

IX. THE BAKERIAN LECTURE.—*Contributions to Molecular Physics.—Being the Fifth Memoir of Researches on Radiant Heat.* By JOHN TYNDALL, F.R.S., Member of the Academies and Societies of Holland, of Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, la Société Philomathique, Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution.

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§ I.

THE natural philosophy of the future must, I imagine, mainly consist in the investigation of the relations which subsist between the ordinary matter of the universe and the ether, in which this matter is immersed. Regarding the motions of the ether itself, as illustrated by the phenomena of reflexion, refraction, interference, and diffraction, the optical investigations of the last half century have left nothing to be desired; but as regards the atoms and molecules whence issue the undulations of light and heat, and their relations to the medium which they move, and by which they are set in motion, these investigations teach us nothing. To come closer to the origin of the ethereal waves—to get, if possible, some experimental hold of the oscillating atoms themselves—has been the main object of the researches in which I have been engaged for the

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last five years. In these researches radiant heat has been used as an instrument for exploring molecular condition, and this is the object which I have kept constantly in view throughout the investigation which I have now the honour to submit to the Royal Society.

The first part of these researches is devoted to the more complete examination of a subject which was briefly touched upon at the conclusion of my Fourth Memoir—namely, the action of liquids, as compared with that of their vapours, upon radiant heat. The differences which exist between different gaseous molecules, as regards their power of emitting and absorbing radiant heat, have been already amply illustrated. When a gas is condensed to a liquid, the molecules approach and grapple with each other by forces which are insensible as long as the gaseous state is maintained. But though thus condensed and enthralled, the ether still surrounds the molecules. If, then, the powers of radiation and absorption depend upon them individually, we may expect that the deportment towards radiant heat which experiment establishes in the case of the free molecule, will maintain itself after the molecule has relinquished its freedom and formed part of a liquid. If, on the other hand, the state of aggregation be of paramount importance, we may expect to find on the part of liquids a deportment altogether different from that of their vapours.

MELLONI, it is well known, examined the diathermancy of various liquids, but he employed for this purpose the flame of an oil-lamp, covered by a glass chimney. His liquids, moreover, were contained in glass cells; hence the radiation from the source was profoundly modified before it entered the liquid at all, for the glass was impervious to a considerable part of the radiation. It was my wish to interfere as little as possible with the primitive emission, and also to compare the action of liquids with that of their vapours, when examined in a tube stopped with plates of rock-salt. I therefore devised an apparatus in which a layer of liquid of any thickness could be enclosed between two polished plates of rock-salt. It was skilfully constructed for me by Mr. BECKER, and the same two plates have already done service in more than six hundred experiments.

The apparatus consists of the following parts:—A B C (fig. 1) is a plate of brass, 3·4 inches long, 2·1 inches wide, and 0·3 of an inch thick. Into it, at its corners, are rigidly fixed four upright pillars, furnished at the top with screws, for the reception of the nuts *qrst*. D E F is a second plate of brass of the same size as the former, and pierced with holes at its four corners, so as to enable it to slip over the four columns of the plate A B C. Both these plates are perforated by circular apertures, *mn* and *op*, 1·35 inch in diameter. G H I is a third plate of brass of the same area as D E F, and, like it, having its centre and its corners perforated. The plate G H I is intended to separate the two plates of rock-salt, which are to form the walls of the cell, and its thickness determines that of the liquid layer. Thus when the plates A B C and D E F are in position, a space of the form of a shallow cylinder is enclosed between them, and this space can be filled with any liquid through the orifice *k*. The separating plate

Fig. 1.

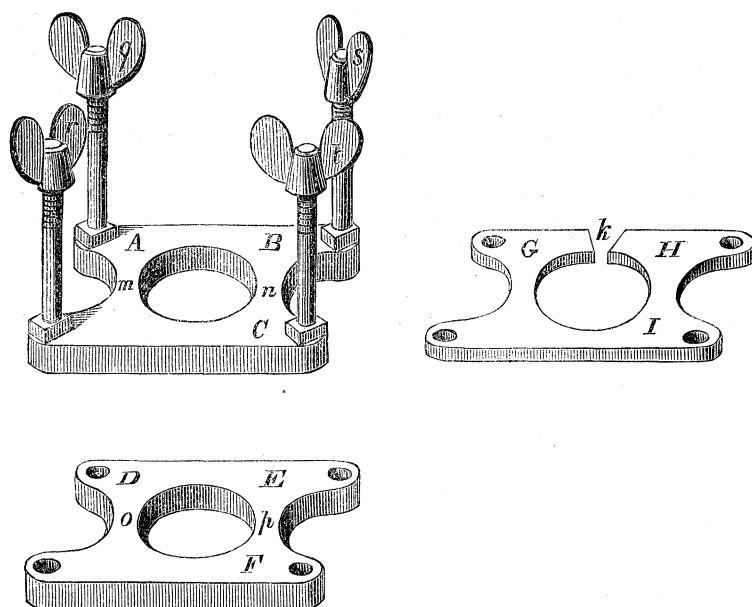
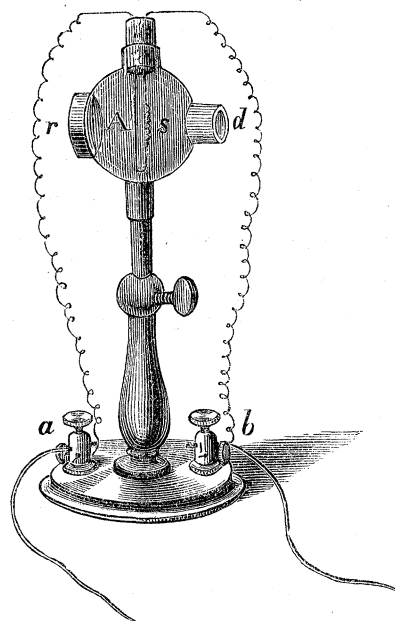


Fig. 2.



G H I was ground with the utmost accuracy, and the surfaces of the plates of salt were polished with extreme care, with a view to rendering the contact between the salt and the brass water-tight. In practice, however, it was found necessary to introduce washers of thin letter-paper between the plates of salt and the separating plate.

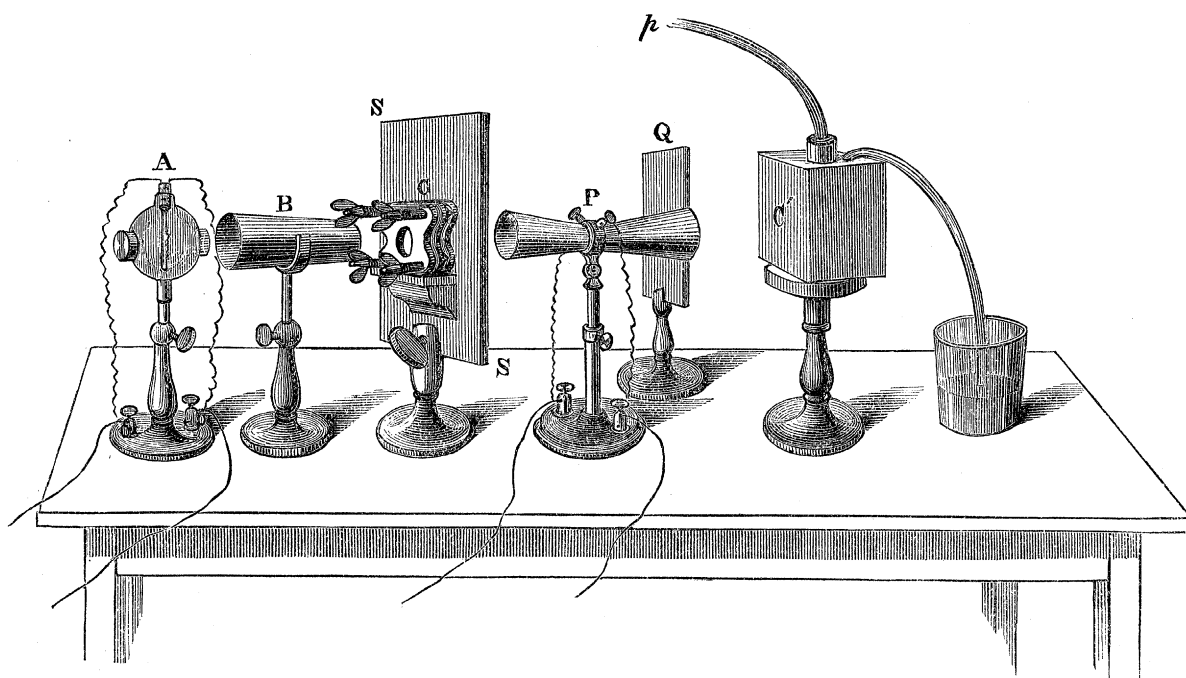
In arranging the cell for experiment, the nuts *qrst* are unscrewed, and a washer of india-rubber is first placed on A B C. On this washer is placed one of the plates of rock-salt. On the plate of rock-salt is placed the washer of letter-paper, and on this again the separating plate G H I. A second washer of paper is placed on this plate, then comes the second plate of salt, on which another india-rubber washer is laid. The plate D E F is finally slipped over the columns, and the whole arrangement is tightly screwed together by the nuts *qrst*. The use of the india-rubber washers is to relieve the crushing pressure which would be applied to the plates of salt if they were in actual contact with the brass plates; and the use of the paper washers is, as already explained, to render the cell liquid-tight. After each experiment, the apparatus is unscrewed, the plates of salt are removed and thoroughly cleansed; the cell is then remounted, and in two or three minutes all is ready for a new experiment.

My next necessity was a perfectly steady source of heat, of sufficient intensity to penetrate the most absorbent of the liquids to be subjected to examination. This was found in a spiral of platinum wire, rendered incandescent by an electric current. The frequent use of this source of heat led me to construct the lamp shown in fig. 2. A is a globe of glass 3 inches in diameter, fixed upon a stand, which can be raised and lowered. At the top of the globe is a tubulure, into which a cork is fitted, and through the cork pass two wires whose ends are united by the platinum spiral S. The wires are carried down to the binding screws *ab*, which are fixed in the foot of the stand

so that when the instrument is attached to the battery no strain is ever exerted on the wires which carry the spiral. The ends of the thick wire to which the spiral is attached are also of stout platinum; for when it was attached to copper wires, unsteadiness was introduced through oxidation. The heat issues from the incandescent spiral by the opening  $d$ , which is an inch and a half in diameter. Behind the spiral, finally, is a metallic reflector,  $r$ , which augments the flux of heat without sensibly changing its quality. In the open air the red-hot spiral is a capricious source of heat; but surrounded by its glass globe its steadiness is admirable.

The whole experimental arrangement will be immediately understood from the sketch

Fig. 3.



given in fig. 3. A is the platinum lamp just described, heated by a current from a Grove's battery of five cells. It is necessary that this lamp should remain perfectly constant throughout the day; and to keep it so, a tangent galvanometer and a rheocord are introduced into the circuit.

In front of the spiral, and surrounding the tubulure of its globe, is the tube B with an interior reflecting surface, through which the heat passes to the rock-salt cell C. This cell is placed on a little stage soldered to the back of the perforated screen SS, so that the heat, after having crossed the cell, passes through the hole in the screen, and afterwards impinges on the thermo-electric pile P. The pile is placed at some distance from the screen SS, so as to render the temperature of the cell C itself of no account. C' is the compensating cube, containing water kept boiling by steam from the pipe  $p$ . Between the cube C' and the pile P is the screen Q, which regulates the amount of heat falling on the posterior face of the pile. The whole arrangement is here exposed;

but in practice the pile P and the cube C' are carefully protected from the capricious action of the surrounding air.

