TRANSACTIONS.

Researches on Heat. FOURTH SERIES. *On the Effect of the Mechanical Texture of Screens on the immediate transmission of Radiant Heat.** By JAMES D. FORBES, Esq., F. R. SS. L. & E., Professor of Natural Philosophy in the University of Edinburgh.

Arts. 1–12, *Laminated and Smoked Surfaces.* 13–29, *Rough Surfaces.* 30–34, *Metallic and other Gratings.* 35–53, *Powdered Surfaces.* 54–65. *Conclusions.*

1. ON the 2d September 1839, M. ARAGO communicated to the Academy of Sciences of Paris a letter by M. MELLONI, containing some very interesting experiments on the transmission of Radiant Heat. M. MELLONI finds that rock-salt (which is well known to transmit rays of heat from all sources yet tried with equal

* The substance of the present paper was communicated to the Royal Society of Edinburgh on the 16th December 1839, in the words of the memorandum which forms part of this Note. The memorandum itself was read, with some verbal explanation and citation of additional facts, on the 6th January. Every experiment to which reference is made in the present paper, was performed between the 12th November 1839 and the 4th March 1840. Since that time, I have not made a single experiment on the subject. Occupation of other kinds has prevented me from digesting, until now, the results of these experiments, and from stating the grounds of the conclusions which I formerly announced. The present paper, as it stands, having been submitted to the Council on the 15th May 1840, is printed by their authority. The following is the memorandum just referred to, reprinted from the *Proceedings of the Royal Society of Edinburgh* :—

“ *On the Effect of the Mechanical Texture of Screens on the immediate Transmission of Radiant Heat.* By Professor Forbes.—On the 2d September 1839, M. ARAGO communicated to the Academy of Sciences a letter by M. MELLONI, containing some very interesting experiments on the transmission of Radiant Heat. M. MELLONI finds, that rock-salt (which is well known to transmit rays from every source with equal facility) acquires, by being *smoked*, the power of transmitting most easily heat of low temperature, or that kind of heat stopped in greatest proportion by glass, alum, and (according to M. MELLONI) every other substance. The experiments contained in the Third Series of my *Researches on Heat*, shew that this is equivalent to saying, that substances in general allow

facility) acquires, by being smoked, the power of transmitting most easily heat of low temperature, or that kind of heat which is stopped in greatest proportion by glass, alum, and (according to M. MELLONI) every other substance.

only the more refrangible rays to pass; and as M. MELLONI had been led by his previous experiments to the same conclusion, his statement amounts to this, that, whilst rock-salt presents the analogy of white glass, by transmitting all rays in equal proportions, every substance hitherto examined acts on the calorific rays as violet or blue glass does on light, absorbing the rays of least refrangibility, and transmitting only the others.

“ M. MELLONI believes, that the first exception to this rule, or the first analogue of red glass, is rock-salt previously smoked. I desire, however, first to call attention to the fact, that, in a paper published in May 1838 (Researches on Heat, Third Series), I described a substance having similar properties, namely, mica split by heat to extreme thinness, such as I employ in polarizing heat. In the month of March 1838, I had established by reiterated experiments, that the transmission of heat through glass, far from rendering it less easily absorbed by mica in this peculiar state, had a contrary effect, and also that heat of low temperature, wholly unaccompanied by light, was transmitted almost as freely as that from a lamp previously passed through glass.

“ It even appears, from experiments I have since made with the same form of mica, that some specimens transmit *scarcely half* as much luminous heat previously passed through glass, as that from a body below visible incandescence.

“ Mica itself, not laminated by the action of fire, possesses, as I have shewn by contrasted tables in the paper referred to (Art. 23, 24), properties exactly the reverse; hence the effect is due to the peculiar mechanical condition of the body, and not to its elementary composition.

“ It, therefore, at once occurred to me, on reading M. MELLONI's communication, that the effect of smoking the salt might be merely owing to a mechanical change in the surface affecting the transmission.

“ Roughening the surface was the most obvious experiment, and I found, as I anticipated, that heat of low temperature is very much easier transmitted by salt scratched by sand-paper in two directions at right angles, than luminous heat. Thus, a plate of salt which, when well polished, transmits 92 per cent. of heat derived from a lamp, and sifted by a glass plate, and also 92 per cent. of heat wholly unaccompanied by light, transmitted, when roughened, only 17 per cent. of the former and 45 per cent. of the latter.

“ A thin plate of mica, when similarly scratched with emery-paper, so as merely to depolish it, transmitted much more nearly the same per-centage of heat from different sources than when *bright*; shewing, that the loss of polish affects the transmission of the more refrangible rays much more sensibly than that of the others.

“ Yet this effect is not attributable to a variation in the ratio of the reflection of heat of different kinds at the surfaces of the plate. For, in the *first* place, I have proved, and already communicated the fact to the Royal Society (see Proceedings for April 1839), that reflection takes place at a polished surface, with almost, if not exactly, the same intensity for all kinds of heat; and, *secondly*, I have found, by direct experiment, that, at least for the higher angles of incidence, reflection is most copious from rough surfaces for heat of low temperature, or the same kind which is most freely transmitted, proving incontestably that the *stifling* action of rough surfaces is the true cause of the inequality.

“ That there is a real modification of the heat in passing through a roughened surface, as well as through laminated mica and the smoky film, appears from direct experiments which I have made on the heat sifted by these different media; which, when transmitted by any one of these, is found in a fitter state to pass through each of the others; and this modification is found to be more per-

2. In the Third Series of these Reseaches, § 3, I have attempted to demonstrate, directly and numerically, that the rays of heat which have passed through alum, glass, and indeed every substance which I tried, have a *mean refrangibility* superior to that of the rays before such transmission; and as M. MELLONI had been led in a general way by his previous experiments to a similar conclusion, he inferred, and justly, that most diathermanous bodies absorb the less refrangible rays in excess, and therefore are to heat what green, blue, or violet diaphanous media are to light. Rock-salt alone (so far as we know) possesses the property of *indifferent diathermancy*, and is the single analogue of white transparent glass.

3. The generalization of this principle is a matter of much importance, and especially as it carries our knowledge a step higher in the scale of truth, by teaching us to refer to the quality of *refrangibility* certain properties of heat, which before were connected only with certain vague characters of the nature of the source whence it was derived. Amongst other things we find, what was long suspected, but what M. MELLONI first conclusively proved, that the presence or absence of light is, to a great extent, immaterial; no doubt a *concomitant*, but

ceptible as the character of the heat is more removed from that which these media transmit most readily, that is, as the temperature of the source is higher. Thus, heat derived from a lamp, has 36 per cent. transmitted by a certain smoked plate of rock-salt. But if the heat transmitted by the smoked salt has previously been sifted or analyzed by transmission through another plate of smoked salt, through laminated mica, and through roughened salt, the per-centage is raised from 36 to 44 in the two former cases, and to $40\frac{1}{2}$ in the latter, proving incontestably the specific action of these transmissions in arresting the more refrangible rays.

“ I next considered, that as a moderate number of scratches appeared to produce this modification, it might be practicable to obtain the effect by transmitting heat simply through fine wire-gauze. I could not obtain it finer than sixty wires to the inch, and in this case I could obtain no indications of differences in the transmitted ratios of one or other kind of heat. The proportion transmitted to the direct effect, was, in every case, almost exactly that of the area of the interstices of the gauze to its entire surface.

“ When fine gratings (used for FRAUNHOFER'S interference fringes) made of cotton-thread were used, even in this case no difference was perceived; here, however, the thread, having probably a certain degree of permeability, might mask the effect.

“ When fine powders were strewed between salt plates, leaving minute interstices, the easier transmission of heat of low temperature was again apparent.

