

Brauner Memorial Lecture.

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THE classification of the elements according to their atomic weights, and the Periodic System on which that classification is based, are associated in the mind of every student of chemistry with the name of Mendelejeff, the Russian genius by whom they were first given to the world in their completed form. Mendelejeff published his first accounts in Russian in the years 1869 and 1870; he used the periodic table as the basis of his presentation in his well-known textbook, "Principles of Chemistry," published in 1869, and in that year he published a short paper in German, announcing his generalisation to the Western world. In 1870 Lothar Meyer compiled his well-known atomic volume curve, including it in a paper in which he referred to Mendelejeff's paper of the previous year. In the following year, 1871, Mendelejeff gave a full, clear and reasoned account of the law and the classification in an essay of 100 pages, published in the 8th supplemental volume of Liebig's *Annalen*.

It may be imagined that the chemists of his time would have welcomed at once and eagerly a generalisation so far-reaching and so fundamental for chemical science. In fact, they did not; for several years there was no response to it whatever. It is true that after this publication Mendelejeff himself did little to make his work familiar to the chemists of his generation in Western Europe. So wide were his other scientific interests, and so great his absorption, during his later years, in the problems of national education and in the organisation of scientific work in Russia, that the periodic law had become for him almost a minor issue long before it had been generally accepted. It was largely owing to the labours of another Slavonic chemist, his friend and disciple, that the classification became eventually the guiding principle of inorganic chemistry, and that the importance of fixing exactly the atomic weights of all the known elements was seen to require and justify the labours of a permanent international committee. That friend and disciple was the great Czech chemist Bohuslav Brauner, to whose memory we are met to-night to do honour.*

Bohuslav Brauner was born on May 8th, 1855, at Prague. His father, Dr. Francis Brauner, a well-known lawyer in that city, played a considerable part in politics as a leader of the Czech party. His mother was a daughter of K. A. Neumann, first professor of chemistry at the Polytechnic Institute of Prague, who was a nephew of Caspar Neumann, professor of pharmacy in Berlin, early in the 18th century.

Young Brauner's attention, whilst he was still a child, was directed to chemistry by his grandfather Neumann, who died when the boy was 11. At an early age, therefore, he became familiar with chemical conceptions, and acquired a love for scientific knowledge which determined his career. When he was 15 he succeeded in obtaining permission to take chemistry at school as a special subject. Both at home and at school he studied languages, and laid the foundation for the astonishing proficiency which he afterwards attained; besides Czech, he read and spoke fluently Russian, English, French, and German.

At the age of 18, Brauner went to the Czech Technical School, and a little later to the German University at Prague. At the University he attended the lectures of Stolba in inorganic chemistry, of Lieben and Linneman in organic chemistry, and of Ernst Mach in physics. His first papers were published in 1877. They included accounts of work on the estimation of arsenic as magnesium pyroarsenate, and of cobalt in the cobaltinitrites, and of some experiments on fluorescence carried out under Ernst Mach.

The tendency to specialise on organic research aroused by the systematisation of that branch of the science was at that time very strong in most of the Universities of Europe.

* I am indebted for much information, and for much kind help in preparing this lecture, to Professor J. Heyrovsky of Prague, a former pupil of Professor Brauner, and his successor at the Charles University. Professor Arthur Smithells has very kindly assisted me and has placed at my disposal a selection of letters, and Dr. Gerald Druce, a former pupil of Professor Brauner, has also given me much help.



Bohuslav Brauner

Though even at this early stage of his scientific career, Brauner's inclination was towards inorganic work, his desire to obtain the doctorate led him to research work under Linneman, whom he assisted in the study of the reactions of *isobutyl iodide*. In 1878 he published a paper on the direct conversion of that substance into trimethylcarbinolamine, and in the following year papers on the reaction between *isobutyl iodide* and silver cyanate and on the molecular orientation of the *isobutyl* group. These were the only papers on organic chemistry which Brauner ever published, and he has himself placed it on record that the work awakened in him no liking for that branch. Possibly this was because at that time he first became acquainted with the work of Mendelejeff, which so fired his imagination that it determined the whole course of his scientific work thereafter.

In 1876 the discovery of gallium by Lecoq de Boisbaudran was announced in the press, with the additional information that the properties of the new element had been predicted many years before by the Russian chemist Mendelejeff. Gallium had been found in fact to correspond in almost every particular with Mendelejeff's eka-aluminium. In this sensational way Brauner first heard the name of Mendelejeff. At once he set himself to discover more about the work which had produced so striking a result, and soon succeeded in finding the memorable paper of 1871 in the *Annalen*. In an obituary essay which he wrote in 1907 on the death of Mendelejeff, Brauner has given an account of the change in his outlook produced by this clear and masterly exposition :—

“ The reading of this article made an enormous impression on me, which can hardly be described. It opened the view to a new world, and to new fields in chemistry hitherto absolutely unknown to me. It was as if the scales fell from my eyes, and I suddenly saw clearly the vast series of wonderful problems of general chemistry. All the problems of organic chemistry I had started to investigate seemed of little importance in comparison with those problems of Mendelejeff. I am not ashamed of my youthful enthusiasm; on the contrary, I feel proud that, notwithstanding that thirty years have passed since then, my admiration for Mendelejeff and his work has not changed, save to grow still more profound.

After reading this wonderful paper, and being at that time not a very hopeful adept of organic chemistry, I soon recognised the direction which I ought to follow in my work. I fixed my life's aim at that moment; it was to be the experimental examination of the problems connected with Mendelejeff's system, and the most important of these seemed to be ‘ What is the position of the so-called rare elements, and especially of those of the rare earths, in Mendelejeff's system? ’ ”

To us, to whom the periodic classification has been made so familiar that we can hardly conceive of chemistry without it, the enthusiasm disclosed in this passage may seem at first sight more than a little surprising. It is true that to the enthusiasm of youth Brauner added the zeal and keenness of a particularly sanguine and eager temperament. The feelings which he describes, however, were evoked to some degree in many of his contemporaries, to whom the chemistry of the schools and universities must have appeared as a science of vague and uncertain aims and extent, resting mainly on experimental observation, and inspired rather by analogy and hypothesis than by recognised fundamental laws. The atomic theory, based on definite laws of behaviour though it was, was still a mere theoretical conception, unrelated to the physical and chemical properties of the elements, and presenting no firm basis on which the mind could rest to survey the chemical domain as a coherent and definite whole.

