"Some Observations on the Amount of Luminous and Non-luminous Radiation emitted by a Gas Flame." By Sir JOHN CONROY, Bart., M.A., Bedford Lecturer of Balliol College and Millard Lecturer of Trinity College, Oxford. Communicated by A. G. VERNON HARCOURT, LL.D., F.R.S. Received November 11. Read December 19, 1889.

In 1863 Julius Thomsen communicated to the "Naturforscher-versammlung" at Stockholm an account of some determinations he had made of "The Mechanical Equivalent of Light," and an abstract of this paper appeared in 'Poggendorff's Annalen' (vol. 125, 1865, p. 348).

He allowed the radiation from a sperm candle, a moderator lamp, and a gas flame, to fall on the face of a thermopile, and noted the deflection of the needle of a galvanometer in the thermoelectric circuit, when the radiation fell directly on the pile, and when it did so after passing through 20 cm. of water contained in a glass cell. In order to reduce the readings to absolute measure, he placed a glass globe containing hot water in front of the thermopile, and observed the deflection of the galvanometer; the mass of water contained in the globe, the water-equivalent of the globe, the temperature of the water, and of the room, being all known, from the observed rate of cooling the radiation, calculated by Dulong's formula, was determined.

By assuming that the 20 cm. of water absorbed all, or nearly all, the heat rays (*i.e.*, the non-visible), and transmitted nearly all the light rays, the loss of light being found experimentally to be only 13 per cent., he was able to calculate the proportion of light and heat (*i.e.*, visible and non-visible) radiations emitted by the flames, and to determine the mechanical equivalent of the light. He found that the ratio of the luminous to the total radiation was about the same for the candle, the oil lamp, and the gas flame, the amount being nearly 2 per cent.

He states "a flame whose light intensity is equal to one light unit, that is, one due to the combustion of 8·2 grams of spermaceti per hour, radiates as light per minute an amount of heat which would raise the temperature of 4·1 grams of water one degree." On this last sentence it must be remarked that a light unit cannot be expressed by a statement of the mass of a combustible consumed, but perhaps the original paper contains qualifications omitted in the Abstract.

Melloni ('Comptes Rendus,' vol. 31, 1850, p. 476) states "Le rayonnement de la flamme d'huile contient 90 parties sur 100 de cette espèce de chaleur (*i.e.*, chaleur obscure), le rayonnement du platine

incandescent en a 98 pour 100, et celui de la flamme d'alcool 99 pour 100."

Tyndall ('Phil. Mag.,' 1864, vol. 28, p. 335; and 'Contributions to Molecular Physics,' p. 260) states that he placed in front of his thermopile a rock-salt cell and observed the deflection of the galvanometer when the radiation from (1) an incandescent platinum wire, (2) the brightest part of a gas flame, (3) an electric arc lamp, passed through the cell, filled first with pure bisulphide of carbon, and then with bisulphide of carbon in which iodine had been dissolved; he found that the percentages of luminous to total radiation from the three sources were—

Incandescent platinum..............	4·17
Bright part of gas flame	4·0
Arc lamp	10·0

From measurements made by Mr. Merritt and Mr. Nakano ("Efficiency of Methods of Artificial Illumination," by Professor E. Nichols; 'The Electrical Engineer,' May, 1889), the efficiency (*i.e.*, the ratio of luminous radiation to total radiation) of arc and incandescent electric lamps appears to be about 10 and 5 per cent. respectively.

The experiments of which an account is contained in this paper were commenced with the object of repeating and extending Thomsen's observations; soon after they had been begun a notice appeared in 'Nature' (July 4, 1889) of a communication made on June 7, 1889, to the Physical Society of Berlin, by Dr. R. von Helmholtz, on the radiation from flames, and under these circumstances it seemed desirable to finish the experiments which had been already commenced, but not to go on with the enquiry until Dr. von Helmholtz's paper should have been published in full.

