

IV. FRIGORIFIC EXPERIMENTS ON THE MECHANICAL EXPANSION OF AIR, *explaining the Cause of the great Degree of Cold on the Summits of high Mountains, the sudden Condensation of aerial Vapour, and of the perpetual Mutability of atmospheric Heat.* By Erasmus Darwin, M. D. F. R. S.; communicated by the Right Honourable Charles Greville, F. R. S.

Read December 13, 1787.

HAVING often revolved in my mind the great degree of cold producible by the well known experiments on evaporation; in which, by the expansion of a few drops of ether into vapour, a thermometer may be sunk much below the freezing point; and recollecting at the same time the great quantity of heat which is necessary to evaporate or convert into steam a few ounces of boiling water; I was led to suspect, that elastic fluids, when they were mechanically expanded, would attract or absorb heat from the bodies in their vicinity; and that, when they were mechanically condensed, the fluid matter of heat would be pressed out of them, and diffused among the adjacent bodies.

As this principle might possibly be extended to elastic solid bodies, as well as to fluid ones, and explain the cause of the heat occasioned by percussion or friction, and by some chemical combinations, as well as the perpetual mutability of it in

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the atmosphere, I have, at different times, endeavoured to subject it to experiment.

1. When Dr. HUTTON of Edinburgh, and Mr. EDGEWORTH of Edgeworthstown in Ireland, were with me about twelve or fourteen years ago, the following experiment, which had been proposed by one of the company, was carefully made. The blast from an air-gun was repeatedly thrown on the bulb of a thermometer, and it uniformly sunk it about two degrees. The thermometer was firmly fixed against a wall, and the air-gun, after being charged, was left for an hour in its vicinity, that it might previously lose the heat acquired in the act of charging; the air was then discharged in a continued stream on the bulb of the thermometer, and the event shewed, that the air at the time of its expansion attracted or absorbed heat from the mercury of the thermometer.

In March 1785, by the assistance of Mr. Fox and Mr. STRUTT, of Derby, a thermometer was fixed in a wooden tube, and so applied to the receiver of an air-gun, that, on discharging the air by means of a screw pressing on the valve of the receiver, a continued stream of air, at the very time of its expansion, passed over the bulb of the thermometer. This experiment was four times repeated in the presence of many observers, and uniformly sunk the thermometer from five to seven degrees. During the time of condensing the air into the receiver, there was a great difference in the heat, as perceived by the hand, at the two ends of the condensing syringe; that next the air-globe was almost painful to the touch; and the globe itself became hotter than could have been expected from its contact with the syringe. Add to this, that in exploding an air-gun, the stream of air always becomes visible, which is owing to the cold then produced precipitating the vapour it contained;

contained; and if this stream of air had previously been more condensed, or in greater quantity, so as not instantly to acquire heat from the common atmosphere in its vicinity, it would probably have fallen in snow, as in the fountain of Hiero, mentioned below.

2. About twelve or fourteen years ago, by the assistance of Mr. WALTIRE, a celebrated itinerant teacher of philosophy, a thermometer was placed in the receiver of an air-pump, and some time being allowed, that it might accurately adapt itself to the heat of the receiver, the air was hastily exhausted; during which the mercury of the thermometer sunk two or three degrees, and after some minutes regained its previous height. In November 1787, by the assistance of my very ingenious friend Mr. FORESTER FRENCH, the above experiment was repeated; but with this difference, that the thermometer was open at the top; so that the diminution of external pressure could not affect the dimensions of the bulb; and the result was the same, the mercury in the thermometer sunk two or three degrees, and gradually rose again. Does not this shew, that the air in the receiver, being expanded during the exhaustion, attracted or absorbed heat from the mercury in the thermometer?

Both during the exhaustion, and during the re-admission of the air into the receiver, a steam was regularly observed to be condensed on the sides of the glass, which in both cases was in a few minutes re-absorbed. This steam must have been precipitated by its being deprived of its heat by the expanded air: if it could have happened from any other cause, the vapour could not, in both situations, *viz.* of exhaustion, and of re-admission, have been taken up again.

3. In December 1784, with the assistance of Mr. Fox, the following experiment was carefully made. A hole, about the size of a crow-quill, was bored into a large air-vessel, placed at the commencement of the principal pipe in the waterworks which supply the town of Derby. The water from four pumps, which are worked by a water-wheel, is first thrown into the lower part of this air-vessel, and from thence rises to the top of St. Michael's Church into a reservoir, which may be about thirty-five or forty feet above the level of the air-vessel.

