

yet to be shown that the common characters which have been induced by a peculiar environment in so many different kinds of birds can have an equal survival value to each of these birds of habits so different. On the facts put thus, the safer assumption would seem to be that similar conditions induce a similar organic reaction irrespective of 'worthiness' or 'unworthiness.'

After all, unworthiness in the evolutionary sense is not likely to survive in hard competition with worthiness, and Mr. Grinnell finally reaches a Darwinian conclusion. "The accumulating evidence of the field naturalist is bringing conviction

that the incipient species in nature, the subspecies, owes its origin to a process, on a vast scale, of trial, discard, and preservation, of individuals, and of groups of individuals comprising populations, which populations from generation to generation are thereby rendered more nearly adjusted to such environments as they can endure at all. But environments themselves never stabilize; they are changing, proliferating, evolving continually. A balanced state of perfect adaptation of the organism can never be attained, but only continually approached, such approach being forced, under penalty of extinction." J. R.

Physical Foundations of Chemical Theory.

NO task is more difficult for the chemist of the present day than that of trying to keep abreast with those advances in atomic physics which affect him so closely that he cannot ignore (even if he cannot hope fully to understand) them. Sidgwick's book on "The Electronic Theory of Valency," which was reviewed at length in these columns last year (April 7, 1928, vol. 121, p. 527), provided a partial solution of the problem from the chemist's point of view; but the brief monograph of Lessheim and Samuel referred to below¹ may be regarded as a complementary contribution of unrivalled value from the physical side. The professional spectroscopist does not often realise how difficult his subject can be made for the lay reader, and it is a common experience, even when reading books or lectures of a semi-popular character, to be pulled up short by technical or controversial details of which no explanation is given or attempted.

In the more leisurely days of the past, there was usually ample time for one fundamental idea to be grasped before attention was distracted by the next new development. Progress was then made by the orderly passing of the ball from one three-quarter back to another, until it was safely placed behind the goal, and in due course 'converted' from speculation or hypothesis to theory. Now, however, the ball progresses amid the confusion of a wild 'forward' rush, in which the casual onlooker can only occasionally get a glimpse of the ball, and has but little chance to observe the effects of individual play, whilst even the professional reporter is in danger of overlooking essential points in the game. Thus, whereas Bohr's 'principal quantum number' n had a sufficient start to secure universal acceptance, and has retained its strictly integral character, it has been followed in the works of subsequent authors by a trail of subsidiary numbers, which are in open competition with one another, and (to add to the confusion) appear at some stage to have undergone a process of 'disintegration' whereby integral quanta have been resolved into proper fractions.

The difficulties arising from such causes as these

are in large measure removed by the careful and concise exposition of Messrs. Lessheim and Samuel, and it is a high compliment to their skill that we can claim to have been able to understand and to make use of the major portion of their monograph. It was, indeed, only on reaching the tenth section of the book that it became necessary to add a marginal comment, "I cannot follow this," and to call in the help of a professional physicist to explain in fuller detail the complex behaviour of systems with several outer electrons. The elaborate spectroscopic analysis of sections 12 and 13 was also too complicated to be understood at one reading, but it would be difficult to praise too highly the way in which the spectroscopic evidence is used in order to provide a sure foundation for definite chemical deductions; and it is one of the conspicuous merits of the book that this evidence is set out in such a convincing way, that its validity is no longer open to question even by the most extreme type of 'sceptical Chymist.'

Much of the charm of the quantum theory of the present day arises from the introduction, by Goudsmit and Uhlenbeck in 1925, of the conception of the spinning electron. This conception has, indeed, done more than anything else to bring order out of the chaos of subsidiary quantum numbers, and thus to restore to Bohr's theory some semblance of the simple and logical character which it possessed in 1913. From the chemical point of view, the principal merits of this early quantum theory was the provision of a logical basis for the valency theories of Kossel and Lewis, since it indicated the existence of groups of electrons with identical 'principal quantum numbers' $n = 1, 2, 3, 4, 5$, etc., corresponding with the K, L, M, N, O , etc., levels of the X-ray spectra of the elements. In this way it explained the inertness of the noble gases, and the ionisation of adjacent elements such as the halogens and the alkali metals, as depending on the exceptional stability of certain completed groups of electrons. Since, however, the theory gave no clue to the number of electrons in each quantum group, these numbers must logically have followed the Rydberg series, with 2, 8, 8, 18, 18, and 32 electrons in successive levels, corresponding with the number of 'cells' which Langmuir postulated in successive layers or 'shells' of his static atomic model.