“ Having procured delicate lines to be drawn with a diamond point on a polished salt surface, first dividing it into squares $1-100$ th inch in the side, then into parallel stripes $1-200$ th inch apart, and finally into squares of the latter dimension, in every case the effect resembled that of random scratches, and was more apparent as the surface was more furrowed.

“ I have finally to observe, that the mere process of natural tarnishing by the exposure of salt to the air, produces a similar effect.

“ These facts evidently point to phenomena in heat, resembling diffraction and periodic colours in light. I cannot doubt that the simple transmission through fine metallic gratings would produce effects similar to those of the striated surfaces of rock-salt.—*December 16. 1839.*”

not an *indispensable* circumstance. Again, certain relations had been established at an early period in the history of the science of heat, between the *colour* of a surface and the quantity of heat which it absorbed, and this relation for any two surfaces compared (as black and white, of similar textures), was first clearly shewn by Sir JOHN LESLIE, to depend upon the luminosity of the source of heat, to which conceiving it proportional, that philosopher based upon it the principle of his Photometer.* Professor POWELL, of Oxford, conceived and executed an ingenious experiment, by which it is demonstrated that the interposition of a screen of glass, though it stops but little light, alters most materially the influence of colour on the transmitted heat, thus annihilating at once the principle of photometric measurement adopted by LESLIE, except in a very limited class of cases.† M. MELLONI has fully confirmed the experiments of Professor POWELL,‡ which therefore may be considered as establishing this conclusion, that the quality of *blackness* or *whiteness* of a surface affects its power of absorbing heat (*not* in proportion to the luminosity of that heat, as was formerly supposed, but) in proportion to its refrangibility.

4. It is both convenient and correct, therefore, to consider the refrangibility of heat as the cause of most of its distinctions of *kind* and *degree* of modification in our experiments, instead of making vague reference to the temperature of the source whence it is derived. Heat derived from the following scale of temperatures corresponds to heat of progressively elevated refrangibility; as, 1. Heat from ice has a less refrangibility than that from, 2. the hand, which again is below, 3. that from boiling-water; then comes, 4. that from a vessel of mercury under its boiling temperature, 5. a piece of smoked metal, heated by an alcohol lamp behind, but itself quite invisible in the dark, 6. incandescent platinum (a coil of wire in an alcohol flame), 7. an oil lamp (LOCATELLI'S). Such is the scale of heat which has often been referred to in M. MELLONI'S researches and my own; but though our apprehension of the temperature of the source ceases to be so clear above this limit, and the colour and brightness of the light which accompanies the heat no longer varies distinguishably, the scale may be carried upwards indefinitely by interposing screens of different materials, which either may be proved *directly* (as I have done in the Third Series of these researches) to increase the refrangibility, or we may take Professor POWELL'S, or any similar test, which our experiments lead us to conclude to be co-ordinate with the fact of refrangibility. Such a prolongation of the scale of heat-sources would be,

* Essay on Heat, 1804.

† Phil. Trans. 1825, p. 187.

‡ Ann. de Chimie, *Avril* 1834. M. MELLONI finds, for instance, that the rays from an oil-lamp falling on black and white surfaces, affects their temperature in the proportion of 1000 : 805. And the same proportion holds if they be transmitted through a plate of rock-salt; but if a plate of alum be used, though equally transparent for light with the salt, the proportion is now 1000 : 429.

8. Oil-lamp heat transmitted by Common Mica.
9. ----- Glass (Argand lamp).
10. ----- Citric Acid.
11. ----- Alum.
12. ----- Ice.

A clear appreciation of the scale of refrangibility as the important test for the qualities of heat cannot be too clearly apprehended and admitted. Heat from *any* source, if it admit of transmission at all through glass, alum, or water, will ultimately have the character of glass-heat, alum-heat, or water-heat, just as light from the sun, or from a candle, becomes red, blue, or green, by transmission through glasses of these colours.

5. Now, when M. MELLONI had shewn (and this experiment I believe was original to him), that substances which stop every ray of even intense light (as opaque glass and some kinds of dark mica), yet transmit a sensible quantity of heat, it was not unnatural to inquire whether the *invisible heat* thus obtained from a *luminous* source, might not possess the qualities of heat from a dark source, in other words, whether bodies, like black glass and mica, instead of stopping the less refrangible rays like glass, alum, &c., would not suffer these to escape, and absorb the most refrangible rays, acting upon heat as a body does upon light, which stops the yellow, blue, and violet rays, that is, as Red glass does.

6. Experiment partly fulfils this expectation, and partly not. The careful and complete series of experiments made by M. MELLONI upon the qualities of the invisible heat thus obtained,* shews, that although it resembles low-temperature-heat, in so far as it is very feebly transmitted by alum or citric acid, yet low-temperature-heat (that from boiling-water for instance), is but very faintly transmitted through the black glass or mica, which ought not to be the case if these bodies acted like a sieve, which arrested the more refrangible rays, and suffered the others to escape.

7. The direct test, however, of examining the refrangibility of the heat-rays issuing from opaque screens yet remained; and in applying this, I proved that opaque glass and mica act as clear glass and mica do in *elevating the mean refrangibility of the transmitted heat*. Hence I concluded that the effect of such media upon heat is to absorb the rays of greatest and least refrangibility, in short, to act as homogeneous yellow glass would do upon light, the *mean* refrangibility being on the whole, however, increased by transmission. I also pointed out that heat from luminous sources is probably far more compound in its nature than dark heat; that the darkness of heat is no test of its refrangibility; and that even the most refrangible rays may contain heat separable from the light which accompanies it.†

8. In all this, then, there appears nothing exactly equivalent to the action

* Annales de Chimie, *Avril* 1834.

† Researches on Heat, Third Series, art. 73, 81, &c.

of red glass upon light,—no substance which transmits most easily heat of low Refrangibility and Temperature, and which separates heat of that description from the compound emanation from luminous sources. Reasoning probably upon the conclusions just stated, M. MELLONI conceived the happy idea of combining an opaque substance, such as smoke, with a solid, which itself should effect no specific change upon the incident heat. He therefore smoked *rock-salt*, and found that it presented a complete analogy to red glass, transmitting most easily heat of low temperature and refrangibility.

9. Whilst I give full credit to M. MELLONI for the ingenuity and importance of his experiment, I must be permitted to state, that I conceive that I preceded him by eighteen months in the discovery of a substance possessing similar properties, although I very readily admit, that, having been led to that observation incidentally, I first pursued the remark into consequences which I considered important, after M. MELLONI had called particular attention to the experiment with smoked surfaces. On the 27th February, 19th and 20th March 1838 (as appears by my Journal of Experiments), I proved that Mica, split into very thin films by the action of heat, such as I employ for polarizing, possesses the property of transmitting in larger proportion several of the less refrangible kinds of heat, and in particular, that it transmits heat from a source perfectly obscure, in almost exactly the same proportion with the highly refrangible heat of a lamp transmitted through glass. I have no hesitation in saying, that no other substance known previously to M. MELLONI's experiments with smoked salt, gave any approximation to the following results, which are taken from the Third Series of my Researches, art. 24.

TABLE of the proportion of Heat from different Sources transmitted by the Polarizing Mica Plates I and K, contrasted with the transmissions by Mica in its usual state, and with Black Glass.

Source of Heat.	Mica split by Heat, Plates I and K.	Mica .015 inch thick.	Opaque Black Glass.*
Locatelli lamp, with glass, . . .	100	100	100
Locatelli,	116	79	70
Incandescent Platinum, . . .	108	70	...
Brass at 700°,	96	21	...
Heat at 212°,	62	11	...
* A contrast experiment made at the same time, March 20. 1838.			