Two thermometers were previously suspended on the leaden air-vessel, that they might become of the same temperature with it; and, as soon as the hole was opened, had their bulbs reciprocally applied so as to receive the stream of air; and the mercury in both of them sunk two divisions, or four degrees. This sinking of the mercury in the thermometers could not be ascribed to any evaporation of moisture from their surfaces, because it was seen, both in exhausting and re-admitting the air into the exhausted receiver, that the vapour which it previously contained was deposited during its expansion.

4. There is a very curious phænomenon observed in the fountain of Hiero, constructed on a very large scale in the Chemnicensian mines in Hungary, which is very similar to the experiments above related. In this machine the air, in a large vessel, is compressed by a column of water 260 feet high: a stop-cock is then opened, and as the air issues out with great vehemence, and, in consequence of its previous condensation, becomes immediately much expanded, the moisture it contained is not only precipitated, as in the exhausted receiver above-mentioned, but falls down in a shower of snow, with icicles, adhering to the nosel of the cock. This remarkable circum-

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stance is described at large, with a plate of the machine, in the Philosophical Transactions for 1761, Vol. LII.

5. From the four experiments already related; first, of the mercury sinking in the thermometer, by being exposed to the stream of air from an air-gun; secondly, from its sinking in the receiver of an air-pump, during the time of exhausting it; thirdly, from its sinking when exposed to a stream of air from the air-vessel of a water-engine; and, lastly, from the curious phænomenon of snow and ice being produced by the stream of expanding air from the fountain of Hiero in an Hungarian mine; there is good reason to conclude, that in all circumstances, when air is mechanically expanded, it becomes capable of attracting the fluid matter of heat from other bodies in contact with it.

Coldness of the Summits of Mountains.

Now, as the vast region of air which surrounds our globe is perpetually moving along its surface, climbing up the sides of mountains, and descending into the vallies; as it passes along, it must be perpetually varying its degree of heat, according to the elevation of the country it traverses: for in rising to the summits of mountains it becomes expanded, having so much of the pressure of the super-incumbent air taken away, and, when thus expanded, it attracts or absorbs heat from the mountains in contiguity with it; and when it descends into the valley, and is again compressed into less compass, it again gives out the heat it has acquired to the bodies it becomes in contact with.

The same thing must happen in respect to the higher regions of the atmosphere, which are regions of perpetual frost, as

was always suspected, and has of late been demonstrated by the aerial navigators. When large districts of air from the lower parts of the atmosphere are raised two or three miles high, they become so much expanded by the great diminution of the pressure over them, and thence become so cold, that hail or snow is produced from the precipitated vapour, if they contain any: and as there is, in these high provinces of the atmosphere, nothing else for the expanded air to acquire heat from, after the precipitation of its vapour, the same degree of cold continues, till the air, on descending to the earth, acquires again its former state of condensation and of warmth.

The Andes, almost under the line, rests its base on burning sands; about its middle height is a most pleasant and temperate climate, covering an extensive plain, on which is built the city of Quito; while its forehead is incircled with eternal snow, coeval perhaps with the elevation of the mountain: yet, according to the accounts of ULLOA, these three discordant climates seldom intrench much upon each other's territories. The hot winds below, if they ascend, become cooled by their expansion, and hence cannot affect the snow upon the summit; and the cold winds, that sweep the summit, become condensed as they descend, and of temperate warmth, before they reach the fertile plains of Quito.

Correspondence of the Heat of the Atmosphere with the Height of the Barometer.

From this principle some of the sudden changes of our atmosphere from hot to cold, and from dry to moist, may likewise be accounted for. During the last year I frequently observed, that when the barometer rose (the wind continuing
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in the same quarter, *viz.* N.E. or S.W.) the air became many degrees warmer. A similar fact is related from MÜSSCHENBROEK, in Mr. KIRWAN's ingenious work on the Temperature of different Latitudes; *viz.* that in winter, when the mercury in the barometer descends, the cold increases. More accurate observations on this subject, when the air is stationary, or when the wind continues in the same quarter, might lead to the discovery of the quantity of heat squeezed out of the air by a certain pressure.

The Devaporation of aerial Moisture.

