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Chemistry and History

Victor Moritz Goldschmidt (1888–1947):

A Tribute to the Founder of Modern Geochemistry on the Fiftieth Anniversary of His Death

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…filled with sorrow and tragedy, he continued to maintain his intense interest in the elements and their genesis, affinities, and associations….

Goldschmidt combined a number of widely separated sciences to synthesize a new structural crystal chemistry. Although his work on the relative abundances of the elements, atomic and ionic radii, interionic distances, the effect of radius ratio on coordination number in crystals, replacement of ions in minerals, and the lanthanide contraction is found in almost every textbook of general and inorganic chemistry and has provided the basis for modern crystal chemistry and the use of size relationships for interpreting properties of inorganic substances, Goldschmidt's name, life, and career remain relatively unknown to most chemical educators and practicing chemists.

Goldschmidt used the basic properties of matter to provide simple and elegant explanations for the composition of our

environment. Throughout his relatively brief career, filled with sorrow and tragedy, he continued to maintain his intense interest in the elements and their genesis, affinities, and associations despite his changes from one method to another in his attempts to obtain new and more complete data. Thus, although he used petrology, crystallography, and chemistry and enriched all these fields greatly, to him they were only tools for exploring the earth and its history.

During the nineteenth and early twentieth centuries chemists and petrologists tried to collect and correlate the chemical and physical data of mineralogical and geological chemistry. Yet, despite the earlier attempts of various chemists such as the Germans Christian Friedrich Schönbein (1799–1868) and Carl Gustav Bischof (1792–1870); the Swede Jöns Jacob Berzelius (1779–1848); the Dutchman Jacobus Henricus van't Hoff (1852–1911); and the Americans Frank Wigglesworth Clarke (1847–1931), President of the American Chemical Society (1901), and Henry Stephens Washington (1867–1934), modern geochemistry really originated with the Swiss-born chemist Victor Moritz Goldschmidt (Figure 1), who discovered the laws determining the distribution of the chemical elements on earth or, more generally, in the universe.

Goldschmidt employed the basic properties of matter to provide simple and elegant explanations of the composition of our environment. Throughout his relatively brief career, filled with sorrow and tragedy, he continued to maintain his intense interest in the elements and their genesis, affinities, and associations despite his changes from one method to another in his attempts to obtain new and more complete data. Thus, although he used petrology, crystallography, and chemistry and enriched all these fields greatly, to him they were only tools for exploring the earth and its history.

Goldschmidt's genius was to bring together a number of widely separated sciences to synthesize a new structural crystal chemistry (Figure 2). Although his work on the relative abundances of the elements, atomic and ionic radii, interionic distances, the effect of radius ratio on coordination number in crystals, replacement of ions in minerals, and the lanthanide contraction is found in almost every textbook of general and inorganic chemistry and has provided the basis for modern crystal chemistry and the introduction of size relationships into the interpretation of properties of inorganic substances, pioneered by Linus Pauling (1901–1994) and others, Goldschmidt and his

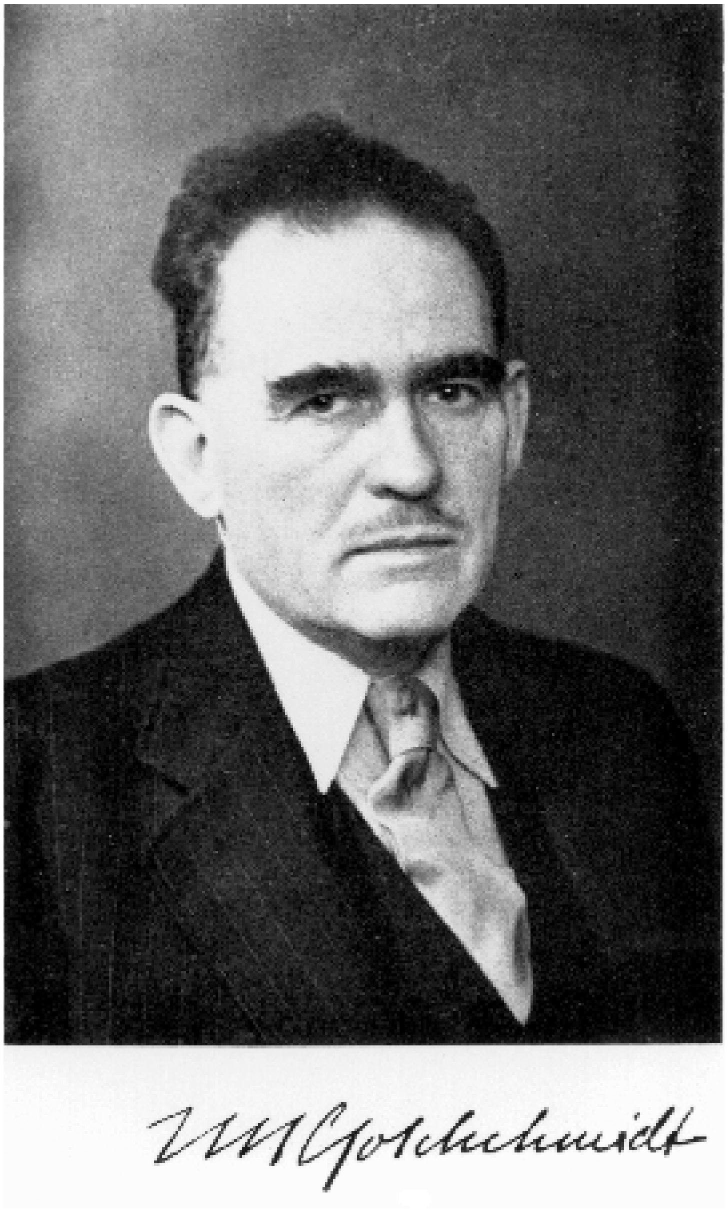

FIGURE 1. VICTOR MORITZ GOLDSCHMIDT (1888–1947), PASSPORT PHOTOGRAPH TAKEN IN 1944 WHILE HE WAS LIVING IN ENGLAND [5].

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life and career remain relatively unknown to most chemical educators and practicing chemists.

Early Life

Victor Moritz Goldschmidt, affectionately known to his friends and colleagues as “V. M.,” was the only child of physical chemist Heinrich Jacob Goldschmidt (1857–1937)

