PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Transmission of Sunlight through the Earth's Atmosphere. Part II. Loss of Light at Different Altitudes

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PHILOSOPHICAL TRANSACTIONS.

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

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Part II.—Loss of Light at different Altitudes.

Introductory.

XXII.—In a previous communication ('Phil. Trans.,' vol. 178, 1887, A., pp. 251–283) the results of the absorption of sunlight by different thicknesses of atmosphere near sea level were found from measurements of the luminosity of the entire spectrum. The method used was that devised by General Festing and the Author, as detailed in the Bakerian Lecture in 1886. The absorption coefficient for the different thicknesses of atmosphere at sea level was found by measurements made principally at South Kensington, and these were compared with measures taken at the Riffel, above Zermatt, at a height of about 8000 feet. It was shown that when the air thickness is represented by x, the minimum intensity for each ray of the spectrum can be fairly represented by $I' = I\epsilon^{-\cdot 013x\lambda^{-4}}$, and the average intensity by $I' = I\epsilon^{-\cdot 017x\lambda^{-4}}$, I' and I being the transmitted and original intensities, and λ the wave length.

Further, it was shown that even if the absorption of each ray was very different from the above, the integral absorption was very accurately expressed by a^{-z}, z being the air thickness, and a a constant. This corresponds to $a^{-\sec\theta}$ corrected for refraction, when θ is the zenith distance.

This result was arrived at by taking the areas of the curves of luminosity as formed from the actual observations as a measure of the luminosity of the total white light which was decomposed into a spectrum. This was admissible, for in the paper already referred to, it was proved that the sum of luminosities of different rays is equal to their luminosity when compounded.

XXIII.—*Objections to the Use of the Formula.*

The formula involving λ^{-4} is the formula theoretically deduced by Lord Rayleigh for the scattering of light by small particles, and its adoption in this research is open to criticism—one being, that if it were absolutely applicable, the light of the sky should probably exhibit greater polarisation in a direction perpendicular to the sun's rays than it does. There is reason for believing, however, that the higher the station at which such observations are made the more complete is the polarisation. In any case, before this can be considered a valid objection, we have to know more than we do at present regarding the condition of the light reflected back from the earth and from the particles themselves.

It must also be admitted that grosser particles exist on some days, and that for these the loss of light must be in the form of $I' = I\epsilon^{-\mu x}$. They would prevent a certain portion of the total light from reaching the observer, whilst the smaller one would selectively reflect, and hence the law would not hold absolutely good, but the small number of gross particles, compared with the fine ones, would not appreciably alter the formula used except the coefficient κ.

Another objection which has been advanced by Mr. S. P. LANGLEY in a private letter against the adoption of the formula is, that if the spectrum were observed with a large dispersion, it will be seen that as the altitude of the sun diminishes the atmospheric lines increase in intensity, and that these must obey the laws of ordinary absorption. This is an objection which at first sight may seem fatal, not to the correctness of the observations, but to the adoption of the law above quoted; but it must be remembered that these special absorptions occupy a very limited area compared with the rest of the spectrum, and that they would practically disappear when the whole loss of light is under consideration, more especially as they would themselves obey the ordinary law of absorption. At any rate, the formula adopted appears to suit the case, and it must be borne in mind, that the results obtained by the integration of the spectrum luminosities bear out the formula which has been universally adopted by astronomers as representing the corrections to be made in star magnitudes when the stars are observed at different altitudes above the horizon.

XXIV.—*The Integration of the Spectrum Luminosities at different Solar Altitudes equivalent to the Luminosity of Monochromatic Light at the same Altitudes.*

In Section XVIII. of the paper of which this is a continuation it was shown that the areas of the curves obtained from the formula $I' = I\epsilon^{-\kappa x \lambda^{-4}}$ being capable of being represented by $I' = I\epsilon^{-\mu x}$ an important deduction could be made.

For the area of the curve is $\epsilon^{\kappa x}\,(a\epsilon^{\lambda_{\prime}^{-4}} + b\epsilon^{-\lambda_{\prime\prime}^{-4}} + c\epsilon^{\lambda_{\prime\prime\prime}^{-4}} + \text{\&c.})$. a, b, c, &c., being the original luminosities of the different rays, must then be represented by $I = I\epsilon^{-\kappa x \Lambda^{-4}}$ where Λ is some one ray, that is $\mu = \kappa\Lambda^{-4}$ or $\frac{\mu}{\kappa} = \Lambda^{-4}$; $\frac{\mu}{\kappa}$ is a constant and was found from the observations to be 105 (on the scale used for Λ^{-4}), which is equivalent to λ 5770, or a ray near the place of maximum luminosity. Hence the visual observations of total sunlight at different zenith distances are equivalent to observing the alteration in intensity of one single ray of that wave length in its spectrum,* and,

* This, of course, is only true within certain limits, but it holds for any thickness of atmosphere through which observations were taken.

therefore, from such observations κ could be at once determined. It was similarly shown that when a photographic silver salt was employed to register the photographic spectrum it was equivalent to measuring the integrated spectrum with a coefficient of absorption μ', and that this was equivalent to observing the alteration in intensity of a ray λ 4540.

XXV.—*Application to the foregoing Results.*

This being the case, if by any photographic means we can measure the total intensity of white light affecting a photographic compound after passing through various air thicknesses, we ought to be able to find the value of μ_1 in the formula $\epsilon^{-\mu_1 z}$, and if we also observe optically the value of light transmitted through various air thicknesses we shall get the value of μ in the formula $\epsilon^{-\mu z}$. As already stated we know that $\mu = 105\kappa$. Similarly, $\mu' = \Lambda_{,}^{-4}.\kappa$, $\Lambda_{,}$ being the equivalent ray observed.

Therefore

$$\frac{\mu'}{\mu} = \frac{\Lambda_{,}^{-4}}{105} \quad \text{or} \quad \Lambda_{,}^{-4} = \frac{105\mu'}{\mu} \quad \text{and} \quad \kappa = \frac{\mu'}{\Lambda_{,}^{-4}},$$

that is, we can find the single ray which is the equivalent of the whole of the spectrum which is impressed on any photographic compound, and having thus found $\Lambda_{,}^{-4}$ we can at once deduce the value of κ—or the coefficient of scattering by the fine particles.

XXVI.—*Sensitive Compound employed.*

The question which presented itself was as to the best form of sensitive salt to use for convenience and accuracy. A process with a silver salt requiring development was almost impracticable. The exposure necessary to give to sunlight would have been so small that accuracy in timing it would have become a very difficult problem. The chloride of silver paper which darkens by sunlight was experimented with, but it had a very serious drawback. ROSCOE and BUNSEN have shown that chloride of silver paper may be prepared, which, when exposed to the same intensity of light for the same time, will always give the same blackness, but it is impossible to keep this paper for more than a few hours, and it would often be inconvenient to prepare it. Further it can never be predicted when a day will be suitable for making observations, and measurements of its blackness would be difficult except at a fixed observing station. There were also two other desiderata which had to be taken into account; one was that the record of the action of light should be as permanent as possible, and the other that it should be *easy to measure* the action produced by the light. Chloride of silver paper fulfilled neither of these desiderata, since fixing the chloride altered all measurement and the darkening was liable to fade even when the paper was fixed, and it was not easy to obtain accurate measures of the darkening owing to its ruddy colour.

In the comparatively new process of platinotype we have, however, a process which is in every way suitable for the purpose. It may be well to call to mind the principle on which it is based. A solution of ferric oxalate is mixed with a proportion of chloroplatinite of potassium and spread over a sized paper and dried. When light acts on this mixture it reduces the iron salt to the ferrous state proportionately to the intensity of the light and to the time during which it acts. When such an exposed paper is placed on a hot solution of potassium oxalate (neutral) the salt reduces the platinum salt, and metallic platinum (platinum black) is deposited. The black or grey produced by this means is most suitable for measuring in the manner which will subsequently be described.

The other desideratum is also found in this process. The prints are absolutely permanent, and the records obtained by it can be referred to at any time, and re-measured if necessary. Further, the paper keeps well before exposure, and after exposure and before development. When kept dry in an air-tight box with calcium chloride in contact with the air, in fact, it will keep unaltered in sensitiveness for several months. As an example of this it may be mentioned that two pieces of paper cut from the same sheet were each exposed to various and similar intensities of light for equal times. One was developed on the potassium oxalate solution immediately after exposure, and the other was not developed till about six weeks had elapsed; on measuring the greys on the two papers their darkness was found to be precisely the same, and the unexposed parts equally white in the two cases.