As heat appears to be the principal cause of evaporation, as well as of solution, and of fluidity in general, the privation of heat may be esteemed the principal cause of devaporation: for though the air may, by its own power of attraction, or by means of the electricity it may contain, dissolve and suspend a portion of water, as water dissolves and suspends a portion of salt; yet, by the application of cold, these are respectively precipitated; and therefore heat may be assumed as the immediate cause of these solutions. Add to this, that water boils *in vacuo* with less heat; that is, it evaporates *in vacuo* faster or easier than in the open air, and therefore the attractive power of the atmosphere does not seem necessary to evaporation.

Now, when the barometer sinks (from whatever cause not yet understood this may happen) the lower stratum of air becomes expanded by its elasticity, being released from a part of the super-incumbent pressure, and, in consequence of its expansion, robs the vapour which it contains of its heat; whence

that vapour becomes condensed, and is precipitated in showers, as is visible in the receiver of an air-pump above mentioned.

There are, however, two other curious circumstances belonging to the devaporation of water, which have not been perhaps much attended to.

First, that the deduction of a small quantity of heat from a cloud or province of vapour, compared with the quantity of heat which was necessary to raise that vapour from water, will devaporate the whole. This circumstance is evident in the operation of common steam-engines, in which a small jet of water, whose heat is often above 48 degrees, perpetually devaporates the steam raised by a comparatively very great quantity of heat under the boiler. This difficult problem is explicable from the principles before established: if a small part of a province of vapour be suddenly condensed, a vacuity takes place, and the contiguous walls of vapour expand themselves into this vacuity; and thus a large area of vapour, perhaps of many miles in circumference, becomes more or less expanded; by this expansion cold is produced (that is, its capacity of receiving heat is increased), and the whole is devaporated.

This very circumstance exactly takes place in the famous steam-engine of Mess. WATT and BOULTON; which, from the happy combination of chemical and mechanic power, may justly be esteemed the first machine of human invention. In this excellent machine, after the cylinder is filled with steam, a communication is opened between this reservoir of steam and a small cell, which is kept cold by surrounding water, and free from air by an air-syringe adapted to it. What then happens? The corner of the steam in the cylinder next to this vacuum (with which it now communicates) rushes into it, and the whole steam in the cylinder is thus suddenly expanded,
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and instantly devaporated: whence the very quick reciprocations of the piston; and that, though the cylinder itself is always kept as hot as boiling water, that is, as hot as the steam was previous to its devaporation.

Something very similar to this is often seen at the commencement of thunder-storms; a small black cloud at first appears, in a few minutes the whole heaven is covered with condensing vapour, and the accumulation or escape of electric matter seems to be rather the consequence than the cause of this sudden and general devaporation.

A second curious circumstance of aërial devaporation is, that when the particles of aqueous vapour begin to approach each other by the diminution of their heat, they do not generate water exactly in proportion to such diminution of heat; but the condensation proceeds further, and not only a greater quantity of water is produced, but also a quantity of heat is set at liberty along with this excess of devaporation, and the atmosphere becomes warmer than before the beginning condensation. This excess of devaporation beyond the cold which produced it, is probably owing to the acquired momentum of the aqueous particles towards each other at the beginning of their condensation, which carries them still nearer each other; and to the small moleculeæ at first formed, possessing a greater attractive power over the uncondensed vapour in their vicinity, and thus pressing out more of the latent or combined heat.

Conclusion.

1. When a small portion of air, suppose a few acres, becomes suddenly contracted into a less compass, either by inci-

dental cold, or by any other cause not yet understood (as the combination of dephlogistic and inflammable gases), the air next in vicinity suddenly expands itself to occupy the vacuity; and by its expansion produces cold and devaporates, and then becomes compressible into less space than it occupied before it parted with its vapour. This then gives occasion to the next circum-ambient portion of air to go through the same process, that is, to expand, attract the heat from its vapours, devaporate, and then become compressible into less space; and thus, from a small and partial contraction or diminution of air, it seems possible to devaporate a great province.

2. The vapour of a great province of air being thus condensed, would leave a great vacuity in that part of the atmosphere, which would be supplied by winds rushing in on all sides. Suppose this to happen to the north of our climate, a south-west wind would be produced here, which is otherwise very difficult to understand: and if it should ever be in the power of human ingenuity to govern the course of the winds, which probably depends on some very small causes; by always keeping the under currents of air from the S.W. and the upper currents from the N.E. I suppose the produce and comfort of this part of the world would be doubled at least to its inhabitants, and the discovery would thence be of greater utility than any that has yet occurred in the annals of mankind.

November 22, 1787.

