EXPERIMENTAL ESSAYS

On the Constitution of mixed GASES; *on the Force of* STEAM *or* VAPOUR *from Water and other Liquids in different temperatures, both in a Torricellian Vacuum and in Air; on* EVAPORATION; *and on the Expansion of* GASES *by Heat.*

BY JOHN DALTON.

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THE progress of philosophical knowledge is advanced by the discovery of new and important facts; but much more when those facts lead to the establishment of *general* laws. It is of importance to understand that the descent of falling bodies is the same every where on the surface of the earth; but from that and some other particular facts to infer the law of gravitation, or that all matter attracts with a force decreasing as the square of the distance, is a much higher attainment in science. In the train of experiments lately engaging my attention some new facts have been ascertained, which with others, seem to authorise the deduction of general laws, and such as will have influence in various departments of natural philosophy and chemistry.

As the detail of experiments will be best understood and their application seen, if the laws of principles alluded to be kept in view, it may be proper here to state them; though it must not be understood that they were proceeded upon hypothetically in the direction of those experiments. On the contrary, the first law, which is as a mirror in which all the experiments are best viewed, was *last* detected, and after all the particular facts had been previously ascertained.

1. When two elastic fluids, denoted by *A* and *B*, are mixed together, there is no mutual repulsion amongst their particles; that is, the particles of *A* do not repel those of *B*, as they do one another. Consequently, the pressure or whole weight upon any one particle arises solely from those of its own kind.

2. The force of steam from all liquids is the same, at equal distances above or below the several temperatures at which they boil in the open air: and that force is the same under any pressure of an other elastic fluid as it is in vacuo. Thus, the force of *aqueous* vapour of 212° is equal to 30 inches of mercury; at 30° below, or

182°, it is of half that force; and at 40° above, or 252°, it is of double the force; so likewise the vapour from sulphuric ether which boils at 102°, then supporting 30 inches of mercury, at 30° below that temperature it has half the force, and at 40° above it, double the force: and so in other liquids. Moreover, the force of aqueous vapour of 60° is nearly equal to $\frac{1}{2}$ inch of mercury, when admitted into a torricellian vacuum; and water of the same temperature, confined with perfectly dry air, increases the elasticity to just the same amount.

3. The quantity of any liquid evaporated in the open air is directly as the force of steam from such liquid at its temperature, all other circumstances being the same.

4. All elastic fluids expand the same quantity by heat: and this expansion is very nearly in the same equable way as that of mercury; at least from 32° to 212°.—It seems probable the expansion of each particle of the same fluid, or its sphere of influence, is directly as the quantity of heat combined with it; and consequently the expansion of the fluid as the cube of the temperature, reckoned from the point of total privation.

Having now stated the chief principles which seem to be established from the following series of facts and observations, I shall proceed to treat of them under the several heads.

ESSAY I.

On the Constitution of mixed Gases: and particularly of the Atmosphere.

Ever since the discovery of the atmosphere consisting of two distinguishable elastic fluids of different specific gravities, it has been a subject of insurmountable difficulty to explain clearly the mode of their combination. Two opinions have been given respecting it: the one supposes that the two fluids are merely mixed together, without any chemical combination; but assigns no reason why they do not separate and the heaviest take the lowest place. The other supposes a true chemical union to exist between the two, and thus obviates the difficulty arising from the consideration of specific gravity; but this produces others of no less magnitude. Why does no change of bulk, of temperature, or of any of their distinct properties take place, which is usual on all other chemical combinations? Why do not oxygenous and azotic gases taken in due proportion, and mixed, constitute nitric acid gas, another elastic fluid, totally distinct in its properties from either of the ingredients? To these questions, and many others that might be proposed, no satisfactory answer has ever been given. Indeed this hypothesis is much the most untenable of the two; the notion of chemical affinity connecting elastic particles mutually *repelling* each other is plainly an absurdity; and if we suppose the particles to have no repulsion to each other, but instead of it to coalesce, then it is impossible to conceive why they do not form nitric acid gas, and why a change of bulk, or temperature, or both does not occur. All these difficulties are entirely removed by the subsequent theory, for the understanding of which it will be needful to premise certain propositions.

