XIV. *Experiments on the Refrangibility of the invisible Rays of the Sun.* *By* William Herschel, *LL. D. F. R. S.*

Read April 24, 1800.

In that section of my former paper which treats of radiant heat, it was hinted, though from imperfect experiments, that the range of its refrangibility is probably more extensive than that of the prismatic colours; but, having lately had some favourable sunshine, and obtained a sufficient confirmation of the same, it will be proper to add the following experiments to those which have been given.

I provided a small stand, with four short legs, and covered it with white paper.* On this I drew five lines, parallel to one end of the stand, at half an inch distance from each other, but so that the first of the lines might only be $\frac{1}{4}$ of an inch from the edge. These lines I intersected at right angles with three others; the 2d and 3d whereof were, respectively, at $2\frac{1}{2}$ and at 4 inches from the first.

The same thermometers that have before been marked No. 1, 2, and 3, mounted upon their small inclined planes, were then placed so as to have the centres of the shadow of their balls thrown on the intersection of these lines. Now, setting my little stand upon a table, I caused the prismatic spectrum to fall with its extreme colour upon the edge of the paper, so that none might advance beyond the first line. In this arrangement,

* See Plate XI.

all the spectrum, except the vanishing last quarter of an inch, which served as a direction, passed down by the edge of the stand, and could not interfere with the experiments. I had also now used the precaution of darkening the window in which the prism was placed, by fixing up a thick dark green curtain, to keep out as much light as convenient.

The thermometers being perfectly settled at the temperature of the room, I placed the stand so that part of the red colour, refracted by the prism, fell on the edge of the paper, before the thermometer No. 1, and about half way, or 1¼ inch, towards the second: it consequently did not come before that, or the 3d thermometer, both which were to be my standards. During the experiment, I kept the last termination of visible red carefully to the first line, as a limit assigned to it, by gently moving the stand when required; and found the thermometers, which were all placed on the second line, affected as follows.

No. 1.		No. 2.		No. 3.
45	- -	45	- -	44
49	- -	45	- -	44
51	- -	44¾	- -	44
50¼	- -	43¾	- -	43½

Here the thermometer No. 1 rose 6½ degrees, in 10 minutes, when its centre was placed ½ inch beyond visible light.

In order to have a confirmation of this fact, I cooled the thermometer No. 1, and placed No. 2 in the room of it: I also put No. 3 in the place of No. 2, and No. 1 in that of No. 3; and, having exposed them as before, arranged on the second line, I had the following result.

No. 2.		No. 3.		No. 1.
44	- -	44	- -	45
47	- -	44	- -	45
$46\frac{3}{4}$	- -	44	- -	45
$46\frac{3}{4}$	- -	44	- -	45

Here the thermometer No. 2 rose $2\frac{3}{4}$ degrees, in 12 minutes; and being, as has been noticed before, much more sensible than No. 1, it came to the temperature of its situation in a short time; but I left it exposed longer, on purpose to be perfectly assured of the result. Its shewing but $2\frac{3}{4}$ degrees advance, when No. 1 shewed $6\frac{1}{2}$, has also been accounted for before.

It being now evident that there was a refraction of rays coming from the sun, which, though not fit for vision, were yet highly invested with a power of occasioning heat, I proceeded to examine its extent as follows.

The thermometers were arranged on the third line, instead of the second; and the stand was, as before, immersed up to the first, in the coloured margin of the vanishing red rays. The result was thus.

No. 1.		No. 2.		No. 3.
46	- -	46	- -	$45\frac{3}{4}$
50	- -	$46\frac{1}{2}$	- -	46
$51\frac{3}{4}$	- -	$46\frac{3}{4}$	- -	$46\frac{1}{4}$
$52\frac{1}{4}$	- -	47	- -	$46\frac{3}{4}$

Here the thermometer No. 1 rose $5\frac{1}{4}$ degrees, in 13 minutes, at 1 inch behind the visible light of the red rays.

I placed now the thermometers on the 4th line, instead of the 3d; and, proceeding as before, I had the following result.

