

ADDRESS

Delivered by the President, Professor E. A. Milne, on the Award of the Gold Medal to Professor Bengt Edlén, Professor of Physics in the University of Lund

The Council has awarded the Society's Gold Medal to Professor Bengt Edlén for his identification of the origin of the principal lines in the coronal spectrum.

It has sometimes been the practice of the Royal Astronomical Society to award its Gold Medal, the highest distinction in its power, in recognition of a life's work devoted to astronomy. At other times the Society has used the award of the Gold Medal to recognise a particular piece of outstanding work. On this occasion the Society is following the latter course, and is honouring the discoverer of the solution of one of the outstanding problems of solar physics. The recipient of our Gold Medal this year is Dr. Bengt Edlén, whose experimental and theoretical work was done largely in the Physical Institute of the University of Uppsala, but who has recently been appointed, most appropriately, to the Chair of Physics, formerly held by Rydberg, in the University of Lund.*

The principal line in the Earth's auroral spectrum, the green line $\lambda 5577.35$, had been produced in the laboratory by McLennan and Shrum † in 1925, and shown to be due to atomic oxygen. The term-levels from which it originates were shown by Hopfield ‡ in 1927 to be associated with the ultra-violet lines $\lambda\lambda 1217.62, 999.47$ of the OI spectrum; the difference between these lines corresponds to a wave-number of 17925.6 cm^{-1} , whereas the auroral line $\lambda 5577.35$ corresponds to a wave-number of 17924.7 cm^{-1} . Further discussion of the physical origin of this line was given in 1928 by Cario.§ It is now known to be due to the forbidden transition $^1D_2 - ^1S_0$ amongst the levels of OI, neutral oxygen. Thus the supposititious element "geo-coronium" was disposed of. It had been so named by analogy with the so-called "coronium" lines in the spectrum of the Sun's corona, but at that time no similar success attended inquiry into the origin of the unknown coronal lines.

To put Edlén's work in its proper setting, it is necessary to mention again the year 1927. In October of that year, in *Nature* ||, I. S. Bowen published his since famous discovery of the origin of the so-called "nebulium" lines—that is, the unclassified lines in the spectra of the gaseous nebulae. His definitive paper was published in the *Astrophysical Journal* ¶ for January 1928. He showed, more particularly in the latter paper, that the nebulium lines, which are of course *emission* lines, were due to forbidden downward transitions from metastable levels in ionized oxygen and nitrogen atoms. For example, there is a well-known pair in the ultra-violet, at wave-lengths $\lambda\lambda 3729, 3726$, these being the strongest ultra-violet lines. Bowen pointed out that in position and separation this pair agreed with the forbidden transitions of type $^4S - ^2D$ in the spectrum of once-ionized oxygen, OII. In the same way he showed that the well-known pair in the green, $\lambda\lambda 5007, 4959$, usually called N_1 and N_2 , could be attributed to forbidden transitions of the type $^3P - ^1D$ of doubly ionized oxygen, OIII. The line $\lambda 4363$ could be attributed to the transition $^1D - ^1S$ amongst the levels of the OIII spectrum also. The pair in the red, $\lambda\lambda 6584, 6548$, could be attributed to the forbidden transitions of

* See *The Observatory*, 65, 252, 1944.

† McLennan and Shrum, *Proc. Roy. Soc.*, 108, A, 501, 1925.

‡ Hopfield, *Phys. Rev.*, 29, 923, 1927.

§ Cario, *Journ. Franklin Inst.*, 205, 515, 1928.

|| I. S. Bowen, *Nature*, 120, 473, 1927.

¶ *Ap. J.*, 67, 1, 1928.

type $^3P - ^1D$ of once-ionized nitrogen, *NII*. In this way, Bowen accounted for almost all of the previously unidentified nebular lines. I append his list given in his letter to *Nature*:

λ	Origin	Transition	λ	Origin	Transition
7325.0	OII	$^2D - ^2P$	4958.91	OIII	$^3P_1 - ^1D$
6583.6	NII	$^3P_2 - ^1D$	4363.21	OIII	$^1D - ^1S$
6548.1	NII	$^3P_1 - ^1D$	3728.91	OII	$^4S - ^2D_3$
5006.84	OIII	$^3P_2 - ^1D$	3726.16	OII	$^4S - ^2D_2$

