FRITZ FEIGL (1891-1971)

The Centennial of a Researcher

Aida Espinola, Universidade Federal do Rio de Janeiro,
Mario Abrantes da Silva Pinto, CONSULTEC, and
Claudio Costa Neto, Universidade Federal do Rio de Janeiro

Fritz Feigl would have celebrated his 100th birthday on May 15, 1991. It was quite unfortunate he passed away on January 23, 1971, from a cerebral thrombosis. This article, representing the gratitude and admiration of his friends and former coworkers from the Laboratorio da Producao Mineral, Rio de Janeiro, Brazil (where he worked from 1940 until his death) is intended to document and analyze the importance of his work. It is divided into three sections: first, an overall view of his life and personality are presented, based, in part, on data extracted from publications celebrating his 70th birthday and memorial lectures (1-7), but mostly from recollections of the authors. This is followed by a critical appraisal of his scientific production. Finally,the response of the scientific world to his discoveries and their ramifications is presented.

Early Life in Europe

Feigl was born in Vienna, then the Austro-Hungarian capital. He descended from a well-to-do Israeli bourgeois family of good cultural background. As a Kohen—a descendent of the priests from the time of the temple of Jerusalem—he was named Efraim ben Shemuel Hakohen. As a member of the highest priestly class, he had the right to bless the Israeli people and to serve in the Temple of Jerusalem (7).

Educated in Vienna, he developed a fine taste in literature and classical music. He liked outdoor activities; when he lived in Europe, he used to climb mountains, ski, and walk in the Wienerwald. The habit of strolling he maintained in Rio, where he used to go on foot daily (ca. five kilometers) along the shores of Ipanema and Copacabana, to his laboratory, located in Praia Vermelha.

After finishing his humanities studies, he graduated in Chemical Engineering from the Technische Hochschule in 1914, the year when the First World War started. He served as an officer in the Austro-Hungarian Army during World War I; was wounded in battle on the Russian front, and returned as captain with a bronze and a silver medal and the Military Service Cross. When the war ended, he resumed studies at the University of Vienna, obtaining his doctorate in chemistry on 1 April 1920, under Prof. Spath, with a thesis entitled "Über die Verwendung von Tüpfelreaktionen in der qualitativen Analyse."

His vocation was dedicated to the academic world; he soon joined the faculty of the University of Vienna as Assistant Professor (1920); became Dozent in 1927, Professor of Inorganic Analytical Chemistry in 1935, Full Professor in 1937, staying until 1938. His teaching extended to the Volkshochschule in Vienna, a School created by the republican government of Austria to give opportunity for study at the university level to those who, returning from war, had to maintain daytime occupations. There he taught undergraduate courses in chemistry for no fee, three times a week, from 6-9 pm, for many years, until his exile in 1938.

At the University of Vienna, G. Hirsch (1921), F. Rappaport (1923), S. Taubes (1924), E. Chargaff (1929), K. Weisslberg (1930), H. Kapulitzas (1930), L. Weidenfeld (1930), E. Rajman (1936), V. Anger (1936), V. Demant (1937), among others, worked under his supervision (8).

Early in his life he met Regine Freier, a seventeen-year-old Israeli girl, who came to Vienna in 1914, as a refugee from Kolomyia, in the Carpathian Mountains, East Oriental Galicia Poland, fleeing from the Russian troops. In Vienna, she initially studied accounting; later,

in 1919, she started chemistry, working under Feigl's supervision, to graduate with a thesis on sulfuric acid. In 1924 Feigl married Regine (she had previously been married to an Austrian banker).

She bore him a son, Hans Ernest, who came to Brazil at an early age and did all his studies through the university in this country. Graduated in chemistry, he became his father's coworker, with some published papers. Hans received a Ph.D. in Chemistry at the University of Zürich, under Paul Karrer, with a thesis entitled "Neuere Arbeiten über syntetische Pterine;" his postdoctorate was terminated abruptly by his death from cancer in 1954; according to his wishes, he was buried in Rio de Janeiro, Brazil.

Regine Feigl had an important role in Feigl's life; she had a strong personality, was a brilliant business woman, and contributed significantly to establish the family's fortune. She would always mention how proud she was of her husband's scientific success.

In 1938, as a consequence of the Anschluss in Austria, the Feigl family emigrated from Vienna to Switzerland, and then to Belgium, where they started their lives again (Feigl had already been, for a long time, a technical consultant on photographic emulsions to Gevaert, in Antwerp). There he carried on research in an industrial laboratory, as well as university teaching in Ghent.

Figure 1 Feigel and son, Hans Ernest

While in Belgium, he received an invitation from the University of St. Andrews, in Scotland, to continue his research at that university; the opportunity to leave Belgium did not materialize, because, as a consequence of Austria's annexation to Germany, his passport became a German one, carrying a capital letter "J" identifying him as a Jew. Due recognition must be made that the 2nd. English edition of his book *Qualitative Analysis by Spot Tests (1939)* carries, in the preface, a dedication to his honored colleagues of the University of St. Andrews, as gratitude for their liberal attitude.