Into the vague and still formless field of chemistry as then presented to the student, the Periodic Law introduced a comprehensive unifying idea which clarified and defined the whole range of the science, bringing order and clearness where before had been only speculation and uncertainty. The clarity and sureness of the reasoning with which Mendelejeff presented his great co-ordinating thesis, the boldness with which he declared that the accepted atomic weights of roughly one-fifth of the known elements must be wrong, and with which he proposed others, all of which have been shown to be approximately correct, and the foresight with which he foretold the existence of elements then

unknown, whilst limiting the total number likely to be found capable of existence, all these excite the wonder and admiration of those who read his famous paper even to-day. When we consider further that it was the discovery of the first of the "foretold" elements which attracted Brauner's attention, we may perhaps more easily understand the zeal and enthusiasm with which the younger Slav resolved to devote his life to the great prospect opened out by the genius of the older.

As soon as the opportunity for acting on this resolution presented itself, Brauner left Prague for Heidelberg, where the great reputation of Bunsen had established the foremost school of inorganic chemistry in Europe. Here he remained for two years, 1878-9, attending the lectures given by Bunsen, and acquiring the technique in analysis and manipulation which the great experience and unrivalled aptitude of the famous German made available to his pupils. Though he started work on the rare earths, his enthusiasm for the periodic law found little encouragement. Bunsen in his lectures never even referred to it. Brauner has recorded that on one occasion, when he pointed out how well the atomic weights of the elements of the rare earths confirmed the positions assigned to them in the table, Bunsen answered, "Leave those conjectures alone." On another occasion, when the regularities co-ordinated by the periodic classification were mentioned before Bunsen, he observed, "You can find that sort of regularity in Stock Exchange quotations." The chemical world, in fact, was still very far from recognising the truth and value of Mendelejeff's work, though ten years had elapsed since his first publication.

In 1880 Brauner obtained his Ph.D. at Prague. In the autumn of that year he came to England, and started work at Owens College, Manchester, to which he was attracted by the work of Sir Henry Roscoe on vanadium. His choice was the more fortunate in that he was elected to a Bishop Berkeley research fellowship of the college. Here he continued his work on the rare earths, and began the publication of the series of papers which was to bring him international reputation in that field.

The atmosphere of Roscoe's laboratory proved in the highest degree congenial, and in the two years he spent there Brauner developed an admiration for English methods and institutions which endured throughout his life. Of his contemporaries there, he became more especially intimate with Arthur Smithells and Sydney Young, with whom he maintained close friendships after leaving Manchester. The impressions made on him during his stay in Manchester were always in his memory. He delighted to recall that it was in company with Smithells that he bought his first copy of *Nature*, to which journal he remained a faithful subscriber; he claimed to have read every issue, except during the war, for more than fifty years. When he returned to Bohemia, he adopted English as the language of his laboratory, and dedicated much of his leisure time to outdoor sports and pastimes to which he had become attached whilst in England, including cycling, swimming, and Association football; he was also a keen hunter, and very fond of skiing and of climbing.

On his return to Prague in 1882, Brauner was appointed lecturer at the Charles University; in 1890 he became assistant professor, and in 1897 was appointed to the chair in chemistry, which he occupied until his retirement in 1925, at the age of 70. In 1886 he married Ludmila, the adopted daughter of Professor Safarik, his predecessor; his wife died in 1920, leaving two sons and a daughter.

In 1881, whilst he was still at Manchester, Brauner had entered into correspondence with Mendelejeff, and in the autumn of 1883, the year following his appointment at Prague, was able to visit him in St. Petersburg. Mendelejeff welcomed him warmly, and the relations between the two became intimate and cordial. Mendelejeff was at that time about fifty years of age, and was so much occupied in his attempt to introduce scientific methods in Russian administration and education that he was quite unable to find opportunity for research work. He was only too happy, therefore, to encourage the zeal and enthusiasm of the younger man in the attack on the problems raised by the periodic system, and particularly on the problem of the place of the rare-earth elements, which both felt to be the most difficult and obscure question of inorganic chemistry.

The two Slavonic chemists remained in close correspondence thereafter, but were able to meet very infrequently. It was not until 1900 that they again saw one another. In

that year Mendelejeff visited Berlin for the celebration of the Prussian Academy, and went to Prague to visit Brauner. At that time Mendelejeff was 66 and Brauner 45 years old. Their third and last meeting was again in St. Petersburg, on the occasion of Brauner's visit in 1902 to deliver before the Russian Science Congress a lecture on the Position of the Rare Earth Elements in the Periodic Table, to which I shall refer again later.

At the time Brauner began his work, the term "rare earths" was rather loosely applied to those earths or oxides which were not of very common occurrence. The chemists of the 18th century and of the first half of the 19th century used the term earth, or earth oxide, to cover generally the basic oxides other than those of the alkali metals and of the heavy metals. The better known earths were the alkaline earths lime, strontia, and baryta, with which magnesia was generally included, and alumina. The lesser known or rare earths included beryllia, zirconia, thoria, and the ceria and yttria oxides. Berzelius regarded all these bases as having the formula RO, that is, as oxides of bivalent metals, with the exception of zirconia, which because of its less strongly marked basic character was thought to have the formula Zr_2O_3 . Beryllia was later considered by Rose to have the formula Be_2O_3 on the same ground, and because of its general similarity to alumina. In 1857 Deville and Troost determined the vapour density of zirconium chloride, which showed that the element must be quadrivalent.

The ceria and yttria oxides had been found to be heterogeneous by Mosander during the years 1839—1843. Ceria he separated into ceria proper, lanthana and didymia, whilst yttria yielded yttria proper, erbia and terbia. All these oxides, from their strongly basic character, were thought to be analogous to the alkaline earths, and to conform to the formula RO.

When Mendelejeff constructed his first periodic table in 1869, therefore, he was certain of the atomic weight of only one of these elements, namely, zirconium. Thorium he placed also in Group IV, from the general analogy of its compounds with those of zirconium, and from the isomorphism of the two oxides. He concluded that beryllium must be bivalent, since no place could be found in the table for a trivalent element of equivalent weight about 4.7; the atomic weight must therefore be about 9.4, and the element fell into place at the head of Group II.

The remaining rare-earth elements presented more difficulty, not only because they were regarded as bivalent, but because of the uncertainties with regard to their individualities, and to the values of the equivalent weights. Erbium and terbium were regarded as particularly doubtful, Bahr and Bunsen having questioned the work of Mosander. If the elements were in fact bivalent, no place could be found for any of them in the table.

The equivalent weight of yttrium as determined by the earlier workers varied from 30.8 to 34. The gap between Sr, atomic weight 87, and Zr, atomic weight 90, should be filled by a trivalent element of atomic weight between these two figures, say 88.5; this element would therefore have an equivalent of 29.5. Mendelejeff had no hesitation in concluding that yttrium must be trivalent, with the atomic weight about 88.5, and that its equivalent must be considerably below any of the figures determined up to that time.

