

V. *Sixth Memoir on Radiation and Absorption.—Influence of Colour and Mechanical Condition on Radiant Heat.* By Professor J. TYNDALL, LL.D., F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, Cherbourg, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution and the Royal School of Mines.

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FRANKLIN placed cloths of various colours upon snow and allowed the sun to shine upon them. They absorbed the solar rays in different degrees, became differently heated, and sank therefore to different depths in the snow beneath them. His conclusion was that dark colours were the best absorbers, and light colours the worst, and to this hour we appear to have been content to accept FRANKLIN'S generalization without qualification. In my last memoir I briefly pointed out its probable defects. Did the emission from luminous sources consist exclusively of visible rays, we might fairly infer from the colour of a substance its capacity to absorb the heat of such sources. But the emission from luminous sources is by no means all visible. In terrestrial sources by far the greater part, and in the case of the sun a very great part of the emission, consists of invisible rays, regarding which colour teaches us nothing.

It remained therefore to examine whether the results of FRANKLIN were the expression of a law of nature. Two cards were taken of the same size and texture; over one of them was shaken the white powder of alum, and over the other the dark powder of iodine. Placed before a glowing fire and permitted to assume the maximum temperature due to their position, it was found that the card bearing the alum became extremely hot, while that bearing the iodine remained cool. No thermometer was necessary to demonstrate this difference. Placing, for example, the back of the iodine card against the forehead or cheek, no inconvenience was experienced; while the back of the alum card similarly placed proved intolerably hot.

This result was corroborated by the following experiments:—One bulb of a differential thermometer was covered with iodine, and the other with alum powder. A red-hot spatula being placed midway between both, the liquid column associated with the alum-covered bulb was immediately forced down, and maintained in an inferior position. Again, two delicate mercurial thermometers had their bulbs coated, the one with iodine, the other with alum. On exposing them at the same distance to the radiation from a gas-flame, the mercury of the alum-covered thermometer rose nearly twice as high as

that of its neighbour. Two sheets of tin were coated, the one with alum, and the other with iodine powder. The sheets were placed parallel to each other and about 10 inches asunder; at the back of each was soldered a little bar of bismuth, which with the tin plate to which it was attached constituted a thermo-electric couple. The two plates were connected together by a wire, and the free ends of the bismuth bars were connected with a galvanometer. Placing a red-hot ball midway between both, the calorific rays fell with the same intensity on the two sheets of tin, but the galvanometer immediately declared that the sheet which bore the alum was the most highly heated.

In some of the foregoing cases the iodine was simply shaken through a muslin sieve; in other cases it was mixed with bisulphide of carbon and applied with a camel's-hair brush. When dried afterwards it was almost as black as soot, but as an absorber of radiant heat it was no match for the perfectly white powder of alum.

The difficulty of warming iodine by radiant heat is evidently due to the diathermic property which it manifests so strikingly when dissolved in bisulphide of carbon. The heat enters the powder, is reflected at the limiting surfaces of the particles, but it does not lodge itself among the atoms of the iodine. When shaken in sufficient quantity on a plate of rock-salt and placed in the path of a calorific beam, iodine cuts the latter off. But its opacity is mainly that of a white powder to light; it is impervious, not through absorption, but through internal reflexion. Ordinary roll sulphur, even in thin cakes, allows no radiant heat to pass through it, but its opacity is also due to repeated internal reflexion. The temperature of ignition of sulphur is about 244°C .; but on placing a small piece of the substance at the focus of the electric lamp where the temperature was sufficient to heat platinum foil in a moment to whiteness, it required exposure for a considerable time to fuse and ignite the sulphur. Though impervious to the heat, it was not adiathermic. The milk of sulphur was also ignited with some difficulty. Sugar is a much less inflammable substance than sulphur, but it is a far better absorber; exposed at the focus, it is speedily fused and burnt up. The heat moreover which is competent to inflame sugar is scarcely competent to warm table salt.

