XIX. *On the optical and physical properties of Tabasheer.* By David Brewster, *LL. D. F. R. S. Lond. and Edin. In a Letter to the Right Hon. Sir* Joseph Banks, *Bart. G. C. B. P. R. S. &c. &c. &c.*

Read May 6, 1819.

My Dear Sir,

The substance called Tabasheer, has been long used as a medicine in Turkey, Syria, Arabia, and Hindostan. It was first made generally known in Europe by Dr. Patrick Russell, who published in the Philosophical Transactions, for 1790, a very interesting account of its natural history, and of the process by which it seems to be formed. From his enquiries it appears, that this substance is found in the cavities of the bamboo, the *Arundo bambos* of Linnæus; and that it exists originally in the state of a transparent fluid, which acquires by degrees the consistency of a mucilage resembling honey, and is afterwards converted by gradual induration into a white solid, called Tabasheer. From the analysis of Mr. Macie (now Mr. Smithson), it appeared to be "perfectly identical with common siliceous earth."*

The celebrated traveller M. Humboldt, discovered the same substance in the bamboos which grow to the west of Pinchincha, in South America, and a portion of what he brought to Europe in 1804, was analyzed by Fourcroy and Vauquelin, who found it to consist of 70 parts of silex, and 30 of potash and lime.†

* See *Philosophical Transactions* for 1791, p. 368.

† *Mémoires de l'Institut,* Tom. vi. p. 382.

About two years ago my friend, Dr. Kennedy, received from India, a considerable quantity of tabasheer, a portion of which he presented to the Royal Society of Edinburgh. From this portion I took two or three fragments, with the view of ascertaining if it possessed any crystalline structure, but having found that it had no particular action upon polarised light, I was not led to any farther examination of its physical properties. In the course, however, of a series of experiments upon the phosphorescence of minerals, I was surprised to observe, that the tabasheer emitted a light when placed upon a hot iron, more intense than most of the phosphorescent minerals. This unexpected property induced me to resume the investigation, and having received, through the kindness of Dr. Kennedy, an additional supply of tabasheer, I was enabled to examine it with peculiar care in all its optical and physical relations.

Among the pieces of tabasheer which I have examined, there appear to be three different kinds. The first has a milky transparency, transmitting a *yellowish*, and reflecting a *bluish white* light. It is easily broken between the fingers, and has a sort of aerial and unsubstantial texture, entirely different from any other solid substance. The second kind is more opaque, and harder than the first, having a slight degree of translucency at the edges; and the third kind is perfectly opaque, resembling a piece of stucco or chalk, or the opaque subsulphate of alumine.

If we form two parallel faces upon a piece of transparent tabasheer, by grinding it on a plate of smooth but unpolished glass, we shall be able to see objects through it with perfect distinctness, although no polish is induced upon the surfaces.

By slightly wetting the tabasheer, it loses all its transparency, and assumes the appearance of a piece of chalk; but if we immerse it in water a great quantity of gas is disengaged, the edges become more transparent than before, and a small white ball appears in the centre, which gradually diminishes till the transparency has extended itself throughout the whole mass. The same effect takes place with the second kind of tabasheer; but the third kind, though it disengages gas like the rest, never loses its chalky opacity.

The property of becoming more transparent by the expulsion of air and the absorption of water, is one which the tabasheer possesses in common with hydrophanous opal; but the faculty of retaining a considerable degree of transparency when it is dry, and its pores filled with air; and the still more extraordinary faculty of becoming quite opaque by the absorption of a small quantity of water, are possessed by no other known substance in nature, and indicate a singularity of structure which it becomes interesting to investigate.

When the pores of hydrophane are filled with air, the difference between the refractive power of the air and the solid substance is so great, that the light is scattered in every direction by refraction, and the mass is consequently white and opaque. As the tabasheer disengages a much greater quantity of air than the hydrophane, its pores must be more numerous, and therefore the transmission of the light, so as to form a perfect image, indicates either an extreme feebleness of refractive power, or some singularity in the form and construction of the pores themselves.