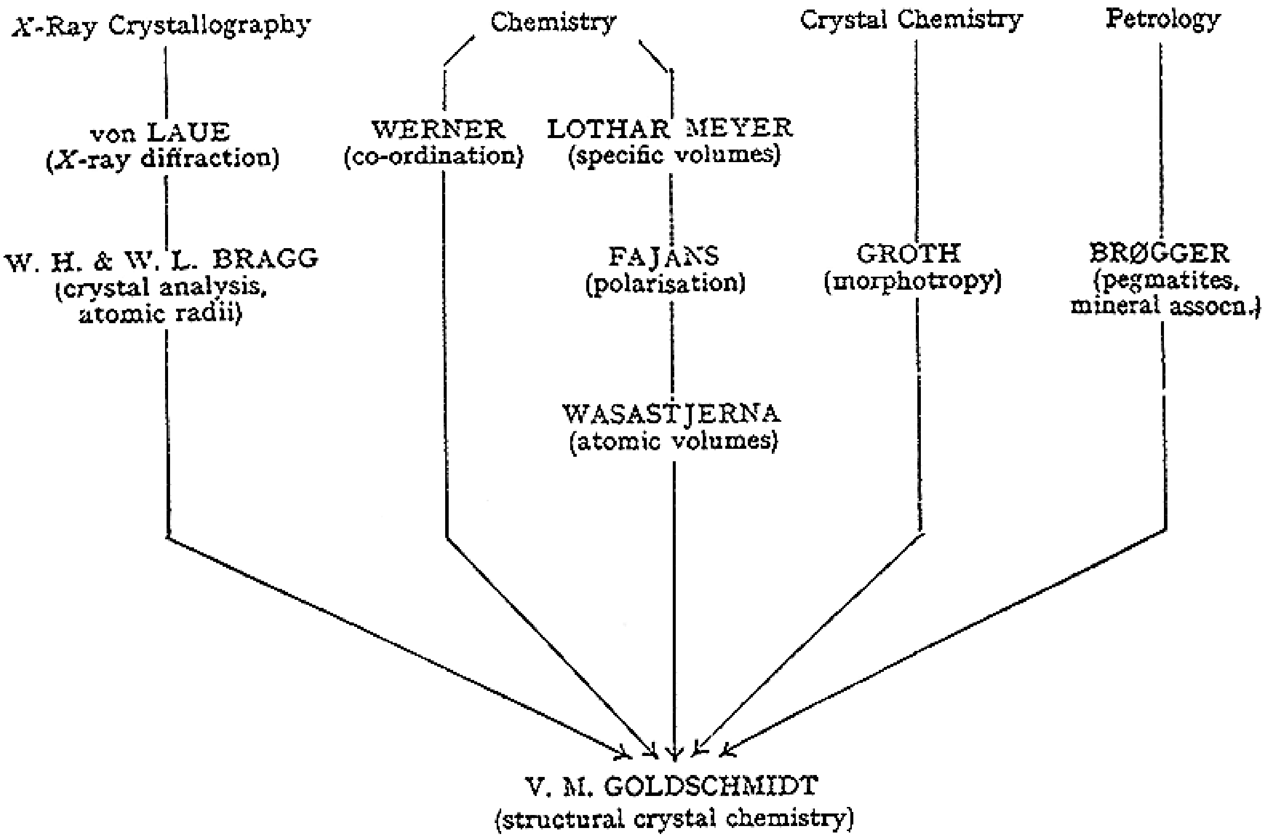

FIGURE 2. RELATIONSHIPS BETWEEN GOLDSCHMIDT'S STRUCTURAL CRYSTAL CHEMISTRY AND OTHER FIELDS [5].

(Figure 3) and Amelie Goldschmidt (née Koehne, 1864–1929), the daughter of a lumber merchant. He was born on January 27, 1888 in Zürich, Switzerland, where his father was *Privat-Dozent* (unsalaried lecturer, 1881–1885) and then Professor (1885–1893) at the Eidgenössisches Polytechnikum (since 1911, the Eidgenössische Technische Hochschule, ETH) [1–10]. He was named Victor after Victor Meyer (1848–1897) [11], the famous chemist and colleague of his father's, and Moritz after his maternal grandfather Moritz Koehne. His paternal forebears were almost all highly educated, being rabbis, professors, physicians, judges, lawyers, and military officers.

In 1893 the family moved to Amsterdam, where Victor's father worked with physical chemist and future (1901) Nobel laureate Jacobus Henricus van't Hoff (1852–1911) [12], then in 1896 to Heidelberg where he became *Extraordinarius Professor* at the university, and then in 1901 to Christiania (since 1925, Oslo), where he succeeded the

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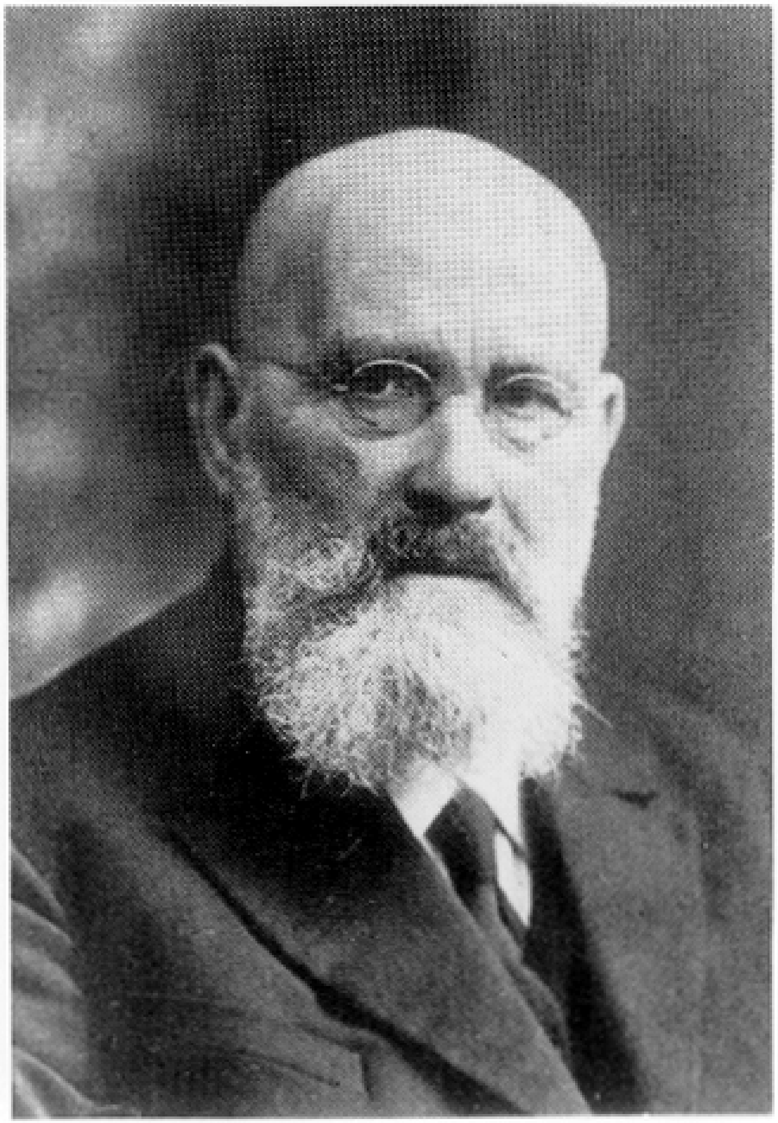

FIGURE 3. HEINRICH GOLDSCHMIDT (1857–1937), VICTOR MORITZ GOLDSCHMIDT'S FATHER [10].

late Peter Waage (1833–1900) of Guldberg and Waage law of mass action fame [13] in the chair of physical chemistry at the university. Victor attended primary school in Amsterdam, a private school in Heidelberg, and the Vestheim Middle School (1901–1903) and a private *Gymnasium* (high school) (1903–1905) in Christiania (Figure 4). He was exempted from the obligatory physical education program because, although he seemed robust, his health was never good, which made him somewhat of a "loner. " He later stated, "Sometimes I regret that I never went out and drank beer with my fellow students."

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FIGURE 4. VICTOR MORITZ GOLDSCHMIDT AT THE AGE OF 15, PENCIL AND CHALK DRAWING MADE IN 1903 BY ASTA ELISA JAKOBINE NÖRREGAARD (1853–1933), A NORWEGIAN HISTORICAL PAINTER WHO LIVED IN OSLO [10].

University Education

Victor quickly learned Norwegian but retained a pronounced accent throughout his life. In 1905, the year in which the unpopular union of Norway with Sweden was peacefully dissolved, the Goldschmidt family became Norwegian citizens, and he entered the University of Christiania where he studied inorganic and physical chemistry, geology, mineralogy, physics, mathematics, zoology, and botany. Norway is a mountainous country, and its scientists have made many important contributions to mineralogy. Goldschmidt developed a deep interest in this science while still in high school, and during a summer vacation in 1904 he discovered an occurrence of fine quartz crystals at Fefor in Gudbrandsdalen, which exhibited a strong pyroluminescence

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(emission of light on heating). He carried out extensive research to explain this unusual phenomenon and its relationship to triboluminescence (emission of light caused by friction) and phosphorescence (emission of light that persists after removal of the exciting source).

