THERMOMETRICAL EXPERIMENTS

AND

OBSERVATIONS.

By TIBERIUS CAVALLO, F.R.S.

Who was nominated by the Prefident and Council to profecute Difcoveries in Natural Hiftory, purfuant to the Will of the late HENRY BAKER, Efq. F. R. S.

Read at the ROYAL SOCIETY, June 15, 1780.

THERMOMETRICAL EXPERIMENTS, &c.

HAVING been appointed by the Prefident and Council of the Royal Society to write the annual differtation, purfuant to the inftitution of HENRY BAKER, Efq. F. R. S. I determined to prefent to the Society the following account of fome thermometrical experiments and obfervations, the greateft part of which were made as long ago as the year 1776. The courfe of thofe experiments having been often interrupted by mechanical defects in the conftruction of inftruments, and by various other circumftances, muft not be confidered as complete inveftigations of the propofed views, but rather as firft attempts, which are to be profecuted in cafe of better opportunities. They contain a few facts, which to me feem new and worthy of notice; and, perhaps, the obfervations concerning the conftruction and ufe of the inftruments ufeful in experiments of this fort, may be of ufe to thofe perfons who have the opportunity, and are willing, to profecute this experimental inquiry.

Having read in a volume of the Philoſophical Tranſactions the account of an experiment made with a thermometer, whoſe bulb was painted black, and was expoſed to the rays of the Sun, in which caſe it had been found, that the thermometer ſhewed a much greater degree of heat than when not blackened, I was deſirous of trying the ultimate limits of this difference. For which purpoſe I conſtructed two thermometers, the ſcales of which (being made by trial) coincided ſo perfectly well together, that when the thermometers were put in equal circumſtances, no difference could be perceived between the degrees of heat ſhewn by them. The method uſed to graduate thoſe thermometers is as follows. The ſcale of one of the thermometers was made in the uſual manner, *viz.* by finding the boiling and freezing water points, and dividing that diſtance into 180 equal parts, which are the degrees according to FAHRENHEIT. Here no regard was paid to the barometrical height at the time of finding the boiling water point, it being uſeleſs for the experiment for which the inſtrument was intended. This done, the balls of the two thermometers were put into hot water, and according as the water cooled, and conſequently the mercury deſcended in the tubes, different marks were put upon the tube of the ungraduated thermometer,

 which

which were nominated after the degree of heat ſhewn at the ſame time by the graduated thermometer. Thus, for inſtance, a mark was put at 140°, another mark was put at 135°, another at 130°, and ſo on. It is plain, that in thoſe points, the thermometers when put in equal circumſtances, muſt coincide perfectly together. Now, on making the ſcale thoſe points are marked firſt, and as the diſtances between thoſe marks were very ſmall (conſiſting of a few degrees) they were divided with the compaſſes in the proper number of equal parts or degrees; and in this manner the ſcale of the other thermometer, was completed, by which means, although theſe two thermometers did not coincide ſo well with other thermometers, yet they coincided perfectly well together, as muſt inevitably be the caſe, even upon the ſuppoſition that their tubes were not perfectly cylindrical. The length of a degree on the ſcale of thoſe thermometers was a little more than $\frac{1}{20}$th of an inch, and although thoſe ſcales were divided into degrees only, yet by inſpection a perſon a little verſed in theſe obſervations could eaſily diſtinguiſh the height of the quickſilver within a quarter of a degree.

Theſe thermometers were both fixed upon the ſame frame at the diſtance of about one inch from one another, having the balls quite detached from the frame, and in this manner they were expoſed to the Sun, or to the light of a lamp.

 When

When theſe thermometers were expoſed to the Sun, or kept in the ſhade, they ſhewed the ſame degree preciſely. The difference between the degree ſhewn by theſe thermometers when expoſed to the Sun, and when kept in the ſhade at about the ſame time of the day, was very trifling.

When the ball of one of thoſe thermometers, which we ſhall call A, was painted black with Indian ink, or with the ſmoke of a candle, and that of the other thermometer B was left clean, on being expoſed to the Sun they ſhewed different degrees of temperature; the quickſilver in the tube of A was much above the quickſilver in the tube of B. This difference ſometimes amounted to about 10°. but it was never conſtant, varying according to the clearneſs of the Sun's light as well as of the air, and alſo according to the different degrees of temperature of the atmoſphere.