It was, for these reasons, determined to use the platinum process for the experiments detailed.

XXVII.—*Instrument used in the Observations.*

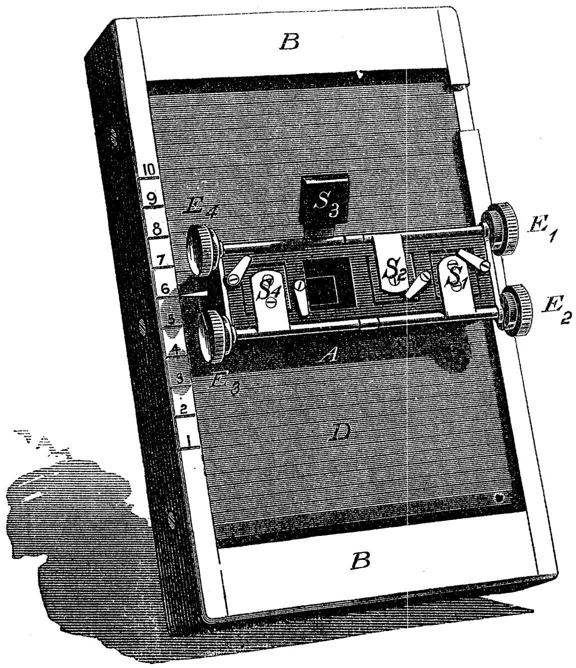
The instrument which was designed for use with this sensitive paper was of the simplest form; one of the conditions which it had to fulfil was whilst exposing the paper it should allow but a small amount of light from the sky to reach it. The latter light is anything but negligible, for absolute measures, in some cases, show that if the photographic intensity of sunlight be called 100, that of the sky might be as much as 50.

To admit only a practical minimum of sky-light, and such as would be negligible in proportion to the sunlight, the instrument was constructed so that only about 10° of skylight fell upon the paper with the sunlight. The diagram, fig. 1, will give an idea of the instrument. B is a frame, in the back and front of the sides of which are cut deep continuous grooves. A wooden shutter, D, formed of narrow laths, glued on to a leather back, runs in these grooves also at the back of the box. This flexible shutter carries an oblong block A, pierced with four square apertures, as shown, which are closed by covers, S_1, S_2, S_3, S_4. The covers can be opened by turning the mill-headed buttons, E_1, E_2, E_3, E_4, which are connected by long pins with the covers.

In order to confine the photographically active spectrum to smaller limits than would be given if the light were unchecked, two thicknesses of cobalt-blue glass were placed in slots running through the length of A. The light had therefore to pass through these two glasses before it reached the paper beneath them.

Experiment has shown that the aperture can be completely uncovered in less than $\frac{1}{10}$th of a second, and closed in the same time; hence no appreciable error in exposure arises from this cause when the exposure lasts several seconds. The paper is placed on a grid, running the whole length of the box behind the flexible shutter, the bars falling between the aperture and different portions of the paper are exposed by moving the block A into different positions. These positions are indicated by a

Fig. 1.



scale engraved on one side of the frame, a mark engraved on the shutter being moved successively to each division of the scale. As there are ten divisions of the scale, it will be seen that forty different exposures can be obtained on the same paper, ten through each aperture. The frame is closed by a wooden back, lined with velvet, which is pressed against the paper by means of a couple of brass springs working against buttons fixed to the frame.

XXVIII.—*Comparison of Results.*

In order to get a scale of blackness, by which to measure the intensity of light acting, it became necessary to have some means of exposing similar paper to light of different known intensities. From the blackness so produced a curve of blackness could be constructed, and the blackness produced by the sun with different exposures could be read off. Now, increase in time of exposure is equivalent to increase in intensity of light acting, at all events, when the exposures are as prolonged as those

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given, that is, if the unit time of exposure be doubled, the same result will be obtained if the intensity of light acting be doubled. This is not a mere theoretical assumption, but one which the writer has amply proved with very numerous experiments. To obtain such a scale, what is known as SPURGE's sensitometer was employed. This is an instrument which was described in detail before the Photographic Society of Great Britain by the inventor. It is only needful to say that it consists of thirty small chambers, 2 centims. in height and 1 centim. square section, placed in six rows, of five chambers each. A brass plate covers one end of these chambers, and in it holes are pierced, of such dimensions that the area of each hole is exactly $\sqrt[3]{2}$ greater than that of the next to it in one row. One of these holes is pierced in the plate exactly over the centre of each chamber. Thus we have a series of graduated intensities of 1, $2^{\frac{1}{3}}$, $2^{\frac{2}{3}}$, 2, $2^{\frac{4}{3}}$, $2^{\frac{5}{3}}$, 4, &c., falling on the bottom of these chambers when the light falling on them comes from a large and equally illuminated surface.

Paper was exposed in this instrument to the light reflected from a large flat card, uniformly illuminated by sun and sky light, and after development the blackness was measured. The paper used was cut from sheets specially prepared by the kindness of Mr. W. WILLIS, of the Platinotype Company, and the sensitiveness of various parts was tried, and if found to be constant, the rest of the sheet was taken to be comparable with those tried. The care with which this paper is prepared is shown by the fact that with several varieties of paper, procured at intervals of several months, the sensitiveness showed no variation in gradation of tints. Latterly the formula seems to have been a little changed, and the sensitometer curve has slightly varied from that found at first; but this is unimportant, as the results are so reduced as to be comparable.

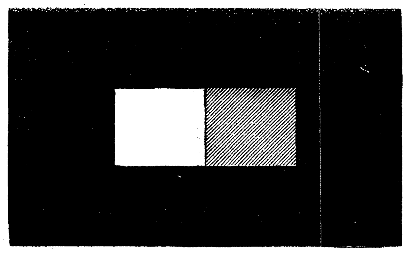
The term "developing" when applied to this paper may be a little misleading. It must not be confounded with the development of plates containing silver salts. In the case of this sensitive paper the amount of platinum deposited is exactly dependent on the amount of the ferric oxalate reduced by light, and if it be exposed to the developing solution after the ferrous salt has reduced the platinum salt in contact with it, no more platinum will be deposited. Hence the deposit of platinum is an exact equivalent of the iron salt reduced, and is a measure of the intensity of light multiplied by the time of exposure. With a silver salt the deposit of silver is increased according to the time during which the developer is in contact with it, and there would, therefore, be a necessity of exposing and developing on the same plate a scale of density together with that produced by the light to be measured.

It is evident that with the platinum process one scale will suffice for a batch of paper which is prepared at one time.

To measure the blackness of the paper a modified RUMFORD method of photometry was employed. A source of light illuminated a small square of white paper (the same as that used in the platinum process to hold the sensitive salt), and one of the blackened squares placed alongside it as in fig. 2.

A rod was so placed that its shadow fell on the white square. A mirror was placed at a little distance to one side of the source of light and the reflected beam was made to illuminate the shadow falling on the white square, and itself to cast a shadow on the dark square. Thus each square was illuminated by the same light, but coming from different points, and the two would be caused to be of equal darkness by placing rotating sectors opening and closing at pleasure in front of one or other of the beams. The amount of light cut off gave a measure of the darkness. Thus, in one case, when both squares were white the sectors had a total aperture of 80° to make them equally luminous; when a grey platinum square was substituted for one of them, the aperture of the sectors was 45°. The grey surface, therefore, only reflected $\frac{45}{80}$ of the light that the white surface reflected. The light to these squares was admitted through an aperture in the front of a closed box, the illumination being judged through an aperture fixed at one corner. The whole apparatus was placed in a darkened and blackened room in which the sole light was that used for the measures.

Fig. 2.