A fragment of almost black amorphous phosphorus was exposed at the dark focus of the electric lamp, but refused to be ignited. A still more remarkable result was obtained with ordinary phosphorus. A small fragment of this exceedingly inflammable substance could be exposed for twenty seconds without ignition at a focus where platinum was almost instantaneously raised to a white heat. Placing a morsel of phosphorus on a plate of rock-salt and holding it before a glowing fire, it bears, as proved by my assistant, Mr. BARRETT, an intense radiation without ignition, but laid upon a plate of glass and similarly exposed, the phosphorus soon fuses and ignites; its ignition, however, is not entirely due to radiant heat, but mainly to the heat imparted to it by the glass*.

The fusing-point of phosphorus is about 44°C ., that of sugar is 160° ; still at the focus of the electric lamp the sugar fuses before the phosphorus. All this is due to the dia-

* I believe this deportment of phosphorus towards radiant heat is not unknown to chemists.

thermancy of the phosphorus. A thin disk of the substance placed between two plates of rock-salt permits of a copious transmission. This substance therefore takes its place with other elementary bodies as regards deportment towards radiant heat.

The more diathermic a body is, the less it is warmed by radiant heat. No perfectly transparent body could be warmed by purely luminous heat. The surface of a vessel covered with a thick fur of hoar frost was exposed to the beam of the electric lamp condensed by a powerful mirror, the beam having been previously sent through a cell containing water; the sifted beam was powerless to remove the frost, though it was competent to set wood on fire. We may largely apply this result. It is not, for example, the luminous rays, but the dark rays of the sun which sweep the snows of winter from the slopes of the Alps. Every glacier stream that rushes through the Alpine valleys is almost wholly the product of invisible radiation. It is also the invisible solar rays which lift the glaciers from the sea-level to the summits of the mountains; for the luminous rays penetrate the tropical ocean to great depths, while the non-luminous ones are absorbed close to the surface, and become the main agents in evaporation.

It is often stated, without limitation, that ether might be exposed at the focus of a concave mirror without being sensibly heated; but this can only be true of a sifted beam. At the focus of the electric lamp, not only ether, but alcohol and water are speedily caused to boil, while bisulphide of carbon, whose boiling-point is only 48° C., cannot be raised to ebullition. In fact exposure for a period sufficient to boil alcohol or water is scarcely sufficient to render bisulphide of carbon sensibly warm.

If any one point came out with more clearness than any other in my experiments on gases, liquids, and vapours, it was the paramount influence which chemical constitution exerted upon the phenomena of radiation and absorption. And seeing how little the character of the radiation was affected by the change of a body from the state of vapour to the state of liquid, I held it to be exceedingly probable that even in the solid state chemical constitution would exert its power. But opposed to this conclusion we had the experiments of MELLONI on chalk and lampblack, and the far more extensive ones of MASSON and COURTÉEPEÉE on powders, which seemed clearly to show that in a state of extremely fine division, as in chemical precipitates, the radiant and absorbent powers of all bodies are the same. From these experiments it was inferred that the influence of physical condition was so predominant as to cause that of chemical constitution to disappear*.

A serious oversight, however, seems to have connected itself with all the experiments of these distinguished men. MELLONI mixed his lampblack and powdered chalk with gum or glue, and applied them by means of a camel's-hair brush on the surfaces of his radiating cube. MASSON and COURTÉEPEÉE did the same. MELLONI, it is true, thus com-

* MASSON and COURTÉEPEÉE, *Comptes Rendus*, vol. xxv. p. 938; JAMIN, *Cours de Physique*, vol. ii. p. 289.

pared a black surface with a white one; but the surfaces were seen to be white and black *through* the transparent gum, which in both cases was the real radiator. The same remark applies to MASSON and COURTÉEPEÉE. Every particle of the precipitates they employed was a varnished particle; and the constancy they observed was, I imagine, due to the fact that the main radiant in all their experiments was the substance employed to make their powders cling to the surfaces of their cubes.