10. This singular result of the mechanical condition of the mica did not fail to strike me greatly at the time, and was not published until after careful repetition. It afforded a triumphant reply to an objection against my experiments which I was then combating, that the quantity of heat absorbed by the polarizing

plates had modified and even inverted the results, and having satisfied myself of that, I did not pursue the matter farther. The moment, however, that I read M. MELLONI'S communication on Smoked Salt, I perceived the important light which the perfectly analogous case of the split mica might throw upon the phenomenon. It was evident that the results were similar in kind, it was probable that they might be made to approximate in degree. Instead, therefore, of interposing mica piles at the great and disadvantageous obliquities which I had employed (when I wished simply to test their action as polarizing plates), I took a split mica pile (frequently referred to in former parts of these memoirs under the designation H) and placed it *perpendicularly* to the incident rays of heat. I obtained the following results:

TRANSMISSION THROUGH SPLIT MICA H, AT A PERPENDICULAR INCIDENCE.		
Source of Heat.	Per 100 of Incident Rays.	Relative Transmission.
Locatelli with glass,	9.2	100
Locatelli,	13.7	150
Dark hot brass,	17.3	188
Hot water,	16.3 *	178
* This observation having been made at a different time from the others, and probably not under exactly the same circumstances, I have stated it in the way least favourable to the views I entertain: the per-centage actually observed was 19.		

11. It appears, then, very clearly, that this peculiar condition of mica induces, in opposition to the natural quality of the substance (9), the same peculiarity which a film of smoke possesses relatively to the incident heat. It is truly for heat what red glass is for light, it transmits most freely rays of lowest refrangibility.

12. Seeing clearly from the first that the change of character in mica was due to the splitting up into an almost infinite number of minute surfaces the natural laminæ of the mineral mica; and attributing the character of redness (so to speak) to the multiplied and irregular reflections and interferences which must so take place, it occurred to me as very probable, that the effect of smoke was due to the superposition of a prodigious number of minute opaque points upon a transparent surface, and *that* not so much from any physical peculiarity of its carbonaceous material, as from the mechanical distribution of opaque dust over the diaphragm of rock-salt.

13. This induced me to try the effect of *mechanical alterations of the physical surface* of the salt, expecting to find an effect analogous to that of smoking, and, guided by no other grounds of conjecture than those which I have stated, I roughened with sand-paper both sides of a polished plate of rock-salt, furrowing each surface rectangularly until it was quite dim. I then examined its trans-

missive power for heat from different sources, and was gratified to find my anticipation realized. The proportion of dark-heat transmitted, compared to that from a lamp sifted by glass, was no less than as 3 to 1.*

14. It thus appeared that there are at least three conditions under which a medium can be found capable of transmitting heat of low refrangibility, and that two of these had reference *solely* to mechanical constitution. It was natural to generalize and attempt to include the case of the film of smoke, as well as the striated and the laminated surface, under one category. I have already said that the mechanical distribution of the opaque carbonaceous particles offered a plausible analogy, which I proceeded to attempt to carry out.

15. The numbers in art. 10, may be compared with the following :

Source of Heat.	Transmission per 100 of Incident Rays, by		Relative Transmission by	
	Smoked Salt.	Rough Salt.	Smoked Salt.	Rough Salt.
Locatelli, with glass,	30	49	100	100
Locatelli,	...	62	...	126
Dark hot brass,	58	70	192	142
Hot water,	67	77	223	157

16. It occurred to me that if the action of the smoke was entirely a *superficial* one, or due to the character of a rough surface applied to the plate of rock-salt, that the effect of two such surfaces upon the transmission of heat would probably differ from that of a single film of smoke, so thick as to produce an

* I state it as a proof of the conviction which I had of the real character of split mica with respect to heat, that the reasoning stated in the text was founded upon no experiments made subsequently to those of March 1838 already quoted. The very first entry in my journal-book of last autumn contains *simultaneous* experiments, (1.) on smoked salt, to verify M. MELLONI's observations : (2.) on split mica, to extend my own of March 1838 to perpendicular incidences : (3.) on scratched surfaces, on the assumption that the two former would be realized. As M. MELLONI thinks that I had not a clear idea of the properties of split mica, which, indeed, if I understand him, he still doubts, I will quote *verbatim* the passage in my laboratory-book alluded to.—“ 1839, Nov. 12. M. MELLONI having lately stated (Comptes Rendus, 2d Sept.) that smoked rock-salt is the only substance known which transmits heat of low temperature easier than luminous, this is in the first place contradicted by my experiments of 1838, Mar. 20. &c. on mica split by heat, already published,—and in the next place, I felt [feel] some doubt whether [in his experiments] it was the quality of the *material* or only the *surface* which affects the result. To try this, and to verify previous experiments, I smoked a plate of rock-salt ; I *roughened* another with sand-paper, first on one, and then on both surfaces ; I had also the split mica plate marked H placed *perpendicularly* to the rays of heat.”

[Here follow the experiments.]

“ It clearly appears, then, that salt simply roughened transmits most Dark Heat. I presume that the effect of smoking is only superficial, and that roughening stifles luminous heat faster than dark heat.”

This is the *first* entry in my book after the publication of M. MELLONI's letter in the Comptes Rendus, and it is given *entire*.

equal absorption of heat of any particular degree of refrangibility. For this purpose I smoked three plates of polished rock-salt, so that two marked D and E absorbed *together* as much dark heat (very nearly) as the third plate A did alone.

17. I may take this opportunity of mentioning the way in which I have succeeded in smoking inflammable surfaces without burning them, or crystallized plates, like rock-salt, which crack and fly by the direct application of the flame of a candle. A coarse gas flame, surrounded by a wide metal tube 10 or 15 inches long, against the side of which the flame partly plays, affords a stream of comparatively cool smoke, which may be applied to any given surface. With these three smoked salt-plates I obtained the following results:

	SOURCE OF HEAT,		
	Locatelli with Glass.	Locatelli.	Dark Heat.
Smoked Salt Plate A,	Per Cent. 8.3	Per Cent. 17.2	Per Cent. 32.9
~~~~~ D, ...	26	41	58
~~~~~ E, ...	23.5	36	53.5
~~~~~ (D + E) . .	7.3	18	32.1

As most of these results are from single experiments, the first and the last line must be considered as almost identical, and certainly do not indicate any material specific difference in the absorbent qualities of one thick and two thin films of smoke, which might be expected if the action were a merely superficial one.

18. From these numbers we deduce another conclusion of some importance. Since a film of smoke transmits most easily heat of low temperature and refrangibility, we may expect that it will modify the quality of any compound beam of heat which it transmits, and that one such transmission will therefore render a second more easy. Now, we find that the plate D transmitted 26 per cent. of heat from the first of the above sources, and that of the 26 rays escaping from D, and falling upon a second smoked film E, E transmitted 7.3, or 28 per cent. of those incident upon it. But by the third line of the table E transmitted 23.5 per cent. only of the direct rays, consequently the capacity for transmission has been increased. In the same way for Locatelli heat we find the per-centage for E raised from 36 to 44 by previous transmission through D; and for dark heat from 53.5 to 56.

19. Hence a useful application of smoked surfaces to which I have sometimes had recourse. It is often important to operate with more or less refrangible rays of heat under exactly the same circumstances of parallelism or divergence, and intensity. Having adjusted an oil-lamp with a salt lens, so as to afford a compound beam stronger than required, we may, by interposing a plate of smoked salt, absorb the most refrangible rays, and suffer the others alone to pass, and by then using a glass of proper thickness, the intensity of the heat may be reduced

in the very same proportion, but the more refrangible (hottest) rays are alone retained.*

20. Now the results of (17), though not what I anticipated as most probable, do not altogether relieve us from some doubt as to the nature of the action of the film of smoke, although those experiments, as well as others which are to be detailed in this paper, incline me to M. MELLONI'S opinion, that the smoke acts by its own intimate constitution, and not by its mechanical arrangement. Though I have examined smoky films with a powerful microscope, I have failed in detecting the minutely divided particles of carbonaceous matter of which it must undoubtedly consist. Still the reticulation which fine powder strewn on a surface must form, if it act by the minuteness of the spaces which are left (as in diffraction-experiments on light), must act more intensely when by superposition such reticulations become more minute and complicated. And it may little matter whether the smoky screens are distinct, and deposited on separate plates mechanically placed in succession, or whether they are accumulated by continued smoking on a single surface. I do not state this with a view to maintain my own original opinion, which I am rather disposed to abandon, and to consider a smoked surface, *diathermanous*, as well as *transparent*, in the full meaning of the words; but in extending my experiments to roughened surfaces, I was rather surprised to find that the continued action of furrowing the surface by scratching it with coarse sand-paper, not only diminished the transmission of heat, but increased the *specific* action on rays of different refrangibility, whilst one would rather have imagined that the action being here due to the destruction of polish, and therefore *superficial*, any exaggeration of the roughness would not have increased the relative *diathermancy* to rays of low refrangibility.

21. Conclusive experiments, however, mark an increased sensibility to various kinds of heat by increased roughness. Two plates of salt, marked *a* and *b*, having been scored with sand-paper in rectangular directions on both sides, were placed so as to intercept similarly a parallel beam of heat. The difference of the following numbers is due to the less degree of roughness of *a*.

	SOURCE OF HEAT.		
	Locatelli with Glass.	Locatelli.	Dark Hot Brass.
Rough Salt Plate <i>a</i> , ...	Per Cent. 30	Per Cent. 48.5	Per Cent. 59
----- <i>b</i> , ...	16.6	28.5	45
----- (<i>a</i> + <i>b</i>), . . .	7.2	16	27.5
Per-centage of heat received } through <i>a</i> transmitted by <i>b</i> , }	24	33	46.5
Ratio of <i>a</i> to <i>b</i> , ...	100 : 55	100 : 58.5	100 : 76

* *Smoked glass* is evidently an excessively opaque compound medium, being composed of two parts which absorb opposite ends of the heat spectrum. It is curious to reflect how little the true

Here, then, we find the per-centage of transmission raised in every case by a previous transmission through a rough surface. The increased facility of transmission is greater in proportion as the incident heat was more heterogeneous; dark heat undergoes very little change. It appears also by the last line of the table, that the increased roughness of *b* compared to *a*, had *enhanced* the characteristic effect (analogous to *redness* for light).

22. I have made a great many experiments to satisfy myself that the action of all the three media already specified (14) is precisely analogous, and that they actually insulate similar rays by absorption. The following table is a specimen, shewing the increased facility with which rays of heat, from whatever source, are transmitted by smoked rock-salt after previous transmission through the same or other substances.

TABLE shewing the Per-centage of Transmission by the Smoked Rock-Salt Plate E for heat from different sources, and modified by passing through the following Media.

Source of Heat,	Heat transmitted by			
	Nothing.	Split Mica H.	Smoked Salt D.	Rough Salt <i>a</i> .
Locatelli with glass, ...	23.5	...	28	29
Locatelli, ...	36	43.5	44	40.4
Dark hot brass, ...	53.5	56	56	55

23. It is very important to consider how this action of rough surfaces may be explained, and whether we have any analogous phenomena in the case of light. Can it be owing to the circumstance that the depolished surface reflecting differently the various kinds of heat, those kinds least copiously reflected persevere, and form the majority of the transmitted rays? To this it may be replied, that the intensity of reflection at polished surfaces, is so insignificant at a perpendicular incidence for either heat or light,* that were the *whole* specularly reflected heat, transmitted in the one case, and absorbed in the other, the difference, instead of amounting to 30 per cent. or more, of the incident heat (21), could not exceed 4 per cent.

24. Arguing from the analogous case of light, I anticipated, on the contrary, that the *reflected* as well as the *transmitted* beam, would be more intense from cause of the opacity of a film of smoke deposited upon glass was understood at the time that it was quoted as a convincing proof of the *immediate* radiation of heat through solid bodies. Far from smoke being the untransparent substance supposed (I use the word loosely in applying it to heat), it transmits a quantity of some kinds of heat really surprising, although the thickness of the smoke be considerable.

* See MELLONI, Ann. de Chimie, Dec. 1835, and my Memorandum on the Intensity of Reflected Heat and Light, Proceedings Royal Society of Edinburgh, p. 254.

such a surface, as it is well known that polish becomes more specular for rays of light consisting of longer undulations, the inequalities of the surface first becoming insignificant for red light.

25. In this I was not deceived. My purpose not being to investigate fully the subject of diffuse reflection, I confined my attention to the establishment of the general fact. Employing an apparatus which I have not yet described, but which bears a great analogy to that figured in the Society's Transactions, vol. xiv, Plate XIII., and described in art. 51 of the Third Series, I observed the intensity of reflection of heat from different sources at a *single* polished surface of flint-glass, and at a similar surface depolished with emery. I obtained at considerable incidences the following striking results as to the increased susceptibility of heat to be *regularly* reflected at a rough surface, when it is of low temperature or refrangibility.

Ratio of the Intensities of Heat reflected by a POLISHED and a ROUGH Surface of Flint-Glass.

Angle of Incidence.	SOURCE OF HEAT.		
	Locatelli with Glass.	Locatelli.	Dark Hot Brass.
60°	...	100 : 34	100 : 35.4
70	100 : 26.5	100 : 38.3	100 : 43.5

So far then the character of the action of depolished surfaces is consistent. *The stifling effect* (which diminishes both the reflected and refracted ray) *of a rough or laminated surface, diminishes with the refrangibility of the incident heat.* That the same thing takes place in the Reflection of light we know ; it is probable that it does so in its transmission likewise, though this has not been so distinctly observed. Most impure substances transmit a ruddy gleam, vapour of water does so whenever it is not colourless,* and every practical optician knows, that in a great majority of media the violet end of the spectrum is first absorbed.

26. A more minute analysis of the influence of surface upon heat is what we now propose. And three questions present themselves for immediate solution, (1.) If deficiency of polish produce a variation in the proportion of not less than 3 to 1 in the quantity of transmitted radiated heat from different sources, can we employ salt plates with the ordinary degree of polish, and yet consider them as equally transparent for every kind of heat, as M. MELLONI'S discovery has hitherto entitled us to do ? (2.) Is the effect of roughness common to other substances as well as rock-salt ? (3.) The operation of depolishing with sand-paper is nothing more than the making of an infinite number of distinct grooves on a polished

* Edinburgh Transactions, vol. xiv. p. 371.

surface; supposing these grooves to be regularly formed, and capable of numerical estimation, will the effect continue?

