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553RD ORDINARY GENERAL MEETING.

HELD (BY KIND PERMISSION) IN THE ROOMS OF THE ROYAL SOCIETY OF ARTS, ON TUESDAY, MARCH 24TH, 1914, AT 4.30 P.M.

THE VERY REVEREND H. WACE, D.D., DEAN OF CANTERBURY, PRESIDED AT THE OPENING OF THE MEETING, AND WAS SUCCEEDED IN THE CHAIR AT 4.50 P.M. BY PROF. D. S. MARGOLIOUTH, D.LITT., LAUDIAN PROFESSOR OF ARABIC.

The Minutes of the preceding Meeting were read and confirmed.

The SECRETARY announced the election of Miss NORAH URE MACKINLAY, PROF. D. S. MARGOLIOUTH, and Dr. F. LAYTON ORR as Associates of the Institute.

The VERY REVEREND THE DEAN OF CANTERBURY opened the proceedings by expressing the great regret which all present must feel for the cause which had prevented the Rev. C. H. W. Johns from giving his expected lecture on "Early Migrations of the Semitic Races." The CHAIRMAN went on to say:

That is a subject of very great importance on which Dr. Johns is one of our highest authorities, and I am sure you will wish your Secretary, Mr. Maunder, to convey to Dr. Johns on your behalf, your regret at the illness which has prevented him coming here on this occasion, and the hope that we shall be able to welcome him here at some later date.

I have no doubt that we owe it to the kind influence of our new Secretary, Mr. Maunder, that this vacancy has been filled by so interesting a subject, and by so competent a lecturer as Dr. Chapman, the Chief Assistant of the Royal Observatory, Greenwich, whom I have now the pleasure to introduce to you. There is perhaps no department of natural science which presents to us such interest, as that which deals with the vast astronomical facts which are being brought before us with ever increasing distinctness day by day. There is only one other subject of the same kind which can rival it in interest, and that is the astonishing minuteness of detail revealed to us by the microscope. What, by a legitimate metaphor, we may call "the stars of the microscope" seem, according to what men of science tell us, to be as numerous and as wonderful as the stars of the heaven above. And it is yet more extraordinary that the very movements of the atoms are like those of the solar system. I will not further encroach upon the time of the Lecturer, who has so much to bring before our notice, but I will now ask Dr. Chapman to address us on "The Number of the Stars."

THE NUMBER OF THE STARS. By SYDNEY CHAPMAN, B.A., D.Sc., F.R.A.S., Chief Assistant at the Royal Observatory, Greenwich.

THE subject of my lecture is the Number of the Stars, a subject which I might almost say did not exist in ancient times, because it was then very generally believed that the stars *had* no number: they were innumerable, infinite in number. In the Bible, for example, we frequently find the number of the stars classed with the sands on the seashore, as an expression for a "multitude which no man can number." We shall see later on that this metaphor does but scant justice to the sands of the seashore, for the number of the stars is really very much smaller than that of the grains of sand.

As we look up to the sky on a clear night, we see a number of stars so great that probably no one in this room has ever thought of trying to count them. The number visible varies with the clearness of the sky and the keenness of the vision of the beholder, so that different observers on different nights and from different stations see different numbers of stars. But the stars visible, separately and discretely, to even the keenest sight and on the clearest night are not nearly so numerous as might be supposed: their number is very limited. But since the stars vary much in their apparent brightness, so that they range from the brightness of Sirius down to those so faint that they are just on the limit of our vision, it is reasonable to suppose that there are stars fainter still, which, if we had better eyesight, we might be able to observe. That indeed is the case; the stars which we can see with our unaided sight have traditionally been divided into classes according to their brightness, classes which are known technically as "magnitudes." Of these magnitudes, there are six for stars within the range of our unassisted sight. The stars of any one class or magnitude are not quite equal in brightness, some being brighter and some fainter than the average brightness of the magnitude. Nevertheless the classification is quite a good working one, and scientific in its principle.