The equivalent weights of cerium, lanthanum, and didymium were very discordant, all the values given lying between 44 and 48. Mendelejeff assumed didymium also to be trivalent, and placed it below yttrium in Group III. Cerium he assumed to be trivalent in the lower salts, and quadrivalent in the higher salts; it fell, therefore, into Group IV below zirconium. To erbium and lanthanum he provisionally assigned places in Groups III and IV respectively, below didymium and cerium, whilst the individuality of terbium was regarded as so doubtful that no place was assigned to it. Query marks were placed to indicate that all these positions were provisional; the table of 1871 with these provisional positions is shown in Table I (*Annalen*, 1871, Suppl. 8, 151).

Mendelejeff stated in his paper of 1871 that he had himself determined the specific heat of metallic cerium, and that the value obtained indicated an atomic weight of about 140, which would be consistent with an equivalent of about 47 if the element were trivalent in the lower salts. The paper containing the description of this work is in Russian, and does not appear to have been translated; prior to that date none of the rare-earth metals had been prepared. In 1875 Hillebrand and Norton (*Pogg. Annalen*, 1875, 155, 631;

TABLE I.

Series.	Group I. $\overline{R_2O}$	Group II. \overline{RO}	Group III. $\overline{R_2O_3}$	Group IV. $\overline{RH_2}$ $\overline{RO_2}$	Group V. $\overline{RH_3}$ $\overline{R_2O_5}$	Group VI. $\overline{RH_4}$ $\overline{RO_3}$	Group VII. \overline{RH} $\overline{R_2O_7}$	Group VIII. $\overline{RO_4}$
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	— = 44	Ti=48	Cr=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	— = 68	— = 72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	— = 100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

156, 466) obtained the metals lanthanum, cerium and the so-called didymium by electrolysis of the fused chlorides, and measured the specific heats; the results showed that all three must have atomic weights about 140. The positions assigned to cerium and didymium were thus confirmed, but that assigned to lanthanum was clearly wrong.

In 1878 Nilson and Petterson (*Ber.*, 1878, **11**, 381) measured the specific heat of beryllium between 0° and 100°, and obtained the value 0.408. By the law of Dulong and Petit it follows that the atomic weight must be about 15, and the element trivalent. Brauner, at that time still a student at Prague, realised the importance of this conclusion. Trivalent beryllium could not be fitted into the table. It was, as he said, a question of life or death for the periodic system. The elements of the cerium and yttrium groups were still so little known, their individuality, properties and atomic weights so uncertain, that the positions assigned to them could not be regarded as final; in any event, there were many vacant spaces available for them. With beryllium the case was different; there could be no other position for it than that at the head of Group II, and therefore it must be bivalent if the system were to stand. In a paper published a few months after the result of Nilson and Petterson was announced, Brauner repeated and elaborated Mendelejeff's contention that the specific heats of many elements of low atomic weight were abnormal between 0° and 100° (*Ber.*, 1878, **11**, 868). Beryllium also must be abnormal in this respect. He suggested that lanthanum should be placed in Group III with atomic weight 139, immediately before cerium in Group IV, atomic weight 141, and that didymium would be found to be quinquevalent in a higher oxide and should be placed in Group V with atomic weight 147. He added "Experience shows that all the elements, not excepting those of the rare earths, fit into the periodic system"—a statement in the attempted verification of which he was to spend many arduous years.

Nilson and Petterson returned to the question in 1880 (*Ber.*, 1880, **13**, 1451), pointing out that the rise in the specific heat of beryllium with increasing temperature was of the same order as the rise in the case of iron, and much less than the rise in the case of the abnormal elements. Nilson was by no means antagonistic to the periodic law. He had just isolated scandium from the mineral euxenite (*Ber.*, 1879, **12**, 550; 1880, **13**, 1439), and had pointed out that it conformed to Mendelejeff's eka-boron in the same way as gallium to eka-aluminium, "Thus confirming," as he said, "in the most striking way the speculations of the Russian chemist, which permitted not only the existence, but also the most important properties of these two bodies to be forecast." Nilson had confirmed in 1879 the extraction of a new rare earth, ytterbia, from erbia by Marignac in 1878, and suggested that the five elements beryllium, scandium, yttrium, erbium, and ytterbium

formed a trivalent series. He set out tables of the molecular heats and molecular volumes of the oxides and sulphates on the assumption that the elements were trivalent. The values for the oxides were very concordant, but the values for the sulphates hardly supported the assumption. He redetermined the equivalent weight of beryllium as 4.55, thus giving the atomic weight as 13.65, and added "The respect in which we hold the originator of the periodic law forbids us to accept it as a mere article of faith, but rather compels us to subject it to experimental proof." In a further paper (*Ber.*, 1880, 13, 2035) Nilson compared beryllium to tellurium, the position of which in the classification is also anomalous, and pointed out that the positions assigned to the rare-earth elements, and particularly to erbium, were far from satisfactory.

In the course of his work at Owens College, Brauner devoted much time to the determination of the specific volumes of the oxides of the lighter elements in an endeavour to show that the molecular volumes of the oxide and sulphate justified the position of beryllium in Group II. A further paper in 1881 (*Ber.*, 1881, 14, 53) including these arguments left the matter still undecided. Finally in 1884 Nilson and Pettersson prepared anhydrous beryllium chloride and determined its vapour density (*Ber.*, 1884, 17, 986), which established beyond dispute the bivalency of the metal and its place in Group II. This result, together with the discovery of the foretold elements scandium and gallium, which fell into the places assigned to them by Mendelejeff, led to the general acceptance of the periodic law and the classification, in spite of the difficulties of the pairs tellurium-iodine and cobalt-nickel, and of the very unsatisfactory state of the problem of the other rare-earth elements.

Brauner meanwhile was working on the ceria group at Manchester. He prepared cerium tetrafluoride, $\text{CeF}_4 \cdot \text{H}_2\text{O}$, by dissolving the higher oxide of cerium in concentrated hydrofluoric acid and drying the product at 100° . This was the first preparation of a definite salt of quadrivalent cerium, and provided a further confirmation of the valencies of the element; if cerium were bivalent in its lower oxide, as had been thought at first, it would be highly improbable that the halogen contents of its haloid salts should be in the ratio 3 : 4. Analysis of the tetrafluoride indicated the atomic weight 141.1 for the element.

He also prepared and analysed the double salt $3\text{KF} \cdot 2\text{CeF}_4 \cdot 2\text{H}_2\text{O}$, and about the same time (*J.*, 1882, 41, 68; *Ber.*, 1881, 14, 1944; *J.*, 1894, 65, 393) prepared lead tetrafluoride and the ternary salt $3\text{KF} \cdot \text{HF} \cdot \text{PbF}_4$. All these compounds on heating evolved water vapour and hydrogen fluoride; the gases evolved at higher temperatures had a smell very strongly resembling that of chlorine. Brauner was satisfied that they contained free fluorine, and records that when they were inhaled and subsequently exhaled, white clouds of hydrofluoric acid were obtained! More convincing, but less dangerous than this highly adventurous physiological test was his observation that silicon burned in the gases evolved from the double lead salt. Ten years later Moissan obtained free fluorine, after having tried a large number of chemical methods without success, by electrolysis of anhydrous hydrogen fluoride containing potassium hydrogen fluoride at -23° in a copper tube, using platinum electrodes and stoppers cut out of fluorspar.

