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Transmission of Sunlight through the Earth's Atmosphere

W. de W. Abney

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IX. *Transmission of Sunlight through the Earth's Atmosphere.*

By CAPT. W. DE W. ABNEY, *R.E., F.R.S.*

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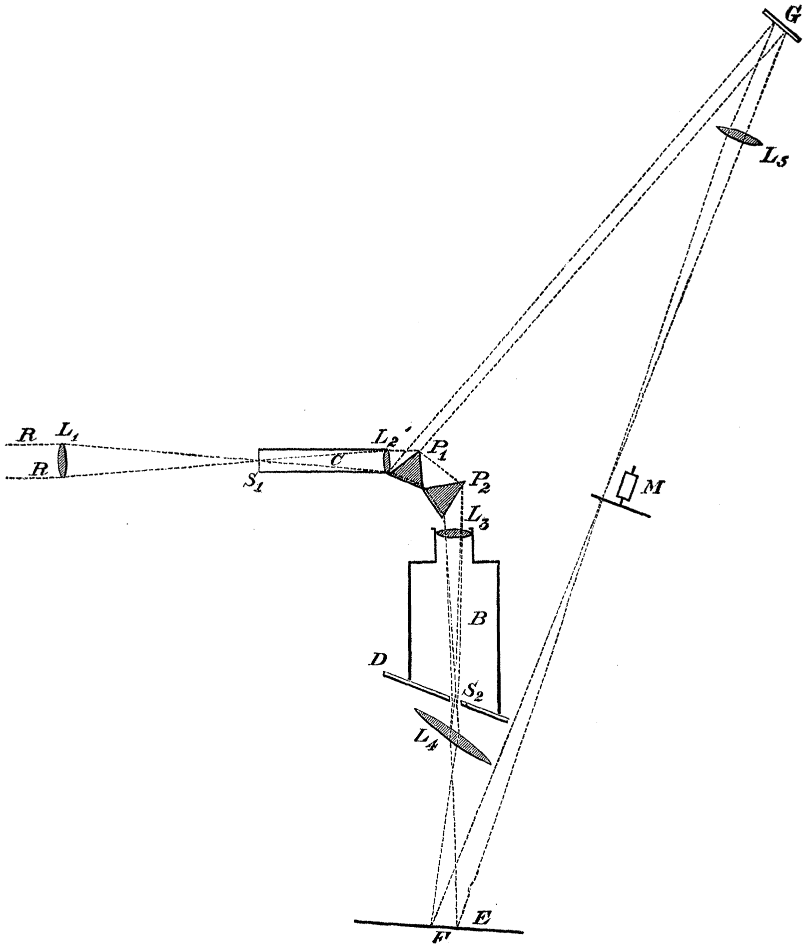
It will be in the recollection of the Royal Society that early last year General FESTING and myself brought forward a method of colour photometry, which is described in a paper in the 'Phil. Trans.,' 1886.

In a postscript, dated June, we added a description of a somewhat modified apparatus in which any variation in the intensity of the light producing the spectrum under measurement was equally reproduced in the comparison-light.

This was effected by causing a part of the light which passed through the slit of the spectroscope to act as the comparison-light. For the sake of easy reference the diagram of the modified apparatus is reproduced in this paper.



R, R, are rays coming from a heliostat, and a solar image is formed by a lens L_1 on the slit S_1 of the collimator C. The parallel rays produced by the lens L_2 are partially refracted and partially reflected. The former pass through the prisms P_1, P_2, and are focussed to form a spectrum by a lens L_3 on D, a moveable screen, in which is a slit S_2. The rays coming through S_2 are collected by a lens L_4 to form a monochromatic image at F of the near surface of the second prism. When D is removed the image of the surface of the prism is white, obtained by tilting the lens L_4 at an angle as shown.

The reflected rays from P_1 fall on G, a silver-on-glass mirror. They are collected by L_5, and form a white image of the prism, also at F.

At M is a small electromotor carrying a disc with moveable sectors, so that any amount of incident light may be cut off.

By this arrangement both the comparison-light and the spectrum itself are formed by the light coming through the slits.

§ I. *Graduation of the Sectors.*

As the intensity of the comparison-light can only be altered by opening or closing the sectors of the rotating discs, it is essential that their graduation shall be good. As a matter of fact, the circles were carefully divided, but the graduation was only regarded as sufficiently accurate when the aperture used was more than 5°, since for very small angles the ratio of any small error in graduation to the aperture used might then not be negligible, which it would be where the aperture was fairly large. As it almost always happened that coloured light had to be measured, which was very much dimmer than the comparison-light diminished by an aperture of 5° in the discs, it became necessary to adopt some other means. To accomplish this, one of the two following methods was employed: 1st, either the light was absorbed by means of coloured glasses; or 2nd, a mirror of unsilvered glass was used. Both of these plans enabled readings of coloured light of feeble intensity to be measured with apertures of the rotating discs, commencing at 90°. With such modified reflected light it was rarely necessary to close the sectors to less than 5°. The glasses used were red, green, blue, or violet, repeated experiment having shown to General FESTING and myself that it makes no difference in the result what colour the comparison-light may be. In every case the ratio of the diminished intensity to the original intensity of the comparison-light was determined, and the measures of the former reduced to the scale of the latter. It has been almost a surprise to find what great accuracy can be attained in reading by the new method. It is a matter of the greatest ease to read within 1 per cent. of the mean of a series of observations when the source of illumination is the sun; the coloured shadows are so steady that the very slightest movement of the slit across the spectrum is at once perceived.

§ II. *Method of observing with Sunlight.*

During the whole of these observations but one instrument was used, so that they compare absolutely with each other. A silvered surface was used to reflect the sunlight on to the condenser, and the image of the central portion of the sun's disc was focussed on the slit and kept upon it. It became a matter of importance that the mirror should remain untarnished, as General FESTING and myself have found that tarnish materially alters the proportions of the reflected rays. These results we intend to bring forward shortly.

§ III. *Times and Places of Observation.*

From November, 1885, to January, 1887, at my laboratory at South Kensington, on every possible occasion when my official duties would allow, I have taken observations of the colour composition of sunlight. But as those before June 1886 were taken by our first plan, I have not included them here. Where my laboratory is situated, in South Kensington, the E.N.E., E., and S.E. are quarters in which the densest parts of commercial London are situated, and consequently, if a wind from any of these quarters prevails, the observations are liable to be marred by smoke; but to the N.N.E., N., N.W., W., and S. there is a comparative freedom from any such source of error; and with a wind blowing from those quarters the sky can be as blue as it is in the most uninhabited part of the country. This is important to remark, since it may be thought that the neighbourhood of a big city like London is an unsuitable one for making sunlight observations. In fact, a comparison of results obtained at South Kensington with those obtained in what is termed pure country air, shows that the latter has no perceptible advantage over the former when the wind is in a suitable quarter.

In September, 1886, I took my apparatus to Switzerland, eventually bringing it to my old observing station on the Riffel, Zermatt, at the height of about 8,000 feet. On three different days I made observations under the most favourable circumstances, which will be described later on. In England my observations were usually made at about either 10, 12, 2, or 5 o'clock; sometimes more than one set was taken on each day. I thought it inadvisable that anyone except myself should take readings, in order to avoid any readings which might be difficult of collation.

§ IV. *Length of Time required for a Set of Observations.*

It may be interesting to note the time it takes to complete a whole set of observations. The way I proceeded was as follows:—The adjustment of the standard light was so made that in most cases the full aperture, 90°, of the rotating discs allowed light to pass which nearly coincided with the illuminating value of the rays of maximum intensity. The aperture was then closed to read 80°, then 70°, and so on till 20°, after which every 5° were used till the final opening was itself 5°. The coloured glass was then placed in front of the comparison-light, or the plain glass substituted for the mirror, and the readings recommenced from 90° until 5° was again reached. The light from the spectrum at this point would ordinarily be so feeble that it would be impossible to read rays of feebler luminosity. Three readings of each setting of the sectors were made and the mean taken. This involved thirty-three readings, or sixty-six in all, and the reverse order of the observations was again carried out, *i.e.*, commencing with 5° aperture and the absorbed (or partially reflected) light up to 90° aperture, and then from 5° back to 90° with an unabsorbed comparison-light. The time of the commencement of each cycle of readings was noted, and the mean taken as the correct time applicable to the mean of the whole set. Twenty-five minutes generally sufficed to make the double set of measures. For two hours on each side of noon the alteration in the sun's zenith distance during twenty-five minutes is not sufficient to make any very material alteration in the relative proportions of the rays, and the mean of the two sets may be taken to be the reading of all the rays at the mean time of observation.

Later in the day, when the sun's zenith distance rapidly increases, the mean values derived from the cycles of observations may not exactly correspond to the mean time, though, perhaps, not very far from it.

§ V. *Comparison of Results.*

I am not at all disposed to think that observations taken during a whole day are likely, as a rule, to give a true value for the coefficients of transmission of the different rays, more particularly in a climate such as that of England. The atmospheric conditions often vary greatly between the evening and morning, and I have come to the conclusion that by combining observations of the sun at different altitudes, but at approximately the same hour, the minimum values of absorption for each ray are more likely to be correctly determined. As a rule, just the contrary mode of proceeding has been taken. In the determination of atmospheric absorption of stellar or lunar light by BOUGUER, SEIDEL, PRITCHARD, MÜLLER, PICKERING, and LANGLEY the days' observations have been compared together. It is probable that the atmospheric conditions obtaining at night are more equable than those in the day.

