

V. *Some Observations on the Heat of Wells and Springs in the Island of Jamaica, and on the Temperature of the Earth below the Surface in different Climates.* By John Hunter, M. D. F. R. S.; communicated by the Hon. Henry Cavendish, F. R. S.

Read December 20, 1787.

TO THE HON. MR. CAVENDISH.

S I R,

THE following observations on the heat of springs and wells, and their application towards determining the mean temperature of the earth in different climates, were suggested by you in some conversation on that subject, previous to my going to Jamaica in 1780. If you think them deserving the attention of the Royal Society, I must beg the favour of you to lay them before that learned Body.

I have the honour to be, &c.

JOHN HUNTER.

Charles-street,
Dec. 11, 1787.

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THE great difference between the temperature of the open air, and that of deep caverns or mines, has long been taken notice of, both as matter of curiosity and surprize. After thermometers were brought to a tolerable degree of perfection, and meteorological registers were kept with accuracy, it became a problem, to determine what the cause was of this difference between the heat of the air, and the heat of the earth; for it was soon found, that the temperature of mines and caverns did not depend upon any thing peculiar to them; but that a certain depth under ground, whether in a cave, a mine, or a well, was sufficient to produce a very sensible difference in the heat. In observations of this kind, there was perhaps nothing more striking, than that the heat in such caves was nearly the same in summer and winter; and this even in changeable climates, that admitted of great variation between the extremes of heat in summer, and cold in winter. There is an example of this in the cave of the Royal Observatory at Paris. The explanations, which have been attempted of this phænomenon, have turned chiefly upon a supposition, that there was an internal source of heat in the earth itself, totally independent of the influence of the sun*. M. DE MAIRAN has bestowed much labour on this subject, and by observation and calculation is led to conclude, that of the 1026° of heat (by REAUMUR'S scale), which he finds to be the heat of summer at Paris, 34°,02 only proceed from the sun, and the remaining 991°,98 from the earth, by emanations of heat from the center †. The proportion therefore of heat derived from this latter source is to that of the sun, as 29,16 to 1. It must be evident, that an hypothesis of this kind, which renders the influence of the sun of small account, is directly contrary to the general

* Vid. MARTINE'S *Essays*, p. 319.

† *Memoir. de l'Acad. des Sciences*, An. 1719 et 1765.

experience and conviction of mankind. Without entering, however, into any discussion of the *data* from whence M. DE MAIRAN draws his conclusions, it will be more satisfactory to consider what the effect of the operation of those laws of heat, with which we are acquainted, would be.

And first, it is well known, that heat in all bodies has a tendency to diffuse itself equally through every part of them, till they become of the same temperature. Again, bodies of a large mass are both cooled and heated slowly. Besides the mass of matter, there are two other considerations of much importance in the slow or quick transmission of heat through bodies; these are their different conducting powers, and their being in a state of solidity or fluidity. The conducting powers of heat are well known to be very various in different bodies; nor are they hitherto reducible to any law, depending either upon the density, or chemical properties of matter. Metals of all kinds are good conductors of heat, while glass, an heavy, solid, homogeneous body, is an extremely bad conductor, even when a metallic calx enters largely into its composition, as in flint-glass. A state of fluidity greatly promotes the diffusion of heat; for a body in a fluid state, by the particles moving readily among each other from their different densities or other causes, mixes the warm and cold parts together, which occasions a quick communication of heat. To apply these observations to the present subject; the surface of the earth being exposed to the great heats of summer, and the colds of winter, or more properly the low degree of heat of winter, will receive a larger proportion of heat in the former season, and a smaller in the latter; and being further of a large mass, and of a porous and spongy substance, and therefore not quickly sensible to small variations of heat, it will become of a mean temperature at a certain depth, between the heat of summer,

and the cold of winter, provided it contain no internal source of heat within itself. This conclusion is strictly agreeable to the experiments and observations hitherto made, in heating and cooling bodies, or in mixing portions of matter of the same kind of different temperatures*. Water, though in a large mass, follows in some degree the heat and cold of our summer and winter, from the mobility of its parts occasioning a more speedy diffusion of heat. Air is quickly susceptible of heat, and from the expansions produced in it, and consequent motions in the whole mass, the temperature is soon rendered uniform.

