"Enhanced Lines of Titanium, Iron, and Chromium in the Fraunhoferic Spectrum." By Sir J. NORMAN LOCKYER, K.C.B., LL.D., F.R.S., and F. E. BAXANDALL, A.R.C.S. Received July 13, 1904.

In previous publications it has been shown that the enhanced lines of some of the metals are prominent in the spectra of α Cygni* and the sun's chromosphere†, while it is generally recognised that the lines in the Fraunhoferic spectrum are mainly the equivalents of lines in the arc spectra of metals. In connection with the work on enhanced lines it has been noted that some of them, at least, appear to correspond with comparatively weak solar lines to which Rowland has attached no origin. With the object of possibly tracing some of the unorigined solar lines to their source, a careful comparison has been made between the enhanced lines shown in the photographic spark spectra of titanium, iron, and chromium, and the solar lines. The photographs used for this purpose were all taken with a Rowland grating, under exactly similar conditions, and on such a scale that the length of spectrum between K and F is about 14 inches (35 cms.). The chemical elements named were first selected for investigation because they furnish by far the greater number of enhanced lines which have been shown to occur in the spectrum of α Cygni. It was an easy matter, owing to the many solar coincidences with lines of these elements, to adjust the compared photographs and get the spectrum lines in proper alignment.

It was found that many of the enhanced lines fell exactly and squarely on isolated lines of the solar spectrum, and in these cases the solar wave-lengths were adopted, and the identification considered established. If, however, for any of these solar lines Rowland had given alternative origins, special comparisons were made of the enhanced line photograph and those of the metals given by Rowland. Notes were made as to the agreement or non-agreement of the metallic lines involved, and also of the relative intensities in their individual spectra, so that due weights could be given to the respective metallic lines which were thought to conjointly produce compound solar lines.

Where there was any doubt as to the exact coincidence of a metallic and solar line, or where by the close grouping of several solar lines it was not possible to say by direct comparison to which solar line the metallic line corresponded, careful measures were made of the metallic line, and its wave-length found by interpolation between closely adjacent lines of known wave-length. The resulting wave-lengths

* 'Roy. Soc. Proc.,' vol. 64, p. 321.
† 'Roy. Soc. Proc.,' vol. 68, p. 178.

were then compared with Rowland's solar wave-lengths, and in cases of close agreement with solar lines it was deemed probable that the two lines were really identical. In this connection, however, the relative intensities of the solar and enhanced lines were, to a great extent, taken into account in judging whether a solar line could be accepted as the analogue of a metallic line.

The three elements investigated are dealt with separately. The tables show the wave-lengths of the enhanced lines as reduced from the most recent and best photographs, their intensities in spark and arc spectra, the wave-lengths of Rowland's solar lines to which they probably correspond, and the origins, if any, to which Rowland has attributed such solar lines.

The wave-lengths of some of the enhanced lines differ in the second decimal place from those published* previously for the same lines. More weight can be given to the present wave-lengths, as in the photographs from which they have been reduced the lines are more sharply defined than in the earlier photographs employed. In the case of chromium a much more extended list of enhanced lines than the previous one has been obtained.

The numbers in the last column refer to the notes at the end of each table.

Titanium.

λ. Enhanced Ti lines.	Intensity.		Fraunhoferic lines (Rowland).		Rowland's origin.	Notes appended.
	Spark, max. 10.	Arc, max. 10.	λ.	Int., max. 1000.		
3813 ·54	4	1—2	3813 ·54	2	C	1
3814 ·72	5	2—3	3814 ·74	3	C	2
3836 ·23	4	1—2	3836 ·23	2	—	3
3900 ·68	10	4	3900 ·68	5	Ti-Fe-Zr	[1]
3913 ·61	10	4	3913 ·61	5	Ti-Fe	[2]
3932 ·16	4	trace	3932 ·16	1	Ti	
3987 ·75	1	0	3987 ·76	2	Ti ?	
4012 ·54	5	1	4012 ·54	4	Ti	
4025 ·29	3	1	4025 ·29	3	Ti	
4028 ·50	6	1	4028 ·50	4	Ti	
4053 ·98	5	trace	4053 ·98	3	Fe-Ti	[3]
4055 ·19	2	1	4055 ·19	3	Ti-Fe	[4]
4161 ·70	2—3	0	4161 ·68	4	—	4
4163 ·82	10	2	4163 ·82	4	Ti, Cr	[5]
4172 ·07	10	1	4172 ·07	2	Ti-Fe	[6]
4173 ·70	3	0	4173 ·71	3	—	[7]
4174 ·20	2	0	4174 ·24	0	—	
4184 ·49	1	0	4184 ·47	2	—	[8]

* 'Roy. Soc. Proc.,' vol. 65, p. 451.