Gum or glue is a powerful radiator; in fact equal to lampblack, and it is a correspondingly powerful absorber. The particles surrounded by it had therefore but small chance of radiating through it. I sought to remedy this by the employment of a diathermic cement. Sulphur is highly diathermic; it dissolves freely in bisulphide of carbon, and at the suggestion of a chemical friend I employed it to fix the powders. The cube was laid upon its side, the surface to be coated being horizontal, and the bisulphide, containing the sulphur in solution, was poured over the surface. Before the liquid film had time to evaporate, the powder was shaken upon it through a muslin sieve. The bisulphide passed rapidly away in vapour, leaving the powder behind imbedded in the sulphur cement. Each powder, moreover, was laid on sufficiently thick to prevent the sulphur from surrounding its particles. This, though not perhaps a perfect way of determining the radiation of powders, was at all events an improvement on former methods, and yielded different results.

Ten or twelve cubes of tin were employed in the investigation. One side of each of them was coated with milk of sulphur, and this substance running through the entire series of cubes, enabled me to connect the results of all of them together. The cubes were heated with boiling water, and placed in succession at the same fixed distance in front of the thermo-electric pile, which as usual was well defended from air-currents and other extraneous sources of disturbance. Before giving the complete table of results I will adduce a few of them, which show in a conclusive manner that in solid bodies radiation is molecular rather than mechanical.

The biniodide of mercury and the red oxide of lead resemble each other physically, both of them being of a brilliant red. Chemically, however, they are very different. Examined in the way indicated, their relative powers as radiators were found to be as follows:—

| Name. | Chemical formula. | Radiation. |
|----------------------------|-----------------------------|------------|
| Biniodide of Mercury . . . | (Hg I ₂) | 39·7 |
| Red oxide of Lead . . . | (2Pb O, Pb O ₂) | 74·1 |

Mixed with gum and applied with a camel's-hair brush to the surfaces of the cube, the radiation from the following two substances fell out thus:—

| Name. | Radiation. |
|--------------------------------|------------|
| Binioxide of Mercury | 80·0 |
| Red oxide of Lead | 80·0 |

Here the influence of the gum entirely masks the difference due to molecular constitution.

The effect of atomic complexity upon the radiation is well illustrated by the deportment of these two substances. It is further illustrated by the deportment of two different iodides of mercury:—

| | Radiation. |
|--|------------|
| Biniodide of Mercury (Hg I_2) | 39·7 |
| Iodide of Mercury ($\text{Hg}_2 \text{I}_2$) | 46·6 |

Here the addition of a second atom of mercury to the molecule of the biniodide raises the radiation seven per cent. The experiment furnishes a kind of physical justification of the practice of chemists in regarding the molecule of yellow iodide of mercury to be $\text{Hg}_2 \text{I}_2$, and not Hg I .

The peroxide and protoxide of iron gave the following results:—

| | Radiation. |
|-----------------------------|------------|
| Peroxide of Iron | 78·4 |
| Protoxide of Iron | 81·3 |

I did not expect this, the protoxide being a less complex molecule than the peroxide. On examination, however, the protoxide was found to be in part the magnetic oxide. The formulæ of the two substances are $\text{Fe}_2 \text{O}_3$ and Fe O , $\text{Fe}_2 \text{O}_3$, and the anomaly therefore disappears.

Amorphous phosphorus and sulphide of iron gave the following results:—

| | Radiation. |
|--------------------------------|------------|
| Amorphous Phosphorus | 63·6 |
| Sulphide of Iron | 81·7 |

Sugar and salt were reduced in a mortar to the state of exceedingly fine powders. In point of cohesion and physical aspect these substances closely resemble each other; their radiative powers, however, are as follows:—

| | Radiation. |
|-----------------|------------|
| Salt | 35·3 |
| Sugar | 70·0* |

In his last interesting paper on emission at a red heat†, M. DESAINS mentions oxide of zinc as a body which at 100°C . has the same emissive power as lampblack. This is nearly true for the hydrated oxide; with the calcined oxide the following is the relation:—

| | Radiation. |
|----------------------------------|------------|
| Lampblack | 84·0 |
| Hydrated oxide of Zinc | 80·4 |
| Calcined | 53·2 |

* I have of course no intention of adducing experiments on sugar and salt, or on powdered rock-salt and alum, as opposed to the results of MASSON and COURTÈPÈRE. They would regard their results as unaffected by such experiments. It is the deportment of the *chemical precipitates* employed, and not that of bodies reduced to powder by mechanical means, that invalidate their conclusions.