§ VI. *Atmospheric Conditions most suitable at the Time of Observation.*

A hazy day is essentially an unfavourable day for taking such observations as I had in view, and I have only used, in my final result for minimum absorption, observations made on such days as appeared suitable from a meteorological aspect. A still day is usually a slightly hazy day, and I preferred, where possible, to utilise those days on which there was a breeze blowing from a favourable direction, such as I have already indicated; and, if the sky were partially cloudy, only those days on which the clouds were collected in cumuli, leaving fairly large spaces in the sky of as dark a blue as is obtainable in England.

I would here interpolate that, from the nature of the loss of light by transmission through the atmosphere, it would be impossible to find a sky of that blue-black which is found at high altitudes; the most that can be expected is a deep blue.

Besides the ordinary meteorological observations which were taken at the Museum at South Kensington, I have had the advantage, through the kindness of Mr. Whipple, and by permission of the Meteorological Council, of obtaining complete records from the Kew Observatory for the days I wished to utilise. As this observatory is but a few miles distant from my place of observation; and, as these records are compiled with every accuracy, I have utilised them for my work.

§ VII. *Atmospheric Conditions at the Riffel.*

The morning atmospheric conditions of the Riffel were perfection on each day of my observations, but after 2.30 P.M. they were unsatisfactory. In the mornings the wind was north, a quarter which is well known to Alpine men as a "fine" quarter, and the sun rose with a whiteness of surface which I suppose we can never see at low elevations. The sky was then intensely blue, and improved to a blue-black as the sun gained in altitude. The distant Oberland ranges of mountains were well defined, no visible haze intervening. The shadows on the distant Bietschhorn were black, and the snow-capped summits stood out with almost undimmed whiteness. At Thebes, in Egypt, where I was for three months in 1874–75, I often remarked upon the depth of shadows of the rocks of the Lybian range, distant some three miles from my station; but the shadows in the Oberland Alps, lying some twenty miles or more away, were on this occasion even darker, showing that the haze caused by dust, which is always more or less prevalent in Egypt, was almost absent. The presumable absence of water particles as well as of dust on my days of observation at the Riffel made the atmosphere clearer than it was in Egypt even under the most favourable conditions. I am not stating this only from recollection, but I have records of the fact in photographs which I took at the time at both places. This state of the atmosphere lasted, as I have said, till the afternoon, when a battle for supremacy was waged between the north wind and the wind coming over from the Italian side of the range. The sky then became more or less hazy, and the observations of sunlight were discontinued. The sky at mid-day, as I have said, was of a blue-black, and in fact, with a pocket spectroscope, the spectrum could barely be seen. On a previous occasion, when photographing the sky spectrum at the same place, and, as far as can be judged, under precisely the same conditions, the exposure necessary to give to the plate was at least some seven or eight times that required in England to obtain similar results, indicating an absence of scattered light, and a consequent increase in direct sunlight. I think, for observations on visible radiation, such a locality as I selected in the Alps is preferable to one of equal altitude in a warmer climate. In Professor LANGLEY's report* on his observation at Mount Whitney, he describes the atmosphere below him as being filled with dust, his lower observing station lying in it. Now in the Alps, on days such as I have described, this dust haze is absent. I have looked down some 10,000 feet and failed to discover it. For these observations perfect dryness of air is not a necessity, though undoubtedly for observations of the dark rays and extreme red rays it must be; aqueous vapour, except it be present in very large quantities, does not affect the visible radiation from the sun at these high altitudes. When pointing a pocket spectroscope at a distant horizon, I have failed to see any of the rain-bands even when the atmosphere was notoriously damp. The only time at an elevation of 8,000 feet when I have seen the rain-band has been when rain has been freely falling. I am not asserting that the rain-bands are never present except under such circumstances, but only that I have not seen them. It has been necessary to be somewhat prolix in describing the atmospheric conditions at the Riffel, as my standard solar spectrum is derived from my observations taken on September 15th, 1886, at noon.

§ VIII. *Law of Diminution of Light.*

The observations carried on throughout the year were undertaken more to obtain a meteorological record than for any other purpose, and it was not till November last that any comparison of the curves I had plotted was undertaken, nor did I opine that any set law governed the absorption of the different rays. LANGLEY's results, contained in the volume I have already quoted, rather forbade the idea that any exact or even approximate law prevailed, since certainly his results gave no clue to any. The plotting of the observations was made on squared paper, and through the points thus obtained a smooth curve was drawn by hand; and it will be seen that all the observations lie very close indeed to the curve so drawn. From the curves the value of illumination at each unit of my scale was noted and tabulated. From such tabulation it became easy to try whether any particular law governed the loss of light by different rays after transmission through a thickness of air. Thus the intensities of visible radiation, as measured at the Riffel on September 15th, could be compared with those at South Kensington on July 1st.

A first trial of Lord RAYLEIGH's theoretical law for loss of light caused by the scattering of small particles, $I'=I\epsilon^{-kx\lambda^{-y}}$ (where I′ and I are the transmitted and original intensities, k a constant, x thickness, and λ the wave-length of any ray),

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* 'Professional Papers of the Signal Service (U.S.A.),' No. XV., "Researches on Solar Heat and its Absorption by the Earth's Atmosphere," LANGLEY.

with the observations at these two dates, showed that the observed values could be accounted for by the theory that the loss at the station of lower altitude was due solely to the suspension of fine particles in the atmosphere. Other days' observations in England were compared in the same way, and in very nearly every case the above law held good, kx, of course, varying as the zenith distance of the sun on the different days varied. A comparison was then made *inter se* of the different days' observations, and the above law, as it should, still held good. Now, on the different days in England on which the observations were made, the mean time of observation was known, and consequently the air-thickness. The air-thicknesses were reduced to a uniform barometric pressure of thirty inches of mercury for one atmosphere.

§ IX. *Conditions of Comparison between the Riffel and South Kensington.*

Evidently the air-thickness at mid-day on the 15th September at the Riffel could not be compared with the air-thicknesses at sea-level, as it by no means followed that the atmospheric conditions were the same, *i.e.*, that the scattering particles assumed by the above theory were as abundant at an altitude of 8,000 feet or more as in London at sea-level in a unit volume. It should be remarked that this does not affect the value of the comparison of the observations made between the two places, since the law would equally apply, were the particles per unit volume more or less. The reduction of the observations showed that the particles were fewer in number, which is equivalent to observing sunlight through an atmosphere less than unity at sea-level, though the absolute air-thickness was slightly greater than unity. It is manifest that there is very great utility in making the illuminating value of the spectrum at the Riffel the standard with which to compare the values obtained with greater air-thicknesses at sea-level; since the differences in the proportions of the different transmitted rays are very much accentuated, and any slight errors in observation, which would mask the results when the differences between the observed air-thicknesses are small, are eliminated.

§ X. *Minimum Loss of Light.*

For the purpose of obtaining the minimum loss of light, I have selected observations made on seven days, all of which are compared with the Riffel observations. The atmospheric conditions were favourable, as will be seen by the meteorological Tables annexed. These days are divided into two groups of three, leaving one odd day. The first three days are June 4th, July 5th, and July 21st, when the observations were made with a thickness of about 1·3 atmosphere. The second group comprises observations 29th October, 4th November, and 18th November, when equally satisfactory atmospheric conditions existed, with thickness of about 3·3 atmospheres. The seventh day is 14th October, when the thickness of atmosphere at the time of observation was about 2 atmospheres. From the first group a mean of the air-thicknesses is taken, and also the mean coefficient, and the second group is treated in the same way. Thus

	Air-thickness.	k
June 4.	1·265	·00190
July 5.	1·373	·00211
July 21	1·295	·00220
Means . . .	1·311	·00207

	Air-thickness.	k
October 29 . . .	3·404	·00472
November 4. . .	3·428	·00500
November 18 . .	3·160	·00412
Means . . .	3·331	·00461

To ascertain the coefficient for one atmosphere, we use the formula

$$\frac{x'-x}{z'-z}=\mu,$$

where x' and x are the coefficients for the two groups, and z' and z the air-thicknesses. In the case before us we thus have

$$\mu=\frac{x'-x}{z'-z}=\frac{\cdot00461-\cdot00207}{3\cdot331-1\cdot311}=\cdot00126\,;$$

that is, the formula

$$\mathrm{I}'=\mathrm{I}\epsilon^{-kx\lambda^{-4}}$$

becomes

$$\mathrm{I}'=\mathrm{I}\epsilon^{-\cdot00126\lambda^{-4}.x},$$

x being air-thickness in terms of one atmosphere at sea-level.

For October 14th the air-thickness is 1·973, and the coefficient is ·00284; according to the above formula, the last should be ·00249.

Combining October 14th with the second group, we have μ=·00130, which is not very different from that derived from Groups 1 and 2.

Now the accuracy of reading may vary about 2 per cent. in the yellow of the spectrum and perhaps more in the blue, and it is believed that greater accuracy at present is not obtainable than the figure in the 4th place of decimals. The adopted minimum loss of light from scattering is therefore represented by $I' = I\epsilon^{-\cdot 0013x\lambda^{-4}}$.