In order to determine this, I formed a prism of tabasheer, and upon measuring its refractive power, I found it to be extremely low, and to vary in different specimens, as stated in the following table.

	Index of Refraction.
Transparent tabasheer from Vellore*	1.1115
Transparent tabasheer from Nagpore	1.1454
Another specimen of the same -	1.1503
A third specimen of the same -	1.1535
A harder and more opaque specimen,	1.1825
Water - - -	1.3358
Flint glass - - -	1.600
Sulphur - - -	2.115
Phosphorus - - -	2.224
Diamond - - -	2.470

Hence it follows, that tabasheer has a lower refractive power than all other bodies, whether solid or fluid; and that it holds an intermediate place between *water* and the *gases*. This extraordinary result which, as it were, insulates tabasheer from all known substances, will enable us to give an explanation of some of its most remarkable properties.

The singular nature of this substance will appear in a still more striking point of view, by comparing its absolute refracting power with that of other bodies. The low refractive power of air, when contrasted with that of water, and of water when contrasted with that of solid bodies, obviously arises from the great difference of their specific gravities, and not from any peculiar action upon light. If we call R the

* This specimen, with which I was favoured by Dr. Hope, formed part of the tabasheer sent by Dr. Patrick Russell to the Royal Society, in 1790. It was yellowish by reflected light, and so extremely tender, that I was obliged to polish it upon the softest silk.

absolute refractive power of any body, m its index of refraction, and S its specific gravity, we shall have $R = \frac{m^2 - 1}{S}$.

By means of this formula I have computed the following table, for the purpose of showing the peculiar nature of tabasheer, and the general progression in the absolute refractive powers of other bodies.

TABLE, *showing the absolute refractive powers of tabasheer and other bodies.*

Tabasheer	-	976.1*
Sulphate of barytes		3829.43
Air, - -	BIOT	4530.

* A distinguished member of the Royal Society, whose opinion is entitled to the highest consideration, has kindly stated to me, that in estimating the absolute refractive power of tabasheer, I should have taken its specific gravity at about 0.66 in place of 2.4, which would have given an absolute refractive power not so marvellously different from that of other bodies.

My reason for retaining the original number of 976.1, is, that the result obtained by using a specific gravity of 0.66 would have been a *theoretical, and not an experimental result.* A body which sinks in water must have a density greater than unity; and I am supported by the high authority of Mr. CAVENDISH, and also by that of Mr. SMITHSON, in considering the specific gravity of tabasheer as nearly 2.412. Capillary spaces which are so large as to contain water, and even the thickest oils and varnishes, can never be regarded as forming a part of the body, though, in the present case, it is highly probable that these spaces modify the action of the solid particles in the manner which I have described.

Although the idea that tabasheer is quartz expanded till its specific gravity is reduced to about 0.66, holds out a sort of general explanation of its singular properties; yet when we consider that *hydrophane,* which is also quartz expanded till it is capable of absorbing water, is actually opaque; and when we recollect also that the refractive power of bodies does not always diminish when they expand, as is proved by the experiments of ALBERT EULER on heated glass, and by the circumstance that the point of maximum density in water is not indicated by a maximum of refractive power, its optical properties must continue to appear as marvellous as before.

Quartz, -	MALUS	5414.57
Calcareous spar,	MALUS	6423.5
Flint glass, *lowest*		7238.
Ruby -		7388.8
Brazilian topaz -		7586.7
Water, -	MALUS	7845.7
Flint glass, highest		8735.
Carbonate of potash		10227.
Chromate of lead		10436.
Nitre -		11962.
Muriate of soda -		12086.
Bees wax, -	MALUS	13308.1
Diamond, -	MALUS	13964.5
Sulphur - -		22000.
Phosphorus -		28857.
Hydrogen -		29964.
——— -		31862.

