

13. ELEMENTS IN THE SUN* (PAPER B)†

(*Phil. Mag., Sr. VI, 40, 809, 1920*)

It is a matter of common knowledge that the continuous spectrum from the photosphere of the sun is crossed by a number of dark lines, which are called Fraunhofer lines in honour of their eminent discoverer. The correct interpretation of these lines was given by Kirchhoff in 1859, who showed that most of the principal lines can be attributed to the absorption of light of proper frequency by the cooler layers of the vapour lying above the photosphere. Since this epoch-making discovery, it has become a part of the routine work of astrophysicists to catalogue and properly measure the wave-length of these lines, and identify them with the emission lines of elements obtained in the laboratory.

The most extensive mapping of the Fraunhofer spectrum is due to Rowland, who counted and catalogued about 20,000 lines, but of these only 6000 have been identified with the lines of known elements. By this means, the presence of thirty-six elements has been definitely established in the sun, with doubtful indications of eight or more. The following are the elements of the existence of which in the sun no evidence yet been obtained¹ in:—

(a) Rubidium, Caesium, Nitrogen, Phosphorous, Boron, Antimony, Bismuth, Arsenic, Sulphur, Selenium, Thallium, Praseodymium.

Doubtful indications have been obtained of the existence of the following elements:—

(b) Radium², elements of the inert group with exception of Helium, which is obtained in the flash spectrum, Osmium, Iridium, Platinum, Ruthenium, Tantalum, Thorium, Tungsten, Uranium.

The following elements are represented by very faint lines in the Fraunhofer spectrum:—

(c) Potassium, Copper and Silver; Cadmium and Zinc; Tin and Lead; and Germanium.

(d) Chlorine, Bromine, Iodine, Fluorine, Tellurium, and many other elements have not been investigated at all.

No satisfactory explanation has yet been offered of the complete non-existence of the lines of elements mentioned in group (a) or (b), or of the faint occurrence of the lines

of elements mentioned in group (c). Similarly, it has not yet been made clear why certain elements like Ca, Fe, V, Ti are so unusually prominent in the solar spectrum. They are represented not only by the absorption lines of the neutral atom, but also by the absorption lines of the ionized atom (enhanced lines).

It is sometimes assumed that these phenomena are due to the chemical composition of the sun—in other words, the elements of which no lines are found either in the Fraunhofer or the flash spectrum are totally absent from the sun. But this view is most unsatisfactory, and can only be regarded as a stop-gap. There is, *à priori*, no reason why, in the sun, certain elements should be preferred to the exclusion of others. On the contrary, it seems natural to infer that the sun is composed of the same elements as the earth, and contains all the 92 elements known to the chemists on the earth.

It therefore becomes increasingly necessary to investigate why certain elements should entirely fail to be recorded on the Fraunhofer or the flash spectrum. It may be supposed that certain elements fail to be recorded because, on account of their heavy atomic weight, they are practically confined to the photosphere. But it is not merely a question of atomic weight, for in the list of missing elements we find light elements like boron and nitrogen side by side with a heavy element like thallium.

The view which is urged in the present paper is that the varying records of different elements in the Fraunhofer spectrum may be regarded as arising from the varying response of these elements with regard to the stimulus existing in the sun. The stimulus existing in the sun is the same for all elements, *viz.*, that arising from a temperature of about 7500°K., but owing to a different internal structure, elements will respond in a varying degree to this stimulus. The manner in which we can quantitatively estimate the effect of the stimulus has been sketched in papers A and C.³ In paper A, the effect of the stimulus on the alkaline earths Ca, Sr, and Ba was estimated. It was shown that while on the photosphere 30, 40 and 57 per cent. of the atoms are respectively ionized, the percentage of ionization increases with height and becomes practically complete for Ca at a pressure of 10^{-6} atm., for Sr at a pressure of

*Much of the introduction is taken, *mutatis mutandis*, from Fowler's report on the subject; vide 'Journal of the British Astronomical Society', May 1918.