The experiments were made by allowing the radiation from an Argand gas flame to fall on the face of a thermopile, either directly or after passing through different thicknesses of water, or of a solution of alum in water, contained in cells with glass ends.

Instead of keeping the source of heat at a fixed distance from the thermopile, and noting the deflections of the galvanometer, which was the method employed by Melloni and those who have followed him, the distance between the source and the face of the pile was made the variable, and the distances noted at which equal deflections were produced; thus the necessity for calibrating the galvanometer was avoided, and also for assuming that the (corrected) deflections of the needle were strictly proportional to the amount of radiant energy incident upon the face of the pile.

On the other hand, it was necessary to assume that the amount of energy which reached the thermopile varied inversely as the square

of the distance from the source, and as the flame and chimney were of considerable size, the position of the source was not well defined; it was also necessary to assume that the amount of absorption due to the air, or to the aqueous vapour it contained, was negligible, or at least that it could be allowed for.

An ordinary thermopile with fifty-four couples and a low resistance Nobili's galvanometer were used. The galvanometer needles, which were rendered as nearly astatic as possible, were suspended in the ordinary way by a silk fibre, a plane mirror was attached to them, and the image of a slit placed in the slide-holder of a magic lantern thrown by reflection from the mirror on to a scale placed about 0·8 metre from the galvanometer. The scale was divided into half centimetres, and the position of the line of light was read to 1 mm. by estimation. A deflection of 4° on the circle of the galvanometer corresponded to about five divisions on the scale.

In order that the galvanometer should have a fairly fixed zero, it was found necessary to place a weak magnet, a slightly magnetised knitting needle, at a short distance from it; this reduced the sensibility of the instrument, but it was still much more sensitive to the feeble thermoelectric currents than a low resistance (0·5 ohm) Thomson galvanometer of the ordinary pattern.

The galvanometer coil was nearly perpendicular to the magnetic meridian, and the adjusting magnet so placed that the needles were parallel to the axis of the coil.

The thermopile was fixed at the end of a horizontal stand, to which a divided scale was attached, and was connected by covered copper wires with the galvanometer, a three-way plug being inserted in the circuit.

Both faces of the thermopile, which had been carefully blackened with camphor smoke, were exposed; the radiation from the lamp whose light-giving power was to be measured fell on the one, and the radiation from a compensating source of heat, an Argand with a metal chimney, on the other. Tin-plate screens were placed on either side of the pile, and the space between them stuffed with cotton wool, to screen it from air currents and from the radiation of surrounding objects, it being impossible to use the reflecting cones with the method of measurement employed.

Four cells of wood well soaked in paraffin were used to hold the water and alum solution; their ends were closed with pieces of crown glass, cut from the same plate of Messrs. Chance's manufacture, which were pressed against the ends of the cells by wooden pressure-plates and screws, a washer of vulcanised sheet-india-rubber being interposed between the cell and the glass. This arrangement enabled the same pair of plates to be used with all four cells. The plates were 1·5 mm. thick, the cells were 15 cm. deep, 10 cm. wide, and

1 cm., 5 cm., 10 cm., and 15 cm., long; each of the washers was about 1 mm. thick, so that the radiations which passed through the cells had to traverse 3 mm. of glass and 1·2 cm., 5·2 cm., 10·2 cm., or 15·2 cm. of water in Cells I, II, III, and IV.

The determinations were made by placing one of the cells in front of the thermopile, and about 9 cm. from it, a screen with a rectangular aperture, 5 cm. by 3 cm., being fixed at about 2 cm. from the end of the cell nearest the pile, in order to prevent any radiations reflected from the surfaces of the water in the cell reaching the pile; the glass plates were always well cleaned immediately before being used, and the cell filled with freshly filtered distilled water.

An Argand burner, 1·5 cm. in diameter, with a glass chimney 4·5 cm. in diameter and 15 cm. high, was placed beyond the cell, a tin-plate screen being interposed.