27. (1.) With respect to the first of these questions, it is satisfactory to be able to answer it affirmatively in a general way. I took two salt plates, of which the surfaces had not been *regularly* polished for a long time, and which, though bright and clear, were by no means particularly even and true. Of heat from LOCATELLI'S lamp previously sifted by glass, these *four surfaces* of rock-salt transmitted 72 per cent. With dark heat from smoked brass the per-centage was 73, a difference which, in this experiment, could hardly be considered as appreciable. *The transmission of these two very different kinds of heat was therefore equal.* M. MELLONI has shewn that when rock-salt is pure and perfectly polished, .92 of the incident heat is transmitted by a pair of surfaces, and therefore four surfaces should transmit $(.92)^2$ or 84.5 per cent. This estimate I have verified, and am satisfied of its accuracy. The deviation in the present case (which I think it right not to pass over) is due partly, no doubt, to the inequalities of surface but chiefly to some imperfections in the salt itself, which, as the experiment was merely a relative one, were not adverted to. In contrast with this, I used at the same time (December 11. 1839) a piece of salt, which once had been polished on both sides, but which, by being laid aside for some years, had become completely dull and grey on its surface. This specimen, then, was simply *depolished*; it contained no furrows, and had been subjected to no mechanical action whatever. Its per-centage of transmission was,

	Locatelli with Glass.	Dark hot Brass.
Tarnished salt, ...	66	77

clearly establishing the general principle.

28. (2.) With respect to the question, whether roughness of surface has a similar effect in modifying the diathermancy of other substances as well as rock-salt, we are able to give a distinctly affirmative answer. Rock-salt being, so to speak, quite indifferent to the quality and source of the incident heat, any cause of specific action becomes immediately apparent. Not so with any other substance, which, exercising already a specific action in virtue of its nature, is to have that specific action modified by a modification of surface. At least the question is, whether or not this modification will occur? An example will best illustrate how this modification may be discovered and expressed. I took a plate of mica with its natural bright surfaces, and so thin as to transmit in considerable abundance heat from different sources. The per-centages in this state were determined as follows:

	Locatelli with Glass.	Locatelli.	Dark heat.
Mica with <i>bright</i> surfaces, ...	83.5	74	37

Both sides of the mica were depolished with emery-paper, and the experiment repeated (27th November 1839),

	Locatelli with Glass.	Locatelli.	Dark Heat.
Mica with <i>rough</i> surfaces, ...	45.5	51	31.5

Denoting the original transmissions by 100, the diminished effect due to the roughness of the surface will be represented by

54	69	85
----	----	----

demonstrating as clearly as possible that the stoppage is proportioned to the temperature of the source of heat; thus, whilst 46 per cent. of the first kind was arrested by the roughness of the surface, only 15 per cent. of dark heat was stopped.

29. (3.) With regard to the third question, the action of a comparatively small number of scratches on a polished surface, instead of a general diminution of its polish, I proceeded thus: I caused a series of extremely minute lines to be drawn mechanically with a diamond point, on a well polished surface of rock-salt, so as to divide it into squares having *one-hundredth* of an inch for their side. A similar plate was scored by fine lines in the same manner, parallel to one another, and *one two-hundredth* of an inch apart. A portion of this second plate was crossed rectangularly, by lines drawn at the same distance, so as to divide the surface into squares four times smaller than in the first instance. These three media gave the following results with two very different kinds of heat (December 6–11. 1839).

Source of Heat.	Scored in squares 100 lines to the inch.	Scored in lines 200 to the inch.	Scored in squares 200 lines to the inch.
Locatelli with glass, ...	76.5	61.5	45
Dark hot brass, ...	82.3	68.5	64.5 *

* The part of the second plate which was scored *across* being more free from flaws than that which was *once* scored, explains the little difference between this number and that in the preceding column.

For heat of 212° the per-centage was still higher, as will afterwards be shewn.

30. *Metallic Gratings.* If the mere defect of transparency were the cause of the peculiar action of scratched surfaces, we might expect that any opaque filaments would act in the same way. Could we dispense with the *medium* altogether, and employ a *screen*, which should have the qualities which we had artificially given to the physical surface of the medium, we should evidently have advanced a step in the interpretation of the phenomena. The action of grooved surfaces and gratings upon light suggested so forcible an analogy, that before I was able to procure the mechanically striated surfaces, described in the last article, I had employed fine metallic wire-gauze as a diffraction-screen, hoping to obtain results similar to those which I anticipated, and afterwards did obtain, by drawing fine lines upon rock-salt.

31. The fact that diffraction-phenomena in light, produced by gratings, are wholly irrespective of the nature of these gratings, as, for instance, whether they be formed of metal-wires, or mere lines drawn through a soapy film stretched on

glass, gave some countenance to this experiment. I was not unaware that diffraction spectra are produced, not by a parallel beam of light, but by a picture, formed of a distant luminous point. Still, though the ground or field illuminated by parallel rays passing through a grating must evidently have a uniform tint, it does not appear absurd to suppose that that tint may be different from white. Nor does this question appear to have occurred to mathematicians or optical writers, until the problem presented itself to me in the course of this investigation.

32. With such wire-gauze as I could easily procure, I failed in obtaining any peculiarity of action as relates to heat from different sources; and farther, the quantity of heat intercepted by the metallic grating appeared to be nearly, or exactly, proportional to the surface of the opaque portion of the screen. Thinking that perhaps finer gauze than that I used (60 wires to the inch) might produce the desired effect, I obtained, through the kind assistance of Sir JOHN ROBISON and M. LEONOR FRESNEL, the finest manufactured in Paris, going as high as about 160 per inch. In general my first results were confirmed, viz. (1.) that the proportion of heat stopped is irrespective of the source; (2.) that it is to the incident heat as the area of the wires is to the area of the surface. It must be observed, however, that the determination of this latter proportion with extreme accuracy by an examination of the grating, is not so easy as might at first sight appear. When the *wire* is fine compared to the *interstices*, the interstices are pretty nearly rectangular and equal-sided. But this is not the case in most manufactured wire-gauze. One set of wires is nearly parallel and straight, but not so the set interlaced with the former, which do not generally make their intersections at right angles, and hence, universally, the interstices are somewhat smaller than a calculation proceeding upon the number of wires per inch, and their diameter would give. Distrusting my own observations, I put three specimens of wire-gauze into Mr JOHN ADIE's hands, requesting him to determine the mean diameters and intervals of the wires. With a very accurate micrometer he determined 14 values for each of these quantities in both directions. From these data the proportion of the Interstices to the whole Surface of each grating is easily calculated, and the results are given below for three sorts of gauze of which I had *previously* determined the permeability for heat.

Micrometric Measurement of Wire-Gauze. Unit of Measure = $\frac{1}{52400}$ inch.

Wire Gauze.	Lengthwise.		Breadthwise.		Ratio of INTERSTICES to SURFACE.
	Interstice.	Wire.	Interstice.	Wire.	
No. 1. (57 per inch), . .	534	371	562	384	.3504
No. 2. (92 per inch), . .	375.6	179.4	402.6	179.6	.4680
No. 3. (129 per inch), .	200	159	284	168	.3500

33. The numbers in the last column (computed on the supposition of the interstices being geometrical rectangles) are to be compared with the following experimental determinations of the proportion of incident heat transmitted by these gratings.

Proportions per 100 of Incident Rays of Heat transmitted by Wire-Gauze.

Wire Gauze.	Locatelli with Glass.	Locatelli.	Dark hot Brass.	Hot Water.
No. 1. (57), . . .	32.5	32	33.5	.....
No. 2. (92), . . .	46.0 *	...	44.7 †	.....
No. 3. (129), . . .	30.5	...	30	29.7

* Two such gratings superimposed, so that the wires formed angles of 45° with one another, gave for the per-centage of transmission 20.7. The square root of this, or effect due to each grating, is 45.5, or almost the same as the number in the text.

† Two superimposed gratings gave 21.2 per cent., or 46 for each system separately.

The differences for each grating, perhaps, do not exceed the errors of experiment. In every case these numbers are *inferior* to the geometrical interstices, but what inclines me to think that this difference is due to the irregularities of figure of the gauze (including the effect of *flattening* of the wires where they overlap, making the interstices obtuse-angled) is this: that No. 2, in which the wires were finer compared to the interstices than in others (the total interstices being one-third part larger in proportion), and the gauze evidently far more regularly formed than in the other cases, the per-centage transmitted differs very little from the geometrical gauge. I own, at the same time, that a difference of 5 per cent. in No. 3 (which is evidently not due to an error of observation), seems to me barely accounted for by this remark.

34. *Thread Gratings.* With gratings of fine cotton-threads $\frac{1}{100}$ inch apart, used for shewing FRAUNHOFER'S Spectra, I obtained a similar result. These threads were arranged parallel-wise on two frames, capable of being superimposed rectangularly. Thus, we can either employ a screen of parallel threads *one-hundredth* of an inch apart, or a screen of mathematically accurate squares, formed by superposition. It is difficult in this case, however, to obtain the diameter of the thread accurately enough to estimate the ratio of interstices.

Per-centage of Incident Heat transmitted by Cotton-Thread Gratings,
 $\frac{1}{100}$ inch apart.

	Locatelli with Glass.	Dark Heat.
Thread Grating, SINGLE, . . .	29.5	30.2
~~~~~ DOUBLE, . . .	9.0 *	8.3 †