†Communicated by the Author.

¹Pringsheim, *Physik der sonne*, p. 116.

²For the controversy regarding the existence of Radium, and the members of the inert group in the flash-spectrum, see 'Observatory', vol. xxxv. pp. 297, 357 and 402.

³Paper A—"Ionization in the Solar Chromosphere", *Phil. Mag.* Oct 1920; Paper C—"On the Temperature Radiation of Gases" (To appear shortly).

10^{-3} , and for Ba at a pressure of 10^{-2} atm. In this connection it may prove interesting to compare the results with the following remarks of Fowler:

"We find further, that while many of the metals are represented by both arc and enhanced lines, there are some which are identified only, or mainly, by their enhanced lines alone. Thus, although Ca shows both classes of lines strongly, Sr and Ba practically show enhanced lines alone".

Fowler ascribes the different behaviour of Ca on the one hand, and Sr and Ba on the other hand, to their differences in atomic weight, but according to the view presented in Paper A, this is mainly due to the varying values of the *ionization potential*. The author's belief is that in the sun and the stars, the attraction due to gravity is largely compensated by selective radiation pressure, and atomic weight is of much less consequence than can be supposed.

The method sketched in paper A has been extended to the alkali metals, and a few other elements. It will be seen that the theory accounts in a most gratifying manner for the varying behaviour of sodium lines in the Fraunhofer spectrum, and its intensification in the sun-spot spectrum, for the faint occurrence of the potassium lines, and for the complete absence of the lines of Cs, and Rb, and for the varying behaviour of the lines of Mg and Mg^+ , though, on this last point, the results are not so satisfactory. There is very little doubt that if proper data be available, the method can be extended to the explanation of all the details of the Fraunhofer spectrum.

For the explanation of the method, the reader is referred to Section 2 and 3 of paper A. The temperature of the photosphere has been taken to be $7500^\circ K.$, the pressure 1 to 10^{-1} atm., while for the high-level chromosphere a temperature of $6000^\circ K.$, has been used.

1. THE ALKALI ELEMENTS IN THE SUN

(a) Sodium

The following table shows the ionization of sodium in percents. under varying conditions of temperature and pressure:

Ionization Potential = 5.12 volts = 1.17×10^6 calories

Pressure Temp.	1.	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
5000	6	19	53	89	98.5	
6000	21	56	90	98.5		
7000	46	85	98			
7500	60	72	99			Complete Ionization.
8000	72	96				
9000	87	98.5				
10000	97					

The table shows that under the solar conditions, 60 per cent of sodium atoms are ionized in the photosphere, and ionization is practically complete at a level where the pressure falls to 10^{-3} atm. The result is in very good agreement with observational facts, for according to Mitchell the D_1 and D_2 lines reach a level of only 1200 kms. Over this height, only ionized Na-atoms are present, the chief emission lines of which lie, according to Goldstein⁴, in the remote ultra-violet, and so escape detection.

Taking the temperature of the spot = $5000^\circ K.$,⁵ we see from the tables that only 6 to 19 per cent of the atoms are ionized. So over the spot, there is a great increase in the proportion of unionized Na-atoms, and we should expect a much stronger absorption of the D_1 and D_2 lines. The following table (taken from Kayser's *Handbuch der Spektroskopie*, vol. vi. p. 114) shows that this is actually the case:

Line	Series-Description	Intensity in the Sun	Intensity in Sun-spot spectrum
D_1 —5896.15	(1,s)—(2, p_2)	20	60
D_2 —5890.19	(1,s)—(2, p_1)	30	90
5682.90	(2, p_2)—(3,d)	5	12
5688.26	(2, p_1)—(3,d)	6	12
6154.44	(2, p_2)—(3,s)	2	8
6161.95	(2, p_1)—(3,s)	3	9

(b) Potassium

The identification of Potassium is rather doubtful. Rowland has identified only two faint Fraunhofer lines $\lambda=4047.36, 4044.29$, with the emission lines (1, s)—(3, p_1), (1, s)—(3, p_2) of potassium. The following table shows that owing to the low value of the ionization potential, potassium is highly ionized throughout the whole of the solar atmosphere.

