THE SUN'S PLACE IN NATURE.[1]

X.

THE NEW CLASSIFICATION OF THE STARS.

I NOW pass to the new classification of stars which has been suggested by the totality of the facts which I have so far brought before you.

Although the first observations of stellar spectra were made by Fraunhofer, we owe to Rutherfurd the first attempt at classification. In December 1862 he wrote as follows:[2]

"The star spectra present such varieties that it is difficult to point out any mode of classification. For the present I divide them into three groups. First, those having many lines and bands and most nearly resembling the Sun, viz. Capella, β Geminorum, α Orionis, Aldebaran, γ Leonis, Arcturus, and β Pegasi. These are all reddish or golden stars. The second group, of which Sirius is the type, presents spectra wholly unlike that of the Sun, and are white stars. The third group, comprising α Virginis, Rigel, &c., are also white stars, but show no lines; perhaps they contain no mineral substance, or are incandescent without flame.

"It is not my intention to hazard any conjecture based upon the foregoing observations; this is more properly the province of the chemist, and a great accumulation of accurate data should be obtained before making the daring attempt to proclaim any of the constituent elements of the stars."

This classification was followed up by Secchi, who practically adopted Rutherfurd's three groups, changing, however, the word group to type, and adding a fourth. On this point Dr. Gould, in his memoir[3] of Rutherfurd, writes as follows:

"I cannot forbear calling attention to the classification, essentially the same, subsequently published by Secchi without reference to this or to any of the other labours of Rutherfurd, and which is generally cited under Secchi's name." (See "Scheiner," p. 258, and "Translation," pp. 235–236.)

In these and other subsequent classifications—and of course we must classify our stars if we are to speak about them with intelligence, and to understand the relations of one body or system of bodies to another—it has been taken for granted that nebulæ have nothing whatever to do with stars, and that all the stars lie along one line of temperature, the highest temperature being at one end, and the lowest at the other. Such, at all events, is Vogel's view. Now we have to conclude that nebulæ are stars to be, and that some apparent stars are really nebulæ; and I think I have shown you sufficient justification for the idea that the undisturbed nebulæ are of relatively low temperature; hence we have bodies getting hotter as well as bodies getting cooler, and both must be provided for.

In 1873 Dr. Vogel brought out a new and much more detailed classification considerably extending the number of groupings employed by Rutherfurd and Secchi. This classification is based on the assumption that all stars began by being very hot, and that the various changes observed in the spectra are due to cooling,[1] and the presence of bright lines is considered as a matter of secondary importance only, and gives rise to sub-groupings only.

Dr. Scheiner has quite recently accepted this statement. He appeals to his new observations of the spectrum of magnesium as a "direct proof of the correctness of the physical interpretation of Vogel's spectral classes, according to which Class II. is developed by cooling from I., and III. by a further process of cooling from II." (*Astronomy and Astro-Physics*, 1894, p. 571.)

Pechüle was the first to object to Vogel's classification, mainly on the ground that Secchi's types 3 and 4 had been improperly brought together.[2] Now the views I have brought before you cut at the root of such a classification as this.

It is perhaps worth while in passing to point out that in the course of lectures I gave here in 1886 I stated, taking the then classification as a basis[3]:—

"On the nebular hypothesis, supposing . . . . that we started with ordinary cometary materials, then, on the beginning of a central condensation which in time is to become a star, as Kant and Laplace suggested, such central condensation should then give us a star of the fourth class. As the energy of condensation increased and the temperature got higher, the spectra would change through the third and second classes, till ultimately, *when the temperature was highest*, the first class spectrum would be reached. *On the slackening down of the temperature* of the now formed star, the spectra of the second, third, and fourth classes would then be reproduced, but, of course, now in the direct order."