Goldschmidt's studies were influenced and inspired by the famous Norwegian petrologist and mineralogist Waldemar Christopher Brøgger (1851–1940) [14], who presented Goldschmidt's work before the Christiania Academy of Sciences on February 9, 1906, resulting in a 19-page paper, "Die Pyrolumineszenz des Quarzes," the 18-year-old youth's first publication, in the academy's journal later that year [15]. Throughout his life Goldschmidt maintained a close friendship with Brøgger, whom he soon equaled in the importance of his petrological and geological work. During the summer of 1906 he studied radioactivity with G. Meyer at the University of Munich, where he developed a lifelong friendship with fellow Jewish student György Hevesy (1885–1966), the Hungarian radiochemist and codiscoverer of hafnium who was to be awarded the 1943 Nobel Prize for chemistry "for his work on the use of isotopes as tracers in the study of chemical processes."

Petrological Studies (1907–1916)

In the spring of 1907 Goldschmidt began his first major research work—on contact metamorphism in the Christiania region [16], which was to result in his doctoral dissertation, published in 1911 [17]. While still a student, he broadened his knowledge of geology and mineralogy by spending summer and fall semesters field mapping as an assistant for the Geological Survey of Norway (Norges Geologiske Undersøkelse) and the winter of 1908–1909 studying optical mineralogical techniques with mineralogist and petrologist Friedrich Becke (1855–1931) in Vienna. In December 1909, he was awarded a university fellowship in mineralogy and petrology, which involved lecturing and leading field trips. In May 1911, he received his doctorate.

Goldschmidt spent the winter of 1911–1912 in Munich with Paul von Groth (1843–1927), the world's leading crystallographer, and two years (1912–1914) as docent in mineralogy and petrology at the University of Christiania. In March 1914, he was elected to Norway's Videnskaps-Akademi, one of the youngest persons so honored. In response to those opposed to his election on the grounds of his youth, Brøgger stated [18]:

> I do not hesitate to say that I consider Victor Goldschmidt the most outstanding Norwegian mineralogist of today—myself not excepted!

In September 1914 he was appointed Professor and Director of the university's Mineralogical Institute at the early age of twenty-six.

The first phase of Goldschmidt's research primarily involved the field of petrology (the scientific study of rocks). His doctoral dissertation, "Die Kontaktmetamorphose im Kristianiagebiet," a 483-page monograph [17], explored the factors determining the mineral associations in contact metamorphic rocks (those produced by the heat and pressure of intruding magma), based on samples collected in southern Norway [19]. Here he applied physical chemistry to geological problems and presented the theoretical basis for rock metamorphism.

Regarding the entire earth as a single physicochemical system, Goldschmidt applied his own mineralogical phase rule (The maximum number of crystalline phases capable of coexisting in stable equilibrium in rocks equals the number of components.) [17, 20–22] as well as Nernst's heat theorem and Guldberg and Waage's law of mass action [13] to complex rock systems. He accounted for changes in igneous rocks (those which have congealed from a molten mass), especially the pegmatites (extremely coarse-grained igneous rocks, usually found as irregular dikes, lenses, or veins), in which rare elements tend to accumulate. His interest in minerals of the rarer elements remained with him throughout his career. He was aware of the curious laws of replacement and isomorphism, which seemed to govern the composition of minerals but were at odds with the ordinary rules of chemical valence. A relatively new tool, X-ray crystallography [23], which enabled him to discover more general laws, came to his attention as a result of the advent of World War I.

Mineral Resources (1917–1922)

During the conflict, Norway was cut off from previously imported essential supplies by German submarines. In 1917 the Norwegian government commissioned detailed research on the country's mineral resources, established a Governmental Commission for Raw Materials, and appointed Goldschmidt as its Chairman as well as Director of the State Raw Materials Laboratory (Statens Råstofflaboratorium) at Tøyen, an Oslo suburb. At about this time Goldschmidt switched his emphasis from field research to

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laboratory research not only because of his position at the Raw Materials Laboratory but also because of the deterioration of his already fragile health.

This practical work of locating Norwegian sources for previously imported materials, an application of science for the benefit of society, constitutes an intermediate period in Goldschmidt's career and resulted in the finding of local sources for previously imported chemicals and minerals [24] and in the extraction of potassium from mica [25]. The latter problem led him into the field of clay mineral studies [26], which in turn led him to investigate the chemical nature of materials of economic importance and thus to the second phase of his career—crystal chemistry and a search for the factors governing the distribution of the chemical elements.

The Discovery of Hafnium (1923)

After Henry Gwynn Jeffreys Moseley (1887–1915) discovered the simple relationship that exists between the X-ray spectrum of an element and its atomic number [27], scientists began to search for the missing elements in the seven unfilled spaces in the periodic table, namely, 43, 61, 72, 75, 85, 87, and 91. In 1911 the French chemist, painter, sculptor, and musician Georges Urbain (1872–1938) reported his discovery of element 72, which he called "celtium," from the arc spectrum of rare earth residues [28]. Danish physicist Niels Bohr (1885–1962) stated that this could not be element 72 because it had been obtained from the tripositive lanthanides; he claimed that on the basis of his quantum theory of atomic structure, element 72 should be tetrapositive and belong to the zirconium family [29]. He therefore advised Goldschmidt's friend György Hevesy to search for it in zirconium ores [30].

In 1921 Goldschmidt's friend, the Swedish geologist and mineralogist Assar Robert Hadding (1886–1962), designed an X-ray spectrograph specifically to analyze minerals, which made it unnecessary to separate the individual elements as in classical chemical analysis. In March 1922 Goldschmidt's principal research associate, Lars Thomassen (1896–1972), constructed an X-ray spectrograph according to Hadding's design, and Goldschmidt and Thomassen employed it to search for the missing element 72 using Moseley's X-ray diffraction method to determine atomic numbers [31]. They were successful and reported the presence of this element in the minerals malacon and alvite, which are varieties of zircon ($ZrSiO_4$ or $ZrO_2{\cdot}SiO_2$). Hevesy and the Dutch physicist Dirk Coster (1889–1950), however, working at Bohr's Institute of

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Theoretical Physics in Copenhagen, reported in a letter dated January 2, 1923, which appeared in the January 20, 1923 issue of *Nature*, their discovery of element 72 in zircon. They named it hafnium after the Latin name for Copenhagen [32]. Unfortunately, Goldschmidt and Thomassen's article [33], published in the first issue of *Norsk Geologisk Tidsskrift* for 1923, was dated January 31, 1923. Hevesy and Coster are universally credited with the discovery, and Mary Elvira Weeks, in her classic monograph, *Discovery of the Elements* [34], mentions Urbain's work but not Goldschmidt and Thomassen's article.

Being beaten to credit for this discovery by a mere 29 days was a great disappointment to Goldschmidt, and for years he devoted himself to a search for the then still unknown element 61 (later reported in 1947 by J. A. Marinsky, L. E. Glendenin, and Charles D. Coryell and named promethium) until the 1930s, when he correctly decided that it did not occur naturally. When Goldschmidt learned that Hevesy, in an invited lecture at the 1923 annual meeting of the Deutsche Chemische Gesellschaft, had failed to mention his gift of a sample of hafnium-containing alvite, he broke off relations with his friend. After Hevesy acknowledged him in the published proceedings, he resumed friendly relations, but his undue sensitivity to professional issues of priority remained with him all his life.

Crystal Chemistry (1923–1929)

The basis for Goldschmidt's now classical geochemical work evolved from his extensive crystallographic studies, which utilized the new X-ray diffraction methods developed by Max von Laue (1879–1960), William Henry Bragg (1862–1942), and his son Sir William Lawrence Bragg (1890–1971). Within two years Goldschmidt and his co-workers, who included many future authorities on geochemistry and crystallography such as Thomas Fredrik Wieby Barth (1899–1971), Gulbrand Oscar Johan Lunde (1901–1942), Ivar Werner Oftedal (1894–1976), and (Fredrik) W(illiam) H(oulder) Zachariasen (1906–1979, later at the University of Chicago), determined the crystal structures of 200 compounds of 75 elements, which were to serve as the basis for his laws of the geochemical distribution of the elements [35, 36]. He used every conceivable method of chemical and physical analysis to amass the immense amount of data required to accomplish this formidable task. He checked or adapted known analytical methods such as X-ray spectroscopy, and he developed new ones such as carbon arc optical spectrography.