The changes in the heat of the air are what we have measured, and we are to be understood to speak of them, when we talk of the temperature of summer and of winter. It may be asked then, is the heat of the sun first communicated to the air, and thereby to the earth? No, the air is susceptible of a very small degree of heat from the rays of the sun passing through it; for it is well known, they produce no heat in a transparent medium, and consequently, that the air is only so far heated as it differs from a medium that is perfectly transparent. The heat produced by the rays of the sun bears a proportion to their number, their duration, and their falling more or less perpendicularly; and it takes place at the points where they strike an opaque and non-reflecting surface. The surface of the earth may therefore be considered as the place, from whence the heat proceeds, which is communicated to the air above, and the earth below. That this is really the case is evident from the superior degree of heat, produced by the action of the rays of the sun upon an opaque body, which will often be heated to 150° (FAHRENHEIT), while the temperature of the air is not above 90° †. It may seem, therefore, that to measure the heat communicated

* Vid. DE LUC *Modifications de l'Atmosphere*, Vol. I. p. 285.

† MARTINE'S *Essays*, p. 309.

to the earth, it should be done at the surface, where the action of the rays immediately takes place. But though the heat be produced at the surface, it is communicated freely to the air as well as the earth; and though the apparent intensity of heat be greater in the earth, from the rays of light acting for a longer time upon the same parts of matter, yet there is little doubt that much the greater part is carried off by the air, which as it is heated flies off, and allows a fresh portion of cold air to come in contact with the heated surface. But still it is immaterial, whether the heat of the sun be excited more in the earth or in the air; for whichever has the larger proportion will in the end communicate a part to the other, and so restore the balance. The same observation applies to such causes of cold as may operate at the surface of the earth, as evaporation, and that taken notice of by Mr. WILSON *. The air, therefore, near the surface of the earth will shew by a thermometer in the shade nearly, if not exactly, the same degree of heat that the sun communicates to our terrestrial globe; and if a mean of the heats thus shewn be taken for the year round, and we penetrate into the earth to that depth, that it is no longer affected either by the daily, monthly, or annual variations of heat, the temperature at such depth should be equal to the annual mean above mentioned. To ascertain this with the utmost precision, it must be obvious, that numerous observations should be made every day, corresponding to the frequent changes of temperature, which are known to happen in the course of the twenty-four hours in all climates; and upon these a daily mean should be taken, and the annual mean deduced therefrom. This has not yet been done, but where we have observations from which a mean temperature can be deduced with any degree of certainty, it will be found not to differ greatly from

* Vid. Phil. Transf. Vol. LXX. p. 451. and Vol. LXXI. p. 386.

the heat of deep caves, or wells in the same climate. If further experience and observation should confirm the above opinions, it will be attended with this advantage, that we shall be possessed of an easy and ready method of ascertaining the mean temperature of any climate; which, with a few observations of the extremes of heat and cold at particular seasons, will teach us as much of the country, with regard to heat and cold, as the meteorological observations of several years.

For obtaining the temperature of the earth the best observations are probably to be collected from wells of a considerable depth, and in which there is not much water. Springs issuing from the earth, although indicating the temperature of the ground from whence they proceed, are not so much to be depended upon as wells; for the course of the spring may be derived from high grounds in the neighbourhood, and it will thence be colder; it may run so near the surface as to be liable to variations of heat and cold from summer and winter; or it may be exposed to local causes of heat in the bowels of the earth. Wells seem also better than deep caverns, for the apertures to such are often large, and may admit enough of the external air to occasion some change in their temperature. Wells are not, however, to be met with in all places, and in that case we must remain satisfied with the temperature of the springs.

The following observations were made in the Island of Jamaica, where there are flat lands in many parts towards the coast, but all the interior part of the country is mountainous. The heat is greatest in the low lands, and decreases as you ascend the mountains. The town of Kingston is supplied with water from wells. The ground on which it stands rises with
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a gentle ascent as you recede from the sea. In the low part of the town the wells are but a few feet deep, and many of them brackish. The heat of the water in some of them I have found as high as 82° ; but they were evidently too near the surface not to be affected by the heat of the seasons. As you ascend, the wells are deeper, and the temperature is nearly 80° in all of them. What variations there are, come within one degree, that is, half a degree less than 80° , or half a degree more. They are of different depths, and some not less than 100 feet; though, after they are of half that depth, the temperature is nearly uniform. At the *Governor's Pen*, which is also in the low part of the country, a well, which is above 60 feet deep, is $79\frac{1}{2}^{\circ}$. There is a well at Half-way-Tree, 243 feet deep, which is 79° . Half-way-Tree is two miles from Kingston, with a very gentle ascent. Near Rock-Fort is a spring, immediately at the foot of the long mountain, which throws out a great body of water; the heat of it is 79° . All the places mentioned are but very little above the level of the sea, probably not more than the depth of the wells at the respective places; for near Kingston there are springs that appear just below the water-mark of the sea, and those that supply the wells are probably upon the same level.

