small, are distinct and complete, and the feathers large and definitely arranged. The emu, cassowary, and apteryx show various degrees of degeneration, which apparently culminated in the dinornis, no trace of a wing-bone of which bird has ever been found. The question which naturally presents itself with regard to these birds is, whether they represent a stage through which all have passed before acquiring perfect wings, or whether they are descendants of birds which had once such wings, but which have become degraded by want of use. In the absence of palæontological evidence it is difficult to decide this point. The complete structure of the bony framework of the ostrich's wing, with its two distinct claws, rather points to its direct descent from the reptilian hand, without ever having passed through the stage of a flying organ. The function of locomotion being entirely performed by powerfully developed hind-legs, and the beak mounted on the long flexible neck being sufficient for the offices commonly performed by hands, the fore-limbs appear to have degenerated or disappeared, just as the hind-limbs of the whales disappeared when their locomotory functions were transferred to the tail. This view is strengthened by the great light that has been thrown on the origin of the wings of the flying birds by the fortunate discovery of the *Archæopteryx* of the Solenhofen beds of Jurassic age, as in this most remarkable animal, half lizard and half bird, the process of modification from hand to perfect flying bird is clearly demonstrated. The three digits which in the existing forms are more or le s pre sed together and imperfect, still retain their freedom and complete number of phalanges, and are each armed with terminal claws, while the flight feathers and remiges of the cubital, metacarpal, and digital series are fully developed and evidently functional. The earlier stages in which the outer digits were still present, and the feathers imperfectly formed or merely altered scales, are not yet in evidence.

Some conception of the process by which a wing may have been formed may also be derived from the study of the growth of feathers on the feet of some domestic varieties of pigeons and poultry, illustrations of which were shown at the lecture.

THE SUN AND STARS[1]

VII.

WE have now to endeavour to apply to the more distant stars some of the facts which I have brought before you touching the nearest one—our sun. What we have to do in the short time at our disposal is to choose those facts which will give us the greatest amount of knowledge concerning the greatest number of those stars.

When the star that is nearest to us has set, the number of stars which a pair of eyes can see on a dark night, whether they happen to be north of the equator or south of it—for the number of stars is pretty equally distributed north and south—is something under 3000. But when we leave behind us the power of the unaided eye, and consider what re ults can be obtained by the optical means now at man's disposal, we have to increase these 6000 to something like forty or fifty millions, so that, if we can by any chance obtain facts touching one star that are applicable to others, we do a great deal. We a-e, in fact, dealing with 50,000,000 bodies instead of one.

The first thing regarding these distant bodies to which I have to draw attention is that they have been divided for purposes of convenience—astronomical and other—into magnitudes such that the first magnitude means the brightest star we can see; and so we go on till now we go down to the sixteenth magnitude.

The order of diminution of brightness is not quite exact from the first magnitude to the faintest visible to the naked eye, but it may be taken on the average to be about two-fifths. If we take this ratio as the normal one down to the sixteenth magnitude we get the following values nearly :—

2½	stars 2nd mag.	=	1 star	1st mag.
6	3rd	=	,,	
16	4th	=	,,	
40	5th	=	,,	
100	6th	=	,,	
⋮				
10,000	11th	=	,,	
⋮	⋮			
1,000,000	16th	=	,,	

[1] A Course of Lectures to Working Men delivered by J. Norman Lockyer, F.R.S., at the Museum of Practical Geology. Revised from shorthand notes. Continued from p. 45.

We not only get the stars thus visible, but, as they can be photographed in a certain period of time, this period measures their photographic brightness. We find, for instance, that a first magnitude star can be photographed in the three-thousandth part of a second; that a star of the seventh magnitude can be photographed in about one second; and when we come to the twelfth magnitude we must turn seconds into minutes, and we shall require two of them to get an impression on the plate; till, working on gradually to the sixteenth magnitude, we find that the photographic plate, which requires only the three-thousandth part of a second for a star of the first magnitude, requires one hour and twenty-three minutes (or eighty-three minutes) to receive the impression, we find the ratio of two-and-a-half times to be practically indicated by the times of exposure.