¹ Die Valenzzahl und ihre Beziehungen zum Bau der Atome. Von Hans Lessheim und Rudolf Samuel. (Fortschritte der Chemie, Physik und physikalische Chemie, herausgegeben von A. Eucken, Band 19, Heft 3.) Pp. 98. (Berlin: Gebrüder Borntraeger, 1927.) 6-40 gold marks.

Two years later, in 1915, Sommerfeld found it necessary to introduce a second ('subsidiary' or 'azimuthal') quantum number k , in order to explain the fine structure of the hydrogen and helium spectra. This 'subsidiary' quantum number immediately assumed a dominant position in spectroscopy, where series of spectroscopic terms for which $k=1, 2, 3, 4$, were distinguished by the capital letters S, P, D, F , corresponding with the initial letters of the 'sharp,' 'principal,' 'diffuse,' and 'fundamental' series of spectral lines with which the terms are associated. It is unfortunate for the lay reader of spectroscopic literature that the fascinating explanation which Sommerfeld gave of the fine structure of hydrogen, as depending on the varying mass of electrons moving with varying velocity in elliptical orbits of different eccentricities, has now been abandoned in favour of a fine structure depending on a third (instead of on the second) quantum number; but the classification of Bohr's 'groups' of electrons into 'sub-groups,' under the headings $n_k=1_1 2_2 3_1 3_2 3_3$, etc., was nevertheless an advance of permanent value. In particular, it was these sub-groups which enabled Bohr in 1921 to develop his well-known classification of the elements, in which the inertness of the noble gases is no longer attributed to the completion of the main groups with principal quantum number $n=1, 2, 3, 4$, etc., but to the completion only of successive n_1 and n_2 sub-groups, as in the table below:

X-ray level.	$K.$	$L.$	$M.$	$N.$	$O.$	$P.$
Quantum No.	1_1	$2_1 2_2$	$3_1 3_2 3_3$	$4_1 4_2 4_3 4_4$	$5_1 5_2 5_3$	$6_1 6_2$
He	$= 2 = 2$					
Ne	$= 10 = 2 + 8$					
A	$= 18 = 2 + 8 + 8$					
Kr	$= 36 = 2 + 8 + 18 + 8$					
X	$= 54 = 2 + 8 + 18 + 18 + 8$					
Rn	$= 86 = 2 + 8 + 18 + 32 + 18 + 8$					

This well-known system of classification assigns an outer shell of 8 electrons to each of the noble gases, and explains the old 'law of octaves' by the repetition which results from building up this outer octet in one level after another. It then proceeds to account for the properties of the transition elements of the first and second long periods as depending on a subsequent expansion of the M and N octets into shells of 18 electrons. The final expansion of the N octet to a shell of 32 electrons (at a stage when the O and P levels are already partially filled) then provides a natural explanation of the still slower gradation of properties in the elements of the rare earth group.

Since the number of similarly placed electrons was still undetermined, Bohr adopted the simple plan of distributing them equally amongst the sub-groups of a given level. The N -level was therefore supposed to contain 4+4 electrons in krypton, 6+6+6 in xenon, and 8+8+8+8 in radon. It is, however, rather illogical to postulate that a condition of maximum stability exists in a

sub-group when occupied by 4 or 6 or 8 electrons. Stoner therefore suggested in 1924 that the various sub-groups should be filled up completely one after another, and then remain full to the end of the chapter. It then follows logically that the sub-groups for which $k=1, 2, 3, 4$, etc., must contain 2, 6, 10, 14, etc., or in general $2(2k-1)$ electrons, whatever may be the value of the principal quantum number n . The close similarity between the members of the various natural families of elements was then explained by the identical development of successive sub-groups differing only in their 'principal' quantum numbers. Thus the alkalis all contain *one* electron in an n_1 sub-group, whilst the alkaline earths contain a complete sub-group of *two* electrons. In the same way carbon and its homologues contain *two* electrons in an n_2 sub-group, in addition to the two electrons in the n_1 sub-group, whilst the inert gases contain a complete sub-group of *six* n_2 electrons.

