



LIX. On the refraction and polarization of heat

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combination." Unless the particles of oxygen were elastic or repulsive as respects the contiguous particles of hydrogen, elasticity could not be a force opposed to affinity, and the diminution of elasticity or repulsion by the action of the plate, could not determine the union of oxygen with hydrogen*.

Manchester, April 7, 1835.

LIX. *On the Refraction and Polarization of Heat.* By JAMES D. FORBES, Esq., F.R.SS. L. & E., Professor of Natural Philosophy in the University of Edinburgh.

[Continued from p. 291, and concluded.]

66. THE table generally points to a coincidence, and that as close as by the nature of the experiments we should perhaps be warranted in expecting. If there be any excess in the second column of results (which the observations with incandescent platinum might lead us to suspect), it is more than probable that it arises from some imperfection in the apparatus employed, such as the incomplete parallelism or perpendicularity of the mica plates employed to polarize, a circumstance which was not minutely attended to.

67. The result, however, is highly satisfactory, as indicating the almost exactly complementary nature of the ordinary and extraordinary pencils, as in light.

68. The somewhat complicated conditions of the variable intensities of the ordinary and extraordinary images (which it is to be recollected correspond to the Parallel and Perpendicular positions of the analysing plate) in the case of light, are easiest kept in mind by Fresnel's formulæ.

$$O^2 = F^2 \left\{ 1 - \sin^2 2i \sin^2 \pi \left(\frac{o - e}{\lambda} \right) \right\}^\dagger$$

$$E^2 = F^2 \left\{ \sin^2 2i \sin^2 \pi \left(\frac{o - e}{\lambda} \right) \right\}$$

where O^2 , E^2 , and F^2 , have the same signification as in (64), and i represents the angle between the plane of polarization and the principal plane of the crystal: $o - e$ is the difference

* In proof that the repulsion existing between unlike gaseous molecules is a force opposed to chemical union, it is worthy of remark, that of such gases as combine *spontaneously*, when simply mingled, one or both are generally found among that class which have been reduced to a liquid form, and in which the repulsive force between the constituent molecules is therefore least energetic.

† This corresponds to the formula $\frac{a^2}{2} \sin^2 2\phi \left\{ 1 - \cos \frac{2\pi l}{\lambda} \right\}$ of

Airy's *Tract on the Undulatory Theory*, Art. 172. Both are only restricted expressions of more general theorems.

of the retardations of the ordinary and extraordinary rays within the crystal, and λ the length of an undulation. The sum of the two is always $= F^2$.

69. Now the quantity $o - e$ may always be known by referring to the retardation, which produces the corresponding tint in Newton's rings, and which is equal to twice the distance between the plates in that experiment. For example, with the thin mica film mentioned in (56), which polarized light circularly, the tint produced (between crossed polarizing and analysing plates) corresponded (by Newton's table) to an interval of about five millionths of an inch between the surfaces of glass, or to a retardation, $(o - e)$, of $\cdot 00001$ inch. The film, marked No. 2, which gave plum-red of the first order (65), gives a retardation of $\cdot 00002$. The film No. 1 (65), gives $\cdot 00004$ inch. From these data, then, having the value of E^2 (68), it is clear that we may calculate the value of λ , or the length of an undulation of heat*.

70. In our present case we have always made $i = 45^\circ$; whence $E^2 = F^2 \sin^2 \pi \left(\frac{o - e}{\lambda} \right)$; and of course $O^2 = F^2 - E^2$.

But in an experiment we must not use the direct indication of the multiplier, when the polarizing and analysing planes are parallel, for the total quantity or F^2 ; for a large proportion of the heat is not completely polarized, and in order to compare the values of E^2 and F^2 , we must determine the value of each directly, that is, not only how much is depolarized, but how much is polarized by the mica plates. This I did by ascertaining alternately with the quantities of depolarization, the total intensity of the polarized part of the heat, which reached the pile. This was effected by rendering the polarizing and analysing plates parallel and perpendicular to one another; whilst the principal section of the interposed mica remained parallel to one or other, so as to exercise no depolarizing influence.

71. To illustrate this mode of investigation, I shall give as an example the very last series of experiments made on this subject, which, whilst it points out the mode of operating, will exhibit the constancy and considerable magnitude of these effects, amidst the complicated changes of condition to which the heat is subjected. The columns marked "corrected," have a small correction applied for the gradual alteration in the quantity of heat reaching the pile, which corrections are

* Of course this is only true on the supposition that rays of heat and light are equally retarded. This is not demonstrated, but it is probable that they are nearly so, since that part of the heat which accompanies the spectrum is so, and the dispersion in the case of double refraction is inconsiderable.

interpolated from the successive observations marked (1), (2), (3), &c. which are made under similar circumstances.