Having shown that the higher oxide of cerium gives salts in which the element is quadrivalent, and that the position assigned to it in Group IV agrees with the atomic weight obtained by analysis of the tetrafluoride, Brauner proceeded to a determination of the atomic weight of lanthanum (*J.*, 1882, 41, 68) by converting the oxide into the anhydrous sulphate. By this method, to which he afterwards devoted a very great deal of time and attention, he obtained the value 139.88, and confirmed thereby that lanthanum falls into Group III immediately before cerium in Group IV, as he had already suggested in 1878. For didymium by the same method he obtained the value 146.6, indicating that it should follow cerium and fall into Group V. If this were so, didymium should give a higher salt-forming oxide, Di_2O_5 , and he endeavoured accordingly to obtain such a compound. After a long series of negative results, he obtained a hydrated oxide corresponding to the formula $\text{Di}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$ by precipitation with potassium hydroxide from a solution of the nitrate in presence of hydrogen peroxide, and drying in a vacuum; by heating the basic nitrate in a current of oxygen, he obtained an anhydrous higher oxide. He was unable to obtain any salts of this higher oxide.

From internal evidence we can now see that Brauner must have been dealing with a

mixture of oxides consisting of neodymia with some samaria and perhaps a little praseodymia; neodymia is capable of taking up additional oxygen under these conditions, though no definite compound appears to be formed. With considerable hesitation, Brauner suggested on the basis of these experiments that didymium should be placed in Group V (*Ber.*, 1882, **15**, 115; *J.*, 1882, **41**, 68). For erbium he suggested tentatively the atomic weight 166 and a place in Group V also, and still more tentatively for terbium the possibility of a higher oxide TbO_3 and a place in Group VI.

Meanwhile Lecoq de Boisbaudran in 1879 had isolated a new oxide from a sample of didymia extracted from the mineral samarskite, and had named the new element samarium. For this new metal Brauner hardly ventured to hope that a place might be found in Group VIII. In the same year Cleve announced the extraction of two new oxides, holmia and thulia, from Mosander's erbia. This rapidly extending list of new substances, so similar to one another in all their chemical and physical properties that separation was a matter of extreme difficulty and uncertainty, was a source of increasing perplexity to the defender of the periodic system. There were spaces in the table as it was then constructed for 17 elements between cerium and tantalum. Excluding thorium, which filled satisfactorily its place in Group IV, six rare-earth elements of higher atomic weight than cerium had so far been definitely announced, and claims were being put forward constantly for supposed new ones. There was still, therefore, plenty of room in the table, but what Lothar Mayer called the endless, laborious and dreary purification of erbia, with this constant shedding off of almost indistinguishable new oxides, showed little promise of filling the gaps with elements the properties of which would support the periodic law.

Still uncertain, in view of the separation of samarium from didymium, of the atomic weight and individuality of the latter, Brauner continued his investigation (*J.*, 1883, **43**, 278; *Monatsh.*, 1882, **3**, 486; *Compt. rend.*, 1882, **94**, 1718). He started with several kilograms of material from the mineral cerite, which had been thought up to that time to contain only elements of the cerium group. He now found for the first time that the oxides separated from the mineral contained considerable quantities of yttria and of the terbia and erbia earths. These he separated by the classical double potassium sulphate method of Berzelius, and then removed ceria as basic ceric nitrate. The fact that cerium alone of the group can form compounds in which it is quadrivalent, as well as derivatives in which it is trivalent, makes this separation a comparatively simple matter; the remaining members of the family are so little distinguishable in their chemical properties that separation of pure compounds requires extremely tedious and systematic repetition of chosen operations.

Taking as a criterion of purity of didymia a light ash-grey colour, Brauner continued his fractionation by the basic nitrate method until the brownish or rusty colour of the oxide first obtained disappeared. In this way he removed from the more basic fraction most of the praseodymium, which gives a strongly coloured brownish-black peroxide, PrO_2 . This more basic fraction he separated into two further fractions, for the elements in which he found the atomic weights to be 138.3—138.8 for the more positive and 140.2 for the less positive. These were fairly pure lanthana and praseodymia respectively. The grey oxide he now proceeded to fractionate by an elaborate application of the graduated ammonia precipitation from the boiling solution of the nitrates. Though it is now known that this method can hardly be expected, however prolonged the series of fractionations, to effect complete separation, he succeeded in obtaining five fractions, for the elements in which he determined the atomic weights as 144.32, 145.16, 145.39, 147.10, and 149.40. It is clear in the light of our present knowledge that the first fraction was nearly pure neodymia, and the last fraction nearly pure samaria, the intermediate ones being mixtures of the two. Brauner perceived that he had in fact effected a separation of didymia into the oxides of at least two elements; he concluded that he had obtained true didymium or didymium- α of atomic weight 145.4, *i.e.*, in the middle one of his five fractions; didymium- β , atomic weight 141, *i.e.*, the less positive of the two fractions in his lanthanum separation; and didymium- γ or samarium, for which he considered the atomic weight should be slightly above 150. The present atomic weights are lanthanum 138.92, praseodymium 140.9, neodymium 144.3, and samarium 150.4.

It was unfortunate for Brauner that Cleve was at the same time working on the separation of didymium (*Compt. rend.*, 1882, **94**, 1528). Their communications overlapped, and Brauner, in deference to his older colleague, discontinued his work. In 1885 the resolution into praseodymium and neodymium was effected by Auer von Welsbach, who employed the fractional crystallisation of the double ammonium nitrates. To praseodymium, which gives green salts, Welsbach assigned the higher atomic weight, 143.6, and to neodymium, which gives rose-red salts, the lower atomic weight, 140.8. It was not until 1898 that Brauner returned to the question; in that year he showed that Welsbach had inverted the order of the atomic weights, and that neodymium has in fact the higher.

Brauner now began to turn his attention more particularly to the determination of atomic weights, especially of those elements of which the position in the classification had been or remained doubtful. His first paper devoted exclusively to this work was published in our *Journal* in 1885, on the atomic weight of cerium (*J.*, 1885, **47**, 879). He considered very carefully all the determinations made up to that date, and criticised the methods and the purity of the materials used. He concluded that in the work of Robinson, who in the previous year had prepared the anhydrous chloride and titrated it with silver nitrate, all experimental errors had been reduced to minimum, and that Robinson's value, 140.26, was the most reliable figure then available.

