XIII. *Continuation of a Paper on the Production of Light and Heat from different Bodies. By Mr.* Thomas Wedgwood; *communicated by Sir* Joseph Banks, *Bart. P.R.S.*

Read May 10, 1792.

EXEPRIMENT I.

In order to discover what effect the *light* of the burning fuel has upon incombustible bodies, I fixed into the end of a tube of earthen ware * two equal cylinders of silver, with polished surfaces, half an inch in length, and a quarter of an inch in diameter (see Tab. V. Fig. 1.); one of the cylinders was painted over, except the end within the tube, with a thin coat of incombustible black colour, to make it *absorb* the incident light; the other, intended to *reflect*, was left with its polished surface. Applying my eye to the opposite extremity of the tube (which it fitted exactly, so that no extraneous light could enter), and directing it towards the two polished ends of the cylinders, I held the tube within a red hot crucible, surrounded by burning coaks, and continually turned it round, that both cylinders might be equally exposed to the light, and heat. The result was, that the end of the blackened cylinder began to shine a considerable time before that of the polished one, and remained constantly somewhat brighter: on removing the tube

* When *earthen ware* is mentioned in this paper, the cream-coloured or queen's ware is meant.

from the crucible, still looking within it, I was surprised to see the appearance reversed, the polished cylinder continuing to shine for some time after the blackened one had ceased. Cylinders of gold, and of iron, treated in the same manner, gave the same general result; but the differences between the polished and the blackened ones were not so remarkable in these, as in the silver.

I repeated this experiment many times, and found, by observations with a stop-watch, that the blackened silver cylinder began to shine, at a medium, in two-thirds of the time which the polished one required; and that, after its removal from the crucible, it continued to shine only two-thirds of the time that the other did. For this latter observation, I was obliged to make a little variation in the apparatus; the tube itself becoming frequently so hot, as to make the cylinders continue longer red than they otherwise would have done: I therefore took them out of the tube, to suspend them by a fine wire, and then heating them in the ignited crucible as equally as possible (for they cannot be made to exhibit to the eye the same precise tinge of redness), I removed them immediately into a dark place.

From this experiment it would seem, that a great part of the *light* emitted by the cylinders was absorbed from the red hot crucible, as the blackened one, which absorbs most rays, not only became first red, but likewise shone brightest. The following experiment, however, affords a different conclusion.

EXPERIMENT II.

An earthen ware pipe, of a zig-zag form (Fig. 2.), was placed in a crucible, which was filled up with sand, the two open ends of the pipe being left uncovered; one of them was of a proper form for receiving the nozzle of a pair of bellows, the other bent into angles of the form of the letter Z: on this last was fastened a globular vessel A, with a lateral bent pipe, to let out air but exclude all external light, and with a neck in which was inserted a circular plate of glass. The crucible, with the sand and the part of the pipe contained in it, was then heated to redness. Having my eye fixed in the neck of the vessel A, and observing it perfectly dark within, I directed an assistant to blow with the bellows. The stream of air, sent through the red hot tube, not being at all luminous, I fixed a small strip of gold into the orifice of the tube at B, which, after two or three blasts, became faintly red; thus proving, that the air, though not luminous, was equal in temperature to what is usually called red heat. I then heated the crucible to a brighter redness: the stream of air, blown through the bright red hot tube, still came out perfectly dark, but the strip of gold, exposed to it, shone both *sooner* and *brighter* than before.

Hence it appears, that the greater brightness of the blackened cylinder, in the first experiment, was owing to its being of a higher temperature; and that it would have been equally bright had it been raised to the same temperature by any other means than the absorption of *light*; the metal being here brought to a faint, and to a bright ignition, without the access of any visible light.

But perhaps another consequence may be fairly drawn from this experiment. As the gold may be made to emit *light* for any length of time, by being supplied with *heat* from the *dark* air of the temperature of red heat, neither the gold nor the air suffering any chemical change whatever, is not the *light emitted* identical with the *heat received?* This identity appears to be confirmed by the following observation: that if the solar rays be made to converge upon one end of a blackened cylinder of metal, the other parts will become red hot, and emit light; or, if the rays be converged upon the tube blackened, and air passed through it, the gold placed in the dark current will yield a constant light.

The simultaneous *absorption* and *emission* of light, in a red hot body, is a subject of very difficult and abstruse investigation, as it involves the nature of the constituent parts of matter, and of their relative actions and arrangements. I shall not attempt to offer any hypothesis for explaining the various phænomena, as I have not been able to form one at all satisfactory to myself; but shall proceed to state a few miscellaneous experiments and observations, which, though apparently unconnected, may yet be of some assistance to the speculation of some abler theorist.