Titanium—*continued.*

λ. Enhanced Ti lines.	Intensity.		Fraunhoferic lines (Rowland).		Rowland's origin.	Notes appended.
	Spark, max. 10.	Arc, max. 10.	λ.	Int. max. 1000.		
4227 ·46	2	0	4227 ·47	1	—	5
4290 ·38	6	2	4290 ·38	2	Ti	
4294 ·20	7	3	4294 ·20	2	Ti	
4300 ·21	6	1—2	4300 ·21	3	Ti	
4302 ·09	3	1—2	4302 ·09	2	Ti	
4308 ·06	7	1—2	4308 ·08	6	Fe	6
4313 ·03	7	1—2	4313 ·03	3	Ti	
4315 ·14	8	1	4315 ·14	3	Ti	
4316 ·96	2	0	4316 ·96	1	Ti ?	
4321 ·12	3	1	4321 ·12	2	—	
4330 ·40	2	trace	4330 ·41	1	—	
4330 ·87	2	trace	4330 ·87	2	Ti-Ni	[9]
4338 ·08	8	4	4338 ·08	4	Ti	
4341 ·53	3	1	4341 ·53	2	Ti ?	
4374 ·96	3	0	4374 ·98	0	Zr	[10]
4387 ·01	5	trace	4387 ·01	1	Ti ?	
4391 ·19	1—2	trace	4391 ·19	1	Ti	
4395 ·20	9	5	4395 ·20	3	Ti	
4396 ·01	2	trace	4396 ·01	1	Ti	
4399 ·94	7	3	4399 ·94	3	Ti-Cr	[11]
4411 ·24	5	trace	4411 ·24	1	Cr	[12]
4417 ·88	6	2	4417 ·88	3	Ti	
4421 ·93	3	2	4421 ·93	00	Ti	
4443 ·98	9	4	4443 ·98	5	Ti	
4450 ·65	3	1	4450 ·65	2	Ti ?	7
4464 ·62	3	1	4464 ·62	2	Ti ?	8
4468 ·66	9	4	4468 ·66	5	Ti	
4488 ·49	5	1	4488 ·49	1	—	
4501 ·45	8	4	4501 ·45	5	Ti	
4529 ·69	3	trace	{ 4529 ·66 4529 ·73	1 1	— —	[13]
4534 ·14	5	2	4534 ·14	6	Ti-Co	[14]
4549 ·81	8	4	4549 ·81	6	Ti-Co	[15]
4563 ·94	7	3	4563 ·94	4	Ti	
4572 ·16	9	4	4572 ·16	6	Ti	
4590 ·13	3	1—2	4590 ·13	3	—	
4657 ·38	2	trace	4657 ·38	2	Ti ?	
4764 ·10	1	0	4764 ·11	4	Ti-Ni	[16]

1. Ti probably true origin.
2. Ti probably true origin.
3. Ti line and solar line exactly coincident.
4. Solar line possibly only partially due to Ti.
5. Solar line exactly coincident with *p* Ti line.
6. This *p* Ti line is apparently exactly coincident with the Fe line, and solar line is probably compounded of both.
7. Solar line doubtless due to Ti.
8. Solar line doubtless due to Ti.

Notes on *p* Ti-Solar Lines.

(The figures at the head of each note refer to Rowland's solar lines.)

[1.] 3900·68 (5), Ti-Fe-Zr.—The titanium line involved in the solar line is one of the very strongest in the spark spectrum. The iron line is only a weak one, and, in the light of other adjacent iron lines of equal intensity, would of itself only produce a solar line of intensity 2 or 3. In apportioning the weights to the various elements, which possibly take part in the formation of the solar line, zirconium can be almost ignored. There are many far stronger lines of zirconium than the one in question which are not represented in the sun at all. It would appear, then, that the solar line 3900·68 is really made up of the *p* Ti and Fe lines in about equal proportions.

[2.] 3913·61 (5), Ti-Fe.—It is very doubtful whether Fe takes any part in the production of this solar line. There is no such iron line recorded by either Kayser and Runge or Exner and Haschek, and there is no trace of a line in any of the Kensington photographs. The titanium line is a very prominent one in the spark spectrum, and quite capable of producing the solar line of itself.