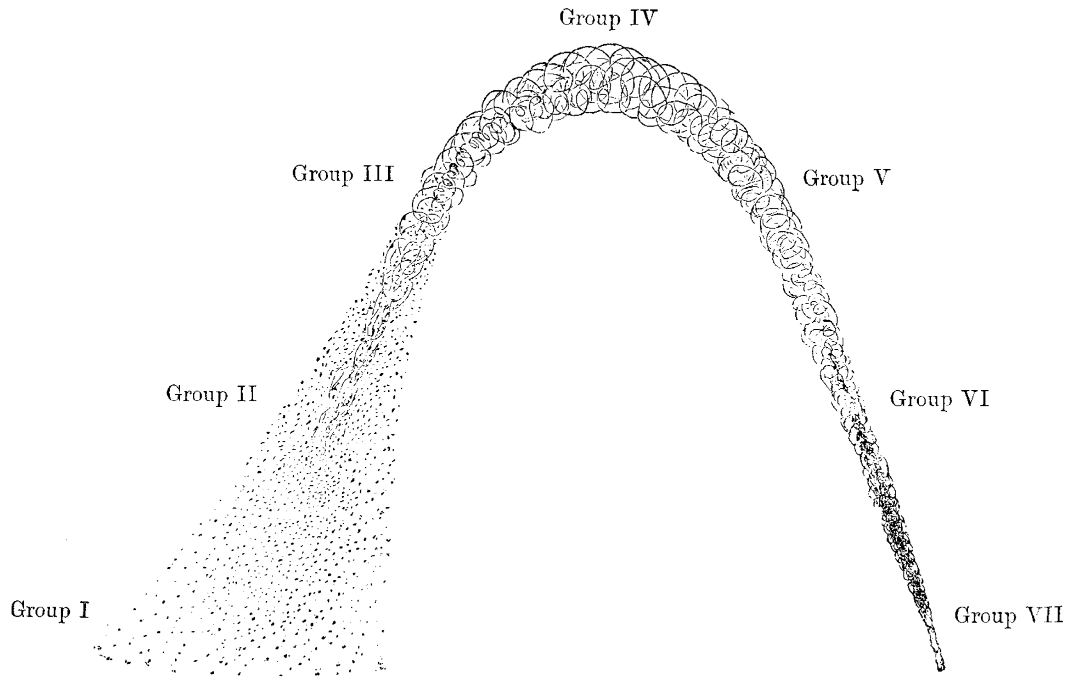

FIG. 38.—Temperature curve.

[1] Revised from shorthand notes of a course of Lectures to Working Men at the Museum of Practical Geology during November and December, 1894. (Continued from page 329.)

[2] *American Journal of Science*, vol. xxxv. p. 71.

[3] Read before the National Academy, April 1895.

[1] "Selon la théorie il faudra que tôt ou tard toutes les étoiles de la première classe deviennent de la seconde, et celles-ci de la troisième." Dunér.

[2] The details of Vogel's classification and Pechüle's criticisms are given in my "Meteoritic Hypothesis," pp. 345-6.

[3] Lockyer, NATURE, vol. xxxiv. 1886, p. 228.

We now know that this classification will not do, since all reference to bright lines is omitted, and every one now agrees that they must take the first place, and this is one of the great teachings of the views I have been bringing forward for the last ten years.

The idea which one arrives at by a discussion of all the spectroscopic facts is that we begin with a condition in which meteorites in swarms and streams are very far apart, and we get from the collisions of these a spectrum which gives us bright flutings and lines, in other words the spectrum of the nebulæ; when they get a little more dense, we get the bright-line stars; and as they get still more dense, we find the star with a mixture of bright and dark flutings. Then we get still more condensation and dark lines, and then the highest temperature of all; after which begins a descent on the other side, till at last we end in cool, dark bodies like the earth and moon.

This seems to be the classification which is necessitated by the consideration of all the facts, and it is, moreover, one which seems to give us possibilities of an explanation of the phenomena of new stars and variable stars, and many other things without going into the region of the unknown and impossible.

It also lands us in the so-called temperature curve along which I ventured to place the various classes of nebulæ and stars some time ago. I am glad to say that so far no valid objection has been made to it.

