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XXIII. *Of the State of Vapour subsisting in the Atmosphere.*

By RICHARD KIRWAN, Esq. LL. D. F. R. S. and P. R. I. A. *

VAPOUR or moisture in the atmosphere may subsist in dense air, or in air highly rarefied: that it is found in the former is well known, and that it may subsist in the latter appears by the observations of Bouguer; for he saw clouds three or four hundred toises above Chiromboracho, and consequently at the height of twenty-two thousand five hundred and twenty-eight English feet, or 4·3 miles over the level of the sea; a height at which in the temperature of 32° a barometer would stand at 12·7 inches. At such heights, and at much inferior, since evaporation proceeds much more quickly, it is not to be supposed that all the vapour so rapidly produced is dissolved in the ambient air, but part rises uncombined, as it does under an exhausted or half-exhausted receiver, and in this case Mr. De Luc's system is admissible. This emission of pure vapour seems to begin at heights at which the density of the air is 25, (that is, at heights at which the barometer would stand at twenty-five inches, and thus I shall in future express the various densities of air,) at least it is very considerable where the density is twenty. This leads me to treat of the properties and state of pure invisible vapour, namely, its specific heat, elasticity, and specific gravity.

The immortal Doctor Black, the father of all discoveries of this kind, informed me that the vapour of water, boiling at 212° , that is, at 180° above the freezing point, and possessing the same sensible heat as the water, contains nine hundred and forty times more latent heat than an equal weight of water does heated to 212° , or 5·222 times more latent heat than it does of sensible heat, counting from the freezing point, for $180 \times 5\cdot222 = 940$ nearly. In this case the pressure or density of the atmosphere is thirty, the barometer standing at the height of thirty inches; and with Doctor Black's account the experiments of Mr. Schmidt of Gießen very nearly agree; for according to him the latent heat of the vapour of water, barometer 29·84 inches, and the heat 212° , is 5·33 times greater than its sensible heat above the freezing point: now $180 \times 5\cdot33 = 959\cdot4$ †. The difference or excess in his experiment proceeds from the pressure of the at-

* From his paper intitled, "Of the Variations of the Atmosphere," Dublin, 1802.

† Gren's Physical Journal, iv. p. 315.

mosphere

mosphere being somewhat lower, as Mr. Watt's experiments prove.

Mr. Watt discovered that the latent heat of steam diminished in proportion as its sensible heat increased, *Phil. Trans.* 1784, p. 335. Now the sensible heat of steam exceeds 180° above the freezing point when the barometer stands above thirty inches, and less than 180° when the barometer stands lower than thirty inches, as Mr. De Luc first discovered, and may be seen in Sir George Schuckburgh's and Mr. De Luc's tables, *Phil. Trans.* 1779, p. 375. From these I have deduced the following table :

Heat of boiling water.	
Bar.	Heat.
30	212° ,
29	$210^{\circ}28$
28	$208^{\circ}52$
27	$206^{\circ}73$
26	$204^{\circ}91$
25	$203^{\circ}06$
24	$201^{\circ}18$
23	$199^{\circ}27$
22	$197^{\circ}33$
21	$195^{\circ}36$
20	$193^{\circ}36$
19	$191^{\circ}06$
18	$188^{\circ}46$
17	$185^{\circ}56$
16	$184^{\circ}36$
15	$180^{\circ}86$
14	$176^{\circ}70$

The accuracy of this table even in the lower part of the scale is sufficiently apparent by the result of the experiments of Saussure on ebullition on Mount Blanc ; for on that enormous mountain, the barometer standing at 16 French inches or $17^{\circ}05$ English, he found water to boil at the heat of $68^{\circ}993^{\circ}$ of Reaumur, a degree which on Geneva thermometers is equal to $185^{\circ}56^{\circ}$ English.—Hence we see that distillation may be more advantageously effected on mountains than on plains, and at low barometrical heights than at the greater, yet within certain limits ; for, at heights that surpass 8 or 10 thousand feet, the fuel, by reason of the rarity of the air, is more slowly consumed. Hence also, from the knowledge of the degree of the heat of ebullition to two or more decimal places, the state of the barometer above or below 212° may be inferred to one or more decimal places. The reason of this rapid diminution of the heat of ebullition below 25 inches is evidently the diminution of resistance, from the diminished weight of the atmosphere, which then is very sensible : but as the cold continually produced by evaporation is then also very considerable, the time necessary to procure ebullition is longer, as Saussure remarked on Mount Blanc. Vol. vii. in 8vo, § 2011, p. 328. He found the heat of ebullition barometer 16 to be $68^{\circ}993$ degrees, or in English measures barometer $17^{\circ}05$. $185^{\circ}5^{\circ}$ of Fahr. (counting one of Reaumur at Geneva = $2^{\circ}225$ of Fahr.)