Keeping the frame with thoſe thermometers, one of which had the ball painted black, hung on the ſide of a window, I obſerved a remarkable fact, *viz.* that theſe thermometers ſhewed unequal degrees of heat, not only when preſented to the Sun, but alſo when expoſed to the ſtrong day-light. I cleaned the bulb of the thermometer A, and blackened that of B, but the effect was conſtant, *viz.* the quickſilver in the tube of the thermometer whoſe

whoſe bulb was painted black, was conſtantly higher than the other, whenever they were expoſed to the ſtrong day-light. This difference was commonly about one-third of a degree, but ſometimes it amounted to three-fourths, and even to a whole degree. The ſituation in which thoſe thermometers were uſually placed was ſuch that the light of the Sun could not be reflected upon them by any object ſtanding before; but the experiment anſwered even when the Sun was hidden by clouds.

This obſervation ſeemed to ſhew that, perhaps, every degree of light is attended with a proportionate degree of heat; and induced me to try, in a ſimilar manner, whether, by directing the concentrated light of the Moon upon the blackened ball of one of theſe thermometers, I could render ſenſible the effect of that light [a]. But although I attempted it ſome time ago with a large lens ſeveral times, and have lately tried it again with a burning mirror of eighteen inches diameter, yet ſometimes for want of proper means of obſerving the height of the mercury in the tubes of the thermometers, ſometimes for want of a continued clear light of the Moon, and in ſhort from one unfavourable circumſtance or

(*a*) The concentrated light of the Moon has often been thrown upon thermometers without any effect; but I do not know that any blackened thermometer was ever uſed before for this purpoſe.

other,

other, I have not yet been able to make a fair and decifive trial of this experiment.

The light of the Sun being very inconftant on account of clouds and of its diurnal motion, I thought to make fome experiments with the above mentioned two thermometers, by expofing them to the light of a lamp, and I found that this light had a confiderable effect upon them.

The ball of one of the thermometers being blackened, and both being fet at two inches diftance from the flame of a lamp, they both rofe from 58°, at which the mercury ftood before the lighting of the lamp, to $65°\frac{1}{2}$, and the blackened thermometer to $67°\frac{1}{2}$. Another time, being fet at the fame diftance from the lamp, the uncoloured thermometer came up to $67°\frac{3}{4}$, and the blackened one to $68°\frac{3}{4}$. In fhort, by various repeated trials it appeared, that the difference generally amounted to about 1°. When the thermometers were put farther than two inches from the lamp, this difference decreafed, and at about fourteen or fifteen inches it vanifhed quite.

It is mathematically true, that emanations which proceed from a center, and expand in a fphere, muft continually become more and more rare in proportion to the fquares of the diftances from the center. Thus it is faid, that the intenfity of light proceeding from a luminous body

body at the double, treble, quadruple, &c. of a given diftance from that body, muft be refpectively four, nine, fixteen times lefs denfe. The fame thing may be faid of heat.

Being willing to afcertain this truth by actual experiment, I placed feveral thermometers, whofe balls were not painted, at different diftances from the flame of the lamp, and expected to find, when the thermometer at four inches diftance was 1° above that placed at eight inches diftance, the thermometer placed at two inches diftance fhould be 4° higher. But upon trying this experiment various times, placing the thermometers at different diftances from the flame of the lamp, and making the proper calculations agreeable to thofe diftances, it appeared, that the intenfity of the heat did not decreafe exactly in the duplicate proportion of the diftances from the flame of the lamp, but fhewed a very odd irregularity. It feemed to decreafe fafter than the duplicate proportion of the diftances for the fpace of two inches and a half or three inches, after which it decreafed much flower. Whether this effect may be attributed to fome different ftate of the air's purity at different diftances from the flame of the lamp, or to the vapours proceeding from the flame, I cannot take upon me to determine.

The

The above mentioned experiments gradually induced me to try the effect of the light of the Sun and of a lamp upon thermometers whofe balls were painted with different colours. Dr. FRANKLIN'S experiment with the pieces of cloth fet upon fnow that was expofed to the Sun is very well known. The doctor found, that thofe pieces of cloth, whofe colour was darker, funk deeper in the fnow than the others, by which it appears, that they became hotter. My view was to examine thofe different degrees of heat imbibed by different coloured fubftances with precifion, in order to obferve if they kept any proportion to the fpaces occupied by the prifmatic colours in the prifmatic fpectrum, or if they followed any other difcoverable law; but thofe attempts met with many difficulties, the greateft of which was the choice of colours. The water colours that are commonly ufed, as carmine, fap-green, &c. are of fo different a nature from one another, that when the balls of the thermometers were painted with them, their furfaces were not equally fmooth, which occafioned great difference in the effect; for I found, that two thermometers, whofe balls had been painted with the fame colour, but the paint laid fmoother on one than on the other, fhewed different degrees of heat when they were both expofed to the rays of the Sun.