The relative photographic light of stars of all magnitudes when the most rapid dry plates are used is shown in the following table :—

Magnitude	Time of exposure m.	s.
1st		0·005
2nd		0·013
3rd		0·03
4th		0·08
5th		0.2
6th		0·5
7th		1·3
8th		3·0
9th		8·0
10th		20·0
11th		50·0
12th	2·0	
13th	5·0	
14th	13·0	
15th	33·0	
16th	83·0	

We must not for one moment imagine that, because for many reasons it has been necessary to divide stars into magnitudes, all the stars are of exactly the same size at different distances, or of different sizes at the same distance. We know very little at present relatively. But this we do know, every new fact has shown us that some of the apparently fainter stars may be very large, and some of apparently the brightest stars may be small. You can understand that the light which we get from the stars will depend upon these two things. Take the case of the sun for instance. We know that the sun is a small star, and yet it gives us a great deal of light because it is near to us. We know that some of the other stars are very distant, and they give us a small amount of light, not because they are small, but because they are so far away.

We are living now in a very interesting time, because people are beginning to work here and there, not in too many places, to get the stars to write their own autobiography, so to speak. In fact, a very important attempt is being made at the present moment to replace observations of the positions of the stars by actual photographs. Observations, you know, being human, are always liable to error. This plate, which I am about to show you, is a photograph that I have received from the Brothers Henry of Paris only this morning, showing what photography can do in registering the exact positions and brightnesses of an almost innumerable army of stars by simply exposing a plate in a telescope.

If it is wished to obtain photographs of stars of the sixteenth magnitude, the plate will have to be exposed eighty-three minutes. If we are content to get stars of the seventh magnitude, then two minutes will be enough.

All the stars that you see here are visible in a very restricted portion of the sky in the constellation Cygnus, not very far from the Milky Way. You can understand what a happy thing it will be for the astronomer of the future if, when he wants to know the state of the heavens in this nineteenth century, instead of having to consult musty books of observations which may probably be wrong, he can refer to a book of which the leaves are made of glass, and on which is recorded the autobiography of every square degree of the heavens as you see on this diagram before you.

In our attempt to apply to these other bodies the knowledge which we have acquired touching the sun, of course we have to consider chiefly the light sent to us by them. You will see in a moment that if the sun were very much farther away from us than it really is—imagine it for a moment so far away that instead of appearing to us with a disk it should appear to us as a star, like Sirius or Capella, for instance—the only difference between its spectrum now and its spectrum then would be that there would be less of it. There would be less light. Consequently it would not be possible for us to see it in all its exquisite detail. But so far as the spectrum went there would be no change in kind, although there might be a change in degree.

Now, if you just assume that for a moment, you see that we shall be in a very fair way to make a very important application of this knowledge, because I was careful to tell you that in the solar system we have indications of a considerable amount of absorption of blue light; so that, if the sun's atmosphere were away and the earth's atmosphere were away, the sunlight, if we are now right in calling it white, would then certainly appear to us as blue, for the reason that the blue light now stopped by the sun's atmosphere and by our own would then be added to the light which we get at the present moment, and the total light therefore received by our eyes would be very much richer in blue rays than it is at present.

Now then, having the fact of this blue absorption in our minds, let us suppose it—to begin with the simplest case—to be enormously increased. Let the blue absorption creep on into the spectrum till at last it reaches the green or the yellow or the red. It is clear that then the sun that we should see would be a red sun, and that sunlight would be no longer white, but red.

Let us next, on the other hand, reduce the quantity of the existing blue absorption. Let us have a solar spectrum as long as the spectrum of the electric light, for instance.