EXPERIMENT III.

A quart of oil was poured into a bright tin vessel, which had a FAHRENHEIT's thermometer fixed in its neck. The mercury standing at 45°, the vessel was plunged into boiling water, and the time which elapsed before the mercury rose to 180° was exactly noted. I then blackened the exterior surface of the tin vessel, and, repeating the experiment, found the thermometer to require exactly the same time as before, to rise to the same degree.

From the foregoing experiment it appears, that *black* matter has no particular attraction to light in a *quiescent* state, that is, when combined, as heat, with other matter.

EXPERIMENT IV.

Three equal cylinders of glazed earthen ware were fixed in the end of a tube (like the two silver ones in Fig. 1.); one of them blackened; another gilt, all but the ends within the tube; and the third with its glassy surface. These, treated in the same manner as the silver cylinders, in the first experiment, all became *red* at the *same time*. Without taking them out of the tube, I removed the whole from the fire, and, still keeping my eye upon their ends, observed them all to disappear together.

To account for the simultaneous ignition of these three cylinders, it must be considered, that earthen ware being a very slow conductor of heat, the surfaces of all of them are, probably, heated to redness some time before any such appearance takes place in the ends within the tube. Now it is not unlikely, that the black matter, the gold, and the glaze, when red hot, may reflect light equally; and, in that case, there should be no perceptible difference in the time of ignition of the ends within the tube, except the little advantage gained by the blackened one before its black coat becomes red hot, which is partly counterbalanced by the powdery matter (of which the coat consists) obstructing the transmission of heat. The surfaces of the silver cylinders (experiment 1.) on the contrary, do not become red any sensible time before the ends within the tube, the metal conducting the heat rapidly through its whole mass.

An earthen ware cylinder, fastened in the end of an earthen ware tube, along with a gold one, and plunged into melted glass, is much longer in heating than the gold one. This is easily explained, upon a well known principle, namely, that in two bodies of unequal temperature, the colder body conducts the heat from the hotter at a rate directly proportionate to their difference of temperature. Now the surface of the earthen ware cylinder, as the heat is conducted very slowly from it by the interior mass, soon becomes very nearly of the temperature of the hot glass contiguous to it. The surface of the gold cylinder, on the contrary, having its heat conducted from it much faster by the interior mass, is of consequence disposed to receive the heat with greater rapidity.

EXPERIMENT V.

Equal pieces of gold, silver, copper, and iron, blackened all over, and suspended by a wire in a red hot crucible, became red in the order in which they are here set down; and when made equally red, and removed into the dark, they disappeared in the same order. When just brought out of the fire, they all looked equally red; but when they had cooled a little, the iron was much the brightest.

An earthen ware cylinder, tried with the metals, disappeared much sooner than any of them, the interior part not communicating its heat quick enough to keep the surface of the temperature of red heat: accordingly, when broken, though the surface gave no light, the mass was luminous internally.

From a parity of reasoning, a gilt earthen ware cylinder, suspended in a red hot crucible along with a gold one, would probably become red on the surface before the gold one.

EXPERIMENT VI.

A tube of unglazed earthen ware, open at top, and having one half of its bottom blackened on the outside, was placed in a red hot crucible, and the eye directed, as before, to the inside: the part which was externally blackened became always red before the other.

The experiment was repeated with a metalline tube; but no difference could here be perceived between the blackened and unblackened half of the bottom. The reason is obvious, from the foregoing observations.

EXPERIMENT VII.

To ascertain whether metals and earthy bodies *begin* to shine at the same temperature, I gilded, in lines running across, a thin piece of earthen ware, of the specific gravity of about 2,000, and luted it to the end of a tube, the gilt side being inwards; then, directing my eye into the tube, I held it within a crucible, which was gradually made red hot; but I could not, after many trials, perceive that either the gold or the earthen ware began to shine first.

As it appears, from this experiment, that gold and earthen ware begin to shine at the same temperature; and as no two bodies can well be more different, in all their sensible properties, may it not be inferred, that almost all bodies begin to shine at the same temperature?

EXPERIMENT VIII.