The two following scales of blackness, or, perhaps more accurately, of whiteness, were obtained by this plan, one or other of which will apply to all the measurements given in the paper :—

Comparative intensities of light.	Curve I.	Curve II.
	Amount of white reflected.	Amount of white reflected.
1	100	100
$2^{\frac{1}{3}}$	99·3	99
$2^{\frac{2}{3}}$	97·2	96
2	93·9	91
$2^{\frac{4}{3}}$	89·5	84·5
$2^{\frac{5}{3}}$	84·6	77
4	78	69
$2^{\frac{7}{3}}$	71	60·5
$2^{\frac{8}{3}}$	64	51·7
8	57	43·2
$2^{\frac{10}{3}}$	50	35·5
$2^{\frac{11}{3}}$	43	28·5
16	37	22·7
$2^{\frac{13}{3}}$	31	17·5
$2^{\frac{14}{3}}$	25·5	13·3
32	21	9·8
$2^{\frac{16}{3}}$	17	
$2^{\frac{17}{3}}$	13·5	
64	10·5	

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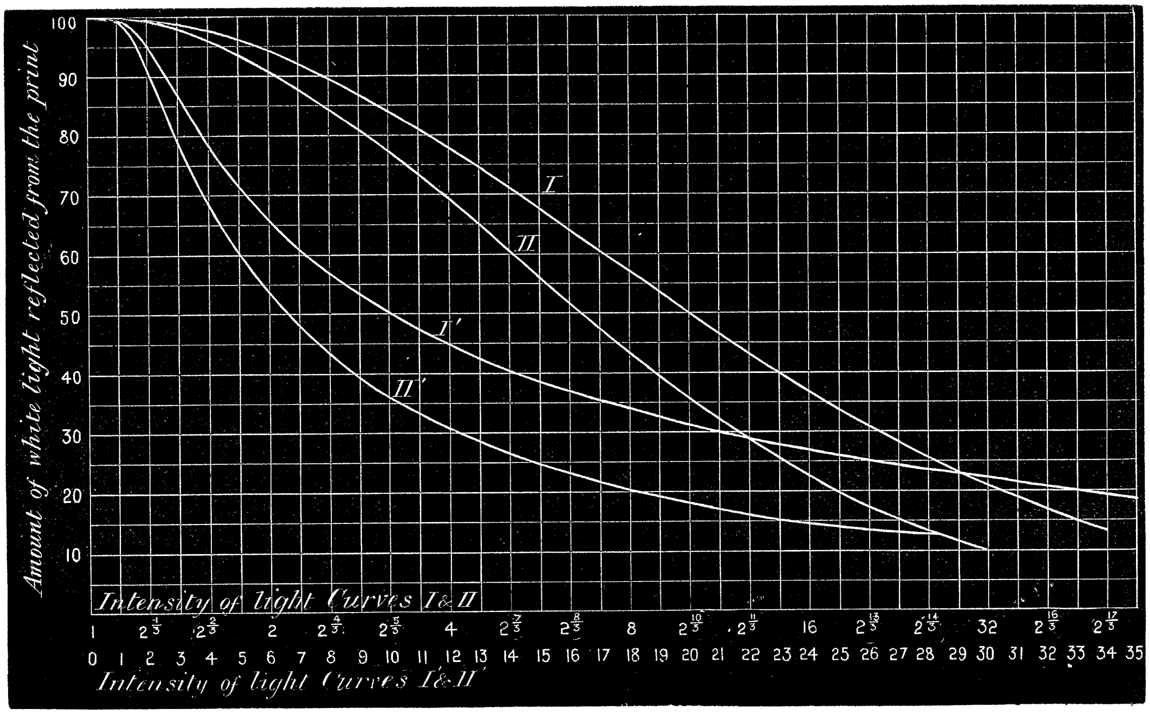
In order to obtain from these measures a scale of the darkening obtained by arithmetical progression in the intensity of light, we have only to recollect that each hole admits $\sqrt[3]{2}$ times the light that the next smaller admits. By easy calculation this scale can be obtained, and is shown in the diagram.

Fig. 3.

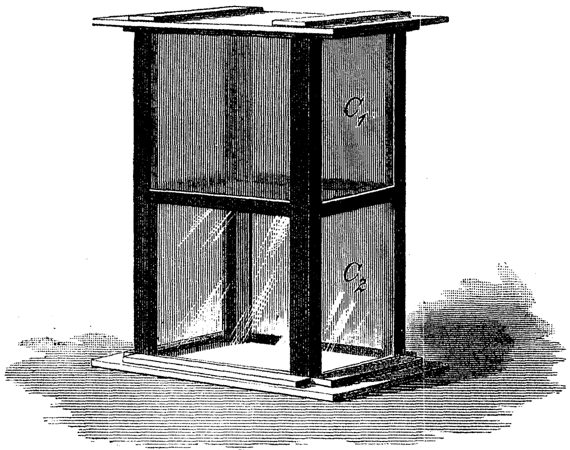


I have shown elsewhere that the curves of blackness on platinum paper can be represented by the formula, $A' = A\epsilon^{-\mu x^2}$ where A′ is the amount of reflected white light, and A the amount reflected from the white paper, μ being a coefficient, and x any power of 2. In this case, for curve I., $\mu = \cdot 00302$, and for curve II., $\mu = \cdot 0103$.

XXIX.—*Method of finding* κ.

In the paper on Colour Photometry which appeared in the 'Phil. Trans.,' General Festing and myself proved that a turbid medium prepared by dropping a solution of mastic dissolved in alcohol into water, obeyed Lord Rayleigh's law, as given above. If, therefore, one part of a piece of platinum paper were exposed for a certain time to sunlight after passing through a cell containing pure water, and a simultaneous exposure made on another portion of the paper with the same light after passing through turbid water prepared as above, the measures of the blackened paper would give the value of μ', the photographic coefficient of absorption in the formula $I' = I\epsilon^{-\mu_1\gamma}$, where γ is the thickness of the turbid medium in any unit we please. Further, if the optical values of the light transmitted were compared when passing through the same media, μ could be found and the value of γ be reduced to atmospheric thicknesses. Now, as the ray is known which, if observed, would give the same alteration in luminosity as that of the whole spectrum, it follows that with these data the equivalent ray for the photographic light can be deduced as shown in § XXV.

Fig. 4.



To ensure accuracy several sets of double cells, C_1 C_2, were prepared, as shown in the figure (fig. 4). The top cell, C_1, contained turbid water, the turbidity being caused by suspended mastic. The mastic was very cautiously precipitated and was thus held in suspension. As a matter of fact turbid water of different turbidities was prepared nearly two years before it was employed; and thus any coarse particles had ample time to settle; for the vessels containing it were kept undisturbed during that period and the liquid was syphoned off as required. The bottom cell, C_2, contained pure water. Behind the cell the exposing box (fig. 1), already described, was placed, and in front of C_2 sectors which rotated by means of clock work. The sectors could be clamped at any desired aperture. The apparatus, as shown, was then placed on a stand at such an angle that the sun's rays fell directly on the platinum paper inside the box B, when the exposing apertures were open. The sectors were closed to the extent which it was judged should suffice to make the blackness of the two exposed squares of platinum paper approximately the same, though it will be seen by the experiments to be subsequently described that this was not always attained. Exposures for different lengths of time were given in each experiment, and consequently any small error in measurement, or from any other cause, became insignificant when the mean was taken.

XXX.—*Examples of the Method.*

The following are examples showing the accord between the different values found for Λ_1^{-4}.

Experiment I.—Sunlight—length of cell (inside measures), 3·15 inches; breadth of cell, 1·7 inches. When light passed through length of cell to the sensitive paper a double sector with an opening of 12° rotated in front of the clear cell. When light passed through the breadth of the cell, the sector opening was 36°·13.

For the cells placed lengthways, the value obtained for the light after passing through the clear cell had to be multiplied 180/12 = 15. When the cells were placed breadthways, the value for the light passing through the clear cell had to be multiplied by 180/36·13 = 4·982.

Cell.	1st exposure.			2nd exposure.		
	Mean reading.		Value from scale.	Mean reading.		Value from scale.
	White = 45.	White = 100.		White = 45.	White = 100.	
3·15 in., clear water	23	51	98	33	73·5	47
3·15 in., turbid „	25	55·5	84	35	78	40

$$\text{1st Exposure } \frac{\text{action through clear water}}{\text{action through turbid water}} = \frac{98}{84} = 1{\cdot}166.$$

$$\text{2nd} \quad ,, \qquad ,, \qquad ,, \qquad = \frac{47}{40} = 1{\cdot}175.$$

$$\text{Mean} = \frac{1{\cdot}166 + 1{\cdot}175}{2} = 1{\cdot}17.$$

The photographic light passing through the clear water = 1·17 × 15 = 17·55 times that passing through the turbid water.

