grant would be required to discuss the mechanism of respiration in different insects. I do not recollect that any notable progress has been made with the inquiry during the last thirty years, and a new observer would find that much remains to be discovered; it is, however, indispensable that he should employ precise methods of investigation. L. C. M.

THE NUMBER AND LIGHT OF THE STARS.

THE number of stars visible to the naked eye on a clear night, in the whole sky, is roughly 5,000—a very moderate total indeed, in spite of the universal custom of using the number of the stars, in common with that of the sands of the sea, as synonymous with infinity. In all ages mankind in general has rightly preferred rather to admire and wonder at the stars than to count them. In the great problem of the structure of the sidereal universe, however, which astronomers are now attacking with much energy and success, one of the essential data is the number of stars in the different regions of the sky, classified according to their brightness or magnitude.

The telescope early revealed the fact that the stars which by reason of their superior brightness force themselves upon our unaided vision shine forth beyond a host of fainter luminaries, the number of which has never yet failed to show an increase as an augmentation of telescopic or photographic power has enabled us to pierce depths of greater and greater obscurity. These fainter stars enormously outnumber the naked-eye stars, which may be compared with an oceanic island, the tiny, outstanding peak of a great mountain growing ever broader beneath the water level.

The bright stars have been divided into six traditional classes or magnitudes, the brightest being called first magnitude stars, and the faintest visible being termed of the sixth magnitude. Pogson placed this classification on a scientific basis, so that it could be extended to telescopic stars of all degrees of faintness. On the conventional standard scale the ratio of the intensities of two stars differing in magnitude by the amount m is $10^{-0 \cdot 4 m}$. The determination of the magnitude of a star on this scale is not an easy matter, as it involves the measurement of the relative brightness of stars often differing much in luminosity.

Photographic methods have been found most suitable for the purpose; the results are rather different from those obtained by visual methods, especially for stars of different colour, since the photographic plate is more sensitive than the eye to blue rays, and less sensitive to red. Magnitudes determined by ordinary photographic methods are called "photographic magnitudes."

During the past three years the fine series of star charts obtained by the late J. Franklin-Adams has been used in the investigation of the number of stars of determined photographic magnitudes in all parts of the sky. Franklin-Adams, using a specially-designed Taylor-Cooke 10-in. lens covering a wide field, photographed the whole sky on 206 plates each 16 in. square, the scale being 20 mm. to 1°; the photographs were taken (the northern set in England, the southern in South Africa) with exposures of from two to two and a half hours, which sufficed to show stars down to the seventeenth magnitude on most of the plates. From a star of this magnitude we receive only one-millionth as much light as from a second magnitude star. On each plate the stars in twenty-five uniformly distributed sample areas have been counted and classified according to the size and greyness of their images; altogether, therefore, sample counts have been made on more than 5000 regions of the sky, at intervals of 3° apart. The areas examined were of different sizes, being chosen, in accordance with the star density in the particular region, so that about sixty stars should be counted in each. The stars could not be classified according to their photographic magnitude directly from the plates, as stars of different magnitudes might show images, identical in size and greyness, on different plates, owing to inequality of the atmospheric transparency during the exposures on the two plates. The photographic magnitudes of a selection of the stars counted on each plate needed, therefore, to be determined directly, which was done by comparing them with the stars of the North Polar Sequence, a set of stars the magnitudes of which have been given very accurately by Prof. E. C. Pickering of Harvard. Auxiliary photographs for this purpose were taken with the 30-in. reflector at Greenwich. After the application of corrections depending on their position on the Franklin-Adams plates it was then possible to classify all the stars counted, upon a true magnitude basis. This complete reduction has so far been effected for thirty out of the 206 plates counted; the results from the 750 areas for which sample counts were thus afforded have recently been published.[1]

The first point of importance which will be mentioned as one on which the evidence derived from this work is decisive is that of the relation between the condensation of the stars towards the galaxy, and their magnitude. While the very brightest stars show little regularity of distribution (to their irregular grouping, indeed, much of the beauty of the constellations is due), the fainter naked-eye stars show a distinct concentration towards the plane of the Milky Way, their density in the galactic belt of the celestial sphere being about twice that near the poles of the Milky Way; still fainter stars down to the ninth magnitude show this phenomenon in a more marked degree, the density of these stars in the galaxy being three or four times that at the galactic pole. The galactic plane is a fundamental one in modern representations of the sidereal universe, which, following Sir W. Herschel's ideas, picture the stellar system as formed of a large central cluster

[1] Chapman and Melotte: The number of stars of each photographic magnitude down to 17·0m., in different galactic latitudes. Memoirs of the R.A.S., lx., 4.
Chapman: On the total light of the stars. Monthly Notices of the R.A.S., lxxiv.