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Simultaneously with their search for element 72, Goldschmidt and Thomassen used the X-ray spectrograph to estimate the relative abundance and distribution of the rare earth elements, for which Goldschmidt introduced the term “lanthanides” [35c]. On the basis of their results, they refined the Oddo-Harkins rule [37] that odd-numbered elements are less abundant to read: “Elements of odd atomic number are less abundant than their immediate neighbors of even atomic number” [35c]. Goldschmidt’s work on the chemical and geochemical behavior of elements of the same valence and almost the same ionic radius is of great importance, especially in connection with the rare earth elements (the celebrated “lanthanide contraction,” which he was the first to recognize and name) [35e]. Together with František Ullrich (1899–1941) and Thomas Barth, Goldschmidt determined the unit cell dimensions of the cubic lanthanide oxides by X-ray diffraction [35d], but because the size of a specific ion was still unknown, they could not determine ionic sizes from such measurements. However, Finnish scientist J. A. Wasastjerna’s determination of the radii of the fluoride (1.33 Å) and oxide (1.32 Å) ions from molecular refraction data [38] provided Goldschmidt with the key to a complete revolution of the science of crystal chemistry. By May 1926 Goldschmidt published the first table of ionic radii [35g], whose close agreement with Linus Pauling’s values, based on a completely different approach, namely, quantum mechanics, and published the following year [39], proved to be a brilliant confirmation of the theoretical background. In Goldschmidt’s words [35g],

> Our results have united crystallography and technology on the basis of new principles; crystal chemistry has provided a series of important laws of geochemical association, has permitted predictions of the geochemical distribution of the elements, and above all the new crystal chemistry provides chemists and metallurgists with theoretical principles and techniques to supplement the previous empirical procedures.

Although differing significantly in some cases from presently accepted values, Goldschmidt’s values of ionic radii in crystals [39h, 40] have provided the basis for modern crystal chemistry and the introduction of size relationships into the interpretation of properties in inorganic chemistry.

In the same article Goldschmidt stated the rules relating ionic size to atomic structure that now appear in almost all general and inorganic chemistry texts [35g]:

> 1. For elements in the same group (vertical column) of the Periodic Table, the ionic radii increase as the atomic numbers of the elements increase.

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2. For positive ions of the same electronic structure the radii decrease with increasing charge.

3. For an element that can exist in several valence states, that is, form ions of different charge, the higher the positive charge on the ion, the smaller the radius.

Goldschmidt applied to the structure of crystals the coordination theory (1893) that Alfred Werner (1866–1919) had postulated to explain the structure of complex compounds. In addition to compiling the first tables of atomic and ionic radii for many of the elements, Goldschmidt recognized the effect of radius ratio (r_{cation}/r_{anion}), a particularly fruitful concept in crystal chemistry, on crystallographic coordination number and therefore on structure. By assuming that ions act as rigid spheres of definite radii, he calculated from geometry the stable arrangements of cations and anions for particular radius ratios [35h] (Table 1). He was the first to distinguish between the relative importance of the polarizability of anions already established by Kasimir Fajans (1887–1975) for their optical properties and the polarizing power of the cation, which is directly proportional to its charge and inversely to its radius (George H. Cartledge's ionic potential, ϕ = charge/radius).

Goldschmidt's work on metals and alloys (he compiled the first table of metallic radii) led physicist and X-ray crystallographer John Desmond Bernal (1901–1971) to regard him as one of the founders of modern alloy chemistry [5]. He also explained many puzzling aspects of isomorphism and polymorphism, concepts whose scope he greatly expanded. He was able to predict the sequence of crystallization for elements of the same size and almost the same ionic radius but of different charge, and thus he could predict in which minerals a given element might be found. He simply and elegantly solved the problem of the substitution of one element for another in minerals, which had bedeviled mineralogists for years [41]. For example, he was able to explain the complex formulas of minerals such as tourmaline [$H_9Al_3(BOH)_2Si_4O_{19}$] and mica [$H_2KAl_3(SiO_4)_3$] by the maintenance of charge neutrality for positive and negative ions through substitution based primarily on size.

Goldschmidt attacked the problem of discovering the general laws and principles of geochemistry "from the viewpoint of atomic physics and atomic chemistry and to find out the relationships between the geochemical distribution of the various elements and the measurable properties of their atoms and ions" [42]. He found that the principal

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TABLE 1. Goldschmidt's geochemical classification of the elements in relation to the periodic system [10; 35a].

Radius ratio (R_{cation}/R_{anion})	Arrangement of anions around cation	Coordination number of cation
0.15–0.22	Corners of an equilateral triangle	3
0.22–0.41	Corners of a tetrahedron	4
0.41–0.73	Corners of an octahedron	6
0.73–1	Corners of a cube	8
>1	Closest packing	12

factor determining the entrance of atoms or ions and the distribution of the rarer elements in the crystalline phases of igneous and metamorphic rocks is the size, rather than the weight, of the atoms or ions. During gradual crystallization of liquid solutions, those atoms or ions that are either too small or too large to be trapped in the crystal lattice are concentrated in the solid phase. Thus Goldschmidt discovered the fundamental relationship between crystal structure and chemical constitution in what is often known as Goldschmidt's Law [40]:

> The structure of a crystal is conditioned by the numerical proportions, the proportion of size and the properties of polarization of its ultimate particles, and not only the structure but also other important properties of crystals, such as hardness, solubility and melting temperature, could be predicted from the properties of the atoms, and so, in the course of our geochemical investigations, the foundations of modern crystal chemistry were laid. These relationships were not limited to crystalline phases, but applied as well to the properties of solidified glasses.

The Geochemical Distribution of the Elements (1923–1937)

Goldschmidt used his ionic radii data to explain the composition of the earth's crust (lithosphere), 99% by weight of which is composed of only nine elements with oxygen predominating [43, 44]. The predominance of oxygen is even more pronounced in terms of volume percent: O (91.77), K (2.14), Na (1.60), Ca (1.48), Si (0.80), Al (0.76), Fe (0.68), Mg (0.56), and Ti (0.22). Goldschmidt considered the crust to be

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essentially a packing of oxygen anions, bonded by silicon and the ions of the common metals, and he stated that the lithosphere might more properly be called the "oxysphere."

Among the other problems that Goldschmidt attacked were the partition of the elements during the geological evolution between gas and coexisting liquid phases; the subsequent crystallization of these phases—of molten iron, iron sulfides, and fused silicates; and the distribution of the chemical constituents in these phases. He considered the earth to have resulted from the condensation of gaseous material into an iron core, an intermediate sulfide-oxide zone, a siliceous envelope, and an atmosphere [45]. Depending on the particular zone in which the elements concentrated during condensation, they were classified by Goldschmidt into four groups related to their locations in the periodic table: (1) siderophile (those with an affinity to Ni-Fe)—a metal core consisting of Periodic Groups VIB (except Cr and U), VIIB (except Mn), and VIII, Au, Ge, and Sn; (2) chalcophile (those that combine with S)—Groups IB (except Au), IIB, IIIA (except B and Al), Pb, VA (except N and P), and VIA (except O); (3) lithophile (those with an affinity for silicates)—a crust or envelope consisting of Groups IA, IIA, IIIB, IVB, VB, and Cr; and (4) atmophile (those normally present as gases, differentiated into the primordial atmosphere during pregeological times)—the noble gases, N, O, and H [35a] (Table 2).