Using the formula $I' = I\epsilon^{-\mu_1 \gamma}$

$$\log 17{\cdot}55 = 2{\cdot}86504 = 3{\cdot}15\mu_1$$
$$\mu_1 = {\cdot}911 \text{ for each inch of turbid water.}$$

Cell.	1st exposure.			2nd exposure.			3rd exposure.		
	Mean reading.		Value.	Mean reading.		Value.	Mean reading.		Value.
	White =45.	White = 100.		White = 45.	White = 100.		White = 45.	White = 100.	
1·7 in., clear water	37	72·5	147	32	63	172	26·5	52	204
1·7 in., turbid „	36	70·5	152	30·5	60	181	25	49	212

$$\text{1st Exposure } \frac{\text{action through clear water}}{\text{action through turbid water}} = \frac{147}{152} = \frac{1}{1\cdot037}.$$

$$\text{2nd} \quad ,, \quad ,, \quad ,, \quad = \frac{172}{181} = \frac{1}{1\cdot052}.$$

$$\text{3rd} \quad ,, \quad ,, \quad ,, \quad = \frac{204}{212} = \frac{1}{1\cdot055}.$$

$$\text{Mean} = \frac{1}{1\cdot05}.$$

The photographic light passing through the clear water $= \frac{4\cdot982}{1\cdot05} = 4\cdot70$ times that passing through the turbid water.

Using the formula $I' = I\epsilon^{-\mu_1\gamma}$

$$\log 4\cdot7 = 1\cdot54756 = 1\cdot7\mu_1$$

$$\mu_1 = \cdot910 \text{ for each inch of turbid water.}$$

The optical measures of the light passing through the clear and turbid cells in the w o directions were

3·15 inches clear water, 48·5 ; turbid water, 18·2.
1·7 ,, ,, 48·5 ; ,, 28·5.

Taking the measurement of the light passing through the 3·15-inch cell as lying on the curve in the formula $I' = I\epsilon^{-\mu\gamma}$,

$$\log 48\cdot5 - \log 18\cdot2 = \mu \times 3\cdot15,$$

$$\mu = 311.$$

If we take the measure of the 1·7-inch water, we have

$$\log 48\cdot5 - \log 28\cdot5 = \mu \times 1\cdot7,$$

$$\mu = \cdot313.$$

$$\text{Mean value} = \cdot312.$$

Now mean value of $\mu_1 = \cdot9105$. Now

$$\frac{\Lambda_1^{-4}}{\mu_1} = \frac{\Lambda^{-4}}{\mu} = \frac{105}{\mu},$$

therefore

$$\Lambda_1^{-4} = \frac{\cdot9015}{\cdot312} \times 105 = 306\cdot6.$$

Experiment II.—Sunlight, June, 1890, midday. Length of cell (inside measures), 3 inches; breadth, 2·1 inches.

When light passed through length of cell to the sensitive paper a double sector, with an opening 36°, rotated in front of clear cell.

When light passed through the breadth, the sector opening was 67°.

Thus, with cells placed lengthways, the value obtained had to be multiplied by 180°/36° = 5. When the cells were placed breadthways, the light passing through the clear cell had to be multiplied by 180/67 = 2·686.

Cells.	1st exposure.			2nd exposure.			3rd exposure.		
	Mean reading.		Value.	Mean reading.		Value.	Mean reading.		Value.
	White = 78.	White = 100.		White = 78.	White = 100.		White = 78.	White = 100.	
3 in., clear . .	70	89·5	21	68	87	23·5	49	63	46
3 in., turbid . .	55	70·5	39	51	65·5	44	32	41	85

$$\text{1st Exposure } \frac{\text{action through clear water}}{\text{action through turbid water}} = \frac{21}{39} = \cdot 538.$$

$$\text{2nd} \quad ,, \quad ,, \quad ,, \quad = \frac{23\cdot 5}{44} = \cdot 534.$$

$$\text{3rd} \quad ,, \quad ,, \quad ,, \quad = \frac{46}{85} = \cdot 541.$$

Mean = ·538.

Photographic light passing through the clear water = ·538 × 5 = 2·69 times that passing through the turbid cell.

Using the formula as before,

$$\mu_1 = \frac{\log 2\cdot 69}{3} = \frac{\cdot 98954}{3} = \cdot 330.$$

Cell.	1st exposure.			2nd exposure.			3rd exposure.		
	Mean reading.		Value.	Mean reading.		Value.	Mean reading.		Value.
	White = 78.	White = 100.		White = 78.	White = 100.		White = 78.	White = 100.	
2·1 in., clear .	57	73	36	41	52·5	62	27	34·5	106
2·1 in., turbid .	48	61·5	48	32	41	85	20	26	140

$$\text{1st Exposure } \frac{\text{action through clear water}}{\text{action through turbid water}} = \frac{36}{48} = \cdot 750.$$

$$\text{2nd} \quad ,, \quad ,, \quad ,, \quad = \frac{62}{85} = \cdot 729.$$

$$\text{3rd} \quad ,, \quad ,, \quad ,, \quad = \frac{140}{106} = \cdot 757.$$

$$\text{Mean} = \cdot 745.$$

Photographic light passing through clear water = ·745 × 2·686 = 2·00 times that passing through turbid water.

Using formula as before,

$$\mu_1 = \frac{\log 2\cdot 00}{2\cdot 1} = \frac{\cdot 69315}{2\cdot 1} = \cdot 330.$$

$$\text{Mean of } \mu_1 = \cdot 330.$$

The optical measures of the clear and turbid cells in the direction of the length were—

3 in., clear water, 36·5 ; turbid water, 26.

$$\frac{\text{Clear water}}{\text{Turbid}} = 1\cdot 4.$$

Using same formula

$$\mu = \frac{\log 1\cdot 4}{3} = \frac{\cdot 33647}{3} = \cdot 1121.$$

The mean value of μ_1 is ·330, and as

$$\Lambda_1^{-4} = \frac{\mu_1}{\mu} \times 105,$$

therefore

$$\Lambda_1^{-4} = \frac{\cdot 330}{\cdot 1121} \times 105 = 309\cdot 1.$$

Experiment III.—Arc electric light; light from crater of positive pole alone used —the arc being cut off by screens.

Length of cell, inside measure, 3 inches; breadth, 1·7 inch. When light passed through length of cells a double sector of $16\frac{1}{2}°$ rotated in front of the cell containing clear water. When passed through the breadth of the cell 28°.

For the cells placed lengthways the value of the light passing through the clear cell had to be multiplied by 180/16·5 = 10·91, when placed breadthways 180/28 = 6·43

Cell.	1st exposure.			2nd exposure.		
	Mean reading.		Value.	Mean reading.		Value.
	White = 78.	White = 100.		White = 78.	White = 100.	
3 in., clear .	40	51·5	63	41	53	61
3 in., turbid .	54	69	40	53	70·5	39

$$\text{1st Exposure } \frac{\text{action through clear water}}{\text{action through turbid water}} = \frac{63}{40} = 1{\cdot}575.$$

$$\text{2nd } \quad ,, \quad ,, \quad ,, \quad = \frac{61}{39} = 1{\cdot}564.$$

$$\text{Mean} = 1{\cdot}57.$$

Photographic light passing through clear water = 1·57 × 10·91 = 17·1 times that passing through the turbid water.

Taking the formula as before

$$\mu = \frac{\log 17{\cdot}1}{3} = \frac{2{\cdot}8390}{3} = {\cdot}946.$$

Cells.	1st exposure.			2nd exposure.			3rd exposure.		
	Mean reading.		Value.	Mean reading.		Value.	Mean reading.		Value.
	White = 78.	White = 100.		White = 78.	White = 100.		White = 78.	White = 100.	
1·7 in., clear .	54	69	40	57	73	36	68	87	22·5
1·7 in., turbid .	47	60	50	50	64	45	64	82	28

$$\text{1st Exposure } \frac{\text{action through clear water}}{\text{action through turbid water}} = \frac{40}{50} = {\cdot}800.$$

$$\text{2nd } \quad ,, \quad ,, \quad ,, \quad = \frac{36}{45} = {\cdot}800.$$

$$\text{3rd } \quad ,, \quad ,, \quad ,, \quad = \frac{22{\cdot}5}{28} = {\cdot}800.$$

$$\text{Mean} = {\cdot}800.$$

Photographic light passing through clear water = ·8 × 6·43 = 5·058 times that passing through the turbid water.