The Move to Brazil

In 1940, Belgium was invaded by the Nazis. As a Jew, Feigl was soon transferred to a concentration camp near Perpignan. Mrs. Feigl, away on that occasion, only later was informed of Feigl's destiny. Regine and Hans moved to Toulouse, near the camp. There she had the opportunity to contact the Brazilian Ambassador in Vichy, Luiz de Souza Dantas, who obtained the necessary visas for them to enter Brazil. They left for Andorra, in the East Pyrenees, and from there went to Portugal; in Lisbon, they embarked to Brazil aboard the ship *Serpa Pinto*, arriving in Rio de Janeiro on 29 November 1940, as a refugee family. Feigl, then 49 years old, settled permanently in Rio.

After the end of World War II, when scientific exchanges were taken up again, Feigl received many invitations to work in other parts of the world, mainly from the United States and England. As gratitude for his and his family's reception in Brazil, as well as for the intervention of Brazilian authorities to rescue Mrs. Feigl's two brothers who were also in a concentration camp in France, they never left Brazil. Within five years, in avowed recognition of his contribution to science, he was granted Brazilian citizenship.

How did Feigl come to settle in the Laboratorio da Producao Mineral-(LPM), in Rio de Janeiro? A professor of the Escola Nacional de Agronomia of the Universidade do Brasil, Coriolano Pereira Jose da Silva, learning of Feigl's arrival in Rio, informed Mario da Silva Pinto, then Director of the LPM, who, understanding the importance of obtaining the cooperation of such a researcher, immediately alerted his superiors, the General Director of the Departamento Nacional da Producao Mineral (DNPM), Jacques de Moraes, as well as the Minister of Agriculture, Fernando Costa. He insisted on the advantages of having Feigl settle in Brazil and establish a research center in microchemistry. It would also be possible to assign him work on a number of relevant technological problems. Within two weeks Feigl was contracted at the LPM and, at the end of 1940, he took up his post as a researcher, which he maintained for over twenty years until his formal retirement in 1961, although he continued working to the end of his days. At the LPM, a small laboratory was set up for him; during

Figure 2 C. P. Ferreira, D. Goldstein, F. Feigl, I. M. Kolthoff, A. Espinola, O. R. Gottlieb (Rio Airport, 1956)

the period of its installation, he went to work as a guest of Prof. Coriolano P.J. da Silva and his assistant Alcides Caldas, in their analytical chemistry laboratory, at the Escola Nacional de Agronomia which was then next to LPM.

At the LPM, Feigl created a new research line. He started with four Brazilian LPM chemists as assistants: G.F. Dacorso, P.E.F. Barbosa, L.I. Miranda and N. Braile; a short course on "Spot Tests" was taught at the end of 1941. His dedication to work was extraordinary; he was the first to arrive at the laboratory in the morning and the last one to leave in the evening. Research papers immediately started appearing, and within one year the Bulletin was published with the title "Microchemical Investigations," a reporting of the work developed in the period May-December 1941. This publication was followed by five other LPM Bulletins on similar subjects. These were followed, in 1943, by two other publications, "A Laboratory Manual of Spot Tests" and "The Spot Tests in Chemical Teaching," both in Portuguese.

Two technological problems were assigned by the Director of the LPM to Feigl: the first one, on caffeine, a scarce but valuable chemical at that time, and the second on the phosphate deposits at Gurupi. He and A. Schaeffer, from the Brazilian Military Technical School, developed a process to extract caffeine from coffee by sublimation at reduced pressure. The process gave excellent results on a bench-scale, but, when it came to scale-up, was unsuccessful. Feigl, then, in a short period devised another process employing the abundant and inexpensive solvent kerosene to extract caffeine from concentrated coffee water extracts, which turned out to be highly efficient. Because Brazil was overproducing coffee, part of this excess was then used to produce caffeine. A quantity of 500 tons of the product was obtained at the Companhia de Produtos Quimicos Alka, in Santo Andre (Sao Paulo), from the expandable quota of the National Coffee Department. About 48,000 tons of coffee were processed instead of being dumped into the sea or incinerated; and the highly valued product which resulted was marketed domestically and exported.

The Companhia de Produtos Quimicos Alka, which had been founded with contributions of share holders, had Mrs. Feigl as Technical Director, Mario A. da Silva Pinto as Technical Consultant, and Ciro Lustosa as Industrial Manager, who was also responsible for running the plant. This lasted for three years; as the war ended, foreign markets were reopened, and all coffee production became negotiable; as a consequence, the necessary raw material was no longer available. The three years of operation made feasible the start of the Feigl family fortune, which later became considerable, due mainly to Mrs. Feigl's extraordinary business competence.

In 1946 another technical problem was assigned to Feigl: the solubilization of the phosphate contained in the phosphorus bauxite of Gurupi; this is an aluminum phosphate, which occurs in this region of Maranhao, Brazil. The process developed was ingenious: a molecular disorder was thermally induced in order to allow the phosphate to become soluble in ammonium citrate. The mined bauxite, after fragmentation, was thermally treated in a rotary furnace. An experimental field test of the practical utilization of the invention was then prepared and put under the responsibility of Alvaro Barcelos Fagundes, at that time Director of the Instituto de Pesquisas Agronomicas. The fertilizer was tested in several experimental stations, but unfortunately this developmental study did not result in any commercial operation although a patent was granted to LPM.