A star is visible to us by the light which we receive from it, and this is focussed by the lens of our eye upon the retina. The impression which the light makes on the retina depends upon the brightness of the beam and its diameter as it enters the eye. Now the pupil of the eye is not always of the same diameter; when we go into a dark place the pupil enlarges, so that more light can enter the eye; thus the amount of light of any given brightness that enters the eye may vary a little, and the impression which the light makes upon us depends upon the two conditions, of the quantity of light entering the eye and its brightness. Since, however, the pupil of the eye does not vary very much in diameter, we must resort to other means if we wish to perceive the light of stars that are intrinsically too faint to produce a sensible impression upon us. If we could enlarge the pupil of the eye indefinitely, stars fainter than the 6th magnitude would no doubt become visible. This is, of course, impossible in itself, but by means of the telescope, we can greatly increase the beam of light from the star which can be collected in the eye and focussed on the retina, so that the telescope enables much fainter stars to be seen than could possibly be viewed by the eye without such assistance.

Every increase in the size of telescopes hitherto has led to an increase in the number of stars rendered visible to us, but in spite of the great advances that have already been made in telescopic power, not even our largest telescope has sufficient light-gathering power to reveal to us half the number of the stars which undoubtedly exist.

Before dealing with the question of the relation between the size of the telescope and the faintness of the stars which we desire that it should reveal to us, it is necessary to say a few words as to the definition of stellar magnitudes, that classification of stars according to their brightness which has been already mentioned.

The light of two candles taken together is of course twice the amount given by one, and the excess of the light of the two over that of one corresponds to a definite difference in the brightness of the two. If now a third candle be added to the two, the increase in the *quantity* of light equals the increase in the light when a second is added to a single candle, but the increase in *brightness* is less in the former case than in the case last mentioned, *i.e.*, the combined brightness of three candles is not greater than that of two in so high a proportion as the brightness of two candles is greater than that of one. To obtain the same *proportionate* increase in the brightness of the light, we must double the number of candles; we must add two to two, just as we added one to one; and if we wish to carry on the process, to obtain the same proportionate increase in brightness once again, we should have to add four additional candles to the existing four.

So it is with the stars; an average star of the 2nd magnitude gives less than half the light of an average first magnitude star; or, in general, two average stars of one magnitude are about equal in light to five average stars of the next. More precisely, a difference of five magnitudes in the light of a star, corresponds to a diminution of light in the ratio of 1 to 100; and a typical star of the 6th magnitude gives only one-hundredth the amount of light of a typical star of the 1st magnitude. In order, therefore, to bring fainter stars down to the 11th magnitude just within the range of visibility of a telescope, we must increase the beam of light entering the eye one hundred times; so that the telescope must have an object glass one hundred times the area of the pupil of the eye. In other words it must be between two and three inches in diameter. In order to reach to stars five magnitudes fainter still, that is to say to render visible stars of the 16th magnitude, the telescope must have an aperture of 28 inches in diameter. Upon this computation, the largest telescope in the world, which is five feet in diameter, will just show stars of between the 17th and 18th magnitude. This is the chief instrument of the Mount Wilson Observatory in California. A still larger telescope, now being built, which in its turn will be the largest telescope in the world, will have a diameter of 100 inches, but this will only enable stars to be seen about 1¼ magnitudes fainter than those visible by means of the great five-foot telescope, now at Mount Wilson. For, when telescopes of dimensions like these are reached, a very great further increase in size is required to obtain only a very small increase in its penetrating power; an immense increase in the size of the instrument, in its cost, and in the difficulty of its manufacture and manipulation, enables the observer to go but a very little way further down the scale of faint stars.