In the periodic classifications of Bohr and of Stoner, the maximum number of sub-groups in a group is fixed by the fact that k may have any integral value between 1 and n . The number of sub-groups is therefore equal to the principal quantum number n , and has the value 1, 2, 3, 4, 5, in the K, L, M, N, O levels. Coster found, however, in 1921, that the X-ray absorption spectra of the elements have a fine structure like that of hydrogen or helium, the number of components in the K, L, M, N, O, P levels being expressed by the series 1, 3, 5, 7, (5), (3), instead of the series 1, 2, 3, 4, 5, 6. In order to explain this result, he introduced a third quantum number in the form $n_{k_1 k_2}$, where k is now written as k_1 and may be any integer between 1 and n as before, whilst k_2 may be either equal to k_1 or 1 unit less. The sub-groups of the preceding classification are thus divided up into 'grouplets' corresponding with a series of triple quantum numbers as follows: 1_{11} ; $2_{11}, 2_{21}$; $3_{11}, 3_{21}, 3_{22}, 3_{32}, 3_{33}$, etc. This system gives the required series of 1, 3, 5, 7 components in the K, L, M, N levels, as required by the X-ray spectra, and we may then suppose that, as in the optical spectra, the O and P levels are only partially filled.

A third quantum number had already been introduced by Sommerfeld in 1920 in order to account for the composite character or 'multiplicity' of lines, such as the sodium doublet, which could not be explained by means of the first two quantum numbers. Sommerfeld's 'inner' quantum number j can have integral values when there are *two* valency electrons which can move from orbit to orbit during the absorption or emission of light by the atom, as in the alkaline earths; but when there is only *one* of these electrons it becomes a half-integer, and its value is given by the relation $j = k_2 - \frac{1}{2}$. This third quantum number is evidently magnetic in origin, since it also explains the multiplicity which is developed when spectral lines are emitted in a strong magnetic field as observed by Zeeman in 1896. Under these conditions a single line is resolved into $2j+1$ components, where j is the inner quantum number.

Thus if j is an integer, the lines break up into an odd number of components, but into an even number if j has a half-integral value.

The significance of the third quantum number becomes clear only when a quantised spin is given to the electron. The magnetic moment s of the spinning electron can then be either positive or negative; but, since there is no intermediate resting state, only a single quantum separates the two states. For the sake of symmetry, therefore, these states are written $s = \pm \frac{1}{2}$ for each electron, and we have at once a plausible explanation of those half-quantum numbers which have so often caused the sceptical to scoff. The total magnetic moment j of a planetary electron is then made up of two parts, the magnetic moment of the orbit l and of the spin s , so that $j = l \pm s$, since the moments may either work together or oppose one another. The magnetic moment l of the orbit is a function of the second or 'subsidiary' quantum number k , and is given by the simple relation $l = k - 1$. Thus if $k = 1$ (as in the S terms of a spectroscopic series) $l = 0$; and since $j = l + s$ cannot be negative, the only possible value of the 'inner' quantum number when $s = \pm \frac{1}{2}$ is $j = \frac{1}{2}$. If, however, $k = 2$ (as in the P terms of a spectroscopic series), then $l = 1$, and $j = l + s$ can have the two values $j = \frac{1}{2}$ or $j = \frac{3}{2}$. An electron-fall from a 2_2 to a 1_1 orbit can thus give rise to the yellow doublet of sodium, since the falling electron may be spinning either in the same sense as its revolution in the orbit or in the opposite sense.