Ionization of Potassium

Ionization Potential = 4.318 volts = 1.00×10^6 calories.

Pressure Temp.	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
3000			2.5	9	28	66
4000	3	11	32	72	97	
5000	15	44	83	98		
6000	41	81	97.5			
7000	70	95				Complete Ionization.
7500	81	98				
8000	87	99				
9000	94					
10000	98					

⁴ Goldstein, *Ann. d. Physik*, vol. xxvii. pp. 773-796; Schillinger, *Wien. Ber.* p. 608 (1919); Nelthorpe, *Astrophysical Journal*, Jan. 1915.

⁵ Emden, *Gas-kugeln*, p. 443, See also numerous papers on the spectra of sun-spots by Fowler, Hale, and others.

The identification of potassium is to be carried by the lines $(1, s)-(3, p_1)$, $(1, s)-(3, p_2)$ which under all circumstances are likely to be much less intense than the leading pair $(1, s)-(2, p_1)$, $(1, s)-(2, p_2)$ which lie in the infra red, $\lambda=7665.3, 7699.3$. This fact, combined with the high proportion of ionization, tends to make the identification rather difficult. The lines of the ionized atom lie in the ultra-violet and so escape detection (Goldstein, *Astro. Journal*, xxvii. pp. 25-34 (1908) and *Ann. d. Phys.* loc. cit.).

Over the spots the potassium lines ought to be strengthened, but no observation seems to have been made on this point.

(c) Rubidium

As has been mentioned in the introduction, no lines of Rubidium have been identified in the Fraunhofer spectrum of the sun, though in the usual flame and arc spectrum there are many strong lines within the available range.

The following table shows the ionization of rubidium. It will be apparent from the tables that in the sun rubidium is completely ionized. Consequently, even if it be present, we shall get the lines due to the ionized atoms only, which according to Goldstein⁶, lie in the ultra-violet. The spot spectrum should show some faint rubidium lines. But no observation seems to have been made on this point.

Ionization Potential $U=96 \times 10^6$ calories = 4.16 volts.

Pressure Temp.	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
2000						1
2500				2	6	20
3000		1	4	13	37	78
4000	4	17	39	80	98	Complete Ionization.
5000	19	51	87			
6000	46	85	98			
7000	75	97				
7500	84	98				
8000	90					
9000	96					
10000	99					

(d) Caesium

No Caesium lines have been identified in the Fraunhofer spectrum. The case is identical with that of rubidium, only in a more marked degree. A table of the ionization

of caesium is appended below:

$U=3.88$ volts = 90×10^6 calories.

Pressure Temp.	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
2000					3	8
2500			1	4	11	34
3000		1	4	12	35	75
4000	7	20	53	89	98.5	Complete Ionization.
5000	25	62	92			
6000	56	90				
7000	81	97.5				
7500	88	99				
8000	92					
9000	98					

Oxygen

The presence of oxygen in the sun was a matter of great controversy until a few years ago. The well-known bands A, B, κ were shown by Jansen⁷ to be of telluric origin—i.e., caused by the absorption of the solar light by the molecular oxygen of our own atmosphere. But Runge and Paschen identified the weak Fraunhofer triplet, $\lambda=7772.20, 7774.43$ and 7775.62 , lying in the extreme red, with the three emission lines of oxygen, having the series formula

$$(2, s)-(m, p_1), (2, s)-(m, p_2), (2, s)-(m, p_3).$$

In the sun, therefore, oxygen exists in the atomic state.

The heat of decomposition of the oxygen molecule is not yet known with certainty. From Langmuir's⁸ observation that at 2400°K . and 10^{-1} atmospheric pressure oxygen is completely dissociated, I have calculated provisionally the heat of decomposition to be less than 50,000 calories, which is less than the corresponding value for hydrogen (84,000 cal.). Since the equation of chemical equilibrium is almost the same in both cases⁹, it follows without any calculation that oxygen should be completely decomposed into atoms in the sun. The ionization potential of oxygen is probably large, and no lines due to ionized oxygen seem to occur in the sun.