Now let us do something else. Let us suppose that in the solar spectrum, as in very many of the spectra that we can observe in our laboratories, there is superadded to this blue absorption a strong absorption of the red, beginning at the other end of the spectrum. We shall get the yellow and the red, say, absorbed on the one side of the spectrum, while we get the blue and violet absorbed on the other. We shall therefore only get the green light to pass.

Do we get evidence that in the heavens among other stars such conditions as these hold? Certainly. A very considerable number of the stars in the heavens are called coloured stars. They are red, or they are blue, or they are green, for the most part, and you see that simply dealing with the absorption of the blue with which we have become familiar in the case of the sun, playing with it a little, giving it a little rope here, shortening the rope there, and adding another exactly equivalent absorption at the other end of the spectrum, we can at once account simply and sufficiently for the colours of the coloured stars. This is one advantage that we have in working from the known to the unknown. If we had begun with the stars and dealt with their phenomena first, it would have been difficult to explain; but now that we know how a thing happens in the case of the sun, it is quite easy for us to imagine the mechanism which must be at work in the atmosphere of the coloured stars to give us in some cases red suns, in others green suns, and in others still blue suns.

So much then for coloured stars.

There is another matter. As I shall have to show you by and by, one of the most important distinctions between the stars in the heavens is one not depending upon their magnitudes, not depending upon their distances, or upon their mass, or upon anything of that kind, but depending upon conditions which we do not know very much about at present, but which bring about this result, that the spectrum in one case is different from the spectrum in another, exactly as in our laboratories we find the spectra of bodies with which we are perfectly acquainted become different if the temperature which we employ is made to differ. For instance, in the case of the vapour of carbon we may employ a low temperature, and get a certain spectrum of the vapour which is called a spectrum of flutings. If we increase the temperature, and then again observe, the flutings have disappeared. They have given way to a system of lines in which the irregularity is just as striking as the exquisite rhythm of the flutings was in the former case. From hundreds of these observations the student of spectrum analysis is not afraid to say that when he sees a spectrum of flutings he knows that he is dealing with the action of vapours at a much lower temperature than exists in those conditions in which the flutings are replaced by lines. And, more than that, so definite is this, so much do we know about the fluted spectra of those substances which exist in the solar atmosphere—giving us, at the temperature of the sun, the line spectrum—that it is easy for us to take the responsibility also of saying that, if the sun's atmosphere were to be suddenly cooled to-morrow, we should get a spectrum of flutings, instead of a spectrum of lines; so that when we get, if we do get, the fluted spectrum in the spectrum of a star, we are justified in saying that some cause has been at work in that star equivalent to a cooling process in the atmosphere of our own star. Thus, if we cooled the sun to-morrow we should produce the spectrum of flutings, and as in cooling down the sun will in all probability pass through a stage indicated by flutings, so also while it was acquiring its present temperature it passed through the same stage.

What, on the other hand, would happen if we had the sun very much hotter to-morrow? It is important to think this out very carefully. According to the views which I have brought before you, we have, outside all, solids absorbing every part of the spectrum. Then we have liquids and dense vapours doing the same: less dense vapours absorbing the red, and finer vapours still absorbing the blue. We have flutings also, but chiefly we have vapours at an enormous temperature which give us the familiar absorption spectrum of Fraunhofer lines.

We have the Fraunhofer spectrum in short giving us the summation of the line absorption of every stratum in the sun's atmosphere. We have also a wonderfully simple spectrum of the chromosphere, of which I gave you the list of lines, writing down for us the absorption of the hottest part of the sun's atmosphere that we can get at.

Now try to think this out quite completely.

The first obvious thing which will strike us is that, if the sun could be made hotter to-morrow than it is to-day, the thing that we should be quite certain about, whatever might happen to the other conditions, would be that the gases which give us that simple spectrum of the chromosphere would have a larger share in the absorption-spectrum, and that therefore the absorption-spectrum of the star would gradually get nearer and nearer to the absorption-spectrum which would be given by the chromosphere itself if it could be seen in all its simplicity. I think that way of reasoning is right. Well, if you think it is, you will find that it will lead us to a very interesting conclusion. If we find any star with practically the spectrum of the chromosphere, we shall be bound to admit that the atmosphere of that star must be hotter than the *average* temperature of the atmosphere of our sun as its spectrum approaches that of the *hottest* part of the sun's atmosphere.

