest increased rapidly, Mark initiated the publication of a series of monographs on 'High Polymers'. In 1946 he started publishing

the Journal of Polymer Sciences; and finally, in assembling a number of qualified co-researchers.

Mark also played the role of a mediator and recruiter for some of his former Viennese collaborators. As polymer research was still in its infancy in America, over the course of the 1940s Mark brought over some former Viennese colleagues to join him, the physicist Robert Simha, the organic chemist Robert Raff and the physical chemist Frederic R. Eirich, all of whom had left Austria after the 'Anschluss' (1938) and were scattered across the British Empire. Other former students did not comply with Mark's request, for example, the Austrian nuclear physicist Engelbert Broda decided to stay at the Cavendish Laboratory in Cambridge, where he was working on nuclear chain reaction, and Max Perutz was already too involved in preparing his masterpiece –the analysis of the structure of haemoglobin, for which he earned the Nobel Prize in 1962.

After the war Mark's former students dispersed and founded new small research groups on polymer chemistry at many universities. Chemical companies also established research laboratories that absorbed the growing number of academic graduates.

It is noteworthy, that the Polymer Research Institute, nowadays located at the renamed Polytechnic New York University, still adheres to the research design introduced by Hermann F. Mark, with sections devoted to synthesis, characterisation, and application. However, what was new and barely recognised in the scientific field in the 1940s, is today called traditional chemistry. As the public web page[21] tells us, the Polymer Research Institute has recently expanded its interests "in addition to the traditional chemistry related areas in macromolecular technology to health related areas." No doubt, the striking of this new path would have been in the spirit of Herman Francis Mark, whose academic achievements deserve a more detailed historical study.[22]

Notes

[1] Walter Adams (Society for the Protection of Science and Learning, London) to The Under-Secretary of State, May 19th, 1938. Personal file of Hermann Mark 219/9; 437/1 at the Archive of the Society for the Protection of Science and Learning (today CARA), Bodleian Library, Oxford.
[2] Jeffrey I. Seeman, "Editor's Note", in Herman F. Mark, *From Small Organic Molecules to Large. A Century of Progress* (Washington: American Chemical Society, 1993), XI-XXV, on XXIII.
[3] Linus Pauling, "My Indebtedness to Herman Mark", in *Polymer Science in the Next Decade. Trends, Opportunities, Promises. An International Symposium Honoring Herman F. Mark on His 90th Birthday*, ed. Otto Vogl, Edmund H. Immergut (New York: John Wiley & Sons, 1987), 19-22.