The lines of O^+ and O^{++} have been qualitatively studied by Lunt, Fowler¹⁰, and Brooksbank, but no series-formulae have yet been obtained for these lines. But Fowler's identification of certain of these lines in the Bo-class of stars and in Wolf-Rayet stars respectively seem to indicate that the first step ionization of oxygen is reached at an approximate temperature of $20,000^\circ\text{K}$. and second step ionization at probably not less than $30,000^\circ\text{K}$.

⁷ Pringsheim, *Physik der Sonne*, p. 119 et seq.

⁸ Langmuir, *Journ. Chem. Soc.*, vol. xxxiv. pp. 864, 1030 (1912)

⁹ Vide Hydrogen in the Sun, Paper A, p. 483.

¹⁰ Fowler and Brooksbank, *Month. Not. Roy. Astr. Soc.*, April 1917.

⁶Goldstein, loc. cit.

Magnesium

The wave-lengths of the strongest lines of the emission spectrum of Mg. viz. lines (1, *s*)—(2, *p*), (1, *s*)—(2, *p*₂), lie beyond the range of atmospheric absorption, so that we have to fall upon the next strongest lines, the triplet (2, *p*)—(3, *d*_{*i*}), *i*=1, 2, 3, $\lambda = 3838.34, 3832.46, 3825.51$, which are very prominent in the flash spectrum, and reach, according to Mitchell, a level of about 7000°km. The height reached by the line (1, *s*)—(2, *p*), $\lambda = 2852$, if it were available for observation, would probably be somewhat higher, say about 9000°km. The brief is strengthened from an examination of the table of ionization given below.

Ionization of Magnesium.

Ionization Potential = 7.65 volts = 1.76×10^6 calories.

Pressure Temp.	1	10 ⁻¹	10 ⁻²	10 ⁻³	10 ⁻⁴
4000		2.10 ⁻³	1	2	9
5000	5.10 ⁻²	1	4	11	32
6000	2	6	18	50	87
7000	6	20	54	89	98
7500	11	32	73	96	Complete Ionization.
8000	17	47	85	98	
9000	34	75	96	Complete Ionization.	
10000	56	90	98		
11000	75	96	Complete Ionization.		
12000	86	98			
13000	93	99	Complete Ionization.		
14000	96	Complete Ionization.			
15000	98				
16000	99	Complete Ionization.			

As the ionization potential of magnesium is rather high, it is ionised to a lesser extent than the other alkaline earths. Total ionization is reached at a pressure of about 10⁻⁶ to 10⁻⁷ atm. in the chromosphere. This is in excellent accord with observational results.

The lines of ionized magnesium have been studied by Fowler. The lines which should theoretically¹¹ turn out to be strongest, all lie in the ultra-violet, as the following table shows—

(1, <i>s</i>)—(2, <i>p</i> ₁)	.....	2795.5 Å.U.
—(2, <i>p</i> ₂)	.....	2802.7
(2, <i>p</i> ₁)—(3, <i>d</i> ₁)	.....	2798.1
(2, <i>p</i> ₂)—(3, <i>d</i> ₂)	.....	2790
(3, <i>d</i> ₁)—(4, <i>f</i>)	.....	4481,

¹¹Fowler, Phil. Trans. vol. ccciv. The intensity given for 4481 is relatively much greater than the intensity of the (1, *s*)—(2, *p*) lines.

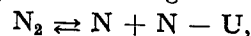
so that the only line available for observation is the leading member of the Bergmann series λ -4481 Å.U. According to observation, this reaches a level of 450 km. only.

According to the considerations presented in paper C, lines of this description under all circumstances require not only a higher stimulus, but also a high density of the radiant particles. Though the upper layers of the chromosphere favour relatively stronger ionization, yet the density is so small that such lines fail to be recorded. They are recorded only from the lower regions where the density is sufficiently great, and the stimulus is not much weakened.