But, in the investigation of faint stars, astronomers are fortunately not confined to those that they can *see*, even with the aid of a great telescope, because here photography comes to

Magnitude.	Number of Stars of each Magnitude.	Total Number of Stars to Magnitude m.	Equivalent Light of Stars.	
			Equivalent Number of 1st Magnitude Stars.	Totals to Magnitude m.
− 1·6	Sirius	1	11	11
− 0·9	Canopus	2	6	17
− 0·0	α Centauri	3	2	19
^{m} 0·0— ^{m} 1·0	8	11	14	33
1·0— 2·0	27	38	17	50
2·0— 3·0	73	111	18	68
3·0— 4·0	189	300	19	87
4·0— 5·0	650	950	26	113
5·0— 6·0	2,200	3,150	35	148
6·0— 7·0	6,660	9,810	42	190
7·0— 8·0	22,550	32,360	56	246
8·0— 9·0	65,000	97,400	65	311
9·0—10·0	174,000	272,000	69	380
10·0—11·0	426,000	698,000	68	448
11·0—12·0	961,000	1,660,000	60	508
12·0—13·0	2,020,000	3,680,000	51	559
13·0—14·0	3,960,000	7,640,000	40	599
14·0—15·0	7,820,000	15,460,000	31	630
15·0—16·0	14,040,000	29,500,000	22	652
16·0—17·0	25,400,000	54,900,000	16	668
17·0—18·0	38,400,000	93,300,000	10	678
18·0—19·0	54,600,000	148,000,000	6	684
19·0—20·0	76,000,000	224,000,000	3	687
All stars fainter than $20^{m}\cdot 0$			3	690

their aid. The eye registers a momentary impression; the photographic plate registers a cumulative effect. The difference between the two can be illustrated by imagining that leaden bullets are being dropped upon a spring balance; if the scale pan is flat, each bullet, as it falls, just depresses the spring, and then rolls off immediately, and the scale pan rises again. If the bullets are falling in a continuous stream, the balance will show a constant small depression of the spring. This last condition is analogous to the impression of light on the eye, but if the scale pan is in the form of a cup, so that it collects and holds the bullets, instead of allowing them to roll off, then, as more and more bullets fall into it, the scale pan sinks lower and lower, and this offers us an analogy to the cumulative action of light on a photographic plate. If particles of dust were slowly falling on the scale pan of a spring balance, the balance would show no appreciable depression due to any one particle, but after a long time enough dust would collect to produce an evident and measurable depression. This example may illustrate how it is possible to photograph very faint stars with the telescope, because the photographic plate accumulates the effect of a constant stream of faint light, concentrated upon it by the lens, and after a long time enables the impression to be recorded of stars far too faint ever to be seen directly by eye with the same telescope; the telescope registers the effect of the light accumulated over a long period of time, while the eye can only register the impression of the moment. Thus the photographic plate can supply us with the images of stars one hundred times as faint as the faintest which can be seen directly by the eye with the same telescope; that is to say, photography adds five magnitudes to our power of detecting faint stars.

The above table gives the number of stars of each magnitude from the very brightest down to the 20th magnitude, those visible to the naked eye being grouped under magnitudes 1 to 6. There is some difference between the scale of magnitude for stars as registered on photographs from the scale adopted for observations made directly by the eye, in other words the visual and the photographic magnitude scales are not identical. The difference between the two scales does not, however, affect the general principle, but whereas there are 3,150 stars down to the 6th magnitude on the photographic magnitude scale, there are in actuality some 6,000 stars visible to the naked eye. This means that the limit for naked eye observations stands at about the magnitude $6\frac{1}{2}$. Of these 6,000 stars, of course only one half can be seen at any one time, as only one hemisphere of the sky can be seen at any moment from a given station. Thus on the clearest night a person with good eyesight can only see distinctly some 3,000 stars. Of course he can see the Milky Way, which is composed of millions of very faint stars, but he cannot isolate their images or see the stars individually.

Down to the 9th magnitude, which is about the limit of visibility in a telescope of between two or three inches aperture, there are just about 100,000 stars, so that quite a small telescope enables us to see more than a dozen times as many stars as can be seen by the naked eye alone, a fact which indicates the tremendous increase in the power of vision which even a small telescope gives as compared with the naked eye. As the table is followed down to the fainter and yet fainter stars, by steps of one magnitude at a time, the number is seen to increase rapidly. Down to the 14th magnitude, the total amounts to over eight millions, or eighty times as many as were registered down to the 9th magnitude. The 14th magnitude is the limit chosen for the great International scheme for photographing the entire heavens in which this country, in conjunction with many others, has taken part, and for a large section of the heavens the stars have already been photographed on this plan, and partly catalogued.