Taking the mean of a large number of days, I find that the average value of κ is ·0017.

§ XI. *Langley's Coefficients of Absorption.*

Turning to the work which Langley has published in the volume already alluded to, I find no single instance of coincidence with the above law. For instance, at page 151 he gives a Table of coefficients of transmission, which are as follows in the visible spectrum :—

λ	3580	3830	4160	4400	4680	5500	6150
Coefficient of transmission for one atmosphere	·449	·531	·600	·636	·677	·734	·781

Taking λ 6150, which agrees nearly with my scale number 47, and λ 4400, which agrees nearly with my scale number 57, it will be seen that the coefficient of absorption increases nearly by λ^{-2} instead of by λ^{-4}. How this wide discrepancy arises, I am at a loss to understand. There is one point, however, to be remembered, which is in favour of the observations I have recorded, that within certain limits I was quite independent of any small haze which might have passed between the slit of the collimator and the sun, as the spectrum was compared with one portion of the light coming through the slit, whilst another portion formed the spectrum itself. Now any small amount of white haze would probably give a general absorption without in any large degree altering the *relative proportions* of the component rays, whilst the bolometer readings would be affected considerably; but this would not be sufficient to account for the systematic and great differences between our two results. A glance at the curve of illumination of the solar spectrum will show that, as far as λ 6500 at least, there can be no difficulty in making visual measures. With the width of slits used, the light coming through scale number 47, a candle had to be placed but 5 inches off the screen on a bright summer day at noon to balance the illuminated shadows; and, as the colour of the candle-light and that of the D-light is very nearly of the same tint, no difficulty could be found in judging of the value of the latter according to the old method,* and this gave identical results with the new method adopted, and described at the beginning of this paper. For that reason I have selected Langley's coefficients of transmission of λ 6150 to compare with mine, as no physiological objections can be brought against such comparison.

The following in Column II. are the coefficients he tabulates for a stratum of air equivalent to a column of 1 decim. of mercury for this wave-length :—

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* "Colour Photometry," 'Phil. Trans.,' 1886.

I.	II.	III.	I.	II.	III.
February 15 . .	·963	*·753*	May 2	·974	*·819*
March 23 . . .	·971	*·799*	May 29 . . .	·973	*·813*
,, . . .	·960	*·733*	,, . . .	·976	*·831*
,, . . .	·967	*·775*	June 22 . . .	·979	*·850*
,, . . .	·961	*·740*	September 12 .	·958	*·722*
,, . . .	·968	*·781*	,, .	·959	*·728*
March 29 . . .	·945	*·651*	September 15 .	·978	*·844*
,, . . .	·9*9	. .	,, .	·976	*·831*
March 31 . . .	·930	*·578*	,, .	·975	*·826*
April 24 . . .	·975	*·826*	November 25 .	·967	*·775*
,, . . .	·976	*·831*			
May 1	·961	*·740*			

Now the mean of these numbers in Column II., which are LANGLEY's measures, gives his adopted coefficient of absorption as ·968 for an air-thickness, equivalent to 1 dcm. of mercury, and the coefficient of transmission for one atmosphere (760 mm. of mercury) as 781. The numbers in Column II. are apparently very concordant, but the coefficient of absorption, it must be recollected, is only for a thickness of atmosphere of 1 dcm. of mercury, and the differences are much more apparent if we reduce them all to coefficients for one atmosphere, as we have done in Column III. For instance, if we take the highest and lowest values in Column II., which are ·930 on the 31st March and ·979 on the 22nd June, and reduce them to the coefficients for one atmosphere, we find that they are ·850 and ·578 respectively, and the mean of the series is ·774. Similarly at page 25, Table VI., of LANGLEY's work the highest and lowest coefficients of absorption for an atmosphere equivalent to 1 dcm. of mercury are ·980 and ·872, which at one thickness of atmosphere are ·858 and ·351.

Again, in the Table p. 151 for λ 440, the highest and lowest coefficients for an atmosphere equivalent to 1 dcm. of mercury are ·974 and ·907, which at one atmosphere give coefficients of ·819 and ·476, whilst the lowest but one, which is ·935, gives ·601 for one atmosphere.

These results have been brought forward to show that in the limits of visibility of the spectrum there are wide discrepancies in the coefficients of transmission, as might be expected, in what may be called uncompensated readings, and it appears that by adopting some method analogous to that which General FESTING and myself adopted in our apparatus—of balancing one side of the bolometer with the spectrum and the other with a fraction of total sunlight—perhaps such great differences in the coefficients might be eliminated. It is at first sight somewhat misleading to tabulate coefficients of such small thickness of atmosphere, since in every case the apparent deviation from the mean will appear slight.

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* This figure is obliterated in my copy.

§ XII. *Loss of Light other than by Scattering.*

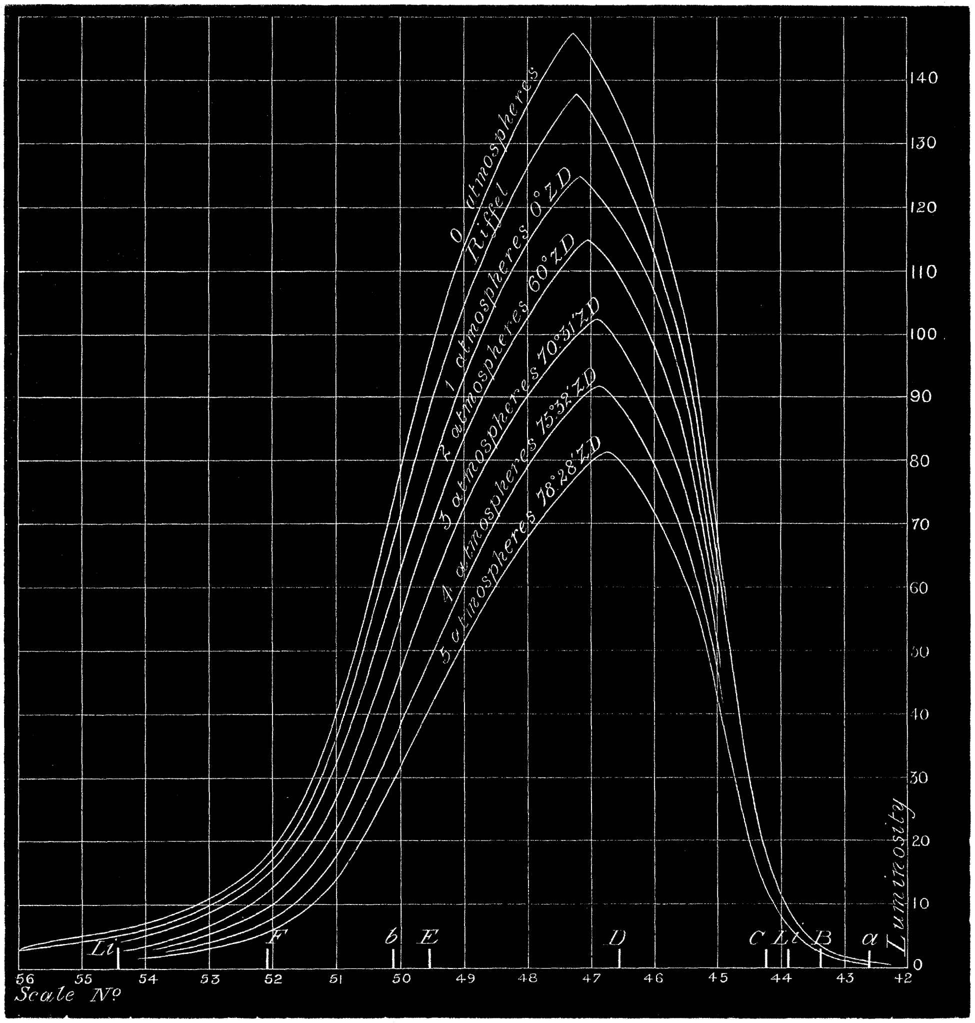
The question arises if there is a loss of light from any other source than the scattering by small particles, and an answer is at once furnished by every-day observation. We know that it is; that a hazy day diminishes sunlight, though often without materially altering the ratio of the components of the light. Now light, *quâ* light, I did not measure on all these occasions; but here the value of the measures taken by means of the candle comes in, assuming that the candle is invariable or only varies slightly. Mr. VERNON HARCOURT tested a candle such as we employ, and got from it a result more satisfactory than with a standard candle; and, as the same brand of candle is always employed, it is believed that the same measurements hold good.

With the instrument unchanged in any respect, the slits having the same width in both cases, an estimation of the total illuminating value of sunlight can be at once ascertained. It happens that on two days which I have selected, viz., 4th June and 29th October, what I may call the candle-value of the spectrum was ascertained. Now the illuminating value of the spectrum, taken by means of the candle, as already has been said, is not such a satisfactory method as that I have latterly employed, and on which the foregoing measures have been based; but an average value for k can be readily ascertained. On the 4th June, about a quarter of an hour later than the time when the printed observations were made, the value of the ray at 47 on my scale was 80, and for the 29th October, also about a quarter of an hour later, it was 62, or 1 to ·775. The value for this ray at the adopted times of observation on the above days is 114·3 and 89·0 respectively, or 1 to ·778. This shows that on these two days any loss of light, except that due to scattering, was very small. On some other days, however, I adopted a different plan, which I had carried out, not for the purpose of applying them to these results, but for estimating the photographic values of skylight and sunlight. Fortunately, also, these measures were carried on at the Riffel: observations of no small value, as it proves.