The experiments are thus performed. The empty rock-salt cell C being placed on its stage, a double silvered screen (not shown in the figure) is first introduced between the end of the tube B and the cell C; the radiation from the spiral being thus totally cut off, and the pile subjected to the action of the cube C' alone. By means of the screen Q, the total heat to be adopted throughout the series of experiments is obtained: say that it is sufficient to produce a galvanometric deflection of 50 degrees. The double screen used to intercept the radiation from the spiral is then gradually withdrawn until this radiation completely neutralizes that from the cube C', and the needle of the galvanometer points steadily to zero. The position of the double screen, once fixed, remains subsequently unchanged, the slight and slow alteration of the source being neutralized by the rheocord. Thus the rays in the first instance pass from the spiral through the empty rock-salt cell. A small funnel, supported by a suitable stand, dips into the aperture which leads into the cell, and through this the liquid is poured. The introduction of the liquid destroys the previous equilibrium, the galvanometer needle moves, and finally assumes a steady deflection; and from this deflection we can immediately calculate the quantity of heat absorbed by the liquid, and express it in hundredths of the entire radiation.

For example, the empty cell being placed upon its stand, and the needle being at 0°, the introduction of iodide of methyl into the cell produced a deflection of 30°·8. The total radiation on this occasion was 44°·2. Taking the force necessary to move the needle from 0° to 1° as our unit, the deflection 30°·8 corresponds to 32 such units, while the deflection 44°·2 corresponds to 58·3 such units. Hence the statement

$$58\cdot3 : 100 = 32 : 54\cdot9,$$

which gives an absorption of 54·9 per cent. for a layer of liquid iodide of methyl 0·07 of an inch in thickness.

§ 2.

The following Table contains the results obtained in this manner with the respective liquids there mentioned. It embraces both the deflection produced by the introduction of the liquid, and the quantity per cent. intercepted of the entire radiation. It has been intimated to me by some of my Continental friends that the publication of such details as would enable a reader to judge of the precision attainable by my apparatus would be desirable. In this paper I shall, to some extent, endeavour to satisfy this desire, making use, however, of my ordinary experiments.

TABLE I.—Radiation of heat through Liquids. Source of heat, red-hot platinum spiral. Thickness of liquid layer 0·07 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Iodide of Methyl . . . . .	30°·8	54·9
Iodide of Ethyl . . . . .	33·0	60·4

TABLE I. (continued).

Name of liquid.	Deflection.	Absorption per 100.
Benzol . . . . .	35 <sup>o</sup> ·3	67·0
Amylene . . . . .	37·7	74·8
Sulphuric Ether . . . . .	39·0	79·4
Acetic Ether . . . . .	39·6	81·6
Alcohol . . . . .	41·0	86·6
Water* . . . . .	43·3	91·4
Total heat . . . . .	44·2	100

In these experiments I employed a less delicate galvanometer than that used in my former researches. The experiments were made on the 29th of September, and on the following day I repeated them with the following results:—

TABLE II.—Radiation of heat through Liquids. Source of heat, red-hot platinum spiral. Thickness of liquid layer 0·07 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Iodide of Methyl . . . . .	33 <sup>o</sup> ·5	53·7
Iodide of Ethyl . . . . .	35·5	58·7
Benzol . . . . .	37·5	64·4
Amylene . . . . .	39·5	70·7
Sulphuric Ether . . . . .	41·0	75·4
Acetic Ether . . . . .	41·5	76·9
Formic Ether . . . . .	42·4	80·0
Alcohol . . . . .	43·5	84·2
Water . . . . .	44·7	90·5
Total heat . . . . .	46·7	100·0

On the 28th of October my most delicate galvanometer was at liberty, and with it I executed the experiments performed with the coarser one. The following are the results:—

TABLE III.—Radiation of heat through Liquids. Source, red-hot platinum spiral. Thickness of liquid layer 0·07 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	9·0	12·5
Chloroform . . . . .	25·2	35·0
Iodide of Methyl . . . . .	36·0	53·2 54·3
Ditto, strongly coloured with iodine . . . . .	36·0	53·2
Iodide of Ethyl . . . . .	38·2	59·0 59·6

\* To prevent the water from attacking the cell, it was always first saturated with the substance of the cell itself, namely, transparent rock-salt.

TABLE III. (continued).

Name of liquid.	Deflection.	Absorption per 100.
Benzol . . . . .	39.2	62.5 65.7
Amylene . . . . .	42.0	73.6 72.3
Sulphuric Ether . . . . .	42.6	76.1 77.4
Acetic Ether . . . . .	43.4	78.0 79.3
Formic Ether . . . . .	43.3	79.0 80.0
Alcohol . . . . .	44.4	83.6 85.4
Water . . . . .	45.6	88.8 90.9
Total heat . . . . .	48.0	100.0

I have here placed beside the results obtained with the delicate galvanometer, the means of those obtained with the coarser one. It is not my object to push these measurements to the last degree of nicety; otherwise the satisfactory agreement here exhibited might be made still better.

To render the experiments on liquid transmission more complete, I operated with layers of various thicknesses, employing throughout my most delicate galvanometer. The results of these measurements are recorded in the following series of Tables:—

TABLE IV.—Radiation of heat through Liquids. Source, red-hot platinum spiral.  
Thickness of liquid layer 0.02 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	4.0	5.5
Chloroform . . . . .	12.0	16.6
Iodide of Methyl . . . . .	26.0	36.1
Iodide of Ethyl . . . . .	27.5	38.2
Benzol . . . . .	31.3	43.4
Amylene . . . . .	38.0	58.3
Boracic Ether . . . . .	39.0	61.8
Sulphuric Ether . . . . .	39.5	63.3
Formic Ether . . . . .	40.0	65.2
Alcohol . . . . .	40.5	67.3
Water . . . . .	43.7	80.7
Total heat . . . . .	48.0	100.0

TABLE V.—Thickness of liquid layer 0.04 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	6.1	8.4
Chloroform . . . . .	18.0	25.0
Iodide of Methyl . . . . .	33.0	46.5
Iodide of Ethyl . . . . .	35.0	50.7

TABLE V. (continued).

Name of liquid.	Deflection.	Absorption per 100.
Benzol . . . . .	37 <sup>o</sup> ·0	55·7
Amylene . . . . .	40·0	65·2
Boracic Ether . . . . .	41·0	69·4
Sulphuric Ether . . . . .	42·0	73·5
Acetic Ether . . . . .	42·1	74·0
Formic Ether . . . . .	42·5	76·3
Alcohol . . . . .	43·2	78·6
Water . . . . .	45·0	86·1
Total heat . . . . .	48·0	100·0

TABLE VI.—Thickness of liquid layer 0·14 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	11 <sup>o</sup> ·0	15·2
Chloroform . . . . .	28·6	40·0
Iodide of Methyl . . . . .	40·0	65·2
Iodide of Ethyl . . . . .	40·9	69·0
Benzol . . . . .	41·5	71·5
Amylene . . . . .	43·0	77·7
Sulphuric Ether . . . . .	43·2	78·6
Acetic Ether . . . . .	44·0	82·0
Formic Ether . . . . .	44·5	84·0
Alcohol . . . . .	44·8	85·3
Water . . . . .	46·3	91·8
Total heat . . . . .	48·0	100·0

TABLE VII.—Thickness of liquid layer 0·27 of an inch.

Name of liquid.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	12 <sup>o</sup> ·5	17·3
Chloroform . . . . .	32·3	44·8
Iodide of Methyl . . . . .	40·8	68·6
Iodide of Ethyl . . . . .	41·5	71·5
Benzol . . . . .	42·0	73·6
Amylene . . . . .	44·1	82·3
Sulphuric Ether . . . . .	44·8	85·2
Acetic Ether . . . . .	45·0	86·1
Formic Ether . . . . .	45·2	87·0
Alcohol . . . . .	45·7	89·1
Water . . . . .	46·1	91·0
Total heat . . . . .	48·0	100·0



The foregoing results are collected together in the following Table:—

TABLE VIII.—Absorption of heat by Liquids. Source, platinum spiral heated to a bright redness by a voltaic current.

Liquid.	Thickness of liquid in parts of an inch.				
	0.02.	0.04.	0.07.	0.14.	0.27.
Bisulphide of Carbon .....	5.5	8.4	12.5	15.2	17.3
Chloroform .....	16.6	25.0	35.0	40.0	44.8
Iodide of Methyl .....	36.1	46.5	53.2	65.2	68.6
Iodide of Ethyl .....	38.2	50.7	59.0	69.0	71.5
Benzol .....	43.4	55.7	62.5	71.5	73.6
Amylene.....	58.3	65.2	73.6	77.7	82.3
Sulphuric Ether.....	63.3	73.5	76.1	78.6	85.2
Acetic Ether .....	.....	74.0	78.0	82.0	86.1
Formic Ether.....	65.2	76.3	79.0	84.0	87.0
Alcohol .....	67.3	78.6	83.6	85.3	89.1
Water.....	80.7	86.1	88.8	91.8	91.0

Had it been desirable to push these measurements to the utmost limit of accuracy, I should have repeated each experiment, and taken the mean of the determinations. But considering the way in which the different thicknesses check each other, an inspection of the Table must produce the conviction that the results express, within small limits of error, the action of the bodies mentioned.

§ 3.

As liquids, then, those bodies are shown to possess very different capacities of intercepting the heat emitted by our radiating source; and we have next to inquire whether these differences continue after the molecules have been released from the bond of cohesion. We must, of course, test the vapours by waves of the same period as those applied to the liquids; and this our mode of experiment renders easy of accomplishment. The heat generated in a wire by a current of a given strength being invariable; it was only necessary, by means of the tangent compass and rheocord, to keep the current constant from day to day in order to obtain, both as regards quantity and quality, an invariable source of heat.

The liquids from which the vapours were derived were placed in a small long flask, a separate flask being devoted to each. The air above the liquid, and within it, being first carefully removed by an air-pump, the flask was attached to the experimental tube in which the vapours were to be examined. This tube was of brass, 49.6 inches long, and 2.4 inches in diameter, its two ends being stopped by plates of rock-salt. Its interior surface was polished. At the commencement of each experiment, the tube having been thoroughly cleansed and exhausted, the needle stood at zero\*. The cock of the flask containing the volatile liquid was then carefully turned on, and the vapour allowed slowly to enter the experimental tube. The barometer attached to the tube was finely graduated, and the descent of the mercurial column was observed through a magnifying lens. When a pressure of 0.5 of an inch was obtained, the vapour was cut

\* It is hardly necessary to remark that the principle of compensation described in my former memoirs was employed here also.

off and the permanent deflection of the needle noted. Knowing the total heat, the absorption in 100ths of the entire radiation could be at once deduced from the deflection. The following Table contains the results of the first series of experiments made with the platinum spiral as source.

TABLE IX.—Radiation of heat through Vapours. Source, red-hot platinum spiral.  
Tension, 0·5 of an inch.

Name of vapour.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	17 <sup>o</sup> ·0	4·7 } Mean.
Bisulphide of Carbon . . . . .	16·8	4·6 } 4·7
Chloroform . . . . .	22·5	6·2 } 6·3
Chloroform . . . . .	22·8	6·3 } 6·3
Iodide of Methyl . . . . .	34·0	9·7 } 9·7
Iodide of Methyl . . . . .	34·0	9·7 } 9·7
Iodide of Ethyl . . . . .	46·0	18·0 } 17·8
Iodide of Ethyl . . . . .	45·5	17·6 } 17·8
Benzol . . . . .	48·5	20·4 } 20·4
Benzol . . . . .	48·5	20·4 } 20·4
Amylene . . . . .	56·3	27·3 } 27·3
Amylene . . . . .	56·2	27·2 } 27·3
Total heat . . . . .	78·3	100·0

The absence of all caprice or uncertainty in the measurements is, I think, demonstrated by the foregoing Table, which is simply an average sample of the degree of coincidence obtained in separate measurements. Two determinations were made in each case; and it will be seen that while, in some instances, the second experiment yielded the same result as the first, in one instance only does the difference amount to half a degree of the galvanometer.

