44. THE ORIGIN OF THE SPECTRUM OF THE SOLAR CORONA

(*Nature*, **121**, 671, 1928)

THE arguments which have been brought forward to explain the origin of the spectra of nebulae may be used with certain modifications to explain the spectrum of the solar corona; for it must be composed of such atoms thrown out by radiation pressure or other agencies from the general atmosphere of the sun. On account of the lower temperature of the sun, the atoms concerned should be non-ionised, or such as can be easily ionised. They should also be light. All these considerations narrow down the choice to a very few elements like Li^+, Be^+, B^+, C, N, O...Si, P, S; P^+, and S^+, etc. It is the object of this note to discuss how these elements can give rise to the coronal spectrum.

It is now generally recognised that matter above the solar photosphere is largely supported by radiation pressure acting in a selective way. Prof. Milne has shown from transition probabilities of the Ca^+-atom (or the average life), that Ca^+ emitting the *H-K* lines is subjected to such a large radiation pressure that it almost overcomes the force of gravity. If this argument be true, the logical consequence would be to extend it to other elements. We can leave out H and He because their resonance lines are in the extreme ultraviolet and their normal atoms would be subjected only to slight radiation pressure. But such is not the case with Li. The resonance line of Li is at 6708 A., the corresponding $E_\lambda = 0{\cdot}8\ E_m$, the maximum emission E_m of the sun regarded as a black body at 6500° K; hence the force of radiation would more than balance the force of gravity; it would be expelled entirely from the solar atmosphere. It can be retained only in the ionised form. The entire absence of Li-lines from the Fraunhofer spectrum seems to support this view. If Li^+ be present, it may or may not be detectable, as the fundamental lines are in the Schumann region, and the excitation required to bring out the next important lines will be too large. The only favourable line is λ5484·69, or λ5484·90 (Rowland's Scale—a very weak line is given at 5484·846 in Rowland's Table, but the identification is doubtful), which belongs to the singlet system of $Li^+(2S—3P)$. Similar considerations would apply to Be^+ and B^+.

In carbon we come across a new feature. This new feature is best explained by taking the case of Si, for which the full details of the spectrum are known. Si has five fundamental levels, $^3P_{012}$, $^1D_2$, $^1S_0$, all arising out of the combination *pp* (or M_2M_2). The next combination is *ps* (M_2N_1), and it gives rise to $^3P_{012}$, $^1P_1$. The lines are shown in the accompanying table, the figures being taken from Fowler, *Phil. Trans.*, vol. 225, p. 45. The table shows that the ($^3P—^3P$) lines are the most fundamental, but their wave-length is at λ2514—2528, while the less fundamental $^1S_0—^1P_1$, $^1S_0—^3P_1$ lines are at λ4103, λ3905. Si is in fact detected in the sun by those two lines, some other subordinate lines, and some lines of Si^+. The problem now arises that if we heat Si to incandescence, to say 4000°C., so that the corresponding wave-length of the maximum emission is towards the red, will the group at λ2514-2517 be more intense or the lines λ4102, λ3905 ? Laws of temperature radiation demand that λ4102, λ3905 will be more intense, while the theories of spectra require that λ2514-2528 will be more intense at all temperatures, as the $^3P_{012}$ states will be much more numerous than the $^1S_0$-states $\left(n_{1S}\ n_{3P}=e^{-\frac{22000}{T}}\right)$, and there is always a greater tendency on the part of the higher excited $^3P_{012}$, $^1P_1$ states to revert to the more fundamental state.

$\frac{L_2L_2.}{L_2M_1}$	$^3P_0$	$^3P_1$	$^3P_2$	$^1D_2$	$^1S_0$
$^3P_0$		2524·118 39605·89(8)			
P_1	2514·331 39760·04(7)	2519·210 39683·03(7)	2528·516 39537·01(9)	2987·65 33461·39	4102·945 24365·89(5)
P_2		2506·904 39877·83(9)	2516·123 39731·73(10)	2970·35 33656·27(1)	
$^1P_1$	2438·782 40991·64(3)	2443·378 40914·54(3)	2452·136 40768·42(3)	2881·585 34692·97(10)	3905·515 25597·61(9)