[4] Linus Pauling, "Pauling on Mark" in *Pioneers in Polymer Science*, ed. Raymond B. Seymour (Dordrecht/Boston/London: Kluwer Academic Publishers, 1989), 153-163, on 163.
[5] Herman F. Mark, *From Small Organic Molecules to Large. A Century of Progress* (Washington: American Chemical Society, 1993).
[6] *Polymers to the Year 2000 and Beyond: A Memorial Symposium for Herman F. Mark*, ed. Sheldon M. Atlas, Eli M. Pearce, F. R. Eirich (New York: John Wiley & Sons, 1993) (*Journal of Polymer Science: Polymer Symposia* 75).
[7] See *Chemical Achievers. The Human Face of the Chemical Sciences*. Cf. *<http://www.chemheritage.org/classroom/ chemach/plastics/carothers.html>*.
[8] Hans Mark, "Herman F. Mark. The Man", in *Polymer Science Overview. A Tribute to Herman F. Mark*, ed. G. Allan Stahl (Washington: American Chemical Society 1981) (ACS Symposium Series 175), 89-92.
[9] Norbert M. Bikales, "Herman Mark's Children", in *Polymers to the Year 2000 and Beyond: A Memorial Symposium for Herman F. Mark*, ed. Sheldon M. Atlas, Eli M. Pearce, F. R. Eirich (New York: John Wiley & Sons 1993) (Journal of Polymer Science: Polymer Symposia 75): 143-150, on 143.
[10] F. R. Eirich, "Remembering Herman F. Mark", in *Polymers for Advanced Technologies* 3 (1992): 102-104. See National Historic Chemical Landmarks: *<http://acswebcontent.acs.org/ landmarks/landmarks/polymer/pol_1.html>*.
[11] Herman F. Marks scientific course of life is documented in an overview on the Internet page of the Chemical Heritage Foundation *(<http://www.chemheritage.org>)* Further material is available on the Internet page of the American Chemical Society *(<http://portal.acs.org/portal/acs/corg/content>) resp. National Historic Chemical Landmarks (<http://acswebcontent.acs.org/landmarks>)*.
[12] Kurt H. Meyer, Hermann Mark, *Der Aufbau der hochpolymeren organischen Naturstoffe auf Grund molekular-morphologischer Betrachtungen* (Leipzig: Akad. Verl.-Ges., 1930).
[13] Herman Mark, "Polymer Chemistry in Europe and America – How It All Began", *Journal of Chemical Education*, 58 (1981): 527-534, on 531-532. See also Ute Deichmann, *Flüchten, Mitmachen, Vergessen. Chemiker und Biochemiker in der NS-Zeit* (Weinheim: Wiley-VCH, 2001), 181-187.
[14] Johannes Feichtinger, *Wissenschaft zwischen den Kulturen. Österreichische Hochschullehrer in der Emigration 1933-1945* (Frankfurt am Main: Campus, 2001).
[15] Shulamit Volkov, "Soziale Ursachen des Erfolgs in der Wisssenschaft – Juden im Kaiserreich", *Historische Zeitschrift* 245 (1987): 315-342.
[16] Johannes Feichtinger, "Kulturelle Marginalität und wissenschaftliche Kreativität. Jüdische Intellektuelle im Österreich der Zwischenkriegszeit", in *Das Gewebe der Kultur. Kulturwissenschaftliche Analysen zur Geschichte und Identität Österreichs in der Moderne*, ed. Johannes Feichtinger, Peter Stachel (Innsbruck/Wien/München: Studienverlag, 2001), 311-333. See also Johannes Feichtinger, "Zur Migration, Akkulturation und Identität österreichischer Intellektueller und Wissenschaftler 1900-1945", in *Österreichische Satire (1933-2000). Exil – Remigration – Assimilation*, ed. Jeanne Benay, Alfred Pfabigan, Anne Saint Sauveur, Bern: Lang, 2003 (Convergences 29), 15-38.
[17] Mark, *From Small Organic Molecules to Large*, 85. See also personal file of Hermann Mark 219/9; 437/1 (Society for the Protection of Science and Learning, Bodleian Library).
[18] Feichtinger, *Wissenschaft zwischen den Kulturen*, 31-54. Johannes Feichtinger, "Migration – Cultural Transfer – Scientific Change. Austrian Scholarly Traditions and their Impact on

Scholarship and Science in the Americas 1933–1945", in *Reverberations. Representations of Modernity, Tradition and Cultural Value in-between Central Europe and North America*, ed. Susan Ingram, Markus Reisenleitner, Cornelia Szabo-Knotik (Frankfurt am Main: Lang, 2002), 223-239.

[19] Joseph Needham to Walter Adams, June, 14th, 1938. Personal file of Hermann Mark 219/9 at the Archive of the Society for the Protection of Science and Learning, Bodleian Library, Oxford.

[20] Mark, "Polymer Chemistry in Europe and America – How It All Began", 532-534. Herman Francis Mark. Transcript of a Tape-recorded Interview conducted by R.S. Marvin, March 19th 1979, archived by the American Institute of Physics, Center for History of Physics, College Park, MD.

[21] Polymer Research Institute. <*http://www.poly.edu/researchcenters/pri/index.php*>.

[22] See the first draft of a planned study on the 'Wiener Schule der Hochpolymerforschung in England und Amerika. Emigration – Wissenschaftswandel – Innovation', manuscript available in German: <*http://www.oeaw.ac.at/kkt/mitarbeit/fei/fei_v99_e.html*>.