far infra-red. Only in the case Ba can we expect ³F to have a sufficiently large value. We have not yet been able to identify the ³F terms without ambiguity, but the following identification may be provisionally given:—

	$\bar{F}_2$(480·2) 19990·3	$\bar{F}_3$(432·2) 19510·1	$\bar{F}_4$ 19077·9
$3^3F_2=7426·8$	(1u) 12563·5		
$3^3F_3=7412·8$	?	(2) 12097·3	(1r) 11665·4
$3^3F_4=7398·6$		(1) 12112·0	(6u) 11679·3

The combination with ³F of state $M_2 M_3$ ought to give us strong lines, but they would be hopelessly in the infra-red if these values of ³F prove to be correct. But we can take the higher Rydberg sequence terms of this ³F, for which Russell and Saunders give the values 4966·3, 4747·5, and 4558·6. We get the following multiplet:—

	$\bar{F}_2$ 19990·3	$\bar{F}_3$ 19510·1	$\bar{F}_4$ 19077·9
$2b^3F_2=4966·3$	(1) 15024·1	(1) 14543·2	
$2b^3F_3=4747·5$	?	(1) 14762·8	(1) 14330·5
$2b^3F_4=4558·6$		?	?

Probably the last term, viz. 4558, has not been correctly identified, for we have failed to establish it from other sources. The reality of the ³F for Ba here given is strengthened by the following further combinations:—

$$19990·3-q_1=13305·2 \ (1u),$$
$$19510·1-3^3F_3=13372·0 \ (2), \ 19510·1-q_2=12270·0 \ (2),$$
$$19510·1-q_3=12311·2 \ (2),$$
$$19077·9-q_3=11880·9 \ (1u).$$

Though the existence of the ³F terms has not yet been established, except in the case of Ba, they form very prominent members in the spectra of Sc⁺, Y⁺, and La⁺. Here ²S—²D of M⁺ (*i.e.* of Sc⁺⁺, Y⁺⁺, La⁺⁺) is negative, *i.e.* the ²D-term is larger than ²S; hence terms which arise when the stationary electron is at M_3 are much larger than the terms arising out of the combination N_1 X : in other words, though the elements have a structure similar to that of the alkaline earths, the spectrum is just reversed, the anomalous terms become normal terms, and the normal terms become anomalous. Thus in Sc⁺,[18] for which the structure diagram is the same as that for Ca, we have the following terms (since the absolute value is not known, the largest term is given the value 0 ; the values of the other terms are obtained by subtracting the number placed against each number from the value of the biggest term :—

Sc⁺

State	Terms	Term values
N_1M_3	³D	0, 67·6, 177·8
	¹D	?
M_2M_3	³F	4802, 4883, 4987
	³P	12073·8, 12101·3, 12154·1
M_2N_2	³F	27440·9, 27602·7, 27841·4
	³D	27918·1, 28021·6, 28161·5
	³P	?

Thus here ³F forms the second biggest set of terms. The same feature is observed in the spectra of Y⁺ and La⁺.[19] The barium spectrum is intermediate in nature between the two groups Ca and Sr on one hand, Sc⁺, Y⁺, L⁺ on the other hand.

[18] S. Goudsmit, J. van der Mark, and P. Zeeman, Proc. Amst. vol. xxviii. p. 127.
[19] Y⁺-spectrum: Meggers, Journ. Opt. Sci. Am. vol. xii. p. 418 (1926). La⁺: Goudsmit, *loc. cit.* Goudsmit has apparently taken the terms in the reverse order.

40. A NOTE ON THE SPECTRUM OF NEON*

Though the spectral lines of Neon have been completely grouped into series by Paschen, the nature of the series terms was not clearly understood, and a good deal of discussion has been devoted to it. Paschen[1] discovered

A set of four terms ($s_2 \ s_3 \ s_4 \ s_5$)
  of value ranging between 38040—39887;
a set of ten terms ($p_1 \ldots\ldots\ldots p_{10}$)
  of value ranging between 20958—25671·65;
a set of 12 terms ($d_1 \ d_1' \ldots\ldots\ldots d_6, s_1', s_1'' \ldots\ldots s''''$)
  of value ranging from 11493—12419.

None of these terms, however, constitute the fundamental level of Neon, which must have a very large value corresponding to the observed ionization potential of 21 volts. This level was discovered by Hertz[2], by means of his vacuum spectrograph. It gives rise to two lines $\lambda=735·7$ and $\lambda=743·5$, separated by a frequency interval of 1428, which is just the difference between the values of Paschen's s_2 and s_4 terms.

From these data, and from a discussion of data on the Zeeman effect of Neon-lines, Goudsmit[3] has proposed the

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*Communicated by the Author.
[1] Paschen, *Ann. d. Physik*, vol. lx, and lxiii.