The table shows that if still fainter stars are embraced, and the survey is extended to the 17th magnitude, the total number is increased to 55,000,000, and this is the limit adopted for a series of photographs taken by the enterprise of the late Mr. Franklin-Adams. This remarkable work owed its origin to a suggestion by the late Sir David Gill, pointing out the desirability of a photographic research into the structure of the Milky Way. Mr. Franklin-Adams subsequently extended the programme to embrace the photography of the entire sky. With this end in view, he obtained in 1898 from Messrs. Cooke and Sons a 6-inch photographic lens, designed by Mr. Dennis Taylor to give good definition over a large field. This lens was so successful that a larger one of similar type was ordered; it was delivered in 1903, and was of 10 inches aperture, and 45 inches focal length, giving good images over a field 15 degrees in diameter.

Mr. Franklin-Adams and his assistant Mr. Kennedy used this lens at the Cape Observatory in the years 1903 to 1904, and the southern sky was photographed with exposures of two hours for each plate. After his return to England, Mr. Franklin-Adams built an observatory adjoining his house at Mervel Hill, near Godalming. During the years 1905 to 1909, the northern sky was photographed, the exposure being increased to 2 hours and 20 minutes for each plate, and experiments were made towards the enumeration and classification of the stars and to ascertain the best means of reproducing the charts on paper. In the course of this work, it was found that the northern plates were so superior to those taken at the Cape, that Mr. Franklin-Adams decided to repeat the southern series. Illness prevented him from undertaking this work himself, and in 1909, he presented his 10-inch object glass to the Transvaal (now the Union) Observatory, and arranged for his assistant, Mr. Mitchell, to go to Johannesburg in December of that year. The new series of plates was begun in April, 1910. Mr. Mitchell was unable to complete the whole of the southern plates, and after his return to England, the series was continued by Mr. Wood under the direction of Dr. Innes, the Director of the Union Observatory.

Failing health rendered it impossible for Mr. Franklin-Adams to complete the two projects that he had in mind: the publication of the photographs, and the statistical discussion of the number of stars of different magnitudes in different parts of the sky. It was arranged that the statistical discussion should be made at Greenwich, and the plates, 206 in number, and each about sixteen inches square were presented to the Royal Observatory.

During the last three or four years, sample counts have been taken of these 206 plates, on small areas uniformly distributed over them, and the number of stars in these areas have been carefully ascertained, the stars being classified according to their brightness. This has necessitated a great amount of very heavy work, into the details of which it is not necessary now to enter. The actual brightness of these stars compared on a uniform plan with other stars over each part of the sky has been determined, and in this way the number in the whole sky has been estimated from the sample counts. Counts have been made from 5,000 selected regions, and the number of stars in the whole sky estimated for each magnitude down to the 17th, the table given above being based upon the results of these counts. The total number of stars down to the 17th magnitude, approximately 55,000,000, is therefore derived from this process of sample counts on the 206 plates covering the entire heavens, which the enterprise of the late Mr. Franklin-Adams has provided.

A consideration of the table will show that, as we pass to fainter and yet fainter stars, their number increases very much, and at a hasty glance it might almost seem that their number was really infinite, that they increase without end. But if the table be examined more critically, it will be seen that the total number of stars down to the 6th magnitude, is nearly four times that down to the 5th; but that the total number down to the 10th magnitude, is not quite three times that to the 9th; and the number to the 17th not even twice the number down to the 16th; so that though the number of stars down to any particular magnitude is always larger than the number down to the preceding magnitude, yet the ratio of the increase is continually diminishing. The number of stars of a given magnitude does not increase in so high a geometrical ratio for the fainter stars as for the brighter ones; and a mathematical examination of the actual numbers in the table shows that two conclusions can be drawn with regard to the whole number of stars, seen and unseen.