Observing that colourless transparent glass had a paler hue, when red hot, than most other bodies, I conceived that it might not be luminous at so low a temperature. I therefore took a circular piece of glass, about $\frac{1}{40}$ of an inch thick, and having gilt one side of it, exposed the ungilt side to a stream of air passed through a red hot tube; but did not perceive that the gold shone at all before the glass. This experiment, however, is not decisive; glass being so slow a conductor of heat, that its exterior surface might have been heated some time before the interior, and thus have deceived the eye. I could not meet with any glass sufficiently thin for this purpose, nor think of any other possible mode of trial.

EXPERIMENT IX.

Having often remarked, that the surfaces of red hot metals had an appearance different from what they present by reflected light when cold, I had an idea that this peculiar appearance might be derived from a transmission of the light through the superficial parts of the ignited body. To ascertain whether they acquired any degree of transparency by heat, I fixed a circular plate of fine gold, about $\frac{1}{60}$ of an inch thick, on the end of a tube, which was perfectly closed by it; then, having heated it to redness, and looking down into the tube, I pressed the outer surface of the gold against single grains of gunpowder: the red light of the gold looked whiter on every flash. To be satisfied that no light found admission through the sides of the tube (which were of thick earthen ware), I covered the exterior surface of the gold plate with a thick coat of clay luting, and again making it red hot, fired gunpowder with it as before, but no increase of light was now perceptible from the flash; which proves, that the sides of the tube were impervious to the light. When this gold was cold, I stuck a few grains of gunpowder upon its surface, and looking within the tube, fired them by pressing them against a hot iron, but the light of the explosions was not then sensible.

Plates of silver, and of iron, gave the same results.

EXPERIMENT X.

A lump of the most luminous marble, and an equal lump of the same marble blackened over, were placed together upon a mass of iron heated just under redness: the former gave out much light, the latter none. Upon a second exposure, the lump not blackened gave a faint light; the blackened one, as before, none at all. Then wiping off the black, and placing them together upon the heater, I found the one which had been blackened to emit as little light as the other: thus the phosphorescent property was nearly destroyed, without any visible light leaving the body.

EXPERIMENT XI.

If a piece of glass, or glazed or unglazed earthen ware, with any enamel, painting, gilding, or writing in ink upon it, be made red hot, the coloured parts appear considerably more red than the others, and continue longer visible. Iron wire, within a red hot glass tube, looks much more red than the glass. Black matter, upon a large polished mass of fine gold, did not remain any longer red than the gold.

EXPERIMENT XII.

A bit of iron wire becomes visibly red hot when immersed in melted glass. Air, therefore, is not necessary to the shining of ignited bodies.

EXPERIMENT XIII.

A piece of red hot metal continues to shine for some time after its removal from the fire; which proves, that constant accessions of light or heat are not necessary to the shining of ignited bodies. If the piece be strongly blown upon, it instantly ceases to shine; for the cold air, continually applied, unites with the light as fast as it leaves the body, and which otherwise would have passed to the eye.

I shall now close this paper with two or three miscellaneous observations.

Red hot bodies, though ignited by *white* light, give out only the *red* rays. Perhaps the other more *refrangible* rays, from their greater attraction to matter, may be circulating as heat, whilst the red ones, having a less attraction, yield sooner to that force which propels the light of red hot bodies. If the intensity of the incident white light be much increased, so as to raise the body to a white heat, the more refrangible rays then come out with the others, constituting together a white light.

The flash of a grain of gunpowder is a pure *white* light: but if the explosion be made within a thin, unglazed, earthen ware tube, close at both ends, all the light that pervades the sides of the tube is red: the other rays must, therefore, remain united with the matter of the tube, whilst the less attractive red ones are transmitted. Thus also, on looking at the sun through the thin bottom of an earthen ware tea-cup, only the red rays are transmitted, so that the others must be retained by the matter of the cup.

It would perhaps be worth trying, whether a body can be made *red* hot by concentrated rays of other colours.

The light produced from bodies by attrition consists of a double light; that which their powder would give out on the heater under redness; and that which particles in their surfaces give out by being made red hot. The sudden heating of a body to redness, by a single rub or blow, is a remarkable phænomenon, and deserves to be investigated. One effect produced upon a body by attrition, is a compression or condensation of the parts in its surface; and it appears from general observation, that a condensation of the parts occasions a diminution of its capacity for heat. Iron may be made red hot by repeated blows of a hammer; and I have found, that if red hot iron be forcibly struck by a heavy hammer, with a sharp edge to concentrate the action, the part so struck emits a white light for a sensible time, and is probably raised to a white heat: also, that my father's thermometer clay has its capacity for heat diminished one-third, by being burnt to 120° of his scale, and thus reduced to about one-half of its bulk; and as it loses in weight little more than two grains on a pound, the diminution of capacity can only be attributed to its condensation. Many other analagous instances might be adduced if necessary;* but these will, perhaps, be deemed sufficient to render it probable, that the sudden ignition of the particles by attrition proceeds from the compression, and consequent diminution of the capacity for heat.