The foregoing measurements were executed on the 5th of October. On the 7th they were in part repeated, with the following results.

TABLE X.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . . . .	16 <sup>o</sup> ·5	4·7
Chloroform . . . . .	22·8	6·5
Iodide of Methyl . . . . .	33·0	9·6
Iodide of Ethyl . . . . .	45·0	17·7
Benzol . . . . .	48·0	20·6
Amylene . . . . .	55·3	27·5
Alcohol . . . . .	55·7	28·1
Formic Ether . . . . .	58·2	31·4
Sulphuric Ether . . . . .	58·5	31·9
Acetic Ether . . . . .	59·9	34·6
Total heat . . . . .	78·0	100·0

Placing these results beside those recorded in Table IX., the manner in which they check each other will appear.

Comparison of Tables IX. and X.—Absorption.

	Table IX.	Table X.
Bisulphide of Carbon . . . . .	4·7	4·7
Chloroform . . . . .	6·3	6·5
Iodide of Methyl. . . . .	9·7	9·6
Iodide of Ethyl . . . . .	17·8	17·7
Benzol . . . . .	20·4	20·6
Amylene . . . . .	27·3	27·5

The agreement, it will be seen, is as perfect as could be desired.

Augmenting the opening through which the heat passed from the source into the experimental tube, the total heat was increased, and the experiments with a few of the vapours were repeated. The total heat in the last case produced a deflection of 78°, which is equal to 350 units; the total heat now employed produced a deflection of 83°, which is equal to 605 units. It is easy to see that the experiments now to be recorded furnish a direct check on the calibration of the galvanometer. As long as the quality of the heat remains unchanged, the absorption ought to be the same with a high total heat as with a low one. But if experiment show that this is the case, it proves also that the calibration on which the calculation of the absorption depends, cannot be in error. The following results were obtained on the 8th of October:—

TABLE X a.

	Deflection.	Absorption.
Amylene . . . . .	6·0	28·7
Alcohol . . . . .	66·4	29·2
Formic Ether . . . . .	68·5	32·5
Formic Ether . . . . .	68·5	32·5
Sulphuric Ether . . . . .	69·2	33·6
Sulphuric Ether . . . . .	69·1	33·4
Acetic Ether . . . . .	69·7	34·5
Acetic Ether . . . . .	69·7	34·5
Total heat . . . . .	83·0	100·0

Placing the results beside those recorded in Table X., we have the following comparison:—

Comparison of Tables X. and X a.

Amylene . . . . .	27·5	28·7
Alcohol . . . . .	28·1	29·2
Formic Ether . . . . .	31·4	32·5
Sulphuric Ether . . . . .	31·9	33·5
Acetic Ether . . . . .	34·6	34·5

The differences here are inconsiderable, and lean to neither side; within these limits, therefore, the calibration must be correct; it shall be tested more severely in another part of this paper.

#### § 4.

We are now in a condition to compare the action of a series of volatile liquids with that of the vapours of those liquids upon radiant heat.

Commencing with the substance of the lowest absorptive energy, and proceeding to the highest, we have the following order of absorption:—

Liquids.	Vapours.
Bisulphide of Carbon.	Bisulphide of Carbon.
Chloroform.	Chloroform.
Iodide of Methyl.	Iodide of Methyl.
Iodide of Ethyl.	Iodide of Ethyl.
Benzol.	Benzol.
Amylene.	Amylene.
Sulphuric Ether.	Alcohol.
Acetic Ether.	Formic Ether.
Formic Ether.	Sulphuric Ether.
Alcohol.	Acetic Ether.
Water.	

Here, as far as amylene, the order of absorption is the same for both liquids and vapours. But from amylene downwards, though strong liquid absorption is in a general way paralleled by strong vapour absorption, the order of both is not the same. There is not the slightest doubt that next to water alcohol is the most powerful absorber in the list of liquids; but there is just as little doubt that the position which it occupies in the list of vapours is the correct one. This has been established by reiterated experiments. Acetic ether, on the other hand, though certainly the most energetic absorber in the state of vapour, falls behind both formic ether and alcohol in the liquid state. Still, on the whole, I think it is impossible to contemplate these results without arriving at the general conclusion that the act of absorption is in the main molecular, and that the molecule maintains its power as an absorber and radiator when it changes its state of aggregation. Should, however, any doubt linger as to the correctness of this conclusion, it will speedily disappear.

A moment's reflection will show that the comparison here instituted is not a strict one. We have taken the liquids at a common thickness, and the vapours at a common volume and pressure. But if the layers of liquid employed were turned bodily into vapour, the volumes obtained would *not* be the same. Hence the quantities of matter traversed by the radiant heat are neither equal nor proportional to each other in the two cases; and to render the comparison strict they ought to be proportional. It is easy, of course, to make them so; for the liquids being examined at a constant volume, their specific gravities give us the relative quantities of matter traversed by the radiant

heat, and from these, and the vapour-densities, we can immediately deduce the corresponding volumes of the vapour. Calling the quantity of matter  $q$ , the vapour-density  $d$ , and the volume  $V$ , we have

$$Vd = q,$$

or

$$V = \frac{q}{d}.$$

Dividing, therefore, the specific gravities of our liquids by the densities of their vapours, we obtain a series of volumes proportional to the masses of the liquids employed. The densities of both liquids and vapours are given in the following Table:—

Table of Densities.

	Vapour.	Liquid.
Bisulphide of Carbon . . . . .	2·63	1·27
Chloroform . . . . .	4·13	1·48
Iodide of Methyl . . . . .	4·90	2·24
Iodide of Ethyl . . . . .	5·39	1·95
Benzol . . . . .	2·69	0·85
Amylene . . . . .	2·42	0·64
Alcohol . . . . .	1·59	0·79
Sulphuric Ether . . . . .	2·56	0·71
Formic Ether . . . . .	2·56	0·91
Acetic Ether . . . . .	3·04	0·89
Water . . . . .	0·63	1·00

Substituting for  $q$  the numbers of the second column, and for  $d$  those of the first, we obtain the following series of vapour volumes, whose weights are proportional to the masses of liquid employed.

Table of Proportional Volumes.

Bisulphide of Carbon . . . . .	0·48
Chloroform . . . . .	0·36
Iodide of Methyl . . . . .	0·46
Iodide of Ethyl . . . . .	0·36
Benzol . . . . .	0·32
Amylene . . . . .	0·26
Alcohol . . . . .	0·50
Sulphuric Ether . . . . .	0·28
Formic Ether . . . . .	0·36
Acetic Ether . . . . .	0·29
Water . . . . .	1·60

Employing the vapours in the volumes here indicated, the following results were obtained:—

TABLE XI.—Radiation of heat through Vapours. Mass of vapour proportional to mass of liquid.

Name of vapour.	Tension in parts of an inch.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	0.48	{ 8.4 } { 8.5 }	4.3
Chloroform . . . . .	0.36	{ 13.0 } { 13.0 }	6.6
Iodide of Methyl . . . . .	0.46	{ 20.0 } { 20.4 }	10.2
Iodide of Ethyl . . . . .	0.36	{ 30.6 } { 30.6 }	15.4
Benzol . . . . .	0.32	{ 33.4 } { 33.1 }	16.8
Amylene . . . . .	0.26	37.7	19.0
Sulphuric Ether . . . . .	0.28	{ 42.5 } { 42.6 }	21.5
Acetic Ether . . . . .	0.29	{ 44.0 } { 44.0 }	22.2
Formic Ether . . . . .	0.36	{ 44.5 } { 44.7 }	22.5
Alcohol . . . . .	0.50	{ 45.0 } { 44.9 }	22.7

Here the discrepancies revealed by our former series of experiments entirely disappear, and it is proved that for heat of the same quality the order of absorption for liquids and their vapours is the same. We may therefore safely infer that the position of a vapour as an absorber or radiator is determined by that of the liquid from which it is derived. Granting the validity of this inference, the position of *water* fixes that of *aqueous vapour*. From the first seven Tables of this memoir, or from the *résumé* of results in Table VIII., it will be seen that for all thicknesses water exceeds the other liquids in the energy of its absorption. Hence, if no single experiment on the vapour of water existed, we should be compelled to conclude, from the deportment of its liquid, that, weight for weight, aqueous vapour transcends all others in absorptive power. Add to this the direct and multiplied experiments by which the action of this substance on radiant heat has been established, and we have before us a body of evidence sufficient, I trust, to set this question for ever at rest, and to induce the meteorologist to apply without misgiving the radiant and absorbent property of aqueous vapour to the phenomena of his science.

## § 5.

The order and relative powers of absorption of our vapours, when equal volumes are compared, are given in Table X.: the chemical formulæ of the substances, and the number of atoms which their molecules embrace, are as follows:—

	Formula.	Number of atoms in molecules.
Bisulphide of Carbon . . . . .	$C S_2$	3
Chloroform . . . . .	$C H Cl_3$	5
Iodide of Methyl. . . . .	$C H_3 I$	5
Iodide of Ethyl . . . . .	$C_2 H_5 I$	8
Benzol . . . . .	$C_6 H_6$	12
Amylene . . . . .	$C_5 H_{10}$	15
Alcohol. . . . .	$C_2 H_6 O$	9
Formic Ether . . . . .	$C_3 H_6 O_2$	11
Sulphuric Ether . . . . .	$C_4 H_{10} O$	15
Acetic Ether . . . . .	$C_4 H_8 O_2$	14
Boracic Ether . . . . .	$B C_6 H_{15} O_3$	25

Here, for the first six vapours, the radiant and absorbent powers augment with the number of atoms contained in the molecules. Alcohol and amylene vapours, however, are nearly alike in absorptive power, the molecule of amylene containing 15 atoms, while that of alcohol embraces only 9. But in alcohol we have a third element introduced, which is absent in the amylene; the oxygen of the alcohol gives its molecule such a character as enables it to transcend that of the amylene, though the latter contains the greater number of atoms. Here the idea of *quality* superadds itself to that of number. Acetic ether also has a less number of atoms in its molecule than sulphuric ether; but whereas the latter has but one atom of oxygen, the former has two. Formic ether and sulphuric ether are almost identical in their absorptive powers for the heat here employed; still formic ether has but 11 atoms in its molecule, while sulphuric has 15. But formic ether possesses two atoms of oxygen, while sulphuric possesses only one. Two things here suggest themselves as influential on the absorbent and radiant power, which may be expressed by the terms *multitude* and *complexity*. As a molecule of multitude, amylene, for example, exceeds alcohol; as a molecule of complexity, alcohol exceeds amylene; and in this case, as regards radiant and absorbent power, the complexity is more than a match for the multitude. The same remarks may be made with reference to sulphuric and formic ether: the former excels in multitude, the latter in complexity, the excess in the one case almost exactly balancing that in the other. Adding two atoms of hydrogen and one of carbon to the formic ether, we obtain acetic ether, and by this addition the balance is turned; for though acetic ether falls short of sulphuric ether in multitude, it transcends it in absorbent and radiant power. Outstanding from all others, when equal volumes are compared, and signaling itself by the enormous magnitude of its absorption, we have boracic ether, each molecule of which embraces no less than 25 atoms. The time now at my disposal enables me to do little more than glance at these singular facts; but I must direct the attention of chemists to the water molecule: its power as a radiant and an absorbent is perfectly unprecedented and anomalous, if the usually recognized formula be correct.

