various conditions I have to thank Messrs. Baxandall, Shackleton, Butler, and Watson. Mr. Baxandall is responsible for the wave-lengths and intensities of most of the metallic and stellar lines given in the paper, and he has also made the maps which deal more especially with the metallic lines. The maps showing the occurrence of the gaseous lines in stellar spectra have been made by Dr. W. J. S. Lockyer, who has also contributed the part relating to series of lines in spectra. To Mr. Fowler I am indebted for help in the general supervision of the various branches of the research, and for assistance in the preparation of the paper.

Note by Professor SCHUSTER, F.R.S., "On the Chemical Constitution of the Stars."

I could have wished that the classification of star spectra had been the only question submitted to us for discussion. The subject is important and difficult enough in itself; there are many points on which opinions might have been profitably exchanged, and I think we might have arrived at some general consensus of opinion which would have left us more fit to form a sound judgment on the fundamental questions brought forward in the second portion of Professor Lockyer's paper, in which we are directly challenged to accept the dissociation theory in its full generality. Had Mr. Lockyer confined himself to bringing forward his hypothesis as one which is legitimate, consistent, and deserving of attention, many of us would, I think, have agreed that he has made out a good case. But he claims his theory as the only one that can explain the facts, and dismisses as unphilosophical the only alternative which he discusses. I think that in this he has gone too far, and to bring matters to an issue I will put the case for the other side; but before doing so I should like to express my concurrence in the general system of classification adopted in the paper. No classification is likely to prove successful which does not constantly appeal to laboratory experiments, and I do not think Professor Lockyer will have much difficulty in convincing the scientific world that he has made a very material advance by his investigations of the "high temperature" or "enhanced" lines of the metals.

"The only change," according to Professor Lockyer, "which we can imagine on the usual hypothesis as resulting from an increase of temperature, is that with the increase in volume there will be a reduction in density, and all the lines will be equally enfeebled." With this remark I cannot agree. The main fact to be explained is the gradual displacement of hydrogen, which is predominant in the hottest stars, by calcium, iron, and other metals. There are in my

opinion several causes at work which might produce that effect. A glowing mass of gas may be either in thermal or in convective equilibrium, and the spectroscopic appearance in the two cases will be profoundly different. In reality an intermediate state probably is arrived at, but there is good evidence to show that the state of convective equilibrium is more nearly approached in our sun than in the hydrogen stars. We know as a fact that there are powerful convection currents near the sun's surface. There is in consequence an approach to a uniform distribution of matter and enormous differences of temperature in layers which are comparatively close together. Those who have not given much attention to this subject will hardly realise the differences of temperature brought about by convection currents. On the surface of the sun the temperature gradient produced by convection currents would be equal to 20,000° for each 100 km. difference in level, so that an angular distance of one second of arc would correspond to a difference of 100,000°. Radiation and condensation will diminish this gradient, but that it is very large is sufficiently proved by the spectroscopic evidence. Thus, according to the results of Messrs. Jewell, Mohler, and Humphreys,* the pressure in the reversing layer for hot calcium giving the H and K lines is about 6 atmospheres, while that for the cooler calcium vapour is about 3 atmospheres. With a gravitational constant 27 times as large as that of our earth, a difference of 3 atmospheres can only mean a comparatively small difference in level. While, then, in the sun we must admit a more or less effectual stirring up of the constituents together with an accompanying rapid temperature gradient, the evidence is just the other way in the case of stars like γ Lyræ. The spectrum of that star, according to Professor Lockyer, contains only the high-temperature lines of iron. This means not only that the reversing layer is very hot, but also that there are no rapid changes of temperature at different levels. It is impossible to imagine this hot layer of gas ending abruptly, it must be surrounded by cooler matter, which cannot be iron, as the low-temperature lines of iron do not appear. In such a star there cannot be an effectual mixing up of the constituents, and hence the layers of gas will arrange themselves according to the laws of diffusion. It would follow that hydrogen being a lighter gas than iron will be chiefly represented in the cooler and outer layers, while iron will be found more particularly in the inner and hotter parts. The relative proportion of different elements in different layers will be regulated partly by their density, but to a great extent also by the total quantities present in the star; for the different gases will not float on each other as liquids might, but the density of each gas will increase steadily from the surface to the centre. The chief difference, according to this view,

* 'Astrophysical Journal,' vol. 3, p. 138.

between a hydrogen and a solar star lies in the more or less effectual mixing up of the constituents. If we could introduce a stirrer into γ Lyræ there can be no doubt whatever that the low-temperature lines of iron would make their appearance, while, on the other hand, if we could stop all convection currents on the surface of the sun the hydrogen which now lies under the photosphere would gradually diffuse out and give greater prominence to its characteristic absorption lines.

In the face of the direct evidence of the absence of convection currents in the hotter stars, it is not necessary for the purpose of my argument to discuss why this is the case, but it can be seen that diminished gravity, diminished density, and consequently increased viscosity, will contribute to the effect, while effectual radiation will, owing to the smaller density, take place more evenly through a thicker layer of the envelope, so that the principal cause of convection currents will also be much diminished. The explanation I have given does not differ materially from that brought forward by Dr. Huggins in his address as president of the British Association at Swansea. I do not say that difficulties may not be raised against it, but difficulties may be raised also against the theory of dissociation, and there is especially one question which Professor Lockyer must be prepared to answer. Amongst the heavier metals, tellurium, antimony, mercury, are not represented in the sun, but they are found in Aldebaran. To be consistent, we must, if we adopt the theory of dissociation, assert that these metals are decomposed in the sun. But if I understand Professor Lockyer right, he believes that with our strongest sparks we can exceed the state of dissociation which exists in the reversing layer of the sun. Take such a strong spark then from a pole of mercury, do you get lines of helium, or of calcium, or of hydrogen? This seems to me to be almost a crucial experiment. Possibly, of course, we should get high-temperature lines not hitherto looked for, but present in the sun. If so, the objection would fall to the ground, but if this is not the case, and if mercury at a high temperature refuses to be dissociated into simpler elements, a most serious objection to the theory would have to be answered.