Upon his arrival in Rio, it was not easy for Herr Prof. Dr. Eng. Fritz Feigl, accustomed to the formal environment of the European universities, to adapt to the atmosphere of freedom and informality of the new world,

more so that of Rio de Janeiro. But he soon learned to enjoy the tropics; all Feigl's homes in Rio were located right on the shore of the most famous beaches, first in Ipanema, later in Copacabana. He just had to walk across the street to the white sand and swim in the warm waters of the Atlantic Ocean. In the long walks from home to his laboratory, his skin acquired a beautiful tanned look, for which he received the kind nickname of "baiano" (native of the state of Bahia).

When Feigl immigrated to Brazil, he already had experience at a university as well as a research career: he had been Full Professor at the University of Vienna, where he published one hundred and sixty papers, three German editions of his book *Qualitative Analyse mit Hilfe von Tüpfelreaktionen* and two English editions of this same book, under the title of *Qualitative Analysis by Spot Tests*. In Brazil, where he directed a large number of competent collaborators, he revealed his incomparable capacity of starting up again without losing his courage, idealism, or confidence in humanity. In this new environment, he encountered a number of young chemists who understood the privilege of working with such a notable man of science; many of them came from abroad, from different countries to his laboratory in LPM: Phillip W. West (Louisiana State Univ.), Hans A. Sutter (Celanese Chemical Co.), and F. L. Chan from the United States; Y. Hashimoto from Kyoto, Japan; E. Jungreis from Israel; and Ramon Rossel from Argentina.

Thirty five Brazilians may be counted as his disciples. Whenever he had an opportunity, he used to exalt the intellectual capacity and the dexterity of his Brazilian coworkers, whom he considered of the same high level as those he had in Vienna. To the competent and studious chemists at LPM the opportunity was given to spend some time in Feigl's laboratory, returning, afterwards, to their regular activities.

Recognition and Honors

Feigl's work found wide recognition in Brazil and abroad. For his outstanding achievements in analytical chemistry, many honors were bestowed on him, which attest to his tireless efforts in internationally promoting interest in spot tests. While still living in Vienna, he received the Heitiger Prize of Chemistry and the Pregl Prize of Microchemistry, from the Austrian Academy of Sciences; later, he was awarded the Weizmann Prize for Natural Exact Sciences of the City of Tel-Aviv, the Hexler Prize of Vienna, the Great Prize of Science and Culture of Austria; the Emisch Medal of the Austrian Academy of Microchemistry; the Gold Medal of the City of Vienna (the Ehrenmedall der Bundeshauptstadt-Wien, 1967), the Wilhelm Exner Medal, of the Austrian Industrial Society; the Talanta Medal, of the Pergamon Press. In Russia in 1962, he received the Lomonosov Medal of the Academy of Sciences of Moscow.

In Brazil, he received the Order of Rio Branco, from the Brazilian government, the Albert Einstein Prize of the Brazilian Academy of Sciences, and the Moinho Santista gold medal Prize from the Moinho Santista Society. He also received many university titles and memorabilia: Doctor Honoris Causa of the Universidade do Brazil (now Universidade Federal do Rio de Janeiro),

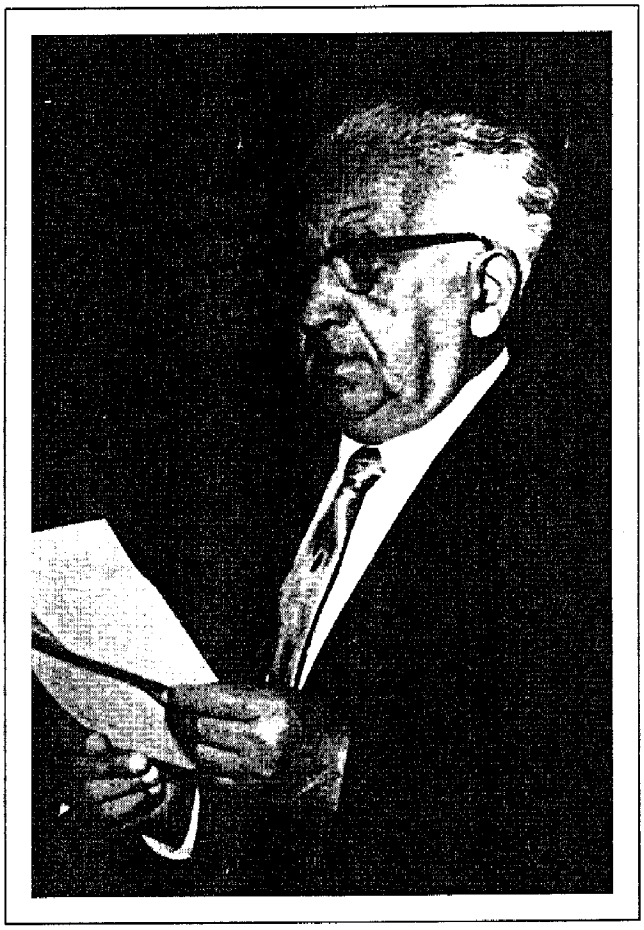

Figure 3 Fritz Feigl, Feigl Symposium, Rio de Janeiro, November, 1962

the Universidade de Sao Paulo, the Pontificia Universidade Catolica do Rio de Janeiro, Technische Hochschule of Vienna and the University of Jerusalem. In 1958, he was made Emeritus Professor of the University of Tokyo, receiving a medal and a bronze sculpture from the Pharmacological Society of Japan. He was Governor of the Hebrew University of Jerusalem and belonged to the Board of Governors of the Weizmann