It is difficult to over-emphasize the importance of this fundamental work by Bowen. Previous to his work, it had been generally concluded from the evidence of the periodic table of the elements and the Rutherford-Bohr picture of the atom, so wonderfully confirmed and made precise by Moseley's work on the atomic numbers of the elements deduced from the X-ray spectra, that there was no room for an unknown element "nebulium" amongst the lighter elements. Lockyer's success in discovering helium on the Sun through its D_3 line before it was isolated terrestrially could not be expected to be repeated with "nebulium". It was therefore realised that the unexplained lines in the nebulae must be due to atoms of familiar kinds in unfamiliar conditions. H. N. Russell suggested that this unfamiliar condition might be very low density.

It was Bowen who showed how very low density could promote the appearance of lines which could not be produced under laboratory conditions. I will quote his words: "One type of line, which would be possible only under conditions of very low density, is that produced by an electron jump from a metastable state. A metastable state may be considered to be one from which jumps are very improbable, *i.e.* one whose mean life before spontaneous emission is very long. Under laboratory conditions the mean time between impacts of a given atom with other atoms is, even in the most extreme cases, only $1/1000$ second. Consequently an atom in a metastable state will, in general, be dropped down to a lower state by a collision of the second kind long before it will be able to return directly with the emission of radiation. In the nebulae, however, where the mean time between impacts is variously estimated at from 10^4 to 10^7 seconds, such atoms will return spontaneously and radiate a line with the frequency corresponding to the difference in energy between the metastable state and the final state. Since the probability of emission of these lines is very small, the probability of their absorption must also be very small. Thus the lines should not be observed in absorption".

He then went on to point out that hydrogen, helium, carbon, nitrogen, oxygen are the only elements known to exist in the gaseous nebulae; that *CI*, *NI*, *NII*, *OI*, *OII*, *OIII* are the only ions of these elements that have metastable states so placed that jumps from them would give rise to lines in the region of wave-lengths that is observable in nebulae. But the degree of excitation in the nebulae is such that neutral carbon, nitrogen and oxygen could be eliminated. There remained therefore as possible ions *NII*, *OII* and *OIII*. A search by Bowen at once revealed that differences between known levels in these ions corresponded to observed emission lines in the nebulae, as has been described above. This work was done in the Norman Bridge Laboratory of Physics, in the California Institute of Technology, Pasadena, in 1927.

Bowen's explanation was rounded off by Eddington *, who in December 1927 showed that to Bowen's condition of low density must be added the further condition that the stimulating radiation must be so weak that the atom is unlikely to absorb a quantum during the full duration of the metastable state. For otherwise the atom in the metastable state would absorb before it had time to emit its forbidden line.

Bowen's work enormously increased the expectation that the other well-known group of unexplained lines in celestial spectra, namely the so-called "coronium" lines in the spectrum of the solar corona, would soon be similarly accounted for, though Eddington's supplementary condition, owing to the intensity of the Sun's radiation passing through

* *M.N.*, 88, 134, 1927.

the corona, made such an explanation less possible. However, the auroral line and the nebular lines were seen to be physically akin. But there, for a long time, success ended. The unknown lines in the solar corona, especially the famous line $\lambda 5303$ in the green, obstinately refused explanation. It still seemed to remain probable that the "coronium" lines were due to light atoms in a moderate state of ionization. But the actual explanation, when it came, was something very different.

The actual level of excitation in the Sun's reversing layer is of the order of 6–7 volts, and it seemed unlikely that that in the corona would be higher. In the nebulae, the excitation potentials corresponding to the metastable levels of Bowen's explanation are even smaller, amounting to 3.3 volts for the OII pair, $\lambda\lambda 3729, 3726$, to 2.5 volts for the N_1, N_2 pair $\lambda\lambda 5007, 4959$ of OIII, and to 1.9 volts for the NII pair $\lambda\lambda 6584, 6548$, to which must be added the ionization potentials—35 volts for OII, 55 volts for OIII and 30 volts for NII. There seemed to be no likelihood of excitation or ionization potentials of a different order of magnitude being in question for the corona, and search was made, though without success, amongst the levels of the earlier stages of ionization of the lighter atoms in the hope of finding coincidences between the level-differences and the actual wave-lengths of the unexplained coronal lines.