In his own work, Brauner employed the ratio anhydrous sulphate : dioxide, and he describes very clearly and concisely the precautions he adopted. One of the chief difficulties was to remove the traces of sulphuric acid which are so tenaciously retained by the hydrated salt. He purified the crude oxide by dissolving it in nitric acid, expelling the excess of acid by evaporation, and pouring the boiling concentrated solution into a large volume of boiling water. This causes the insoluble basic nitrate to separate, leaving the nitrates of the trivalent elements in solution. He repeated the procedure many times, and found that after six repetitions the atomic weight remained constant; the pure dioxide obtained was not entirely white, but had a faint creamy tint.

The oxide was dissolved in dilute sulphuric acid, and the solution after reduction was evaporated and heated to expel as much acid as possible; the residue was dissolved in ice-water (the solubilities of the rare-earth sulphates diminish with rising temperature), and the solution treated with hydrogen sulphide to remove the last traces of heavy metals. The purified solution on addition of absolute alcohol gave a precipitate of the octahydrate almost free from acid, and on a repetition of this treatment a completely neutral salt was obtained. This material, however, was found to contain traces of organic matter; it was dissolved in ice-water, and the solution raised very rapidly to the boiling point; on stirring, he obtained the pure hexahydrate as a fine crystalline powder.

He next conducted a series of tests to find within what temperature range this hydrate loses all its water without evolution of acid, and finding the boiling point of sulphur to be suitable, he devised a simple apparatus in which the material, contained in a platinum crucible suspended in a tube heated externally by the vapour of boiling sulphur, could be left at that temperature for any desired time. The pure weighed anhydrous sulphate was finally converted into the dioxide by ignition. As a mean of no fewer than 23 very concordant determinations, he obtained the value 140.22. Robinson's value of 140.26, when converted for the modern values of silver and chlorine, is 140.19.

In this and his subsequent work on atomic weights, Brauner used only vessels which had been previously treated with purified acids for long periods. All the acids used were freshly distilled from a platinum retort through a platinum condenser, and all water and alcohol were similarly treated. Brauner was an extremely skilful and careful manipulator, and the accuracy of his work on atomic weights established his reputation as one of the leading authorities on these determinations.

Tellurium was the element to which he next turned his attention. Though it is clear from its chemical and physical properties that this element must fall into Group VI, and equally clear that iodine must fall into Group VII, the accepted atomic weight of tellurium was 128 and that of iodine 127. This anomaly was a source of the most profound perplexity to Brauner. He felt that tellurium as generally obtained must be admixed with some closely related element of higher atomic weight, and over many years he spent much time

in examination of the problem. In 1889 he published in our Journal the results of a most searching investigation (J., 1889, 55, 382). The element was dissolved in nitric acid, converted into the chloride, and precipitated by reduction with sulphur dioxide. The dried precipitate was fused with potassium cyanide, the melt dissolved, and tellurium precipitated by a current of air drawn through the solution. The dried material was then distilled in a current of hydrogen. All the precautions employed in his atomic weight determinations were applied to this preparation, and he could detect no impurity in the final product. With this material he tried a large number of reactions in order to select a conversion suitable for the atomic weight determination, and finally was able to prepare the pure tetrabromide and to titrate this with silver nitrate.

The finely divided tellurium was dissolved in bromine, and the excess of the latter removed by heating. Some tellurium always remained unchanged, and on further heating reacted with the tetrabromide to form dibromide. The dibromide is somewhat more volatile than the tetrabromide, and was removed by fractional sublimation in a vacuum. The residual tetrabromide was then separately sublimed in a vacuum, the sublimate dissolved in concentrated tartaric acid solution, and the solution diluted, decomposed with nitric acid, and finally treated with silver nitrate. To prevent the formation of insoluble silver telluryl tartrate, he found it necessary to avoid excess of silver nitrate.

In the course of this work, he examined highly purified silver for the oxygen content reported by Dumas, and was able to show that it was very much smaller than had been supposed, so small, in fact, as to be negligible. His extremely concordant analyses, both gravimetric and volumetric, gave results for the atomic weight of tellurium varying from 127.59 to 127.63, and he accepted the mean figure 127.61. In 1933 Hönigschmid and his pupils confirmed this result, using exactly the same method and arriving at exactly the same figure as Brauner had obtained 44 years before.

In spite of the fact that his atomic weight was still considerably above the accepted figure for iodine, Brauner felt that it was impossible to doubt the accuracy of his work or the purity of his material. To satisfy himself of the homogeneity of his distilled tetrabromide, he subjected it to a further exhaustive fractional sublimation in a vacuum. He divided a portion in this way into nine fractions, but on analysis the first and the last gave identical results. He carried out fractional precipitation of the solution from the potassium cyanide fusion, and fractional precipitation from hydrochloric acid solution with ammonia; in every case the result was the same.

With tellurium which had not been distilled, but only fused in an atmosphere of hydrogen, he obtained fractions which gave varying values, and concluded that the element might not be homogeneous; this conclusion, however, he subsequently abandoned, finding that material which had not been distilled still contained traces of foreign elements (J., 1895, 67, 549).

In the course of this work on tellurium, he examined the possibility of employing volumetric methods of estimation, on which he published two papers in our Journal (J., 1891, 59, 58, 238). He found that reduction with stannous chloride and oxidation with alkaline permanganate were both quantitative, and described titration methods based on these reactions which are sufficiently quick and accurate for ordinary laboratory purposes.

His attention was now again directed to lanthanum by the publication of the work of Winkler (*Ber.*, 1891, 24, 889), who in 1891 prepared and analysed what he believed to be hydrides of the cerium group of elements. On the basis of this work, Winkler arrived at the conclusion that lanthanum must be quadrivalent, and criticised the value 138.88 for the atomic weight which Brauner had obtained in 1882. In a paper published in 1891 (*Ber.*, 1891, 24, 1328), Brauner replied to this criticism, and found no difficulty in bringing forward evidence in support of the fact that lanthanum is trivalent. In 1901 he began a further series of determinations of the atomic weight, in some of which he was assisted by Pavlíček (P., 1901, 17, 63; J., 1902, 81, 1243; *Z. anorg. Chem.*, 1903, 33, 317). He again employed the ratio sulphate:oxide, but in addition devised a new method by analysis of the oxalate. In the latter method the purified oxalate was titrated with permanganate, another portion being ignited to oxide, so that the ratio oxide:oxalic acid was determined directly.

The chief difficulty in the sulphate method arises from the remarkable stability of the acid sulphate of lanthanum. He found that this compound could not be completely decomposed even at 600°, whilst at 650° basic sulphate began to form. He therefore heated the sulphate to 600°, and determined the proportion of acid sulphate remaining thereafter by dissolving the product and titrating the solution, using methyl-orange, to obtain a correction factor; this factor was separately determined in every determination of the atomic weight. The anhydrous sulphate is extremely hygroscopic; to prevent the absorption of traces of moisture during cooling, Brauner devised a special form of desiccator. The value obtained by the sulphate method was 139.04, and by the oxalate method 139.07, both somewhat higher than the value 138.88 which he had obtained in 1882. The present accepted value, based on the analysis of the anhydrous chloride by Baxter and his pupils, is 138.92, which falls between the values determined by Brauner.