It will be noticed that in the classification I have suggested I use the word "group," first employed by Rutherfurd; it is one which ought never to have been changed.

With regard to this subject, Prof. Keeler, one of our most important authorities in this matter, agrees that a classification which depends on this temperature curve certainly has advantages over other systems. He writes [1]:—

"Prof. Lockyer's system of stellar classification provides for both an ascending and a descending branch of the temperature curve, and in this respect it certainly has advantages over other systems which claim to have a rational basis."

I am also more glad than I can say that Prof. Pickering, who has now given many years, with the aid of appliances beyond all precedent, to the study of these questions, has arrived at conclusions strikingly similar to my own.

In the first place he includes the nebulæ as well as the stars in his system; but it is right that I should add that he does not commit himself to any statements relating to the relative temperature of the different groups, although he distinctly accepts the idea of evolution, or what he terms an order of growth.

He writes (*Astronomy and Astro-Physics*, 1893, p. 722):

"In general, it may be stated that, with a few exceptions, all the stars may be arranged in a sequence, beginning with the planetary nebulæ, passing through the bright-line stars to the Orion stars, thence to the first type stars, and by insensible changes to the second and third type stars. The evidence that the same plan governs the construction of all parts of the visible universe is thus conclusive."

Prof. Pickering's results may be shown in tabular form, but first it will be well to show the general differences between the more recent classifications:—

	Secchi.	Vogel.	Lockyer.
Nebulæ	Not classified.	Not classified.	Group I.
Bright-line stars ...	,,	,,	
Mixed fluting stars ..	Type III.	Class IIIa.	,, II.
Dark line stars (ascending)	,, II.	,, II.	,, III.
Broad hydrogen stars ...	,, I.	,, I.	,, IV.
Solar stars	,, II.	,, II.	,, V.
Carbon absorption stars...	,, IV.	,, IIIb.	,, VI.

In his classification, Prof. Pickering begins with the earliest stages, taking the planetary nebulæ and such nebulæ as that of Orion; he then comes to the bright-line stars, and then to such stars as those of Orion, and ultimately places the Sun, as I also do, after the spectrum of such a star as Sirius. There are practically two departures in his classification from that given by myself. One is that what I call the bright and dark fluting group of stars, represented by several of the red, and brightest, stars in the heavens, he makes cooler than the Sun. And the class of stars which I group together and call Group VI., in which we get mainly the absorption of carbon in the atmosphere, he omits altogether, possibly for a very wise reason, as they are certainly the most difficult stars to tackle; but you see the divergences in his classification from mine are small as compared with those between Dr. Vogel and myself, and he, I repeat, like myself, attributes the variation to an "order of growth."

[1] *Astronomy and Astro-Physics*, 1894, p. 60.

This premised, the differences of sequence between Prof. Pickering and myself may be shown as follows:—

Lockyer.	Pickering.
I.	I.
II.	
III.	III.
IV.	IV.
V.	V.
VI.	II.

Prof. Pickering, in the Draper Catalogue, combines like stars under the different letters of the alphabet. The distribution of these letters in relation to my Groups is as follows:—

	Lockyer.	Pickering. (Draper catalogue.)
Nebulæ	I.	P. (Planetary Nebulæ.)
Bright-line stars...		O.
Mixed fluting stars	II.	M.
Dark-line stars (ascending) ...	III.	B. H. I. K. (?)
Broad hydrogen stars	IV.	A.
Solar stars	V.	F. G. K. L.
Carbon absorption stars ...	VI.	N.

It will be seen that certain groups are represented by more than one letter, but it is to be noted that here again Prof. Pickering and myself have arrived at very nearly similar results, for generally a different letter with him represents a sub-group with me. This will be gathered from the subjoined table.

Table showing the subdivisions of Groups III. and V.

Group.	Pickering.
III. α	H.
III. β	I. (some Q.)
III. γ	B.
V. α	F.
V. β	G.
V. γ	K. L.