Saha remarks in his recent paper * "On a physical theory of the solar corona" that he, and probably many others, "spent considerable time in ransacking the available literature for forbidden lines of elements which may coincide with some of the coronal lines, but without success". He adds that "the hunt was confined to only singly and doubly and sometimes trebly ionized atoms, because it was considered improbable that more highly ionized atoms can, without violating ordinary laws of physics, occur in the corona". It should be mentioned that the coronal lines occur only well outside the chromosphere, and extend to a considerable distance outside the Sun's limb, so that Bowen's condition of extreme tenuity is likely to hold good. It was, however, concluded by Swings even so late as 1939 † that the origin of the coronal lines remained as mysterious as ever.

The solar corona had been observed in ancient times, and is said by Young to be described by Philostratus and Plutarch much as we should describe it to-day. But the first solar eclipse to be scientifically observed and seriously described was that of 1842, for which the line of totality traversed Spain, France and Italy, and of which the results obtained were summarised by Arago in 1846.‡ It was not at this time established that the corona was a solar and not a lunar appendage, and for a time attention was chiefly concentrated on the prominences. Photography was employed for the first time at the eclipse of 1860, for which Secchi published a drawing of the corona. This was the year in which Kirchhoff § first applied the ideas of the complementarity of emission and absorption of radiation to the solar spectrum, and soon after that, in 1868, occurred the first applications of spectral analysis to the solar envelopes. The green emission line $\lambda 5303$ in the corona was discovered independently by Harkness and Young || at the eclipse of 1869. Curiously enough, this line was at first erroneously attributed by Kirchhoff and Ångström to the spectrum of iron, but it was later shown that the *Fe* line is the lower component of the line, which had been found to be double in 1876.¶ Since 1869, somewhat more than twenty relatively well-measured lines have been discovered which are specifically characteristic of the corona. Eleven of these were photographed,

* *Proc. Nat. Inst. Sci. India*, 8, 99, 1942.

† Swings, *Scientia*, 1939, p. 69.

‡ *Annuaire du Bureau des Longitudes, Paris*. This information, together with other points in eclipse history, is extracted from Deslandres' *Histoire des Idées et des Recherches sur le Soleil* (published in the same *Annuaire* for 1906), a copy of which is in the writer's possession.

§ Poggendorff's *Annalen*, Bd. 109, 1860. The "Untersuchungen über das Sonnenspectrum" was first published in *Abh. Königl. Akad. Wiss.*, Berlin, 1861. My own copy is a reprint dated 1862.

|| Young, *The Sun* (1882), p. 224.

¶ Young, *loc. cit.*, p. 230.

five for the first time, by Lyot * without an eclipse, and their wave-lengths tabulated. None of these lines have been observed in any terrestrial source, or, until 1933, in any other celestial source. In that year, Adams and Joy † observed some characteristic coronal lines during the nova outburst of RS Ophiuchi.

The story of Edlén's identification of the origin of the coronal lines begins perhaps with Spencer Jones's observation ‡ of certain new unidentifiable lines in the later spectrum of Nova RR Pictoris 1925, in particular $\lambda\lambda$ 5723, 6087. These were described by Spencer Jones as forming the most interesting feature of the later spectrum of this nova. A suggested identification of λ 5723 with a forbidden line of FeIII by certain writers § was criticised by Swings and Edlén || on the ground that the supposed identification gave both the wrong wave-length and the wrong character to the line. This early betrayed Edlén's interest in unknown lines. In the following years he worked in the laboratory analysing many of the higher spark spectra of the elements with a vacuum spectrograph, publishing numerous papers in *Zeitschrift für Physik* on the subject. With Bowen he returned to the subject of Spencer Jones's lines in Nova RR Pictoris in 1939 in a letter to *Nature*. ¶ In that communication, armed with Edlén's garnered experimental results, these writers attributed the unidentified lines $\lambda\lambda$ 5723, 6087 to forbidden transitions amongst the levels of the six-fold ionized iron atom, FeVII. They gave the series classification as

$$\begin{array}{ll} \lambda 5723, & {}^3F_2 - {}^1D_2, \\ \lambda 6087, & {}^3F_3 - {}^1D_2. \end{array}$$

The separation of λ 5723 and λ 6087 in wave-number showed them to have precisely the separation of the observed 3F_2 and 3F_3 levels of FeVII. The agreement was found to be in fact very close.