of stars in the form of an oblate spheroid, equatorially surrounded by a belt of irregular star-clouds composing the Milky Way. In connection with such a theory it is of obvious importance to know whether the condensation towards the galaxy shown by the stars of magnitudes five to nine persists for still fainter stars, and in what degree. Very different views have been held on this matter. In regard to the stars classified according to their visual magnitudes, Kapteyn concluded that the galactic condensation increases very much with diminishing brightness, giving its value for all the stars brighter than 17^m as 45. Pickering, on the contrary, found no marked change in the relative densities in the galaxy and at its poles, down to the thirteenth magnitude (the limit of his data). The counts on the Franklin-Adams plates, based on a photographic magnitude classification, lead to a similar result; the density of all the stars brighter than 17^m in the galaxy does not exceed six times that at the galactic poles, and the ratio is perhaps not more than four. Although it is possible that there may be a systematic change of colour of the stars with increasing faintness, different in different galactic latitudes, which would make results derived from counts of stars of determined *visual* magnitudes differ systematically from those based on photographic magnitudes, yet such evidence upon the point as already exists renders it probable that the galactic condensation is in either case nearly constant from the sixth to the seventeenth magnitude.

On this account the rate of increase in the number of stars per magnitude will be nearly constant all over the sky, so that this rate may conveniently be studied from a table giving the numbers of stars in the whole sky brighter than each magnitude m; this will be denoted by N_m. All the best available data have been embodied in the following table, giving N_m for values of m down to 17. The values of $\Delta_m (= \log N_{m+1}/N_m)$ are also given, as they provide a measure of the geometric ratio of increase in the number of the stars.

TABLE I.—*The Number of Stars in the Whole Sky Brighter than Magnitude m.*

m	N_m	$\log N_m$	Δ_m
2	38	1·58	
3	111	2·05	0·47
4	300	2·48	0·43
5	950	2·98	0·50
6	3,150	3·50	0·52
7	9,810	3·99	0·49
8	32,360	4·51	0·52
9	97,400	4·99	0·48
10	271,800	5·43	0·44
11	698,000	5·84	0·41
12	1,659,000	6·22	0·38
13	3,682,000	6·57	0·35
14	7,646,000	6·88	0·31
15	15,470,000	7·19	0·31
16	29,510,000	7·47	0·28
17	54,900,000	7·74	0·27

The data for the stars of magnitudes 2 to 6 are somewhat uncertain, which accounts for the irregular run of the first few values of Δ_m, but beyond this point the steady decrease in Δ_m is very noticeable. This clearly shows that modern photographic telescopes now penetrate to regions of space where the stars begin to thin out in numbers to a quite considerable extent, for it is easy to prove that if the stars were distributed uniformly throughout space, Δ_m should preserve the constant value 0·6. This assumes, what appears to be fairly correct, that any possible absorption of light in space does not materially diminish Δ_m.

From the numbers in the foregoing table, the following simple rational formula can be derived,

$$\log \frac{dN_m}{dm} = a + bm - cm^2,$$

or, in an equivalent form,

$$N_m = A \frac{1}{\sqrt{\pi}} \int_{-\infty}^{B(m-C)} e^{-x^2} dx.$$

The latter formula, which is the integral of the error curve, implies that the total number of the stars is finite, and this is now generally accepted as true; A represents this total number, while C denotes the magnitude which divides all the stars into two equal groups, those brighter being equal in number to those fainter. A, B, C can be deduced from a, b, c, which are readily obtained from the observed values of N_m, but A is not narrowly determined—its value seems to be not less than 1000 million, and probably not greater than 2000 million, so that the total number of the stars is comparable with the population of the earth (this is roughly estimated as 1600 million). The constant C is more closely determined, and is approximately 23 or 24. Stars of this magnitude could just be photographed, with many hours exposure, with the largest telescope in the world, the 60-in. reflector at the Mount Wilson observatory. There remain, therefore, beyond our present powers of exploration still fainter stars equal in number to all those which could possibly be examined at the present time.

These impressive numbers shrink into a smaller compass when the total *light* of the stars is considered. It may readily be shown that if the formula for N_m is correct, the total intensity I_m of all the stars brighter than magnitude m can be represented by an expression identical in form with that for N_m; but whereas the peak for the error curve, the integral of which represents N_m or I_m, is in the former case (C=23 or 24) beyond the limits of the observed data, in the case of I_m it is well within these limits—in fact, half the total light of the stars comes from those brighter than about $9{\cdot}5^m$. Up to this point the light received from all the stars of magnitude m to $m+1$ increases; beyond this it diminishes rapidly, the increase in the number of the faint stars, great though it is, being insufficient to counterbalance their diminished brightness. Owing to the formula for N_m giving too small a number of bright stars (a defect of little moment for most values of m, in the case of N_m, but of serious importance when the total light of the stars is under consideration), the following table has been constructed from Table I., in order to give the actually-observed light of the stars so far as magnitude 17, the formula being used only beyond this point, where it is quite sufficiently accurate for the purpose. The light is given in terms of the number of first magnitude stars of equivalent intensity. Three very bright stars are given individually.