§ XIII. *Loss of Total Light by Transmission through the Atmosphere.*

Before entering into this more fully, something must be said as to the value of total sunlight as derived from my observations, assuming for the present that there is no diminution of light except from the scattering by the small particles. Having obtained the coefficient of transmission per atmosphere for each ray, it is easy to construct curves representing the luminosity for every air-thickness, and, having so constructed them, to find the value of the areas of each. These areas then represent the values of total illumination which would be observed, were the total light under measurement, as General FESTING and myself have shown in the paper before quoted. Having found the areas, it is easy to see if any law holds good connecting total light and air-thickness. This latter problem is one which astronomers have long studied, and their researches point out that, if I′ and I be the values of the light before and after traversing an air-thickness, θ be the zenith distance, and a the constant of transmission, then $I' = Ia^{-\sec\theta}$.

Diagram 1.



Owing to refraction, the formula $a^{-\sec\theta}$ cannot apply accurately where θ is very large. This was pointed out by Bouguer, who calculated the variation of the thickness of the atmosphere traversed at different zenith distances, allowing for refraction. This calculation was subsequently verified by Professor Forbes, and the results are tabulated in his Bakerian Lecture "On the Transparency of the Atmosphere and the Law of Extinction of the Solar Rays in passing through it," which appeared in the 'Phil. Trans.,' 1842, Part II. Since this volume may be difficult to refer to, I quote part of his Table to show these variations.

Z.D.	Sec Z.D.	Forbes' Value.	Bouguer's Value.
0	1·0000	1·0000	1·0000
10	1·0154	1·0164	1·0153
20	1·0642	1·0651	1·0642
30	1·1547	1·1556	1·1547
40	1·3054	1·3062	1·3050
50	1·5557	1·5550	1·5561
60	2·0000	1·9954	1·9903
70	2·9238	2·9023	2·8998
75	3·8637	3·8087	3·8046
80	5·7588	5·5711	5·5600
82·30	7·6613	7·2343	—
85	11·4737	10·2165	10·2002
86	14·3356	12·1512	12·1401
88	28·6537	18·8825	19·0307
90	Infinite	35·5034	35·4955

Astronomers have made various estimations of the value of what they term absorption, and perhaps no astronomical problem has received more attention than this one. The determination of the coefficient of absorption is a necessary preliminary for ascertaining star magnitudes, and thus has an importance peculiarly its own. Professor LANGLEY, to whose work I shall presently have to refer, made two estimations, one on Etna at 4,000 feet elevation, and another at Mount Whitney, at a still higher altitude. At both of these localities he found a value for the coefficient of transmission to be ·88, though at the latter station he disclaims any great accuracy as likely, which is indeed the case, considering the method he caused to be employed. The other values obtained were as follows :—

PRITCHARD at Cairo and at Oxford, ·843 and ·791 respectively ; BOUGUER ·812 ; SEIDEL ·794 ; and MÜLLER ·825 : or a mean of ·804 at low-level stations.

Professor LANGLEY, assuming from his observations with the bolometer, regards these results as being liable to error. He says, "For be it observed in general terms that, since the rays with large coefficients are represented by diminishing geometric progressions, whose common ratio is near unity, these rays will persist, whilst others with small coefficients are early extinguished. . . . . But what we desire now further to point out is that, according as the difference of these coefficients of transmission for the different portions of the light of the same star is greater, so will the error of the result in treating them as equal be larger : a consequence so obvious that it is only necessary to make the statement in order to have its truth recognised.

"Since it has now been demonstrated that the formula ordinarily employed leads to too small results, it might properly be left to those who still employ it to show that their error is negligible ; but this has never been done. There is possibly an impression that if there were any considerable error its results would become apparent in such numerous observations as have been made all over the world in stellar photometry during this century. But it is, in my opinion, a fallacy to think so; and I believe, as I have elsewhere tried to show, that the error *might* be enormous—that the actual absorption *might* be twice what it is customarily taken, or 40 per cent. instead of 20 per cent., without the errors being detected by such observations as are now made."

It will be found from my observations, and also from those of Professor LANGLEY himself, that the error made by astronomers in not taking into account the different coefficients of absorption of the different rays is negligible.

I will first of all take a value which was derived for atmospheric absorption in which k was ·001183. (Be it remembered, this is not one I adopt, but it was a value obtained by certain combinations.) The areas obtained for the curves of illumination of 0, 1, 2, 3, 4 atmospheres, and which would have been the values observed by any integration method, were as follows:—

740, 657, 572, 505, 441.

Now, as the least atmosphere through which an observer can observe at sea-level is 1, we may take 1 and 4 atmospheres as lying on the true curve and calculate the others from them, using the formula $I' = I\epsilon^{-\mu x}$, where μ is the coefficient of absorption and x the thickness in atmospheres. We find

$$\log 657 = -\mu + \log I$$
$$\text{and } \log 441 = -4\mu + \log I;$$
$$\text{from which } \mu = \cdot 1324.$$

The calculated values for 0, 2, and 3 atmospheres are then 749, 573, and 503 respectively, values which might be said to be identical with the above.

It may be thought that it is owing to a happy accident that these numbers are so close. If we take the value of the coefficient $k = \cdot 0015$, we find that the values of the areas for 0, 1, 2, 3, and 4 atmospheres are—

730, 625, 534, 459, and 396

respectively. Using the logarithmic formula, we find that the value of μ is ·1529 and the values of light passing through the above thicknesses are—

730, 627, 538, 461, and 396

respectively. In this case, if a be the coefficient of transmission,

$$a^x = \epsilon^{-\mu x},$$

and

$$a = \cdot 858.$$

Once more we may take the coefficient of scattering as $k = \cdot 0019$, and we find that areas of the curves for 0, 1, 2, 3, and 4 atmospheres are—

930, 755, 623, 513, and 418.

The values derived from the formula are as follows—

917, 755, 620, 508, and 418.

This gives a, the coefficient of transmission, $=$ ·822. It may be imagined that the same result would not obtain if the coefficients of absorption for the different rays were other than those obtained from Lord RAYLEIGH'S law. We have at hand values of the atmospheric absorption for the different rays which Professor LANGLEY has adopted. They are to be found in the volume to which we have referred.

For the purpose in view, I have assumed that my estimation of the illuminating value for one atmosphere with a coefficient of ·001183 holds good, and constructed curves with the coefficients of absorption which he gives, and then taken the areas as giving the value of total illumination at different thicknesses. The values are, for 0, 1, 2, 3, and 4 atmospheres—

1,000, 657, 393, 236, 142,

and the values obtained by using the logarithmic formula are—

1009, 657, 394, 237, and 142,

a sufficiently close agreement to need no comment; but it should be remarked that, as $\mu =$ ·5109, the coefficient of transmission $a =$ ·6 nearly, a value far lower than has been found by astronomers.

Finally, I give the results by the above method, which are obtained from the areas of the curves derived from the minimum coefficient of absorption ($k =$ ·0013), which are as follows for 0, 1, 2, 3, and 4 atmospheres, viz. :—

762, 662, 578, 504, 439.

Taking 762 and 439 as points on the curve $I\epsilon^{-\mu x} = I'$, we get the following numbers ($\mu =$ ·1385)—

762, 664, 578, 504, 439 ;

which gives the coefficient of transmission $=$ ·869 ; which, it will be seen, is higher than any value assigned to the coefficient of atmospheric transmission that has been obtained by astronomers ; but to this I shall refer presently.

§ XIV. *Observations of Total Light by Colour-blind Persons.*

It was interesting to ascertain what would be the effect of the observations of total light by a colour-blind person as regards accuracy of result in comparison with a normal-eyed person.

To ascertain this, it was supposed that the observer R[*] had taken the luminosity observations, and the curves for the sunlight were reduced proportionally by the amount by which the normal curve of the electric light was shown to be reduced by this observer—an inadmissible assumption, as General FESTING and myself have shown. The curves so reduced were plotted out, and the areas taken.

It was found that, when $k =$ ·0013, for 0, 1, 2, 3, and 4 atmospheres the areas were

532, 455, 389, 334, 287.

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[*] See BAKERIAN LECTURE, 1886.

Taking 532 and 287 as lying on the curve derived from $I' = I\epsilon^{-\mu x}$, the values obtained were as follows—

532, 456, 391, 335, 287;

and the value for the coefficient of transmission was = ·862, a value somewhat lower than that obtained for the normal-eyed person, though not very far from it.

I think in the foregoing enough has been adduced to show that, whether the loss of intensity by different rays in passing through the atmosphere obeys Lord RAYLEIGH's law or follows the observations made by LANGLEY, astronomers have been quite warranted in using the logarithmic law, at all events in observations made to 75° zenith distance.

§ XV. *Photographic Values of the Integral Value of Light through different Air-Thicknesses.*

We thus see that as far as light, *quâ* light, is concerned the method of observing the integration of the different wave-lengths gives results concordant with those obtained by treating the light analytically. The point that next presented itself was as to whether the photographic values of radiation when treated in the same manner would give a similarly satisfactory result. If so, then the photographic values of sunlight which I had obtained could be applied to the question of total value of sunlight on any particular day.