Hence since, according to Mr. Watt, the sensible heats of the vapours of boiling water at different barometrical heights are as the barometrical heights reciprocally, and the specific heats

heats of the vapours of water boiling are as the sensible heats reciprocally, it being known, that the specific heat of the vapour of water heated to 180 degrees above the freezing point is 940. The specific or latent heat of the vapour of boiling water, whose sensible heat is known, (and it may be known by the barometrical height as shown in the above table and the notes) may also be discovered.

Thus the sensible heat of the vapour of boiling water barometer 30 being 180° above the freezing point ($212^{\circ} - 32^{\circ} = 180^{\circ}$) and the specific or latent heat of vapour, whose sensible heat is 208.56° (that is 176.56 above 32°) as it is when the barometer stands at 28 inches, is 958 for $\div 176.56. 180 :: 940.958^{\circ}$ *.

As pure invisible vapour does not in my opinion (of which I have already stated the grounds) exist in the atmosphere when its density is higher than 25, as it is in most of the inhabited parts of the globe, but is always in this case united to air, an inquiry into its latent heat at different temperatures below ebullition were superfluous. But as it does exist in air whose density is 25 or less, since it is found in air whose density is 12.5 , it becomes necessary to examine its latent heat in such cases, in all temperatures inferior to that of ebullition. Now, by analogy, I apprehend this latent heat in all inferior temperatures may thus be determined.

As the *sensible* heat of ebullition, when the barometer is at 25 or below 25, is to the *latent* heat of the vapour at ebullition, so is the *sensible* heat of water heated to any inferior degree above 32° to the latent heat of its vapour, multiplied by 5.222. Thus the sensible heat of water in ebullition barometer 25 being 171.4° ($= 203.4^{\circ} - 32^{\circ}$) its specific heat is 987 ($= \frac{169206}{171.4}$) the latent heat of the vapour of water at 22° above congelation (that is 52° on Fahr. scale) is 657 for $\div 171.4^{\circ} 987 :: 22^{\circ}. 1:6 \times 5.22 = 657$. The latent heat of vapour in such cases cannot be determined by experiment, on account of the admixture of atmospheric air: we must therefore resort to analogy, which in this case is perfect.

The latent heat of pure vapour at greater heights is more considerable: thus at heights, at which the barometer stands at 20 inches, the latent heat of vapour whose temperature is 22° above 32° , as in the last case, is 730; for the heat of ebullition is 141.8° , per table, $= 162.8^{\circ}$, above 32° : and the latent heat of the vapour at ebullition is 1039. Now $\div 162.8. 1039 :: 22. 140$ and $140 \times 5.22 = 730$.

* Hence 169206, being the product of $180^{\circ} \times 940$, is the common dividend of all sensible heats below 180° , when the latent heat of the vapour is sought at barometrical heights below 30 inches.

As air is cooled by the reception of moisture dissolved in it, we must infer that its capacity for containing heat is increased, and hence moist air is more difficultly heated or cooled than dry air of the same temperature. (For the cold proceeds from the absorption and not from the expulsion of caloric.)

The elasticity or expansive force of pure vapour has been examined at every fifth degree of Reaumur above 0 to 110°, by Mr. Betancourt, and may be seen in an excellent work of Prouy's, his *Architecture Hydraulique*: he has by a most ingenious calculation interpolated the expansions answering to the intermediate degrees. But Mr. Schmidt seems to have determined this expansive force still more exactly than Betancourt. Hence I here insert this table, adding Fahrenheit's for Reaumur's degrees, and distinguishing the expansions interpolated by calculation from those actually observed by I. The forces are measured by the elevation of a mercurial column in inches and hundreds of a French inch*.

Reaum.	Fahren.	Expansive Force.	Reaum.	Fahren.	Expansive Force.
1	34°25'	·01 I	21	79°25'	1°01 I
2	36°5	·03 I	22	81°5	1°01
3	38°75	·05 I	23	83°75	1°19 I
4	41°	·07 I	24	86°	1°29 I
5	43°25	·11	25	88°25	1°30
6	45°5	·15	26	90°5	1°38 I
7	47°75	·16 I	27	92°75	1°42
8	50°	·20 I	28	95°	1°60 I
9	52°25	·25 I	29	97°25	1°80 I
10	54°5	·28	30	99°5	1°93
11	56°75	·34 I	31	101°75	1°02 I
12	59°	·38	32	104°	1°12 I
13	61°25	·44	33	106°25	2°23
14	63°5	·50 I	34	108°5	2°40 I
15	65°75	·55	35	110°75	2°68
16	68°	·61	36	113°	2°80 I
17	70°25	·69 I	37	115°25	3°20
18	72°5	·76	38	117°5	
19	74°75	·84 I	39	119°75	3°40
20	77°	·90	40	122°	3°64
			80	212°	28°

* The Paris cubic inch = 1·21 English. Now the English cubic inch of mercury when its specific gravity is 13·6 weighs 3443·2 English grains: therefore the Paris inch weighs 4186 English grains, and 1-10th of this inch = 418·6 grains: and 1-100th of this inch 41·86 grains.