With regard to Prof. Pickering, then, I have chiefly to justify the place I have given to the stars of my Group II., which I place after the nebulæ and bright-line stars, and he places after the Sun.

I fancy that one of the reasons which has led Prof. Pickering to this conclusion is to be found in the assumption that strong indications of calcium and iron can only mark one stage of growth, while I think it is certain they must mark two.

We know they mark the present stage of the Sun's history, and taking meteorites as we find them, a relatively low temperature would provide us with more calcium and iron vapours to act as absorbers round each one than anything else.

Now we have strong indications of calcium and iron absorption in such stars as α Herculis as well as in the Sun, but the general appearance of the spectra of these stars is so different that both Secchi and Vogel have classified them apart, and so indeed does Prof. Pickering.

But the reason that I classified these stars also in different groups, and one on the rising and the other on the descending arm of the temperature curve, was that in those like α Herculis we have enormous variability as well as bright lines and flutings indicative of sparse swarms, while in those like the Sun the production of such phenomena is almost unthinkable. The special variability of stars of my Group II. (Secchi's type III.) and the production of bright lines at maximum is now freely acknowledged. On this point Prof. Pickering remarks [1]:—

"Long period variables in general are of the third type, and have the hydrogen lines bright when near their maxima, as stated above. This property has led to the discovery of more

[1] *Astronomy and Astro-Physics*, 1893, p. 721.

than twenty objects of this class, and no exception has been found of a star having this spectrum whose light does not really vary. Of the variables of long period which have been discovered visually, the hydrogen lines have been photographed as bright in forty-one, the greater portion of the others being too faint or too red to be studied with our present means."

As said before, it seems impossible to imagine how our Sun, as it proceeds along its "order of growth," should change into a body with such characteristics as these. But on this point we

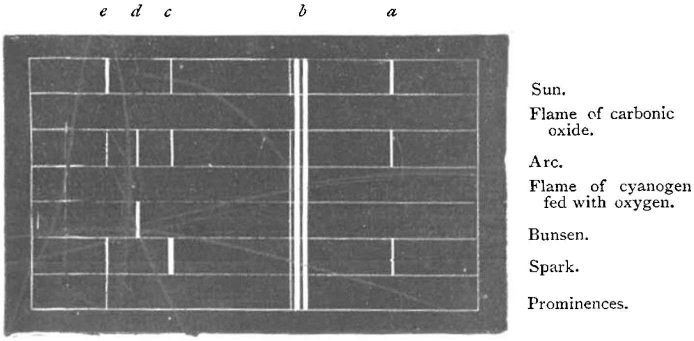

FIG. 39.—Showing the various intensities of the lines of magnesium as seen under different conditions.

must wait for more large scale photographic spectra; in other words, more facts.

Associated with this change in the order of evolution, Prof. Pickering classes the chief stars in Orion, such as Bellatrix, characterised by spectra containing hydrogen and a few other dark lines of unknown origin, as early forms. On this point I may also quote the following from Prof. Campbell (*Astronomy and Astro-Physics*, 1894, p. 475):—

"In conclusion, I think we can say, from the foregoing observations, that the spectra of the Wolf-Rayet stars are not closely related to any other known type. They appear to have several points in common with the nebular and Orion type spectra; but the last two appear to be much more closely related to each other than to the Wolf-Rayet spectra. It is therefore difficult to place these stars between the nebulæ and Orion stars. They certainly do not come *after* the Orion stars, and one does not like to place them before the nebulæ. We can probably say that the bright lines are chromospheric, owing their origin to very extensive and highly-heated atmospheres, but showing very little relation, in constitution and physical condition, to that of our own Sun. For the present, at least, this type of spectrum must be considered as distinct from every other known type, just as the nebular spectrum is distinct, and like the nebular spectrum containing lines whose origin cannot now be assigned."