In the first place it appears from this examination that there *is* a total number of the stars; that is to say that the number of the stars is not infinite. As we go from the number of stars of any one given magnitude to the number of the next fainter magnitude, we are dealing with a series which does not tend to increase without limit: the ratio of increase continually diminishes, and therefore a point will be reached beyond which the actual number of stars of any particular magnitude will no longer be greater than the number of the preceding magnitude. The series becomes a "convergent" one, and the total number of stars must therefore approach a limit; in other words it is finite; an extremely large number as we shall see, but quite a finite one. The stars therefore vary in brightness from Sirius, the brightest star of which we know, down to the 17th magnitude, the limit for the Franklin-Adams photographs; and still fainter than any limit which at present we can possibly reach; indeed very much fainter. In fact there are possibly stars of almost all conceivable degrees of faintness, but their total number is limited, and this conclusion is enforced upon us, and generally accepted, on other grounds beside those indicated above.

In the second place, the series shown in the table and derived from these counts of the Franklin-Adams plates gives us an indication of the limit of magnitude to which we should have to penetrate to secure half the total number of stars. As we have seen, the plates themselves carry us down to the 17th magnitude with the images of some 55,000,000 of stars. This is very far short of half the total number. To attain that limit, we should have to penetrate down six or seven magnitudes fainter still; *i.e.*, to the 23rd or 24th magnitude. It is probable that the great 5-foot telescope of the great Mount Wilson Observatory, which is at present the largest telescope in the world, could by photography, with very long exposures, just reach down to this limit; so that half the stars could now be registered if anyone wished to take the trouble to do it.

The calculations above referred to, lead to the conclusion that the total number of the stars is not less than 1,000,000,000, and that it cannot much exceed twice this amount, so that perhaps we are warranted in saying that it is probably less than 3,000,000,000.

It is interesting to notice that this is comparable with the population of the earth, which is estimated to be about 1,500,000,000. This is also about the number of spores which are produced by half-a-dozen mushrooms.

With these figures before us, we may proceed to enquire what and where are the stars. Omitting details and explanations, the facts that have been already ascertained may be summarized as follows:—

The stars are suns, generally similar to our own in structure, but at immensely great distances from us. The nearest star, so far as we know at present, is that known as Alpha Centauri, and is twenty million of million miles away. In the neighbourhood of the sun, that is to say, within distances not extravagantly greater than this, the stars are probably scattered with some fair approach to uniformity in space, but their brightness varies enormously from one star to another. We know of some stars that are actually one hundred times as bright as the sun, while there are others not nearly so bright, some giving indeed only one ten-thousandth part the light of our sun. On the whole the sun, as compared with other stars, is fairly high up in the scale of brightness.

It can be shown mathematically that if we take any mixture of stars of varying brightness, and repeat this mixture uniformly throughout space, that is to say, if we have throughout all space a uniform distribution of stars, not all of the same brightness but the same kind of mixture everywhere, then the total amount of light which these stars would give to us would not be finite but infinite; the heavens would be one complete blaze of light. And on that basis of a uniform mixture of stars of varying brightness, the relative rate of increase in the number of stars from magnitude to magnitude can be calculated, and it is found that the number of faint stars would increase far more rapidly than they do in fact. From these two arguments, that such a distribution of stars would appear to be infinitely bright, and the actual excess of the rate of increase in the number of stars as calculated over that which is observed, it is clear either that the stars must be distributed so as to become less numerous as we proceed outwards from the sun, or else they must become intrinsically fainter. There is also a third possible explanation, that the light may be absorbed before it reaches us. Without ruling out this latter possibility of there being in space a certain amount of absorption of the light of the stars, it appears that the stars do get less numerous as we proceed outwards from the sun, at any rate in most directions. As the size of telescopes is increased or the time of exposure of photographs is lengthened, more and more faint stars are detected, but it is probable that a point has now already been reached at which a large proportion of the faintest stars revealed are not stars fainter by reason of their greater distance, but are stars intrinsically fainter than those previously detected and that they are mingled amongst them. We are thus led to a conception of the universe as being of limited extent, containing a great number of stars in the form of a huge oblate spheroid, encircled by that great stellar band which we term the Milky Way. This great stellar system is finite, and if we were to travel outwards from the sun, beyond a certain distance, the number of stars would be found to thin out, and finally we should come to a region where there were few stars or none at all.