In the 'Proceedings of the Royal Society' I have shown the photographic sensibility of a particular salt of silver for the different rays of the spectrum; and, knowing the day and hour on which that value was determined, and assuming the minimum value of the coefficient for scattering as applicable, after constructing the necessary curves and taking the areas, the following results were obtained at 1, 2, 3, and 4 atmospheres. The values of areas of the curves were—

621, 457, 340, 253,

and those derived from using the formula $I' = I\epsilon^{-\mu x}$, μ being ·2993 and a ·74, were—

621, 461, 342, and 253.

The maximum value of the spectrum on this salt of silver lies well in blue, and it was thought that a theoretical consideration of the value when the photograph was taken on a salt of silver which had a maximum in the extreme violet would be useful, since such a salt—the chloride—is used in ROSCOE's actinometer. The spectrum value of this salt had been previously carefully taken by myself, and the values were applied to each unit of my scale. The values obtained for 0, 1, 2, 3, and 4 atmospheres from the curves were as follow—

690, 413, 246, 147, 87;

the values from the formula $I' = I\epsilon^{-\mu x}$, μ being ·5192 and a ·595, were—

689, 413, 248, 148, 87;

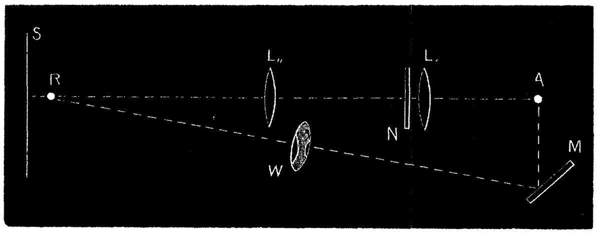
again a sufficiently close value to show that it may be safely used.

§ XVI. *Experimental Photographic and Optical Tests of the Logarithmic Formula.*

A great many tests with turbid water were made to ascertain if the same held good experimentally. The same photographic preparation as that already referred to was used. A cell 6 inches long and 4 inches wide was employed, and different portions of the same photographic plate were used for obtaining impressions of the light acting. The light was allowed to fall through the cell, containing clear water, on an isolated portion of the plate $\frac{3}{4}$-inch square. Eight different exposures were given to various portions of the plate to form a scale of density of deposit. Exposures were given to the other parts of the same plate to light from a constant source passing through the 4-inch and the 6-inch thicknesses of clear and turbid water. The plate was then developed with ferrous oxalate,* fixed, and dried. The density of deposit of each square was next measured by a plan which I have described in the 'Photographic Journal.'

§ XVII. *Mode of measuring the Density of Deposit on a Photographic Plate.*

From the paper in question I have made the following extract:—



"The light, whatever it may be, is placed at A; a lens L_{I} at distance of its equivalent focus, in this case 9 inches. The negative, N, is placed in front of this, and another lens, L_{II}, throws the image on the screen S, in front of which is a rod, R, whose shadow is cast by the light coming through L_{II}.

"This is the ordinary optical lantern form of apparatus. At one side, at a convenient distance, I place a mirror, M, with the angle so adjusted in azimuth that it reflects the light from A over the patch illuminated by the lens L_{II}. This naturally throws another shadow of the rod alongside the first shadow. If desirable, I can place the other lenses, L_{III} and L_{IV}, the latter forming the image of L_{III}, upon the first patch of light. (As a rule, these last two lenses are unnecessary.) The screen, S, may be transparent

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* This developer was used for convenience, as it gave a black deposit, which was useful for subsequent measures.

or opaque, whichever is deemed best. Where the shadows of the rod fall, I cut out a square mask to enable me to view the two shades without distraction to my eyes by glare from adjacent parts. It will be seen that, as the light and the reflected beam are stationary, the method of varying distance cannot be adopted to vary the intensity of the light. To obtain the necessary variation, I employ revolving sectors. These sectors, being connected with a small electro-motor wheel, work with four Grove's cells. The aperture of the sectors can be increased or diminished during motion by a simple arrangement. This is an admirable plan of graduating light, and answers for all purposes of the sort. It will now be apparent that, should the light vary, the results will not be vitiated in the least, since the original light is made to act as the comparison-light as well."

By this arrangement a "density curve" for the exposures given to the plate through the clear water was constructed, and the values of the other exposures through the turbid medium, in terms of the exposure through the clear water, were determined. A screen with squares of different translucencies, which had been carefully measured, was placed in front of the plate.

The following is an example :—

6-inch turbid water.	
Opacity of screen.	Equivalent exposure through clear cell.
39·5	= 9
29·0	= 6·5
22·0	= 5·0
90·5	20·5

Or it required 4·415 times the exposure through the 6-in. turbid cell to be equivalent to a unit exposure through the clear cell.

4-inch turbid water.	
Opacity of screen.	Equivalent exposure through clear cell.
39·5	= 14
29·0	= 11·5
22·0	= 8·0
90·5	33·5

Or it required 2·70 times the exposure through the 4-in. turbid cell to be equivalent to a unit exposure through the clear cell.

In the above example, for convenience sake, the clear cell was exposed for two minutes through rotating sectors having an aperture of 30°.

The 4-inch turbid cell was exposed for five minutes through rotating sectors having an aperture of 45°.

The 6-inch turbid cell was exposed for five minutes through rotating sectors having an aperture of 90°.

Hence the above values have to be multiplied by 7·50 and 3·75 respectively, and we find the relative values of a unit exposure to be—

Clear cell.	4-inch turbid.	6-inch turbid.
1	$\frac{1}{10{\cdot}125}$	$\frac{1}{33{\cdot}1}$

Using the logarithmic formula, we get, taking the clear cell and the 6-in. turbid cell as giving points in the curve,

$$\mu = 5832\,;$$

and the value for the 4-in. cell becomes 1/10·3, which is sufficiently close to 1/10·125 to show that it holds good.

The optical values were also taken by means of the rotating sectors, and found to be—

Clear cell.	4-inch turbid water.	6-inch turbid water.
75·5	26·5	15·5

Using the first and last as giving points lying in the curve derived from the logarithmic formula, we get $\mu' = {\cdot}2639$, and find the values to be 75·5, 26·3, and 15·5 ; a coincidence which is nearly exact.

Now we find that

$$\frac{\mu}{\mu'} = \frac{{\cdot}5832}{{\cdot}2639} = 2{\cdot}21\,;$$

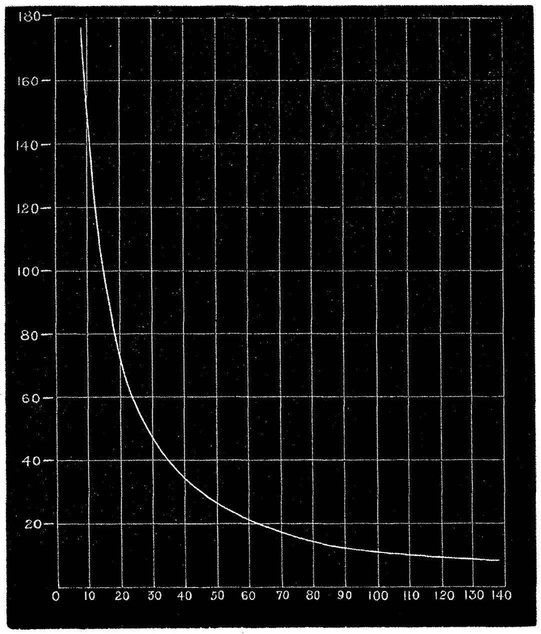
and if we compare the value of the optical measure of the areas of the sun curves with the measure of the photographically derived curves in the same way in the results we have given, it will be found that the factor μ'/μ is very nearly the same as the above. This close approximation leaves no doubt that the logarithmic formula is sufficiently exact to be employed.

Another example may be quoted, which will, with a diagram, still further explain the mode adopted. An exposure to lamp-light was given to portions of plates in succession by means of the rotating disc, for 15 seconds each exposure. The apertures were as follows, and the densities, measured as described, are placed in juxtaposition :—

Aperture.	Relative transparency of negative.
8½°	177
18½	83
28½	51½
38½	34½
48½	27
58½	22
71½	16½
86½	12½
98½	11¾
138	7½
180	5½

Diagram 2 shows this plotted.

Diagram 2.



Photographs were then taken through a clear-water cell, through 3·069-in. turbid water, and through 1·759-in. the same water, the light being admitted through varying apertures of the rotating disc. The results are as follows :—

Clear Cell ; 20 sec. exposure.

Aperture.	Density.	Equivalent on above scale.	
48½	30½	42	Therefore 1 = ·865. Reduced to standard of 1 min. exposure, 1 = 2·595.
38½	42	33	
28½	59	25	
18½	96	17	
134	. .	117	

1¾-in. turbid ; 1 min. exposure.

Aperture.	Density.	Equivalent on above scale.	
17½	104	14	Therefore 1 = ·795.
28½	60½	23	
58½	29	45	
86½	18½	70	
191	. .	152	

3-in. turbid ; 3 min. exposure.

Aperture.	Density.	Equivalent on above scale.	
17½ 28½ 58½ 86½	84 51 22½ 13½	18 28 59 84	Therefore 1 = ·984. Reduced to 1 min. exposure, 1 = ·328.
191	..	189	

Using the first and last for points in the logarithmic curves, we get the observed values

$$2·595, \quad ·795, \quad \text{and} \quad ·328 ;$$

$$\text{calculated} \quad 2·595, \quad ·786, \quad \text{and} \quad ·328 ;$$

$$\mu = ·677.$$

The optical values were next observed, from which $\mu' = ·306$ when $\mu/\mu' = 2·21$, which agrees with the foregoing example.