Using formula as before

$$\mu_1 = \frac{\log 5{\cdot}06}{1{\cdot}7} = \frac{1{\cdot}62136}{1{\cdot}7} = {\cdot}953.$$

The optical measures of the clear and turbid cells—

3 inches, clear water 59, turbid, 22·5,
1·7 inch, ,, 59, ,, 34.

Taking the light through the 3-inch length of the cell as lying on the curve and using the formula

$$\mu = \frac{\log 59 - \log 22{\cdot}5}{3} = \frac{1{\cdot}77495 - {\cdot}81093}{3} = \frac{{\cdot}96402}{3}$$
$$= {\cdot}321.$$

Taking 1·7-inch breadth of the cell

$$\mu = \frac{\log 59 - \log 34}{1{\cdot}7} = \frac{1{\cdot}77495 - 1{\cdot}22377}{1{\cdot}7},$$
$$= \frac{{\cdot}55118}{1{\cdot}7} = {\cdot}324.$$

Mean of these values = ·3225.
Mean of μ^1 = ·950.

$$\Lambda_1^{-4} = \frac{\mu_1}{\mu} \times 105 = \frac{{\cdot}950}{{\cdot}3225} \times 105,$$
$$= 309{\cdot}3.$$

From these three experiments we may derive a very good approximation to the true value of Λ_1. The following are the values obtained for Λ_1^{-4}—

1st experiment	306·6
2nd ,, ...	309·1
3rd ,, ...	309·3
Mean	308·3

Therefore

$$\Lambda = 4244 \text{ wave length.}$$

That is, the variation in the intensities of the spectrum, as photographed on platinum paper, is the same as would be observed if a ray of λ 4244 were isolated and the variation in its intensity were observed optically or otherwise.

Further, it must be observed that if we find μ_1 from the photographs, we can at once find μ for the visual intensity; for since

$$\frac{\mu_1}{\mu} = \frac{\Lambda_1^{-4}}{105} = \frac{308}{105},$$

therefore

$$\mu = \frac{105}{308}\mu' = \cdot 341\,\mu' \quad \text{or} \quad \mu = \tfrac{1}{3}\mu' \text{ nearly.}$$

Now

$$\mu = \kappa\Lambda^{-4} \text{ in Lord Rayleigh's formula,}$$

and

$$\mu_1 = \kappa\Lambda_1^{-4},$$

therefore

$$\kappa = \frac{\mu}{105} = \frac{\mu'}{308}.$$

Thus by finding either μ or μ' the absorption of every ray of the spectrum can be determined.

XXXI.—*Absorption of the Blue Glass.*

As the platinum paper was exposed through blue glass, it becomes necessary to know the coefficient of absorption of the glass for the photographically active rays. Experiments have been made with this view, and exposures have been made simultaneously through the blue glass, and without any glass intervening. The results obtained were that the same blackness would be produced if exposure to light through blue glass to that without were as 2·15 to 1. In the tables of exposure, which are annexed, it follows that to obtain the true photographic intensity of total sunlight, the values given must be multiplied by 2·15.

TABLE of Sensitiveness of Platinum Paper to the different parts of the Solar Spectrum when the exposure was made through blue glass, as used in the apparatus with which the observations were made.

Scale number.	Relative sensitiveness.	Scale number.	Relative sensitiveness.
7	0	13	86
8	4	13·5	70
8·5	10	14	56
9	20	14·5	42
10	50	15	30
10·5	66	16	16
11	84	17	6
11·5	95	18	2
12	100	19	1
12·5	97	20	0

H is at 13·8; G at 11·1; Li at 9; and D at 4·3.

Scale No. 12 has a wave length of 4260.

A reference to the spectrum curve, fig. 5, will show that this wave length of 4244 is close to the maximum sensitiveness. This is what was to be expected when it is remembered that the equivalent ray for the optically observed spectrum was close to the place of maximum luminosity.

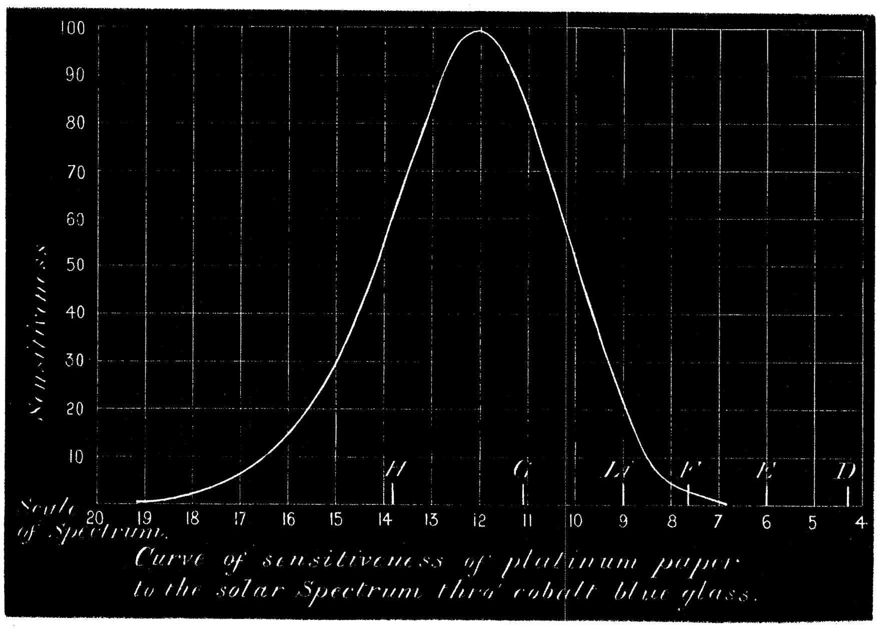
We are now in a position to reduce all the photographically measured coefficients of intensity to those which would have been observed optically.

XXXII.—*Places of Observation.*

It has been the object of these observations to determine, as far as possible, the different coefficients of absorption at different altitudes, and with this object in view the instrument has been taken to various places at different altitudes. Thus, South Kensington, Weybourne, Oxford, Derby, which may be taken as places at sea level. Grindelwald, in the valley, and on the various hills surrounding it, up to 8900 feet on the Faulhorn.

Como, Perarola, Cortina, and Interlaken, also Chamounix and Zermatt, with their surrounding mountains, have also been observing stations.

Fig. 5.



Curve of sensitiveness of platinum paper to the solar Spectrum thro' cobalt blue glass.

These stations are at various altitudes above the sea, and the results obtained are such as to show that the loss of light varies enormously, according as the altitude of the observing station is increased. This is a result which of course may be looked for. The observations of LANGLEY on Etna, and at Pike's Peak, show such to be the case; but it is necessarily more marked in the case of these observations owing to the part of the spectrum employed being that which suffers most loss by the scattering action of small particles. The blue end of the spectrum for this purpose has evidently a greater advantage over the red end and darker portions, more particularly over the latter, for in it the water absorptions play such an important *rôle* that the law of scattering could hardly be taken into account also. It will be noticed that observations have been made at all times of the year, and that the winter observations, when the surface of the ground at Grindelwald has been covered with snow and the air has been intensely cold (the thermometer sometimes showing as much as 40° F. of frost), give the coefficients of least absorption. The writer has held that most of the scattering particles are water in an extremely fine state of division, and that there is a probability that such is the case is shown by the fact that the most transparent atmosphere is that in which there is most warm aqueous vapour present. A change in the summer to what artists call an "atmospheric landscape" invariably shows a higher coefficient of absorption. Whatever these particles may be, there is no doubt that they are in the same volume fewer in number at high altitudes than they are at lower ones; as the coefficient of absorption is so much less in the former case than in the latter. Any one who has observed the sky at these higher altitudes will have observed that when the sun is brightest and highest, the sky is blackest, that is, that there are fewer scattering particles.