No. 1.			No. 2.			No. 3.
$48\frac{1}{4}$	-	-	$48\frac{1}{4}$	-	-	$47\frac{3}{4}$
$51\frac{1}{2}$	-	-	$48\frac{3}{8}$	-	-	$47\frac{7}{8}$

Therefore, the thermometer No. 1 rose $3\frac{1}{8}$ degree, in 10 minutes, at $1\frac{1}{2}$ inch beyond the visible light of the red rays.

I might now have gone on to the 5th line; but, so fine a day, with regard to clearness of sky and perfect calmness, was not to be expected often, at this time of the year; I therefore hastened to make a trial of the other extreme of the prismatic spectrum. This was attended with some difficulty, as the illumination of the violet rays is so feeble, that a precise termination of it cannot be perceived. However, as well as could be judged, I placed the thermometers one inch beyond the reach of the violet rays, and found the result as follows,

No. 1.			No. 2.			No. 3.
48	-	-	48	-	-	$47\frac{3}{4}$
48	-	-	48	-	-	$47\frac{3}{4}$
48	-	-	$47\frac{1}{2}$	-	-	47
$48\frac{1}{2}$	-	-	$47\frac{1}{2}$	-	-	47
48	-	-	48	-	-	$47\frac{3}{4}$

Here the several indications of the thermometers, two of which, No. 1 and 2, were used as variable, while the 3d was kept as the standard, were read off during a time that lasted 12 minutes; but they afford, as may be seen by inspection, no ground for ascribing any of their small changes to other causes than the accidental disturbance which will arise from the motion of the air, in a room where some employment is carried on.

I exposed the thermometer now to the line of the very first perceptible violet light; but so that No. 1 and 2 might again be in the illumination, while No. 3 remained a standard. The result proved as follows.

No. 1.		No. 2.		No. 3.
48	- -	48	- -	47¾
48½	- -	48	- -	47¾
48¾	- -	48½	- -	47¾
49	- -	48½	- -	47¾

Here the thermometer No. 1 rose 1 degree, in 15 minutes; and No. 2 rose ½ degree, in the same time.

From these last experiments, I was now sufficiently persuaded, that no rays which might fall beyond the violet, could have any perceptible power, either of illuminating or of heating; and that both these powers continued together throughout the prismatic spectrum, and ended where the faintest violet vanishes.

A very material point remained still to be determined, which was, the situation of the maximum of the heating power.

As I knew already that it did not lie on the violet side of the red, I began at the full red colour, and exposed my thermometers, arranged on a line, so as to have the ball of No. 1 in the midst of its rays, while the other two remained at the side, unaffected by them.

No. 1.		No. 2.		No. 3.
48½	- -	48½	-	48
55½	-	48½	- -	48
55½	-	48½	- -	48

Here the thermometer No. 1 rose 7 degrees, in 10 minutes, by an exposure to the full red coloured rays.

I drew back the stand, till the centre of the ball of No. 1 was just at the vanishing of the red colour, so that half its ball was within, and half without, the visible rays of the sun.

No. 1.	No. 2.	No. 3.
$48\frac{1}{2}$ - -	$48\frac{1}{2}$ - -	48
$55\frac{1}{2}$ - -	$48\frac{1}{2}$ - -	48
57 - -	49 - -	$48\frac{1}{2}$

Here the thermometer No. 1 rose 8 degrees, in 10 minutes.

By way of not losing time, in order to connect these last observations the better together, I did not bring back the thermometer No. 1 to the temperature of the room, being already well acquainted with its rate of shewing, compared to that of No. 2, but went on to the next experiment, by withdrawing the stand, till the whole ball of No. 1 was completely out of the sun's visible rays, yet so as to bring the termination of the line of the red colour as near the outside of the ball as could be, without touching it.

No. 1.	No. 2.	No. 3.
57 - -	49 - -	$48\frac{1}{2}$
$58\frac{1}{2}$ - -	$49\frac{3}{4}$ - -	49
59 - -	$50\frac{1}{4}$ - -	$49\frac{3}{4}$
59 - -	50 -	$49\frac{1}{2}$

Here the thermometer No. 1 rose, in 10 minutes, another degree higher than in its former situation it could be brought up to; and was now 9 degrees above the standard. The ball of this thermometer, as has been noticed, is exactly half an inch in diameter; and its centre therefore was $\frac{1}{4}$ inch beyond the visible illumination, to which no part of it was exposed.