The temperature of the air at Kingston admits but of small variation. The thermometer, at the hottest time of the day, and during the hottest season of the year, ranges from 85° to 90° ; in the coolest season, and observed about sun-rise, which is the coldest time in the twenty-four hours, it ranges from 70° to 77° . I have seen it once as low as 69° , and two different times as high as 91° . The annual mean temperature cannot, therefore, either much exceed, or fall much short of, 80° , as indicated by the wells.

The following springs were examined with much accuracy by the Hon. Mr. SEWELL, Attorney General of the Island.

Ayscough's spring, on the road from Spanish Town to Pufey's, in St. John's parish, 75° .

Pufey's spring, still higher in the mountains, $72^{\circ}\frac{3}{4}$.

A spring near the barracks at Points Hill in St. John's parish, 70° .

The thermometer in the shade at Pufey's, during part of the month of June, was found to range from $69^{\circ}\frac{1}{2}$ to $79^{\circ}\frac{1}{2}$. It was observed both late at night, and early in the morning before sun-rise.

The spring in Brailsford Valley, about ten miles above Spanish Town, is 75° . The spring at Stoney Hill is 71° . These were examined by Mr. HOME.

Mr. WALLEN's house, at Cold Spring, stands the highest of any in the island. By a measurement, said to have been made by Mr. M^c FARLANE, it is reported to be 1400 yards above the level of the sea. On the road to it, and about a mile below Mr. WALLEN's house, there is a spring that issues from the side of the hill, of the temperature of 65° . Cold Spring, which gives a name to the place, is about fifty feet below the house, and the heat of it is $61^{\circ}\frac{3}{4}$. The thermometer in the shade at Mr. WALLEN's house, for some days in the month of April, ranged from 57° to 67° . It may be remarked, that the higher the springs the colder they are; and, as far as a conjecture can be formed from so few observations, they would appear not to differ much from the mean temperature of their respective places*.

It will not be out of place to add some observations made in England, relative to the same subject. The wells in and

* The thermometers made use of were all made by Mr. RAMSDEN.

about London are either of no great depth, or are full of water, which are both considerable objections to their giving a mean temperature. The want of depth will make them subject to the variations of the seasons; and a large quantity of water, even in a deep well, will take the temperature of the air more or less: for any change of temperature communicated at the surface will, from the fluidity of the water, be readily diffused through the whole. I suspect it is owing to this cause, that the wells in the neighbourhood of Brighthelmstone vary from 50° to 52° , for those were the highest that had most water in them. My observations were made in summer. These wells are of various depths, from 15 to 150 feet. That which I always found the coldest is not more than 22 feet deep; I never found its heat greater than 50° . It is near the beach, and is a tide well, that is, the water in it rises and falls, and in so doing does not correspond exactly with the tides, but follows them with an interval of about three hours. At the lowest there is not more than a foot of water in it; and it may be considered as a subterraneous spring running through the bottom of the well. There are in fact numerous springs that break out upon the sand, a few feet above the low-water mark, which are doubtless the same that supply the wells. As we are not acquainted with any cause that produces cold in the bowels of the earth, we must necessarily in every climate, consider the lowest degree of heat as approaching nearest to the mean temperature; and therefore we cannot conclude the mean temperature at Brighthelmstone to be more than 50° . The mean temperature of London is computed about 52° *; but Brighthelmstone is nearly fifty miles farther south than London, and is immediately upon the sea,

* KIRWAN'S Temperature of different Latitudes, p. 73.