[3.] 4053·98 (3), Fe-Ti.—The iron line is an extremely faint one, while the titanium line is well marked. The solar line is probably a composite one, but more attributable to titanium than iron.

[4.] 4055·19 (3), Ti-Fe.—The iron and titanium lines are coincident, and about equally strong. Solar line probably due to both.

[5.] 4163·82 (4), Ti-Cr.—Both the titanium and chromium lines are well marked in their respective spectra. The former seems to be slightly less refrangible than the other. The solar line is probably a very close double, and due to both Ti and Cr.

[6.] 4172·07 (2), Ti-Fe.—The iron line is extremely weak, while the *p* Ti line is one of the strongest in the spectrum. The solar line is probably due chiefly to Ti.

[7.] 4173·71 (1); no origin by Rowland.—The mean result of two measurements of this enhanced titanium line gives λ 4173·71. Its identity with the solar line is therefore well established.

[8.] 4184·47 (2); no origin by Rowland.—The published wave-length of this enhanced titanium line was 4184·40. A re-estimation from a later grating photograph gives as a resulting wave-length 4184·49. There is little doubt of its identity with the solar line 4184·47.

[9.] 4330·87 (2), Ti-Ni.—The nickel line is an exceedingly weak one, and it is doubtful whether the solar line is partially produced by it. Rowland, in a footnote in his 'Tables of Solar Wave-Lengths,' says: "This is a weak, hazy, nickel line. It is on the red edge of the solar line, and the Ti line is nearer the centre."

[10.] 4374·98 (0), Zr.—The published wave-length of the enhanced titanium line was 4374·90. A re-estimation from a better photograph gives 4374·99. It is probably identical with the weak solar line 4374·98, which Rowland ascribes to Zr.

[11.] 4399·94 (3), Ti-Cr.—The chromium line, although apparently coincident with the titanium and solar lines, is a very weak one. On the other hand, the titanium line is quite well marked. The solar line is therefore probably due chiefly to titanium.

[12.] 4411·24 (1), Cr.—Re-measurement of the proto-titanium line gives λ 4411·24. It is apparently coincident both with the chromium and solar lines. The chromium line is a weak one, whereas the titanium line is well marked, and there is little doubt that the solar line is partially, if not chiefly, due to titanium.

[13.] 4529·66 (1), 4529·73 (1)} No origin by Rowland.—The published wave-length of the enhanced titanium line was 4529·60. Re-measurement from the latest grating photograph gives λ 4529·69. It is doubtful which of the two solar lines, 4529·66,

4529·73, the titanium line represents. It is quite possible that the latter is a very close double, and may account for both solar lines.

[14.] 4534·14 (6), Ti-Co.—Both the titanium and cobalt lines are well marked in their respective spectra, and there is little doubt that the solar line is compounded of the two.

[15.] 4549·81 (6), Ti-Co.—The titanium and cobalt lines are apparently coincident, and as each is a strong line in its own spectrum, the solar line is probably compounded of both in about equal proportion.

[16.] 4764·11 (4), Ti-Ni.—The enhanced titanium line is a very weak one, and the probability is that Ni is the chief origin of the solar line.

Iron.