Goldschmidt's fundamental laws of geochemistry and crystal chemistry appeared in his 600-page monumental series of monographs titled "Geochemische Verteilungsgesetze der Elemente" (Geochemical Laws of Distribution of the Elements) in the *Kongelike Norske Videnskabers Selskabs Skrifter* from 1923 to 1937 [35]. The first eight volumes [35a–34h] contain the results of his work at Oslo, while the last volume [35i], which he called his "Ninth Symphony" in reference to Beethoven's last great symphony, critically reviewed not only all the data on the abundances of the elements obtained by him at Göttingen and by others but also related these to nuclear structure. Volume 7 [35g] contains his famous laws of crystal chemistry, and Volume 8 [35h] describes the relationships between the structure and properties of crystals, for example, how the hardness of a crystal depends on the interatomic distance, the valence, and the type of structure.

The final volume, No. 9 [35i], contains Goldschmidt's work on the cosmic and terrestrial distribution of the elements and on the isotopic compositions of elements in

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TABLE 2. Goldschmidt's relationship between radius ratio and coordination number for ions as rigid spheres [10; 35h].

Atmophile: N
Lithophile: Na
Chalocophile: Zn
Siderophile: Fe

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo		Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi			
			Th		U												

minerals. Its table of cosmic abundances provided the basis for later theories of atomic structure and the origin of the elements, as well as for two Nobel prizes in physics—Eugene P. Wigner, Maria Goeppert-Mayer, and J. Hans D. Jensen for their theory of nuclear shell structure (1963) and William A. Fowler "for theoretical and experimental studies of the nuclear reactions of importance in the formation of the chemical elements in the universe" (1983).

In this volume Goldschmidt also speculated on the possible existence of transuranium elements, a topic that he had considered in a prescient paper that he had presented at a conference of February 8, 1934, commemorating the centenary of the birth of Dmitrii Ivanovich Mendeleev (1834–1907) [46]. He predicted that they would belong to a series analogous to the lanthanides, which he called "thorides" and which Glenn T. Seaborg later called actinides. He even argued that their ionic radii would exhibit a contraction with increasing atomic number similar to the lanthanide contraction, and he even estimated the radii of the tetrapositive ions. After the discovery of neptunium (element 93) and plutonium (element 94), he called attention to the confirmation of his predictions [47].

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The Move to Göttingen (1929–1935)

Because of his growing reputation, during the 1920s Goldschmidt received several offers of professorships from European universities. In 1924 Paul von Groth retired as Professor of Mineralogy at the University of Munich, suggesting that Goldschmidt be named his successor. When the faculty rejected this appointment "because they did not want a scholar of presumably Jewish descent (or probably partly Jewish)" [48], 1915 Nobel chemistry laureate Richard Martin Willstätter (1872–1942), himself a Jew, resigned his own professorship at Munich in protest. This incident was not to be Goldschmidt's last encounter with anti-Semitism.

In 1925 Goldschmidt accepted an extremely attractive offer from the Technische Hochschule in Berlin, but Brøgger and former Norwegian Prime Minister Gunnar Knudsen convinced him to withdraw his acceptance. In 1927 Goldschmidt entered into negotiations with the University of Göttingen, where he worked for two years, combining this with his chair in Oslo and traveling between the two cities by airplane. In 1929 he settled in Göttingen, becoming Professor in the Faculty of Natural Sciences and Head of the new Mineralogical Institute built to his own specifications.

At Göttingen Goldschmidt continued his work on crystal chemistry and geochemistry, developing new analytical methods such as the cathode layer technique for the detection of elements at low concentration. He considered the wider implications of the abundance and distribution of the elements in terms of the geochemical cycle at the earth's surface, which he regarded as similar to the separation of the elements in a classical chemical analysis [44, 49]. He attempted to quantify this cycle and to follow the course of specific elements proceeding through its stages. He also began geochemical studies of germanium [50, 52], rhenium [51], gallium [52, 53], silicon [52], aluminum [52], scandium [54], boron [55], beryllium [56], selenium [57], the rarer elements [58], arsenic [59], chromium, molybdenum, nickel, the rare earths, strontium, zinc, and the noble [60] and alkali [61] metals.

Goldschmidt's years at Göttingen were probably his happiest. Unlike his tenure at Oslo, where he was a lone wolf at odds with many of his colleagues, here he not only inspired his students but was also inspired by his colleagues and the frequent foreign guests who visited his institute. However, with the ascent of the Nazis to power in 1933, this situation changed abruptly. Although they had not previously identified with any religion, Goldschmidt and his father ostentatiously joined the Göttingen Jewish

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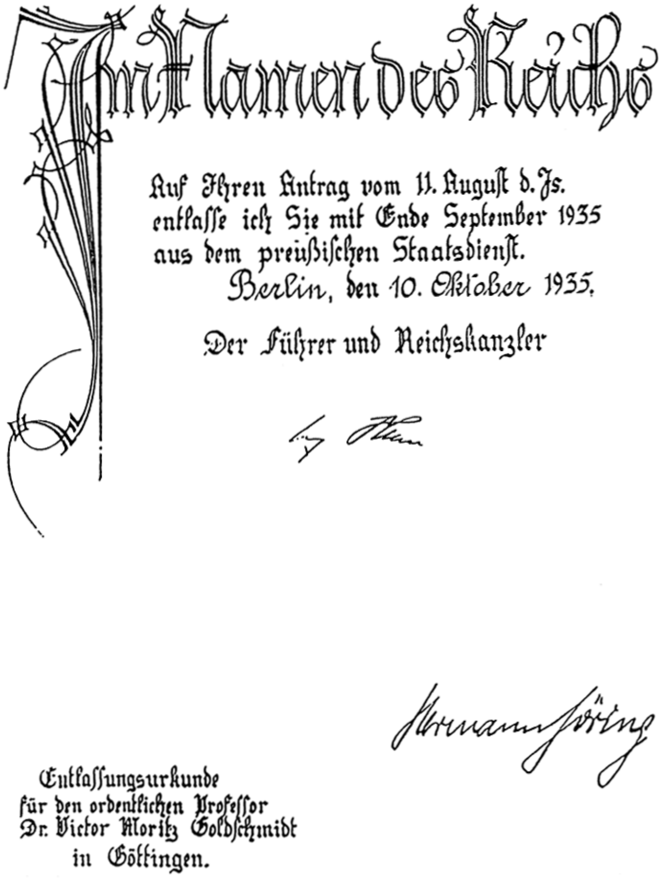

Im Namen des Reichs

Auf Ihren Antrag vom 11. Auguſt d. Js.
entlaſſe ich Sie mit Ende September 1935
aus dem preußiſchen Staatsdienſt.
Berlin, den 10. Oktober 1935.

Der Führer und Reichskanzler

Hermann Göring

Entlaſſungsurkunde
für den ordentlichen Profeſſor
Dr. Victor Moritz Goldſchmidt
in Göttingen.

FIGURE 5. GOLDSCHMIDT’S DISMISSAL LETTER OF OCTOBER 10, 1935, SIGNED BY ADOLF HITLER AND HERMANN GÖRING: “IN THE NAME OF THE REICH AT YOUR REQUEST OF AUGUST 11 OF THIS YEAR I RELEASE YOU AT THE END OF SEPTEMBER 1935 FROM THE PRUSSIAN STATE SERVICE” [10].

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community. His already grim sense of humor became grimmer. When asked at a meeting why he was wearing his hair unusually short, he tapped his head and replied, “So that it will roll more easily” (On coming to power Hitler had declared, “Heads must roll”) [10, p. 66]. Although Goldschmidt considered it his duty to continue his work at the institute as long as possible, after a sign reading “Jews not desired” was erected near his institute, he resigned on August 11, 1935. His dismissal letter (Figure 5) was signed by Hitler and Göring.