§ XVIII. *The Measurement of the Photographic and Optical Values of Total Intensity equivalent to the Measurement of a Single Ray.*

A remarkable deduction now presents itself from the fact that, if we divide μ and μ' by k in the results given by plotting the areas, we find that the results are numbers which are about 105 and 235, and these represent wave-lengths 5570 and 4540 respectively ; so that, if we observe the total value of light optically, it is equivalent to observing monochromatic light of λ 5570, and if we use bromoiodide of silver for registering the intensity it is equivalent to measuring a ray of λ 4540.

We may apply any of the results obtained by astronomers to find the value of k.

	Coefficient of atmospheric transmission.	μ	k
LANGLEY (on Etna)	·880	1·274	·00122
*PRITCHARD (at Cairo)	·843	1·704	·00164
,, (at Oxford)	·791	2·333	·00224
BOUGUER	·812	2·070	·00199
SEIDEL and PICKERING	·794	2·311	·00222
MÜLLER	·825	1·924	·00185

With these factors we may construct the curves of illumination for any air-thickness.

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[*] Professor PRITCHARD's maximum value, as far as I have calculated it, is very close to mine, viz., 860.

It should be remarked that the methods adopted in determining the absorption by astronomers practically eliminated any variation due to haze, since the stars were compared *inter se*, which is what the method employed in the foregoing observations also does, though in a more complete manner.

The above plan of obtaining the coefficient of k leads to another very important result, which is that on any day, by taking an optical measure of the *total* light with any standard, such as a candle, and also a photographic measure of the same, we can fix the coefficient k to be applied to each wave-length, and also the loss by general absorption, with very great exactness, as two equations are formed from which each can be deduced.

I would point out that even a simpler method is to expose a sensitive surface to rays coming through an orange medium and also through a blue medium, and measure the relative densities or blackness of the resulting photographs. The exposure through the orange medium will be equivalent to an optical measure.

It must be recollected, however, that each different sensitive photographic compound will give results for different parts of the spectrum.

§ XIX. *Application of the above Law for the Comparison of the Actual Variations in Sunlight.*

Now on various days exposures were made on sensitive paper during the time of observation, and the depth of density measured, and from these measures were derived the intensity of the light acting. If the loss of light is alone caused by the scattering of small particles, and from no other cause, then the values of the ordinates of the different curves belonging to the days on which simultaneous observations were taken ought, at scale number 56, to be proportional to the values obtained from the photographs, the times being those given in the Tables. At the Riffel the photographic value on September 15th was 256; at South Kensington on July 21st, 172; on October 29th, 72; on November 4th, 72. The values of scale number 56, taken from the curves, are as follows:—Riffel, 2·45; 21st July, 1·74; October 29th, ·73; November 4th, ·7; which are fairly in accord. On the other hand, there are values, as for the 8th November and 23rd December, which are not concordant, showing that there was a general absorption of light as well as a scattering in its passage through the atmosphere.

§ XX. *Considerations as to the Amount of Scattering.*

We are bound to ask ourselves what is the cause of the different coefficients for the scattering of light in its passage through the atmosphere. It must be recollected that small particles of any kind will suffice for the purpose, and that it is merely a question of quantity which determines the coefficient. Greater or less amount of dust will affect the question, and dry weather is not the weather in which, from this cause, the scattering should be least. Again, small particles of water must always be more or less present, and it is believed by the writer that these are the most active causes in diminishing the amount of transmitted light. Lord RAYLEIGH has shown that the sizes of the particles have a considerable effect in the scattering, and when we have white mist the scattering of light must be general rather than selective. But it may happen that the general aggregate of particles present may be of sizes which to a greater or less degree refuse to scatter light of wave-lengths not taken between certain limits. Or the sizes of the particles may be so varied that, whilst one gives a limit of scattering for one certain wave-length, another may give a limit for another, and so on till the final outcome may be to give a loss of light not exactly varying as λ^{-4}. This, it appears to me, may be the meaning of this law being obeyed on days which are perceptibly misty, as in some November and December days, and in which the integration method by photography is not in accord with the optical method adopted. On the whole, I am inclined to think that on fine days, near mid-day, with pure blue sky, the water particles are present in numbers, and, if dust be fairly absent, that then we get the minimum loss. At night, when the temperature is diminished, the water vapour probably condenses to give a larger number of small water particles, and hence star observations give a greater value for the coefficient of transmission than I have obtained for the minimum, though the mean value they have deduced is not far from the value I obtain when the coefficient kx is equal to ·0019, which is a value that on several occasions I obtained. That these water particles have much to say to the coefficient of transmission is shown by PRITCHARD's determinations at Oxford and Cairo respectively; the former gave a coefficient of ·791 and the latter ·841.

§ XXI. *Deductions from the Riffel Observations.*

It would be premature to deduce too much from the observations taken at the Riffel. It will be seen that the air-thickness at the Riffel at noon on the day observed is equivalent to 1 atmosphere at sea-level, and that our equivalent value is really a good deal less than that thickness. This means that there are at higher altitudes proportionally fewer particles to scatter the light than at sea-level. I refrain from giving the values I obtained near sunset at the same place, but the value of absorption I found to be startlingly smaller, so much so that my results must be repeated before I can vouch for the deductions to be made. It seems to me that in the Alps we have the most favourable conditions for studying the atmospheric permeability for light, owing, in proper seasons of the year, to the absence of dust. It should be pointed out that the radiations which act on our eyes as light are less absorbed by aqueous vapour than are those radiations which lie in the infra-red, and that it by no means follows that, if the district of the Alps is a good locality for observing the one, it is therefore also good for observing the other. As to that I express no opinion. Probably a spot like Mount Whitney, where LANGLEY observed, might be preferable, more particularly as the long waves are much less scattered than the short waves.

§ XXII. *Relative Colour Brightness of different Parts of the Solar Spectrum.*

ROOD, in his 'Modern Chromatics,' gives the value of the brightness of different parts of the spectrum under the head of different colours. His Table he constructed from VIERORDT'S curve, which General FESTING and myself criticised in our paper on "Colour Photometry." Taking a June day near mid-day, the following values were derived, and they are compared with ROOD'S :—

ROOD'S scale.	ROOD'S nomenclature of colour.	ROOD'S value of brightness.	ABNEY'S value of brightness.
0 to 149	Red	54	65
149 „ 194	Orange-red	140	138
194 „ 210	Orange	80	61
210 „ 230	Orange-yellow	114	77
230 „ 240	Yellow	54	39
240 „ 344	Yellow-green and green-yellow .	327	365
344 „ 447	Green and blue-green	134	183
447 „ 495	Cyan blue	32	33
495 „ 806	Blue and blue-violet.	60	36
806 „ 1000	Violet.	5	3

In this scale A = 0, $a = 40{\cdot}05$, B = 74·02, C = 112·71, D = 220·31, E = 363·11, F = 493·22, G = 753·58, H = 1000.

TABLE of Wave-lengths.

Scale number.	λ	$\frac{1}{\lambda^4}$
44	662	52
45	629	64
46	601	76·5
47	577	90
48	557	104
49	538	120
50	519	138
51	502	158
52	487	178
53	474	198
54	464	216
55	454	235
56	445	255
57	436	276
58	428	298

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, June 5. Time: 10^{h}. Secant Z.D.: 1·258. Barometer: 30·159 inches. Air-thickness: 1·265 atmospheres. kx: ·00190.	I. Ordinates at the Riffel . .	11·6	64·4	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates. . . .	9·5	51	88	102	92·5	75	50	24	11	5·8	3·4	2·1	1·35		
	I. ÷ II. Observed	12·2	1·28	1·29	1·33	1·37	1·4	1·44	1·5	1·55	1·64	1·69	1·74	1·82		
	I. ÷ II. Calculated	12·4	1·26	1·3	1·33	1·37	1·41	1·45	1·51	1·57	1·63	1·69	1·75	1·82		
	III. Ordinates reduced to compare with I.	10·5	57	98·3	114·3	104·1	84	55·4	26·6	12·2	6·5	3·8	2·3	1·5		

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, July 1. Time: 2^{h} 30^{m}. Secant Z.D.: 1·30. Barometer: 30·246 inches. Air-thickness: 1·31 atmospheres. kc: ·00532.	I. Ordinates at the Riffel . .	11·6	64·4	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates. . . .	10	52·5	86	98	86	62	39	18	7·5	3·8	2·05	1·18	·71	·46	·33
	I. ÷ II. Observed	11·6	1·24	1·32	1·39	1·51	1·67	1·87	2	2·27	2·5	2·79	3·08	3·45	3·83	4·38
	I. ÷ II. Calculated	11·6	1·24	1·32	1·42	1·53	1·66	1·84	2·04	2·27	2·53	2·78	3·08	3·43	3·85	4·31
	III. Ordinates reduced to compare with I.	. .	45·7	76	85	73	55·8	34·6	15·5	6·5	3·28	1·82	1·04	·61	·41	·3