The stars then are gathered together in a single great system, and much is already known about it. It is a system characterized in its motions (for the stars are moving), its composition (for that is largely known), and in its structure, by unity and order, not less than by its almost unending variety. All these combine to make the stellar universe the most magnificent object of contemplation in the whole range of material things.

The stars may be regarded from another point of view, from which, perhaps, they appear to lose that impressiveness which these large numbers give to them. Yet this is only at first sight, as will speedily appear. When we pass from the total number of the stars to the total amount of light which they give us, we pass from quantities that are impressive by their extreme vastness to quantities that are almost insignificant, for though the stars are so numerous, yet all their vast numbers combined together yield to us very little light indeed. Yet, if we do not realize how faint the great majority of the stars are as they appear to us, we shall not understand how distant they must be, and how great must be that universe which can contain bodies really so vast and so intensely bright, and yet, on account of their distance, apparently so extremely faint.

The table given earlier showed how rapidly the number of faint stars increases, as we go from magnitude to magnitude in the order of decreasing brightness. Their greater faintness, combined with their enormously increased numbers, allows of two possibilities. Does the increase in number as we proceed from one magnitude to the next fainter make the total brightness of each fainter class of star increase, so that the number of stars between one magnitude and the next may be sufficient, in spite of the increased faintness of each star, for their total light to exceed the total light of the magnitude one higher up, or does it make it diminish? The table gives the answer to this question by showing the number of stars of the 1st magnitude which would give an equal amount of light with the stars of each successive fainter magnitude. Stars of the 1st magnitude are the brightest of those that we see by the unassisted sight, and of these a few are really considerably brighter than the average 1st magnitude star. The brightest star is Sirius, which gives eleven times as much light as a typical star of the 1st magnitude. Then comes Canopus, giving six times the light of a 1st magnitude star, and Alpha Centauri, our nearest neighbour in the stellar depths, which is equal to two 1st magnitude stars. Eight stars follow down to the typical 1st magnitude star which together are equal in light to fourteen stars of the 1st magnitude, twenty-seven stars between the 1st and 2nd magnitudes, give an amount of light equal to seventeen stars of the adopted standard, and seventy-three stars between the 2nd and 3rd magnitudes are equal to eighteen stars of the standard magnitude. As the table is followed downward, it will be seen that the equivalent light given by each succeeding magnitude increases till we reach the 10th magnitude, after which it begins to diminish. Thus some idea can be formed of the extreme faintness of these fainter stars. Two million stars between the 12th and 13th magnitudes only give light equal to fifty-one of the standard 1st magnitude, and as we pass to still fainter stars, twenty-five millions between the 16th and 17th magnitudes are only equal to sixteen standard stars.

Beyond the 17th magnitude, the numbers are not derived directly from observation, but have been calculated from the numbers higher up, by a simple mathematical formula, and from this it appears that the stars between the 17th and 18th magnitudes would only give an amount of light equal to ten standard stars, and that the whole mass of stars fainter still would be barely equal to twelve of the 1st magnitude. Thus the total light of all stars, seen and unseen, would, it appears from this table, come to about that of 700 typical stars of the 1st magnitude. It has already been mentioned that half the stars are fainter than the 23rd or 24th magnitude, but their total light, though they number several hundred millions, does not equal the light of a single 1st magnitude star. Perhaps that single consideration gives as good an idea as we can possibly form of their almost unimaginable faintness.

But the table reveals another curious circumstance. The stars visible to the naked eye render to us only about one-fourth the total amount of starlight. If, therefore, all the stars that we can discern individually by our unassisted sight were blotted out, the total amount of starlight would only be diminished by one-quarter. The midnight sky would not be seriously less luminous than it is at present, though it is needless to say its beauty and interest would suffer woefully.

The light which the stars send to us can be measured in another way by comparing it with the light of the full moon. It is, of course, clear to everyone that when there is a full moon the night is much lighter than when there is no moon at all, and we are dependent simply upon the light of the stars. It has been calculated that the total light of all the stars is only one-hundredth that of the full moon. Or the total starlight may be compared to the light of an ordinary electric lamp of 16 candle-power placed at a distance of from 45 to 50 yards. Such a lamp would give us as much light as we receive from all these many millions of stars put together.