## § 6.

In Table III. a fact is revealed which is worth a little further attention. The measurements there recorded show that the absorption of a layer of iodide of methyl, strongly coloured with iodine (which, doubtless, had been liberated by the action of light), was precisely the same as that of a perfectly transparent layer of the liquid. The iodine, which produced so marked an effect on light, did not sensibly affect the radiant heat emitted by the platinum spiral. Here are the numbers:—

	Absorption.
Iodide of Methyl (transparent) . . . . .	: 53·2
Iodide of Methyl (strongly coloured with iodine) . . . . .	53·2

In this case, the incandescent spiral, or a flame, was visible when looked at through the liquid; I therefore intentionally deepened the colour (a rich brown), by adding iodine, until the layer was of sufficient opacity to cut off wholly the light of a brilliant jet of gas. The transparency of the liquid to the radiant heat was not sensibly affected by the addition of the iodine. The luminous heat was of course cut off; but this, as compared with the whole radiation, was so small as to be insensible in the experiments.

It is known that iodine dissolves freely in the bisulphide of carbon, the colour of the solution in thin layers being a splendid purple; but in layers of moderate thickness it may be rendered perfectly opaque to light. I dissolved in the liquid a quantity of the iodine sufficient, when introduced into a cell 0·07 of an inch wide, to cut off wholly the light of the most brilliant gas-flame. Comparing the opaque solution with the transparent bisulphide, the following results were obtained:—

	Deflection.	Absorption.
Bisulphide of Carbon (opaque) . . . . .	9·0	12·5
Bisulphide of Carbon (transparent) . . . . .	9·0	12·5

Here the presence of a quantity of iodine, perfectly opaque to a brilliant light, was without measureable effect upon the heat emanating from our platinum spiral. The liquid was sensibly thickened by the quantity of iodine dissolved in it.

The same liquid was placed in a cell 0·27 of an inch in width; that is to say, a solution which was perfectly opaque to light, at a thickness of 0·07 was employed in a layer of nearly four times this thickness. Here are the results:—

	Deflection.	Absorption.
Bisulphide of Carbon (transparent) . . . . .	13·6	18·8
Bisulphide of Carbon (opaque) . . . . .	13·7	19·0

The difference between the two measurements lies within the limits of possible error.

Bisulphide of carbon is commonly used to fill hollow prisms, when considerable dispersion is sought for in the decomposition of white light. Such prisms, filled with the opaque solution, intercept entirely the luminous part of the spectrum, but allow the extra-red rays free passage. A heat-spectrum of the sun, or of the electric light, may be thus



obtained entirely separated from the luminous one. By means of a prism of the transparent bisulphide, I determined the position of the spectrum of the electric light upon a screen, and behind the screen placed a thermo-electric pile so that when the screen was removed the extra-red rays fell upon the pile. I then substituted an opaque prism for the transparent one: there was no visible spectrum on the screen; but the removal of the latter at once demonstrated the existence of an invisible spectrum by the thermo-electric current which is generated, and which was powerful enough to dash violently aside the needles of a large lecture-room galvanometer.

To what, then, are we to ascribe the deportment of iodine towards luminous and obscure heat? The difference between both qualities of heat is simply one of period: in the one case the waves which convey the energy are short and of rapid recurrence; in the other case they are long and of slow recurrence. The former are intercepted by the iodine, and the latter are allowed to pass. Why? There can, I think, be only one answer to this question—that the intercepted waves are those whose periods coincide with the periods of oscillation possible to the atoms of the dissolved iodine. Supposing waves of any period to impinge upon an assemblage of molecules of any other period, it is, I think, physically certain that a tremor of greater or less intensity will be set up among the molecules; but for the motion to *accumulate* so as to produce sensible absorption, coincidence of period is necessary. Briefly defined, therefore, transparency is synonymous with *discord*, while opacity is synonymous with *accord* between the periods of the waves of ether and those of the molecules of the body on which they impinge. The opacity, then, of our solution of iodine to light shows that its atoms are competent to vibrate in all periods which lie within the limits of the visible spectrum; while its transparency to the extra-red undulations demonstrates the incompetency of its atoms to vibrate in unison with the longer waves.

This simple conception will, I think, be found sufficient to conduct us with intellectual clearness through a multitude of otherwise perplexing phenomena. It may of course be applied immediately to that numerous class of bodies which are transparent to light, but opaque in a greater or less degree to radiant heat. Water, for example, is an eminent example of this class of bodies: while it allows the luminous rays to pass with freedom, it is highly opaque to all radiations emanating from obscure sources. A layer of this substance one-twentieth of an inch thick is competent, as MELLONI has shown, to intercept all rays issuing from bodies heated under incandescence. Hence we may infer that, throughout the range of the visible spectrum, the periods of the water-molecules are in discord with those of the ethereal waves, while beyond the red we have coincidence between both.

What is true of water is, of course, true in a less degree of glass, alum, calcareous spar, and of all the substances named in the first section of this paper. They are all in discord with the visible spectrum; they are all more or less in accord with the extra-red undulations of the spectrum.

Thus also as regards lampblack: the blackness of the substance is due to the accord which reigns between the oscillating periods of its atoms and those of the waves embraced within the limits of the visible spectrum. The substance which is thus impervious to the luminous rays is moreover the very one from which the whitest light of our lamps is derived. It can absorb all the rays of the visible spectrum, it can also emit them. But though in a far less degree than iodine, lampblack is also to some extent transparent to the longer undulations. MELLONI was the first to prove this; and in an experiment described in a former memoir, I myself found that 30 per cent. of the radiation from an obscure source found its way through a layer of lampblack, which cut off totally the light of the most brilliant jet of gas. I shall have occasion to show that, for certain sources of heat of long period, between 40 and 50 per cent. of the entire radiation is transmitted by a layer of lampblack which is perfectly opaque to our most brilliant artificial lights. Hence, in the case of lampblack, while accord exists between the periods of its atoms and those of the light-exciting waves, discord, to a considerable extent, exists between the periods of the same atoms and those of the extra-red undulations.

## § 7.

The power of varying at will the temperature of the platinum spiral, renders it peculiarly suitable for the examination of the influence of temperature on the transmission of radiant heat. To obtain sources of different temperatures, MELLONI resorted to lamps, to spirals heated to incandescence by the flame of alcohol, to copper laminæ heated by flame, and to the surfaces of vessels containing boiling water. No conclusions regarding temperature can, as will afterwards be shown, be drawn from such experiments; but by means of the platinum spiral we can go through all those changes of temperature, *retaining throughout the same vibrating atoms*, and we can therefore investigate how the alteration of the rate of vibration affects the rate of absorption. The following series of experiments were executed on the 9th of October, with a platinum spiral raised to barely visible redness, and vapours at a tension of 0·5 of an inch.

TABLE XII.—Radiation of heat through Vapours. Source of heat, platinum spiral barely visible in the dark.

Name of vapour.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	7·5	6·5
Bisulphide of Carbon . . . . .	7·45	6·4
Chloroform . . . . .	10·5	9·1
Chloroform . . . . .	10·5	9·1
Iodide of Methyl . . . . .	14·5	12·5
Iodide of Methyl . . . . .	14·5	12·5
Iodide of Ethyl . . . . .	24·2	20·9
Iodide of Ethyl . . . . .	24·5	21·1

TABLE XII. (continued).

Name of vapour.	Deflection.	Absorption per 100.
Benzol . . . . .	31.0	26.7}
Benzol . . . . .	30.0	25.9}
Amylene . . . . .	37.6	35.6}
Amylene . . . . .	37.8	35.9}
Sulphuric Ether . . . . .	41.1	43.4}
Sulphuric Ether . . . . .	41.0	43.4}
Formic Ether . . . . .	41.7	45.0}
Formic Ether . . . . .	41.8	45.3}
Acetic Ether . . . . .	43.6	49.8}
Acetic Ether . . . . .	43.4	49.3}

On the 10th of October the following results were obtained with the same platinum spiral, raised to a white heat:—

TABLE XIII.—Radiation of heat through Vapours. Source, white-hot platinum spiral.

Name of vapour.	Deflection.	Absorption per 100.
Bisulphide of Carbon . . . . .	3.5	2.9}
Bisulphide of Carbon . . . . .	3.4	2.8}
Chloroform . . . . .	6.7	5.6}
Chloroform . . . . .	6.7	5.6}
Iodide of Methyl . . . . .	9.2	7.7}
Iodide of Methyl . . . . .	9.4	7.9}
Iodide of Ethyl . . . . .	15.4	13.0}
Iodide of Ethyl . . . . .	15.0	12.6}
Benzol . . . . .	19.3	16.6}
Benzol . . . . .	19.0	16.4}
Total heat . . . . .	59.2	100.0
Amylene . . . . .	27.6	22.6}
Amylene . . . . .	27.7	22.7}
Formic Ether . . . . .	30.5	25.0}
Formic Ether . . . . .	30.7	25.2}
Sulphuric Ether . . . . .	31.4	25.7}
Sulphuric Ether . . . . .	31.7	26.0}
Acetic Ether . . . . .	33.0	27.0}
Acetic Ether . . . . .	33.2	27.3}
Total heat . . . . .	60.0	100.0

With the same spiral, brought still nearer to its point of fusion, the following results were obtained with four of the vapours:—

TABLE XIV.—Radiation through Vapours. Source, platinum spiral at an intense white heat.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . .	14.5	2.5}
Bisulphide of Carbon . . .	14.5	2.5}
Chloroform . . . . .	23.0	3.9}
Chloroform . . . . .	23.0	3.9}
Formic Ether . . . . .	60.4	21.3}
Formic Ether . . . . .	60.5	21.3}
Sulphuric Ether . . . . .	62.3	23.6}
Sulphuric Ether . . . . .	62.5	23.8}
Total heat . . . . .	82.7	100.0

In the experiments recorded in the foregoing Table, a total heat of 82°·7, or 588 units, was employed; and to test whether the absorption calculated from this high total agreed with the absorptions calculated from a low total, a portion of the current was diverted, the branch passing through the galvanometer producing a deflection of 49°·4. This corresponds to 77 units. The source, it will be observed, is here quite unchanged; the rays are of the same quality, and pass through the tube in the same quantity as before; but in the one case the absorption is calculated from the deflection among the high degrees, and in the other case it is calculated from deflections among the low degrees of the galvanometer.

The experiments were limited to formic and sulphuric ether, with the following results:—

	Deflection.	Absorption.	Absorption from Table XIV.
Formic Ether . . .	17.7	23	21.3
Sulphuric Ether . .	19.1	24.8	23.7

The agreement is such as to prove that no material error can have crept into the calibration.

Placing the results obtained with the respective sources side by side, the influence of temperature on the transmission comes out in a very decided manner.

TABLE XV.—Absorption of heat by Vapours. Tension 0·5 of an inch.

Name of vapour.	Source, platinum spiral.			
	Barely visible.	Bright red.	White hot.	Near fusion.
Bisulphide of Carbon . . . . .	6·5	4·7	2·9	2·5
Chloroform . . . . .	9·1	6·3	5·6	3·9
Iodide of Methyl . . . . .	12·5	9·6	7·8	
Iodide of Ethyl . . . . .	21·0	17·7	12·8	
Benzol . . . . .	26·3	20·6	16·5	
Amylene . . . . .	35·8	27·5	22·7	
Sulphuric Ether . . . . .	43·4	31·4	25·9	23·7
Formic Ether . . . . .	45·2	31·9	25·1	21·3
Acetic Ether . . . . .	49·6	34·6	27·2	

The gradual augmentation of penetrative power as the temperature is augmented is here very manifest. By raising the spiral from a barely visible heat to an intense white heat, we reduce the absorption, in the cases of bisulphide of carbon and chloroform, to less than one-half. At barely visible redness, moreover, 56·6 and 54·8 per 100 get through sulphuric and formic ether respectively; while, of the intensely white-hot spiral, 76·3 and 78·7 per 100 pass through the same vapours. By augmenting the temperature of solid platinum, we introduce into the radiation waves of shorter period, which, being in discord with the periods of the vapours, get more easily through them.