* Corresponding *single* action = 30.0 per cent.
† ~~~~~ = 28.8 ~~~~~

The difference here seems imperceptible, the differences, such as they are, being in opposite directions. The results in the last column are from single experiments (November 28. 1839).

35. *Action of Powders.* Adhering to the idea (12) that the action of a smoked surface was due to the mechanical action of a number of minute opaque points distributed over a transparent body, it occurred to me almost at the commencement of these experiments, to try the effect of powders artificially sifted on such a surface. Any ingredient, however, which could make the powders adhere to the surface, would have vitiated the experiment, by introducing its own proper diathermancy. I therefore included the powders between two polished plates of rock-salt, closed at the edges with wax. The preliminary experiment (27), to shew that the salt surfaces, in the state in which I commonly employed them, exercise no perceptible influence on the quality of the transmitted heat, was evidently a very important one for the conclusions I meant to draw. It was, as I have stated, quite satisfactory.

36. The first experiments which I made with powders (December 6. 1839), were with Chalk and Alum, finely dusted between two plates of salt. I selected the chalk on account of its absolutely uncrystalline and opaque character; and alum, because its power of stopping rays of heat of low temperature was so very great, that I judged that if the influence as a *mechanical modifier of surface* should prove predominant, and allow as much, or more, heat of *low* than of *high* temperature to pass, the *mechanical* influence of a substance in fine powder would be clearly established.

37. Now, the result at which I arrived, and which was entirely conformable to my anticipation, may serve to shew the caution requisite in drawing conclusions from limited data, however apparently conclusive. The surfaces powdered with chalk suffered *rather more* heat of low than of high temperature to pass (viz. 34.5 per cent. dark heat, and only 30.5 of heat from LOCATELLI lamp, transmitted through a thick glass-lens), whilst the salt strewed with alum appeared quite indifferent to the kind of heat incident,* (transmitting only 17 per cent. of both, thus shewing that the powder was in considerable quantity). I concluded, therefore, with apparent reason, that the chalk having no *specific* action, or being (most probably) opaque or *athermanous*, the powder of it acting mechanically, allowed low-temperature-heat to pass in excess, whilst in the case of alum, the *specific* action was entirely counteracted by the *mechanical* action of the powder. I simply stated the fact amongst others detailed in the preceding pages, in a Memorandum presented to the Royal Society of Edinburgh on the 16th December 1839,† and a few days after, in a slightly different form, communicated to M. ARAGO, and printed in the *Comptes Rendus de l'Academie des Sciences*, 6th January 1840. On the 28th December, I

* Yet an alum plate of a certain thickness transmits no less than 27 per cent. of the one kind of heat, and *no sensible portion* of the other (MELLONI).

† See note page 1 of this paper.

obtained a similar result for Charcoal powder (whose affinity with smoke suggested its use), and yet it does not appear that the general conclusion which I intended is entirely warranted.

37. It is well known that Sir ISAAC NEWTON overlooked the variable dispersive power of bodies for light, in consequence of having compared two, in which the dispersion *happened* to be proportional to the mean refraction. A similar haste to generalize would have led to error on the present occasion, had not a simultaneous investigation led me to re-consider the subject of powders. Whilst waiting for the arrival of fine wire-gauze from Paris, it occurred to me to try the effect of metals in a state of extreme division. It seemed, however, first desirable to ascertain whether the metals are as incapable of transmitting heat as is commonly supposed.

38. For this purpose, I stretched a piece of the thinnest gold-leaf across a wide diaphragm of pasteboard, and suffered an intense parallel beam of heat from LOCATELLI'S lamp to fall directly upon the pile. A screen of glass was interposed, which, by experiment, was known to stop 43 per cent. of this sort of heat. The needle of the galvanometer deviated $31^{\circ}.2$, the glass being interposed; the equivalent direct effect would have been $31.2 \times \frac{100}{43} = 72^{\circ}$. When the glass was removed, and the gold-leaf put in its place, on the brass screen being alternately introduced and removed, not the faintest motion was perceptible in the needle; had it amounted to $\frac{1}{20}$ of a degree, that is, had $\frac{1}{1400}$ of the incident heat been transmitted by the gold-leaf, I considered that the effect would have been perceptible. Yet this gold-leaf was so thin that the features of a landscape could be distinctly seen through it, of the usual bluish-green tint. No more convincing proof certainly can be desired, that conduction plays no sensible part in these experiments, since it did not sensibly act on a film of one of the best known conductors of heat, and perhaps not more than $\frac{1}{300000}$ th of an inch thick. I thought it worth while to repeat the experiment with dark-heat, and with the same results. The analogy of the action of split mica on light to metallic reflection led me to suspect, that if any kind of heat were transmitted by metallic leaves, it would be that of low temperature.

39. The imperviousness to heat of gold-leaf, the thinnest continuous film of metal which we can obtain, satisfied me of the importance of obtaining the metals in a condition to verify my experiments with the powder of other substances. When the hope diminished of obtaining wire-gauze of a degree of fineness (I mean fineness in the *wire*, not closeness of texture, for that was comparatively immaterial), which might vie with the diamond scratches on the salt surface, which presented, under the microscope, an irregular furrow, probably nearly $\frac{1}{2000}$ inch in mean breadth,—I recurred to the project of using the metals in *powder*. It was evident from the experiments on depolished and scored surfaces, that the *irregularity* of these streaks had nothing whatever to do with the phenomenon of checking rays of high refrangibility and admitting others. Sand-paper scratches.

than which nothing can be more irregular, produced the effect, and that more intensely as the surface became more coarsely and closely furrowed. Nay, it occurs in natural tarnish, where there can be no linear arrangement of the points affected. It seemed to me, therefore, that a surface covered with a metallic powder, presented the *limit* of a grating where the interstices were not required to have any regular form.

40. The next difficulty was to obtain impalpable powders indubitably metallic, to which I attached very considerable importance, for it was quite conceivable that the metallic sulphurets and other substances employed for the fictitious metallic powders called gold, silver, and copper bronzes, might have specific diathermancies which might injure the experiment. I at length succeeded in obtaining silver by precipitation, and copper from DANIELL'S Battery; and with some difficulty I procured from a large manufacturer coinage silver and gold, reduced by mechanical trituration to a perfectly impalpable and beautifully metallic powder. These expensive preparations are now wholly superseded by the admirable fictitious bronzes in use in the arts. These, together with metallic copper-bronze, perfectly impalpable, furnished by the same individual, and a much coarser tin powder used by druggists, formed the material of a very careful series of experiments, which I extended over a very considerable period, and varied in a great many ways. (1840, Jan. 28, &c.)

41. The following table contains the results of my experiments on Metallic Powders, which (with the exception of tin), may be considered as perfectly impalpable, adhering to the dry finger, and *undoubtedly metallic*.

Per-centage of Heat from different Sources transmitted by Metallic Powders.

Powder.	Locatelli Lamp.			Dark hot Brass.	Hot Water.	REMARKS.
	Glass interposed.	Direct.	Smoked Salt interposed.			
GOLD, No. 1, (adhering to a single surface of salt),	58	...	50.5	...	...	{ Mean of a considerable number of results.
GOLD, No. 2, (between two salt plates), . . . }	7.4 *	...	...	4.1 *	...	
SILVER, No. 1, (between two salt plates), . . }	25.3	24.2	...	21.8	...	
SILVER, No. 2, (adhering to a single surface of salt),						{ The same plate was used, but differently placed in respect of the pile, so that each series stands by itself.
1st Series,	27.7	...	18.5	...	...	
2d Series,	29.5	...	22.1	...	25	
COPPER, No. 1, (between two salt plates),						
1st Series,	14.8	...	16.0	...	...	
2d Series,	17.4	...	...	18.7	17	
COPPER, No. 2, (between two salt plates), . . }	5.6 *	...	...	4.05 *	...	{ Mean of a considerable number of results.
TIN (between two salt plates), }	27.0	26.0	...	25.5	...	