Although Dr. Vogel and others apparently still hold in the main to the classification which assumes that all stars were created hot, and that nebulæ have nothing to do with them; that, in short, every star began in the highest stage of temperature, so that the whole history of every star in the heavens has been a process of cooling, there are signs of wavering here and there. Some of the definitions are being "edited" and re-edited to fit the facts which the photographic record is pouring in upon us. I may take, as an instance, the following statement made by Dr. Scheiner with reference to α Cygni, which is classified by Dr. Vogel as a solar star.

"These figures plainly show that the spectrum of α Cygni, in spite of the large number of its lines, has no resemblance with that of the sun. While it is possible to identify most of the lines with solar lines in respect to their position, yet the total lack of agreement as to intensity of the lines makes many of these identifications worthless."

The "figures" referred to are micrometer measures of a photograph. My experience in these matters is that it is a pure waste of time to measure a photograph until it has been compared with others to which it is important to refer it, enlarged up to the same scale. In this I think I carry Prof. Keeler with me (*Astronomy and Astro-Physics*, 1894, p. 485). "The coincidence of . . . lines is shown more beautifully by inspection of . . . photographs than by any process of measurement." Thus a comparison of the spectra of α Cygni and of the Sun *which Dr. Vogel classes together*, shows at once the dissimilarity pointed out above without any measurement whatever. I am glad, however, to find that Dr. Scheiner now regards the identification as "worthless," because it is such differences as these which have compelled me to reject Dr. Vogel's classification.

Dr. Scheiner then goes on:—

"The magnesium line at λ 4481 is the strongest in the entire spectrum. The other strong lines coincide for the most part with the fainter solar lines. The presence of numerous iron lines can be scarcely doubted, but here again we have the peculiar phenomenon that the fainter, instead of the stronger, lines occur. We may conclude from all these facts that very different conditions as to temperature must prevail in α Cygni from those in the stars of class I*a*." (Scheiner's "Astronomical Spectroscopy," Frost's translation, p. 247.)

Much of the work of the future, which eventually must smooth down all differences between stellar classifications, must consist of the study of single lines in the spectra of different stars, and I am rejoiced to find that the Potsdam observers are at length beginning to take this matter up. Dr. Scheiner, one of the Potsdam assistants, has, as seen above, called attention to the behaviour of the line 4481 of magnesium, and agrees that the variations in the line observed are due to differences of temperature, and that therefore it may be used as a stellar thermometer.[1]

But for this work an acquaintance with the literature of the subject is desirable. Had Dr. Scheiner been acquainted with it, I am certain he would have done me the honour to quote, or at all events to refer to, a communication I made to the Royal Society (16 years ago!), pointing out that the line in question was visible only at high temperatures, and that such work would help us in the study of "the atmospheres of the hottest stars."[2] In the same connection, in the "Chemistry of the Sun," published in 1887, I gave the diagrams, here reproduced, indicating the lines, visible at various temperatures in the laboratory, and in the Sun and prominences.

Having said so much on the different classifications of stars, and indicated, I trust judicially, that the one suggested by the meteoritic hypothesis is so far holding its own, I now pass on to some recent work which was undertaken to test it by a limited photographic survey. In the first instance I had used the eye observations of others; a study of spectra, entirely photographic, it was hoped would enable an independent estimate to be formed as to the validity of the hypothesis.

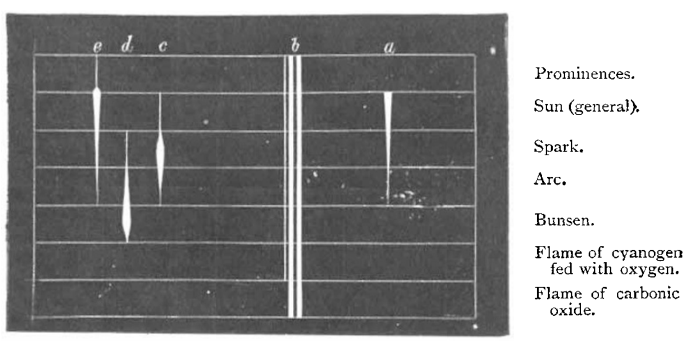

FIG. 40.—The various intensities of the lines of magnesium arranged in order of increasing temperatures. The lines marked *a b c d e* in the diagrams have the following wave-lengths:—5209·8, 517 (*b*), 4703·5, 4570·3, 4481.