What becomes of the more slowly recurrent vibrations as the more rapid ones are introduced? Do the latter take the place of the former? This question is answered by experiments made with an opaque solution of iodine, and with lampblack. As the temperature of the platinum spiral increases from a dark heat to the most intense white heat, the absolute quantity transmitted through both these bodies steadily augments. But this heat is wholly obscure, for both the solution and the lampblack intercept all the luminous heat. Hence the conclusion that the augmentation of temperature which introduces the shorter waves augments at the same time the amplitude of the longer ones, and hence also the inference that a body like the sun must of necessity include in its radiation waves of the same period as those emitted by obscure bodies.

### § 8.

Running the eye along the numbers which express the absorptions of sulphuric and formic ether in Table XV., we find that, for the lowest heat, the absorption of the latter exceeds that of the former; for a bright red heat they are nearly equal, but the formic still retains a slight predominance; at a white heat, however, the sulphuric slips in advance, and at the heat near fusion its predominance is decided. I have tested this result in various ways, and by multiplied experiments, and placed it beyond doubt. We may at once infer from it that the capacity of the molecule of formic ether to enter into rapid vibration is less than that of sulphuric. By augmenting the temperature of the spiral we produce vibrations of quicker periods, and the more of these that are introduced, the

more transparent, in comparison with sulphuric ether, does formic ether become. Thus what I have called its complexity tells upon the vibrating periods of the formic ether; the atom of oxygen which it possesses in excess of sulphuric ether renders it more sluggish as a vibrator. Experiments made with a source of  $212^{\circ}$  Fahr. establish more decidedly the preponderance of the formic ether for vibrations of slow period.

TABLE XVI.—Radiation through Vapours. Source, LESLIE'S cube, coated with lamp-black. Temperature,  $212^{\circ}$  Fahr.

Name of vapour.	Absorption.
Bisulphide of Carbon . . . . .	6.4
Iodide of Methyl . . . . .	18.4
Chloroform . . . . .	19.5
Sulphuric Ether . . . . .	54.8
Formic Ether . . . . .	60.9

For heat issuing from this source, the absorption by formic ether is 6.1 per cent. in excess of that by sulphuric.

Deeming the result worthy of rigid confirmation, I repeated the experiments, and obtained the following deflections:—

TABLE XVII.

Name of vapour.	Deflections.
Bisulphide of Carbon . . . . .	9.3
Iodide of Methyl . . . . .	25.0
Chloroform . . . . .	26.5
Iodide of Ethyl . . . . .	34.0
Benzol . . . . .	35.5
Amylene . . . . .	46.8
Sulphuric Ether . . . . .	47.3
Sulphuric Ether . . . . .	47.7
Formic Ether . . . . .	49.7
Formic Ether . . . . .	49.9
Acetic Ether . . . . .	51.4

When the absorptions were calculated from these deflections, the absorption of formic ether was found to be 6.3 per cent. in advance of that of sulphuric.

But in both Tables XVI. and XVII. we notice another case of reversal. In all the experiments with the platinum spiral recorded in Table XV., chloroform showed itself less energetic as an absorber than iodide of methyl; but in Tables XVI. and XVII. chloroform shows itself to be decidedly the more powerful of the two. Cases of this kind have, in my estimation, a peculiar significance, and I therefore take care to verify them. The experiments with all the vapours were therefore repeated, with the following results:—

TABLE XVIII.—Radiation through Vapours. Source, LESLIE'S cube at 212° Fahr.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . . . .	15 <sup>o</sup> 0	6·6
Iodide of Methyl . . . . .	38·3	18·8
Chloroform . . . . .	40·7	21·6
Iodide of Ethyl . . . . .	46·2	29·0
Benzol . . . . .	50·0	34·5
Amylene . . . . .	57·8	47·1
Sulphuric Ether . . . . .	60·3	54·1
Formic Ether . . . . .	62·1	60·4
Acetic Ether . . . . .	64·3	69·9
Total heat . . . . .	71·4	100·0

The absorption by formic ether is here also 6·3 per cent. in excess of that effected by sulphuric ether; while, as in the last two Tables, chloroform excels iodide of methyl.

Preserving the quality of the heat unchanged, but reducing its quantity from 71<sup>o</sup>·4 = 227 units to 52<sup>o</sup>·3 = 86·5 units, the following results were obtained:—

TABLE XIX.

Name of vapour.	Deflection.	Absorption.
Iodide of Methyl . . . . .	16·5	18·3
Chloroform . . . . .	18·5	20·6
Iodide of Ethyl . . . . .	24·4	27·1
Benzol . . . . .	30·0	33·3
Amylene . . . . .	38·6	48·6
Sulphuric Ether . . . . .	40·3	53·2
Formic Ether . . . . .	42·8	60·0

Placing the figures of Tables XVI., XVIII. and XIX. side by side, we have an opportunity of seeing how results obtained on different days check each other.

TABLE XX.—Source, blackened cube of boiling water.

Name of vapour.	Absorptions from		
	Table XVI.	Table XVIII.	Table XIX.
Bisulphide of Carbon . . . . .	6·4	6·6	
Iodide of Methyl . . . . .	18·4	18·8	18·3
Chloroform . . . . .	19·5	21·6	20·6
Iodide of Ethyl . . . . .	—	29·0	27·1
Benzol . . . . .	—	34·5	33·3
Amylene . . . . .	—	47·1	48·6
Sulphuric Ether . . . . .	54·8	54·1	53·2
Formic Ether . . . . .	60·9	60·4	60·0
Acetic Ether . . . . .	—	69·9	

Were it essential to my purpose, I should certainly be able to make even the small differences which here show themselves to disappear. But the agreement is such as to place the reliability of the experiments beyond doubt. *It will be seen that, contrary to the results obtained with a white-hot spiral, in all three cases, where a blackened cube of boiling water was the source, chloroform exceeds iodide of methyl, and formic ether exceeds sulphuric in absorbent power.* To confirm the demonstration, I once more resorted to the white-hot spiral, and obtained the following results:—

TABLE XXI.—Radiation through Vapours. Source, white-hot platinum spiral.

Name of vapour.	Deflection.	Absorption.
Chloroform . . . . .	9 <sup>o</sup> ·8	4·5
Chloroform . . . . .	9·5	4·5
Iodide of Methyl . . . . .	16·0	7·3
Iodide of Methyl . . . . .	15·8	7·3
Formic Ether . . . . .	42·1	24·2
Formic Ether . . . . .	42·3	24·5
Sulphuric Ether . . . . .	43·6	26·3
Sulphuric Ether . . . . .	43·5	26·2
Total heat . . . . .	70·9	100·0

Here chloroform retreats once more behind iodide of methyl, and formic ether behind sulphuric.

The positions of sulphuric and formic ether are reversed within the range of the experiments made with the platinum spiral, but this is not the case with the chloroform and the iodide of methyl. Even when the spiral was at a barely visible heat, the iodide was decidedly the most opaque of the two; the same result was obtained with a spiral heated under redness, as proved by the following figures:—

Name of vapour.	Deflection.	Absorption.
Chloroform . . . . .	8 <sup>o</sup> ·5	12·14
Chloroform . . . . .	8·5	12·14
Iodide of Methyl . . . . .	10·0	14·28
Iodide of Methyl . . . . .	10·0	14·28
Total heat . . . . .	47·3	100·0

Here the iodide is still predominant. Is it, then, a question of *temperature* merely? or is there a special flux emitted by the lampblack, to which chloroform is particularly opaque? In other words, is there a special accord between the rates of vibration of lampblack and chloroform? To answer this question I operated thus:—The platinum spiral was heated by only two cells, and the strength of this current was lowered by the introduction of resistance. When decidedly below a red heat, the spiral was plunged into boiling water. Bubbles of steam issued from it, proving that its temperature was



above 212° Fahr. By augmenting the resistance its heat was lowered, until it was no longer competent to produce the least ebullition. It was then withdrawn from the water, and employed as a source: the following are the results:—

TABLE XXII.—Source, platinum spiral at 100° C.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . . . .	5·7	7·03
Chloroform . . . . .	14·0	16·8
Iodide of Methyl . . . . .	15·3	18·0

No reversal was here obtained. The temperature was then reduced so that the total heat fell from 81 units to 59 units; but not even in this case (when the temperature was considerably below that of boiling water) could the reversal be obtained. The absorptions approach each other, but the iodide has still the advantage of the chloroform.

TABLE XXIII.—Source, platinum spiral, heated under 100° C.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . . . .	5·2	9·2
Chloroform . . . . .	10·0	17·3
Iodide of Methyl . . . . .	10·8	18·2

It is not, therefore, temperature alone which determines the inversion: the experiments prove that there is a greater synchronism between the vibrating periods of chloroform and lampblack than between those of chloroform and platinum raised to the temperature of the lampblack. It will be seen, however, that as the temperature of the platinum falls, the opacity of the chloroform increases more quickly than that of the iodide: with an intensely white-hot spiral, as shown in Table XXI., the absorption of chloroform is to that of the iodide as 100:162, while, with the spiral heated to a temperature of 212° Fahr., the ratio of the absorptions is as 100:105.

§ 9.

We have hitherto occupied ourselves with the radiation from heated solids: I will now pass on to the examination of the radiation from flames. The first experiments were made with a steady jet of gas issuing from a small circular burner, the flame being long and tapering. The top and bottom of the flame were excluded, and its most brilliant portion was chosen as the source. The following results were obtained:—

TABLE XXIV.—Radiation of heat through Vapours. Source, a highly luminous jet of gas.

Name of vapour.	Deflection.	Absorption.	White-hot spiral.
Bisulphide of Carbon . . . . .	8·9	9·8	2·9
Chloroform . . . . .	10·9	12·0	5·6
Iodide of Methyl . . . . .	15·4	16·5	7·8
Iodide of Ethyl . . . . .	17·7	19·5	12·8
Benzol . . . . .	20·0	22·0	16·5
Amylene . . . . .	27·5	30·2	22·7
Formic Ether . . . . .	31·5	34·6	25·1
Sulphuric Ether . . . . .	32·5	35·7	25·9
Acetic Ether . . . . .	34·2	38·7	27·2
Total heat . . . . .	53·8	100·0	

It is interesting to compare the heat emitted by the white-hot carbon with that emitted by the white-hot platinum; and to facilitate the comparison, I have placed beside the results in the last Table those recorded in Table XIII. The emission from the flame is thus proved to be far more powerfully absorbed than the emission from the spiral. Doubtless, however, the carbon, in reaching incandescence, passes through lower stages of temperature, and in those stages emits heat more in accord with the vapours. It is also mixed with the vapour of water and carbonic acid, both of which contribute their quota to the total radiation. It is therefore probable that the greater accord between the periods of the flame and those of the vapours is due to the slower periods of the substances which are unavoidably mixed with the body to which the flame mainly owes its light.

The next source of heat employed was the flame of a BUNSEN'S burner, the temperature of which is known to be very high. The flame was of a pale-blue colour, and emitted a very feeble light. The following results were obtained:—

TABLE XXV.—Radiation of heat through Vapours. Source, pale-blue flame of BUNSEN'S burner.