In the experiments recorded in this paper the axis of the burner was 31·8 cm. from the face of the pile.

The index of the galvanometer was then, if necessary, brought to zero and the circuit closed; closing the circuit almost always caused the line of light to move in one or other direction. By adjusting the height of the flame of the compensating burner, which was invariably small, from 0·3 cm. to 0·8 cm., and its distance from the thermopile, the line of light was brought back to the zero, or nearly so.

A horizontal wire was clamped to the stand of the burner whose radiation was to be observed, 10 cm. above the plate of the burner, and by means of a tap the height of the flame so regulated that its tip just appeared above the wire.

The metal screen was then removed, the amplitude of the first swing of the galvanometer needle observed, and the screen replaced.

The oscillations of the needle were extremely slow, and, therefore, instead of always waiting till it had completely come to rest again, as soon as the oscillations had become small, about half a division of the scale or less, the screen was again removed and another reading made, care being taken to always remove the screen whilst the index was passing the point taken as zero, and in the opposite direction to that in which the deflection due to the heat would occur.

In this way twelve readings were made, and then the cell was removed and the lamp placed at a greater distance from the pile, which was shielded by a tin-plate screen which could be moved to and fro by strings.

It was usually necessary to readjust the compensating lamp, and when the index had again been brought to zero the screen was removed and the deflection noted. After a few trials a position was found for the lamp in which the deflection was about the same as that produced by the radiation which had passed through the water; a reading of the deflection was made with the lamp in this position, and

then it was moved 10 cm. along the scale, and another readiug made; the distances were thus ascertained at which the whole radiation from the lamp produced a somewhat less and a somewhat greater effect upon the galvanometer than had been produced by that portion of the radiation which had passed through the glass and water of the cell, with the lamp close to the pile.

The measurements were repeated six times for each position of the lamp; a curve was then plotted with the distances at which the lamp had been placed when no cell had been interposed between it and the pile as abscissæ, and the mean deflections corresponding to each of these positions as ordinates, and then the abscissa of a point whose ordinate was equal to the mean deflection when the cell had been interposed ascertained. This indirect method was adopted, as it would have been impossible, without making a very large number of measurements, to have ascertained the exact position of the lamp for which the direct radiation produced the same effect as that portion of it which had passed through the water.

Table I gives one set of readings made in this way with Cell I, and Table II the mean of three sets of readings made with the four cells, and with the lamp at different distances from the thermopile, the actual readings being about as concordant as those contained in Table I.

Table I.

Deflection of Galvanometer.

							Mean.
With cell.........	3·5 3·7	3·6 3·8	3·8 3·9	3·7 3·6	3·6 3·8	3·7 3·6	3·7
Lamp at 110......	4·5	4·2	4·1	4·0	4·3	4·0	4·2
„ 120......	4·2	3·6	3·3	3·2	3·6	3·6	3·6
„ 130......	3·5	3·4	3·0	3·2	3·0	2·8	3·15

Table II.

Mean Deflection of Galvanometer.

				Mean.
Cell I	3·7	4·0	4·25	3·98
Cell II................	2·05	2·27	2·2	2·17
Cell III	1·8	1·9	1·8	1·83
Cell IV................	1·9	1·9	1·9	1·9
Lamp at 110...........	4·2	4·13	4·1	4·14
„ 120...........	3·6	3·7	3·6	3·63
„ 130...........	3·15	—	—	—
„ 160...........	2·4	2·43	2·2	2·34
„ 170...........	2·0	2·03	2·15	2·06
„ 180...........	1·8	1·8	1·9	1·83
„ 190...........	1·7	1·76	1·7	1·72

In the case of the first set of measurements made with Cell I (those contained in Table I) the equivalent distance for the lamp is

clearly at about 120 on the scale, and its value, as deduced in the manner above described, is 118·5. From the face of the thermopile to the zero of the scale was 40 cm.; this quantity had, of course, to be added to the scale readings of the position of the lamp. The distance of the axis of the lamp from the face of the thermopile, when the cell was interposed, was 31·8 cm.; the glass and water of the cell being more refractive than air, interposing the cell virtually reduced the distance between the pile and the lamp. The rays which traversed the cell differing in refrangibility, and being incident upon the glass at different angles, the simplest form of the formula $x = e\left(1 - \frac{1}{n}\right)$ (in which n was taken as 1·33, and the glass and water treated as if they had the same index) was used for calculating the optical shortening of the distance.