The conclusions I came to in the first instance were necessarily based on observations made by others, for the reason that my own work up to that time had been chiefly directed to the Sun.

So soon, however, as my solar work rendered it necessary to determine the Sun's true place among the stars in regard to its

1 "Astronomical Spectroscopy," p. viii.
2 *Roy. Soc. Proc.* vol. xxx. p. 22, 1879.

temperature and physical conditions, arrangements were made to photograph the spectra of stars and nebulæ, in order to test the view, employing a quite new basis of facts; this new basis of the inquiry consists of 443 photographs of 171 of the brighter stars.

Having this new and accurate basis of induction, the objects were to determine whether the hypothesis founded on eye observations is also demanded by the photographs, and in the affirmative case to discover and apply new tests of its validity, or otherwise.

The results as yet obtained are not sufficient to permit a discussion of all points bearing upon the new classification, but most of the crucial ones are certainly covered by the photographs already obtained.

The main instrument employed in the work has been a 6-inch refracting telescope, with an object-glass made and corrected for G by the Brothers Henry. This was at first used in conjunction with a prism of $7\frac{1}{2}°$ of dense glass by Hilger. The object-glass and prism are fixed at the end of a wooden tube, which is attached to the side of the 10-inch equatorial, at such an angle that the spectrum of a star falls on the middle of the photographic plate when its image is at the centre of the field of the larger instrument. The camera is arranged to take plates of the ordinary commercial size, $4\frac{1}{4} \times 3\frac{1}{4}$ inches. The spectra obtained with this instrument are 0·6 inch long from F to K. An excellent photograph of the spectrum of a first magnitude star can be obtained with an exposure of five minutes. Afterwards a 6-inch prism, with a refracting angle of 45°, obtained from the Brothers Henry, was used with the Henry 6-inch object glass. The spectra obtained with the latter are two inches long from F to K, and the definition is exquisite. In some photographs the calcium line at H is very clearly separated from the line of hydrogen, which occupies very nearly the same position. It is unnecessary to swing the back of the camera in order to get a perfect focus from F to K. The deviation of the prism is so great that it would be very inconvenient to incline the tube which supports it at the proper angle to the larger telescope. When photographing the spectrum of a star, therefore, the star is first brought to the centre of the field of the large telescope, and the proper deviation is then given by reading off on the declination circle. This method has been found to work quite satisfactorily.

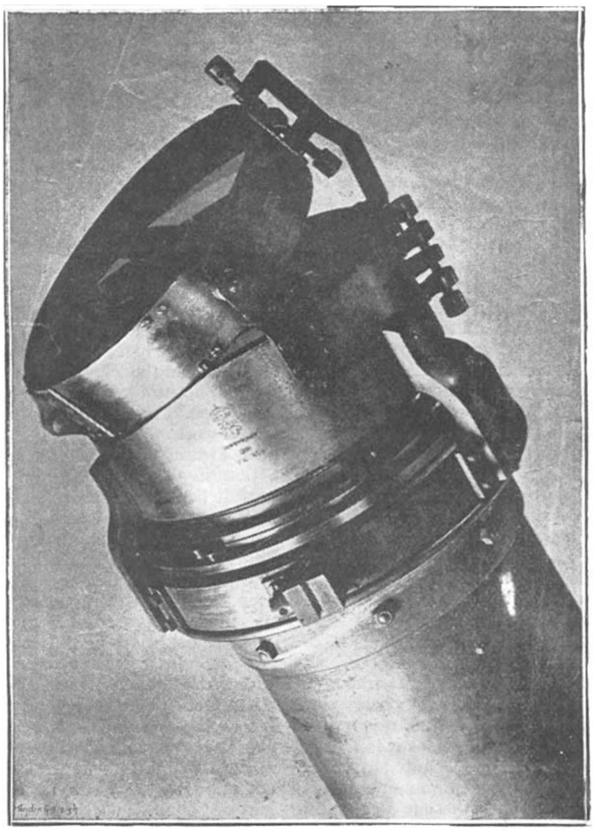

FIG. 41.—Objective prism fitted to object-glass.