[2] Hertz, *Zs. für Physik*, vol. xxxii. p. 933.
[3] See Goudsmit, *Zs. f. Physik*, vol. xxxii. and Back, vol. xxxvii.

following new designation of Paschen's terms. Goudsmit's schemes explains the structure of the Neon spectrum far better than Landé's theory of Spectra of the Second Degree (Spektra der Zweiter Stufe) which he deduced from his 'Verzweigungsprinzip.'

Terms (Paschen's Notation)	Designation according to Goudsmit	Observed g-factor.	Theoretical g-factor.
Hertz's fundamental level.	$^1S_0$	0/0	0/0
s_2	$^1P_1$	1	1
s_3	^3P	?	$\frac{0}{0}$
s_4	$^3P_1$	$\frac{3}{2}$	$\frac{3}{2}$
s_5	$^3P_2$	?	$\frac{3}{2}$
p_1	$^1S_0$		$\frac{0}{0}$
p_5	$^1P_1$	1	1
p_8	$^1D_2$	1·137	1
p_{10}	$^3S_1$	2	2
p_3	$^3P_0$	?	$\frac{0}{0}$
p_2	$^3P_1$	$\frac{4}{3}$	$\frac{3}{2}$
p_4	$^3P_2$	$\frac{3}{3}$	$\frac{3}{2}$
p_7	$^3D_1$	$\frac{3}{3}$	$\frac{1}{2}$
p_6	$^3D_2$	$\frac{7}{6}$	$\frac{7}{6}$
p_9	$^3D_3$	?	$\frac{4}{3}$

The nature of the next group of terms called d's and s's by Paschen has been fixed up by Hund, though their g-factor is yet unknown. Most of the lines arising from the combination of these terms with the p's lie in the extreme infra red, so that it would be very difficult to observe their Zeeman effect. It is, however, evident that they cannot all belong to the d group, for d_6 has the inner quantum number 4, and no triplet term up to d can have such a high inner quantum number. Higher terms like ^3F are clearly involved. In this note, the above facts discovered by Hund and Goudsmit are put in new symbols explained by the author in an earlier paper (Saha, Phil. Mag., June 1927).

The number below each term like M denotes the full number of electrons required to close the subgroup completely. A level like L_2 was subdivided into L_{21}, L_{22}, by Stoner with two and four electrons respectively, but this has been omitted.

Advantage of this Method of Representation.

The first period Li to Ne ... is formed when the electrons are made to fill the L-levels. The second period (11) Na to (19) A when the M, and M_2 levels are filled up. It is now known, that if a fresh electron is now brought up, instead of going to M_3, it comes over to N_1, forming K and Ca.

The negative energy value of the electron in position N_1 is therefore larger than the value in position M_3. To represent this state of affairs, we have written N_1 below M_2 and not following M_3, as is usually the custom. We have followed this system all throughout. Thus roughly if by (X) we represent the energy value of any level, then

$$(K_1) > L_1 > (L_2), (M_1)$$
$$> (M_2), (N_1)$$
$$> (M_3), (N_2), (O_1)$$

etc., etc.

Chart illustrating the Formation of Atoms.

H / He	K_1 (2)				Transition I 21 Sc to 28 Ni	Group II 39 V to 46 Pa	Rare Earths 57 La to 70 Yb	Transition Group III 71 Lu to 78 Pt			
3 Li to 10 Ne		L_1 (2)	L_2 (6)								
11 Na to 18 A			M_1 (2)	M_2 (6)	M_3 (10)						
29 Cu to 36 Kr		19 K / 20 Ca		N_1 (2)	N_2 (6)	N_3 (10)	N_4 (14)				
47 Ag to 54 Xe		37 Rb / 38 Sr			O_1 (2)	O_2 (6)	O_3 (10)	O_4	O^5		
79 Au to 86 Nt		55 Ca / 56 Ba				P_1 (2)	P_2 (6)	P_3	P_4	P_5	P_6

Terms on the same vertical column like (L_2) (N_1) or (M_3) (N_2) (O_1)....have the same order of energy value, though each preceding term is larger than the next.

The diagram makes clear the formation of the transitional groups, and rare earths, and persistence of the pair of alkali and alkaline earths throughout the whole system. After Argon, we have K and Ca formed in which the N_1-level is filled up. The next electron must go to the M_3-level. This happens till the M_3-level is completely filled up. Then with copper, a new group begins to be formed. In this way, we can explain the formation of pairs of alkalies and alkaline earth $(O_1$—Rb and Sr$)$, $(P_1$—Cs and Ba$)$, the successive transitional groups, and the rare earths.

Application to Spectroscopy.

But the scheme is more fruitful when we utilize it for the explanation of spectra :—

Taking Na, we again write out the structure diagram, but now with the higher levels unfilled :—

Spectrum of Sodium.