The FeVII ion has $26 - 6 = 20$ electrons, of which two lie outside the inner closed groups, as a pair of $3d$ electrons. These contribute the spectrum of the FeVII ion. Starting with an arbitrary zero, the actual $3d^2$ levels located in the FeVII spectrum were given as

$$\begin{array}{ll} {}^3F_2 & 0, \quad {}^3P_0 \text{ 20037.} \\ {}^3F_3 & 1047, \quad {}^3P_1 \text{ 20428.} \\ {}^3F_4 & 2327, \quad {}^3P_2 \text{ 21275.} \\ {}^1D_2 & 17475, \quad {}^1G_4 \text{ 28916.} \end{array}$$

The corresponding calculated wave-lengths were given as

$$\begin{array}{ll} {}^3F - {}^1G, & \lambda \text{ 3457.3, 3587.2, 3759.9.} \\ {}^3F - {}^3P, & \lambda \text{ 4699.0, 4893.9, 4942.3, 4989.4, 5158.3, 5276.1.} \\ {}^3F - {}^1D, & \lambda \text{ 5720.9, 6085.5, 6599.7.} \end{array}$$

The list of lines observed in Nova Pictoris, of unknown origin, including the pair already mentioned, was

$$\lambda \text{ 3760.0, 4944.7, 5275.6, 4701.2, 4986.1, 5723.4, 4894.8, 5155.3, 6087.5.}$$

Thus the *complete* array of FeVII forbidden transitions in the region accessible to observation occurs in the spectrum of Nova Pictoris. Moreover, *all* the lines of hitherto unknown origin in the later stages of the spectrum of Nova Pictoris were accounted for. It was pointed out also that λ 6087 was also coincident with a line of CaV. It is thus a

* *M.N.*, 99, 590, 1939.

† *P.A.S.P.*, 45, 301, 1933.

‡ *M.N.*, 94, 34 and 816, 1933-34.

§ *Proc. Nat. Acad. Sci.*, 19, 581, 1933.

|| *C.R.*, 198, 1842, 1934.

¶ I. S. Bowen and B. Edlén, *Nature*, 143, 374, 1939.

blend, and the difference in intensity-variations in time, between it and $\lambda 5723$, hitherto held to preclude a common origin for the two lines, could be held to be explained.

Thus Bowen and Edlén produced indisputable evidence that a higher level of excitation than had been previously supposed possible was present in at least some celestial spectra.

This letter to *Nature*, published 1939 March 4, was at once noticed by W. Grotrian, of the Astrophysikalisches Observatorium at Potsdam, and he sent a note * to *Die Naturwissenschaften*, dated 1939 March 16, of which I append a translation of the opening paragraph:

"Since the recent demonstration by I. S. Bowen and B. Edlén that forbidden lines of FeVII have appeared in the spectrum of Nova RR Pictoris 1925, and since the occurrence of five coronal lines in the nova-like outburst of RS Ophiuchi in the year 1933 has been conclusively proved, and since finally signs are growing that in the outer zones of the Sun's atmosphere conditions for the stimulation of spectral lines appear to be present which far exceed what would be expected on thermal equilibrium, it seems to me no longer out of the way to discuss the question whether the coronal lines can be considered as forbidden lines of highly ionized atoms".

There we have the chain of argument explicitly stated. Grotrian then considered the coronal lines $\lambda 6374$ and $\lambda 7892$. Using Edlén's observations of term-values he suggested the following identifications:—

Coronal wave-length observed, $\lambda 6374.51$. Wave number observed $\nu = 15,683 \text{ cm.}^{-1}$.

Attribution. FeX, $3s^23p^5$, $^2P_{3/2} - ^2P_{1/2}$, $\nu(\text{calc.}) = 15,685 \text{ cm.}^{-1}$.

Coronal wave-length observed $\lambda 7891.94$. Wave number observed $\nu = 12,668 \text{ cm.}^{-1}$.

Attribution. FeXI, $3s^23p^4$, $^3P_1 - ^3P_2$, $\nu(\text{calc.}) = 12,675 \text{ cm.}^{-1}$.

Grotrian thus attributed $\lambda 6374$ to the nine-fold ionized iron atom, and $\lambda 7892$ to the ten-fold ionized iron atom.

Grotrian also pointed out that whilst the bright coronal line $\lambda 5303$ had a different intensity-distribution in the corona from $\lambda 6374$, $\lambda 6374$ and $\lambda 7892$ (Lyot's recently found line) had similar behaviours, thus suggesting confirmation of his identification with two highly ionized iron atoms in stages of ionization differing by only one electron.