† Comptes Rendus, July 3rd, 1859; Phil. Mag. Aug. 1865.

Two red powders have been already compared together, I will now compare two black ones. With black platinum and black oxide of iron the following results were obtained:—

| | Radiation. |
|---|------------|
| Black Platinum (electrolytic) | 59·0 |
| Black oxide of Iron | 81·3 |

The black platinum here employed was obtained by electrolysis, a sheet of platinum foil being coated with the substance.

Let us now compare two white powders. Chloride of silver and carbonate of zinc gave the following results:—

| | Radiation. |
|------------------------------|------------|
| Chloride of Silver | 32·5 |
| Carbonate of Zinc | 77·7 |

As in all the other cases the influence of chemical constitution makes its appearance here.

When held upon its cube by the sulphur cement, the chloride of silver soon darkens in the diffuse light of the laboratory. It first becomes lavender, and passes through various stages of brown to black. During these changes, which may be associated with a chemical reaction between the chloride of silver and the sulphur in which it is imbedded, the radiation steadily augments. Beginning in one instance with a radiation of 25, the chloride ended with a radiation of 60.

We have thus far compared two red surfaces, two black surfaces, and two white surfaces together. The comparison of a black and white surface gave the following result:—

| | Radiation. |
|--|------------|
| Black Platinum | 59·0 |
| White hydrated oxide of Zinc | 80·4 |

Here the radiation from the white body far transcends that from the black one.

Again, comparing black and white, we have the following result:—

| | Radiation. |
|-----------------------------|------------|
| Oxide of Cobalt | 76·5 |
| Carbonate of Zinc | 77·7 |

Here the black radiation is sensibly equal to the white one.

Finally, comparing black and white, we have the following result:—

| | Radiation. |
|----------------------------|------------|
| Lampblack | 84·0 |
| Chloride of Lead | 55·4 |

Here the radiation from the black body far transcends that from the white one.

We have thus compared red powders with red, black with black, white with white, and black with white; and the conclusion to be drawn from the experiments is, I think, that chemical constitution, so far from being of vanishing value, is the really potent influence in the experiments.

Were the radiative power of these substances determined by the state of division, I think it must make itself sensible even in a case where the division is effected by the pestle and mortar; but I do not find this to be the case. A plate of glass was fixed against the polished surface of a LESLIE'S cube, and on the plate the powder of glass, rendered as fine as the pestle and mortar could make it, was strewn. It was caused to adhere without cement of any kind. The cube was filled with boiling water and presented to the thermo-electric pile until a permanent deflection was obtained. Permitting the cube to remain in its position, the powder was removed with a camel's-hair brush. An inconsiderable augmentation of the radiation was the result, the increase being such as might be expected to follow from the slight difference of temperature between the surface of the glass plate and the powder which had been strewn upon it. Similar experiments were made with a plate of rock-salt, on which finely divided powder of rock-salt was shaken. The result was precisely similar to that obtained with the glass powder.

One side of a LESLIE'S cube was covered by a sheet of bright platinum foil, and a second face by a similar sheet on which black platinum had been deposited by electrolysis. As radiators these two sheets of foil behaved in the following manner:—

| | Radiation. |
|--------------------------------|------------|
| Bright Platinum foil | 6·0 |
| Platinized Platinum | 45·2 |

Here the radiation of the black platinum is nearly eight times that of the bright substance.

Having thus shown, I trust conclusively, that the influence of chemical constitution makes itself felt in all states of aggregation, for the sake of reference, I will here tabulate the results obtained with a considerable number of powders when subjected to the same conditions of experiment.