1835. Jan. 16.—*Source of Heat. Incandescent Platinum. Polarizing Mica Plates E and F. Film of Mica interposed, No. I.*

Position of Mica plates.	Principal Section of interposed Mica, at	Multiplier.	Total Polarization.	Depolarization.	Total Polarization corrected	Depolarization corrected	Ratio.			
[E at 0°	{ 45° (1)	{ 14·8 }	.....	+ 2°·8 }	6·0	2°·75	100 : 46		
F at 90°	{ 0	{ 12·0 }	6·0	- 2°·7 }						
F at 0°	{ 0	{ 18·0 }								
F at 0°	{ 45 (2)	{ 15·3 }	.....	+ 2°·2 }	4·2	2·1	100 : 50		
F at 90°	{ 45 (2)	{ 14·8 }	.....	- 2°·4 }					
F at 0°	{ 0	{ 12·6 }	4·0							
F at 0°	{ 0	{ 16·6 }	4·8	+ 2°·5 }	4·9	2·65	100 : 54			
F at 90°	{ 45 (3)	{ 14·1 }	.....	- 3°·0 }					
F at 0°	{ 0	{ 11·6 }	4·8							
F at 0°	{ 45 (4)	{ 16·4 }	.....	+ 2°·0 }	4·5	2·2	100 : 49		
F at 90°	{ 45 (4)	{ 13·4 }	.....	- 2°·5 }					
F at 0°	{ 0	{ 13·8 }	4·5							
F at 0°	{ 0	{ 11·8 }	4·9	+ 2°·4 }	5·0	2·2	100 : 44			
F at 90°	{ 45 (5)	{ 16·3 }	.....	- 2°·3 }					
F at 0°	{ 0	{ 13·6 }	4·9							
F at 0°	{ 0	{ 11·2 }	5·0	+ 2°·4 }	5·1	2·2	100 : 43			
F at 90°	{ 45 (6)	{ 16·1 }	.....	- 2°·1 }					
F at 0°	{ 0	{ 13·8 }	5·0							
F at 0°	{ 45 (6)	{ 13·0 }	.....	+ 2°·4 }	5·1	2·2	100 : 43		
F at 90°	{ 45 (6)	{ 10·6 }	5·0	- 2°·1 }						
F at 0°	{ 0	{ 15·6 }	5·0					- 2°·1 }		
F at 0°	{ 45	{ 13·5 }								
Mean,							100 : 48			

When the analysing plate F is said to be at 0°, it is parallel to the plate E. When the principal section of the interposed film is at 0°, it is parallel to the plane of incidence at the plate E; at 45° it is inclined 45° to that plane. The signs + and — in the column of “depolarization,” indicate whether the effect of the interposed film was to increase or diminish the heat transmitted.

72. The physical meaning of the expression for the intensity of the depolarized light, $E^2 = F^2 \sin^2 \pi \left(\frac{0 - e}{\lambda} \right)$ will be found to be this. When the thickness of the interposed film is such as to give a retardation of 0, λ , or any whole multiple of λ , E is equal to nothing, or no light is depolarized, and between those values the amount of E^2 , or the intensity of the depolarized light, will gradually increase from the values 0,

λ , 2λ , &c. to the values $\frac{\lambda}{2}$, $\frac{3\lambda}{2}$, $\frac{5\lambda}{2}$, &c. and again diminish in the same manner to the next limit. When the retardation is $\frac{\lambda}{4}$, $\frac{3\lambda}{4}$, $\frac{5\lambda}{4}$, &c., half the light exactly is depolarized; it is then circularly polarized; in other cases, it is plane or elliptically polarized.

73. Similar effects might be expected to occur in the case of heat. But we must recollect that it is even more difficult to obtain *homogeneous heat*, than *homogeneous light*, and that we shall have portions of heat differently depolarized by the same plate, (in consequence of the different character of refrangibility, indicating a different length of undulation,) exactly as when we operate upon white light. We know that heat of various degrees of refrangibility constitutes the solar heat, and probably all other kinds. Hence, no one plate can completely depolarize all these varieties. As far as my experiments go, made similarly to that of (71), heat unaccompanied by light is generally *less* depolarized by a plate of given thickness than heat vividly luminous. In the case of contrasting heat from an Argand lamp with that from incandescent platinum, and heat quite dark, this is strikingly marked, though not so decisively in comparing the two last kinds. If the inaccuracy be not in the experiments, it may very probably arise from the want of homogeneity in the heat just alluded to. The want of any apparent depolarizing power for dark heat in the thin mica film mentioned in (56) is now easily explained. Its thickness was such as to polarize (nearly) circularly, the mean luminous rays. Its retardation, or $o - e$ was then $= \frac{\lambda}{4}$ for these rays. But we know from Melloni's experiments, that the heating rays are *less* refrangible than the luminous rays (I mean in heat from terrestrial sources, as well as that of the solar rays), and that generally in proportion to this obscurity. Therefore, on the undulatory hypothesis, their waves are longer. Hence a retardation of $\frac{\lambda}{4}$ for light, would be a

retardation of less than $\frac{\lambda}{4}$, if λ be the length of a wave of heat from an Argand lamp; it would be still less for heat from incandescent platinum, and least of all for dark heat; hence, as the retardation is a smaller fraction of λ or approaches zero, the depolarization or the value of E^2 approaches zero. This perfectly coincides with the experiment of (56).