It is clear that Grotrian's discovery of the wave-length coincidences between two coronal lines and forbidden transitions between FeX and FeXI levels was fundamentally important. It was a daring step to take, to suggest such highly stripped atoms as the source of any of the coronal lines.

As Edlén says in his paper of 1941 March 12 †, Grotrian's paper "gave the impulse to a systematic search for analogous term separations". Edlén was in a strong position to conduct such a search, having available his own observations of term-levels found for highly stripped atoms from his researches of several years with vacuum spectrographs. I shall follow the details given in Edlén's simpler preliminary paper mentioned above rather than in his definitive paper ‡ published later in *Zeitschrift für Astrophysik*, as the latter is only available in this country so far in microfilm form, though I have also consulted this latter.

Edlén at once found that two other coronal lines, namely $\lambda 3328$ and $\lambda 4086$, could be attributed to the $^2P_{3/2} - ^2P_{1/2}$ and $^3P_2 - ^3P_1$ transitions in the spectra of CaXII and CaXIII respectively, as given by his own unpublished measurements; that is to say, to the eleven-fold and twelve-fold ionized calcium atoms. This in turn suggested to Edlén that Grotrian's and his wave-length coincidences did not happen by chance, and that "the whole coronal spectrum might consist of forbidden lines analogous to those of gaseous

* *Naturwiss.*, 27, 214, 1939. (Published 1939 March 31.)

† "An attempt to identify the emission lines in the spectrum of the solar corona", *Arkiv. för Mat., Astron. och Fys.*, Bd. 28 B, No. 1, 1941.

‡ *Zeits. für Astrophys.*, 22, 30-64, 1942.

nebulae but from atoms much more highly ionized than had previously been considered at all".

The ionization potentials for Grotrian's *FeX* and *FeXI* ions amounted to 233 volts and 261 volts respectively; those for Edlén's *CaXII* and *CaXIII* ions to 589 and 655 volts respectively (I take the figures from Edlén's published table). Now the kinetic energy of an electron falling through 500 volts corresponds to the mean energy of a particle at 3,800,000 degrees. The degree of excitation was therefore enormous compared with what would be expected in the vicinity of the Sun's surface.

The ions of *CaXII* and *FeX* are known as iso-electronic. This means not that they have the same numbers of electrons, but that they have the same numbers of electrons in the spectroscopically active part of the ion—the outer shell of electrons. This may be verified as follows. The atomic number of calcium is $Z=20$. The ion *CaXII* has lost 11 electrons, and there thus remain 9. Of these the two innermost form the closed K-shell, consisting of two (1s) electrons, and the remaining seven are present as two (2s) electrons and five (2p) electrons. The atomic number of iron is $Z=26$. The ion *FeX* has lost 9 electrons, and there thus remain 17. Of these the two innermost form the closed K-shell of two (1s) electrons, the next eight form the closed L-shell of two (2s) electrons and six (2p) electrons, and the remaining seven are present as two (3s) electrons and five (3p) electrons. Thus the *CaXII* and *FeX* ions each possess seven outer electrons, and are spectroscopically equivalent to the halogens.

Similarly *CaXIII* and *FeXI* are iso-electronic, each possessing 6 outer electrons. They are spectroscopically equivalent to once-ionized halogens. Their complete relations are shown in the following short table:—

Coronal Line	Ion	Z	Number of Electrons remaining	Arrangement	Transition	I.P. Volts
λ 6374.51	<i>FeX</i>	26	17 = 2 + 8 + 7	(1s ²)(2s ² 2p ⁶)(3s ² 3p ⁵)	² P _{3/2} - ² P _{1/2}	233
λ 3328.1	<i>CaXII</i>	20	9 = 2 + 7	(1s ²)(2s ² 2p ⁵)	² P _{3/2} - ² P _{1/2}	589
λ 7891.94	<i>FeXI</i>	26	16 = 2 + 8 + 6	(1s ²)(2s ² 2p ⁶)(3s ² 3p ⁴)	³ P ₂ - ³ P ₁	261
λ 4086.29	<i>CaXIII</i>	20	8 = 2 + 6	(1s ²)(2s ² 2p ⁴)	³ P ₂ - ³ P ₁	655

Unfortunately Edlén had no more *observed* term-differences giving lines in the observable region at his disposal. He therefore proceeded to predict by extrapolation term-differences likely to be found in the corona according to those already found. The prediction was by iso-electronic sequences, *i.e.* by considering a sequence of spectra derived from ions having the same outer configurations of electrons. Edlén's own work on ultra-violet spectra, published at length in various papers in *Zeitschrift für Physik* gave him the required data.