There is one other point that I have to bring before you before I go further, and it is this. We have had a great deal to say about the photosphere of the sun and the surrounding envelopes. We saw that when any vapours were located between our eye and the bright sun in the centre we then got absorption-lines, for the reason that the sun was hotter than the vapour on this side of the sun, so to speak, and therefore light was stopped by the cooler vapour in the atmosphere, and we got a dark line. The moment however, we work outside the disk, and study a prominence on the limb of the sun, or even a part of the corona, we observe them by means of their bright lines—by means of their radiation. There is no hotter light source behind them, and therefore we deal simply with radiation.

Now, that being so, you will understand how it is that in the general spectrum of the sun all the lines are dark, because we found that while the bright central part of the sun was not very much less than the whole volume, something like a tenth, it was very much hotter, so that we get many thousand times more light from the centre of the sun. If a substance in the outer atmosphere gives us a bright line corresponding with a dark line given us from this central portion due to the atmospheric absorption, all it can do is to reduce the intensity of the dark line produced by the intensely illuminated central portion.

It is a question of area. The difference of area is small, smaller than the difference of illumination, and therefore anything which happens outside does not get its record written at all, the area being five or six to one, and the intensity of the light in the centre being, say, ten thousand to one.

Now let us consider another case. Let us suppose that there is a star (never mind which it is) the atmosphere of which is so enormous that its diameter to the diameter of the central photosphere is represented by two concentric circles—one very large, the other very small. Here the difference of area between the inner circle, which gives us dark lines, and the larger exterior space, which gives us bright lines, if it gives us anything, is so enormous that it may be greater than the difference of the intensity of the light; so that if the inner light is ten times brighter than the light which comes from the outer area, which, let us say, is a couple of hundred times greater, in that case we shall be bound to have bright lines from the exterior regions mixing with the dark lines coming from the interior regions. Hence we see that the spectra which we may get from stars will not depend upon the diameter of the stars at all, but may depend upon the difference of area simply which we should get by cutting a section at right angles to the line of sight from the earth through the star and its whole atmosphere.

It comes to this: Suppose some stars have very large coronal atmospheres; if the area of the coronal atmosphere is small compared with the area of the section of the true disk of the sun, of course we shall get an ordinary spectrum of the star; that is to say, we shall get the indications of absorption which make us class the stars apart; we shall get a continuous spectrum barred by dark lines. But suppose that the area of the coronal atmosphere is something very considerable indeed, let us assume that it has an area, say fifty times greater than the section of the kernel of the star itself; now, although each unit of surface of that coronal atmosphere may be much less luminous than an equal unit of surface of the true star at the centre, yet if the area be very large, the spectroscopic writing of that large area will become visible side by side with the dark lines due to the brilliant region in the centre where we can study absorption; other lines (bright ones) proceeding from the exterior portion of that star will be visible in the spectrum of the apparent *point* we call a star.[1]

Those things, then, being premised, we are now in a position to approach the subject of stellar spectra. Much work is now being done in this direction, but we must not forget the early workers. We must not forget that it was Fraunhofer at the beginning of this century who first saw and carefully observed several spectra of stars, and we must be all the more careful to remember that, since really more than half a century passed before anybody took the trouble either to repeat his observations or to extend them. Some twenty years ago, however, several observations had been brought together by the labours of Italian and American men of science (scarcely a stellar spectrum had been observed in England). This enabled a distinguished American, Mr. Rutherfurd, to begin to put a little order into the facts which had so far been acquired.