I attempted

I attempted to make thermometers with tubes of differently coloured glaſs, but when a ball was formed with any of thoſe tubes, the ſubſtance of the glaſs in the ball, being much thinner than in the tube, differed very little from clear colourleſs glaſs.

To include the thermometers in cloſe boxes, in which the rays entered through coloured glaſſes, was alſo found ineffectual; not only becauſe the colours ſo tranſmitted were far from being homogeneous, but eſpecially becauſe ſome of thoſe glaſſes are much more opaque than others, even of the ſame colour.

The leaſt ambiguous method, therefore, was that of painting the balls of the thermometers with water-colours, taking care to lay them as equally ſmooth as poſſible. In this manner I repeated ſeveral experiments, uſing ſometimes a dozen of thermometers at once, whoſe balls were painted with various colours, and were expoſed to the Sun; and from a vaſt number of experiments, and after ſome weeks obſervation, it could be only deduced, that if the colours, with which the balls of the thermometer were painted, were pretty like the priſmatic colours, thoſe thermometers ſhewed a greater degree of heat, whoſe colours were nearer to the violet in the order of the priſmatic colours, and contrarywiſe; but they were all, even that painted with white lead, in ſome intermediate degree between the blackened thermometer and the naked or unpainted one. If the colours had not the proper degree of denſity, the effects were very different: thus a thermometer painted with a light blue was lower than another thermometer painted red with good carmine.

I ſhall now deſcribe the manner of conſtructing the ſcales of thoſe thermometers, which was contrived ſo as to be very expeditious; becauſe ſome of thoſe thermometers were often broken by ſome accident or other, and that new ſchemes often required new thermometers, to conſtruct the ſcales of which in a formal manner would have required a very long time. Thoſe methods therefore may be of uſe to other perſons.

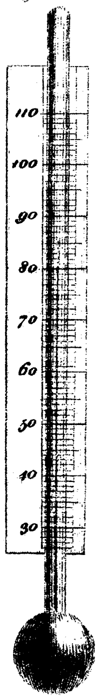
When the thermometers were intended to be expoſed to the flame of the lamp, at a given diſtance from it, their ſcales were drawn upon ſlips of paper which were glued to their tubes in the manner repreſented by fig. 1. The thermometers were then ſet horizontally upon a book, ſo that their balls were out of the book, and at any required diſtances from the flame of the lamp, which diſtances were meaſured with a pair of compaſſes. But when the thermometers were only to be expoſed to the Sun, I then uſed the following very expeditious method, ſee fig. 2. Upon an oblong board ABCD of about 14 inches by 18, and nearly one inch thick, I pasted a piece of white paper, and delineated upon it a right-angled triangle EGF, one side GF of which came very near the edge CD of the board; the other side EF, which stands perpendicular to GF, was divided into equal parts, representing degrees of FAHRENHEIT's thermometrical scale. The lowest of those degrees was near the freezing point, and the upper was not above the 110°, it being as much as I was in want of. From the point G right lines were drawn to all the degrees in the scale EF, and many other right lines parallel to the scale EF, and consequently perpendicular to the base GF, were drawn through the whole area of the triangle. Now when the thermometers were constructed, I found, by comparison with a standard thermometer, two points whatever, which I marked with the file upon the tube, and by a note of these thermometers I knew to what degrees they answered. Thus, for instance, upon the thermometer HL two marks were made, *viz.* I answering to the 40th degree, and K to the 70th degree. Now when this thermometer was to be used I placed it upon the board ABCD with the tube parallel to the scale EF, which could be easily done by the help of the parallel lines drawn upon the triangle, the ball of the thermometer being out of the board; thus I slid the thermometer backwards and forwards till the mark I, which was the 40th degree, coincided with the line, which went from the point G to the 40th degree on the ſcale, and the mark K coincided with the line which went from G to the 70th degree. In that place the thermometer was left, and in order to keep it ſteady, a piece of lead (O) was uſually put upon the extremity of its tube. In this ſituation the interſections of the tube, and the lines drawn from G to the degrees in EF, ſhewed the degrees, or ſerved for a ſcale to the thermometer HL. Thus, ſuppoſe that the quickſilver in its tube was at P, it is plain, that it was at 55°, becauſe at that point the tube is interſected by the line which goes from G to the 55th degree on the ſcale EF. This board, therefore, ſerved for a univerſal ſcale, and upon it I uſed to fix ſeveral thermometers at a time, and expoſe them all together to the Sun.