The introduction of the second quantum number had the effect of breaking up the main groups of 2, 8, 18, 32 electrons into sub-groups of 2, 2 + 6, 2 + 6 + 10, and 2 + 6 + 10 + 14 electrons. The third quantum number has the effect of breaking up these sub-groups into tiny grouplets containing small even numbers of electrons. Thus Bohr's big group of 32 N electrons is resolved into the following grouplets:

$$\begin{matrix} 4_{11} & 4_{21} & 4_{22} & 4_{32} & 4_{33} & 4_{43} & 4_{44} \\ 2 & 2 & 4 & 4 & 6 & 6 & 8 ; \end{matrix}$$

and the 54 electrons of xenon are now distributed amongst 17 grouplets as follows: 2, 2 + 2 + 4, 2 + 2 + 4 + 4 + 6, 2 + 2 + 4 + 4 + 6, 2 + 2 + 4. This has the effect of emphasising more strongly than ever the significance of the duplet or pair of electrons, since each completed grouplet is magnetically inert; but the octet is relegated to a subsidiary position as a mere summation of the first three grouplets in a group which contains $2n - 1$ of these tiny clusters.

In order to complete this process of resolution, we must now proceed to consider the fourth quantum number m , which represents the various settings of the atom in an external magnetic field. This fourth quantum number changes by one unit at a time from $+j$ to $-j$, and may therefore be either integral or half-integral. The number of settings for a given value of j is given by the

formula $2j + 1$; thus if $j = \frac{1}{2}$, $m = \pm \frac{1}{2}$ and has two values; if $j = 1$, $m = -1, 0, +1$ and has three values; whilst if $j = \frac{3}{2}$, $m = -\frac{3}{2}, -\frac{1}{2}, +\frac{1}{2}, +\frac{3}{2}$ and has four values. The total number of settings of the four quantum numbers n, l, j , and m is then found to agree exactly with the maximum number of electrons that can be collected in groups, sub-groups, and grouplets round the nucleus. We are therefore at last in a position to appreciate Pauli's 'exclusion rule,' according to which no two electrons in an atom can have the same four quantum numbers, n, l, j , and m . A sample of the table which expresses this rule is reproduced below:

$n = 1, 2, 3, 4, 5, 6.$	$l = 0$	$\left\{ \begin{matrix} j = \frac{1}{2} \\ m = -\frac{1}{2} + \frac{1}{2} \end{matrix} \right.$	Number of Settings.
$n = 2, 3, 4, 5, 6.$	$l = 1$	$\left\{ \begin{matrix} j = \frac{3}{2} \\ m = -\frac{3}{2} + \frac{1}{2} \\ m = -\frac{1}{2} + \frac{1}{2} \\ m = +\frac{1}{2} + \frac{1}{2} \\ m = +\frac{3}{2} + \frac{1}{2} \end{matrix} \right.$	$\left. \begin{matrix} 2 & 2 \\ 2 & 2 \\ 4 & 4 \\ 4 & 4 \\ 6 & 6 \\ 6 & 6 \end{matrix} \right\} 8$
$n = 3, 4, 5, 6.$	$l = 2$	$\left\{ \begin{matrix} j = \frac{5}{2} \\ m = -\frac{5}{2} + \frac{1}{2} \\ m = -\frac{3}{2} + \frac{1}{2} \\ m = -\frac{1}{2} + \frac{1}{2} \\ m = +\frac{1}{2} + \frac{1}{2} \\ m = +\frac{3}{2} + \frac{1}{2} \\ m = +\frac{5}{2} + \frac{1}{2} \end{matrix} \right.$	$\left. \begin{matrix} 2 & 2 \\ 2 & 2 \\ 4 & 4 \\ 4 & 4 \\ 6 & 6 \\ 6 & 6 \\ 8 & 8 \end{matrix} \right\} 18$
$n = 4, 5, 6.$	$l = 3$	$\left\{ \begin{matrix} j = \frac{7}{2} \\ m = -\frac{7}{2} + \frac{1}{2} \\ m = -\frac{5}{2} + \frac{1}{2} \\ m = -\frac{3}{2} + \frac{1}{2} \\ m = -\frac{1}{2} + \frac{1}{2} \\ m = +\frac{1}{2} + \frac{1}{2} \\ m = +\frac{3}{2} + \frac{1}{2} \\ m = +\frac{5}{2} + \frac{1}{2} \\ m = +\frac{7}{2} + \frac{1}{2} \end{matrix} \right.$	$\left. \begin{matrix} 2 & 2 \\ 2 & 2 \\ 4 & 4 \\ 4 & 4 \\ 6 & 6 \\ 6 & 6 \\ 8 & 8 \\ 8 & 8 \end{matrix} \right\} 32$