42. These observations are confessedly very imperfect. I am persuaded, however, that the apparent anomalies are not errors of observation: other in-

* See the next Article.

stances will presently occur. With a view to determine the quality of thickly strewn surfaces yielding a very feeble per-centage of transmitted heat, it was desirable to use an intense incident beam. In order, however, to keep the comparison within the range of galvanometer degrees, whose numerical values have been tested (Second Series, arts. 7-8), the observations in the preceding table marked thus * were made in the following manner. The *direct* effect of the incident heat on the pile was never observed, but only that part of it which penetrated the wire-gauze, No. 3 of art. 33, which transmits almost exactly 30 per cent. of every kind of heat. The direct effect was estimated at $\frac{100}{30}$ of the degrees of deviation corresponding to this transmission, and then the wire-gauze being removed, and the medium to be examined substituted, the effect was compared to the computed direct effect. For example, with the copper powder, No. 2, the effect of the LOCATELLI lamp, heat transmitted through thick plate-glass, and then modified by wire-gauze, was 22°.57

$$\text{Direct effect} = 22.57 \times \frac{10}{3} \quad 75.2$$

Wire-gauze removed, and copper substituted, 4.15
 Ratio to direct, 5.52:100

In this way per-centages may be obtained with very nice accuracy: Another experiment gave in the same case 5.60:100.

43. The Table in art. 41. demonstrates to my conviction (strengthened by a careful examination of the very consistent observations on which it is founded), (1.) That gold, silver, and tin powders, instead of having the property which I was disposed to assign to opaque powders generally, do really transmit more heat of high than of low temperature; that is, act like glass, alum, and other transparent media in their common state. (2.) With respect to copper, two series give one result, and a third the opposite. Yet all of these were made with great care, and contain internal evidence of their accuracy. I am confident that the differences are not due to errors of observation; and I have observed other cases, in which an increase of thickness of the obstructing medium, and an increased intensity of the incident heat, gave altered results as to permeability, a result by no means paradoxical, since intense heat may be sensibly transmitted through a nearly opaque substance, and thence acquire a new character, which a feebler beam, transmitted through a less obstructing medium, would not possess. At all events, I can offer no farther explanation at present. That copper possesses a peculiar character, distinct from the other metals which I tried, I am fully persuaded.

44. The evidence which the experiments on metallic powders gave of the inadequacy of the *mere powdery form* to produce the effect of smoke, forced me to a more critical examination of other bodies in a similar state.

45. I repeated my experiments with increased care on the powders already employed. I tried a great number of new ones, chosen amongst substances differing as widely in nature as possible. Some of these substances were repeatedly

tried in different specimens, the powder more or less thickly strewed, and at different times.

46. One circumstance in particular raised a doubt as to the result of my former conclusion, where it seemed most incontrovertible. I had argued, that if alum in powder arrested equally all kinds of heat, the *mechanical* action of the powder must have opposed and destroyed the *specific* action of the alum (36.) I was gradually, however, led to admit, that, *in the state of powder, most diathermanous bodies are almost equally opaque*, or, rather perhaps, I should say, equally indifferent to the *kind* of incident heat (*i. e.* colourless in optics).

47. So far as the eye could judge of the proportion of obstacles in surfaces strewed with different kinds of powders, there did not seem any very marked peculiarity in their transparency for heat. A surface dusted with alum or citric acid appeared to transmit nearly as much as one strewed with powdered rock-salt. Nor could this arise merely from the *minute thickness* of the substance, which is well known to produce in heat, as in light, an approximation to a Colourless character; for the proportion stopped by the powder was always a large fraction (usually from $\frac{3}{4}$ ths to $\frac{9}{10}$ ths) of the incident heat. The opacity, then, is the result of the innumerable reflections and interferences which *scatter* and *stifle* the transmitted heat; and this is almost equally effectually done, whatever be the nature of the substance. On reflection, therefore, this general result does not appear surprising. I will quote one experiment, in particular, in illustration of it.

48. When I was at a loss to procure fine metallic fibres, I thought of employing a diaphragm irregularly covered with fine threads of spun glass, with a view (just as in the case of the alum powder) of ascertaining how far the mechanical condition of the glass might modify its well known qualities with respect to the transmission of heat. When Locatelli lamp-heat, having been transmitted by *thick plate-glass*, fell upon the spun-glass fibres, forming an irregularly reticulated diaphragm, no more than 47.5 per cent. of the incident heat was transmitted. Now, we know perfectly from the experiments of DE LA ROCHE and MELLONI, that, after passing through such a thickness of plate-glass, an additional film, the thickness of the glass fibres used, would produce *no sensible resistance* to the farther passage of the heat, excepting only its superficial reflection. The loss of 52.5 per cent. of the heat was therefore due to the *scattering* and *stifling* of heat by Reflection at the surfaces of the fibres, Refraction through their cylindric surfaces, and Interference. We cannot, therefore, be surprised, if the refracted part of the heat reaching the pile (the only portion very materially affected by the nature of the medium) should not greatly alter the quantity of different sorts of heat indicated by the galvanometer. Accordingly, we find, that heat from a dark surface of brass warmed by an alcohol lamp, had 44 per cent. transmitted under the same circumstances; and even hot water had 42 per cent. although a small thickness of glass is sensibly opaque for that kind of heat.

49. If this be the case,—if the differences be so trifling—for a reticulation of regularly-formed, transparent, and polished threads of glass, much more must it hold with impalpable crystalline or other powders, presenting (no doubt) minute surfaces at every angle, and minute fissures in every direction.

50. The following Table contains the results of a large number of experiments on powders of various kinds, many of them repeated under various circumstances. The investigation is, as in the case of the metallic powders, confessedly imperfect; but since the broad simple principle which I at first tried to establish respecting the diathermanous quality of opaque powders does not appear to hold universally, I stopped this series of experiments, which were troublesome and laborious, after establishing a few general facts, which I will presently lay down, without attempting to exhaust a subject of which, by and by, we shall no doubt know more, but which at present it would be perhaps a waste of time to pursue into its insulated details. These powders were in all cases dusted between polished salt-plates, united at the edges, and then attached to diaphragms of card, so arranged as to transmit the heat in every case through the same parts of the surface.

Per-centage of Transmission of Heat, from different sources, through Non-Metallic¹ Powders.

Powder of	SOURCE OF HEAT.			
	Locatelli Lamp		Dark Hot Brass.	Hot Water.
	Through Glass.	Through Smoked Salt.		
Alum, No. 1.	17.0	...	17.1	...
~~~~~ No. 2.	15.2 *	...	13.0 *	...
Citric Acid, No. 1.	29	30	33 †	31.5
~~~~~ No. 2.	12.9 *	...	8.7 *	...
Rock-salt, No. 1.	12.8 * 13.4	11.8	11.3	...
~~~~~ No. 2.	31.5 ‡	...	29.2 ‡	...
Sulphur, ...	50.0	...	44.7	...
Red Lead, ...	30.2	...	34.0	...
Galena, ...	26.3	22.4	...	...
Charcoal A.	5	...	9	...
~~~~~ No. 1. 1st Series, §	11.4	13.9	...	...
~~~~~ 2d Series, §	15.1	...	16.0	17
~~~~~ No. 2.	3.2 *	...	3.5 *	...
Chalk, No. 1.	30.5	...	34.5	...
~~~~~ No. 2.	15.5 * 15.6	18.4	17.9	...
~~~~~ No. 3.	27.5	...	32.0	...
Carbonate of Magnesia, .	8.3	12.6	...	...