Nitrogen in the Sun

The emission spectrum of Nitrogen is a rather difficult matter to deal with. Under the stimulus in which most of the other elements can be made to emit their characteristic line spectrum or even their enhanced lines, nitrogen gives only several classes of band or molecular spectra. The line spectra seem to require a very great stimulus for their production. But the existing knowledge on the subject is too meagre to allow the discussion of the line emission of atomic nitrogen from the present standpoint. According to a recent paper, the ionization potential of N is 17-18 volts, but this must be made up of the energy of dissociation of the molecule plus the energy of ionization of the atom.

If the so-called cyanogen band having its head at $\lambda = 3883^{12}$ be really due to molecular nitrogen, the conclusion follows that in the sun nitrogen occurs in the molecular state. There may be a fair proportion of atomic nitrogen, but the stimulus is not sufficiently strong to make it emit the lines we are familiar with. All these characteristics are in very good accord with the chemical inertness of nitrogen, which is again due to the high value of the heat of dissociation of the N₂ molecule. The fact is only qualitatively known. According to Langmuir¹³, less than 5 per cent of nitrogen is dissociated at 3500°K. and at atmospheric pressure. From this we may calculate the heat of dissociation in the following manner. The reaction takes place according to the scheme



and if *x* be the fraction dissociated, P the partial pressure, we have

$$\log \frac{x^2}{1-x^2} P = - \frac{U}{2.3 RT} + \frac{3}{2} \log T + \Sigma C.$$

$$\text{Now } \Sigma C = 2 C_N - C_{N_2}.$$

According to the Tetrode-Sackur formula,

$$C_N = -1.6 + \frac{3}{2} \log M = .119,$$

¹²This is the opinion of Runge and Grotian (*Phys. Zeits.* vol. xv. 1914). Fowler, on the contrary, believes that the band is due to CN (cyanogen). See also Barratt, Proc. Roy. Soc. Lond. vol. xcvi.

¹³Langmuir, *Journal of the American Chem. Soc.*, vol. xxxiv. p. 860 (1919).

and $C_{N_2} = -0.5$.¹⁴

Taking $x=0.3$ in Langmuir's experiment, we can calculate U from the above formula; we obtain

$$U=1.50 \times 10^5 \text{ calories, in round numbers.}$$

Taking $T=7000^\circ\text{C.}$, we can now calculate the value of $\log \frac{x^2}{1-x^2} P$. This becomes 1.390. If $P=1$ atm., almost 98 per cent of the nitrogen ought to be completely broken up into atoms. For $P=10$ atms., the proportion is 83 per cent.

Thus the calculation does not seem to favour the suggestion that a certain percentage of nitrogen occurs in the sun in the molecular state. But the data used for calculation are of the roughest nature, and nothing definitely can be said until better data are available.

Helium

It is well known that none of the Helium lines occur in the Fraunhofer spectrum, though occasional reversals of the D_3 have been observed in the spectra of the penumbra of sun-spots¹⁵. But in the flash spectrum, helium lines are very prominent, the D_3 reaching a height of 7500 km. in the chromosphere. These facts may be explained in the following manner:

The lines by means of which helium is detected belong to the series-combination $(2, p) - (m, d)$, or $(2, s) - (m, p)$. These lines cannot be absorbed by the ordinary He-atoms, which possess $(1, s)$ orbits, but by such atoms as possess the $(2, p)$ or $(2, s)$ orbits. These orbits can only be produced under very great stimulus. It is known from the 'Harvard Annals' (vol. xxviii. 91) that the absorption lines of helium disappear below stars of the A_0 class. Hence a temperature of about $11,000^\circ\text{K.}$ (temperature of the A_0 class) is required for producing a sufficient number of He-atoms with $(2, p)$ orbits, when the pressure is one atmosphere. These conditions are not attained on the photospheric level; but at great heights, owing to diminished concentration, not only (m, p) but also (m, d) orbits are produced. As these absorbing atoms occur only at large heights in regions of low concentration, they are not in sufficient number to produce a weakening of the corresponding regions of the continuous spectrum by absorption.