It appears from the preceding table, that tabasheer, which was placed between water and air, in the comparison of their indices of refraction, is now not only the lowest of all substances in its absolute refractive power, but it is so extremely low as to be separated by a great interval from them all. The very high refractive power of sulphur, phosphorus and hydrogen, and the great interval between diamond and sulphur are very remarkable, and indicate that hydrogen may enter largely into the composition of sulphur and phosphorus.

I now saturated the prism of tabasheer with *water* and with oil of cassia in succession, and I found that, in the first case, its refractive power was raised to 1.4012 higher than that of water, and in the second case to 1.6423, a little greater than that of oil of cassia. The oil communicated to the prism a very yellow tinge, and was retained by it for a very long time.

Tabasheer readily imbibes all the volatile and fat oils, and indeed all the fluids that I have tried. The essential oils are quickly absorbed, and with the exception of oil of cassia are as quickly evaporated, while the fat oils are slowly drawn in and remain a long time in its pores; and in all these cases an opacity is produced by a partial absorption exactly as in the case of water.

When the oils or other fluids have a colour of their own, or are tinged with any colouring matter, the tabasheer exhibits a similar tint, so that it is easy to communicate to it any colour that we please. From a solution of acetate of copper, it acquires the colour of the emerald; from any of the oils coloured with anchusa root, it receives the tints of the ruby; from oil of beech nut, the colour of the chryso-beryl; from sulphuric acid, that of the pink topaz; and from malic acid, that of the Brazilian topaz. These different colours may be all discharged by exposing the tabasheer to a red heat, and thus expelling the absorbed fluid to which they owe their origin.

The opaque tabasheer, which retains its opacity when its pores are filled with water, acquires the most beautiful transparency from the absorption of oil of beech nut; and it is curious to observe a substance like chalk, and consisting apparently of a number of particles in a state of accidental aggregation, converted into a transparent mass, which the light freely penetrates in every direction. Having saturated a large piece of this kind of tabasheer with oil of beech nut, coloured with anchusa root, I laid it on a mass of lead of a lower temperature than that of the room. The oil instantly retired from the surface of the tabasheer into its interior, and the transparent mass became opaque like a piece of red brick. Upon removing it from the lead into its former temperature, the oil returned to the surface, and the tabasheer resumed its transparency. If, on the other hand, we place it in a higher temperature than that of the room, a part of the oil will be discharged, and when it is brought back to its first temperature, it will become opaque like a piece of brick. Even when a small part of the oil remains, the transparency may be readily restored by the application of a sufficiently high degree of heat. The phenomena which have now been described admit of a satisfactory explanation from the difference between the expansion of the oil and that of the tabasheer; but the effect appears to be too great to arise from this cause, and I am rather disposed to ascribe it to a variation in the capacity of the tabasheer for the oil by a change of temperature.

In order to observe the nature of the penumbral boundary which might be supposed to separate the opaque from the transparent part, if they could be both rendered visible in the same mass, I saturated the largest piece of tabasheer that I had with the coloured oil, and having discharged a good deal of it by heat, it became of course opaque. I now held to the flame of a candle one of its extremities, which immediately became diaphanous, and the transparency gradually pervaded the opaque mass. As soon as the opacity disappeared, I allowed one extremity of it to cool; the transparency immediately disappeared at that part, and the opacity gradually advanced like a black cloud, till the whole was overshadowed by the retreat of the oil into the interior of the mass. In both these cases the penumbra, which separated the opaque and transparent portions, had a ragged or branching appearance when seen by a microscope, as if the oil had been shooting into crystals during the progress of the opacity, and as if these crystals had been dissolving during its retreat.