TABLE I.—Radiation from Powders imbedded in Sulphur Cement.

| Substance. | Radiation. |
|-------------------------------------|------------|
| Rock-salt | 35·3 |
| Biniiodide of Mercury | 39·7 |
| Milk of Sulphur | 40·6 |
| Common Salt | 41·3 |
| Yellow iodide of Mercury | 46·6 |
| Sulphide of Mercury | 46·6 |
| Iodide of Lead | 47·3 |
| Chloride of Lead | 55·4 |
| Chloride of Cadmium | 56·5 |
| Chloride of Barium | 58·2 |
| Chloride of Silver (dark) | 58·6 |

TABLE I. (continued).

| Substance. | Radiation. |
|-----------------------------------|------------|
| Fluor-spar | 68·4 |
| Tersulphide of Antimony | 69·4 |
| Carbonate of Lime | 70·2 |
| Oxysulphide of Antimony | 70·5 |
| Sulphide of Calcium | 71·0 |
| Sulphide of Molybdenum | 71·3 |
| Sulphate of Baryta | 71·6 |
| Chromate of Lead | 74·1 |
| Red oxide of Lead | 74·2 |
| Sulphide of Cadmium | 76·3 |
| Subchloride of Copper | 76·5 |
| Oxide of Cobalt | 76·7 |
| Sulphate of Lime | 77·7 |
| Carbonate of Zinc | 77·7 |
| Red oxide of Iron | 78·4 |
| Sulphide of Copper | 79·0 |
| Hydrated oxide of Zinc | 80·4 |
| Black oxide of Iron | 81·3 |
| Sulphate of Iron | 81·7 |
| Iodide of Copper | 82·0 |
| Lampblack | 84·0 |

I subsequently endeavoured to get rid of the sulphur cement and to make the powders adhere by wetting them with pure bisulphide of carbon, applying them to the cubes while wet. Some of the powders clung, others did not. My ingenious friend Mr. DUPPA suggested to me that the powders might be held on by electrifying the cubes. I tried this plan, and found it simple and practicable. It was, however, aided by a circumstance which we did not anticipate. The cube being placed upon an insulating stand, the powder was shaken over it, and electrified by a few turns of a machine. It was found that the cube might then be discharged and set upright, the powders clinging to it in this position. The results obtained with this arrangement are recorded in the following Table:—

TABLE II.—Radiation from Powders held by Electricity.

| Substance. | Radiation. |
|--------------------------------------|------------|
| Rock-salt | 24·5 |
| Chloride of Silver (white) | 25·0 |
| Milk of Sulphur | 25·8 |
| Biniiodide of Mercury | 26·0 |

TABLE II. (continued).

| Substance. | Radiation. |
|--------------------------------------|------------|
| Iodide of Lead | 36·0 |
| Sulphide of Mercury | 30·6 |
| Spongy Platinum | 31·5 |
| Washed Sulphur (flowers) | 32·3 |
| Sulphide of Zinc | 36·1 |
| Amorphous Phosphorus | 38·0 |
| Chloride of Lead | 39·0 |
| Chloride of Cadmium | 40·0 |
| Fluor-spar | 48·6 |
| Sulphide of Calcium | 49·1 |
| Sulphate of Baryta | 51·3 |
| Sugar | 52·1 |
| Red oxide of Lead | 56·5 |
| Sulphide of Cadmium | 56·9 |
| Sulphate of Lime | 59·3 |
| Chloride of Silver (black) | 60·0 |
| Carbonate of Zinc | 62·0 |
| Oxide of Cobalt | 62·5 |
| Iodide of Copper | 63·0 |
| Red oxide of Iron | 63·8 |
| Sulphide of Iron | 65·5 |
| Black oxide of Iron | 65·8 |

The agreement as regards relative radiative power between this and the former Table is as good as could under the circumstances be expected. The experiments have been several times repeated, and the Table contains the means of results which were never widely different from each other.

The *quantity* of radiant heat emitted by bodies in all states of aggregation having been thus conclusively shown to depend mainly upon its molecular character, the question as to the *quality* of the heat emitted next arises. In examining this point, I contented myself with testing the heat by its transmission through rock-salt. The choice of this substance involved the solution of the still disputed question whether rock-salt is equally pervious to all kinds of rays*. For if it absorbed the radiation from two different bodies in different degrees, it would not only show a difference of quality in the radiations, but also demonstrate its own incapacity to transmit equally rays of all descriptions.