Brauner employed both the sulphate and the oxalate method in his determinations of the atomic weights of praseodymium and neodymium (P., 1898, 14, 70; 1901, 17, 63). For the former he obtained the value 140.94, almost identical with the figure 140.92 accepted to-day. For neodymium his values were 143.6 and 143.9; the accepted figure is 144.27. Our present figures for praseodymium and neodymium are based on the analyses of the anhydrous chlorides by Baxter and his pupils. It is interesting that the atomic weight of neodymium based on the masses and relative proportions of its isotopes as determined by Aston in 1934 is 143.5, which agrees much more closely with Brauner's values than with those obtained by Baxter.

Brauner employed his oxalate method also in the determination of the atomic weight of thorium (J., 1898, 73, 951; P., 1901, 17, 63), for which he obtained the value 232.42, somewhat higher than the accepted figure of 232.12, which is based on the analysis of the tetrabromide by Hönigschmid. In separating thorium from the rare-earth group, he made use of the fact that thorium oxalate is readily soluble in ammonium oxalate solution, whilst the oxalates of the other elements are very sparingly soluble. He investigated this difference, and separated a complex salt, ammonium thorioxalate, of the formula $\text{Th}(\text{C}_2\text{O}_4\text{NH}_4)_4$.

The value 140.22 which Brauner had obtained in 1885 for the atomic weight of cerium was adversely criticised by Wyruboff and Verneuil in 1897 (*Compt. rend.*, 1897, 124, 1300). These authors, who even at that late date continued to hold the view that the rare-earth elements were bivalent, stated that cerium sulphate octahydrate could be completely dehydrated at 250°, and concluded that the atomic weight must lie between 139.2 and 139.5. Brauner carried out another extensive purification of ceria in 1903. Together with Batek (*Z. anorg. Chem.*, 1903, 34, 103), he repeated his earlier work on the conversion of the sulphate into the oxide, and he confirmed the values by analysis of the oxalate (*ibid.*, p. 207). The results varied from 140.21 to 140.26. The value 140.25 based on this work was accepted until, in 1928, analysis of the anhydrous chloride by Hönigschmid and Holch gave the value 140.125, which is the accepted figure to-day.

In connection with his work on the sulphate method of determining the atomic weights of the rare-earth elements, Brauner together with Picek devised a method of preparing the acid sulphates in the pure state (*Z. anorg. Chem.*, 1904, 38, 322). If the oxides are dissolved in sulphuric acid, most of the excess acid can be removed by heating, but decomposition of the acid sulphates begins before all the free acid can be driven off. Brauner obtained the pure acid sulphates by removing the excess of acid at 130° in the vacuum of the Sprengel pump. In the same year, 1904 (*ibid.*, 39, 261), he described an interesting series of double sulphates of the rare-earth elements with ceric sulphate, of the general formula $\text{RHCe}(\text{SO}_4)_4 \cdot 12\text{H}_2\text{O}$.

Brauner took a leading part in the long drawn-out controversy which ended at the beginning of this century concerning the standard to be adopted for expressing the atomic weights. In his classical determinations, Stas had used both the oxygen and the hydrogen standard, accepting the value 15.96 for the oxygen-hydrogen ratio. In 1888 Brauner pointed out (*Chem. News*, 1888, 58, 307) that the values determined for that ratio up to that time varied from 15.87 to 16.01, a variation which would correspond to a difference of more than one unit for the atomic weight of antimony, and to more than two units in the

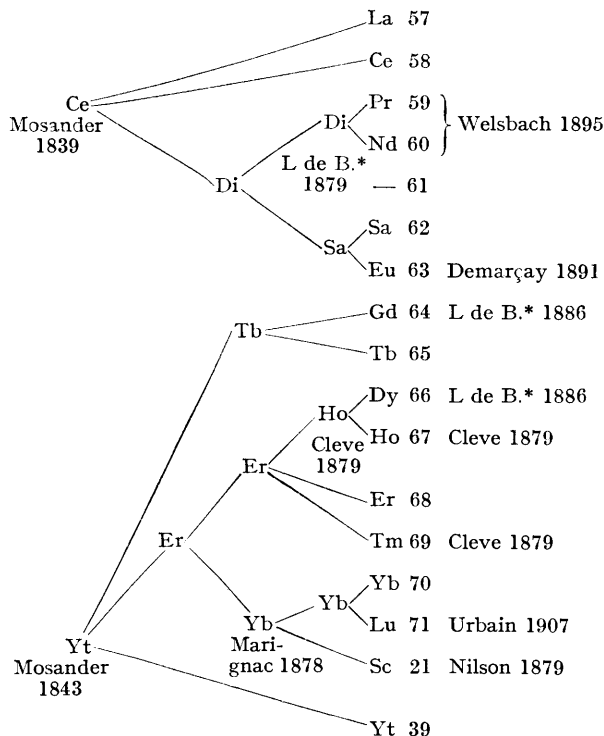
case of uranium. As no means existed for deciding what was the true ratio, it was obviously desirable to choose one standard or the other. He expressed preference for Marignac's proposal to adopt the standard $O = 16$, since most of the determinations were based on methods involving comparison with oxygen. With that standard, as he pointed out, values for many of the elements came very close to whole numbers. With the hydrogen standard, it would be necessary at every fresh determination of the oxygen-hydrogen ratio to recalculate all those atomic weights which had been determined by comparison with oxygen. Horstmann, Lothar Meyer, and Seubert came forward as advocates of the hydrogen standard, pinning their faith to the value 15.96 for the ratio. Brauner was supported by Venable, Noyes, and Ostwald. The authoritative determination of the ratio by Morley in 1895, which gave the unexpectedly low value 15.88, greatly strengthened the advocates of the oxygen standard. Brauner attended the Toronto meeting of the British Association in 1897; T. W. Richards and he addressed the meeting on the question and were strongly supported. The oxygen standard was finally adopted at the Paris Congress of 1900. The opposition was by no means ended, however, and for many years agitation continued for the restoration of the basis $H = 1$, which was represented as the pure doctrine of Dalton. For many years atomic weights were expressed on both standards, but ultimately the scale based on oxygen as 16 prevailed. All the atomic weights given in this paper are on that scale.

It is interesting to observe that the discovery of the isotopes of oxygen of mass 17 and 18 has now revealed that the choice of the oxygen standard has in fact given us only a conventional whole number, and not a true whole number on the mass scale, as the basis of our atomic weights; the balance of convenience, however, is against further change.