The values of x for the four cells were 0·4 mm., 1·4 mm., 2·7 mm., and 4 mm.; these amounts subtracted from 31·8 cm., gave the virtual distances in the four cases.

Calling the two distances of the lamp d_1 and d_2, the intensity of the lamp I, and the coefficient of transmission K,

then $$\frac{\mathrm{I}}{d_1^2} = \mathrm{K}\frac{\mathrm{I}}{d_2^2}, \text{ whence } \mathrm{K} = \left(\frac{d_2}{d_1}\right)^2.$$

Table III gives the results of measurements made in this way with the different cells. Column 2 gives the values of d_1, that is, the scale reading of the position of the lamp without the cell, plus the distance between the zero and the pile; column 3 the corrected distances with the cell, *i.e.*, the measured distance less the correction for the refraction of the cell, and column 4 the coefficients of transmission.

Table III.

	d_1.	d_2.	K.
Cell I	154·0	31·4	0·04157
	148·0	31·4	0·04501
	158·5	31·4	0·03925
			0·04194
Cell II	204·0	30·4	0·02221
	200·0	30·4	0·02310
	208·5	30·4	0·02126
			0·02219
Cell III	215 0	29·1	0·01832
	225·0	29·1	0·01673
	224·0	29·1	0·01688
			0·01731

Cell IV................	215·0	27·8	0·01672
	220·0	27·8	0·01593
	215·0	27·8	0·01672
			0·01646

It is usually stated that water saturated with alum is more adiathermanous than pure water.

Melloni found ('Annales de Chimie,' vol. 153, 1833, p. 1) that 12 per cent. of the total radiation of an oil lamp with double air current passed through 9·21 mm. of a solution of alum contained in a glass cell, whilst 11 per cent. passed through the same thickness of water, or that the diathermancy of these two liquids in glass cells was practically the same.

It seems very unlikely that no other observations should have been made on this point, but a careful search has failed to disclose the record of any.

A solution of ammonia alum, saturated at about 15°, was prepared, and some preliminary observations were made with it in the manner already described; the coefficient of transmission for Cell I appeared to be slightly less, and that for Cell II slightly greater than when the cells were filled with water, but the differences were so small that it was thought that it would be more satisfactory to fill Cell I alternately with the alum solution and with pure water, and note the deflections of the galvanometer. Table IV gives a number of these readings: twelve were first made with the alum solution, and then twelve with water, and then twelve more with the alum, and finally twelve with water.

Table IV.

Deflection of Galvanometer.

							Mean.
Cell I. With solution of alum.....	3·7	3·8	3·2	3·7	3·2	3·5	3·55
	3·6	3·0	3·4	3·7	3·7	3·9	
	3·5	3·8	3·8	3·7	3·7	3·6	
	3·5	3·5	3·3	3·1	3·6	3·8	
Cell I. With water...............	3·4	3·6	3·3	3·9	3·6	3·4	3·60
	3·9	3·7	3·5	3·6	3·7	3·5	
	3·9	3·8	3·4	3·6	3·7	3·7	
	3·6	3·7	3·4	3·2	3·6	3·7	

The table shows that with the form of apparatus used there is no measurable difference between the absorption of an alum solution contained in a glass cell and that of pure water.