λ. Enhanced Fe lines.	Intensity.		Fraunhoferic lines (Rowland).			Notes appended.
	Spark, max. 10.	Arc. max. 10.	λ.	Int., max. 1000.	Origin.	
3839·78	2—3	0	3839·76	2	Fe	
3846·55	2—3	1	3846·55	2	Fe	
3863·87	3	1—2	3863·89	3	Fe	
3871·86	4	1—2	3871·96	2	Fe	
3906·14	1	0	3906·17	00	—	
3935·92	5	4	3935·97	2	Fe	
3939·28	1—2	0	3939·29	0	—	
4002·77	1—2	trace	4002·81	0	—	
4048·93	3—4	2	4048·91	5	Mn-Cr	1
4055·73	3	2	4055·70	6	Mn	2
4173·61	3	1—2	4173·62	3	—	
4179·05	3—4	trace	4179·03	3	—	
4233·32	4—5	0	4233·33	4	Mn-Fe	[1]
4296·72	2	0	4296·74	3	—	
4302·35	2—3	2	4302·35	2	Fe	
4303·34	3—4	0	4303·34	2	—	
4351·93	5	0	4351·93	5	Cr	[2]
4385·55	3—4	trace	4385·55	2	—	
4451·75	3	2	4451·75	3	Mn	3
4462·30	2	0	—	—	—	4
4489·35	1	0	4489·35	2	—	
4491·57	2	0	4491·57	2	—	
4508·46	5	trace	4508·46	4	Fe ?	
4515·51	4	trace	4515·51	3	—	
4520·40	3	1	4520·40	3	Fe ?	
4522·77	6	2	4522·81	0	—	5
4541·46	3	1	4541·48	0	—	
4549·64	7	1	4549·64	2	Fe	
4556·09	5	0	4556·06	3	—	
4576·51		0	4576·51	2	—	
4584·02	8	1	4584·02	4	Fe	
4629·51	4	0	4629·52	6	Ti-Co	[3]
4635·50	3	0	4635·49	0	—	
4924·11	8	0	4924·11	5	Fe	
5018·63	7	1	5018·63	4	Fe	
5169·07 } 5169·22 }	6	2	{ 5169·07 5169·22	3 / 4	Fe / Fe	
5276·17	2	0	5276·17	3	Fe ?	
5316·79	3	0	5316·79	4	Fe	

1. Probably partly due to the enhanced Fe line, in addition to Mn and Cr.
2. Solar line probably due partly to *p* Fe. K and R's λ 4055·63 (4).
3. Solar line probably compounded of the *p* Fe and Mn lines.
4. The *p* Fe line is apparently slightly more refrangible than solar line 4462·37.
5. This *p* Fe line is probably identical with Rowland's solar line 4522·81 rather than with 4522·69, to which he gives a Fe? origin.

Notes on Certain *p* Fe-Solar Lines.

[1.] λ 4233·33 (4).—This solar line was ascribed by Rowland to Mn-Fe in his "Preliminary Table of Solar Wave-lengths." In the revised table* the Fe origin is discarded and the sole origin given as Mn. There appears to be, however, no evidence for the line being due to manganese. There is no trace whatever of a line in this position in any of the Kensington photographs of the manganese spectrum, and no such line is given by Hasselberg† in his comprehensive list of manganese arc lines. Although the arc line of iron at the corresponding wave-length is exceedingly weak—in many photographs it does not occur at all—there is no doubt about there being a prominent line in the spark spectrum. The solar line in question is probably due solely to iron, and is the counterpart of the enhanced line of that metal. In α Cygni the line 4233·33 is quite an outstanding line and one of the very strongest in the spectrum.

[2.] 4351·93 (5), Cr.—This solar line is ascribed by Rowland solely to Cr. Although the chromium line is a moderately strong one it is scarcely likely that its solar equivalent would be as strong as that of the chromium line 4289·89, one of the very strongest lines in the spectrum of that element. The two solar lines mentioned being, however, of the same intensity, in all probability that at λ 4351·93 is partially due to some other element. The strongly enhanced Fe line 4351·93 is apparently exactly coincident with the Cr line, and as other similarly enhanced Fe lines occur amongst the Fraunhoferic lines it is probable that the solar line in question is compounded of the iron and chromium lines.

In α Cygni there is a corresponding well-marked line which, in the light of the complete absence from the stellar spectrum of chromium arc lines, can only be attributed to proto-iron. This is the more likely as the other enhanced lines of iron are so prominent in the α Cygni spectrum.

This line in stellar spectra has been attributed by Scheiner to the magnesium arc line 4352·08 and on its behaviour with respect to the stellar representative of the characteristic spark line of magnesium 4481·3, he has based conclusions‡ on the relative temperatures of the absorbing atmospheres of various stars. Such conclusions are not trustworthy, as the origin of the line is obviously not the same in all stellar spectra. In stars of the solar type the line is probably of a complex origin, Cr 4351·93, Mg 4352·08, and *p* Fe 4351·93, all being involved. In higher temperatures stars like α Cygni, Sirius, and Rigel there is abundant evidence in favour of a proto-Fe origin and little or none for either chromium or magnesium. Thus, other lines of Cr and Mg, which are similar in intensity and behaviour in their respective spectra to those mentioned above, are all unrepresented in these stellar spectra, whereas all the enhanced Fe lines of similar intensity and behaviour to the line 4351·93 are strongly represented in the same stellar spectra.