Institute in Rehovot, Israel. He was made honorary citizen of the State of Guanabara, Brazil, and of the city of Baton Rouge, in the USA.

Feigl was a corresponding member of the Austrian Academy of Sciences and Fellow of the Academies of Science of Gothenburg and of New York. He was a Full Member of the Swedish Academy of Sciences and of the Brazilian Academy of Sciences. He was also a member of the Austrian Society of Microchemistry, the Austrian Association of Chemistry, the Midland Section of the Society for Analytical Chemistry, the Society for Analytical Chemistry (London), the Japanese Society for Analytical Chemistry, the Japanese Society for Pharmaceutical Chemistry and of the Brazilian Pharmaceutical Association. On 10 April 1970, he was elected Member of the Pontifical Academy of Sciences of the Vatican, in chair number 54.

Laboratories were named in his honor: his laboratory in the LPM, as well as one in the Weizmann Institute and another at the University of Recife (Brazil).

His 70th birthday was extensively celebrated. The Chemical Society of Midland sponsored a symposium in Birmingham, from 9-12 April 1952, which was attended by nearly 500 scientists from 24 countries. All plenary sessions were related to spot tests. The proceedings of this symposium characterized Feigl by saying that "His incomparable knowledge of chemical reactions and his ability to explore them for analytical purposes qualify him as one of the greatest analytical chemists of all times." Commemoration of his 70th birthday in Brazil included the placement of an engraved bronze plate in his laboratory at the LPM and the "Feigl's Symposium," which was held by the Brazilian Academy of Sciences from 16-23 of November, 1962, in Rio de Janeiro. This symposium was sponsored by the Academy, the Brazilian Research Council, the University of Brazil, the University Sao Paulo, the Pontifical University of Rio de Janeiro, and the Brazilian Chemical Society. Papers were presented by the most representative members of the Brazilian chemical community, and several foreign researchers participated: R. Belcher (U. of Birmingham, UK), P. W. West (Louisiana State U., Baton Rouge, USA), H. Malissa (Institut für analytische Chemie, der Technische Hochschule, Wien, Austria), D. L. Rucknagel (Univ. of Michigan, Ann Arbor, USA), H. J. McDonald (Stricht School of Medicine of the Loyola Univ., Chicago, USA), C. Djerassi (Stanford Univ., Calif., USA), A. Bondi (Agricultural Research Station, Rehovot, Israel), H. Weiss (Chemisches Institut der Universität Freiburg, Germany) (9).

Feigl was proud of the capacity of the Jews to revive, reestablish, become active and flourish again, after persecutions and losses. He was proud of the reconstruction of the State of Israel and contributed to the grandeur of the University of Jerusalem. Regine Feigl, a Jew, was also a good friend of Catholics; in Galicia, Poland, she studied in an Ursuline school because of the good quality of education provided. The Feigl family was very interested in the Jewish community of Rio, his name appearing in all new organizations, such as the Federation of Israeli Societies of Rio de Janeiro and the Israeli Confederation of Brazil; Feigl was the Chairman of the Brazilian Israeli Society. Good benefactors, they contributed with substantial donations to the Pontificia Universidade Catolica do Rio de Janeiro and to universities and research centers in Israel, to causes for poor students, providing them with scholarships.

Feigl died when he was almost 80 years of age. He maintained his interest in chemistry and in research for ten years after his retirement from LPM; his mind was clear until October, 1969, when a thrombosis incapacitated him until January 23, 1971, the date of his death. In the words of Dr. Henrique Lemle, Grao-Rabino of the Israeli Religious Association of Rio de Janeiro, at Feigl's funeral, "All three crowns - the Tora (of knowledge), the Kehuma (of the priesthood), and the Kalkhut (of the kingdom) characterize in a special form the life of Fritz Feigl (7)."

Everybody who worked with Fritz Feigl held the conviction that he was a great scientist and admired him for his intuition, his knowledge of chemical reactions, and his incredible ability to develop new spot tests. His strength in dealing with adversities, contagious enthusiasm, happiness, and satisfaction with work can never be forgotten by his LPM colleagues. He is sadly missed by his many disciples everywhere.

His Work

Feigl was a very productive scientist. It is to be noted that he started publishing in 1919 and maintained a considerable level of creativity except in the period 1940-1941, during his persecution by the Nazis and his move to Brazil.