I am not certain that the increase of brightness in the gold plate, experiment IX. must be attributed to its transparency: it may arise from the gold being suddenly heated to a white heat by the light of the explosion; or the force of the explosion

* See Dr. DARWIN's excellent paper of Frigorific Experiments on the mechanical Expansion of Air, &c. Phil. Trans. Vol. LXXVIII. p. 43.

may condense its parts, and diminish its capacity for heat or light. There is, however, a strong analogical argument for the transparency of the gold: every body whatever, when extremely thin, is pervious to light in such quantity as to be perceptible to our eye-sight: thus gold, perhaps the most opake of all bodies, platina excepted, when beaten into leaf gold, is so pervious to the green rays, that, if held close to the eye, all objects are seen through it with considerable distinctness, appearing of a deepish green hue. Now the particles of matter in the gold plate being much separated from one another, if not more regularly arranged, by the heat; and the intensity of the light in the explosion of the grains of gunpowder being so great; it is not improbable that some few rays may be transmitted through the gold.

After some reflection upon the curious result of experiment 1, I am inclined to think, that the blackened cylinder does not begin to shine at so low a temperature as the polished one; and, consequently, that the *commencement* of ignition is not, in all cases, a certain indication of a particular temperature. For, when the two cylinders were removed from the ignited crucible (see Fig. 1.) the blackened one looked of a brighter red than the polished, and yet, in the course of cooling, disappeared in about two-thirds of the time that the polished one continued to shine, without any apparent reason for its cooling at a faster rate. Should it not, therefore, seem that it requires a greater heat to make it shine?

I am well aware, that these appearances may be differently explained; and, to determine this point, I would propose the following experiment. Put larger cylinders into the tube; and, having made them red hot, drop them separately, each at the instant of its disappearing, into cups of weighed water, of the temperature of between 211 and 212° of FAHRENHEIT: then, as any addition of heat will expand the water into steam, the loss of weight of each vessel will give an exact measure of the heat of the cylinders at the time of immersion.

Fig. 1.

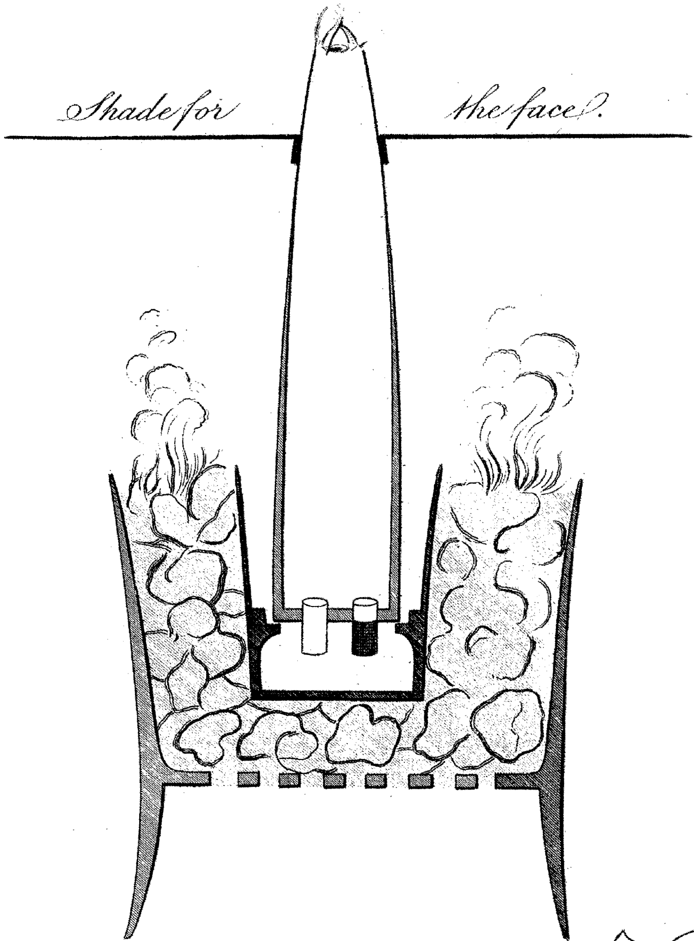

Fig. 2.