XXXIII.—*Standard of Light.*

It is somewhat difficult to know as to what standard of light to refer the light of the sun. The Author has made many comparisons between it and an amyl acetate lamp, and has come to the conclusion that at midday at sea level, and in the clearest atmosphere, the brightness of the sun exactly overhead would be close upon 7000 such standard lights at 1 foot distant from the screen, which would be equivalent to 5600 standard candles at the same distance. For the purpose of this paper, it is, however, unnecessary to refer the light to any particular standard, since all that was sought for was to obtain a comparison of the losses suffered on any one day by the light after passing through various thicknesses of atmosphere. It will be noticed in the various tables that the calculated brightness at the zenith varies very considerably even at the same altitudes. This must be laid down to one of three causes: (1) either an error in calculating the coefficients; (2) a slight haze of coarse particles intervening; or (3) owing to a varying sensitiveness in the paper used. Where the actual observed intensities throughout a day do not vary much more than those calculated, it may be presumed that the coefficient is not very far from the truth, and, consequently, the variation will in all probability be due to the second cause. As stated before, there was a change made in the paper which occurred in 1889, and it will be found that the intensities are practically the same before and after the above year.

XXXIV.—*Description, Tabulation, and Discussion of Results.*

The results which are tabulated do not show by any means all the observations made. They have been carried on for four years, and only those days are recorded in this paper when the sky has been practically cloudless whilst the observations have been taken. It need scarcely be said that the observations on three out of four days have been incomplete owing to atmospheric conditions not remaining constant. Every one of these has been tabulated, however, in the note books, and a check has thus been introduced in estimating the relative intensities of the light at the same altitudes of the sun above the horizon at the same observing station, for, in many instances, two or three observations under favourable conditions were made, the remainder being useless for the purpose of obtaining the coefficients of absorption.

Even the observations which are recorded are apparently so discordant, that it might appear difficult to arrange them in any order sufficient to get any empirical law which might connect barometric pressure with the exponential coefficient of transparency. As necessarily any approach to a law can only be an approximation, it has not been considered necessary to enter into any refinements such as the varying distance of the sun from the earth at different seasons, since any differences due to difference in atmospheric condition would more than hide any alteration due to that cause.

On certain days remarks are made that the atmosphere is exceptionally clear, and when we group such days together the results are not devoid of regularity.

Taking the observations at Faulhorn when the barometer was 21·5 inches, and when the day was noted as exceptionally fine, we get two values, ·231 and ·235 μ'. These are winter observations. We may take ·233 as the mean exponential coefficient at this barometric height in the clearest weather.

We also have on similar days—

	Bar.	μ_1.
At Derby	29·6	·437
Above Zweilutchinen	26·6	·356
,, Grindelwald	24·4	·307 and ·307
,, ,,	23·3	·275 ,, ·273
Faulhorn	21·5	·231 ,, ·233

In addition to the observations given in the tables others were made at higher altitudes up to 12,000 feet at Zermatt on suitable days. It was not practicable to take a whole series of readings at these high altitudes, as it was not possible under ordinary circumstances to spend sufficient time at such elevations and that to get a difference in zenith distance sufficient to give a variation in air-thickness of such a magnitude as would give a reliable coefficient. As, however, the expeditions were made at such a time of the day as enabled a return to a station where the lapse of a few hours in the afternoon sufficed to obtained a large variation in the air-thickness, it became possible, by calculating first the coefficient of this station, and thence calculating the readings which would have been obtained at the time when the observations at the higher altitudes were made, to calculate the coefficient for the latter, assuming, of course, that no alteration in the general condition of the sky had taken place. Thus, at the Riffel house it was calculated that the coefficient at a barometric pressure of 21·2 inches, was ·222; and from observations made with the barometer at 18·9, it was calculated the coefficient would be ·182. Similarly, with the barometer at 19·9, it was calculated to be ·196.

It will be seen, if we take the Faulhorn observations as a standard, that we get what appears to be a very close approximation to the law that the exponential coefficient varies as the square of the barometric pressure.

The following is a table calculated on this assumption :—

30 inches	·453
29 ,,	·423
28 ,,	·394
27 ,,	·367
26 ,,	·340
25 ,,	·314
24 ,,	·289
23 ,,	·266
22 ,,	·244
21 ,,	·222
20 ,,	·201
19 ,,	·182

It will be seen that the coefficients obtained on these exceptionally clear days fall extremely close to the calculated values. The calculation for

29·6 is 441, 26·6 is 356, 24·4 is 299,
23·4 is 276, 21·5 is 232.

On the day when the Faulhorn observation gave a value to the coefficient of ·261, the sky was fairly good. If we take this as a starting point and calculate as before, we find the following table :—

30 inches	·509
29 ,,	·477
27 ,,	·412
26 ,,	·381
25 ,,	·353
24 ,,	·325
23 ,,	·297
21·5 ,,	·261

THE following coefficients were obtained from observations made on days which were classed as ordinarily bright.

Barometer.		Observed.	Calculated.
21·5	Faulhorn	·261	·261
23·4	Above Grindelwald . .	·290	·306
25·6	Montanvert	·384	·370
26·6	Grindelwald	·400	·400
29·7	Derby	·514	·497

It will be seen that on such days the same order of change in the coefficients is to be found.

Other coefficients were obtained on moderately bright days, which are higher than the above for the varying heights of the barometer. These observations are given to show the great variations which may occur owing to atmospheric conditions.

It thus appears that the light acting on platinum paper at any altitude up to those observed can be expressed by

$$I' = I\epsilon^{-\mu_1 h^2 x/30},$$

where h is the height of the barometer and μ_1 is the coefficient of absorption.

In the case of the most transparent atmosphere $\mu_1 = \cdot 453$ at a barometer of 30 inches in height.

Therefore

$$I' = I\epsilon^{-\cdot 0005033 h^2}.$$

The coefficient for the visual absorption is $\cdot 341\mu'$.

$$A' = A\epsilon^{-\cdot 0001716 h^2},$$

where A and A′ are the original and transmitted lights.

We thus arrive at the following results :—

Barometer.	μ'	a'	μ	a
30	·453	·639	·154	·853
29	·423	·654	·144	·866
28	·344	·671	·134	·875
27	·367	·689	·124	·884
26	·340	·708	·115	·891
25	·314	·730	·107	·899
24	·289	·746	·098	·908
23	·266	·763	·090	·915
22	·244	·787	·083	·922
21	·222	·800	·075	·928
20	·201	·819	·068	·934
19	·182	·833	·062	·940

μ' and μ are the exponential coefficients as before. a' and a are the constants in the formula, $\mathrm{I}a^z = \mathrm{I}'$, z being the air thickness, and I and I′ the intensities before and after transmission.

We are now in a position to determine the constant κ in the formula

$$\mathrm{I}' = \mathrm{I}\epsilon^{-\kappa x \lambda^{-2}}$$

at sea-level with the barometer at 30 in. and in a very clear sky, for as

$$\kappa \Lambda^{-4} = \mu_1,$$

therefore

$$\kappa = \frac{\mu'}{\Lambda^{-4}} = \frac{\cdot 453}{308} = \cdot 00146\,;$$

in the case of fairly clear skies,

$$\kappa = \frac{\cdot 497}{\cdot 308} = \cdot 00161.$$

In Part I. of this paper the minimum value of κ was found to be ·0013, and a mean value about ·0017, so that these observations are fairly accordant.

κ may be taken to be a measure of the number of particles the rays encounter, and thence it may be concluded that the number of particles at any thin layer of the atmosphere is αh. The formula, therefore, for the scattering of a ray of any wave-length at any altitude becomes

$$\mathrm{I}' = \mathrm{I}\epsilon^{-ch^2 x \lambda^{-4}}$$

where c is a constant, h the height of the barometer, and x the air thickness, those of the zenith being "unity."

In comparing the comparative scattering of a ray at the same zenith distance, but at different altitudes, $\lambda \alpha x$ are constants, and

$$\mathrm{I}' = \mathrm{I}\epsilon^{-mh^2}$$

where m is a constant and h the variable. This formula and that of the law of error are identical.