This table gives a picture of the periodic classification from which all individuality is excluded, since exactly the same sequence recurs when $n = 2, 3, 4$, etc. It thus represents one of the main characteristics of the elements perfectly, namely, the recurrence of types such as the halogens, noble gases, and alkalis at appropriate intervals; but in practice the elements of a given family are far from uniform in their behaviour, so that even the formal valencies vary erratically in a family such as copper, silver, gold. It is therefore satisfactory to find that the spectroscopic evidence, when examined in detail, gives similar indications of more complex developments. Thus it is found experimentally that, in the elements of the first transition series, the grouplet 4_{11} of the N level is occupied by two electrons (except in chromium and copper) so that all these elements readily form bivalent ions. In the same way, the first two elements (yttrium, zirconium) of the second transition series have two electrons in the 5_{11} grouplet of the O level; but at this stage there is an abrupt change, since the following elements (niobium, *et seq.*) have only one electron in the 5_{11} grouplet, and palladium actually has none. In the next group of transition elements tungsten appears to have two electrons in the 6_{11} grouplet; but no conclusion can be drawn in reference to the other elements of this transition series, since the relevant spectroscopic data are not yet available. These unforeseen 'anomalies' are of peculiar interest, since they show that the individuality of the elements, which makes inorganic chemistry appear so much less systematic than organic chemistry, is manifested also in their spectroscopic behaviour, which may therefore be expected to provide a clue to the common origin of these physical and chemical anomalies in the electronic configuration of the atom.

A particularly interesting comparison can be made between nickel, palladium, and platinum. The structure of these three elements could be represented most easily by assigning an outer

shell of 18 electrons to each metal, as in the scheme :

$$\begin{array}{rcccccl} & K. & L. & M. & N. & O. & \\ \text{Ni} & = & 2 + 8 + 18 & & & = & 28 \\ \text{Pd} & = & 2 + 8 + 18 + 18 & & & = & 46 \\ \text{Pt} & = & 2 + 8 + 18 + 32 + 18 & = & 78 & & \end{array}$$

This structure is correct in the case of palladium, which appears to contain a series of complete grouplets, since it is only feebly paramagnetic and gives a spectrum with some of the characteristics of a noble gas ; but it is no longer true for nickel and platinum, the spectra of which are more like those of the alkaline earths, so that their structure may be represented more efficiently by the schemes $2 + 8 + 16 + 2$ and $2 + 8 + 18 + 32 + 16 + 2$.

The spectroscopic data thus explain the typical bivalency of nickel and its resemblance to the bivalent transition elements with which it is associated ; but they do not throw much light on the chemistry of palladium and platinum, since these two metals do not show any analogous contrast in their chemical behaviour. If, however, we consider the coinage metals of the succeeding family, $\text{Cu} = 29$, $\text{Ag} = 47$, $\text{Au} = 79$, the value of the spectroscopic data is at once seen. Thus, since palladium contains only completed groups or sub-groups of electrons, and has therefore a very stable electronic configuration, it is natural that silver should exhibit the simple spectrum and rigid univalency of an alkali metal, as expressed in the scheme $\text{Ag} = 2 + 8 + 18 + 18 + 1$. In the case of copper, the univalency of the element in its cuprous salts is similarly expressed in the scheme $\text{Cu} = 2 + 8 + 18 + 1$. In strict conformity with this scheme, the cuprous ion, $\text{Cu}^+ = 2 + 8 + 18$, which has three levels completely filled, is diamagnetic ; but the cupric ion, which possesses an incomplete shell $\text{Cu}^{++} = 2 + 8 + 17$ is paramagnetic. Since copper is usually bivalent, we might expect to find spectroscopic evidence of a configuration $\text{Cu} = 2 + 8 + 17 + 2$, corresponding with $\text{Ni} = 2 + 8 + 16 + 2$, with two electrons in the 4_{11} grouplet, but this does not appear to have been observed. On the contrary, the presence of quadruplet groups in the spectrum of copper indicates the presence of *three* unpaired electrons round the central nucleus. This brings the metal into line with nickel, but in a different way, since the stable core of electrons has $2 + 8 + 16$ electrons in each case ; but it is not in accord with the chemical properties of the element, which may be univalent but is never tervalent.