[3.] 4629·52 (6), Ti-Co.—It is doubtful whether the Ti and Co lines are collectively strong enough to account for the intensity of the solar line. The equally strong Co line 4663·59 only furnishes a solar line of intensity 0, and the stronger

* 'Ast. Phys. Jour.,' vol. 6, p. 384, 1897.
† 'Kongl. Sv. Vet. Akademiens Handlingar,' Bd. 30, No. 2.
‡ 'Ast. and Ast. Phys.,' vol. 13, p. 569.

Ti line 4623·28 corresponds to a solar line of intensity 2. It is scarcely likely, then, that the superposition of the Ti and Co lines at 4629·60 would produce a solar line of intensity 6. The proto-iron line at the same wave-length probably supplies the deficiency in intensity. The enhanced line of iron 4515·51, which is of about equal prominence as 4629·60, has an equivalent solar line of intensity 3, and if the *p* Fe line 4629·60 of itself produces a similar solar line, then the intensity 6 of the solar 4629·60 could be easily accounted for. In fact, it is quite probable that the solar line in question is built up of the lines at the same wave-length belonging to Ti, Co, and *p* Fe, and that the proto-iron line has, if anything, the greatest share in its production.

There is a fairly good corresponding line in the chromospheric spectrum, and, in the publication of eclipse results by various observers, the origin of the line is invariably given as Ti-Co, presumably because they have established its identity with the Fraunhoferic line and accepted Rowland's origin as a correct and sufficient one. In the chromosphere it is probably chiefly due to *p* Fe, as the ordinary Ti and Co lines are there only weak, while the enhanced iron lines are well marked. There is also a corresponding line in the spectrum of α Cygni. Here, however, the origin is evidently proto-iron only, as the arc lines of cobalt and titanium are entirely missing from the stellar spectrum; whereas nearly all the proto-iron lines are well seen.

Chromium.

λ. Enhanced Cr lines.	Intensity.		Fraunhoferic lines (Rowland).		Rowland's origin.	Notes appended.
	Spark, max. 10.	Arc, max. 10.	λ.	Int., max. 1000.		
3814·07	2	0	3814·07	1	—	
3865·67	7	<1	3865·67	7	Fe-Cr	1
3866·69	1—2	0	—	—	—	
3905·66	6	0	3905·66	12	Si	2
3979·66	5—6	0	3979·66	4	Co	[1]
4003·55	4	0	—	—	—	
4012·63	6—7	2	4012·63	0	Cr	
4038·10	4—5	0	—	—	—	
4052·10	3	0	4052·18	0	—	
4058·92	5	3—4	4058·92	3	Fe-Cr	3
4071·07	4	0	4071·14	00	—	
4082·50	2—3	0	4082·43	0	—	
4111·25	4	0	—	—	—	
4145·91	6	0	4145·91	1	—	
4225·02	4	0	4225·02	2	—	
4233·50	2—3	0	—	—	—	
4242·54	6—7	0	4242·54	2	—	
4252·80	3	0	4252·79	0	—	
4262·15	5	0	{ 4262·09	1	—	4
			4262·14	1	—	
4269·41	2	0	4269·45	0	—	
4284·38	3—4	0	4284·38	2	—	5
4307·20	2—3	0	—	—	—	
4555·16	5—6	1	4555·16	2	—	
4558·83	10	1	4558·83	3	Cr?	
4588·38	10	1	4588·38	3	—	

Chromium—*continued.*

λ. Enhanced Cr lines.	Intensity.		Fraunhoferic lines (Rowland).		Rowland's origin.	Notes appended.
	Spark, max. 10.	Arc, max. 10.	λ.	Int., max. 1000.		
4592·23	4—5	0	4592·23	1	Cr	
4616·80	3—4	0	4616·80	1	—	
4618·97	8	0	4618·97	4	Fe	[2]
4634·25	8	0	4634·25	2	—	
4812·72	2—3	0	—	—	—	
4824·33	8	0	4824·33	3	Fe	6
4836·40	2—3	0	4836·42	0	—	
4848·44	6	0	4848·44	2	—	
4856·37	1	0	—	—	—	
4864·51	5	0	4864·51	1	—	
4876·59	5	0	4876·59	1	—	

1. Fe line and *p* Cr lines apparently coincident. Solar line probably compounded of both.

2. *p* Cr and Si lines exactly coincident. Solar line probably due to both, but mostly to Si.

3. Solar line probably due more to *p* Cr than Fe.

4. *p* Cr line possibly double.