The amount of light transmitted by the four cells was determined, the photometric arrangement used being the one described in the 'Philosophical Transactions,' A, vol. 180, 1889, p. 248. It consisted essentially of a small Argand gas burner and of two mirrors, so placed that they reflected the light of the lamp towards each other. The photometer was placed between them, and the cell between the photometer and one of the mirrors, and six readings made of the position in which there was equality of illumination; the cell was then placed on the other side of the photometer, and six more readings made of the new position of equality of illumination; from these measurements the value of k, the coefficient of transparency, was calculated by the expression (*loc. cit.*, p. 250) $k = \frac{x_1(x - x_2)}{x_2(x - x_1)}$; x being the distance between the two images of the lamp, x_1 and x_2 the two positions of the photometer in which there was equality of illumination, the optical shortening of the path of the light due to its passage through the glass and water being, of course, allowed for.

Table V gives these results.

Table V.

	x_1.	$x - x_1$.	x_2.	$x - x_2$.	Per cent. of incident light transmitted.
Cell I.........	185·5	199·1	199·3	185·3	86·62
	186·0	198·6	199·0	185·6	87·35
	185·5	199·1	199·1	185·5	86·80
				Mean..	86·92
Cell II........	184·7	198·9	199·2	184·4	85·96
	184·8	198·8	199·1	184·5	86·14
	185·2	198·4	199·3	184·3	86·32
				Mean..	86·14
Cell III	182·9	199·4	198·1	184·2	85·29
	182·7	199·2	198·3	183·7	84·84
	182·7	199·2	198·6	183·7	85·11
				Mean..	85·08
Cell IV	182·3	198·7	198·6	182·4	84·26
	182·8	198·2	198·3	182·7	84·98
	182·9	198·1	198·6	182·4	84·80
				Mean..	84·68

The table shows that the loss of light increased from 13·1 per cent. with Cell I to 15·3 per cent. with Cell IV; the loss being due to

reflection at the surfaces of the glass and water, and to obstruction (*i.e.*, absorption and scattering) by the glass, and by the water. Calling r and r_1 the ratios of the light reflected from the surface of the glass and water and obstructed by the glass, at the two ends of the cell, to the light incident upon them, α the coefficient of transmission of the water, and t the thickness of the water, then the intensity of the transmitted beam is given by the expression $i = I\rho\rho'\alpha^t$, where $\rho = (1 - r)$ and $\rho' = (1 - r_1)$. I, i, and t being known, by eliminating $\rho\rho'$ α can be readily calculated.

Table VI gives the values of α for a thickness of 1 cm. of water, obtained by combining in pairs the values obtained with the four cells.

Table VI.

	Values of α.
	0·9977
	0·9974
	0·9981
	0·9975
	0·9983
	0·9990
Mean..	0·9980

In a former paper ('Phil. Trans.,' A, 180, 1889, p. 280) it is shown that the value of α per millimetre, for the crown and flint glass experimented with, was 0·99735 and 0·99884; the transparency of water appears to exceed considerably that of either kind of glass, being 0·9998 per millimetre.

From the mean value of α the values of ρ, on the assumption that $\rho = \rho'$, were obtained by calculating the value of α^t for the different thicknesses of water, and then introducing this value into the equation $i = I\rho\rho'\alpha^t$, where i is the measured amount of the percentage transmitted by each of the cells.

Table VII.

	Values of ρ.
Cell I....	0·9334
,, II....	0·9330
,, III....	0·9319
,, IV....	0·9343
	0·9331

Hence the amount of light reflected at the two surfaces of each of the glass plates, and obstructed by the glass, would appear to be about 6·69 per cent.

The agreement between the values of ρ, as deduced from the measurements made with each of the four cells, confirms the general accuracy of the photometric observations.

Glass and water transmit, as is well known, radiations differing in wave-length with very different degrees of facility; all the kinds of radiations which affect the eye as light suffer about the same amount of absorption (*i.e.*, these media are colourless); but, as Melloni showed many years ago, the case is very different when the total radiation from any source of light and heat is considered.