I ſhall conclude this paper with mentioning an experiment, which, although not thermometrical, is yet uſeful in removing a wrong notion ſome perſons have concerning the effect of light.

Having ſeen in ſome book that the common black pyrophorus, or HOMBERG's pyrophorus, was impaired by light, I was deſirous to try the truth of this aſſertion. Accordingly towards the beginning of the laſt year I prepared ſome pyrophorus, and incloſed portions of it in three glaſs tubes, which were immediately ſealed

I hermetically,

Fig. 1.


110
100
90
80
70
60
50
40
30

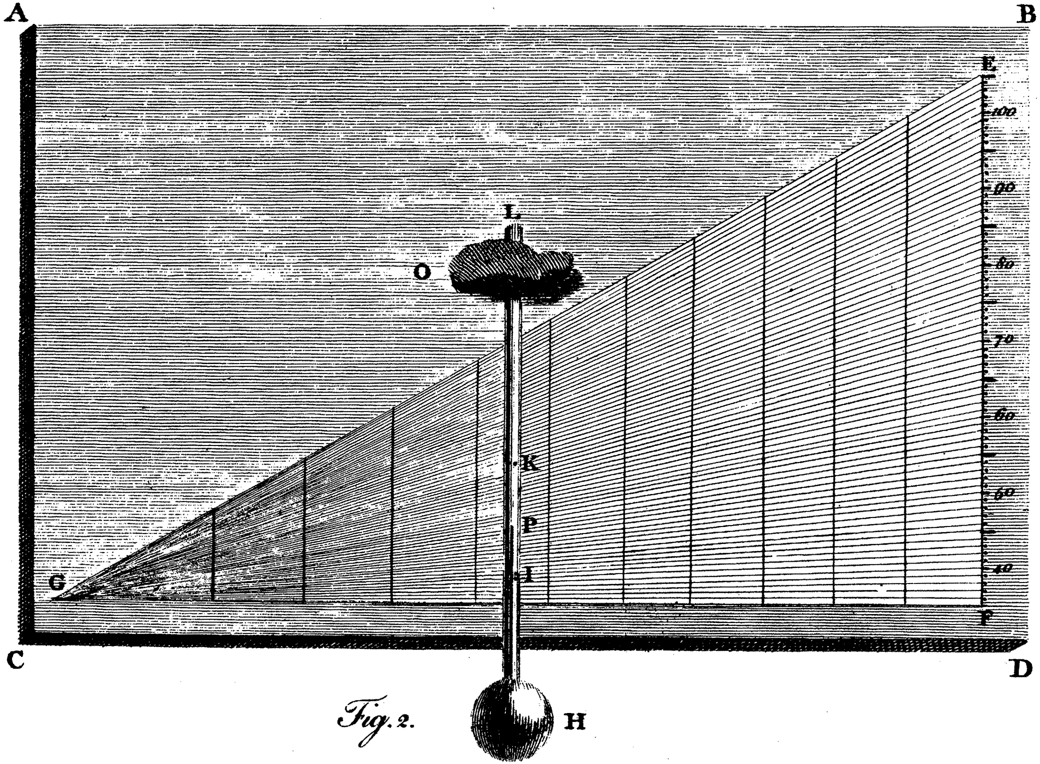
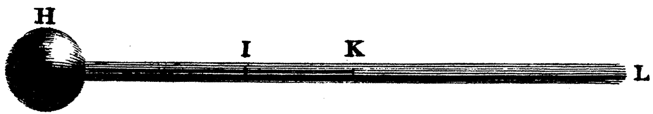

A
B
C
D
E
F
G
O
L
K
P
I
H
100
90
80
70
60
50
40

Fig. 2.


H
I
K
L

hermetically, and on the 20th of May, 1779, two of them were ſuſpended to a nail out of a window, and the third was wrapped up in paper, and was incloſed in a box, where not the leaſt glimmering of light could enter. In this ſituation they were left for above a year, and laſt week I broke one of thoſe that had been kept out of the window, and that which had been in the dark, in preſence of Mr. KIRWAN, F. R. S.; but the pyrophorus of each tube ſeemed to be equally good, taking fire within about half a minute after being taken out of the tubes, and expoſed to the air upon pieces of paper, which ſhews that neither the preſence or abſence of light had injured it.

June 7, 1780.

P. S. Having mentioned to ſeveral perſons my intention of making ſome experiments upon the temperature of the atmoſphere with a new metalline thermometer, and of giving an account of them in this paper, I muſt here mention, that as the inſtrument was not finiſhed in proper time, I ſhall defer giving a deſcription of it, as well as an account of the experiments, &c. to another opportunity.