With this combination the exposure required for a first magnitude star is about twenty minutes. The method of mounting the prism is shown in Fig. 41.

For the fainter stars, the 6-inch prism of $7\frac{1}{2}°$ has been adapted to a Dallmeyer rectilinear lens of 6 inches aperture and 48 inches focal length. At times prisms of $7\frac{1}{2}°$ have been used on a 10-inch equatorial.

Since the spectrum of a point of light such as a star is a line so fine that the spectral lines would not be measurable, it is necessary to give it breadth. This is done by adjusting the prism so that the spectrum lies along a meridian of R.A. and altering the rate of the clock.

J. NORMAN LOCKYER.

(*To be continued.*)

THE IRON AND STEEL INSTITUTE.

THE annual summer meeting of the Iron and Steel Institute was held in Birmingham last week, commencing Tuesday, the 20th inst., and extending over Friday, the 23rd inst. Sir David Dale, the President, took the chair at the sittings for the reading of papers, and it may be said here that the meeting was remarkably successful throughout, being one of the pleasantest and most instructive gatherings that has been held for a long time past; both Mr. Brough, the Secretary of the Institute, and the local committee are to be congratulated on the excellence of their arrangements.

There were twelve papers down for reading and discussion, of which the following is a list:—

"On the Direct Puddling of Iron," by E. Bonehill (Marchienne-au-Pont, Belgium).

"On the Production of Iron by a New Process," by R. A. Hadfield, member of Council (Sheffield).

"On the Thermo-Chemistry of the Bessemer Process," by Prof. W. N. Hartley, F.R.S. (Dublin).

"On the Hardening of Steel," by H. M. Howe (Boston, U.S.A.).

"On the Mineral Resources of South Staffordshire," by H. W. Hughes (Dudley).

"On the Iron Industry of South Staffordshire," by D. Jones, Secretary of the South Staffordshire Ironmasters' Association (Shifnal).

"On the Iron Industry of the South of Russia," by George Kamensky (St. Petersburg).

"On Cooling Curves and Tests of Cast Iron," by W. J. Keep (Detroit, U.S.A.).

"On the Analysis of Ferro-Chromium," by E. H. Saniter (Wigan).

"On Small Cast Ingots," by R. Smith-Casson (Birmingham).

"On Tests of Cast Iron," by T. D. West (Sharpsville, Pennsylvania).

"On Nickel Steel," by H. A. Wiggin (Birmingham).

The papers of Mr. West and Mr. Keep were taken as read, all the others being read and discussed.

On the members assembling on Tuesday morning, in the Council House of Birmingham Corporation, they were welcomed by the Mayor, and by the members of the local reception committee.

The first paper taken was that by Mr. D. Jones, on the iron industry of South Staffordshire. This was an interesting contribution, but mainly historical in its character. It dealt with the rise and progress of the iron industry of the district from its earliest days, and, in treating of more modern times, pointed out how the production of wrought-iron had decreased as steel had taken its place, although a good deal of puddled iron is still produced in the district. The paper of Mr. Hughes, on the mineral resources of South Staffordshire, was very much of the same character, and gave, in a convenient form, many facts relating to the subject.

M. Bonehill's paper on the direct puddling of iron was next read. This process appears to be a revival of, and doubtless an improvement on, a method of puddling which was proposed, and to a limited extent carried out, in the earlier years of the century, but which never obtained any great hold in the iron