* The last publication on this subject is from the pen of that extremely able experimenter, Professor KNOBLAUCH. After discussing the results of DE LA PROVOSTAYE and DESAINS, and of Mr. BALFOUR STEWART, he arrives at a different conclusion, namely, that pure rock-salt is equally pervious to all kinds of heat.—Pogg. Ann. 1863, vol. cxx. p. 177.

The plate of rock-salt chosen for this purpose was a very perfect one. I have never seen one more pellucid. The thickness was 0·8 of an inch, and its size, compared with the aperture in front of which it was placed, was such as to prevent any part of the rays reflected from its lateral boundaries from mingling with the direct radiation. M. KNOBLAUCH has clearly shown how the absence of caution in this particular may lead to error. The mode of experiment was that usually followed: the source was first permitted to radiate against the pile, and the deflection produced by the total radiation noted. The plate of rock-salt being then interposed, the deflection sank, and from its new value the transmission through the rock-salt was calculated and expressed in hundredths of the total radiation.

TABLE III.—Transmission through Rock-salt from the following substances raised to a temperature of 100° C.

| Substance. | Transmission. | Radiation. |
|-------------------------------------|---------------|------------|
| Rock-salt | 67·2 | 35·3 |
| Biniodide of Mercury | 76·3* | 39·7 |
| Milk of Sulphur | 76·9* | 40·6 |
| Common Salt | 70·8 | 41·3 |
| Yellow iodide of Mercury | 79·0* | 46·6 |
| Sulphide of Mercury | 73·1 | 46·6 |
| Iodide of Lead | 73·8 | 47·3 |
| Chloride of Lead | 73·1 | 55·4 |
| Chloride of Cadmium | 73·2 | 56·5 |
| Chloride of Barium | 70·7* | 58·2 |
| Chloride of Silver (dark) | 74·2 | 58·6 |
| Fluor-spar | 70·5* | 68·4 |
| Tersulphide of Antimony | 77·1 | 69·4 |
| Carbonate of Lime | 77·6 | 70·2 |
| Oxysulphide of Antimony | 77·6 | 70·5 |
| Sulphide of Molybdenum | 78·4 | 71·3 |
| Sulphate of Baryta | 71·3 | 78·4 |
| Chromate of Lead | 71·6 | 79·2 |
| Red oxide of Lead | 74·1 | 79·2 |
| Subchloride of Copper | 76·3 | 78·6 |
| Oxide of Cobalt | 76·5 | 79·7 |
| Red oxide of Iron | 78·4 | 81·0 |
| Sulphide of Copper | 79·0 | 82·3 |
| Black oxide of Iron | 81·3 | 82·7 |
| Sulphide of Iron | 81·7 | 83·3 |
| Lampblack | 84·0 | 83·3 |

Here we have a transmission varying from 67 per cent. in the case of powdered rock-salt to 84 per cent. in the case of lampblack. The powders employed were fixed by the sulphur cement. The same powders held by electricity, and permitted to radiate through the rock-salt, gave the following transmissions:—

TABLE IV.

| Substance. | Transmission. |
|--------------------------------------|---------------|
| Rock-salt | 62·8 |
| Chloride of Silver (white) | 69·7 |
| Fluor-spar | 70·7 |
| Sulphide of Mercury | 71·0 |
| Sulphide of Calcium | 72·5 |
| Milk of Sulphur | 72·8 |
| Sulphide of Cadmium | 73·3 |
| Biniodide of Mercury | 73·7 |
| Washed Sulphur | 74·0 |
| Iodide of Lead | 74·1 |
| Sulphate of Lime | 74·2 |
| Sulphide of Zinc | 74·4 |
| Carbonate of Zinc | 74·8 |
| Sulphate of Baryta | 75·0 |
| Common Sugar | 75·4 |
| Sulphide of Copper | 76·5 |
| Iodide of Copper | 76·5 |
| Red oxide of Iron | 76·8 |
| Chloride of Silver (black) | 77·3 |
| Amorphous Phosphorus | 78·0 |
| Oxide of Cobalt | 78·2 |
| Sulphide of Iron | 78·5 |
| Black oxide of Iron | 79·7 |
| Black Platinum | 89·0 |

The transmissions here are lower than when the sulphur cement was employed. I do not, however, think that the differences are due to the employment of the cement, but to a slight source of disturbance, which was removed in the later experiments.