Note.

Note.—1°. Most of the interpolations from the 88th degree to the 122nd I have myself inserted, as those calculated by Schmidt erred too widely by his own account.—Gren's *Phys. Jour.* iv. 273.

2do. Mr. Piçtet has also made a set of curious experiments on the elasticity of pure vapour in low temperatures. *Essais de Physique*, p. 157. He found that a grain of warm water in *vacuo* evaporates in forty minutes in the temperature of 38° Fahr. under a receiver containing 1452 English cubic inches*, but that it did not diffuse itself equally in less than six hours, and then raised the hygrometer from 17° to 60°, that is 43°; and during this whole time the cold under the receiver was constantly decreasing, though slowly; which decrease undoubtedly contributed to the diffusion of the vapour.

Mr. Schmidt has also made a series of experiments upon the dilatibility of air, made as *dry* as possible by exposure to hot tartarin—an object of great importance, that had never before been examined. This table I here insert, converting Reaumur's degrees into those of Fahr. and adding from his formula the degrees he omitted.

Reau.	Fahren.	Expansion of one inch at 32°.	Reau.	Fahren.	Expansion of one inch at 32°.
1	34°25'	·0044675		79°25'	·0938175
	36°5'	·0089350		81°5'	·0982850
	38°75'	·0134025		83°75'	·1027525
4	41°	·0178700	24	86°	·1072200
	43°25'	·0223375		88°25'	·1116875
	45°5'	·0268050		90°5'	·116155
	47°75'	·0312726		92°75'	·1206225
8	50°	·035740	28	95°	·1250909
	52°25'	·0402075		97°25'	·1295557
	54°5'	·0446750		99°5'	·1340250
	56°75'	·0491425		101°75'	·1384925
12	59°	·0536100	32	104°	·1429600
	61°25'	·0580775		106°25'	·1474275
	63°5'	·0625450		108°5'	·1518950
	65°75'	·0670125		110°75'	·1563625
16	68°	·0714800	36	113°	·1608300
	70°25'	·0759475		115°25'	·1652975
	72°5'	·0804150		117°5'	·1697650
	74°75'	·0848825		119°75'	·1742325
20	77°	·0893500	40	122°	·1787000
				212°	·3574000

* Ibid. page 91.

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Note.

Note —1°. Hence we see that 1000 inches or measures of dry air at 32° would become 1004·4675 at 34·25 Fahr. and at 50° would become 1017·87. Hence 1000 measures of *dry* air gain 1·98555, &c. by each degree of Fahr. above 32° (or more compendiously 1·9856, which is true to two decimal places) or nearly two.

2do. We see the source of the discordant results of D'Amontons, De Luc, Lambert, Schuckburgh, Roy, Berthollet, and Monge, &c.; for they all operated upon air more impregnated with various degrees of moisture; besides taking the boiling point at different barometrical heights; in the present experiments it was taken at 29·841 English inches.

3tio. It appears that the expansions are as the differences of heat above 32°, as D'Amontons, Lambert and Schuckburgh also noticed; though their experiments, not being made on perfectly dry air, could not be very exact.

[To be continued.]

XXIV. *Some Conjectures respecting the Origin of Stones which have been observed to fall from the Clouds.* By WILLIAM BEAUFORD, A.M.*

THE falling of stones from the clouds, a natural phenomenon not generally understood, is by no means a novel circumstance in the history of nature. Several stones were observed to fall from the clouds in Yorkshire in 1360, in Bohemia and Saxony in 1480, in Bohemia about 1753, in Sienna in 1794, in Portugal in 1796, in Yorkshire in England in 1795, and near Benares in the East Indies in 1798. From an analysis made of these stones by the French academicians in 1768, and by the Royal Society of London in 1802, they are all found similar in their component parts to each other, but dissimilar to all bodies found in mines and quarries, being composed principally of four kinds of substances: the first being in the form of dark grains, composed of flint, magnesia, iron, and nickel; the second, a kind of pyrites; the third, metallic iron; and the fourth, a gray earthy substance which serves as a cement to the others, and with which they were coated. From these compositions the matter seems to be of volcanic origin; yet it is difficult to conceive how stones of any considerable magnitude could be thrown at such a distance from any volcano as those found in Bohemia, Saxony, and Britain. The nearest volcanos to Britain are those of Vesuvius, *Ætna*, and *Hecla*: a stone to be thrown into Bri-

* Communicated by the Author.