His productivity in Europe, up to 1939, totaled 160 papers; as a grand total, he published 436 articles, according to a complete list of his original papers presented by Anger (10). A list of his twenty books can be found in the 1971 *Almanac of the Austrian Academy of Sciences* (11) and in *Analytica Chimica Acta* (10). The present authors raise this number to 24, by including

the Portuguese publication *Reacoes de Toque no Ensino da Quimica*, (Boletim n. 12 do Laboratorio da Producao Mineral, Rio de Janeiro, Brasil, 1943, 112 pp); two translations in Russian of the *Spot Tests in Inorganic Analysis* (12) and a Japanese version of *Spot Tests in Organic Analysis*, 5th edition.

His first book, *Qualitative Analyze mit Hilfe von Tüpfelreaktionen*, Academische Verlag-schaften, Leipzig, 1931, with 387 pages, appeared in several editions and translations into English and other languages, each new edition being enlarged and improved, containing a considerable number of new tests, improvements to known ones and updated explanations of the chemistry of the reactions on the basis of new concepts. These books reflect his personal experience since most of the tests were developed either by himself or under his direction.

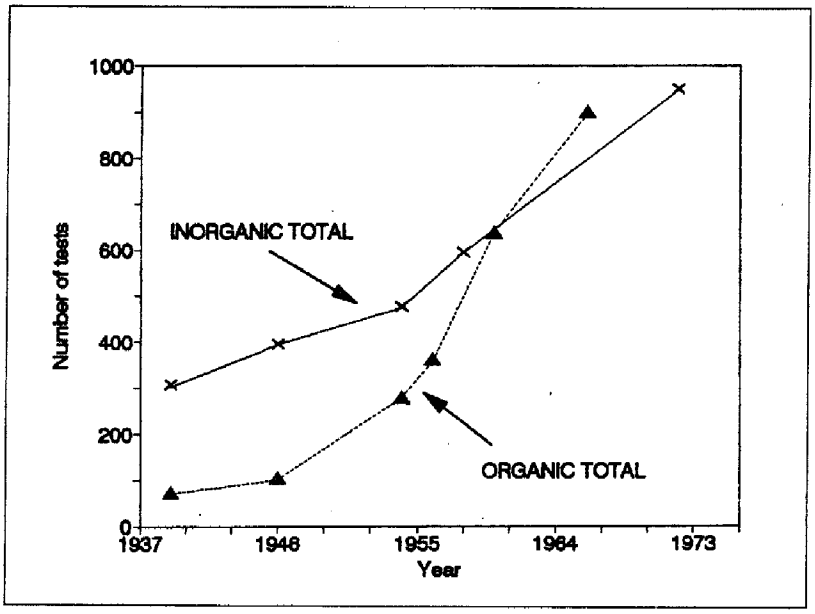

Figure 4 Number of Spot tests in Editions of Feigl's Texts

The progression of the number of new tests presented in the various editions of the *Spot Tests* is shown in Fig. 4 (13). The dramatic increase of organic tests in each new edition is particularly striking.

His Brazilian research production was larger than that of the European epoch. Out of his total of 436 articles, 276 were written in Brazil, in collaboration with Brazilian chemists. His masterpiece, *The Chemistry of Specific, Selective and Sensitive Reactions* was entirely written in Brazil (13).

His Legacy

Although Feigl was the great developer of spot tests, the earliest "spot test" registered in the literature was Hugo Schiff's detection of uric acid in 1859 (14): a drop of an aqueous solution of this acid placed on filter paper impregnated with silver carbonate resulted in a gray or black fleck of finely divided silver. This finding coincided with the first studies of Christian Friedrich Schönberg and Friedrich Goppelsröder on capillary analysis. It can be said that Feigl's work was based on these pioneering ideas. His early association with Friedrich Emich was also of great influence to his work; as a researcher in microchemistry, he followed F. Emich and F. Pregl, already well known researchers in this field. In the period 1917-1923 he introduced new methodology for the characterization of inorganic species, exploring the combination with organic reagents, which led to intensely colored products. This gave rise to the technique of spot tests ("Tüpfelanalyse" in German, "Analise de Touche" in French, "Analise de Toque" in Portuguese).

The spot test method allowed for the detection of as little as one nanogram of the substrate in a drop of solution, corresponding to a dilution of 1:5,000 - 1:500,000,000. The important concepts of "Limit of Identification" and "Dilution Limit" (or its reciprocal, the "Concentration Limit") all defined by numerical values, were developed by Feigl to deal with these levels of detection of the substances. As important as these concepts for analytical chemistry was the differentiation between "specific" and "selective" reactions (and reagents), accepted and recommended by IUPAC (16, 17) as an "official" jargon for analytical reactions.