The occasional reversals of He-lines in the penumbra of sun-spots seem to be an effect of diminished concentration without a corresponding loss in temperature. The temperature of the penumbra is intermediate between those of the spot and the undisturbed photosphere, and may be supposed to lie between 6500°K. and 7000°K. We have no direct observational result which can give us some idea of the pressure, but Evershed¹⁶ has found

that gases are flowing through the penumbra radially outwards, parallel to the surface of the sun, with velocities ranging from rather small values to about three or four kilometers per second. As the mass-motion of a quantity of gas is always attended with a fall in pressure, the penumbral regions certainly possess lower pressure than the undisturbed photosphere. The physical conditions in the penumbra are therefore favourable to the production of a larger percentage of He-atoms with the $(2, p)$ orbits. Probably this accounts for the occasional weak reversal of He-lines over the penumbra.

The Flash Spectrum

From paper A and the foregoing part of the present paper, it will be seen that Fraunhofer spectrum can mainly be regarded as function of a single physical condition, viz., the temperature. The flash spectrum is, on the other-hand, a function of temperature and concentration, a low concentration favouring a greater percentage of ionization and consequently a *relative* intensification of the enhanced lines. Special attention is called to the word "relative" when terrestrial sources of limited extent are considered, for though the percentage of ionized atoms becomes greater, the absolute number of particles becomes less, and hence all lines, as a rule, become fainter. But the lines of neutral atoms would become much fainter than the enhanced lines.

All this was substantially stated in paper A, but at the time of writing this paper I was acquainted with no experimental work which could be cited in support of the view. I have since come across some works which support my case. The following is an experimental work by Loving on the comparative intensities of Ca and Mg lines in ordinary arc and vacuum arc. (Astrophysical Journal, vol. xxii, p. 300, 1905). Fowler also noted that the enhanced lines of Mg, Zn, and Cd are greatly intensified in a vacuum arc (Fowler and Payn, Proc. Roy. Soc. lxxii. 1903).

Element	Open arc	Vacuum arc	Relative weakening	Spark	Chromosphere
K-3934	500	25	$\frac{1}{20}$	1000	75
H-3968	300	20	$\frac{1}{15}$	500	60
g-4227	1000	8	$\frac{1}{125}$	100	8
Magnesium					
2852	500	8	$\frac{1}{60}$	100	—
4481 (+Mg)	0*	20	—	50	1

¹⁴Laski, *Phys. Zeits.* xx. p. 269 (1919).

¹⁵Pringsheim, *Physik der Sonne*, p. 123.

¹⁶Evershed, *Astrophysical Journal*, vol xxv. (1909); Hale, loc. cit. vol. xxviii (1910).

Thus the tables show that in the vacuum arc the ratio Ca^+/Ca is 6-8 times its value in the ordinary arc. Unfortunately the pressure, which is a vital point, is not stated. In the case of Mg, the stimulus at the open arc is not even sufficient to excite the ionized line 4481. But a diminution in concentration brings about ionization. This case is rather remarkable because it affords an experimental basis for the view that temperature remaining the same, a diminished concentration can bring about a higher stimulus.

Conclusion

The foregoing work will probably make it clear that the theory of temperature ionization developed by the author in paper A, and more fully applied in the present paper, is capable of throwing much light on many obscure and puzzling questions of solar physics. We are precluded from making further applications owing to lack of necessary data, viz., the value of the ionization potential of elements or the value of the term or terms $(1, s)$. If this and the spectral properties of all elements were known with as much certainty and exactness as in the case of alkaline earths, details of the Fraunhofer spectrum could be very satisfactorily explained.