XXXV.—*Conclusions.*

In conclusion, it should be remarked that the loss of light as light from transmission through the atmosphere is, and must be, very different to that of the heating effect of the solar radiation. The latter is not principally dependent on scattering by small particles, but on the absorption of aqueous vapour, which is a very different matter. LANGLEY has shown that the heating effect diminishes much more rapidly as the barometric pressure is diminished than is usually supposed, and this is not to be wondered at. For it must be recollected that the absorption by aqueous vapour takes place principally in the infra-red region of the spectrum, and, if it were entirely confined to that region, the presence or absence of the aqueous vapour would have no practical effect on the luminosity of the visible rays transmitted.* The absorption by this vapour where it takes place is large and follows the ordinary laws, as already stated, being principally in the infra-red of the spectrum, the heating effect will therefore diminish much more rapidly than the total illuminating value of sunlight as increased thickness of atmosphere is penetrated. In other words, the amount of light transmitted from the sun bears no comparison with that of its total heating effect.

It should be remarked that the portion of the spectrum used in these observations is almost free from any absorption by aqueous vapour, and, consequently, the scattering effect of the small particles in the atmosphere is probably almost entirely the cause of the loss of light from it, and enables a factor for such scattering to be arrived at without much difficulty. The measurement of the amount of light transmitted through different thicknesses of atmosphere has hitherto been almost entirely made on star and moon light, and, for reasons given in Part I. of this paper, the coefficients arrived at are probably slightly too large for the transmission of sunlight.

The results of these observations made at different altitudes, combined with others made in the laboratory, point to a probability that the particles which selectively scatter light are due to water. Their dimensions are probably very closely, if not exactly, the same, and the "mist" particles are large compared with them.

* See a paper in No. 224 of the 'Proceedings of the Royal Society,' 1883, by General FESTING and the Author.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

GRINDELWALD, 16th May, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	—	6.48	26·4	2·49				100	97	$u = \cdot 408$.
2	18				33·2	182	101			Fairly clear sky.
3	40				16·5	400	100			
4	10	7.45		1·90	45	120	120	120	124	
5	20				29·7	210	105			
6	25				21·7	300	120			
7	5	9.55		1·26	62·5	67	134	164	162	
8	10				36·2	160	160			
9	9				39	146	162			
10	19				21	310	163			
11	5	P.M. 1.55		1·24	56·5	82	164	164	163	
12	10				36·2	168	168			
13	30				14·5	480	160			
14	15	3.16		1·50	30·5	204	136	132	146	
15	40				12·2	512	128			
16	10	6.0		4·04	68	57	57	51	51	
17	30				37·5	154	51			
18	60				16	310	51			
19	30				37·5	154	51			

ZWEILÜTCHINEN, 2nd May, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	5				70·5	52	104			$\mu = \cdot356$.
2	10	12.0	26·4	1·17	42·5	130	130	130	135	
3	20				—	—	—			
4	5				63·5	65	130			Very clear.
5	10	1.25		1·23	41·5	132	132	131	131	
6	30				89·2	360	120			
7	—									
8	5				76	43	86			
9	20	2.18		1·35	36·5	160	80	83	126	
10	20				—	—	—			
11	5				69	51	102			
12	10	4.8		1·98	50	102	102	102	100	
13	20				29·5	207	103			
14	—									
15	5				84·5	31	62			
16	10	4.50		2·51	56·5	82	82	83	83	
17	20				35	170	85			
18	5	5.30		3·53	88	27	54	52	56·7	
19	20				50·5	100	50			
20	20	6.25		7·8	90	24	12	12	12·6	

MONTANVERT, 10th August, 1890.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	10	12.55	25·6	1·19	68	45	45	48	52·7	μ = ·384.
2	20				42	90	45			
3	20				—	96	48			Fairly bright.
4	30				28·7	142	48			Sky clear.
5	10				69	44	44			
6	15	3.0		1·5	50	72	48	47	47	
7	10				67·5	46	46			
8	24				35	112	46·6			
9	10				64	49	49			
10	22				37·5	106	47·2			
11	10	4.0		1·89	75	38	38	37·5	40·4	
12	15				60	55	37			
13	20				47·5	76	38			
14	20				48·5	74	37			
15	20	5.0		2·72	66	47	23·5	26·5	29·6	
16	30				47·5	76	25·3			
17	40				37	108	27			
18	45	5.56		4·8	55·5	61	13·5	13·2	13·2	
19	75				35·5	112	13			
20	120	6.5		7	44	78	6·5	6·5	5·7	

ABOVE Grindelwald, 23rd December, 1890.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	10		23·4		91·3	19	19			$\mu =$ ·273.
2	20	1.15		3·23	75	32	16	17·5	17·5	Very clear sky, sun very hot, and light excellent.
3	30				53	53	17·6			
4	10				96					
5	20				82	27	13·5			
6	30				67·3	38	13			
7	10	2.15		4·2	94			13·1	13·5	
8	20				84	26	13			
9	30				70	37	12·6			
10										
11	10				96					
12	20	2.40		5·03	86	22	11	10·8	10·7	
13	30				77	32	10·6			

ABOVE Grindelwald, 2nd January, 1891.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	17	1.10	23·4	3·1	72·7	34	20	19·5	19·3	μ = ·290.
2	30				47·4	60	20			
3	45				35	88	19·6			
4	30				48·7	59	18·3			Sky deep.
5	17	2.45		5·11	93·5	18	10·6	11·1	10·7	Very good sun.
6	30				72	34	11·3			
7	45				56·2	48	10·6			
8	60				44	66	11			
9	80				35	88	11			
10	—									
11	120	3.14		7·04	38·6	76	6·3	6·2	6·2	
12	120				40	73	6·1			

FAULHORN, 13th January, 1888.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	20	9.50	24·56		33	91	45·5	54		μ = ·235.
2	30				32	162	54			Splendid sky for depth, sun very bright.
3	30				21	162	54			
4	20	12.13	21·6	2·6	23	144	72	72	72	
5	20				24·5	137	68·5			
6	30				15·5	216	72			
7	20	2.13	21·6	3·5	28	116	58	57	58	
8	20				28·5	114	57			
9	30				21·5	160	53·3			
10	30				19·5	177	59			
11	30				21	162	54			
12	30				18·5	185	61·6			
13	20	3.8	21·6	5	38	72	36	40	40	
14	30				27	122	41			
15	30				27·5	120	40			

FAULHORN, 18th January, 1888.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	10	8.55	25		60	24	24	30		$\mu = \cdot 231$.
2	20				43	58	28			
3	30				33	92	31			
4	30				33	91	30			Same as January 13.
5	10	12.0	21·9	2·5	33	91	91	92·5	92·5	
6	20				18·5	185	92·5			
7	20				18·5	185	92·5			
8	30				12·6	280	93·3			
9	20	1.45	21·7	3	21	162	81	81	82·3	
10	10				37	68	68			
11	20				23	146	73			
12	20				21	162	81			
13	30				14·5	243	81			
14	30				14·5	243	81			
15	10	3.10	21·7	4·9	44	52	52	53	53	
16	20				31	100	50			
17	30				21	164	55			

GRINDELWALD, 12th August, 1888.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	20	6.48	26·6	2·84	38	94	47	47	47	$\mu = 400$.
2	40				17·5	197	44			Fair sky.
3	30				27·5	132	44			
4	60				12	276	49			
5	5	7.40			56·5	25	50	48		
6	20				35	100	50			
7	30				28	130	43			
8	20				37	96	48			
9	25				28·5	128	51			
10	15	8.2			37·5	96	64	68	68	
11	15				32·7	102	68			
12	20				25	144	72			
13	10	8.58			42·5	81	81	81	80	
14	15				30	122	81			
15	25				19·7	182	73			
16	13	10.24			32	114	89	89	89	
17	20				20·5	172	86			
18	20				18·7	178	89			

GRINDELWALD, 23rd May, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	10	11.40	26·6		59·5	74	74	67		$\mu = {\cdot}381$.
2	20				41	136	68			Very fair sky; good sun.
3	10				66	60	60			
4	20				41	136	68			
5	10				63	66	66			
6	10	1.33		1·24	58·5	76	76	75	75	
7	20				39·7	143	71·5			
8	20				37·5	154	77			
9	10	2.48		1·41	62	68	68	70	70·4	
10	20				39·5	144	72			
11	10	4.30		2·02	74	46	46	57·5	56·5	
12	20				47	112	56			
13	30				34	178	59			
14	15	5.20		2·64	70·5	52	35	41	43·9	
15	30				45	119	40			
16	45				32	189	42			
17	40	5.52		3·31	39	146	36·5	35·8	34·7	
18	60				29	212	35·3			
19	60	6.18		4·46	42·5	130	22	22	22	
20	60				42·5	130	22			