Organic reagents exhibited a special suitability for spot tests. A systematic study of the use of organic reagents in chemical analysis led Feigl to pioneer a relationship between selective and specific properties of reagents and certain structural factors, the reactive groups. In 1936 he authored the first analytical and interpretative presentation in English on the use of organic reagents in inorganic analysis (18). This was followed by another article (19) and by his major literary production in book form, *Chemistry of Specific, Selective and Sensitive Reactions* (15). The search for new spot reactions or the improvement of the selectivity for the ones already known had a definite role in stimulating the preparation of new organic compounds. The sys-

tematization of relationships between atomic groupings in organic compounds and selective action on metal ions enriched the chemistry of coordination compounds, leading to the isolation of new complex organometallic compounds. This happened in his own laboratory with Goldstein's discovery of glyoxal bis(2-hydroxyanil) as a reagent for calcium (20). Feigl's research extended the ways in which chemical reactions can be employed in analysis: the widespread use of organic compounds as precipitation, color, and masking agents; the utilization of catalyzed and induced reactions; solid-phase reactions at elevated temperatures and reactions in the gas phase through contact with suitable solid or dissolved partners (21); pyroreactions, as pyrohydrolyses and pyroammonolyses; reactions yielding fluorescent products or those that quench fluorescence; interfacial effects such as the adsorption of dyestuffs on metal oxides or hydroxides, producing colored lakes, in which chelate bonding is fundamental. Last but not least should be mentioned the importance of conditioning of tests to enhance sensitivity or selectivity; he emphasized that it is not correct to speak of the sensitivity of a reaction without reference to the conditions under which the test is performed.

Results from other fields were introduced by Feigl in spot tests. The use of induced and catalytic effects was entirely new in analytical chemistry at the time he published his first paper on the subject. Some outstanding examples of contributions are given below.

• Test by catalytic acceleration of the iodine-azide reaction (22). The redox reaction

$$2\ NaN_3 + I_2 \rightarrow 2\ NaI + 3\ N_2(1)$$

is very slow. Nevertheless, it can be catalyzed by inorganic sulfides, thiosulfates and thiocyanates, and also traces of solid or dissolved organic compounds containing the C=S or C-SH groups. A very sensitive detection procedure for these groups was accomplished by spot tests, with extraordinary limits of identification, as, for example, 0.0003γ for thioacetic acid at a dilution limit of 1:100,000,000.

• Test by catalytic acceleration of the formaldehyde-o-dinitrobenzene reaction (23). The reduction of o-dinitrobenzene by formaldehyde proceeds very slowly in alkaline carbonate solution, but 1-2-dioxo compounds catalytically accelerate this reaction to such an extent as to effect a very sensitive test for α-diketones, p- and o-quinones. The sensitivity is extraordinary for the following dioxo compounds: 0.05γ diacetyl; 0.05γ anthraquinone; 0.002γ phenanthraquinone; 0.01γ 2-methyl-1-4-naphthoquinone (vitamin K_3); 0.002γ 3-nitrophenanthraquinone.

• Test for basic compounds with nickel dimethylglyoxime or zinc 8-hydroxyquinoline solutions (24). The reagent is the saturated nickel dimethylglyoxime (water-alcohol) equilibrium solution containing Ni^{2+} and H^+ ions. As basic materials such as ethylenediamine, diethanolamine, benzidine, etc., remove H^+ ions, black nickel dimethylglyoxime precipitates. The sensitivity of this test is 5γ ethylenediamine, 20γ diethanolamine, 2γ α-naphthylamine, 15γ p-phenylenediamine, 10γ benzidine, and 15γ tetrabase (4). Inorganic analysis also benefitted from spot tests. Relevant examples of very sensitive inorganic spot tests are shown in Table 1 (23).

Despite the sophistication of modern instrumental analyses, spot tests find large-scale application in areas in which it is important to obtain a quick response, with a simple, rapid, and inexpensive technique. These are, for instance, "screening tests" in clinical analysis; control of the quality of air; food analysis, water analysis; soil tests; geochemical prospection; forensic tests. Some of the most frequently performed tests routinely applied are described by Jungreis, who published a descriptive book with details and methodology of some hundreds of applications of spot tests to these various fields (26). Many companies in the US and Europe manufacture compact systems ("kits") based on spot tests applied to clinical analyses (26). Such kits are produced either in the form of tablets or as plastic strips ("dipsticks") with eight or nine separate reagent areas affixed, which may be interpreted visually or, preferably, with a reflectance scanning instrument. These "dipsticks" allow for measuring of glucose, protein, ketones, occult blood, nitrite, bilirubin, and urobilinogen at different concentrations of each substance.

The Spot Tests philosophy applied by Costa Neto has led in other directions, as, for example, that in the analysis of geochemicals (bitumes, kerogen, oil, etc.) and other complex mixtures such as plant extracts, beverages, etc. (27). This approach, now called "Solid Phase Functional Group Analysis," comprises three main methods: the Solid Phase Extraction (a separation method used to fractionate complex mixtures according to its functional group content); the Solid Phase Functional Reagents (functional group reagents, leading to colored products, bound to a solid matrix, used to analyze trace amounts of compounds in dark materials like bitumes etc.) and the Functional Marker Method, used to analyze functional groups in solid materials (as kerogen, for instance).