Throughout his work on atomic weights, Brauner was constantly preoccupied with the remaining problems of the periodic classification. The establishment of the true atomic weight of beryllium in 1884 had effectively disposed of the most serious. The discovery of argon and helium for a time appeared to bring new difficulties. Brauner happened to be present in Ramsay's laboratory on the eventful afternoon when the discovery of helium was made, but could not at first bring himself to believe that here were further new elements. "As an orthodox Mendelejeffian," he wrote concerning argon, "I find great difficulty in assuming the existence of a new elementary gas having the atomic weight 20 or 40 or 80 and the boiling point -187° " (*Chem. News*, 1895, 71, 79). He thought that helium might be an allotrope of hydrogen, and argon an allotrope of nitrogen; the existence of argon as an element of atomic weight 39.88 seemed to him at that time absolutely incompatible with the periodic system. The difficulty was to some degree removed by the discovery of the remaining members of the group of inert gases, which completed a new family of chemically neutral elements between the strongly negative halogens and the strongly positive alkali metals. A minor anomaly remained in the fact that the atomic weight of argon was higher than that of potassium, instead of lower, and the similar anomalies of tellurium and iodine and of cobalt and nickel still remained without explanation.

The rare-earth elements, however, still presented the most baffling question connected with the periodic law. By the beginning of this century, it was recognised that beryllium, zirconium and thorium were not so closely related to the other members as had been originally supposed, and the term rare earths was beginning to be restricted to the ceria and yttria oxides. Of the elements of the group in this narrower sense, scandium, yttrium, lanthanum and cerium fell into definite places in the table. The outstanding difficulty, therefore, was to decide the relationship of the elements falling between cerium and tantalum to the grouping which expressed the periodic relationship. Eleven of the twelve elements now known in that range had already been discovered (see Table II), but the individuality of several of them was still doubtful. These elements exhibit an extraordinary degree of similarity to one another, which not only makes the separation and identification of individual members a matter of the greatest uncertainty, but is absolutely incompatible with Mendelejeff's principle that the properties of the elements are a periodic function of their atomic weights. The properties of these elements vary very gradually, and not periodically, with increasing atomic weight.

TABLE II.
Historical Development of the Separation of the
Rare-earth Elements.



The atomic numbers are given in the last column on the right.

* Lecoq de Boisbaudran.

At the beginning of 1902, Brauner delivered before the Russian Science Congress at St. Petersburg the lecture on the position of the rare-earth elements in the periodic classification to which I have already referred. This paper, which was published in the *Zeitschrift für anorganische Chemie* (1902, 32, 2) about the time it was delivered, embodied probably the most important contribution to the theory of the classification which had been made since Mendelejeff's essay of 1871. Brauner put forward the view that the rare-earth elements should be regarded as a sort of zone or belt of closely related individuals occupying the place of a single element in the table, using as an analogy the existence of asteroid belts in the solar system. Accepting the hypothesis that all the elements might be composed or built up of one fundamental material, he suggested that the condensation or aggregation of this material might be regarded as not having gone so far with the rare-earth elements as with the other elements, or as having taken a different course. It could hardly be a mere accident that no other elements having atomic weights between that of cerium and that of tantalum, and having properties which would be consistent with positions in the normal vertical groups of the table, had so far been discovered. The rare-earth elements may therefore be regarded as a transition zone between cerium and tantalum, and it is probable that no elements of other families than the rare-earth family will ever be discovered between these two. Hence the whole series of empty spaces between them may be discarded.

Brauner presented the table in this form, including in one place with cerium all the remaining elements of the family (Table III). He pointed out that the table now had only nine vacant spaces, of which two might be occupied by radium and its emanation, and a

third by a radioactive rare-earth element; this third place is now filled by actinium, which appears to be almost identical chemically with lanthanum. He considered that further rare-earth elements might be discovered, as the asteroid hypothesis removed the limit on the possible number hitherto imposed by the table, and speculated on the possibility of separating additional elements from those already known.

TABLE III.

Series.	Group 0.	Group I.	Group II.	Group III.	Group IV.	Group V.	Group VI.	Group VII.	Group VIII.
	—	—	—	—	RH ₄	RH ₃	RH ₂	RH	—
	R	R ₂ O	RO	R ₂ O ₃	RO ₂	R ₂ O ₅	RO ₃	R ₂ O ₇	RO ₄
1		1 H							
2	He 4	Li 7	Be 9	B 11	C 12	N 14	O 16	F 19	
3	20 Ne	23 Na	24 Mg	27 Al	28 Si	31 P	32 S	35.5 Cl	
4	A 40	K 39	Ca 40	Sc 44	Ti 48	V 51	Cr 52	Mn 55	Fe 56 Co 59 Ni 59 Cu 63
5		63 Cu	65 Zn	70 Ga	72 Ge	75 As	79 Se	80 Br	
6	Kr 82	Rb 85	Sr 87	Y 89	Zr 90	Nb 94	Mo 96	— 100	Ru 102 Rh 103 Pd 106 Ag 108
7		108 Ag	112 Cd	114 In	119 Sn	120 Sb	128 Te	127 J	
8	Xe 128	Cs 133	Ba 137	La 138	Ce etc. 140—178	Ta 182	W 184	— 190	Os 191 Ir 193 Pt 195 Au 197
9		197 Au	200 Hg	204 Tl	207 Pb	209 Bi	212 —	214 —	
10	218	— 220	Rd 225?	— 230	Th 233	— 235	U 239		
11									

It may be said against the arrangement which groups all the rare-earth elements of higher atomic weight than cerium in the same position as cerium itself that, whilst the latter falls properly into Group IV by analogy in its higher salt-forming oxide with zirconium and thorium, the remaining elements, so far as was known in 1902, are uniformly trivalent. On the other hand, it reduces the table to its simplest possible form in two dimensions, and expresses very clearly the view, since confirmed by the atomic numbers, that no elements exhibiting periodic changes in properties can exist between cerium and tantalum. The view that the rare-earth elements constitute a transition zone in the interval which otherwise should be occupied by elements showing normal changes in properties may be regarded as the culmination of Brauner's work on this question, and as the best solution which could be reached, in the existing state of knowledge, of the problem to which he had addressed himself.

Mendelejeff was not prepared to go as far as Brauner. He felt that the law of periodicity, however much it might appear to be obscured, must still operate, and that fuller knowledge of the rare-earth elements would reveal some periodic variations. In the preface to the 7th Russian edition of his famous textbook, written in 1902, he says "A whole long period in the table is wanting between cerium with atomic weight 140 and tantalum with atomic weight 183, but the series of rare elements, not yet fully investigated, have so far as is now known atomic weights which exactly fill this interval, and therefore this portion of the periodic system is in a way broken and requires fresh researches." He thus adhered to the view that eighteen elements must exist within this range.