The univalency of gold finds expression in the configurations

$$\text{Au} = 2 + 8 + 18 + 32 + 18 + 1,$$

$$\text{Au}^+ = 2 + 8 + 18 + 32 + 18,$$

which show the presence of *one* easily detached electron in the *P* level. Its tervalency can be deduced from the analogy between the spectra of platinum and those of the alkaline earths with *two* easily detached electrons, since this indicates the existence of a stable core with 16 *O*-electrons as in the scheme

$$\text{Au}^{+++} = 2 + 8 + 18 + 32 + 16,$$

$$\text{compare Pt} = 2 + 8 + 18 + 32 + 16 + 2.$$

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In this connexion, the univalency of thallium, which finds expression in the scheme $\text{Tl}^+ = 2 + 8 + 18 + 32 + 18 + 2$, is of interest, since it provides further evidence of the stability of the outer sub-group of two 6_1 electrons which has already been deduced from the spectroscopic data for platinum.

The introduction of sub-groups of elements has the interesting effect of removing carbon and silicon from the central position which they have long occupied in the minds of chemists as the middle

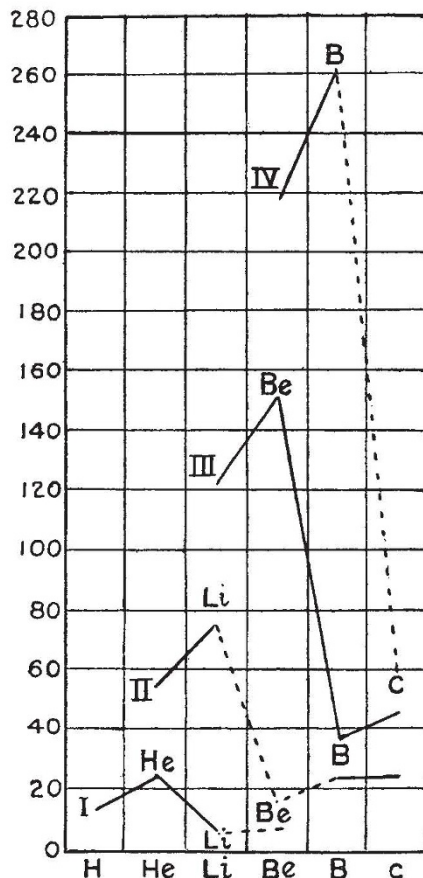


FIG. 1.—Diagram showing the ionisation potentials required to remove 1, 2, 3, or 4 electrons from the first six elements.

members of the two short periods of elements. From the spectroscopist's point of view, however, a sub-group 2_1 or 3_1 has been completed at beryllium and magnesium, and it only remains to build up the six electrons of the 2_2 or 3_2 sub-groups in order to give the configuration of a noble gas. In this process, nitrogen and phosphorus usurp the median positions, and this is revealed by an unexpected symmetry in the spectroscopic terms of the elements on either side. Thus the spectrum of magnesium shows some resemblance to that of argon, whilst aluminium and chlorine, and silicon and sulphur form similar pairs, in which the electrons which are present in one element are represented by gaps in the other. A similar symmetry is seen on either side of manganese in the transition elements of the first long period,

where the 3_3 sub-group is being filled up; but in this case the symmetry is marred by the fact that chromium and copper have only *one* outer electron instead of two in the 4_{11} grouplet. In the elements of the rare earths, where the 4_3 sub-group is being filled with fourteen electrons, gadolinium occupies a central position in a series of fifteen elements ranging from lanthanum to cassiopeium; but in this case the central element is characterised by an extraordinary maximum of multiplicity, $r=17$, which is far in excess of the previous maximum values, namely, $r=4$ for nitrogen and phosphorus, and $r=6$ for manganese, or $r=7$ for the anomalous spectrum of chromium.