For the heat emitted by black platinum rock-salt manifests its maximum power of transmission, which would lead us to ascribe a maximum dissonance between the vibrating periods of rock-salt and of black platinum. It will also be remarked that, as a general rule, the powerful radiator has its heat more copiously transmitted by the rock-salt than the feeble radiator. To render this clear, I have in Table III. appended to the transmission the corresponding total radiation. The only striking exceptions to

this rule exhibited in Table III. are marked with asterisks. This result, I think, is what might fairly be expected; for the character which enables a molecule of one substance to radiate a greater quantity of heat than another, may also be expected to influence its rate of oscillation. Hence, as a general rule, a greater dissonance will exist between the vibrating periods of good radiators and bad radiators, than between the periods of the members of either class. But the greater the dissonance the less will be the absorption; hence, as regards transmission through rock-salt, we have reason to expect that powerful radiators will find a more open door to their emission than feeble ones. This is, as I have said, in general the case. But the rule is not without its exceptions, and the most striking of these is the case of black platinum, which, though but a moderate radiator, sends a greater proportion of heat through rock-salt than any other known substance.

In his latest investigation KNOBLAUCH examined at great length the diathermancy of rock-salt. With his usual acuteness he points out several possible sources of error, and with his customary skill he neutralizes these sources. His conclusion is the same as that of MELLONI, namely, that rock-salt transmits in the same proportion all sorts of rays. On the opposite side we find the experiments of MM. DE LA PROVOSTAYE and DESAINS, and those of Mr. BALFOUR STEWART*, both of which are discussed by KNOBLAUCH. He differs from those experimenters, while my results bear them out. Considering the slow augmentation of transmission which the foregoing Tables reveal, and the considerable number of bodies whose heat is transmitted in almost the same proportion by rock-salt, it is easy to see that, where the number of radiants is restricted, such a uniformity of transmission might manifest itself as would lead to the conclusion of MELLONI and KNOBLAUCH. It was only by the selection and extension of the substances chosen as radiators that the differences were brought out with the distinctness recorded in the foregoing Tables.

The differences in point of quality and the absence of perfect diathermancy in rock-salt appear more striking when instead of the transmissions we take the absorptions. In the case of the radiation from powdered rock-salt, for example, 37·2 per cent. of the whole radiation is intercepted by the rock-salt plate. According to MELLONI, between 7 and 8 per cent. of this is lost by reflexion at the two surfaces of the salt. This would leave in round numbers a true absorption of 30 per cent. by the plate of rock-salt. In the case of black platinum, the absorption similarly deduced amounts to only 4 per cent. of the total radiation. Instead, therefore, of the radiation from those two sources being absorbed in the same proportion, the ratio in the one case is more than seven times that in the other. For the sake of illustration here follow a few of the absorptions determined in this way:—

* I think the important experiment first executed by Mr. BALFOUR STEWART, of rock-salt radiating through rock-salt, is by itself sufficient to demonstrate in the most unequivocal manner that this substance is not equally pervious to all kinds of rays.

TABLE V.

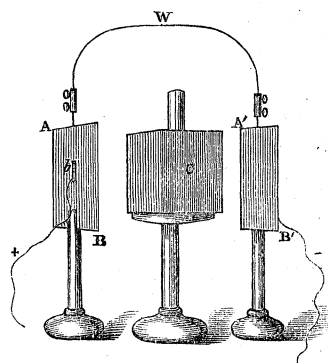
Radiation through Rock-salt.

| Source. | Absorption. |
|-------------------------------|-------------|
| Black Platinum | 3·7 |
| Black oxide of Iron | 13·0 |
| Red oxide of Iron | 15·9 |
| Sugar | 17·3 |
| Chloride of Silver. | 22·6 |
| Rock-salt | 29·9 |

These differences of absorption are so great as to enable every experimenter to satisfy himself with the utmost ease as to the unequal permeability of rock-salt, and this facility of demonstration will, I trust, contribute to make inquirers unanimous on this important point.