* The observations marked thus were made with a powerful beam of heat in the way described in Art. 42.
† Not directly comparable with the other two observations on the same line, and probably 3 or 4 per cent. too high.
‡ Extremely good observations.
|| The intensities very feeble.
§ The circumstances in these two series varied, so as to make the one not directly comparable with the other; but each is perfectly good.

51. On the preceding table, I would observe, (1.) That the pulverized crys-

¹ By *non-metallic* is meant, not in the state of a *pure* or uncombined metal.

talline bodies, such as rock-salt, alum, citric acid, and sulphur, exhibit no decided tendency to transmit an excess of heat of low temperature, depending on their powdery form. The carefully repeated experiment with rock-salt is, on this point, very conclusive, since its indifference as a substance to the quality of the heat which it transmits would at once leave the effect, if any, due to mechanical condition, apparent. It even very evidently appears in this state to transmit *less* freely heat of low than heat of high temperature. (2.) Galena, the crystallized sulphuret of lead, in fine powder, appears to possess the qualities of gold, silver, and tin (43.) (3.) Red lead, charcoal, chalk, and magnesia, all substances in an opaque *earthy* condition, appear certainly to transmit an excess of *Dark Heat*. I think it probable that this list might be extended to most bodies having a similar mechanical constitution.

53. These distinctions, I am well aware, leave the *causes* of the difference of character of powders, and the peculiarities of tarnished surfaces, nearly in the same obscurity as before. In particular, I cannot but regard it as being singular, that a surface covered with powdered salt has no analogy, but even opposite properties, to one of the same material mechanically furrowed.* The contrariety of action of metallic powders to those of opaque earths, is as singular as it was unexpected. I have already stated, however, my doubt whether a complete investigation of the peculiarities of specific substances would, *at present*, reward the necessary labour. I have made experiments on a few fibrous substances, as paper and membrane, which I thought might very probably act as tarnished surfaces do. There is an approximation to this, as will be seen, in the common cambric or tissue-paper. In the kind of tracing-paper employed (which is made in Paris, I believe, under the name of *papier vegetal*), there is evidently some foreign matter introduced to produce the transparency, which modifies the transmission. A close reticulation of cotton fibres has already been shewn to exercise no specific action (34.). The following Table contains a few results not included in preceding ones, and illustrating in several substances the quality of *heat-colour*, which in this paper we have been considering.

Per-centage of Heat transmitted by several Bodies.

Substance.	SOURCE OF HEAT.		
	Locatelli Lamp with Glass.	Dark hot Brass.	Hot Water.
Gold-beater's Skin,	60	28	...
Cambric or Tissue Paper, . . .	8.6	10.5	...
Tracing Paper (<i>Papier vegetal</i>),	36	28	...
Fibres of Spun Glass,	47.5	44	42
Smoked Salt,	30.2	58	67
Roughened Salt,	49	73	76
Polished Salt, scored into 200 } × 200 squares per inch, . }	49.5	73	77

* To put this in the most clear point of view, I used and compared two such plates in the same experiment.

54. The leading facts contained in this paper are these :

55. I. The peculiar (*red-like*) character of films of smoke in transmitting heat of low temperature is partaken,—

- A. By simple powder of charcoal.
- B. By (at least some) other dull earthy powders.
- C. By surfaces simply *dull* or devoid of polish.
- D. By surfaces irregularly furrowed, as with emery or sand-paper.
- E. By polished surfaces, on which fine distinct lines have been drawn.
- F. By the mechanical lamination of transparent mica, which, as a continuous medium, possesses opposite properties.

56. II. The following media seem *indifferent* to the kind of heat which they transmit:—

- A. The thinnest gold-leaf is impervious to any.
- B. Metallic gratings transmit all kinds of heat in a proportion which is probably exactly as the area of the interstices which they present.
- C. Thread gratings.
- D. In a state of powder, most crystalline bodies *approach* to a condition of opacity for heat.

57. III. The following bodies, in addition to those commonly known, transmit most heat of high temperature (*violet-like heat*).

- A. Several pure metallic powders.
- B. Rock-salt in powder; and many other powders.
- C. Animal membrane.

58. IV. Heat of low temperature is most regularly reflected at imperfectly polished surfaces. It is also, we have seen, most regularly transmitted. These facts are of great importance to the Theory of Heat; and may probably suggest inquiries of no small interest with regard to light, and especially the phenomena of absorption.

59. We have already (24) noticed the analogy which the fact stated in the last article bears to the easier reflection of red than violet light from depolished surfaces, and in that fact we find a confirmation of the application of the undulatory doctrine to heat, and of the opinion that the waves producing heat, are longer in proportion as the temperature of the source is less. The phenomena of transmission are more obscure; they may be compared either to the Diffraction, or to the Absorption, of light.

60. The action of lines on polished surfaces, similar to those used in many diffraction experiments, led to the inquiry (31), whether the mean colour of light transmitted by gratings was necessarily unchanged? The question does not seem to have occurred to any one to whom I have mentioned it; and though the most likely result would seem to be, that there should be no change, the grounds of such an *à priori* opinion do not appear absolutely conclusive. Professor KELLAND, how-

ever, has, I believe, first succeeded in integrating the expression for the illumination of a screen placed behind a grating of any kind (See AIRY'S Mathematical Tracts, page 328) on which a plane wave falls, and he informs me, that in every case where the breadth of the interstices is any multiple of the breadth of the wires or opaque spaces, the intensity is the same as if there were a diaphragm equal in size to the sum of the interstices of the grating,

61. This result (which seems quite sufficiently general for our purpose) is so far confirmed by the absolute *indifference* of metallic gratings to the quality of the incident heat.

62. It remains, however, to be explained how furrowed surfaces can act, except by intercepting, as an opaque network would do, a part of the heat. I cannot give an explanation which appears full and satisfactory, but the condition of mica split into thin laminæ by heat, and producing the same effect, may serve to guide us, perhaps, to something like the true cause.

63. A number of thin plates, of *exactly uniform* thickness, would transmit a certain colour, and reflect the complementary one. If there be a great preponderance of plates approximating to a certain thickness, and if the disproportion of the lengths of the incident waves be great, a large proportion will be in like manner transmitted, and the remainder stifled or reflected. If this effect is not so frequently observed in bodies mechanically separated into films as we might expect, this is owing to the small range of length of wave in the visible parts of the spectrum. A small variation in the thickness of the film transmits or annihilates by interference each colour of the spectrum in succession. If the waves of heat be much more heterogeneous (as I have already surmised) than those of light, such effects would be proportionably more sensible.

64. Possibly a grooved surface may be considered as presenting a number of polished surfaces, partially detached from the general surface, under small obliquities to the incident rays; and we may suppose that these rays, after separation by partial reflection and refraction, reunite with unequal retardations, producing *first* a destructive effect upon the shorter waves, and suffering the others to persevere. I have already adverted to the fact, that most turbid fluids transmit chiefly the longer luminous waves. I offer these, however, but as vague conjectures upon a very obscure subject. I think that experiments on the Colour of media, such as those we have employed, and especially of depolished plates, might not be without value in illustrating the phenomena of Absorption in Optics.

65. In conclusion, it might perhaps be expected that I should take some notice of the experiments and reasonings of which M. MELLONI has addressed an account to M. ARAGO, in two letters dated the 4th and 14th of March last, and published in the Comptes Rendus for the 30th of the same month. These letters were

occasioned by the announcement of my Researches, in the same work, for the 6th January. The present paper, founded *solely* upon experiments undertaken and completed before the dispatch of the earliest of M. MELLONI'S communications, will, I think, sufficiently answer all the questions which are started in his letters to M. ARAGO, at least all those in which my experiments are concerned.

12th May 1840.