5. Solar line possibly due partly to some other element.

6 Solar line probably compounded of Fe and *p* Cr lines.

Notes on Certain *p* Cr-Solar Lines.

[1.] λ 3979·66, Co (4).—This enhanced line of chromium is apparently coincident with a cobalt line, and also with the solar line λ 3979·664, to which Rowland assigns a cobalt origin. As the adjacent cobalt line 3958·07 is quite as strong as 3979·66, and only furnishes a solar line of intensity 2, it is not probable that the solar line corresponding to 3979·66 would be of intensity 4, unless a line of some other element were involved. It is very probable that the solar line in question is compounded of the *p* Cr and Co lines.

[2.] λ 4618·97, Fe (4).—This strongly enhanced Cr line is apparently coincident with the solar line 4618·97 (intensity 4), Rowland's origin for which is Fe. The nearest line of iron to this in Kayser and Runge's list is 4618·88 (2). Assuming that this is identical in position with the solar line, its intensity is far too low to account for the solar intensity. The closely adjacent iron line 4619·40, which is of intensity 6, gives a solar line of intensity 3, so that it is very improbable that the far weaker iron line 4618·21 will produce a solar line of intensity 4. There is little doubt that the solar line 4618·97 is chiefly accounted for by the strongly enhanced chromium line, but the iron line at the same position probably adds slightly to the solar intensity.

Fraunhoferic Lines due to *p* Ti, *p* Fe, or *p* Cr.

The following table contains the Fraunhoferic lines which are, as a result of the present discussion, considered to be due, either wholly or partially, to enhanced lines of titanium, iron, or chromium. Rowland's wave-lengths have been adopted with the modification that the last figure in the decimals has been dropped, and the numbers given to the nearest second decimal. In such an inquiry as the present one, this can be done without affecting the validity of the results. In the first place, the spark lines are generally of a wider and hazier nature than the arc lines, and consequently their wave-lengths cannot be estimated to as great a degree of accuracy. Again, the conclusions as to the identity of the solar and enhanced lines are not based on one or two coincidences only, but on the apparent agreement of a whole series of lines for each element.

It will be seen that some forty-two lines which were unorigined by Rowland are here attributed to proto-titanium, proto-iron, or proto-chromium. Compared with the host of lines in Rowland's tables this may seem a very insignificant number, but the importance of establishing their origins does not lie in their number, but in the fact that they are lines of a special nature, and just those metallic lines which are prevalent in the spectra of the higher temperature stars, such as α Cygni and Sirius, to the exclusion of the great majority of the other solar lines.

The enhanced lines have previously been identified with stellar lines, which in such stars as α Cygni, Sirius, and Rigel are of a more isolated nature than in the solar spectrum, and if the same lines can be established as occurring in the solar spectrum it at once standardises the wave-lengths of many stellar lines, and will thus be of importance in any stellar inquiry in which it is necessary to have accurate wave-lengths for the spectral lines.

In some cases it has been found that there is no justification for the origin given by Rowland. These, however, are very few, and are indicated in the notes appended.

In others, Rowland's origin does not appear to be a sufficient one, that is, the intensity of the solar lines cannot be adequately accounted for by the lines of the elements to which he ascribes them. In such cases it is probable that the solar lines are due partly to the arc lines of the elements quoted by Rowland and partly to the enhanced lines of either Fe, Ti, or Cr, which occur at or very near the same wave-lengths.

A glance at the table will show that for many lines the same element is given in the two columns for origins, the Kensington origin having the prefix "p." This simply means that there is an enhanced line of that particular element at the given wave-length, which is not

entirely absent from the arc spectrum, and that Rowland has identified the solar line with the arc equivalent of the enhanced line. Seeing, however, that most of these lines occur in stellar spectra, where hosts of stronger arc lines are missing; it will, perhaps, be more appropriate to designate them as of a proto-metallic origin even in the sun.

Solar Lines due either wholly or partially to Enhanced Lines of Ti, Fe, or Cr.