GRINDELWALD, 7th July, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	—		26·6							$\mu = \cdot 71$.
2	10	12.40		1·075	43·5	126	126	125	125	
3	15				33	184	123			
4	5				66	60	120			
5	10	2.42		1·26	47·5	110	110	111	110	Poor sky; milky.
6	20				27·8	224	112			
7	5				80·5	37	37			
8	10	5.40		2·63	70·5	51	35	36·7	37·5	
9	20				51·5	96	48			
10	30				46·2	115	38			
11	15				79	39	26			
12	20	6.10		3·34	71·5	51	25·5	25	25	
13	30				59·5	74	24·7			
14	40				50	100	25			
15	20				86	29	14·5			
16	25	6.35		4·28	82·5	34	13·6	13·3	13·6	
17	40				72·5	49	12			
18	20				99	11	5·5			
19	40	7.0		5·5	93·5	21	5·2	5·5	5·4	
20	60				82	34	5·7			

Como, 28th May, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	5 }		29·1		64	64	128 }			$\mu = \cdot 55$.
2	10 }	10.45		1·142	46	115	115 }	120	120	
3	20 }				27	232	116 }			Blue sky but rather milky.
4	5 }				62	68	132 }			
5	10 }	12.30			41·5	134	134 }	128	123	
6	20 }				25·2	255	128 }			
7	5 }				75	50	100 }			
8	10 }	3.23			50	101	101 }	100	100	
9	20 }				31	100	100 }			

ROSENLAUI, 4th July, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	5		26·5		72	50	100			$\mu = \cdot 435$.
2	10	7.5		2·19	50	100	100	98	98	
3	20				32	190	95			Fairly good sky. Clouded over about 1.30.
4	5				53	92	184			
5	10	8.50		1·4	39	140	146	143	143	
6	20				23	280	140			
7	5				52	94	188			
8	10	11.15		1·02	36·5	160	160	163	163	
9	15				25·5	250	167			
10	20				19·2	326	163			

GRINDELWALD, 24th June, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	5		26·2		77	34	68			$\mu = {\cdot}707$.
2	10	12.0		1·09	49	68	68	68	68	
3	20				27	134	67			Milky sky, cloudy in morning, bright after 11.
4	5				76	33	66			
5	10	1.10		1·125	51·5	64	64	65	66·5	
6	20				28	130	65			
7	5				84	18	36			
8	10	4.25		1·842	69·5	40	40	39·6	40	
9	20				40	87	43			

South Kensington, 25th September, 1889.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	10		29·6		75·5	34	34			$\mu = \cdot627$.
2	20	12.40		1·75	48·5	68	34	34	34	
3	40				28·2	130	32·5			Poor sky, but same tint maintained.
4	10				85	25	25			
5	20	2.0		1·91	64	45	22·5	26	30·5	
6	40				35	104	26			
7	15				79·5	30	20			
8	30	3.0		2·48	56·5	57	19·5	21·5	21·4	
9	40				41·2	88	22			
10	10				98	14	14			
11	15	3.55			90	21	14			
12	30				71	38	12·7			
13	10				96	—				
14	20				86	24	12			
15	40	4.2		3·4	65·5	44	11	12	12	
16	10				98	14	14			
17	20				85	25	12·5			
18	40				65	44	11			

ABOVE Grindelwald towards Faulhorn, 25th December, 1890.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint, White, =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	15	12.0	24·4	2·92	82·5	26	17·3	17·7		μ = ·307.
2	30				53·3	53	17·6			Beautifully deep sky; sun very bright.
3	30				53·3	53	17·6			
4	45				36·7	82	18·2			
5	30	12.25		3	52	55	18·3	18·5	18·5	
6	15				80	28	18·6			
7	10	1.30		3·4	95	17	17	16·5	16·5	
8	20				73·5	33	16·5			
9	30				52·7	54	18			
10	20				72·5	32	16			
11	20	2.0		3·8	77·5	30	15·	14·5	14·5	
12	40				49·5	58	14·5			
13	60				36	86	14·5			
14										
15	30	2.40		5	79	29	9·7	9·7	9·7	
16	45				60	45	10			
17	60				50·7	57	9·5			
8	30	3.30		7·6	97	15	5	4·7	4·5	
19	60				85·5	28	4·7			
20	60				87	27	4·5			

ABOVE Grindelwald towards Faulhorn, 27th December, 1890.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White $=\cdot100$.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	15	12·0		2·9	83	27	18	16·3		$\mu = \cdot275$.
2	30				58·5	47	15·7			
3	45				42·5	68	15·1			
4	15	12.25	24·4	3	81	28	18·6	18·3	18·3	
5	30				52·5	54	18			
6	15	1.45	23·4	3·6	86·5	23	15·3	15·3	15·3	$\mu = \cdot306$.
7	30				57	48	16			
8	—									
9	45				44	66	14·7			Beautiful black sky; sun very bright.
10	30	2.35	23·4	4·9	72	34	11·3	10·7	10·7	
11	60				47	61	10·2			
12	60	3.34	24·4		95·5	15	2·5	2·5	2·5	
13	120				84	26	2·2			

FAULHORN, 8th July, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White = ·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
		A.M.								
1	15	5.10	21·4	6·7	68·5	56	42	40	40	$\mu = {\cdot}261$.
2	40				38	151	38			
3	80				19	350	41			
4	10	5.40		4·55	65	62	62	70	70	Good sky, sun rose yellow.
5	20				44·5	122	61			
6	60				16·5	420	70			Sky good at top and at Grindelwald.
7	10	6.40		2·55	50	101	101	114	116	
8	20				29	210	105			
9	35				17	400	114			
10	11	8.10		1·6	36·2	161	146	147	147	
11	9				42	132	147			
12	15				28	222	147			
13	—									
14	5	9.45		1·24	54·5	87	174	160	163	
15	10				36·5	160	160			
16	20				20·5	320	160			
17	10	10.15		1·18	34	170	170	170	170	
18	15				25	255	170			
19	10	1.55		1·20	47	112	112	112	—	
20	15				34·5	172	113			

DERBY, 27th August, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec. exposure.	Calculated intensity.	Remarks.
1	10	3.17	29·6	1·90	65·4	61	61	56	56·1	$\mu = \cdot 514$.
2	20				47·2	109	54·5			
3	30				34·7	171	57			
4	20				48·6	104	52			Sky rather milky but sun good.
5	10	4.9		2·41	75	44	44	42	44·5	
6	20				54·2	86	43			
7	30				43	126	42			
8	40				34·7	165	41			
9	—									
10	20	4.46		3·00	66·7	58	29	32·3	31·9	
11	30				49·3	102	34			
12	10				82	34	34			
13	20	5.15		3·85	80·5	36	18	18·2	20·6	
14	40				61·1	69	17·3			
15	60				47·2	109	18·2			
16	30				75	44	14·3			
17	60	5.40		5·07	61·1	69	11·5	11	11	
18	90				51·4	94	10·4			
19	80	5.58		6·59	77·7	40	5	5	5	
20	120				68	56	4·6			

DERBY, 28th August, 1887.

No. of exposure.	Exposure in seconds.	Time.	Barometer, pressure in inches.	Air thickness, that of ZD being 1.	Depth of tint. White =·100.	Equivalent in intensity.	Intensity for 10 sec. exposure.	Adopted mean intensity for 10 sec exposure.	Calculated intensity.	Remarks.
1	—		29·6							$\mu = \cdot437$.
2	10	12.25		1·37	54·5	87	87	86	87	Exceptionally clear. Saw the Malvern Hills distinctly. *The* one day of the year probably.
3	20				35·5	166	83			
4	15				42	132	88			
5	10	1.3		1·42	52·5	93	93	88	88	
6	15				42·5	130	86			
7	20				34·5	174	87			
8	10	2.4		1·53	48·5	107	107	83·5	83·8	
9	20				35·5	168	84			
10	12				50·5	99	83			
11	10	3.15		1·89	59	74	74	72	71·6	
12	20				40·5	139	70			
13	8	4.13		2·47	44·5	41	51	51	55·6	
14	20				51·5	99	49			
15	40				30·5	204	51			
16	20	4.45		3·04	54	88	44	44	43·3	
17	80	5.16		3·96	30·5	234	29	29	29	
18	40				46·5	114	28·5			