Return to Oslo (1935–1942)

On September 6, 1935 Goldschmidt, his father, and housekeeper left Göttingen and fled, almost penniless, to Oslo. Here he returned to the Norwegian Raw Materials

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Laboratory and resumed the industrial work that he had done during and after World War I. For example, he developed techniques for using Norwegian olivine [$(Mg,Fe)_2SiO_4$ or $2(Mg,Fe)O \cdot SiO_2$] in refractories [62], the patents for which afforded him considerable royalties. Today olivine is a major mineral product of Norway. Goldschmidt also accelerated the laboratory's work on the use of low-grade phosphate deposits containing apatite [$(CaX)Ca_4(PO_4)_3$ or $3Ca_3P_2O_8 \cdot CaX_2$, where X = F or Cl] as a source of agricultural fertilizer—research which was to save him temporarily from deportation in 1942 to a concentration camp in Poland.

Together with Aslak Kvalheim (b. 1911), who was Director of the Raw Materials Laboratory during Goldschmidt's absences, Goldschmidt wrote Part X, "Über die Verteilung einiger Elemente in Meteoriten," of his "Geochemische Verteilungsgesetze der Elemente;" on May 24, 1940 he submitted it to the Videnskaps-Akademi, but it was never published. He then began work on Part XI, which also was never published.

After the Germans occupied Norway in April 1940, Goldschmidt routinely carried a cyanide capsule in his pocket to commit suicide if necessary. When an Oslo colleague asked him for a capsule, he answered with his characteristic grim humor, "This poison is for professors of chemistry only. You, as professor of mechanics will have to use the rope" [6]. When his former assistant, Gulbrand Lunde, who had joined the Nasjonal Samling (Norwegian Union Party) of Vidkun Quisling (1887–1945), whose name has became a synonym for traitor, was appointed to Quisling's government as Minister of Propaganda in April 1940, Goldschmidt broke off relations with him.

When the Nazi-controlled Ministry of Education demanded information on each governmental employee's ethnic background, Goldschmidt, knowing that if one or more of a person's grandparents were Jewish, he or she would be considered Jewish and subject to deportation, proudly announced that all four of his grandparents were pure Jewish.

In October 1942 Goldschmidt, like most of Norway's 2000 Jews, was arrested by the German Schutzstaffel (SS), his property was confiscated, and he was imprisoned in the Berg concentration camp on the outskirts of Tønsberg near Oslo. In November 1942 he was listed for deportation to Poland, but because of his poor health (heart insufficiency, chronic nephritis, and other illnesses) and the intervention of the Norwegian police, he was released temporarily. With the help of the Norwegian

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resistance, on December 18, 1942 he was smuggled into neutral Sweden in a load of hay, which German soldiers prodded with a pitchfork.

Soil Geochemistry in Great Britain (1943–1946)

Although Goldschmidt could have remained in neutral Sweden (he was offered the chair of mineralogy at Uppsala), he thought that his knowledge of Norwegian technical developments would be of great value to the Allies, so on March 3, 1943 he made his way to Great Britain. Under the auspices of the British Agricultural Research Council, he applied his geochemical concepts to soil science at the Macaulay Institute for Soil Research at Craigiebuckler, near Aberdeen, Scotland. In 1944 he moved to the Rothamsted Experimental Station near Harpenden, England, some thirty miles north of London, where, affectionately called “Goldie” by his colleagues, he worked on the distribution of trace elements in soil. He also devoted much of his time applying geochemistry to the problem of preventing silicosis and skin cancer in foundry workers. After a severe heart attack on December 14, 1944 and several weeks in the hospital, he spent his remaining year and a half in England in a nursing home.

Final Return to Oslo (1946–1947)

After Norway was liberated in May 1945, despite offers of positions from Britain, China, and the University of Göttingen, Goldschmidt was determined to return to the University of Oslo. He arrived on June 26, 1946 but was immediately hospitalized for three weeks before he was able to reoccupy his former positions of Director of the Geological Museum and of the Raw Materials Laboratory. He tried to complete his *magnum opus* summarizing his life’s work, but, after a minor operation on his leg, he died suddenly of a cerebral hemorrhage on March 20, 1947 at the age of 59 without completing the task. The 730-page volume, titled *Geochemistry* [63], was finally completed by Alex Muir of the Rothamsted Experimental Station with the collaboration of Aslak Kvalheim. According to Goldschmidt’s will, royalties from the book, which reflects his great versatility and ability to correlate and synthesize a tremendous amount of scientific data, were bequeathed to the Raw Materials Laboratory and Muir.

As an example of Goldschmidt’s grim, sarcastic humor, chemist and editor Paul Rosbaud (1896–1963) related [6]:

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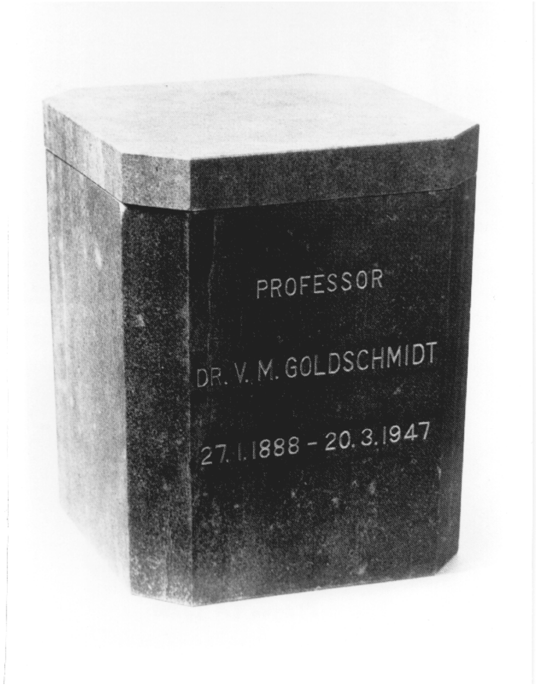

FIGURE 6. URN (36 CM IN HEIGHT) OF BEAUTIFUL GREEN OLIVINE ROCK, IN WHICH GOLDSCHMIDT'S ASHES WERE PLACED [10].

> We stood reverently in front of the urns, all made of beautiful green Norwegian olivine, two with the ashes of his parents and a third, empty and destined to hold his own, and finally V. M. remarked dryly: “Ja, Ja, the whole family in magnesium orthosilicate.”

Goldschmidt was cremated and his ashes preserved in the urn shown in Figure 6. In May 1986, together with those of his father and mother, the ashes were buried in the graveyard of the Western Crematorium in Oslo, while the three empty urns are preserved at the Geological Museum. In 1974 Norway issued a postage stamp with Goldschmidt's portrait, engraved from a photograph taken in 1923 (Figure 7).

Personality

A lifelong bachelor, Goldschmidt was cared for by a cook-housekeeper, Marie Brendingen (1891–1980), who joined the household in 1927, when his mother suffered a stroke, and remained with him until his death. He bequeathed to her a large part of his estate. He was especially depressed by his father's sudden death of a heart attack in 1937 and became more lonely, pessimistic, and withdrawn than he had been previously, and his health deteriorated.