We can, however, make the following suggestions with regard to future work on the subject:—Elements like Fe, Ti, V, Ni have probably ionization potentials varying from 6 to 9 volts, so that their behaviour is almost parallel to that of calcium and magnesium. Elements which are missing from the sun can be broadly subdivided into two groups: 1st, those which are completely ionized, e.g. Rb, Cs, and probably thallium; 2nd, elements of which the ionization and radiation potentials are so high that they are not in a state capable of absorbing those of their characteristic lines which occur in the continuous photospheric spectrum (vide paper C). Helium and most of the inert gases fall within this group. The case of helium has already been considered.

Neon, Argon¹⁷, and other inert gases have very high ionization potentials, the value being 16 volts for argon. Their principal emission lines $(1, s) - (2, p)$ lie in the ultra-violet, and identification is to be carried on by lines $(2, s) - (m, p)$ or $(2, p) - (m, d)$ or $(2, p) - (m, s)$. As the intensity of the photospheric radiation in the region $(1, s) - (2, p)$ is very small, the compensating value of the radiation pressure is also small, and the elements fail to reach great heights. In the lower regions, the stimulus is not sufficient enough to convert the atoms to the state $(2, s)$ or $(2, p)$ and hence these lines do not occur in the Fraunhofer spectrum¹⁸.

¹⁷For the spectral grouping of the lines Ne and A, see Paschen, *Ann. d. Physik.* vol. lx.

¹⁸Probably the metalloids As, Sb, Bi, etc. fall in this category, for it is well known that they can be made to emit their line spectrum at a comparatively low temperature, vide paper C, Introduction.

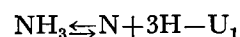
The Case of the Unidentified Fraunhofer Lines.

As has been mentioned in the introduction, about 60 per cent of the Fraunhofer lines catalogued by Rowland still remain to be identified. According to Fowler, a large proportion of these are due to molecules and molecular compounds.

The best known example is the so-called cyanogen band with its head at $\lambda = 3883$, now attributed by Grotian and Runge to molecular nitrogen. Other examples are Newall's identification of the G-group of the Fraunhofer spectra with the band-lines of hydrocarbons, and Fowler's detection of ammonia and water-vapour bands in the ultra-violet part of the solar spectrum.

These identifications raise a very important point, viz., is it possible, under the conditions prevailing in the sun, for any molecule or molecular compound to exist in the undissociated state? The problems are essentially of the same nature as those which are treated by the physical chemist in the laboratory, only repeated on a scale which is not available on the earth. But thanks to the recent developments in thermodynamics by Nernst, Planck, Sackur, and others, we can now handle these problems from the theoretical side in a very satisfactory manner, if only proper data are available. Examples have already been given; it has been shown that in the sun, hydrogen and oxygen are in wholly dissociated conditions, while some proportions of nitrogen may remain in the molecular state.

The chief data which are required are heats of dissociation, the specific heat of the components, and the value of the chemical constants of the components. Thus to take a concrete case, let us consider the chemical equilibrium of NH_3 . The reaction is of the type



and the chemical equilibrium is given by the law

$$\log \frac{P^3 x^4}{(1+3x)^3(1-x)} = -\frac{U_1}{2 \cdot 3RT} + \frac{\sum \nu C_p}{R} \log T + \Sigma C,$$

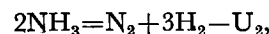
where x is the fraction dissociated.

$$\text{Now } \sum \nu C_p = (C_p)_N + 3(C_p)_H - (C_p)_{\text{NH}_3}$$

$$\text{and } \sum \nu C = C_N + 3C_H - C_{\text{NH}_3}.$$

All of these quantities can be calculated theoretically excepting C_{NH_3} . (The theory of the chemical constant for polyatomic gases is yet to be developed—see paper mentioned below¹⁹)

It should be remembered that U_1 is different from the energy evolved in the reaction,



$$\text{if } \text{N}_2 = \text{N} + \text{N} - U_N,$$

$$\text{and } \text{H}_2 = \text{H} + \text{H} - U_H,$$

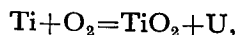
¹⁹"On the Chemical Constant of Diatomic Gases" Leon Schames, *Phys. Zeits.* vol. xxi. p. 41 (1920).

it is easy to see from the energy principle that

$$U_1 = \frac{U_N + 3U_H + U_2}{2}$$

and cannot be estimated before all these quantities are known.