Fraunhoferic lines (Rowland).			Probable origin (Kensington).	Notes appended.
λ.	Int., max. 1000.	Origin.		
3813·54	2	C	*p* Ti	
3814·74	3	C	*p* Ti	
3836·23	2	—	*p* Ti	
3839·76	2	Fe	*p* Fe	
3846·55	2	Fe	*p* Fe	
3863·89	3	Fe	*p* Fe	
3865·67	7	Fe-C	Fe-*p* Cr	
3871·96	2	Fe	*p* Fe	
3900·68	5	Ti-Fe-Zr	*p* Ti-Fe	1
3905·66	12	Si	Si *p* Cr	
3906·17	00	—	*p* Fe	
3913·61	5	Ti-Fe	*p* Ti	2
3932·16	1	Ti	*p* Ti	
3935·97	2	Fe	*p* Fe	
3939·29	0	—	*p* Fe	
3979·66	4	Co	Co *p* Cr	
3987·76	2	Ti ?	*p* Ti	
4002·81	0	—	*p* Fe	
4012·54	4	Ti	*p* Ti	
4012·63	0	Cr	*p* Cr	
4025·29	3	Ti	*p* Ti	
4028·50	4	Ti	*p* Ti	
4048·91	5	Mn-Cr	Mn-Cr-*p* Fe	3
4053·98	3	Fe-Ti	*p* Ti-Fe	
4055·19	3	Ti-Fe	*p* Ti, Fe	
4055·70	6	Mn	Mn *p* Fe	4
4058·92	3	Fe-Cr	Cr *p* Fe	5
4145·91	1	—	*p* Cr	
4161·68	4	—	*p* Ti	6
4163·82	4	Ti-Cr	*p* Ti, Cr	
4172·07	2	Ti-Fe	*p* Ti	7
4173·62	3	—	*p* Fe	
4173·71	3	—	*p* Ti	
4174·24	0	—	*p* Ti	
4179·03	3	—	*p* Fe	
4184·47	2	—	*p* Ti	
4225·02	2	—	*p* Cr	
4227·47	1	—	*p* Ti	
4233·33	4	Mn	*p* Fe	8
4242·54	2	—	*p* Cr	
4252·79	0	—	*p* Cr	
4262·09 }	1	—	} *p* Cr	9
4262·14 }	1	—		

Solar Lines due to Enhanced Lines of Ti, Fe, or Cr—*continued.*

Fraunhoferic lines (Rowland).			Probable origin (Kensington).	Notes appended.
λ.	Int., max. 1000.	Origin.		
4284·38	2	—	*p* Cr	
4290·38	2	Ti	*p* Ti	
4294·20	2	Ti	*p* Ti	
4296·74	3	—	*p* Fe	
4300·21	3	Ti	*p* Ti	
4302·09	2	Ti	*p* Ti	
4302·35	2	Fe	*p* Fe	
4303·34	2	—	*p* Fe	
4308·08	6	Fe	Fe *p* Ti	
4313·03	3	Ti	*p* Ti	
4315·14	3	Ti	*p* Ti	
4316·96	1	Ti ?	*p* Ti	
4321·12	2	—	*p* Ti	
4330·41	1	—	*p* Ti	
4330·87	2	Ti-Ni	*p* Ti	10
4338·08	4	Ti	*p* Ti	
4341·53	2	Ti ?	*p* Ti	
4344·45	2	Ti	*p* Ti	
4351·00	1	Ti	*p* Ti	
4351·93	5	Cr	Cr *p* Fe	
4367·84	2	Ti	*p* Ti	
4374·98	0	Zr	*p* Ti	11
4385·55	2	—	*p* Fe	
4387·01	1	Ti ?	*p* Ti	
4391·19	1	Ti	*p* Ti	
4395·20	3	Ti	*p* Ti	
4396·01	1	Ti	*p* Ti	
4399·94	3	Ti-Cr	*p* Ti Cr	12
4411·24	1	Cr	*p* Ti Cr	
4417·88	3	Ti	*p* Ti	
4421·93	00	Ti	*p* Ti	
4443·98	5	Ti	*p* Ti	
4450·65	2	Ti ?	*p* Ti	
4451·75	3	Mn	Mn *p* Fe	
4464·62	2	Ti ?	*p* Ti	
4468·66	5	Ti	*p* Ti	
4488·49	1	—	*p* Ti	
4489·35	2	—	*p* Fe	
4491·57	2	—	*p* Fe	
4501·45	5	Ti	*p* Ti	
4508·46	4	Fe ?	*p* Fe	
4515·51	3	—	*p* Fe	
4520·40	3	Fe ?	*p* Fe	
4522·81	3	—	*p* Fe	
4529·66 }	1	—	} *p* Ti	13
4529·73 }	1	—		
4534·14	6	Ti-Co	*p* Ti-Co	
4541·48	0	—	*p* Fe	
4549·64	2	Fe	*p* Fe	
4549·81	6	Ti-Co	*p* Ti, Co	
4555·16	2	—	*p* Cr	
4556·06	3	—	*p* Fe	
4558·83	3	Cr ?	*p* Cr	