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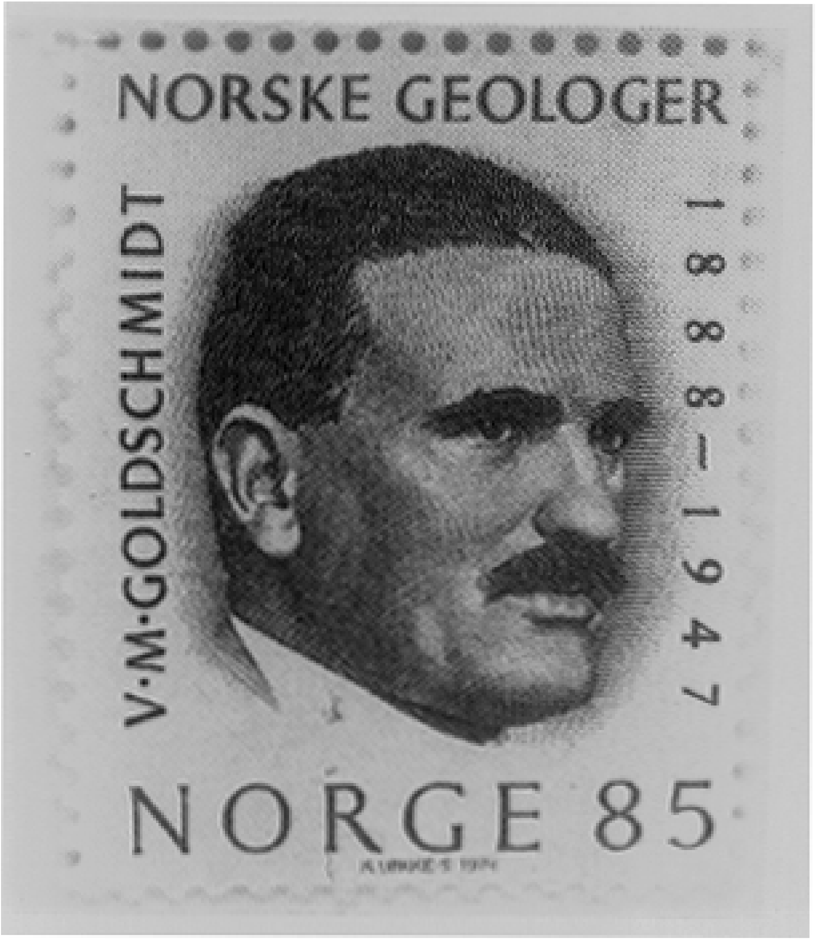

FIGURE 7. NORWEGIAN POSTAGE STAMP ISSUED IN 1974 WITH GOLDSCHMIDT'S PORTRAIT, ENGRAVED FROM A PHOTOGRAPH TAKEN IN 1923 [10].

Although Goldschmidt inspired lifelong devotion in most of his research associates and students, he was overly sensitive to questions of scientific credit and priority, particularly with his colleagues at the University of Oslo, where his bitter feud with former student Thomas Barth adversely affected faculty relations. An unduly suspicious person, he padlocked all the cabinets in his museum office for fear that his research materials might be stolen.

Goldschmidt had a number of "enemies" among well-known scientists. He was not the most diplomatic of men and could denigrate a colleague with a thoughtless comment. His lack of knowledge of human nature made him uncertain of new acquaintances. His experiences with anti-Semitism gave him a feeling of persecution, led him to distrust strangers, and made him quick to take offense where none was intended; however, it

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also made him very responsive to genuine gestures of friendship. On those few occasions when his explosive temper erupted, he usually apologized profusely afterwards.

Awards and Honors

In addition to being elected a member, foreign member, or honorary member of various academies of sciences and scientific societies, Goldschmidt was awarded the Norwegian Academy of Sciences' Fridtjof Nansen Prize in 1912. When Goldschmidt left Norway in 1929, King Haakon VII made him a Knight of the Royal Norwegian Order of St. Olav for his services to Norwegian science. He received honorary doctorates from three universities—Freiburg im Breisgau (1932), Utrecht (1936), and Aberdeen (1944)—as well as the Geological Society of London's highest honor, the Wollaston Medal (1944) [64].

The author of more than 200 articles, Goldschmidt was nominated unsuccessfully for the Nobel Prize for Chemistry ten times: 1929 by Brøgger; 1930 by Walter Hieber; 1931 by Alfred Coehn and Max Planck; 1932 by Adolf Deissmann, Max Planck, and Arthur Kötz (the last disallowed because the nomination was received after the February 1 deadline); 1933 by Fritz Haber; 1934 by Fritz Haber; and 1936 by Otto Ruff [65]. In 1972 the Geochemical Society established the Goldschmidt Medal, endowed monetarily by Goldschmidt's American student and colleague, Lester William Strock (1906–1982), as its highest award.

Conclusion

Goldschmidt is universally recognized as the founder of modern geochemistry. Only the Ukrainian polymath Vladimir Ivanovich Vernadsky (1863–1945) [66], the founder of biogeochemistry, made anywhere near the number of contributions that Goldschmidt made. Before Goldschmidt's pioneering work, geochemistry was a somewhat incoherent collection of factual data; after it, geochemistry became a true science based on his geochemical cycle in which the individual elements play their respective roles according to well established principles. In Goldschmidt's words, "The basic problem of geochemistry is to determine the quantitative chemical composition of the earth and to find the laws which underlie the frequency and distribution of the various elements in nature" [6].

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Goldschmidt not only produced an enormous amount of experimental data, but he also rationally interpreted geochemical problems in terms of crystal chemistry and ultimately, of physics. We owe to him the view of atoms and ions as particles of definite measurable sizes and of their combination as a function of size. According to Bernal, his "concepts of atomic radii and coordination will provide a clue for the complex transformations that have accounted for the history of the earth on which we live" [5].

REFERENCES

1. Hassel, O. *Det Norske Videnskaps-Akademi i Oslo, Årbok*, **1947**, 85.
2. Correns, C. W. *Naturwiss.* **1947**, *34*, 129.
3. Oftedal, I. *Proc. Geolog. Soc. Amer.* **1948**, 149.
4. Tilley, C. E. *Obit. Notices, Fellows Roy. Soc.* **1948–1949**, *6*, 51.
5. Bernal, J. D. *J. Chem. Soc.* **1949**, 2108.
6. Rosbaud, P. In *Great Chemists*; Farber, E., Ed.; Wiley-Interscience: New York, 1961; pp 1564–1586.
7. Goldberg, E. D. In *Dictionary of Scientific Biography*; Gillispie, C. C., Ed.; Scribner's: New York, 1972; Vol. 5, pp 456–458.
8. Kauffman, G. B. *Indust. Chemist* **1988**, *9*(*1*), 46.
9. Kullerud, G. *The World & I* **1990**, *4*(*4*), 320.
10. Mason, B. *Victor Moritz Goldschmidt: Father of Modern Geochemistry*; Special Publication No. 4; The Geological Society: San Antonio, TX, 1992.
11. Cameron, M. D. *J. Chem. Educ.* **1949**, *26*, 521.
12. Kauffman, G. B. *Educ. Chem.* **1987**, *24*, 168; In *Encyclopedia of Chemistry;* Lagowski, J. J., Ed.; Macmillan: New York, 1997; Vol. 4, pp 1482–1483.
13. Kauffman, G. B. *Indust. Chem. News* **1986**, *7*(*11*), 16.
14. Goldschmidt, V. M. *Tidssk. kemi Farm. Terapi* **1911**, *8*, 337; *Tidsskr. Kemi Bergv*. **1940**, *20*, 21; In *Det Norske Videnskaps-akademi i Oslo, Årbok* 1940; Oslo, 1941; pp 29–41.
15. Goldschmidt, V. M. *Forh. Vidensk. Selsk. Kristiania* **1906**, *5*.

ISSN 1430-4171
http://journals.springer-ny.com/chedr
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S 1430-4171 (97)05143-3

16. Goldschmidt, V. M. *Zentbl. Miner. Geol. Paläont.* **1909**, *13*, 405.

17. Goldschmidt, V. M. *Vidensk. skrifter I. Mat.-naturv. klasse* **1911**, *No. 1*.

18. Amundsen, L. *Videnskapsakademi Historie*; Oslo, 1960; Vol. 2, p 27.

19. Goldschmidt, V. M. *Vidensk. skrifter I. Mat.-naturv. klasse* **1912**, *Nos. 18, 19*; **1915**, *No. 10*; **1916**, *No. 2*; **1920**, *No. 10*.

20. Goldschmidt, V. M. *Z. anorg. Chem.* **1911**, *71*, 313.

21. Goldschmidt, V. M. *Z. Elektrochem.* **1911**, *17*, 686.

22. Goldschmidt, V. M. *Zentr. Miner*. **1912**, 574.

23. Goldschmidt, V. M. *Z. Kristallogr*. **1929**, *69*, 213; *Ergebnisse techn. Röntgenkunde* **1931**, *2*, 152; *Fortschr. Miner. Kristallogr. Petrogr*. **1931**, *15*, 73.