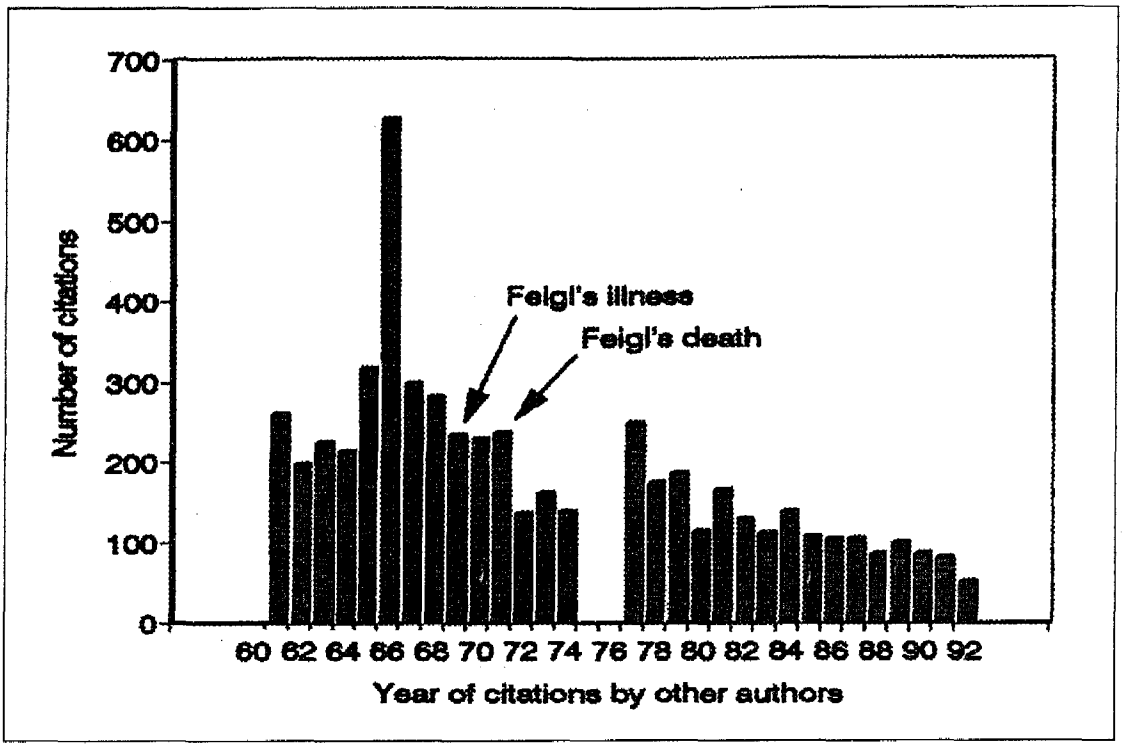

Figure 5 Citation of Feigl's Publications (*Science Citation Index*)

The development of reactions and methods of analyses based on Feigl's discoveries is impressive. Figure 5 shows the data between the period 1961 to the present for 3,560 references to his work, recorded in *Science Citation Index* (28). More impressive still is the existence of 52 references to his work in 1992, twenty-one years after his death. It is estimated that Feigl's work has been cited 5,000 times since 1961.

Feigl was not a man of only hands-on work at the laboratory bench, but also a philosopher of chemistry. As he used to say, "Chemical equations don't translate all changes in a reaction system; they convey the chemical fate of the reactant system." This is also referred to in one of his articles in Portuguese (29) as well as in Chap. XI of one of his books (15), when he says: "If the formation of materials by chemical means involved nothing beyond the mere reaction, then, the chemical process which is accomplished in accord with its stoichiometric formulation would invariably lead to products of the same form, species, color, solubility, etc. Experience has repeatedly demonstrated that this is not always true. Although an equation represents the most important part of a chemical event, nevertheless, it cannot portray everything that happens in the course of the formulation of a material."

ACKNOWLEDGMENTS

The authors are grateful to Dr. Aida Hasson Voloch and Dr. Mitka Freier for the kindness of lending two of the photographs which appear in this paper; to Mr. Carlos Marcelo Juarez for the computer graphics; and to Prof. Bruce Kover for a critical reading of the typescript.

REFERENCES AND NOTES

1. M.A.S. Pinto, "O Prof. Fritz Feigl no Brasil," *Carta Mensal* of the Conselho Tecnico da Confederacao Nacional do Comercio, **1983**, *XIX* (340) 3-15.
2. C. Chagas Filho, "Fritz Feigl," *Ciencia e Cultura*, **1972**, *24* (11) , 1091-97.
3. C. Chagas Filho, "Fritz Feigl, o Homem e a Obra," *J. do Comercio*, May 28, 1991, Rio de Janerio.
4. L. Hainberger, "A Vida e a Obra de Fritz Feigl," *Quim. Nova*, **1983**, **6**, 55-60.
5. M. K. Zacherl, "Fritz Feigl und sein Werk," *Mikrochim. Acta*, **1962**, (1-2), 1-6.
6. P. W. West, "Prof. Dr. Ing. Fritz Feigl," *Anal. Chim. Acta*, **1961**,*25*, 205-207.
7. H. Lemle, Obituary: A Farewell Speech at Feigl's Funeral, Rio de Janeiro, Jan. 27, 1971.
8. Data extracted from references in F. Feigl, *Spot Tests in Inorganic Analysis*, 6th ed., Elsevier, Amsterdam, 1972.