He argued that there were good reasons to expect intense lines of the ions *FeXIII* and *FeXIV* because, first, of the rich abundance of iron as judged from the intensity of *FeX* and *FeXI*, secondly because an intense degree of ionization was expected to be possible, since the *CaVII* lines of Nova Pictoris* were absent, whilst the I.P.'s of *CaXII* and *CaXIII* were much higher than the I.P.'s of *FeX* and *FeXI*, as stated above. Now the I.P.'s of *FeXIII* and *FeXIV* are 325 volts and 355 volts, and so intermediate between the two groups just mentioned. It was at once found that the extrapolated separation in the ground term of *FeXIV* (which has three outer electrons) corresponded to the strongest and best-known line in the coronal spectrum, λ 5303, and that the three next strongest coronal lines $\lambda\lambda$ 10,747, 10,798 and 3388 corresponded to transitions of the ion *FeXIII* (four outer electrons). In addition, the fainter line λ 3987 could be attributed to another transition in the *FeXI* ion already found by Grotrian, namely the transition ³P₁ - ¹D₂. Thus altogether, the *FeX*, XI, XIII and XIV identifications comprised more than nine-tenths of the total coronal emission. The ion *FeXII* is missing because the

* *V. supra.*

extrapolated $FeXII$ transitions are unobservable, and none of $FeVIII$, IX, XV, XVI, XVII have any deep-lying metastable levels.

Accepting these identifications, it was then possible to examine the corresponding transitions in the neighbouring elements in the periodic table. The element *nickel* has atomic number $Z=28$, and the ions $NiXII$, XIII, XV, XVI possess in their outer configurations 7, 6, 4, 3 electrons respectively, and so are iso-electronic with FeX , XI, XIII, XIV respectively. The complete set of transitions extrapolated to Ni was now found in the remaining coronal lines with the same relative intensities as for Fe , though with much smaller absolute intensities. This identified 6 more coronal lines. The Fe lines were on the average about 10 times as strong as the corresponding Ni lines. The suggested identifications agreed, moreover, well with Lyot's intensity-groupings. The nickel identifications accounted for a further 7 per cent. of the total coronal emission, leaving less than 3 per cent. of the total emission unidentified.

The elements potassium, chromium, manganese and cobalt, of atomic numbers $N=19, 24, 25, 27$, which might have been expected to be present in the corona, are unrepresented, save possibly for a very faint line attributed by D. Kundu (1941) to $CoXV$. Edlén suggested in consequence that these elements are effectively absent; and he pointed out that if the corona consists principally of calcium, iron and nickel, it corresponds in composition to the average composition of the stony and iron meteorites. The suggestion would be that the coronal gases are formed by the vaporization of inward-falling meteoritic dust. However, this suggestion is considered by Saha to be untenable, on the ground that the coronal lines *widen* as we pass inwards, whereas owing to resistance the meteoritic velocity would be expected to *diminish* inwards. Further, Saha considered it could be shown that an iron atom vaporized from a meteor striking the Sun with the velocity of free fall (600 kms. sec.⁻¹) could not be relieved of as many as 14 electrons whilst passing to the inner corona. Saha has been hence led to attribute the high state of ionization found by Grotrian and Edlén in the corona to some kind of nuclear reaction, similar to uranium fission, occurring within the Sun's reversing layer or chromosphere, the formation of the outer corona being ascribed to the constant stream of δ -rays ejected from the solar atoms by the high-speed ions.

This theory involves an *ad hoc* hypothesis and can hardly yet be considered convincing. The problem of the origin of the coronal ionization remains. The old objection to the possibility of the coronal lines being originated as forbidden transitions on the ground that the intense solar radiation would quickly raise the metastable states to higher levels and so leave insufficient time for a natural emission is, however, now removed; for the metastable levels in question are such that to excite them the exciting radiation would have to be in the soft X-ray region, where the Sun's radiation may be expected to be weak.