For a chemical reaction of the type



the equation of chemical equilibrium is given by the formula

$$\log \frac{P^{2x^3}}{(1+2x)^2(1-x)} = -\frac{U}{2 \cdot 30RT} + \frac{\sum \nu C_p}{R} \log T + \sum \nu C,$$

which reduces to

$$\log \frac{P^{2x^3}}{(1+2x)^2(1-x)} = -\frac{U}{2 \cdot 30RT} + 3 \log T + C_{\text{Ti}} + 2C_{\text{O}} - C_{\text{TiO}_2},$$

if, in accordance with the kinetic theory of specific heat, we

$$\text{put } (C_p)_{\text{TiO}_2} = \frac{9R}{2}.$$

This class of chemical reaction is likely to have wide application in the treatment of the spectra of sun-spots, for a large number of spot-lines were identified by Fowler,

Hale, and Olmsted with the band-lines of MgH_2 , TiO_2 and, CaH_2 (tri-atomic compounds)²⁰.

It appears that no attention has yet been paid to the study of the spectra of the faculae, which are believed, on the basis of very sound physical arguments, to be regions of higher temperature than the photosphere. Supposing the temperature of the faculae to range between 8000°K and 9000°K, their spectra are likely to show very important differences from the spectra of the ordinary photosphere, and to be similar to the spectra of the F_0 to F_5G classes of stars, just as the spectra of sun-spots are similar to those of the Antarian stars (K-class). At any rate, the subject seems to offer a very rich field for investigation.

If the necessary data be available, these questions will be taken up in a future communication.

I have much pleasure in recording my best thanks to my students of the Post-graduate classes in physics for much useful help in preparation of this paper.

University College of Science, Calcutta.

May 22, 1920.

²⁰Pringsheim, *Physik der sonne*, pp. 211 to 217.

14. ON THE PROBLEM OF NOVA AQUILA III

(*Jour. Astr. Soc. Ind.*, **10**, 36, 1920)

The spectrum of Nova Aquila III has been studied in its various stages by many astrophysicists, all over the world, and has yielded a crop of extremely interesting results. It appears to me that in view of these results, it is now possible to seek for a plausible physical cause underlying this singular phenomenon. The results are fairly concordant and may thus be briefly summarised:

The spectrum of the Nova is a composite one and consists of four superposed spectra due to 4 distinct bodies. The first spectrum consists of bright-line emission bands of Hydrogen, Nebulium (?), Titanium, and other gases. The centres of the bands are displaced towards the red and are of enormous width. The spectrum reminds one forcibly of a pressure-shift, as mentioned by Father Cortie, (*M. N. R. A. S.*, January 1919) and is most probably due to emission by the gases aforesaid under enormous pressure (Vide Rossi's work in *Proc. Roy. Soc. Lond.*, Vol. 83).

Superposed upon this are three continuous spectra having

dark absorption-lines. Prof. Newall¹ finds that these spectra can be identified with that of the Star Cygni, when velocities of amounts,—1650 Km. per sec, and—2797 Km per sec are impressed upon that star. (These results are practically identical with those obtained by Evershed² and Lunt³; i.e. in other words, we are witnessing here the emission from three distinct gaseous bodies of the type of Cygni, but moving respectively with the enormous velocities of—1650 Km per sec,—2291 Km per sec. and—2797 Km per sec. in the line of sight, but these three gaseous masses, if they really existed, had very transient existence, because none of them were recorded on Father Cortie's plate exposed on June 30th, while the emission spectrum is of much longer duration, though undergoing changes all the while.

Now I should particularly emphasise upon a point

¹ *M.N.R.A.S.*, 1919, December.

² *Nature*, Vol 102, p 105.

³ Lunt, *The Observatory*, 1918, November.