An experiment was performed at this laboratory by Messrs. Majumdar and Kichlu to decide this question. They did not work with silicon, but with the more easily manageable thallium. This has two fundamental states, $2p_1$, $2p_2$, separated by a large interval $> \nu = 7793$, so that $n_2p_2/n_2p_1 = \frac{1}{2}e^{-\frac{25011}{T}}$ They heated thallium in a vacuum graphite furnace to about 2500° A. and photographed the spectrum of thallium vapour. The $2p_1$—$3s$ line has the wave-length λ3775·72, the $2p_2$-$3s$ line has the wave-length λ5350·46. As the $2p_1$ state is about a hundred times more in abundance, we expected that the line λ3775·72 would be more intense; at any rate it would not have less than half the intensity of λ5350·46 (because the weights of $2p_1$ and $2p_2$ states are as (1 : 2). But λ5350·46 was at least ten times more intense than λ3775·72. This fact is therefore more in accordance with the view that thallium vapour is partly in equilibrium with temperature radiation from the walls. But still we have to find out why the larger proportion of the $2p_1$-atoms is maintained. This is met by assuming that the prohibited transition $2p_1$-$2p_2$ occurs in large proportion—in other words, under the influence of the existing field of radiation, most of the thallium atoms in the $3s$-state return first to the $2p_2$-state, and then from the $2p_2$-state they return by the prohibited transition to the $2p_1$-state, so that the equilibrium between the proportion of atoms between the $2p_1$-and $2p_2$-states is maintained by the prohibited transition, which marks the emission of the line $\nu = 2p_1 - 2p_2$.

Turning now to the case of silicon in the sun, we find that the same argument can be applied. The emissivity of the sun is almost a maximum at λ4102 and λ3905; at λ2500, the emissivity is about 0·57 of the maximum. When silicon atoms are traversed by a radiation field of this type, we shall find that transitions corresponding to the emission of ${}^1S_0 - {}^1P_1$, ${}^1S_0 - {}^3P_1$ of silicon will be very frequent, while the transitions ${}^3P_{012} - {}^3P_{012}$ will be too small. The proportion between the fundamental ${}^3P$ and metastable ${}^1D_2$, ${}^1S_0$ levels will be maintained by the prohibited transitions ${}^3P_1 - {}^1S_0$, ${}^3P_{1\,2} - {}^1D_2$. Also it follows that if the transitions from the excited ${}^1P_1$, ${}^3P_1$-state to the ${}^1S_0$-state are as numerous as in the case of calcium, then silicon, being much lighter than calcium, would be thrown out into the corona in the metastable state ${}^1S_0$. Hence the coronal spectrum would show the prohibited transition.

If these hypotheses regarding the presence of silicon are correct, we should expect the following deductions to be verified:

(1) The Fraunhofer spectrum of the sun should show the line corresponding to ${}^3P_1 - {}^1S_0$, $\lambda = 6527{\cdot}05$ (Rowland Scale). Rowland's table shows a line at λ6526·89, intensity zero. The agreement is not satisfactory.

(2) The coronal spectrum should also show this line. There is a line of approximately this wave-length in Father Cortie's table of coronal lines; the wave-length is given as λ6528·9.

(3) The silicon lines λ4103 and λ3905·67 should be high chromospheric lines. This is not quite confirmed; in Mitchell's tables they are stated to reach only heights of 500 km. and 800 km. This may be due to paucity of transitions from the ${}^1P_1$-state to the ${}^1S_0$-state.

Excited silicon atoms may or may not (in the ${}^1S_0$-state) form a constituent of the corona. But the above arguments will apply to other suitable elements. I have chosen silicon for illustration because we know all about its spectrum. The same cannot be said of carbon, nitrogen, and oxygen, to which similar arguments can be applied, because in these cases the differences in value between the metastable states are only roughly known. To take carbon; this has an ionisation potential of about 11·3 volts; the spectrum is in all respects similar to silicon. The fundamental ${}^3P - {}^3P$ lines are at λ1656-1658, but the metastable ${}^1S_0 - {}^1P_1$-line is probably the line λ2478. Hence it can be stated that metastable carbon atoms, being very light, would be thrown into the corona, and there give rise to prohibited transitions ${}^3P_1 - {}^1S_0$, ${}^3P_{1\,2} - {}^1D_2$. The electrical field in the corona would increase the number of transitions. The frequencies of such lines are of the same order as the frequencies of the more intense coronal lines, but whether they agree absolutely will depend upon the exact determination of the value of these terms.

Similar, prohibited transitions between the fundamental levels of N and O, P and S, P^+ and S^+, may account for some of the coronal lines. The present spectroscopic knowledge of the metastable states of these elements is so meagre, and the wave-lengths of the coronium lines are so roughly known, that I have not yet tried to institute any search for their origin amongst these states.