9. "The Feigl's Symposium," Academia Brasileira de Ciencias, Rio de Janeiro, 16-23 Nov. 1962.
10. V. Anger, "Fritz Feigl, 1891-1971," *Anal. Chim. Acta*, **1972**, *59*, 117.
11. F. Hecht, *Almanach der Oesterreichischen Akademie der Wissenschaften*, 1971, 121, 327.
12. F. Feigl and V. Anger, Kapel'nyi Analiz Neorganicheskikh Veshchestv, Tom I, 1976, Mir, Moscow, USSR, 390 pp; *ibid.*, Kapel'nyi Analiz Neorganicheskikh Veshchestv, Tom II, 1976, Mir, Moscow, USSR, 320 pp.
13. Estimates made from the "Tabular Summaries" in the several editions of F. Feigl's *Qualitative Analysis by Spot Tests*, 2nd English edition, Elsevier, Amsterdam, dates from 1939 and 3rd edition from 1946. In the 4th edition the *Spot Tests* was divided into two volumes: Vol. I for Inorganic Applications and Vol. II for Organic Applications. *Spot Tests: Inorganic Analysis*, 4th edition, appeared in 1954; the 5th in 1958; and the 6th in 1972; the 4th edition of *Spot Tests: Organic Applications* was published in 1954; the 5th in 1956; the 6th in 1960; and the 7th edition appeared in 1966. The 7th edition had additional printings in 1971, 1975, and 1983, with no increments in the number of tests; these editions, as well as the two Russian translations, were published posthumously. The 2nd edition (1939) contained 308 inorganic and 72 organic tests; the 3rd edition (1946), 395 inorganic and 104 organic ones; Vol. I, 4th edition (1954), 477 tests; the 5th edition (1958), 594 tests; and the 6th edition (1972), 979 tests. Vol. II, 4th edition, appeared in 1954 with 278 tests, the 5th edition in 1956 with 363 tests, the 6th edition in 1960 with 637 tests, and the 7th edition in 1966 with 899 tests.
14. H. Schiff, *Ann.*, **1859**, *109*, 67.
15. F. Feigl, *Chemistry of Specific, Selective and Sensitive Reactions*, Academic Press, N.Y., 1949.
16. IUPAC, Mitteilung der Internationalen Kommission für Analytische Reacktionen, on "The Classification of Qualitative Analytical Reactions," *Mikrochim Acta*, **1937**, *1*, 253.
17. "The Intern. Commission for New Analytical Reactions and Reagents," (1937) was composed of W Bottger (Leipzig), F. Feigl (Wien), A. S. Komarowsky (Odessa), C. J. Van Nieuwenburg (Delft), and W. Strafford (Manchester).
18. F. Feigl, "Organic Reagents in Inorganic Analysis," *Ind. & Eng. Chem., Anal. Ed.*, **1936**, *8*, 404.
19. F. Feigl, "The Role of Organic Reagents in the Chemistry of Specific Selective and Sensitive Reactions," *Anal. Chem.*, **1949**, *21*, 1298-1313.
20. D. Goldstein and C. Stark-Meyer, "New Specific Test for Calcium", *Anal. Chim. Acta*, **1958**, *19*, 437.
21. F. Feigl, L. I. Miranda and H. A. Sutter, "The Direct Reactions of Solids,"*J. Chem. Educ.*, **1944**, *21*, 18-23.
22. F. Feigl, *Spot Tests: Organic Applications, Elsevier*, Amsterdam, 7th Edition, 1966, p.219.
23. *Ibid*, p. 330.
24. *Ibid*, p. 108.
25. F. Feigl and V. Anger, *Spot Tests in Inorganic Analysis*, Elsevier, Amsterdam, 6th Edition, 1972.
26. E. Jungreis, *Spot Test Analysis: Clinical, Environmental, Forensic and Geochemical Applications*, John Wiley & Sons, N.Y., 1985.
27. C. Costa Neto, "Use of the Methods of Solid Phase Functional Group Analysis for the Characterization of Organic Functionalities in Brazilian Oil Shales," *Quimica Nova*, 1988, *11 (4)* 384-392.
28. *Science Citation Index*, period 1961-1992.
29. F. Feigl, "Reacoes de Toque no Ensino da Quimica," Bol. n° 12, Laboratorio da Producao Mineral, Rio de Janeiro, 1943, Cap. IX.

ABOUT THE AUTHOR

Professor Espinola, trained in chemical engineering and chemistry, carries out research in applied electrochemistry. She is currently Professor at the Coordination of Graduate Programs in Engineering (COPPE/UFRJ), C.P. 68505, 21945-970 Rio de Janeiro, Brasil. A student of mining engineering in Brasil, Sr. Pinto has served as General Director of Departamento Nacional da Producao Mineral (DNPM); he is founder and Director of Consultec. Dr. Neto, a student of Feigl, has taught organic analysis since 1959 at the Instituto de Quimica of the Federal University of Rio de Janeiro.