74. Without attaching much weight to the *numerical accuracy*. Third Series. Vol. 6. No. 35. May 1835. 3 B

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racy of the following results, it is worth quoting them as confirming the general fact, that obscure heat has longer undulations than luminous heat. The numbers derived from plate No. 2. (see 65,) are most to be depended upon, and the agreement of the different series made with dark heat is highly satisfactory. The numbers correspond to those of the last column in the example of (71).

Mica Plate, No. 1. *Retardation for Light,*
or $o - e = \cdot 00004$ inch. Ratio of Total Polarization and
Depolarization or $F^2 : E^2$.

Number of Comparisons.		
Argand lamp,	4	100 : 80
Incandescent platinum, ...	4	100 : 78
Brass about 700° ,	4	100 : 69

Mica Plate, No. 2. *Retardation for Light,*
or $o - e = \cdot 00002$ inch.

Argand lamp,	3	100 : 66
Incandescent platinum, ...	6	100 : 47
Brass about 700° ,	7	100 : 52
Ditto,	4	100 : 51
Mercury about 500° , ...	5	100 : 52

In discussing these observations, it would be necessary to attend to the remark of (73), respecting the want of homogeneity in the heat.

75. From the last series it appears that a plate of mica which transmits by polarized light (when the polarizing plates are crossed) red of the first order, almost exactly circularly polarizes obscure heat, for it depolarizes half the heat. The characteristic property of circularly polarized light was observed, viz. that little or no difference of result was obtained whilst the mica film was interposed (its principal section being inclined 45° to the plane of polarization), whether the analysing plate was at 0° or 90° . With incandescent platinum the effect is exceedingly striking; for, if the mica film be at 0° , the polarizing effect on crossing the plates is about 40 per cent. of the whole.

76. It is almost unnecessary to add, that what we have now said, inferring the undulatory theory of light to be true, might be translated into the language of the Newtonian theory of emission.

77. In conclusion, I would recapitulate the chief results at which I have arrived*.

* These conclusions were stated nearly in their present form (excepting the 6th), to the Royal Society [of Edinburgh] at their meeting of the 5th January. The whole of the experiments detailed in this paper (excepting only the repetition of M. Melloni's experiment on the refraction of heat (16), were made between the 22nd November and the 16th January, but all the general consequences had been clearly made out before the close of 1834.

1. Heat, whether luminous or obscure, is capable of polarization by tourmaline.
2. It may be polarized by refraction.
3. It may be polarized by reflection.
4. It may be depolarized by doubly refracting crystals.

Hence,

5. It is capable of double refraction, and the two rays are polarized. When suitably modified, these rays are capable of interfering like those of light.

6. The characteristic law of depolarization in the case of light holds in that of heat, viz. that the intensities in rectangular positions of the analysing plate, are complementary to one another.

7. As a necessary consequence of the above, confirmed by experiment, heat is susceptible of circular and elliptic polarization.

8. The undulations of obscure heat are probably longer than those of light. A method is pointed out for deducing their length numerically.

78. Of the evidence for these conclusions I have enabled the reader to judge, by specifying numerical results. But I must further add, that all the principal conclusions were arrived at by the indications of the galvanometer, observed by the naked eye, including the chief phenomena of depolarization. Since I thought of the method of magnifying the divisions (described in (5).) I had little else to perform than the agreeable task of verifying and defining my first conclusions.

Edinburgh, 19th January, 1835.

LX. *Proceedings of Learned Societies.*

ROYAL SOCIETY.

1835, Feb. 19.—A PAPER was read, entitled, “On the probable Position of the South Magnetic Pole.” By Edward Rudge, Esq., F.R.S., &c.

The recent discovery of the site of the North Magnetic Pole, which has resulted from the experiments of Capt. James Ross, suggested to the author the inquiry whether any similar indications of an approach to the South Magnetic Pole can be gathered from any observations now on record. With this view a table is given of the observations made by Tasman in 1642 and 1643, during his voyage of discovery in the Southern Ocean, extracted from his journal; from which it appears that he on one occasion noticed the continual agitation of the horizontal needle, in south latitude $42^{\circ} 25'$, and longitude from Paris 160° . On the presumption that the South Magnetic Pole was at that time near this spot, and that it has since been retrograding towards the East, the author conjectures that it will now be found