He pointed out that it was easy to arrange these stars into classes—that all the spectra were not alike. There was a wonderful family likeness among three groups of them, and he showed that you might divide these spectra into three very definite classes. After him came two countrymen of our own, Dr. Huggins and Dr. Miller, who, when they did begin their work, certainly put into it an amount of vigour and assiduity which had never been approached before their time. They not only gave us careful drawings of the spectra of the stars which they

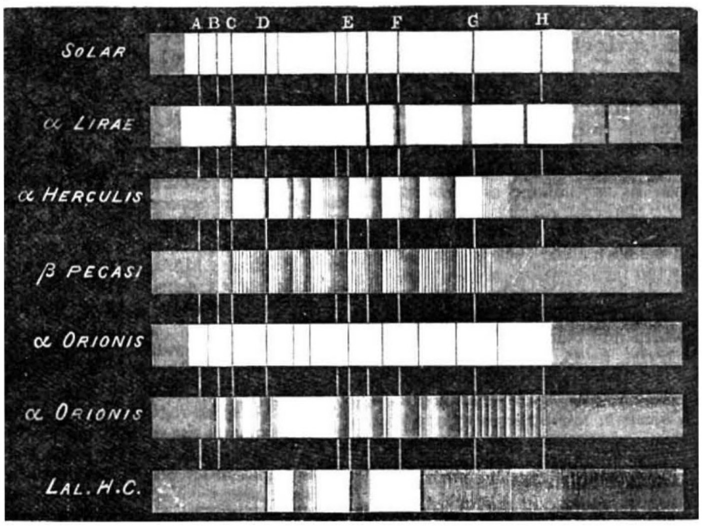

FIG. 21.—Various types of stellar spectra.

observed, but with infinite care and patience they made comparisons, as we may say, to determine the origin of the lines in exactly the same way as I have pointed out that Kirchhoff, Ångström, and Thalèn discovered the origin of the lines in the spectrum of the sun. Indeed, they did not rest here, or rather, one of them did not rest here, for Dr. Huggins subsequently introduced a system of photography, and now, thanks to his skill, we have several photographs, of priceless value, of some of the brighter stars. And while I am lecturing to you here in London there is one observer in Berlin, Dr. Vogel, and another in the north of Europe, Dr. Dunop, doing all they can to give us a complete and perfect spectroscopic catalogue of every star that shines in the northern heavens, so that you can see that the work is going on.

Now, before I say any more about it, I will refer to a diagram which gives an idea of the kind of thing that one sees when these observations are being made.

We will just run through them one by one. There is a very rough and general view of the spectrum of the sun. The actual spectrum of the sun has been thrown on the screen before you, and therefore it will be quite understood that there we have a very rough copy of it for diagrammatic purposes, indicating merely the most obvious among the Fraunhofer lines. When we pass from the sun to α Lyræ, we pass from a star having a relatively large number of lines to one having a small number; and this small number of lines is further remarkable from the fact that the lines are much thicker than those seen ordinarily in the solar spectrum. Keeping to the stars which give us spectra of lines, here in α Orionis we get another case in which the lines do not occupy the places occupied by lines in the spectrum of the sun, nor, at the same time, are they so thick as the lines in stars of the Lyra type. We can also learn from this diagram, by the examination of the spectra of α Herculis and β Pegasi, that we get flutings from stars as well as lined spectra. We also see that these flutings are not all exactly in the same place, by which we can infer that the flutings are not all probably of the same chemical origin. Of that further by and by. The use of the diagram is to give a general idea. J. NORMAN LOCKYER

(*To be continued.*)

SCIENTIFIC SERIALS

The American Journal of Science, June.—The Biela meteors of November 27, 1885, by H. A. Newton. From a general survey of the observations made in various places, the author infers that the maximum of the shower was about 6h. 15m. Greenwich mean time; that the total hourly number of meteors visible at one place in a clear sky was at the utmost 75,000; that the densest part of the stream was not over 100,000 miles in thickness; that the meteors of November 27,

[1] *Proc.* Roy. Soc., No. 185, 1878.