With regard to the division of stars into those of rising and those of falling temperature, some of Professor Lockyer's remarks lead me to think that he has not followed the recent development of the nebular theory. To him the nebular theory is still that of Kant and Laplace, while Lane, Lord Kelvin, and Ritter have applied the dynamical theory of heat to the treatment of gaseous masses, contracting under their own gravitation, and have clearly shown that a *radiating* and *contracting* mass is not necessarily a *cooling* mass; on the contrary the interior of our sun is almost certainly rising in temperature at the present moment. Ritter's work is of great importance.

He showed in the year* 1883 that the total amount of light emitted by a star will, on the nebular hypothesis, first rise and then fall, and he then suggested that the stars of Secchi's Class IV were falling in temperature, while those of Secchi's Class III were rising. This is the same distinction which Lockyer afterwards based on his meteoric theory, and this division is therefore not dependent on the truth of that theory.

While I think that we shall all admit that different stars are in different stages of development, and that hydrogen stars will ultimately approach more nearly to the state of our sun, it would be unwise to push the argument of uniformity too far, and to say that every star will pass exactly through the same stages. Ritter, who is favourably inclined to the dissociation hypothesis,† gives good reason to believe that the sun's surface was never much hotter than it is now, and that the higher temperature of hydrogen stars is connected with their greater masses. It is, in fact, impossible to admit that the process of development should be quite independent of the total mass of the star. It may be urged that Arcturus must have a mass much larger than that of our sun, and its spectrum, according to Professor Lockyer, is identical with that of the sun. But I suppose that that statement only refers to the blue and violet region, for according to Dr. Huggins, to whose early stellar photographs we owe so much, the spectrum of Arcturus in the ultra-violet approaches that of Sirius.

Further, though I am ready to agree with the general statement that the chemical elements in the stars are the same as those in the sun, and probably in not widely different proportions, I am not convinced that the difference in the spectra of stars, which Mr. Lockyer ascribes to ascending and descending temperatures, are not due to a real difference of constitution.

We have no reason to believe that the nebulæ of the present day resemble our sun's ancestor. Some of the stars which are now in an early stage of development may be forming through the condensation of matter which has been left over by others; and it would not be surprising if the youngest star did not agree in constitution with its aged companions.

I now pass on to say a few words on Mr. Lockyer's final conclusions:—Most of us are convinced in our innermost hearts that matter is ultimately of one kind, whatever ideas we may have formed as to the nature of the primordial substance. That opinion is not under discussion. The question is not whether we believe in the unity of matter, but whether a direct proof of it can be derived from the spectroscopic evidence of stars; for that is what Professor Lockyer claims. It must be observed that even according to him,

* 'Wied. Annalen,' vol. 20, p. 156.

† 'Wied. Annalen,' vol. 20, p. 152.

we do not witness in these stars the original formation of our elements; for his own theory supposes the stars to be formed from condensing matter originally cool, in which the metals, as we know them, are already present. What we see in these stars, as I understand his theory, is a case of atavism, a temporary relapse of our elements into their original state. That may be so. It is in my opinion as I have already stated, a perfectly legitimate hypothesis, one that at present has not been disproved, and for which, as well as against which, a good deal might be said, but I cannot admit the claim, that it is demonstrated. Nor do I believe that it will be generally accepted until some direct experimental evidence is obtained. The resources of our laboratories are not yet exhausted; and we have not arrived at the limit to which we can push the intensity of our electric sparks. If Mr. Lockyer is right we must look forward to finding some trace of helium, or calcium, or hydrogen in the discharge taken from iron poles. When that is done, and not till then, will this theory be considered as proved.

Additional Remarks by Mr. J. Norman Lockyer.

Mr. Lockyer, in his reply, pointed out that it was not open to him to discuss the question of classification. He had been asked to prepare a paper on another subject, for the proper consideration of which the question of classification had to be referred to. If Professor Schuster, as he says he does, concurs generally in Mr. Lockyer's scheme of classification, he must acknowledge that there must be a very great difference in the amount of "stirring" on the two sides of the temperature curve, and that powerful convection currents must exist in the hotter stars in which the temperature is rising; and yet as a matter of fact the line absorption is very similar in both arms of the curve.

Mr. Lockyer has nowhere claimed that his hypothesis is the only one which can explain the facts, he only claims that it is simple and sufficient.

Note by Mr. Frank McClean, F.R.S., "On Comparative Photographic Spectra of Stars to the 3½ Magnitude."

The 160 photographs which accompany the paper* include, with insignificant exceptions, all stars equal to and brighter than the 3½ magnitude contained in five out of eight equal areas, into which the celestial sphere has been divided.

* The paper to which reference is made, and on which Mr. McClean's remarks were based, was read subsequently, at the meeting of April 8.