Since the corona can have only a slight excess of negative charge, the presence of these so highly ionized atoms must be accompanied with an atmosphere of free electrons to neutralise it, the partial pressure of free electrons being of the order of a dozen times the partial pressure of the atoms. These free electrons may account for the continuous spectrum of the corona. An extensive distribution of free electrons in the corona used to be frequently suggested, more especially by Wilhelm Anderson of Dorpat. Edlén's work gives the justification.

However, it is not my duty to-day to go further into the physical state of the corona, but to emphasize to you the splendid success of Dr. Bengt Edlén in following up his experimental researches in vacuum-spark spectroscopy with this brilliant attribution of the coronal lines to highly ionized atoms of iron, calcium and metal. I append a list, in continuation of my former table, of the remaining identifications, adapted from Edlén's paper. Ions with the same electronic arrangement give rise to spectroscopically similar lines. Thus the analogue of the green line $\lambda 5303$, due to thirteen-fold ionized iron, with three outer electrons, is the ultra-violet line $\lambda 3600.97$, attributed to fifteen-fold ionized

Coronal Line	Ion	Z	Number of Electrons remaining	Arrangement	Transition	I.P. Volts
λ 3986.88	FeXI	26	16 = 2 + 8 + 6	$(1s^2)(2s^2 2p^6)(3s^2 3p^4)$	$^3P_1 - ^1D_2$	261
λ 3388.10	FeXIII	26	14 = 2 + 8 + 4	$(1s^2)(2s^2 2p^6)(3s^2 3p^2)$	$^3P_2 - ^1D_2$	325
λ 10746.80	FeXIII	26	14 = 2 + 8 + 4	$(1s^2)(2s^2 2p^6)(3s^2 3p^2)$	$^3P_0 - ^3P_1$	325
λ 10797.95	FeXIII	26	14 = 2 + 8 + 4	$(1s^2)(2s^2 2p^6)(3s^2 3p^2)$	$^3P_1 - ^3P_2$	325
λ 5302.86	FeXIV	26	13 = 2 + 8 + 3	$(1s^2)(2s^2 2p^6)(3s^2 3p)$	$^2P_{\frac{3}{2}} - ^2P_{\frac{1}{2}}$	355
λ 4231.4	NiXII	28	17 = 2 + 8 + 7	$(1s^2)(2s^2 2p^6)(3s^2 3p^5)$	$^2P_{\frac{3}{2}} - ^2P_{\frac{1}{2}}$	318
λ 3642.87	NiXIII	28	16 = 2 + 8 + 6	$(1s^2)(2s^2 2p^6)(3s^2 3p^4)$	$^3P_1 - ^1D_2$	350
λ 5116.03	NiXIII	28	16 = 2 + 8 + 6	$(1s^2)(2s^2 2p^6)(3s^2 3p^4)$	$^3P_2 - ^3P_1$	350
λ 6701.83	NiXV	28	14 = 2 + 8 + 4	$(1s^2)(2s^2 2p^6)(3s^2 3p^2)$	$^3P_0 - ^3P_1$	422
λ 8024.21	NiXV	28	14 = 2 + 8 + 4	$(1s^2)(2s^2 2p^6)(3s^2 3p^2)$	$^3P_1 - ^3P_2$	422
λ 3600.97	NiXVI	28	13 = 2 + 8 + 3	$(1s^2)(2s^2 2p^6)(3s^2 3p)$	$^2P_{\frac{3}{2}} - ^2P_{\frac{1}{2}}$	455

nickel, also with three outer electrons. This is the strongest of the lines attributed to nickel, according to Grotrian's intensity measures *, being of estimated intensity 12 on a scale on which λ 5303 was 20.

We have with us a representative of the Swedish Legation, and I have great pleasure in handing him the Society's Gold Medal, for transmission to Professor Edlén. With it we offer our hearty congratulations to Professor Edlén on the achievement of the identification, in an unexpected way, of the principal unknown lines in the Sun's coronal spectrum, coupled with the best wishes for his future researches and the earnest hopes that these researches will continue to aid in the solution of the fascinating problems they have opened up.†

* Grotrian, *Zeits. für Astrophys.*, 2, 106, 1931.

† In preparing this address, I have been indebted to Prof. H. H. Plaskett for several references; and also to an article by Dr. A. Hunter, "Solar Physics," in *Reports on Progress in Physics*, 9, 101, 1943.