$\frac{K_1}{2}$					
	$\frac{L_1}{2}$	$\frac{L_2}{6}$			
	M_1 (1) ^2S	M_2 (1) ^2P	M_3 (1) 1^2D		
	N_1 (1) 2^2S	N_2 (1) 2^2P	N_3 (1) 2^2D	N_4 (1) 1^2F	

M_1 L denotes the normal level of the atom. It is the first term of the S-series, and may be written as 1^2S_1, using Russell and Saunders' notation. The electron, as it runs through the higher levels denoted by (1), gives rise to the spectral terms written under that level. The diagram also gives a rough indication of the sequence of values of successive terms. Thus

$$1^2S_1 > 1\,^2P_{1,\,2},\ 2\,^2S$$
$$> 1\,^2D_{2,\,3},\ 2\,^2P_{1,\,2},\ 3^2S_1$$
$$> 1\,_2F_{3,\,4},\ 2\,^2D_{2,\,3},\ 3\,^2P_{1,\,2},\ 4\,^2S.$$

Of course these inequalities are only roughly obeyed.

In the construction of the spectra of alkaline earths, we have to keep one electron fixed at N_1, O_1 or P_1, as the case may be and allow the other electron to run through the higher levels. The methods of working have already been discussed in a previous paper communicated to the Philosophical Magazine.

We shall now discuss the spectrum of Neon.

Explanation of the Spectrum of Neon.

$\frac{K_1}{2}$						
	$\frac{L_1}{2}$	$\frac{L_2}{5,1}$				
	M_1 (1)	M_2 (1)	M_3 (1)			
	N_1 (1)	N_2 (1)	N_3 (1)	N (1)		
	O_1 (1)	O_2 (1)	O_3 (1)	O_4 (1)		

The normal state of Neon is obtained when all the six electrons are allowed to fill the L_2-level. It has got $I_k=0$, $I_r=0$, hence it is an $^1S_0$-term.

The higher orbits are produced when we keep 5 electrons in L_2 and allow the other to pass through the higher levels. The 5 electrons in L_2 give us a doublet P-level, so that we can construct the terms successively as follows:—

Running electron in M_1 }   Combination of ^2P with $^2S_1$, $I_r=\frac{2}{2}$, 0, $I_k=\mid 1+0 \mid\ =1$.

Hence we get $^1P_1$, $^3P_{0,1,2}$ which are identified by Goudsmit with Paschen's s_2, s_3, s_4, s_5.

If the running electron is in N_1, O_1, P_1... ... ..., we shall get the higher Rydberg sequences of these terms.

Running electron in M_2 }   Combination of ^2P with ^2P. $I_k=\mid 1+1 \mid\ =2,\ 1,\ 0.$

Hence we expect

$$c^1S_0 \qquad c^3S_1,$$
$$c^1\overline{P}_1 \qquad c^3\overline{P}_{0,1,2},$$
$$c^1D_2 \qquad c^3D_{1,2,3}.$$

These are the terms which have been obtained by Goudsmit by a similar process, and identified with Paschen's p's. Now it is quite evident that the p-terms arising from this process will be capable of combining with the previous p-terms (Paschen's s's). For the process simply means transition of the electron from $M_1 \rightarrow M_2$ and it is perfectly admissible. The present p-terms must therefore be dashed, while the s-and d-terms must remain undashed.

Since all these terms arise from the same level, they have approximately the same scale of values, as observed.

If the electron is in any one of the higher 2-levels, as N_2 or D_2, or P_2, they will give rise to the higher Rydberg sequences to the present set, having identical combinatory powers.

Running electron in M_3 {   Combination of ^2P with ^2D. We have $I_k=\mid 2+1 \mid\ =3,\ 2,\ 1.$

Hence we expect

$$d^1P_1 \qquad d^3P_{0,1,2},$$
$$d^1\overline{D}_2 \qquad d^3\overline{D}_{1,2,3},$$
$$d^1F_3 \qquad d^3F_{2,3,4},$$

We expect twelve terms.

Now Paschen has given exactly twelve terms with

$j=0$, for d_6 $\therefore d_6 = c^3P_0$

$j=1$, for $(d_2\ d_5\ s_1') = (c^1P_1,\ c^3P_1,\ c^3D_1)$,

$j=2$, for $(d_1''\ d_3\ s_1''\ s_1'''') = (c^1\overline{D}_2,\ c^3P_2,\ c^3\overline{D}_2,\ c^3F_2)$,

$j=3$, for $(d_1'\ d_4\ s_1''') = (c^1F_3,\ c^3\overline{D}_3,\ c^3F_3)$,

$j=4$, for $d_4^1 = c^3F_4.$

The explanation of these terms is due to Hund, but detailed identification is difficult, and an attempt has been made by writing down the multiplets and comparing the intensities according to that to be expected from the

Sommerfeld-Ornstein-Dorgelo scheme. Table I shows the results of detailed identification.