Theory alone would lead us to the conclusion that the absorptive power of the substances mentioned in Table I. is proportional to their radiative power; nevertheless a few actual experiments on absorption will serve as a check upon those recorded in the Table. These were conducted in the following manner:—

A B is a sheet of common block tin, 5 inches high by 4 in width, fixed upon a suitable stand. At the back of A B is soldered one end of the small bar of bismuth *b*, the remainder of the bar, to its free end, being kept out of contact with the plate by a bit of cardboard. To the free end of *b* is soldered a wire which can be connected with a galvanometer. A' B' is a second plate of metal in every respect similar to A B. From one plate to the other stretches the wire W. C is a cube containing boiling water, placed midway between the two plates of metal.



The plates were in the first instance coated uniformly with lampblack, and the two surfaces of the cube which radiated against the plates were similarly coated. The rays from C being emitted equally right and left, and absorbed equally by the two coated plates A B and A' B', warmed these plates to the same degree; it is manifest from the arrangement that, if the thermo-electric junctions were equally sensitive, the current generated at the one ought exactly to neutralize the current from the other junction. This was found to be very nearly the case. It is difficult to make both junctions of absolutely the same sensitiveness; but the moving of the feebler plate a hair's breadth nearer to the cube C enabled it to neutralize exactly the radiation from its opposite neighbour. My object now was to compare the lampblack coating of the plate A B with a series of other coatings, which were placed in succession on the other plate. These latter coatings were the powders already employed, and they were held upon A' B' by their own adhesion.

When A B was coated with lampblack and A' B' with rock-salt powder, the equili-

brium observed when both the plates were coated with lampblack did not exist. The lampblack, by its greater absorption, heated its bismuth junction most, and a permanent deflection of 59° in favour of the lampblack was obtained. Other powders were then substituted for the rock-salt, and the difference between them and the lampblack was determined in the same way. When, for example, sulphide of iron was employed, there was a deflection of 30° in favour of lampblack. The results obtained with six different powders thus compared with lampblack are given in the following Table:—

TABLE VI.

| | | |
|---------------------------|-----------------------|-------------------------|
| Excess of lampblack above | Rock-salt | $59^\circ = 112$ units. |
| „ | „ Fluor-spar | $46 = 68$ „ |
| „ | „ Red Lead | $40 = 45$ „ |
| „ | „ Oxide of Cobalt . . | $37 = 42$ „ |
| „ | „ Sulphide of Iron . | $30 = 30$ „ |

The order of absorption here shown coincides with the order of radiation of the same substances shown in Table III. But we can go further than the mere order of absorption. Removing the opposing plate, and allowing the standard lampblack to exert its full action upon the galvanometer, the deflection observed was

$$65^\circ = 163 \text{ units.}$$

The numbers in Table VI. show us the excess of the lampblack over the substances there employed; its excess in the case of rock-salt, a bad absorber, being 112, its excess in the case of sulphide of iron being only 30. Deducting, therefore, the numbers given in Table VI. from 163, the total absorption of lampblack, we obtain a series of numbers which expresses the absorptions of the other substances. This series stands as follows:—

TABLE VII.

| Substance. | Relative absorptions. | | Radiation. |
|---------------------|-----------------------|------|------------|
| Rock-salt | 51 | 25.5 | 25 |
| Fluor-spar | 95 | 47.5 | 49 |
| Red Lead | 118 | 59.0 | 57 |
| Oxide of Cobalt . . | 121 | 60.5 | 62 |
| Sulphide of Iron . | 133 | 66.5 | 66 |

The first column of figures expresses the relative absorptions; for the sake of comparison with the corresponding radiations, I have placed the halves of these numbers in the second column of figures, and in the third column the radiations obtained from Table II. The approximation of the figures in the second and third columns is seen to be extremely close.

Throughout this investigation I have been efficiently assisted by Mr. W. F. BARRETT, whose rapid progress in scientific knowledge and experimental skill during the three years that he has assisted me has given me great satisfaction.