The culminating feature of Messrs. Lessheim and Samuel's monograph, in our experience, is found in a diagram of ionisation potentials (Fig. 1), which provides the most convincing proof of the real existence of electron-groups. The minima at Li^+ , Be^{++} , B^{+++} , and C^{++++} show how easy it is to remove the whole of the electrons from the L level in lithium, beryllium, boron, and carbon; but, on attempting to remove one more electron, an immense resistance is at once encountered to the disintegration of the still complete K -shell,

and the ionisation potential leaps up to a maximum. When once this shell is broken, however, only a feeble resistance is offered to its complete removal. Thus the two L electrons can be removed from an atom of beryllium by two increments of about 8 and 7 volts, but the removal of the two K electrons requires the successive addition of 138 and 46 volts to the previous total of about 15 volts. The most striking feature of these numbers is the drop of nearly 100 volts in the extra work that is required to strip the nucleus bare by the removal of one more electron when once the K -shell has been broken. Even the tiny duplet of the 2_{11} grouplet appears, however, to put up an appreciable resistance to disruption, since rather less extra work is required to remove an electron from the ion Be^+ than from the neutral atom Be . Facts such as these provide ideal evidence in support of the main thesis of the electronic theory of valency, that chemical affinity in all its various manifestations depends on the superior stability of certain numerical groups of electrons when under the influence of a positively charged nucleus. In our opinion, this thesis now rests on an impregnable rock of experimental proof. T. M. LOWRY.

Christian Huygens, 1629-95.

OF all men of science whose lives were passed within the compass of the seventeenth century, none has a more lasting reputation than the Dutch mathematician, natural philosopher, and inventor, Christian Huygens. Born on April 14, 1629, three hundred years ago, at a time when the work of Kepler, Galileo, Napier, Gilbert, and Harvey was slowly gaining acceptance, he lived to read Newton's "Principia," and during the course of his career saw the rise of experimental science, the erection of famous observatories, and the foundation of our greatest scientific societies, the Royal Society and the Paris Academy of Sciences, of the latter of which he was the first foreign associate.

Huygens' birth, and his death on June 8, 1695, both took place at the Hague, and his tomb, like that of his illustrious countryman, Boerhaave, is there in St. Peter's Church. With advantages of birth, education, wealth, and position, Huygens possessed a studious and industrious mind, and an even and cheerful temper, and by the exercise of his brilliant intellect he raised himself to pre-eminence among his contemporaries. Trained in the law and for a short time attached to a Dutch embassy, he was all his life free to follow his own bent, and his long sojourn in Paris, where he enjoyed the seclusion of the Bibliothèque Roi, and his visits to England, no less than his investigations, discoveries, and inventions, led to his being esteemed by a wide circle of friends.

The life and works of Huygens have been published and republished, but reference can be made to only one or two of his great contributions to the advancement of knowledge. Attracted in his youth, like many of his fellows, to the construction and improvement of telescopes, on Mar. 25, 1655, Huygens discovered Titan, the

sixth, but the first seen, of the satellites of Saturn, and then gave the true explanation of the curious appearance of the 'triple planet.' This discovery of Saturn's ring he made known in the form of a logograph, which is reproduced by Grant in his "History of Physical Astronomy." In after years Huygens presented to the Royal Society an object glass of 122 feet focal length for an 'aerial telescope,' for the mounting of which Halley was commissioned by the Society to "view the scaffolding of St. Paul's Church" to see if it could be used for erecting the object glass.

From astronomy and telescopes Huygens turned to clocks, and on June 16, 1657, presented the first pendulum clock to the States General. Described later in his famous work "Horologium Oscillatorium," of 1673, a replica of the clock is to be seen in the Science Museum. Of that famous work, it has been said that it contained original discoveries sufficient to have furnished material for half a dozen striking disquisitions, while "the theorems on the composition of forces in circular motion with which it concluded formed the true prelude to Newton's 'Principia' and would alone suffice to establish the claim of Huygens to the highest rank among mechanical inventors." This work, like his "Traité de la Lumière," in which he enunciated the undulatory theory of light, was written while he lived in Paris.

Returning to his native country in 1681, Huygens continued his writings, and his last work, "Cosmotheoros," was in the printers' hands when he was attacked by the illness which proved fatal. It is said that Flamsteed recommended the "Cosmotheoros" to Dr. Plume, archdeacon of Rochester, who was so struck with it that he left £1800 to found the well-known Plumian professorship of astronomy at Cambridge.