24. Goldschmidt, V. M. *Bergverksnyt.* **1918**, *73*; *Tidsskr. Kemi, Farm. Terapi* **1918**, *15*, 325; *Tek. Ukebl*. **1918**, *37*, 6; *Tidsskr. Kemi* **1919**, *16*, 65.

25. Goldschmidt, V. M. *Norsk Landmansblad.* **1922**, *41*, 268.

26. Goldschmidt, V. M. *Tidsskr. Kemi Bergv*. **1924**, *4*, 9, 38, 116; *Nord. Jordbr. Forsk*. **1926**, 434; In *Det Norske Videnskaps-akademi i Oslo, Årbok* 1926; Oslo, 1927; pp 23–24; *ibid*. 1927; Oslo, 1928; pp 12–13.

27. Moseley, H. G. *J. Phil. Mag.* **1913**, *26*(*December*), 1024; **1914**, *27*(*April*), 703.

28. Urbain, G. *Compt. rend.* **1911**, *152*(*January 16*), 141.

29. Bohr, N. *The Theory of Atomic Spectra and Atomic Constitution, Three Essays*; Cambridge University Press: Cambridge, England, 1924; pp 110, 114. Although Bohr's prediction of the chemical nature of element 72 has frequently been cited as an example of a successful chemical prediction on the basis of quantum theory, Helge Kragh (*J. Chem. Educ*. **1977**, *54*, 208; *Historical Studies in the Physical Sciences* **1979**, *10*, 123) and Eric R. Scerri (*Ann. Sci.* **1994**, *51*, 137) have questioned this view.

30. Hopkins, B. S. *Sci. Am.* **1927**, *136*(*February*), 87; Urbain, G.; Dauvillier, A. *Nature* **1923**, *111*, 218; Coster, D.; Hevesy, G. *Nature* **1923**, *182*, 252.

31. Arrhenius, G.; Levi, H. In *George de Hevesy, 1885–1966;* Marx, G., Ed.; Akadémiai Kiadó: Budapest, 1988; pp 11–36.

32. Coster, D.; Hevesy, G. *Nature* **1923**, *111*, 79.

33. Goldschmidt, V. M.; Thomassen, L. *Norsk geol. Tidsskr.* **1923**, *7*, 61.

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http://journals.springer-ny.com/chedr
S 1430-4171 (97)05143-3

34. Weeks, M. E. *Discovery of the Elements*, 7th ed.; Leicester, H. M., Reviser; Journal of Chemical Education: Easton PA, 1968; pp 820–823.

35. Goldschmidt, V. M.; (a) *Vidensk. skrifter. I. Mat.-naturv. klasse* **1923**, *No. 3*; (b) **1924,** *No. 4*; (c) Goldschmidt, V. M.; Thomassen, L. **1924**, *No. 5*; (d) Goldschmidt, V. M.; Ulrich, F.; Barth, T. *Skrifter utg. av det Norske Videnskaps-akademi i Oslo. I. Mat.-naturv. klasse* **1925**, *No. 5*; (e) Goldschmidt, V. M.; Barth, T.; Lunde, G. **1925**, *No. 7*; (f) Goldschmidt, V. M.; Barth, T.; Holmsen, P.; Lunde, G.; Zachariasen, W. **1926**, *No. 1*; (g) Goldschmidt, V. M.; Barth, T.; Lunde, G.; Zachariasen, W. **1926**, *No. 2*; (h) Goldschmidt, V. M. **1926**, *No. 8*; (i) **1937**, *No. 4*.

36. Goldschmidt, V. M. *Physik. Z.* **1929**, *30*, 519.

37. Harkins,W. D. *Chem. Rev.* **1928**, *5*, 371.

38. Wasastjerna, J. A. *Z. physik. Chem.* **1922**, *101*, 193; *Soc. Sci. Fennica, Comm. Phys.-Math.* **1923**, *1*, 38.

39. Pauling, L. *J. Am. Chem. Soc.* **1927**, *49*, 763.

40. Goldschmidt, V. M. *Trans. Faraday Soc.* **1929**, *25*, 253.

41. Goldschmidt, V. M. *Ber.* **1927**, *60*, 1263.

42. Goldschmidt, V. M. *Chemical Products* **1944**, (*March/April*), 1.

43. Goldschmidt, V. M. *Neues Jahrb. Mineral. Beilage, Abt. A* **1928**, *57*, 1119.

44. Goldschmidt, V. M. *J. Chem. Soc.* **1937**, 655.

45. Gibson, D. T. *Quart. Revs.* **1949**, *3*, 263.

46. Goldschmidt, V. M. *Travaux du congrès jubilaire Mendeléev II. Acad. Sci. U.R.S.S.* **1937**, 387.

47. Goldschmidt, V. M. *Fra fysikkens verden. Oslo* **1941/42**, *3*, 179.

48. Willstätter, R. M. *From My Life*; Hornig, L. S., Transl.; W. A. Benjamin: New York, 1965; p 363.

49. Goldschmidt, V. M. *Geol. För. Stockh. Förh.* **1934,** *56*, 385.

50. Goldschmidt, V. M. *Naturwiss.* **1926**, *14*, 295; *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1930**, 398; *ibid.* **1931**, 184; *Z. physik. Chem., Abt. A* **1930**, *146,* 404; *ibid.* **1932**, *17*, 172; Goldschmidt, V. M.; Peters, C. *ibid.* **1933**, 141.

51. Goldschmidt, V. M. *Naturwiss.* **1929**, *17*, 134; *Z. physik. Chem., Abt. B* **1929**, *2*, 244.

52. Goldschmidt, V. M. *Norsk geol. Tidsskr.* **1931**, *12*, 247.

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53. Goldschmidt, V. M.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1931**, 165.

54. Goldschmidt, V. M.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1931**, 257.

55. Goldschmidt, V. M.; Hauptmann, H. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1932**, 53; Goldschmidt, V. M.; Peters, C. *ibid.* **1932**, 402, 528.

56. Goldschmidt, V. M.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1932**, 360.

57. Goldschmidt, V. M.; Hefter, O. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1933**, 245; Goldschmidt, V. M.; Strock, L. W. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl., N. F. Fachgruppe IV (1934–40)*, **1941**, *1*, 123.

58. Goldschmidt, V. M.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1933**, 371; Goldschmidt, V. M.; Hauptmann, H.; Peters, C. *Naturwiss.* **1933**, *21*, 363; Goldschmidt, V. M. *Ind. Eng. Chem.* **1935**, *27*, 1100.

59. Goldschmidt, V. M.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl., N. F. Fachgruppe IV (1934-40)*, **1941**, 11.

60. Goldschmidt, V. M.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1932**, 377.

61. Goldschmidt, V. M.; Berman, H.; Hauptmann, H.; Peters, C. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl.* **1933**, 235; Goldschmidt, V. M.; Bauer, H.; Witte, H. *Nachr. Ges. Wiss. Göttingen, Math.-phys. Kl., N. F. Fachgruppe IV (1934-40)* **1941**, 39.

62. Goldschmidt, V. M. *Ind. Eng. Chem.* **1938**, *30*, 32.

63. Goldschmidt, V. M. *Geochemistry;* Muir, A., Ed.; Clarendon: Oxford, England, 1954.

64. Goldschmidt, V. M. *Proc. Geol. Soc., London* **1944**, (*May*).

65. Crawford, E.; Heilbron, J. L.; Ullrich, R. *The Nobel Population 1901–1937: A Census of the Nominators and Nominees for the Prizes in Physics and Chemistry*; Office for History of Science and Technology, University of California: Berkeley; Office for History of Science, Uppsala University: Uppsala, 1987; pp 248, 254, 256, 260, 262, 264, 268, 276.

66. Kauffman, G. B. *The World & I* **1991**, *6*(*10*), 316; *South African J. Sci.* **1996**, *92*, 519.