Name of vapour.	Deflection.	Absorption.	From Table XXIV. Luminous jet of gas.
Chloroform . . . . .	5·0	6·2	12·0
Bisulphide of Carbon . . . . .	9·0	11·1	9·8
Iodide of Ethyl . . . . .	11·3	14·0	19·5
Benzol . . . . .	14·5	17·9	22·0
Amylene . . . . .	19·6	24·2	30·2
Sulphuric Ether . . . . .	25·8	31·9	35·7
Formic Ether . . . . .	27·0	33·3	34·6
Acetic Ether . . . . .	29·4	36·3	38·7
Total heat . . . . .	50·6	100·0	100·0

The total heat radiated from the flame of BUNSEN'S burner is greatly less than that radiated when the incandescent carbon is present in the flame. The moment the air is permitted to mix with the luminous flame, the radiation falls so considerably that the diminution is at once detected, even by the hand or face brought near the flame. Comparing Tables XXIV. and XXV., we see that the radiation from the BUNSEN'S burner is, on the whole, less powerfully absorbed than that from the luminous gas jet. In some cases, as in that of formic ether, they come very close to each other; in the case of amylen, and a few other substances, they differ more markedly. But an extremely interesting case of reversal here shows itself. Bisulphide of carbon, instead of being first, stands decidedly below chloroform. With the luminous jet, the absorption of bisulphide of carbon is to that of chloroform as 100 : 122, while with the flame of BUNSEN'S burner the ratio is 100 : 56; the removal of the carbon from the flame more than doubles the relative transparency of the chloroform. The case is of too much interest to be passed over without verification: here is the result obtained with a different total heat:—

	Deflection.	Absorption.
Chloroform . . . . .	16 <sup>o</sup> ·5	8·4
Chloroform . . . . .	16·0	8·2
Bisulphide of Carbon . . . . .	19·0	9·7
Bisulphide of Carbon . . . . .	19·4	9·9
Total heat . . . . .	68·4	100·0

And again, with an intermediate total heat,—

	Deflection.	Absorption.
Chloroform . . . . .	10 <sup>o</sup> ·2	8·4
Chloroform . . . . .	10·0	8·4
Bisulphide of Carbon . . . . .	12·0	9·8
Bisulphide of Carbon . . . . .	11·8	9·7
Total heat . . . . .	60·0	100·0

There is therefore no doubt that, while in the case of a platinum spiral at all temperatures, of a luminous gas flame, and, more especially, in the case of lampblack heated to 212° Fahr. the absorption of chloroform exceeds that of bisulphide of carbon, for the flame of BUNSEN'S burner the bisulphide is the more powerful absorber of the two. The absorptive energy of the chloroform, as shown in Table XX., is more than three times that of the bisulphide, while in Table XXV. the action of the bisulphide is nearly twice that of the chloroform. We have here, moreover, another instance of the reversal of formic and sulphuric ether. For the luminous jet the sulphuric ether is decidedly the more opaque; for the flame of BUNSEN'S burner it is excelled in opacity by the formic.

§ 10.

The main radiating bodies in the flame of a BUNSEN'S burner are, no doubt, aqueous

vapour and carbonic acid. Highly heated nitrogen is also present, which may produce a sensible effect: the unburnt gas, moreover, in proximity with the flame, and warmed by it, may contribute to the radiation, even before it unites with the atmospheric oxygen. But the main source of the radiation is, no doubt, the aqueous vapour and the carbonic acid. I wished to separate these two constituents, and to study them separately. The radiation of aqueous vapour could be obtained from a flame of pure hydrogen, while that of carbonic acid could be obtained from an ignited jet of carbonic oxide. To me the radiation from the hydrogen-flame possessed a peculiar interest; for notwithstanding the high temperature of such a flame, I thought it likely that the accord between its periods of vibration and those of the cool aqueous vapour of the atmosphere would still be such as to cause the atmospheric vapour to exert a special absorbent power upon the radiation. The following experiments test this surmise:—

TABLE XXVI.—Radiation through Atmospheric Air. Source, a hydrogen-flame.

	Deflection.	Absorption.
Dry air . . . . .	0	0
Undried air . . . . .	21·5	17·20
Total heat . . . . .	60·4	100·0

Thus, in a polished tube 4 feet long, the aqueous vapour of our laboratory air absorbed 17 per cent. of the radiation from the hydrogen-flame. A platinum spiral, raised by electricity to a degree of incandescence not greater than that obtainable by plunging a wire into the hydrogen-flame, was used as a source of heat; of its radiation, the undried air of the laboratory absorbed

5·8 per cent.,

or one-third of the quantity absorbed when the flame of hydrogen was employed.

The plunging of a spiral of platinum wire into the flame reduces its temperature; but it at the same time introduces vibrations which are not in accord with those of aqueous vapour: the absorption by ordinary undried air of heat emitted by this composite source amounted to

8·6 per cent.

On humid days the absorption of the rays emitted by a hydrogen-flame exceeds even the above large figure. Employing the same experimental tube and a new burner, the experiments were repeated some days subsequently, with the following result:—

TABLE XXVII.—Radiation through Air. Source, hydrogen-flame.

	Absorption.
Dry air . . . . .	0
Undried air . . . . .	20·3

The undried air here made use of embraced the carbonic acid of the atmosphere; after the foregoing experiments, the air was conducted through a tube containing a solution

of caustic potash, in which the carbonic acid was intercepted, while the air charged itself with a little additional moisture. The absorption then observed amounted to

20·3 per cent.

of the entire radiation. The exact agreement of this with the last result is, of course, an accident; the additional humidity of the air derived from the solution of potash happened to compensate for the action of the carbonic acid withdrawn.

The other component of the flame of BUNSEN'S burner is carbonic acid; and the radiation of this substance is immediately obtained from a flame of carbonic oxide. With the air of the laboratory the following results were obtained:—

TABLE XXVIII.—Radiation through Atmospheric Air. Source, carbonic-oxide flame (very small).

	Deflection.	Absorption.
Dry air . . . . .	0	0
Undried air . . . . .	10·0	16·1

Of the heat emitted by carbonic acid, 16 per cent. was absorbed by the common air of the laboratory. After the air had been passed through sulphuric acid, the aqueous vapour being thus removed while the carbonic acid remained, the absorption was 13·8 per cent.

An india-rubber bag was filled from the lungs; it contained therefore both the aqueous vapour and the carbonic acid of the breath. The air from the bag was conducted through a drying apparatus, the mixed air and carbonic acid being permitted to enter the experimental tube. The following results were obtained:—

TABLE XXIX.—Air from the lungs containing C O<sub>2</sub>. Source, carbonic-oxide flame.

Tension in inches.	Deflection.	Absorption.
1	7·2	12·0
3	15·0	25·0
5	20·0	33·3
30	30·8	50·0

Thus the tube filled with dry air from the lungs intercepted 50 per cent. of the entire radiation from a carbonic-oxide flame. It is quite manifest that we have here a means of testing with surpassing delicacy the amount of carbonic acid emitted under various circumstances by the act of expiration.

That pure carbonic acid is highly opaque to the radiation from the carbonic-oxide flame, is forcibly evidenced by the results recorded in the following Table.

TABLE XXX.

Radiation through dry Carbonic Acid. Source, carbonic-oxide flame.

Tension in inches.	Deflection.	Absorption.
1·0	33·7	53·0
2·0	37·0	61·7
3·0	38·6	66·9
4·0	39·4	70·0
5·0	40·0	72·3
10·0	41·4	78·7

About four months subsequent to the performance of these experiments they were repeated, using as a source a much smaller flame of carbonic oxide. The absorptions were found somewhat less, but still very high. They follow in the next Table.

TABLE XXXI.

Radiation through dry Carbonic Acid. Source, small carbonic-oxide flame.

Tension in inches.	Deflection.	Absorption.
1·0	17·3	48·0
2·0	20·0	55·5
3·0	21·7	60·3
4·0	22·8	65·1
5·0	24·0	68·6
10·0	26·0	74·3

For the rays emanating from the heated solids employed in all my former researches, carbonic acid proved to be one of the most feeble absorbers; but here, when the waves sent into it emanate from molecules of its own substance, its absorbent energy is enormous. The thirtieth of an atmosphere of the gas cuts off half the entire radiation; while at a tension of 4 inches, nearly 70 per cent. of the whole radiation is intercepted.

The energy of olefiant gas, both as an absorbent and a radiant, is well known; for the solid sources of heat just referred to, its power is incomparably greater than that of carbonic acid; but, for the radiation from the carbonic-oxide flame, the power of olefiant gas is feeble when compared with that of carbonic acid. This is proved by the experiments recorded in the following Table:—

TABLE XXXII.

Radiation through dry Olefiant Gas. Source, carbonic-oxide flame.

Tension in inches.	Deflection.	Absorption.
1	17·0	24·2
2	26·0	37·1
4	33·0	49·1
Total heat . .	47·3	100·0

Four months subsequent to the performance of the above experiments, a second series were made with olefiant gas, and the following results obtained:—

TABLE XXXIII.

Radiation through dry Olefiant Gas. Source, small carbonic-oxide flame.

Tension in inches.	Deflection.	Absorption.	From Table XXXI.
1·0	11·4	23·2	48·0
2·0	17·0	34·7	55·5
3·0	21·6	44·0	60·3
4·0	24·8	50·6	65·1
5·0	27·0	55·1	68·6
10·0	32·1	65·5	74·3

Beside the absorption by olefiant gas, I have placed that by carbonic acid derived from Table XXXI. The superior power of the acid is most decided in the smaller tensions; at a tension of an inch it is twice that of the olefiant gas. The substances approach each other more closely as the quantity of gas augments. Here, in fact, both of them approach perfect opacity; and as they draw near to this common limit, their absorptions, as a matter of course, approximate.

The temperature of a hydrogen-flame, as calculated by BUNSEN, is 3259° C., while that of a carbonic-oxide flame is 3042° C. The foregoing experiments demonstrate that accord subsists between the oscillating periods of these sources and the periods of aqueous vapour and carbonic acid at a temperature of 15° C. The heat of the flame goes to augment the amplitude, and not to quicken the vibration.

Sent through carbonic oxide, the radiation from the carbonic-oxide flame gave the following absorptions:—

TABLE XXXIV.

Radiation through Carbonic Oxide. Source, carbonic-oxide flame.

Tension in inches.	Deflection.	Absorption.
1	18·0	29·0
2	27·0	43·5
4	34·0	56·4
10	37·3	65·5

The absorptive energy is here high—greater, indeed, than that of olefiant gas; it falls considerably short, however, of that exhibited by carbonic acid. This result shows us that the main radiant in the flame is its *product* of combustion, and not the carbonic oxide heated prior to combustion.

Wishing to examine the radiation from a flame whose product of combustion is sulphurous acid, through sulphurous acid, I resorted to the flame of bisulphide of carbon.

Here, however,<sup>7</sup> we had carbonic acid mixed with the sulphurous acid of the flame. Of the heat radiated by this composite source, the absorption by an atmosphere of sulphurous acid amounted to

60 per cent.

The gas was sent from its generating retort through drying-tubes of sulphuric acid into a glass experimental tube 2·8 feet long. The comparative shortness of the tube, and the mixed character of the radiation, rendered the absorption less than it would have been had a source of pure sulphurous acid and a tube as long as that used in the other experiments been employed.

I subsequently caused the radiation from the carbonic-oxide flame to pass through a few of our vapours, with the following results:—

TABLE XXXV.

Radiation through Vapours (tension 0·5 inch). Source, carbonic-oxide flame.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . . . .	5·5	9·8
Chloroform . . . . .	6·0	10·7
Formic Ether . . . . .	14·5	25·8
Sulphuric Ether . . . . .	18·0	32·1
Total heat . . . . .	43·0	100·0

The same vapours were employed to test the radiation from the hydrogen-flame, with the following results:—

TABLE XXXVI.

Radiation through Vapours (tension 0·5 inch). Source, hydrogen-flame.