Upon examining the appearance of the tabasheer when it had the colour of red brick, after the discharge of a portion of its oil, I was surprised to observe a beautiful veined structure, exactly like that of the agate, the veins being sometimes parallel, sometimes inflected, and sometimes curved. In some specimens the veins were alternately opaque and translucent, and in others red and white, as if one set of strata had a greater capacity for the oil than the rest. This effect is almost universal; but as soon as the oil is completely discharged, the veined structure entirely disappears, and the whole mass assumes the homogeneous appearance of chalk.

In order to observe the circumstances under which the chalky tabasheer became transparent by the absorption of oils, I cut four plates out of the same piece, and immersed them separately in oil of cassia, alcohol, water, and oil of beech nut. The plates that had absorbed the three first of these fluids remained quite opaque, but the plate that was placed in the oil of beech nut gradually acquired a translucency by the rapid extrication of air. After a certain time it appeared to be covered with scratches and small opaque portions; but these appearances, which arose from remaining vesicles of air, vanished by degrees. By the application of a microscope, I observed the air form itself into globules in the interior of the tabasheer, which slowly advanced to the edge of it, and at last escaped into the oil. After a lapse of nearly two hours the greater part of the air was extricated, and the expulsion of the remainder was quickly effected by a gentle heat; but the transparency was of that imperfect kind, which results from the union of two bodies of different refractive powers. By increasing the heat, the tabasheer became more transparent, and at a certain temperature it could scarcely be seen in the oil in which it was placed. When the heat was still farther augmented, it became more and more opaque, and a corresponding opacity was induced by cooling it down as much below the temperature of maximum transparency.

When pure tabasheer is boiled for any length of time, or is brought to a red or a white heat, it suffers no change either in its colour or in its optical and physical properties: if we wrap it, however, in a piece of paper, and set the paper on fire, the tabasheer becomes either black, or brownish black, and the black colour increases in depth by the repetition of the experiment. When immersed in water, it disengages the included air, but with less rapidity than before; and when it is broken and pounded, its fracture and its powder are black.

If the blackened tabasheer is brought to a red heat, it is restored to its primitive whiteness, and resumes all its former properties; but if the heat is considerably below redness, some specimens acquire a slight transparency, and a dark slaty blue colour, shading in some places into whiteness. When slightly wetted in this state, it becomes chalky white; with a greater portion of water it becomes black; and with a still greater portion, it becomes again transparent. If we break a piece of tabasheer a few days after it has received a deep black tint, we shall find that it has often a fine ash grey colour, which becomes deeply black when wetted, and afterwards resumes its primitive tint when dry.

As the blackness communicated to the tabasheer is not produced by heat alone, or by any particular method of cooling, it cannot arise from any mechanical change, similar to that which THENARD observed in the cooling of melted phosphorus; and there is reason to believe that it does not arise from the absorption of any sooty matter thrown off during the combustion of the paper, as the blackened tabasheer almost always recovers a certain degree of whiteness, and imbibes water almost as freely as in its original state. With the view of discovering if the blackness was owing to any vegetable matter in the tabasheer, I repeated the operation of blackening it and restoring its colour by heat about 50 times; but after all these operations, it became black as readily as at first. The specimen that had undergone these changes had increased in hardness and lustre, and had the appearance of the finest Indian ink. Upon breaking it in two, the fracture was perfectly black, but assumed a dark blue colour by exposure to the air; and upon putting a drop of pure water upon the blue fracture, it was instantly converted into a deep and glossy black.

When the pure tabasheer was exposed to a white heat for several hours, and was then burned in paper, it received its black colour as before. When it was held in the flame of alcohol or of carburetted hydrogen, it was merely stained in a slight degree, which was probably owing to the intensity of the heat, which may have discharged the black tint as soon as it was formed.