It would not have been proper to compare these last observations with those taken at an earlier period this morning, in order to obtain a true maximum, as the sun was now more powerful than it had been at that time; for which reason, I caused the line of termination of visible light, now to fall again just ½ inch from the centre of the ball; and had the following result.

No. 1.			No. 2.			No. 3.
50½	-	-	50½	-	-	50
57¾	-	-	50	-	-	49½
58½	-	-	50	-	-	49½
58¾	-	-	50	-	-	49½

And here the thermometer No. 1 rose, in 16 minutes, 8¾ degrees, when its centre was ½ inch out of the visible rays of the sun. Now, as before we had a rising of 9 degrees, and here 8¾, the difference is almost too trifling to suppose, that this latter situation of the thermometer was much beyond the maximum of the heating power; while, at the same time, the experiment sufficiently indicates, that the place inquired after need not be looked for at a greater distance.

It will now be easy to draw the result of these observations into a very narrow compass.

The first four experiments prove, that there are rays coming from the sun, which are less refrangible than any of those that affect the sight. They are invested with a high power of heating bodies, but with none of illuminating objects; and this explains the reason why they have hitherto escaped unnoticed.

My present intention is, not to assign the angle of the least refrangibility belonging to these rays, for which purpose more accurate, repeated, and extended experiments are required. But, at the distance of 52 inches from the prism, there was still a considerable heating power exerted by our invisible rays, one inch and a half beyond the red ones, measured upon their projection on a horizontal plane. I have no doubt but that their efficacy may be traced still somewhat farther.

The 5th and 6th experiments shew, that the power of heating is extended to the utmost limits of the visible violet rays, but not beyond them; and that it is gradually impaired, as the rays grow more refrangible.

The four last experiments prove, that the maximum of the heating power is vested among the invisible rays; and is probably not less than half an inch beyond the last visible ones, when projected in the manner before mentioned. The same experiments also shew, that the sun's invisible rays, in their less refrangible state, and considerably beyond the maximum, still exert a heating power fully equal to that of red-coloured light; and that, consequently, if we may infer the quantity of the efficient from the effect produced, the invisible rays of the sun probably far exceed the visible ones in number.

To conclude, if we call *light*, those rays which illuminate objects, and *radiant heat*, those which heat bodies, it may be inquired, whether light be essentially different from radiant heat? In answer to which I would suggest, that we are not allowed, by the rules of philosophizing, to admit two different causes to explain certain effects, if they may be accounted for by one. A beam of radiant heat, emanating from the sun, consists of rays that are differently refrangible. The range of their extent, when dispersed by a prism, begins at violet-coloured light, where they are most refracted, and have the least efficacy. We have traced these calorific rays throughout the whole extent of the prismatic spectrum; and found their power increasing, while their refrangibility was lessened, as far as to the confines of red-coloured light. But their diminishing refrangibility, and increasing power, did not stop here; for we have pursued them a considerable way beyond the *prismatic spectrum*, into an invisible state, still exerting their increasing energy, with a decrease of refrangibility up to the maximum of their power; and have also traced them to that state where, though still less refracted, their energy, on account, we may suppose, of their now failing density, decreased pretty fast; after which, the invisible *thermometrical spectrum*, if I may so call it, soon vanished.

If this be a true account of solar heat, for the support of which I appeal to my experiments, it remains only for us to admit, that such of the rays of the sun as have the refrangibility of those which are contained in the prismatic spectrum, by the construction of the organs of sight, are admitted, under the appearance of light and colours; and that the rest, being stopped in the coats and humours of the eye, act upon them, as they are known to do upon all the other parts of our body, by occasioning a sensation of heat.

Slough, near Windsor,
March 17, 1800.

EXPLANATION OF PLATE XI.