Name of vapour.	Deflection.	Absorption.
Bisulphide of Carbon . . . . .	8·8	11·9
Chloroform . . . . .	9·9	13·4
Sulphuric Ether . . . . .	32·0	42·2
Formic Ether . . . . .	35·0	49·3
Total heat . . . . .	48·5	100·0

We here find that, in the case of every one of the four vapours, the synchronism with hot aqueous vapour is greater than with hot carbonic acid. The temperature of the hydrogen-flame is higher than that of the carbonic oxide; but the radiation from the more intense source is most copiously absorbed. It has been already proved that, for waves of slow period, formic ether is more absorbent than sulphuric ether; while for waves of rapid period, the sulphuric ether is the more powerful absorber. For the radiation from hot carbonic acid, the absorption of sulphuric ether, as shown in Table XXXV., is between 6 and 7 per cent. in excess of that of formic ether; while for the radiation from hot aqueous vapour, the absorption by formic ether, as shown in Table XXXVI., is 7 per cent. in excess of that by sulphuric. That the periods of aqueous



vapour, as compared with those of carbonic acid, are slow, may therefore be inferred from these experiments.

The two following Tables illustrate the action of carbonic acid gas and olefiant gas respectively, on the radiation from a flame of hydrogen:—

TABLE XXXVII.—Radiation through Carbonic Acid Gas. Source, hydrogen-flame.

Tension in inches.	Deflection.	Absorption.
1	5·5	7·4
2	9·5	12·8
4	11·0	14·9
30	19·0	25·7
Total heat . . . .	48·5	100·0

TABLE XXXVIII.—Radiation through Olefiant Gas. Source, hydrogen-flame.

Tension in inches.	Deflection.	Absorption.	From Table XXXVII.
1	12·0	16·2	7·4
2	18·0	24·3	12·8
4	24·0	32·4	14·9
30	38·5	58·8	25·7
Total heat . . . .	48·5	100·0	100·0

A comparison of the last two columns, one of which is transferred from Table XXXVII., proves the absorption of the rays from a hydrogen-flame by olefiant gas to be about twice that of carbonic acid; while, when the source was a carbonic oxide flame, the absorption by carbonic acid at small tensions was more than twice that effected by olefiant gas.

§ 11.

Water at moderate thickness is a very transparent substance; that is to say, the periods of its molecules are in discord with those of the visible spectrum. It is also highly transparent to the extra-violet rays; so that we may safely infer from the deportment of this substance its incompetence to enter into rapid molecular vibration. When, however, we once quit the visible spectrum for the rays beyond the red, the opacity of the substance begins to show itself: for such rays, indeed, its absorbent power is unequalled. The synchronism of the periods of the water-molecules with those of the extra-red waves is thus demonstrated. I have already proved that undried atmospheric air manifests an extraordinary opacity for the radiation from a hydrogen-flame, and from this deportment I inferred the synchronism of the cold vapour of the air and the hot vapour of the flame. The vibrating-period of a molecule is, no doubt, determined by the elastic forces which separate it from other molecules, and it is worth inquiring how these forces are affected when a change so great as that of the passage of a vapour to a liquid occurs. The fact established in the earlier sections of this paper, that the order of absorption for liquids and their vapours is the same, renders it extremely probable

that the period of vibration is not materially affected by the change from vapour to liquid; for, if changed, it would probably be changed in different degrees for the different liquids, and the order of absorption would be thereby disturbed\*. The following Table, in which the department of our series of liquids towards the radiation from a hydrogen-flame is recorded, will throw additional light upon this question:—

TABLE XXXIX.—Radiation through Liquids. Source, hydrogen-flame. Thickness of liquid layer 0·07 of an inch.

Name of liquid.	Absorption.	Transmission.
Bisulphide of Carbon . . . . .	27·7	72·3
Chloroform . . . . .	49·3	50·7
Iodide of Ethyl . . . . .	75·6	24·4
Benzol . . . . .	82·3	17·7
Amylene . . . . .	87·9	12·1
Sulphuric Ether . . . . .	92·6	7·4
Formic Ether . . . . .	93·5	6·5
Acetic Ether . . . . .	93·9	6·1
Water . . . . .	100·0	0·0

Through a layer of water 9·21 millimetres thick, MELLONI found a transmission of 11 per cent. of the heat of a Locatelli lamp. Here we employ a source of higher temperature, and a layer of water only one-fifth of the thickness used by MELLONI, and still we find the whole of the heat intercepted†. A layer of water, 0·07 of an inch in thickness, is sensibly opaque to the radiation from a hydrogen-flame. Hence we may infer the coincidence in period between cold water and aqueous vapour heated to a temperature of 3259° C.; and inasmuch as the period of the water-molecules has been proved to be extra-red, the period of the vapour-molecules in the hydrogen-flame must be extra-red also.

Another point of considerable interest may here be adverted to. Professor STOKES has demonstrated that a change of period is possible to those rays which belong to the violet and extra-violet end of the spectrum, the change showing itself by a degradation of the refrangibility. That is to say, vibrations of a rapid period are absorbed, and the absorbing substance has become the source of vibrations of a longer period. Efforts, I believe, have been made to obtain an analogous result at the red end of the spectrum, but hitherto without result; and it has been considered improbable that a change of period can occur which should *raise* the refrangibility of the light or heat. Such a change, I

\* The general agreement, in point of colour between a liquid and its vapour, favours the idea that the period, at all events in the great majority of cases, remains constant when the state of aggregation is changed.

† From the opacity of water to the radiation from aqueous vapour, we may infer the opacity of aqueous vapour to the radiation from water, and hence conclude that the very act of nocturnal refrigeration which causes the condensation of water on the earth's surface gives to terrestrial radiation that particular character which renders it most liable to be intercepted by the aqueous vapour of the air.

believe, occurs when we plunge a platinum wire into a hydrogen-flame. The platinum is rendered white by the collision of molecules whose periods of oscillation are incompetent to excite vision. There is in this common experiment an actual breaking up of the long periods into short ones—a true rendering of unvisual periods visual. The change of refrangibility differs from that of Professor STOKES, firstly, in its being in the opposite direction—that is, from low to high; and secondly, in the circumstance that the platinum is heated by the collision of the molecules of aqueous vapour, and before their heat has assumed the *radiant form*. But it cannot be doubted that the same effect would be produced by radiant heat of the same period, provided the motion of the ether could be raised to a sufficient intensity. The effect in principle is the same, whether we consider the platinum wire to be struck by a particle of aqueous vapour oscillating at a certain rate, or by a particle of ether oscillating at the same rate. And thus, I imagine, by a chain of rigid reasoning, we arrive at the conclusion that a degree of incandescence, equal to that of the sun itself, might be produced by the impact of waves, of themselves incompetent to excite vision\*.

The change of quality produced in the radiation by the introduction of a platinum spiral into a hydrogen-flame is illustrated by a series of experiments, executed for me by my assistant, Mr. BARRETT, and inserted subsequently to the presentation of this memoir.

TABLE XXXIX. *a*.—Radiation through Liquids. Sources: 1. hydrogen-flame; 2. hydrogen-flame and platinum spiral.

Name of liquid.	Transmission.			
	Thickness of liquid 0·04 inch.		Thickness of liquid 0·07 inch.	
	Flame only.	Flame and spiral.	Flame only.	Flame and spiral.
Bisulphide of Carbon . . . . .	77·7	87·2	70·4	86·0
Chloroform . . . . .	54·0	72·8	50·7	69·0
Iodide of Methyl . . . . .	31·6	42·4	26·2	36·2
Iodide of Ethyl . . . . .	30·3	36·8	24·2	32·6
Benzol . . . . .	24·1	32·6	17·9	28·8
Amylene . . . . .	14·9	25·8	12·4	24·3
Sulphuric Ether . . . . .	13·1	22·6	8·1	22·0
Acetic Ether . . . . .	10·1	18·3	6·6	18·5
Alcohol . . . . .	9·4	14·7	5·8	12·3
Water . . . . .	3·2	7·5	2·0	6·4

Here the introduction of the platinum spiral changed the periods of the flame into others more in discord with the periods of the liquid-molecules, and hence the more

\* Some time after this was written I learned that Dr. AKIN had previously inferred, from the paucity of luminous and extra-violet rays in the hydrogen-flame, that its periods must be extra-red. And he deduced from this that the heating of a platinum-wire in a hydrogen-flame must consist of a change of period. A very interesting communication from Dr. AKIN on this and kindred subjects, will be found in the 'Reader' for the 26th of September 1863.—April 5th, 1864.

copious transmission when the spiral was employed. It will be seen that a transmission of 2 per cent. is here obtained through a layer of water 0.07 of an inch in thickness.

Another series of experiments, also executed by my assistant, gave the following results of the radiation of a hydrogen-flame through layers of water of five different thicknesses:—

Radiation through Water. Source, hydrogen-flame.

	Thickness of liquid.				
	0.02 inch.	0.04 inch.	0.07 inch.	0.14 inch.	0.27 inch.
Transmission per 100 . . .	5.8	2.8	1.1	0.5	0.0

Wishing to compare the radiation from a flame of ordinary coal-gas with that of our hydrogen-flame, I reduced the former to the dimensions of the latter. The flame thus diminished, had a blue base and bright top, and the whole of it was permitted to radiate through our series of liquids. The following results were obtained:—

TABLE XL.—Radiation through Liquids. Source, small gas-flame. Thickness of liquid layer 0.07 of an inch.

Name of liquid.	Deflection.	Absorption.	From Table XXXIX.
Chloroform . . . . .	28.7	39.8	49.3
Bisulphide of Carbon . . . . .	36.0	53.2	27.7
Iodide of Ethyl . . . . .	41.7	72.3	75.6
Benzol . . . . .	43.4	79.4	82.3
Amylene . . . . .	45.0	86.1	87.9
Sulphuric Ether . . . . .	46.6	93.3	92.6
Formic Ether . . . . .	46.6	93.3	93.5
Alcohol . . . . .	46.8	94.1	
Acetic Ether . . . . .	46.9	94.4	93.9
Water . . . . .	47.4	97.1	100.0
Total heat . . . . .	48.0	100.0	

I have placed the results obtained with the hydrogen-flame in the third column of figures. For some of the liquids it will be observed that the absorption of the heat issuing from the small gas-flame is nearly the same as that of the heat issuing from the flame of hydrogen. A very remarkable difference, however, shows itself in the deportment of bisulphide of carbon, as compared with that of chloroform. For the small gas-flame chloroform is the most transparent body in the list; it is markedly more transparent than the bisulphide of carbon, while for the hydrogen-flame the bisulphide greatly excels the chloroform in transparency. The large luminous gas-flame previously experimented with differs also from the small one here employed. With the large flame, the absorption by the bisulphide is to that by the chloroform as

while with the small flame the absorptions of the same two substances stand to each other in the ratio of

100 : 76.

Numerous experiments were subsequently made, with a view of testing this result, but in all cases the bisulphide was found more opaque than the chloroform to the radiation of the small gas-flame. The same result was obtained when a very small oil-flame was employed; and it came out in a very decided manner when the source of heat was a flame of bisulphide of carbon. *It was found moreover that, whenever two liquids underwent a change of position of this kind, the vapours of the liquids underwent a similar change*; in its finest gradations, the deportment of the liquid was imitated by that of its vapour.

### § 12.

And here we find ourselves in a position to offer solutions of various facts which have hitherto stood as enigmas in researches upon radiant heat. It was for a time generally supposed that the power of heat to penetrate diathermic substances augmented as the temperature of the source of heat became more elevated. KNOBLAUCH contended against this notion, showing that the heat emitted by a platinum wire plunged into an alcohol flame was less absorbed by certain diathermic screens than the heat of the flame itself, and justly arguing that the temperature of the spiral could not be higher than that of the body from which it derived its heat. A plate of glass being introduced between his source and his thermo-electric pile, the deflection of his needle fell from  $35^{\circ}$  to  $19^{\circ}$  when the source was the platinum spiral; while, when the source was the flame of alcohol, when the glass was introduced the deflection fell from  $35^{\circ}$  to  $16^{\circ}$ , proving that the radiation from the flame was intercepted more powerfully than that from the spiral—showing, in other words, that the heat emanating from the body of highest temperature possessed the least penetrative power. MELLONI afterwards corroborated this experiment.