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, July 5. Time: 2^{h} 45^{m}. Secant Z.D.: 1·364. Barometer: 30·243 inches. Air-thickness: 1·373 atmospheres. kx: ·00211.	I. Ordinates at the Riffel . .	11·6	64·4	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates. . . .	8·5	47	80	95	85	69	45	21·5	10	5·25	3	1·8	1·61	·8	·5
	I. ÷ II. Observed	1 36	1·37	1·42	1·43	1·49	1·52	1·6	1·67	1·7	1·83	1·91	2·03	2·04	2·2	2·29
	I. ÷ II. Calculated	1·33	1·36	1·4	1·44	1·48	1·53	1·59	1·66	1·73	1·81	1·88	1·95	2·04	2·13	2·23
	III. Ordinates reduced to compare with I.	10·3	55	95	114	102·4	81·4	53·7	25·9	11·6	6·3	3·6	2·2	1·4	9·5	·7

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, July 21. Time: $2^h\ 10^m$. Secant Z.D.: 1·306. Barometer: 29·815 inches. Air-thickness: 1·295 atmospheres. kx: ·0022.	I. Ordinates at the Riffel	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates.	9·5	50	87	100	93	71	48	23	10·5	5·6	3·2	2	1·3	·85	·7
	I. ÷ II. Observed	1·22	1·28	1·31	1·36	1·37	1·45	1·5	1·56	1·62	1·7	1·79	1·82	1·9	2·01	2·13
	I. ÷ II. Calculated	1·24	1·27	1·31	1·35	1·39	1·44	1·5	1·56	1·64	1·71	1·77	1·85	1·93	2·03	2·13
	III. Ordinates reduced to compare with I.	10·4	55·6	96·6	111·5	101·6	80·8	53	25·3	11·5	6·2	3·5	1·9	1·4	·9	·8

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Oct. 14. Time: $11^h\ 35^m$. Secant Z.D.: 1·993. Barometer: 29·710 inches. Air-thickness: 1·973 atmospheres. kx: ·00284.	I. Ordinates at the Riffel	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates.	9	47	80	92	83	64	42	20	9	4·7	2·7	1·6	1·05		
	I. ÷ II. Observed	1·29	1·36	1·43	1·48	1·53	1·64	1·71	1·8	1·88	2·03	2·12	2·27	2·33		
	I. ÷ II. Calculated	1·33	1·38	1·43	1·47	1·54	1·61	1·7	1·8	1·91	2·02	2·12	2·24	2·37		
	III. Ordinates reduced to compare with I.	10	53·3	92	105	94·7	74·5	48·6	22·9	10·8	5·4	3·1	1·8	1·2		

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Oct. 29. Time: $2^h\ 30^m$. Secant Z.D.: 3·369. Barometer: 30·320 inches. Air-thickness: 3·404 atmospheres. kx: ·00472.	I. Ordinates at the Riffel	11·6	64·4	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates.	10	53	87	97	83	65	41	18	8·25	4	2·5	1·3	·8		
	I. ÷ II. Observed	1·16	1·22	1·28	1·4	1·54	1·61	1·76	2	2·12	2·38	2·5	2·71	3·06		
	I. ÷ II. Calculated	1·17	1·24	1·31	1·4	1·5	1·6	1·76	1·93	2·12	2·33	2·54	2·77	3·05		
	III. Ordinates reduced to compare with I.	9·9	47·4	77·7	88·8	77·9	60	37·5	17	7·4	3·8	..	..	·73		

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Nov. 4.	I. Ordinates at the Riffel . .	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
Time: 2^{h} 15^{m}.	II. Observed ordinates	10	52	85	97	83	62	40	18	8	4	2·25	1·2	·8		
Secant Z.D.: 3·443.	I. ÷ II. Observed	1·16	1·23	1·32	1·41	1·53	1·67	1·8	2	2·13	2·38	2·60	3·04	3·22		
Barometer: 29·667 inches.	I. ÷ II. Calculated	1·17	1·24	1·32	1·41	1·51	1·63	1·79	1·98	2·19	2·42	2·64	2·91	3·22		
Air-thickness: 3·428 atmospheres.	III. Ordinates reduced to compare with I.	9	46·4	77·5	87·4	75·2	58	36	16·4	6·8	3·5	1·9	1·1	·7		
kx: ·00500.																

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Nov. 8.	I. Ordinates at the Riffel . .	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·79	1·49
Time: 10^{h} 25^{m}.	II. Observed ordinates	10·75	57	88	98	86	63	37	18	6·5	3·5	1·8	1·1	·66	·41	
Secant Z.D.: 3·35.	I. ÷ II. Observed	1·1	1·13	1·28	1·39	1·48	1·66	1·98	2	2·43	2·63	2·86	3·4	3·69	4·29	
Barometer: 29·789 inches.	I. ÷ II. Calculated	1·1	1·19	1·27	1·39	1·51	1·66	1·85	2·08	2·34	2·64	2·93	3·2	3·69	4·20	
Air-thickness: 3·326 atmospheres.	III. Ordinates reduced to compare with I.	8·5	43·8	72·6	80	68·7	51·9	31·8	14·1	5·8	2·94	1·59	·91	·55	·34	
kx: ·00592.																

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Nov. 16.	I. Ordinates at the Riffel . .	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45		
Time: 2^{h} 35^{m}.	II. Observed ordinates	11	58	90	97	82	60	35	16	6·5	3·2	1·7	·9	·45		
Secant Z.D.: 5·042.	I. ÷ II. Observed	1·05	1·1	1·27	1·4	1·56	1·75	2·06	2·25	2·62	2·97	3·38	4·05	4·45		
Barometer: 29·664 inches.	I. ÷ II. Calculated	1·06	1·15	1·26	1·39	1·53	1·72	2·05	2 25	2·61	2·98	3·41	3·9	4·5		
Air-thickness: 4·985 atmospheres.	III. Ordinates reduced to compare with I.	8	40·5	66·3	72	61	44·7	27	11·7	4·9	2·4	1·23	·68	·40		
kx: ·00712.																

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Nov. 18. Time: $11^h 10^m$. Secant Z.D.: 3·173. Barometer: 30 inches. Air-thickness: 3·173 atmospheres. kx: ·00412.	I. Ordinates at the Riffel . .	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates . . .	. .	54	90	100	89	68	43	20	8·5	4·5	2·5	1·45	·94		
	I. ÷ II. { Observed	. .	1·18	1·27	1·36	1·43	1·53	1·67	1·8	2	2·11	2·30	2·51	2·64		
	I. ÷ II. { Calculated	. .	1·22	1·29	1·36	1·44	1·53	1·66	1·8	1·95	2·12	2·28	2·48	2·68		
	III. Ordinates reduced to compare with I.	. .	51·1	83·2	93·8	84·1	64·4	40·9	18·8	8·4	4·1	2·3	1·4	·9		

South Kensington—place of observation.		Scale numbers.														
		44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Date: 1886, Dec. 23. Time: $1^h 45^m$. Secant Z.D.: 4·973. Barometer: 29·801 inches. Air-thickness: 4·812 atmospheres. kx: ·00848.	I. Ordinates at the Riffel . .	11·6	64	114	136	127	105	72	36	17	9·52	5·73	3·65	2·45	1·76	1·49
	II. Observed ordinates	10·5	60	95	100	83	61	35	14	6	2·8	1·4				
	I. ÷ II. { Observed	1·01	1·07	1·2	1·36	1·53	1·72	2·06	2·56	2·83	3·4	4·1				
	I. ÷ II. { Calculated.	·99	1·09	1·22	1·36	1·53	1·75	2·03	2·42	2·87	3·4	3·96				
	III. Ordinates reduced to compare with I.	6·9	37·2	59·4	63·5	52·4	37·8	22·3	9·4	3·7	1·77	·9				

July 1, 2h 35m.			July 5.			July 21.			October 14, 11h 35m.			October 29.		
Aperture.	Scale Numbers.		Aperture.	Scale Numbers.		Aperture.	Scale Numbers.		Aperture.	Scale Numbers.		Aperture.	Scale Numbers.	
98	47·03	46·94	95	47·00	. .	97·8	47·24	46·77	92	47·40	46·60	94	47·30	46·34
89	47·70	46·15	90	47·60	46·60	87	48·18	45·97	87	47·75	46·52	82·3	48·04	45·82
80·3	48·32	45·65	82	48·20	46·10	81·5	48·52	45·80	76	48·30	45·81	70	48·75	45·43
71·4	48·60	45·42	73	48·80	45·60	76·1	48·61	45·63	65	48·96	45·51	59	49·20	45·14
62·5	49·02	45·15	64	49·20	45·32	70·3	48·84	45·52	54	49·46	45·32	47	49·70	44·90
53·5	49·40	45·05	55	49·61	45·20	68·8	49·14	45·50	49	49·60	45·11	35	50·25	44·64
44·6	49·71	44·82	46	49·92	44·95	65·2	49·18	45·40	43·5	49·96	44·90	29·5	50·40	44·51
35·6	50·10	44·55	37	50·24	44·81	58·0	49·64	45·17	32·5	50·40	44·75	23·5	50·66	44·38
26·7	50·50	44·43	27	50·64	44·66	50·8	49·87	45·06	22	50·90	44·57	17·5	50·92	44·26
17·9	51·00	44·26	20	51·06	44·40	43·5	50·09	44·83	16·5	51·15	44·39	11·7	51·50	44·04
8·9	51·69	43·90	18	51·16	44·50	36·3	50·53	44·60	11	51·75	44·12	7·16	52·15	43·70
4·5	52·68	43·57	10	51·95	43·95	29·0	50·76	44·40	5·5	52·78	43·85	3·6	53·13	48·31
3·5	53·18	43·37	9·1	52·14	44·08	25·3	50·87	44·40	2·7	54·07	43·58	1·8	54·36	42·61
2·75	53·67	43·27	6·6	52·60	43·84	21·7	51·10	44·38	1·35	55·76	43·18	·9	55·60	42·30
1·5	54·46	43·17	4·9	53·14	43·84	14·5	51·56	44·26	·67	60·46	42·91			
1	55·46	43·07	3·3	53·75	43·54	10·8	51·90	44·03						
·5	56·37	42·97	1·6	55·15	43·28	7·25	52·62	43·80						
·25	58·90	42·57				5·43	53·15	43·63						
						3·62	53·84	43·58						
						2·17	54·75	43·35						
						1·45	55·89	43·01						
						·72	57·94	42·67						
						·24	61·59	42·21						