I was now anxious to see the effect produced upon tabasheer by the absorption of iodine gas, and for this purpose I took several opaque and transparent fragments, and having saturated some of them with moisture, and left others dry, I placed them in different glass tubes, which were hermetically sealed after a portion of iodine had been introduced. Previous to the application of heat the tabasheer assumed a yellow tinge, which deepened into a pale orange, and a veined structure appeared in one of the fragments. When the iodine was converted into gas by heat, the colour of the fragments grew more and more red; the transparent pieces were like garnets, and the opaque ones like fragments of red brick; and after standing two or three days the opaque pieces became perfectly transparent. The iodine vapour, therefore, seems to have taken the place of the water in the wetted fragments, and of the common air in the dry ones; and it appears to have retained its gaseous form within the tabasheer, when the external gas had returned to the solid state. Upon taking the tabasheer out of the glass tubes, the iodine was slowly expelled, a yellow tinge appeared even after 30 hours exposure to the air, and it was not entirely removed by immersing the fragments in water.

The difference in the properties of the opaque and the transparent tabasheer, rendered it desirable to have accurate measures of their specific gravities, and I have been fortunate enough to procure them to a great degree of exactness, through the kindness of my friend, Mr. James Jardine, who obtained for me the following results.

	Grains.
No. I. Seven pieces of opaque tabasheer, weighed in air. - -	665
The same pieces when thoroughly soaked in water, weighed in air -	14,10
The same weighed in water at the temperature of 52° - -	3,42

Hence the specific gravity of the parcel when dry, is 2.059
And the specific gravity of the parcel when wet, is 1.320

	Grains
No. II. Several small fragments of transparent tabasheer, weighed in air -	1,23
The same pieces when thoroughly soaked in water, weighed in air -	2,54
The same weighed in water at the temperature of 52° - -	0,72

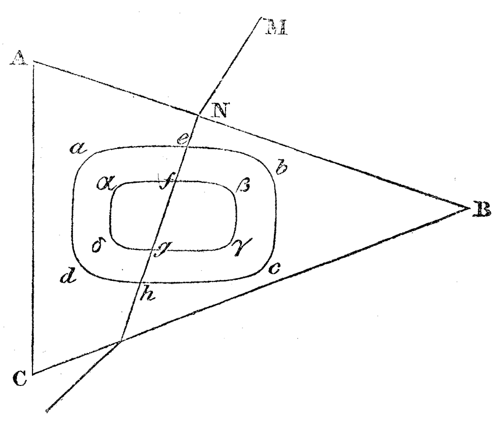
Hence the specific gravity of the parcel when dry, is 2,412
And the specific gravity of the parcel when wet, is 1,396

Mr. MACIE found the specific gravity of a parcel of opaque and transparent tabasheer to be 2,188 ; and Mr. CAVENDISH, having tried the same parcel, found it to be 2,169. The mean of Mr. JARDINE's results is 2,235, which exceeds the measures of MACIE and CAVENDISH, because the opaque fragments in their parcels must have been more numerous than the transparent ones, in consequence of the rarity of the latter.

It appears from the preceding results, that in both kinds of tabasheer the quantity of water imbibed exceeds in weight that of the tabasheer itself; and that in the opaque kinds, the space occupied by the pores is to the space occupied by the tabasheer, as 2,307 to 1 ; while in the transparent kinds, it is 2,5656 to 1. This result indicates a very remarkable degree of porosity; and as it makes the pore more extensive in the transparent than in the opaque kind, contrary to what we should expect from their specific gravities, it seems to follow, that the water was not capable of insinuating itself into all the pores of the opaque tabasheer. This conclusion is rendered more probable, when we consider the extreme difficulty with which the oil of beech nut displaces the last portions of included air; and it affords a very plausible explanation of the fact, that the chalky tabasheer cannot be rendered transparent by the absorption of water.

We are now prepared by the preceding observations, for investigating the cause of the remarkable paradox exhibited by the transparent tabasheer, in becoming perfectly opaque and white, by absorbing a small quantity of water, and perfectly transparent when that quantity is increased. As this effect takes place indiscriminately with all fluids, it cannot be the result of any chemical action, and therefore its cause must be sought for in the changes which the light suffers in traversing the vacuities of the tabasheer.