Table VIII gives the percentage amounts of total and visible radiation transmitted by the four cells, and also the transmission coefficients A and α for the total and visible radiations, as deduced from the measurements made with each pair of cells.

Table VIII.

	Per cent. total radiation transmitted.	Per cent. visible radiation transmitted.	A.	α.
Cell I. 3 mm. glass and 12 mm. water	4·194	86·92		
			0·8529	0·9977
Cell II. 3 mm. glass and 52 mm. water	2·219	86·14		
			0·9515	0·9975
Cell III. 3 mm. glass and 102 mm. water	1·731	85·08		
			0·9900	0·9990
Cell IV. 3 mm. glass and 152 mm. water	1·646	84·68		

The table shows that the percentage amount of visible radiation absorbed by the water increases regularly with the thickness, but that in the case of the total radiation each additional centimetre of water absorbs less than those that have preceded it, and that the transmission coefficients for the total radiation increase as the thickness increases, whilst those for the visible radiation remain nearly constant. From the values of these coefficients it appears that a thickness of 3 mm. of glass and 102 mm. of water is not sufficient to arrest all the non-luminous radiations emitted by an Argand gas burner. The transmission coefficients for the total and visible radiations as deduced from the measurements made with Cells III and IV are much closer together than those deduced from the measurements made with Cells I and II, and II and III, and this seems to show that the amount of non-luminous radiation which passed through Cell IV was very small, and that, therefore, the 1·646 per cent. transmitted consisted almost exclusively of visible radiation, *i.e.*, light.

The photometric measurements show that 84·68 per cent. of the

incident light traversed Cell IV; hence it would appear, if we assume that neither the air nor the aqueous vapour absorbed a measurable amount of the radiation, that the total radiation of the gas burner contained $1{\cdot}646 \times \frac{100}{84{\cdot}68}$ or 1·94 per cent. of luminous radiation, a result that agrees with that obtained by Julius Thomsen.

As has already been stated, the method employed was based on the assumption that the amount of absorption due to the air or to the aqueous vapour it contained was negligible, or at least that it could be allowed for. The experiments were made in an underground room in which the temperature and the hygrometric condition of the air varied but slightly. The readings of a wet and dry bulb thermometer never differed during the course of the experiments more than about 1° F., the temperature of the air varying from about 59° F. to 67° F. Hence it was always nearly saturated, and the mass of water-vapour per unit volume of air was nearly the same.

Professor Tyndall states ('Contributions to Molecular Physics,' p. 133) that 4 feet of saturated air (the temperature of the air and the nature of the source of radiation, which from the diagram was apparently a gas flame, are not mentioned) absorbed $5\frac{1}{2}$ per cent. of the total radiation.

If we assume that for very small angles (and in the course of these experiments the angles never exceeded 4°) the deflections of the galvanometer were strictly proportional to the amount of radiant energy incident upon the face of the thermopile, and that the radiation from the lamp suffered no absorption before it reached the thermopile, then the deflections of the galvanometer would vary inversely with the square of the distance of the lamp. Table II shows that the mean deflection when the lamp was 150 cm. from the thermopile was 4·14 scale divisions. The deflections corresponding to other positions of the lamp were calculated by the expression $\frac{(150)^2 \times 4{\cdot}14}{x^2} = d$, where x is the distance of the lamp, and d the scale reading; the results are set forth in Table IX, column 2.

If, however, a portion of the radiation from the lamp was absorbed by the air, or the aqueous vapour it contained, then the decrease in the deflection as the lamp was moved further and further off would be partially due to the increased amount of absorption produced by the longer column of air and aqueous vapour.

Taking Professor Tyndall's value for the absorption (5·5 per cent. in 4 feet), the percentage amount that would be absorbed in passing through 10 cm., 50 cm., 60 cm., 70 cm., and 80 cm. of saturated air was calculated, and thence, by the expression given above, the value for the deflection; x^2 being taken as $\frac{(\text{distance of lamp})^2 \times 100}{100 - \text{absorption}}$.