Transparent glass allows the rays of the visible spectrum to pass freely through it; but it is well known to be highly opaque to the radiation from obscure sources—in other words, to waves of long period. A plate 2.6 millimetres thick intercepts all the rays from a source of  $100^{\circ}$  C., and allows only 6 per cent. of the heat emitted by copper raised to  $400^{\circ}$  C. to pass through it\*. Now the products of the combustion of alcohol are aqueous vapour and carbonic acid, whose waves have been proved to be of slow period, and hence of that particular character which are most powerfully intercepted by glass; but by plunging a platinum wire into such a flame, we virtually convert its heat into heat of higher refrangibility; we break up the long periods into shorter ones, and thus establish the discord between the periods of the source and the periods of the diathermic glass, which, as before defined, is the physical cause of the transparency. On purely *à priori* grounds, therefore, we might infer that the introduction of the platinum

\* MELLONI.

spiral would augment the penetrative power of the heat through the glass. MELLONI, with two plates of glass of different thicknesses, found the following transmissions for the flame and the spiral:—

For the flame.	For the platinum.
41·2	52·8
5·7	26·2

The same remarks apply to the transparent selenite examined by MELLONI. This substance is highly opaque to the extra-red undulations; but the radiation from an alcohol flame is almost wholly extra-red, and hence the opacity of the selenite to this radiation. The introduction of the platinum spiral shortens the periods and augments the transmission. Thus, with two specimens of selenite, of different thicknesses, MELLONI found the transmission to be as follows:—

Flame.	Platinum.
4·4	19·5
1·7	3·5

So far the results of MELLONI correspond with those of M. KNOBLAUCH; but the Italian philosopher pursues the matter further, and shows that M. KNOBLAUCH'S results, though true for the particular substances examined by him, are far from being applicable to diathermic media generally. MELLONI shows that in the case of *black* glass and *black* mica, a striking inversion of the effect is observed; that is to say, that through these substances the radiation from the flame is more copiously transmitted than the radiation from the platinum spiral. For two pieces of black glass of different thicknesses, he found the following transmissions:—

From the flame.	From the platinum.
52·6	42·8
29·9	27·1

And for two plates of black mica the following transmissions were found:—

From the flame.	From the platinum.
62·8	52·5
43·3	28·9

These results were left unexplained by MELLONI; but the solution is now easy. The black glass and the black mica owe their blackness to the carbon incorporated in them, and the blackness of this substance, as already remarked, proves the accord of its vibrating periods with those of the visible spectrum. But it has been proved that carbon is in a considerable degree pervious to the waves of long period—that is to say, to such waves as are emitted by a flame of alcohol. The case of the carbon is therefore precisely antithetical to that of the transparent glass—the former transmitting the heat of long period most freely, and the latter transmitting the heat of short period most freely. Hence it follows that the introduction of the platinum wire, by converting

the long periods of the flame into short ones, augments the transmission through the transparent glass and selenite, and diminishes it through the black glass and the black mica.

§ 13.

Lampblack, as already stated, is in accord with the undulations of the visible spectrum; it absorbs them all; but it is partially transparent to the waves of slow period. As, therefore, the waves issuing from a flame of hydrogen have been proved to be of slow period, we may with probability infer that its radiation will penetrate the lampblack. A plate of rock-salt was placed over an oil-lamp until the layer of soot deposited on it was sufficient to intercept the light of the brightest gas-flame. The smoked plate was introduced in the path of the rays from the hydrogen-flame, and its absorption was measured; the plate was then cleansed, and its absorption again determined. The difference of both gave the absorption of the layer of lampblack. The results were as follows:—

TABLE XLI.

	Deflection.	Absorption.
Smoked rock-salt . .	44·2	82·7
Unsmoked plate . .	15·8	24·0

The difference between these gives us the absorption of the lampblack; it is 58·7 per cent.; and this corresponds to a transmission of

41·3

per cent. of the radiation from the hydrogen-flame.

Iodine, in a solution sufficiently opaque to cut off the light of our most brilliant lamps, transmitted of the heat of the hydrogen-flame

99 per cent.

In experimenting on liquids with heat of slow period, I noticed that the introduction of the empty rock-salt cell caused the needle to move through a much larger arc than when the source was a luminous one. This suggested to me that a greater proportion of the heat of slow period was absorbed by the rock-salt. I made a few experiments to test the diathermancy of the salt, with the following results:—

For the heat of a hydrogen-flame, the transmission through a perfectly transparent plate of rock-salt was

82·3 per cent.

For a spiral of platinum wire heated to whiteness by an electric current, the transmission was

87 per cent.

For the same spiral lowered to bright redness, the transmission was

84·4 per cent.

For the same spiral lowered to moderate redness, the transmission was

83·6 per cent.

Nothing was changed in these experiments but the heat of the spiral; the direction of the rays, and the size of the radiating body, remained throughout the same; still we find a gradually augmenting opacity on the part of the rock-salt as the temperature of the source is lowered. There cannot, I think, be a doubt that MM. DE LA PROVOSTAYE and DESAINS are right in their conclusion that rock-salt acts differently on different caloric rays, and is not, as MELLONI supposed, equally transparent to all. For the heat of the hydrogen-flame it is more opaque than for that of the moderately red spiral.

#### § 14.

This memoir ought perhaps to end here; I would, however, ask permission to make a few additional remarks on a subject which was briefly touched upon towards the conclusion of the first of this series of memoirs. I make these remarks with diffidence, for I have reason to know that authorities for whom I entertain the highest respect do not share my views regarding the connexion which subsists between the radiation and conduction of heat.

Let us suppose heat to be communicated to the superficial stratum of the molecules of any body; say, the molecules at the extremity of a metal bar. They vibrate, and the motion communicated by them to the external ether is dispatched in waves through space. The vibrating superficial molecules must also set in motion the ether *within* the body, and a portion of this motion will be transferred to the stratum of molecules next adjacent to the superficial ones, heat as a consequence appearing to penetrate the mass. But irrespective of the ether, the molecules of the body occupy positions which are determined by their attractive and repulsive forces; so that if any one molecule be forcibly moved from its position of equilibrium, it will of necessity disturb its neighbours. In a system of molecules so related, it is manifest that motion could be transmitted independently of the ether which surrounds them. If we could imagine the ether entirely away, the motion that we call heat would still be propagated from molecule to molecule through such a body. *Conduction* would manifest itself, while radiation would be absent through want of a medium.

In matter, however, as we have it, molecular motion is only in part transmitted *immediately* from molecule to molecule, being in part transmitted mediately by the ether. Now the quantity of motion transmitted by the ether to our second stratum of molecules cannot be the *whole* of that which the first or superficial stratum imparted to the ether. The ether must retard and indeed squander the internal molecular motion; and were the medium absent—were the cushion removed which interferes with the direct propagation of motion from molecule to molecule—conduction would be freer than at present; the heat would penetrate further into the mass than when the ether intervenes.



The reasoning just employed leads to the inference that those molecules which experience most resistance from the ether, must be the least competent to transfer the motion of heat from one to the other. The *direct* power of communication is enfeebled by the ether, and the motion obtained *indirectly* cannot make good the loss. We are thus led to the conclusion that the best radiators ought to prove themselves the worst conductors.

A broad consideration of the subject shows that the conclusion is in general harmony with observed facts. Organic substances are all exceedingly imperfect conductors of heat, and they are all excellent radiators. The moment we pass from the metals to their compounds we pass from a series of good conductors to bad ones, and from a series of bad radiators to good ones\*.

In the earlier memoirs of MM. DE LE PROVOSTAYE and DESAINS†, and in that of MM. WIEDEMANN and FRANZ, I find the following facts:—The radiative power of platinum is five times that of silver; its conductive power is one-tenth that of silver. Platinum has more than twice the radiative power of gold; it has only one-seventh of the conducting-power. Zinc and tin are almost equal as conductors, and they are also nearly equal as radiators. Silver has about six times the conductive power of zinc and tin; it has only one-fourth of their radiative powers. Brass possesses but one-half the radiative energy of platinum; it possesses more than twice its conductivity. Other experiments of MM. DE LA PROVOSTAYE and DESAINS‡ confirm those hitherto referred to. Taking the absorbent power, as determined by these excellent experimenters, to express the radiating power, and multiplying their results by a common factor to facilitate comparison

\* And we also pass, as a general rule, from a series of bodies which vibrate in accord with the visible spectrum to a series which vibrate in discord with the spectrum. The lowering of the rate of vibration is a consequence of chemical union. The comparative incompetence of *compound* bodies to oscillate in visual periods has incessantly declared itself in these researches. I would here refer to a most interesting illustration of the same kind, derived from the experiments of MM. DE LA PROVOSTAYE and DESAINS. These distinguished experimenters were the first to record the important fact that the qualities of heat emitted by bodies at the same temperature may be very unlike. Two experiments illustrate this fact. The first is recorded in the Comptes Rendus, vol. xxxiv. p. 951. One half of a cube was coated with lampblack, and the other half with cinnabar. The cube being filled with oil at a temperature of 173° C., it was found that the emission from the cinnabar was more copiously absorbed by a plate of glass than that from the lampblack. In the second experiment, they found that, while 39 per cent. of the radiation from a bright surface of platinum was transmitted by a plate of glass, only 29 per cent. of the radiation from the opposite surface of the same plate, which was coated with borate of lead, was transmitted. These results are quite in harmony with the views which I have ventured to enunciate. We may infer from them that the heat emitted by the respective *compounds*—the cinnabar and the borate of lead—is of slower period than that emitted by the *elements*; for experiment proves that as the periods are quickened the glass becomes more transparent. At a temperature of 100° C., moreover, the emission from borate of lead was found equal to that from lampblack (Comptes Rendus, vol. xxxviii. p. 442), while at a temperature of 550° C. it had only three-fourths of the emissive power of the lampblack. With reference to the theoretic views which these researches are intended to foreshadow, the results of MM. DE LA PROVOSTAYE and DESAINS are of the highest interest.

† Comptes Rendus, 1846, vol. xxii. p. 1139.

‡ Annales de Chimie, 1850, vol. xxx. p. 442.

with those of MM. WIEDEMANN and FRANZ on conduction, we obtain the following Table:—

TABLE XLII.—Comparison of Conduction and Radiation.

Name of metal.	Conduction.	Radiation.
Silver . . . . .	100	11
Gold . . . . .	53	27
Brass . . . . .	24	42
Tin . . . . .	15	90
Platinum . . . . .	8	100

We here find that, as the power of conduction diminishes, the power of radiation augments—a result, I think, completely in harmony with that to which a consideration of the molecular mechanism leads us. There is but one serious exception known to me to the law here indicated; this is copper, which MM. DE LA PROVOSTAYE and DESAINS place higher than gold as a radiator, though it is also higher as a conductor. When, however, the immense change in radiative power which the slightest film of oxide can produce, and the liability of heated copper to contract such a film, are taken into account, the apparent exception will not have too much weight ascribed to it. I have had a cube of brass coated electrolytically with copper, silver, and gold; and, of all its faces, that coated with copper has the least emissive power. This is probably due to some slight impurity contracted by the silver. What we know of the deportment of minerals also illustrates the law. Rock-salt I find to be a far better conductor than glass, while MM. DE LA PROVOSTAYE and DESAINS find the relative emissive powers of the two substances to be as 17 to 6: the radiant power of the salt is little more than one-third that of the glass. So also with regard to alum: as a conductor it is immensely behind rock-salt; as a radiator it is immensely in advance of it.

*Royal Institution, March 1864.*