In this preface, also, Mendelejeff set out his considered view on the hypothesis that all the elements may be built up of one fundamental material. "The more I have thought on the nature of the chemical elements," he wrote, "the more decidedly have I turned away from the classical notion of a primary matter, and from the hope of attaining the desired end by a study of electrical and optical phenomena. . . . The return to electro-chemistry which is so evident in the supporters of the hypothesis of 'electrolytic dissociation' and the notion of splitting atoms into 'electrons' in my opinion only complicate and in no way explain a matter so real, since the days of Lavoisier, as the chemical changes of substances, which led to the recognition of the invariable and ponderable atoms of simple bodies."

Mendeleeff died early in 1907, before the evidence of the complexity of atomic structure had become sufficiently clear and definite to convince him. Brauner, as is apparent from the views he expressed in 1902, had already accepted the view that the atoms are not simple bodies. The periodic law itself seemed to him to favour that view, and he followed eagerly all the developments of the last thirty years which have thrown so much light on the ultimate constitution of the atom.

Moseley's discovery that the order of increasing atomic weight of the elements can be simply related with the wave-lengths of the X-ray spectra has provided the means of completing the classification and delimitation of the elements. The assignment to each element of a number based on actual measurement, which, except in the cases of the pairs argon-potassium, tellurium-iodine, and cobalt-nickel, agrees with the order of atomic weights, has indeed confirmed the fundamental nature of the atom as the chemical unit, but it has shown the limited significance of the property of mass. Structure, not mass, is the basis of the chemical properties, though it may become necessary to revise our definition of chemical properties. We can no longer say, as Mendeleeff and Brauner said, that all the atoms of an element have the same chemical and physical properties. We cannot even say, having regard to the properties of deuterium, that all the atoms of an element have the same chemical properties, unless we regard hydrogen and deuterium as different elements; and as they both possess the atomic number 1, and have the same planetary electron structure, we cannot logically say that they are different elements, unless we are prepared to say that different isotopes of the same atomic number are all different elements. A revision of our definitions, however, will be a small price to pay for the clarification of our conceptions.

It is perhaps in the field of the rare-earth elements that the conception of atomic numbers has brought the greatest clarification. It has established conclusively the individuality of the known elements and determined the number of possible members of the group. It has confirmed the positions assigned to beryllium, scandium, yttrium, lanthanum, and cerium, and has demonstrated the soundness of Brauner's view that the remaining elements form a transition group between cerium, number 58, and tantalum, number 73. It has limited the possible number of elements within this range to fourteen, of which thirteen are known with certainty. Element number 61, the discovery of which has not yet been confirmed, may be expected to be trivalent, and to be very similar in properties to its neighbours, neodymium, number 60, and samarium, number 62. Element number 72, hafnium, is quadrivalent, and in chemical and physical properties falls between cerium and thorium in Group IV; it is not, therefore, to be regarded as a member of the rare-earth family in the narrowest sense.

In the classification of Mendeleeff, the elements of higher atomic weight than hydrogen, including the inert gases, fall into two short periods, each of eight, and four long periods, each of eighteen elements, with another long period incomplete after uranium. The table of Brauner, interpreted by aid of the atomic numbers, is divided into two periods each of eight, two periods each of eighteen, one period of thirty-two elements, and a final incomplete period. We have now good reason to believe that the numbers 8, 18, and 32 are in fact the numbers of planetary electrons which can constitute successive completed rings or energy levels in the atomic structure. The elaboration by Bohr, Lewis, Langmuir, and others of the Rutherford nucleus atom is building up a new science of intra-atomic dynamics, which is already reaching the stage at which it would be possible for a mathematician, with no knowledge of chemistry, to build up for himself the full table of the chemical elements and deduce all their properties. On this basis, the extremely slight variations in the physical and chemical properties of all the elements of the cerium and yttrium groups in their trivalent condition are explained by the identity of the structures of the two outer rings of planetary electrons, which consist of 8 and 3 electrons respectively for every member.

It may be observed that any discovery which might be made in the future of further new elements in these groups, which have been such a prolific source of new elements during the last hundred years, would be even more embarrassing to our present views on the constitution of matter than the additions of the last two decades of the 19th century were to the protagonists of the periodic law.

It is impossible for me, in the time at my disposal, to deal fully with all Brauner's work, or even to mention some of his contributions to chemistry. Soon after the lecture of 1902, in which he set out the views I have just discussed, he began the series of critical essays on the atomic weights of the elements which he contributed to successive volumes of Abegg's "Handbuch." He dealt in 1905 with Group II, in 1906 with Group III, including the rare-earth elements, in 1907 with Group V, in 1908 with Group I, in 1909 with Group IV, and in 1913 with Group VII. In 1906 also he contributed the section on the rare earths to Mendelejeff's "Principles of Chemistry." This work made great inroads on the little time left to him by his University activities, which increased continuously throughout his life until his retirement in 1925, after 43 years of teaching. During this period he had seen the transfer of the chemical department of the Charles University from very inadequate accommodation in old private houses, to the large and well-equipped Chemical Institute which was erected in 1904, largely as a result of his own unremitting efforts. He was a stimulating and most successful teacher; all the professors at the two Czech Universities, and most of those engaged in the profession of chemistry in Czecho-Slovakia to-day, are his pupils.

The occasion of his 70th birthday in 1925, the year of his retirement, was marked by the publication of a Jubilee number of the *Recueil des Travaux Chimiques des Pays-Bas*, containing more than thirty papers contributed by his friends and pupils. His 75th birthday in 1930 was similarly marked by the publication of a special number of the *Collections of Czecho-Slovak Chemical Communications*. These special numbers constitute an impressive testimony to the strength and quality of chemical research in Czecho-Slovakia, which owe so much to his inspiration and example.

Nor did the world fail to recognise during his lifetime his great services to chemistry. He was an honorary fellow of the American, French, Polish, and Russian Chemical Societies, as well as of our own Society; of the American, Russian, and Polish Academies of Science, and of the Czech Academy of Science and Art. He received decorations from the Austrian, Russian, and Jugo-Slavian governments, was a Chevalier of the Légion d'Honneur, and a member of the Czech National Research Council. He was a member of the Committee on the Chemical Elements of the International Union of Pure and Applied Chemistry, and filled the office of President of the Sub-Committee on Atomic Weights from 1922 to 1930.

Brauner died in February, 1935, in his 80th year. His life was devoted to the advancement of chemistry, and filled with an enthusiastic interest in every branch of science. The affection and admiration which he felt so strongly for England and her institutions, and the interest he took in our own Journal, to which he made many valuable contributions, intensify for us the sense of the loss which our Society has suffered. His work and his example will keep his memory fresh, and his name will always be honoured no less by chemists in England than by those in his own country.