and must therefore be at least as warm as London. It is evident, that the observations from which the mean is taken, must generally contain more of the extremes of heat than of cold, as the former happen in the day-time, and the latter in the night, in consequence of which they will often escape notice. There is a table constructed by Dr. HEBERDEN *, expressing the heat in London for every month in the year, from a mean of ten years beginning with 1763, and ending with 1772. The mean temperature is given both at 8 A.M. and 2 P.M. There is further in the table, a column of the mean of the greatest monthly colds in the night, observed during the same ten years by Lord CHARLES CAVENDISH, in Marlborough-street. There will not probably be any great error in considering the heat observed at 2 P.M. as the greatest daily heat; and taking a mean between the greatest heats of the day, and greatest colds of the night, they give $49^{\circ},196$ for an annual mean, which is much lower than is commonly supposed. At the house of GEORGE GLENNY, Esq. near Bromley, there is a well seventy-five feet deep, which I found in November $49^{\circ}\frac{1}{2}$. M. DE MAIRAN has given a table of the greatest heats and greatest colds observed at Paris for fifty-six years, beginning from 1701; and a mean of them is 10° above freezing, or 1010° , of REAUMUR's scale †. The temperature of the cave of the Observatory where those observations were made, is $10^{\circ}\frac{1}{4}$ above freezing, by the same scale of REAUMUR. There appears not therefore any necessity for an internal heat; on the contrary, it is matter of demonstration, that were there any source of heat in the earth which was not equally in the air, the heat of the interior parts ought to be

* The Table alluded to follows this Paper.

† Mem. de l'Acad. des Sciences, An. 1765, p. 202.

higher than a mean: and did the *central heat* bear as high a proportion to that of the sun as M. DE MAIRAN alledges, the heat of the earth itself ought to be a great deal above the mean temperature of the air, which from observation there is no ground for believing. It is easy to see the source of M. DE MAIRAN's error; he has founded his calculations upon the scale of REAUMUR, and considers the degrees of his thermometer as marking the real proportions, and absolute quantity of heat*. It is a matter that cannot be denied, that we know nothing of the absolute quantities of heat; and that the degrees of our thermometers are only to be considered as a few of the middle links of a chain, the length of which we are totally ignorant of, and therefore in no condition to compare its proportional parts. It deserves, however, to be remarked, that observations of a late date have shewn, that the notions of cold upon which REAUMUR's scale was constructed, and upon which M. DE MAIRAN's calculations are founded, are imaginary and without foundation †.

Hot springs and volcanos may be produced as proofs of the existence of an internal source of heat in the earth; but their operation appears to be limited to a very small extent, and scarcely deserving of notice in the present discussion. It is no uncommon thing to find springs of the usual temperature close by hot springs; and no volcano, with which we are yet acquainted, appears to have raised the temperature of the country immediately adjoining to it.

The sea admits of change of temperature more quickly than the earth, particularly near the shore. The mean heat of the

* Vid. Memoir. de l'Acad. des Sciences, An. 1765, p. 143.

† Vid. Phil. Trans, Vol. LXXIII. p. * 303. 303. and 329.

sea at Brighthelmstone, during the months of July, August, September, and October, was as follows :

July	$63^{\circ}\frac{1}{7}$
August	$63^{\circ}\frac{1}{2}$
September	58°
October	53°

The observations were made with a view to ascertain the temperature of the sea as a bath, and therefore the heat was taken about nine in the morning, and near the shore, the usual time and place of bathing. The water gets hotter towards three o'clock in the afternoon, so that it not only follows the monthly, but even the daily changes of the temperature of the air. In the four months just mentioned, the extremes of heat and cold are considerable: I have seen it as hot as 71° , and as cold as 49° . In the month of August last, Sir HENRY ENGLEFIELD examined the heat of the sea at the same time that I did, and we both found it 71° : it was about 4 P.M. of a very hot day. I may be allowed to remark, that sea-bathing is a very different thing at different seasons of the year, and requires an acquaintance with the variations of the temperature, to adapt it to particular cases.

It were to be wished, that the heat of wells and springs were examined at different seasons of the year, in order to ascertain the effect of summer and of winter upon them. The wells at New York are from 32 to 40 feet in depth, and Dr. NOOTH found them to have an annual variation of two degrees from 54° to 56° . There are few countries, in which the annual range of the thermometer is greater than at New York, and the neighbouring parts of America. In the summer it is often as high as 96° , and in winter it has been observed several degrees below the zero of FAHRENHEIT's scale.

We may, I think, from all the observations we are yet in possession of, conclude, that there is at present no source of heat in the earth, capable of affecting the temperature of a country, which is not derived from the sun; and that the earth, whatever changes of temperature it may be conjectured to have undergone in former periods, is now reduced to a mean of the heat produced by the sun in different seasons, and in different climates.