Solar Lines due to Enhanced Lines of Ti, Fe, and Cr—*continued.*

Fraunhoferic lines (Rowland).			Probable origin (Kensington).	Notes appended.
λ.	Int., max. 1000.	Origin.		
4563 ·94	4	Ti	*p* Ti	
4572 ·16	6	Ti	*p* Ti	
4576 ·51	2	—	*p* Fe	
4584 ·02	4	Fe	*p* Fe	
4588 ·38	3	—	*p* Cr	
4590 ·13	3	—	*p* Ti	
4592 ·25	1	Cr	*p* Cr	
4616 ·81	1	—	*p* Cr	
4618 ·97	4	Fe	*p* Cr-Fe	14
4629 ·52	6	Ti Co	*p* Fe, Ti, Co	
4634 ·25	2	—	*p* Cr	
4635 ·49	0	—	*p* Fe	
4657 ·38	2	Ti ?	*p* Ti	
4824 ·33	3	Fe	Fe *p* Cr	
4836 ·42	0	—	*p* Cr	
4848 ·44	2	—	*p* Cr	
4864 ·51	1	—	*p* Cr	
4876 ·59	1	—	*p* Cr	

1. Zr negligible.
2. No evidence for Fe origin.
3. Chiefly due to Mn.
4. Chiefly due to Mn.
5. Chiefly due to *p* Cr.
6. Possibly due partially to some other element.
7. No evidence for Fe origin.
8. No evidence for Mn.
9. Doubtful which is really due to *p* Cr.
10. Evidence for Ni doubtful.
11. No evidence for Zr.
12. Chiefly due to *p* Ti.
13. Doubtful which is really due to *p* Ti.
14. Chiefly due to *p* Cr.

General Conclusions.

As a general summary of the results of the foregoing analysis it may be stated :—

1. The enhanced lines of titanium and iron are practically all represented in the Fraunhoferic spectrum, but in some cases the corresponding solar lines are compound, and only partly due to one or other of these metals.

2. The corresponding solar lines are, generally speaking, comparatively weak ones.

3. The majority of the chromium enhanced lines occur in the solar spectrum, though some appear to be missing.

4. Some of the Fraunhoferic lines correspond to metallic lines special to the spark spectrum, and lacking in the arc, and probably for this reason they were left unorigined by Rowland.

"Air Resistance Encountered by Projectiles at Velocities up to 4500 Feet per Second." By A. Mallock, F.R.S. Received November 3,—Read November 17, 1904.

The work done by Prof. Bashforth on the subject of air resistance is so well known that I need hardly refer to it except to say that his results have, with minor alterations, been confirmed by subsequent experimenters. The greater part of Professor Bashforth's work related to velocities under 2500 feet per second, and the object of the present experiments was to examine the co-efficient of air resistance at higher speeds.

In the years 1895–97, Major the Hon. T. F. Fremantle and Colonel H. Mellish made a series of experiments on the remaining velocities of the service ·303 bullet by shooting into a ballistic pendulum from ranges varying from 12 up to 1000 yards. These experiments were made with great care, each bullet and charge being separately weighed, and from the results which they communicated to me I computed the co-efficient of resistance for velocities ranging from 2100 f.s. to 900 f.s. I suggested then that with light bullets we could probably extend the ballistic tables very considerably, using the pendulum to measure the velocity, and shortly after this we made some trials with various aluminium bullets. We found, however, that with cordite of the size used for the service charge of the ·303 rifle a great part of the explosive was blown out unburnt when the light bullets were used. It was evident, therefore, that in order to get the velocities we required, a much finer cordite than the No. 3 of the service charge would have to be used. We found also that a considerable deposit of aluminium was left in the barrel after firing.

From various causes I have not been able to proceed with the experiments until the present year, when having obtained some cordite of diameter ·01 inch, I again tried aluminium bullets, but the metallic fouling proved fatal to accurate and consistent results. I then tried shooting with lignum vitæ plugs which did very well up to velocities of about 2500 f.s., but at this velocity, sometimes, and generally at higher velocities, the plugs broke up under the action of centrifugal force. I again, therefore, reverted to aluminium, but on the bullets I made two small cannelures, fig. 1, which were filled with a composi-