November 4, $2^h\ 15^m$.			November 8, $10^h\ 25^m$.			November 16.			November 18, $1^h\ 40^m$.			December 23, $1^h\ 55^m$.		
Aperture.	Scale Numbers.		Aperture.	Scale Numbers.		Aperture.	Scale Numbers.		Aperture.	Scale Numbers.		Aperture.	Scale Numbers.	
98·7	46·78	..	97	47·22	46·64	100	46·60	..	100	47·25	46·50	100	47·00	..
92·3	47·51	46·34	90	47·77	46·14	95·2	47·25	46·21	95	47·64	46·21	90	47·82	45·75
79	48·16	45·82	74·6	48·55	45·50	85·7	47·80	45·69	90	48·16	46·00	80	48·20	45·40
66	48·81	45·43	60	49·07	45·04	76·2	48·29	45·17	80	48·42	45·56	70	48·65	45·25
52·7	49·46	45·04	45	49·59	44·78	66·6	48·60	45·08	70	48·81	45·30	60	49·05	45·00
39·5	50·04	44·78	30	50·24	44·52	57·1	49·12	44·91	60	49·30	45·04	50	49·40	44·90
26·3	50·50	44·52	15	50·88	44·13	47·6	49·49	44·86	50	49·59	49·91	40	49·80	44·70
19·7	50·70	44·39	7·5	51·54	43·74	38·1	50·90	44·65	40	49·98	44·78	30	50·15	44·50
13·2	51·28	44·13	5·0	52·45	43·48	28·5	50·27	44·39	30	50·37	44·65	20	50·52	44·30
7 9	52·06	43·85	2·5	53·62	43·35	19	50·76	44·20	20	50·76	44·39	18	50·70	44·22
5·3	52·58	43·48	1·6	54·40	43·14	9·5	51·45	43·80	10	51·54	44·13	9	51·53	43·90
2·6	53·74	43·22	·8	55·70	42·83	5·2	52·06	43·48	5	52·58	43·61	6	52·02	43·74
·9	55·70	42·96	·4	57·26	..	3·4	52·75	43·30	2·5	53·62	43·48	3	52·91	43·66
·5	57·78	42·60				1·7	54·00	43·09	1·25	55·70	43·22	1	55·13	43·38
						1·2	54·33	42·83						
						·6	55·82	42·71						

ADOPTED Readings.

Scale number.	June 5.	July 1.	July 5.	July 21.	Oct. 14.	Oct. 29.	Nov. 4.	Nov. 8.	Nov. 16.	Nov. 18. $11^h\ 10^m$	Nov. 18. $1^h\ 10^m$	Dec. 23.	Riffel.
44	9·5	10	8·5	9·5	9	10	10	10·5	11	..	..	10·5	11·6
45	51	52·5	47	50	47	53	52	57	58	54	57	60	64
46	88	86	80	87	80	87	85	88	90	90	90	95	114
47	102	98	95	100	92	97	97	98	97	100	102·5	100	136
48	92·5	86	85	93	83	83	83	86	82	89	88	83	127
49	75	62	69	71	64	65	62	63	60	68	65	61	105
50	50	39	45	48	42	41	40	37	35	43	40	35	72
51	24	18	21·5	23	20	18	18	18	16	20	17	14	36
52	11	7·5	10	10·5	9	8·25	8	6·5	6·5	8·5	7	6	17
53	5·8	3·8	5·25	5·6	4·7	4	4	3·5	3·2	4·5	3·5	2·8	9·52
54	3·4	2·05	3·0	3·2	2·7	2·3	2·25	1·8	1·7	2·5	1·9	1·4	5·73
55	2·1	1·18	1·8	1·7	1·6	1·3	1·2	1·1	·9	1·45	..	..	3·65
56	1·35	·71	1·6	1·3	1·05	·8	·8	..	·45	·94	..	..	2·45
57	..	·46	·8	·85	..	..	..	·41	..	..	..	..	1·76
58	..	·33	·5	·70	..	..	..	..	..	..	..	..	1·49

METEOROLOGICAL Data extracted from the Records of the Kew Observatory.

Date.	Hour.	Barometer readings reduced to 32° and to M.S.L.	Thermometer.		Solar radiation.	Grass minimum.	Wind.		Cloud.			Remarks.
			Dry.	Wet.			Direction.	Velocity.	Amount.	Form.	Direction.	
		inches	°	°	°	°		miles p.h.				
June 4, 1886 .	10 A.M.	30·190	52·9	46·6	. .	. .	N.N.E.	14	2	small cu.	. .	Very fine day, with visibility in afternoon.
	2 P.M.	30·159	58·5	51·4	120	38·8	N.N.E.	11	4	ci. str. cu.	N.N.E.	
June 5	10 A.M.	30·127	52·1	46·5	. .	. .	N.E.	11	2	ci.	Slowly N.E.	Very fine day; mock-sun seen about 6 P.M., and solar halo during evening.
	2 P.M.	30·067	58·4	51·0	117	36·5	N.	10	4	ci. low ci. str.	N.E.	
July 1	10 A.M.	30·285	63·4	54·9	. .	. .	N.E.	13	1	small cu.	E.N.E.	Very fine; ground fog at night.
	2 P.M.	30·246	68·2	59·0	118	40	E.	13	3	cu.	E.N.E.	
July 5	10 A.M.	30·269	70·1	58·8	. .	. .	N.N.W.	9	0	. .	. .	Very fine.
	2 P.M.	30·243	76·5	62·1	133	49	N.W.	9	0			
July 21	10 A.M.	29·867	74·6	68·6	. .	. .	S.E.	13	6	cir.: cir. str. cu.	S.S.W.	Day fine, but night stormy.
	2 P.M.	29·815	81·5	70·1	139	. .	S.	25	6	cir. str., and cir. str. cu.	S.S.W.	
Oct. 14	10 A.M.	29·695	51·7	48·5	. .	. .	W.	10	1	sm. cu.	W.	Day fine; evening overcast, with lunar halo.
	2 P.M.	29·728	56·2	49·6	110	30	W.	12	7	cir. str. cu.	W.N.W.	

METEOROLOGICAL Data extracted from the Records of the Kew Observatory—*continued.*

Date.	Hour.	Barometer readings reduced to 32° and to M. S. L.	Thermometer.		Solar radiation.	Grass minimum.	Wind.		Cloud.			Remarks.
			Dry.	Wet.			Direction.	Velocity.	Amount.	Form.	Direction.	
		inches	°	°	°	°		miles p.h.				
Oct. 29, 1886 .	10 A.M.	30·274	57·1	55·2	. .	. .	S.	13	7	st. det. scud.	S.W.	Fine.
	2 P.M.	30·320	60·5	54·4	104	39	S.W.	15	5	st. cu.	S.W.	
Nov. 4 . . .	10 A.M.	29·911	45·5	43·5	. .	. .	W.S.W.	9	1	high st. cir. str.	? W.S.W.	Very fine day.
	2 P.M.	29·867	52·7	46·4	94	30	S.W.	13	8	str. cu.	W. W.	
Nov. 8 . . .	10 A.M.	29·789	37·6	36·5	. .	. .	S.W.	5	0	. .	. .	Fine, but large amount of sheet cirrus in evening; with lunar halo.
	2 P.M.	29·703	45·9	39·6	89	23	S.W.	13	7	cir. str. cu.	S.W.	
Nov. 16 . .	10 A.M.	29·618	45·3	42·5	. .	. .	W.S.W.	6	6	low ci. det. str.	S.S.W. W.S.W.	Fine day; rain during night.
	2 P.M.	29·656	47·6	41·9	89	41	W.	10	3	ci. str. cu.	S.S.W. W.	
Nov. 18 . .	10 A.M.	29·984	45·4	41·9	. .	. .	W.	15	5	ci. det. str.	N.W.	A very fine day.
	2 P.M.	30·052	48·6	43·1	88	30·9	N.W.	14	2	ci. st. : cu.	N.W.	
Dec. 23 . . .	10 A.M.	29·743	39·0	35·5	. .	. .	W.	20	3	ci. str.	N.W.	Fine and bright.
	2 P.M.	29·803	41·4	37·5	72	29·3	W.N.W.	13	9	ci. str. ragged cu.	N.W.	