TABLE I

Spectral Term	Term in Paschen's notation	Term Values	Inner Quantum Number
d^1P_1	s_1'	11493·76	1
*$d^1\overline{D}_2$	d_1''	12229·69	2
†d^1F_3	s_1'''	11519·27	3
d^3P_0	d_6	12419·90	0
$^3P_1$	d_5	12405·20	1
$^3P_2$	d_3	12322·24	2
$d^3\overline{D}_1$	d_2	12292·98	1
*$d^3\overline{D}_2$	s_1''	11509·52	2
$d^3\overline{D}_3$	d_1'	12228·26	3
†d^3F_2	s_1''''	11520·80	2
d^3F_3	d_4	12337·35	3
d^3F_4	d_4'	12339·15	4

*The positions of these two terms may be interchanged.
†Positions interchangeable.

The identification is somewhat ambiguous in certain cases. How far the intensity rules are followed will be seen from the following tables. Certain values like $(d_1' \ d_1'')$ are so close to each other that the lines occurring from them cannot be separated from each other, and the intensity-data in these cases are open to certain amount of doubt. The values of all these terms are of the same order and approximately equal to $\dfrac{N}{3^2}$. Some of the multiplets with intensities are shown in the following tables.

TABLE II

The c^3 D—d^3 F-multiplet

$c=5L_2M_2$ / $d=5L_2M_3$	(p_7) $^3D_1$	(p_6) $^3D_2$	(p_9) $^0D_3$
$(s''')^3F_2$	8136·4 (7) 12287·0	8267·14 (3) 12092·7	
$(d_4)^3F_3$		8865·7 (3) 11276·3	8376·4 (1) 11934·9
$(d_4')^3F_4$			8377·63 (7) 11933·3
$(d_6)^3P_0$	5934·46 (7) 16846·0		
$(d_5)^3P_1$	?	6000·95 (6) 16659·4	
$(d_3)^3P_2$	5919·04 (2) 16889·9	5987·93 (8) 16695·6	5760·58 (7) 17354·5

The multiplet represents the combination of ^{3}D, and second Rydberg sequence of ^{3}P terms.

The c^3D—$d^3\overline{D}$-multiplet

c / d	(p_7) $^3D_1$	(p_6) $^3D_2$	(p_9) $^3D_3$
$(d_2)^3\overline{D}_1$	8681·93 (3) 11515·0	8830·80 (0) 11320·9	
$(s_1'')^3\overline{D}_2$	8128·95 (3) 12298·3	8259·39 (4) 12104·1	7833·12 (1) 12762·8
$(d_1') \ \overline{D}_3$		8780·63 (4) 11385·6	8300·34 (7) 12044·4

Singlet-Combinations

c / d	p_{10} S_1
$(s_1')^1P_1$	7051·29 (5) 14177·9
$(d_6)^3P_0$	7544·08 (6) 13251·8
$(d_5)^3P_1$	7535·78 (8) 13266·4
$(d_3)^3P_2$	7488·85 (9) 13349·5
$d_2{}^3\overline{D}_1$	7472·42 (4) 13378·8

It will thus be seen that the complicated spectrum of Neon is very simply explained on the recent theories of complicated spectra. The theory accounts for not only the fundamental levels, but also for all the higher levels, the Rydberg sequences, and the order of values observed in each case. It also gives a very cogent explanation of the origin of the dashed terms, and explains such transitions as apparently break the selection principle, e.g. $\triangle$K=2, or 3.

We can summarize the results as follows:—

Position	Term
(a) $6L_2$,	$^1S_0$
(b) $5L_2$, M_1	$^1P_1$, $^3P_{0,1,2}$
N_1	Higher Rydberg sequence terms to the above.
(c) $5L_2$, M_2	b^1S_0 $\quad b^3S_1$ $b^1\overline{P}_1$ $\quad b^3P_{0,1,2}$ $b^1\overline{D}_2$ $\quad b^3\overline{D}_{1,2,3}$
$5L_2$, N_2 } O_2	Same terms but of higher Rydberg sequence.
(d) $5L_2$, M_3	$_1c\overline{P}^1$ $\quad c^3P_{0,1,2}$ $c^1\overline{D}_2$ $\quad c^3\overline{D}_{1,2,3}$ c^1F_3 $\quad c^3F_{2,3,4}$
$5L_2$, N_3 } O_3	Gives higher Rydberg sequence terms.

Transitions take place between terms of groups

$$(a)\rightarrow(b)\rightarrow(c)\rightarrow(d)\rightarrow$$

Corresponding to the transition of the electron from

$$L_2\rightarrow M_1\rightarrow M_2\rightarrow M_3$$

The scheme also explains that the fundamental term $^1S_0$ will be rather solitary, i.e. will not have terms of higher Rydberg sequence following it.