But the light of the stars does not reach us with the uninteresting homogeneity which characterizes the light from the ordinary electric lamp. The starlight is differentiated not only in direction and colour but in many other ways, and from these variations, as we learn to interpret them better, we shall gain more and more knowledge of the stellar universe. It is this tiny stream of light, though in its brightness it is only equal to that of an ordinary 16 candle-power lamp, placed at a distance of 45 yards, that has furnished us with all the knowledge of the heavenly bodies which we possess. It is to this that we owe the profound influence which astronomy has exercised upon our ideas of the universe, of man's place in it, and of the almighty power of God.

Discussion.

The Chairman (Professor D. S. Margoliouth): Ladies and Gentlemen, it is my very pleasant duty to ask you to join with me in thanking the Lecturer for his exceedingly lucid and admirable discourse upon a subject which I am convinced is of the greatest interest to all of us. I am sure we all have to thank him, both for his lucidity and also for the beautiful slides with which he has illustrated his lecture. I have, myself, heard a great deal on the subject of the International Photographic Map of the Heavens, because Professor H. H. Turner, the Savilian Professor of Astronomy in Oxford, is a colleague of mine with whom I am much associated, and we in Oxford are very glad to get an opportunity of obtaining fresh information on this abstruse subject when he is lecturing upon it. . . . I do not wish to speak for anyone else in the audience, but for my own part, I can only say that a considerable number of the facts which Dr. Chapman has brought before us this afternoon, were new to me, and I now know a good deal more about the Number of the Stars and the light which we receive from them than I did when I entered this room. I feel sure that all here will join with me in thanking the Lecturer most heartily for his admirable discourse.

Mr. E. Walter Maunder: I think Mr. Chairman, that we owe a very great debt, indeed a double debt, to Dr. Chapman for having come here this afternoon for, as you know, he is not down upon our published programme. The lecture we had expected to have this afternoon, was one which Dr. C. H. W. Johns had promised to give us on "Early Semitic Migrations," but just before the last meeting of the Institute, we received a letter from Dr. Johns saying that failure of health would prevent his fulfilling his engagement. In this great difficulty, I wondered to whom I could turn for help in order that this afternoon should be filled up, and as I knew that Dr. Chapman had just completed an important research upon the subject of the Number of the Stars, I turned to him. I felt when I approached him that it was hardly a fair request that I was making to ask him at such short notice to come and give us an address of so much importance. But he acceded to my request at once with the greatest possible good grace and willingness, and I think we are very deeply indebted to him on this special account, seeing that he had so short a time to prepare the paper for us. We owe a further great indebtedness to him in that he has given us the very latest results of his own special work. It was only at the last meeting of the Royal Astronomical Society that Dr. Chapman read a paper on the Total Light of the Stars, a subject which he has included in the address to which we have just listened.

The work from which Dr. Chapman has derived the results which he has given us this afternoon has been an extremely toilsome one ; it has involved not only the counting of the star images in five thousand areas, carefully distributed over the heavens, but it has meant the creation of standards of stellar magnitude for each order of magnitude under examination, and the estimation of the magnitude of every star image examined. Our debt, therefore, to Dr. Chapman is exceedingly great, both for the self-sacrificing way in which he has come forward to supply our need, for the interest, the value and the freshness of the information which he has given us, and for the admirably clear way in which he has presented it.

THE ASTRONOMER ROYAL (Dr. F. W. DYSON) said that the last time he had had the pleasure of hearing an address in that hall it had been one given by the late Sir David Gill, who was, he believed, one of their Honorary Correspondents. He could not help thinking as he listened to Dr. Chapman's address how pleased Sir David would have been to hear of the progress that had been made, and was still being made, in this particular branch of astronomy, and he could imagine how delighted he would have been with the account which Dr. Chapman had just given of the results which had been obtained—largely from an enterprise which Sir David himself had originally inspired—in this interesting and difficult subject of the dimensions of the stellar universe. He thought that they were warranted in saying that there was on the whole a general agreement amongst astronomers that the universe of stars was bounded : it did not stretch out infinitely. They had now a definite idea as to the number and extent of the stars, and their knowledge concerning them was comparable with, but nothing like so accurate as, their knowledge of the solar system. Modern astronomers were largely concerned with the problem of finding out some analogy to the bright points of light that the stars present to us. The point of view of astronomy is really a descriptive one; astronomy is a descriptive science, and he supposed that that was very largely true of science in general. It gives no precise answer to the questions, "How does this come about?" or "Why does it come?" The answers that it gives are mainly to the question, "What does it resemble?"