TABLE II.—*The Equivalent Light of the Stars.*

Magnitude	Number	Equivalent number of 1st magnitude stars	Totals to magnitude *m*
−1·6	Sirius	11	—
−0·9	α Carinæ	6	—
−0·0	α Centauri	2	—
m m			
0·0–1·0	8	14	33
1·0–2·0	27	17	50
2·0–3·0	73	18	68
3·0–4·0	189	19	87
4·0–5·0	650	26	113
5·0–6·0	2,200	35	148
6·0–7·0	6,600	42	190
7·0–8·0	22,550	56	246
8·0–9·0	65,000	65	311
9·0–10·0	174,000	69	380
10·0–11·0	426,000	68	448
11·0–12·0	961,000	60	508
12·0–13·0	2,020,000	51	559
13·0–14·0	3,960,000	40	599
14·0–15·0	7,820,000	31	630
15·0–16·0	14,040,000	22	652
16·0–17·0	25,400,000	16	668
17·0–18·0	38,400,000	10	678
18·0–19·0	54,600,000	6	684
19·0–20·0	76,000,000	3	687
All stars fainters than 20m·0		3	690

It appears that the total light of the stars is approximately equal to that of 700 first magnitude stars. Previous estimates of this number have greatly erred on the side of excess (more than three times the present value having been given, though these estimates should be reduced by about 20 per cent. for comparison with the present one, since they have been expressed in terms of first magnitude stars on the visual scale). The present value can scarcely be much affected by our ignorance as to the exact numbers of stars fainter than 17*m*, as it is a fairly safe deduction from the above formulæ that the stars fainter than 15*m* contribute less than one-eighth of the total light. Indeed, the fainter half of the stars, several hundred millions in number, account for only ¼ per cent. of the total light, about equal to that of four second magnitude stars. It may be of interest, in conclusion, to express the total light of the stars in terms of the light of the full moon and of the standard candle; using some Harvard data for the brightness of these two sources of light, it appears that the full moon is very nearly one hundred times as bright as a star of magnitude −6·1, the light of which would equal the combined light of all the stars, while light of the same intensity would be received from an ordinary 16-candle-power electric lamp at forty-five or fifty yards distance.

S. CHAPMAN.

THE STONE TECHNIQUE OF THE MAORI.[1]

THE Maori have long been famous as past masters in the art of working stone, the ornaments and implements of the beautiful nephrite ("jade") of New Zealand being especially noteworthy. It is, therefore, with peculiar pleasure that we welcome the appearance of a monograph which deals in an adequate manner with this important subject; indeed this is the only complete account we have of stone technique in Oceania. The student must not overlook, however, the beautifully-illustrated monograph on "Ancient Hawaiian Stone Implements," by W. T. Brigham (*Mem. Bernice Pauahi Bishop Museum*, vol. i., No. 4, 1902), in which many implements from New Zealand are figured.

The preparation of the present memoir could not have been entrusted to a more competent student, as Mr. Elsdon Best has gained a deservedly high reputation for his intimate and sympathetic knowledge of the ancient lore of the Maori, and for his acquaintance with the literature of all that pertains to New Zealand. An authoritative account is given of the native terminology for the various kinds of implements and of the stones employed for the blades, as well as of the methods for the manufacture of the ordinary stone tools, the information being culled from numerous published sources and from the natives themselves. There is a certain amount of *tapu* pertaining to the task of cutting nephrite and no woman was allowed to come near the workers, but there was no *tapu* in connection with the working of any other stone. Holes were drilled in stone by means of the cord drill, but the bow drill (with or without a mouthpiece) and the pump drill seem to have been unknown to the Maori in pre-European times. The same appears to hold good for Polynesia, though it is not easy to see how the pump drill of New Guinea could have been introduced by Europeans. Having chipped and bruised his implement into the desired form,

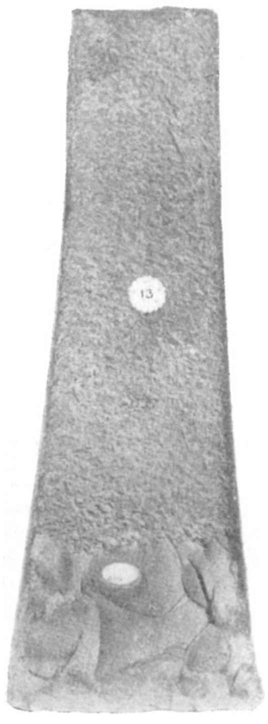

FIG. 1.—Unfinished adze-blade of very fine-grained black aphanite, illustrating the fine symmetrical form attained under the processes of flaking (or chipping) and bruising, without any grinding whatever. The tool could be utilised as an adze if only the lower part of the blade were ground. Length 12½ in. This is also a common Hawaiian type.

[1] Dominion Museum Bulletin No. 4. The Stone Implements of the Maori. By Elsdon Best. (Wellington: J. Macay, Government Printer, 1912.)