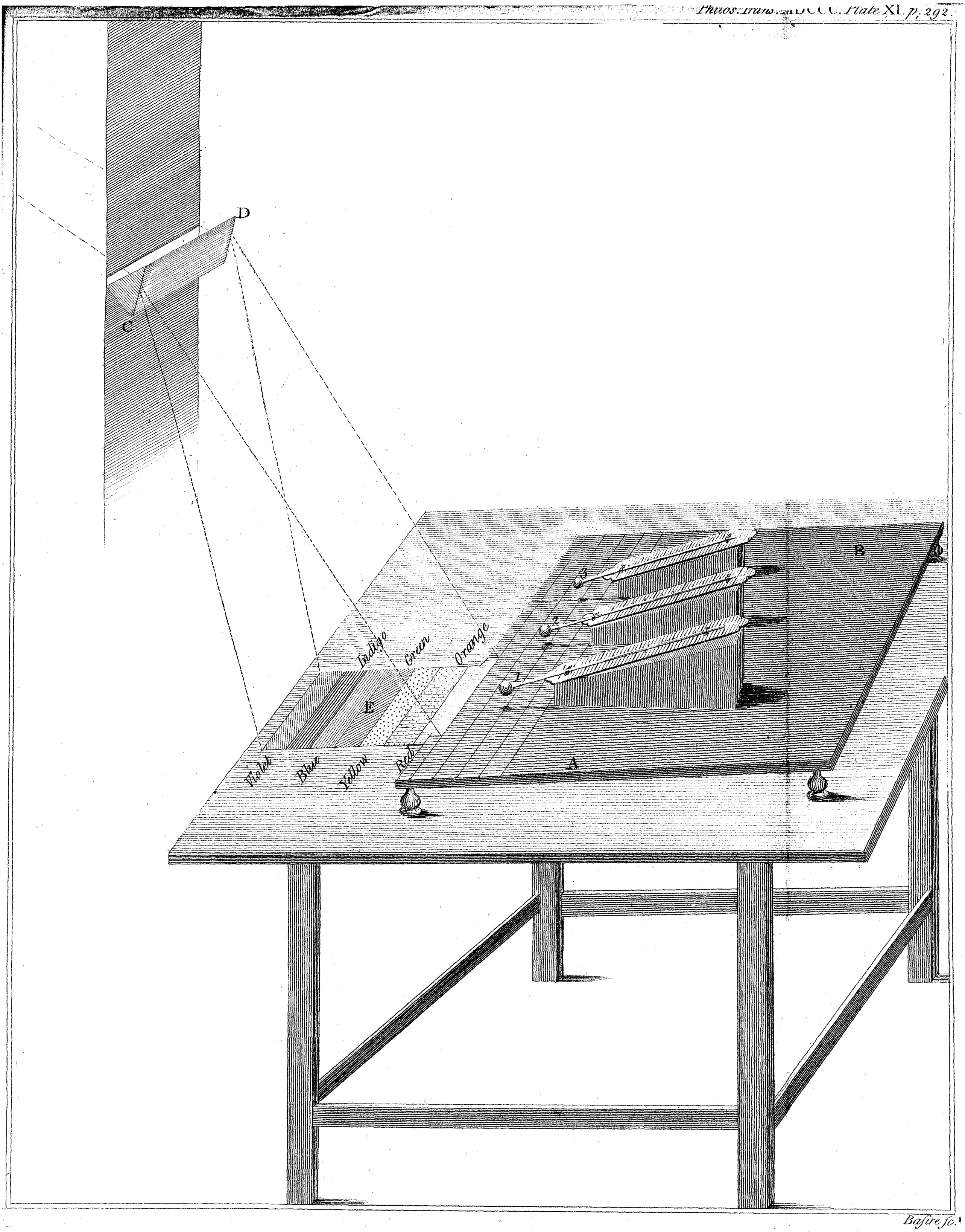
IN WHICH IS GIVEN A VIEW OF THE APPARATUS.

A B. The small stand.

1, 2, 3. The thermometers upon it.

C D. The prism at the window.

E. The spectrum thrown upon the table, so as to bring the last quarter of an inch of the red colour upon the stand.



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