In thinking about the Number of the Stars, although that subject is so interesting in itself, it is almost as interesting to recollect how this knowledge has been acquired. It has been acquired by thought, but the thought itself has been supplemented in very curious fashions. It was certainly remarkable that had it not been that people had learnt to shape pieces of glass so as to make spectacles, and had then gradually developed this art of figuring glass until they formed the lenses of which Dr. Chapman has spoken, had it not been for the development of that art, our knowledge of the stars must have remained extremely limited. The telescope was a beautiful and wonderful instrument, simply on the ground that it magnified our faculties so much. The same remark applied to the microscope, and those electrical instruments by which whole series of phenomena had been discovered of which otherwise we should have known nothing at all. When they considered the heavens and the number and brightness of the stars themselves, he thought they would all feel still more impressively that as religious man had always looked with wonder and reverence on the skies, so that the more we learnt concerning them, the more that wonder and reverence was increased.

A MEMBER enquired how it was possible to find out the rate of movement of the stars by means of the spectroscope. Also what was, approximately, the centre of the stellar universe.

Capt. McNEILE asked whether there were not many dark stars, and Mr. M. L. ROUSE asked how long it was since it was thought that the stars were suns.

The LECTURER in reply, said: The first question was as to our knowledge of the motions and of the constitution of the stars revealed to us by the spectroscope. I suppose that we all know, or have been told, that when a railway train is approaching us, and steam is being let off, so that its whistle is blowing, the note appears shriller than when it is going away from us. The sharp note as the train approaches is due to sound waves in the air, which travel with a certain definite speed. If the source of these waves is approaching us, we receive the waves more quickly than if the source were at rest, and if the source is receding from us, we receive fewer waves in a given time. The sensation of shrillness is greater or less according to the greater or less rapidity with which the waves reach our ear. That is analogous to the behaviour of light. The eye is able to discriminate between the rays of light which come to us with different numbers of waves each second, and it discriminates between them by means of the colour sense. The spectroscope enables us to learn of what colours are the various rays of light which go to form a given beam, and by means of it we are able to measure the number of waves reaching us per second in the case of the different component waves. Certain stars, however, send us light, of which the number of waves reaching us per second varies from time to time, and this has been interpreted in the same way as the analogous phenomena of sound, as showing that the source of light is alternately approaching and receding—probably (certainly in some cases) due to the revolution of one star round another just as the earth revolves round the sun. As to the centre of the stellar universe, no one knows exactly where that is, because we do not know the bounds of the universe at all correctly. The centre, like the North Pole or the Equator of the earth, is probably not marked by any definite object, but it is generally considered that our solar system is near the centre of the universe. One reason for this conclusion is that the Milky Way, which appears to be a great band of stars encircling the universe, is seen by us nearly as a great circle in the sky, and is of approximately equal thickness in its different parts, so that we are apparently near the centre of the galaxy, and therefore, according to our ideas of the universe, we must be also near the centre of the latter.

A question was asked about dark stars. In one sense most of the stars of which I have been speaking, are dark stars; that is to say, we never see them with the naked eye. But there are also stars which we have never been able to photograph, which are known only from their effect upon others. With regard to the stars being thought to be suns, it was about the middle of the last century, or perhaps a little earlier than that, that the distances of some stars were first measured. It then became, for the first time, possible to calculate from their distance, the brightness that they would have if they were as near us as the sun is, and consequently how they compared with the sun as to the actual amount of light which they radiated

The Meeting adjourned at 6.20.