These values are contained in Table IX, column 3; they agree more closely with the observed values contained in column 4 than those calculated on the assumption that there was no absorption. The deflections of the galvanometer, however, were so small, and therefore the difference between the two sets of calculated values for the deflections, and the observed values, so slight, that no very definite conclusions can be drawn from them; they seem, however, to show that some absorption did take place, and to about the same amount as stated by Professor Tyndall.

Table IX.

Distances of lamp.	Deflection of galvanometer.		
	Calculated.		Observed.
cm.			
150	..	..	4·14
160	3·64	3·62	3·63
200	2·33	2·28	2·34
210	2·11	2·05	2·06
220	1·92	1·86	1·83
230	1·76	1·70	1·72

In the experiments made with Cell IV, the radiation from the lamp had to traverse about 15 cm. of air when the cell was interposed between the lamp and the pile, and about 215 cm. when the cell was removed. The absorption in the former case must, according to Professor Tyndall's experiments, have been insensible, and in the latter case have amounted to about 9·7 per cent.; assuming that the absorption is proportional to the length of air traversed, an assumption which in all probability is not strictly true.

Calling the total amount of radiation from the lamp, 100, the expression for K under the given conditions is $\frac{90{\cdot}3}{84{\cdot}68}\left(\frac{d_2}{d_1}\right)^2 = 1{\cdot}751$.

Thus, allowing for the absorption due to the aqueous vapour, and to the loss which the light suffered in passing through the cell, it appears that the total radiation from the lamp consisted of 1·75 per cent. luminous and 98·25 per cent. non-luminous radiation: a somewhat smaller value for the percentage of luminous radiation than that found by Julius Thomsen.

Conclusion.

These experiments show:—

(1.) That 3 mm. of glass and 10 cm. of water transmit a small

portion of the non-luminous radiation of an Argand gas burner, but that when the thickness of the water is increased to 15 cm. the transmitted radiation consists exclusively, or almost exclusively, of those kinds of radiation which affect the eye as light.

(2.) That with the form of apparatus employed (a thermopile and galvanometer) there is no measurable difference between the diathermancy of pure water and of a solution of alum.

(3.) That the radiation from an Argand gas burner consists of about 1·75 per cent. luminous and 98·25 per cent. non-luminous radiation.

[*Note.*—After this paper had been presented to the Royal Society, I was made aware for the first time, by means of a reprint in the December number of 'Wiedemann's Annalen' (vol. 38, 1889, p. 640), of a paper on "the mechanical equivalent of light," which O. Tumlirz had communicated to the Vienna Academy in the summer of this year. He states that the total radiation from the amyl acetate lamp he employed contained 2·4 per cent. of luminous radiation. He obtained this result by allowing either the whole radiation from the lamp, or that portion of it which had traversed a glass cell containing water, to fall upon the face of a thermopile, and noting in the two cases the deflections of the needle of a galvanometer in the thermo-electric circuit.—December 27, 1889.]

"Observations on the Spark Discharge." By J. JOLY, M.A., B.E. Communicated by Prof. G. F. FITZGERALD, F.R.S. Received June 15,—Read June 20, 1889.

[PLATES 1—5.]

Path of Discharge over the Surface of a Dielectric.

The subject of dust-figures produced by electrical discharge has received much attention at various times. In the following notes I have refrained, to the best of my knowledge, from going over old ground. The subject has been reviewed in Lehmann's recently published 'Molekularphysik.' It is a sufficient substitute for the customary *résumé* of past observations to refer to that work.

(1.) When a spark discharge occurs in a homogeneous dielectric medium, the path of discharge, as is known, in general lies in a fairly straight line between the points of discharge. If the dielectric medium be heterogeneous in character, the path chosen by the spark will vary with the circumstances. Thus, if the straight line between the conductors be interrupted by a layer of a substance offering a higher resistance to discharge than the surrounding dielectric, the