Let ABC be a prism of this substance, and *abcd* one of its pores highly magnified. We know that this pore is filled with air; and that when a ray of light MN enters the separating surface *ab* at *e*, and quits it at *h*, it suffers so little refraction, and is therefore so little scattered, that the tabasheer appears transparent, and allows us to see objects



distinctly through it. This effect, which could not take place in any other porous substance, arises from the small difference between the refractive power of air and tabasheer. Let us now suppose that a small quantity of water is introduced into the pore *abcd*, so as not to fill it, but merely to line its circumference with a film contained between *abcd* and $\alpha\beta\gamma\delta$. Then the light which was formerly scattered by the slight refraction at *e* and *h* in passing from tabasheer into air, will now be a little less scattered at these points, since it passes from tabasheer into water, where the difference of refractive power is less; but in passing from the film of water into the air at *f*, and in entering the water again at *g*, the scattering of the rays will be very considerable, from the great difference in the refractive powers of air and water. In passing through every pore, therefore, the light is refracted, and consequently scattered no less than four times; and hence the piece of tabasheer must appear to be opaque. If we now saturate it with water, the pore *abcd* will be completely filled; the two great refractions which took place at *f* and *g*, will no longer exist; and the light will suffer only a slight refraction at *e* and *h*, by which it will be less scattered than when the tabasheer was dry. Hence it follows, that when the tabasheer is saturated with water, it ought to transmit the incident light freely, and to be more transparent than when it is quite dry, a result which is perfectly conformable to observation.

The very singular anomaly presented by the chalky tabasheer in becoming transparent by means of oil of beech nut, and not by means of oil of cassia or water, and the additional transparency communicated to the transparent fragments by immersion in oil, if they do not arise from the existence of minute pores, which admit the oil and keep out the water, must be ascribed to a very considerable refractive density in the solid parts of the substance. The experiments made with the oil at different temperatures, indeed, seem to prove that the refractive power of the solid parts of the tabasheer is equal to about 1,500, or that of oil of beech nut raised to the temperature which produces the maximum transparency; but as the refractive power of a prism of tabasheer is greatly inferior to that of water, we shall now proceed to consider how these apparently opposite results can be reconciled, and what inferences can be drawn from them.

When alcohol is poured into water in a glass vessel, a scattering of the transmitted light is immediately visible, in consequence of their imperfect mixture, and of the difference of their refractive powers; but in a short time the union of the fluids is so complete, that the light is transmitted as freely as through either of them separately. Chemistry does not inform us how the particles of alcohol and of water are combined so as to produce this effect; but we know that the refractive power of the compound is intermediate between that of the two ingredients; and hence it is certain, that the refraction of the incident light is produced by their joint action. If we increase the quantity of water successively, the particles of alcohol will be thrown to a greater and greater distance, and the refractive power of the compound will be proportionally diminished. Let us now suppose that all the aqueous particles are extinguished, and that their place is occupied with a less refractive fluid, such as air; then it is obvious that the refractive power of the compound will be inferior to that of water, and will approach to that of air, in proportion to the quantity of air united with the alcohol.

This hypothetical combination of air and alcohol, represents exactly what I conceive to be the condition of the dry and transparent tabasheer. The refractive power of the solid parts is not far from 1,500; but the substance is so formed, that its particles are kept at a great distance by means of vacuities filled with air, and arranged in such a manner, that the light passes from the particles of tabasheer into the particles of air without suffering refraction, in the same manner as it passes from the particles of alcohol to the particles of water, when these fluids are chemically united. That there is not a chemical union between the air and the tabasheer, is certain, because the air may be displaced, and the transparency preserved in *vacuo;* and hence we may draw the important inference, of which we have no other example in physics, that the tabasheer and its included air exercise a joint action upon light, in the same manner as if they were in a state of chemical union. I have the honour to be, &c. &c. &c.

DAVID BREWSTER.

Edinburgh, March 2, 1819.