Prop. 1. The density of elastic fluids is exactly as the compressing force, all other circumstances alike.

This is a physical proposition and depends upon experiment for proof. All experiments agree that if a quantity of air be pressed with two, three, &c. times the force of the atmosphere, it will occupy $\frac{1}{2}$, $\frac{1}{3}$, &c. of the space occupied before; and when the pressure of the atmosphere is taken off it expands accordingly. This I find is not *strictly* true with regard to atmospheric air; which, when condensed with a double force, occupies a space something *less* than what the above ratio assigns; because aqueous vapour, one of the elements of atmospheric air, loses its form, or becomes partly converted into water by pressure. If air confined by sulphuric acid be tried, it accords very exactly with the above law. If air confined by water be tried, the condensed air is always something *less* and the rarefied air something *more* than what the theory assigns, which is entirely owing to the destruction or formation of a quantity of aqueous vapour. My method of experimenting is very simple; it consists in condensing or rarefying the air by a column of mercury in a long straight tube, divided into equal portions; the tube must be $\frac{1}{12}$ or $\frac{1}{15}$ of an inch internal diameter, and then it may be inverted without losing its contents, if the mercurial column be less than 30 inches, when the rarefaction of air is the object.

Prop. 2. Homogeneous elastic fluids are constituted of particles that repel one another with a force decreasing directly as the distance of their centres from each other.

This proposition is a mathematical one, and its demonstration founded upon the fact of the density being as the pressure. The proof may be seen in the Principia, B. 2. Prop. 23. It follows too that the distances of the centres of the particles, or which is the same thing, the diameters of the spheres of influence of each particle, are inversely as the cube root of the density of the fluid.

The proposition applies to *homogeneous* elastic fluids only; how far it may apply to mixed fluids remains to be considered.—With regard to the constitution of such there may be several hypotheses; some of which we shall now consider.

1. *The particles of one elastic fluid may repel those of another with the same force as they repel those of their own kind.*

In this case, if m measures of A were mixed with n measures of B, in the pneumatic apparatus, and under the atmospheric pressure of 30 inches of mercury, the two would occupy $m+n$ measures of space. If they were of the same specific gravity, they would remain in the situation they were left, of intimate mixture or of separation, as it happened. If they were of different specific gravities, the lightest would rise to the top of the vessel:—The pressure on each particle of the mixture would be equal to 30 inches of mercury.

Now with regard to the application of these principles; as we know of no two elastic fluids, which when mixed, obey the laws of their specific gravities; this hypothesis is inconsistent with the phenomena.

2. *Particles of one elastic fluid may repel those of another with forces greater or less than what they exert upon their own kind.*

Here again m measures of A, with n measures of B would occupy $m+n$ measures, and the pressure on each particle of the mixture be the same, and equal to 30 inches of mercury. But the fluids in this case could not remain mixed or diffused intimately through each other; that fluid of the greatest specific gravity must take the lowest place.—This therefore is equally inconsistent with the known phenomena, and must be rejected also.

3. *The particles of one elastic fluid may have a chemical affinity or attraction for those of another.*

Here if m measures of A and n measures of B were mixed, a union of particles ensues, and the new compound may assume the solid, liquid or aëriform state according to its nature. If the compound be of the solid or liquid form, the two elastic fluids may wholly disappear; if it be aëriform, then a diminution of bulk, an increase of temperature and of specific gravity may be expected——Several facts in chemistry accord with this hypothesis.—When muriatic acid gas and ammoniacal gas are mixed together in due proportion, a solid substance, muriate of ammonia, is formed, and the gases wholly disappear. When ammoniacal gas and aqueous vapour are mixed, the two unite and a portion of the compound becomes liquid. When nitrous gas and oxygenous gas are mixed in due proportion, the two unite and form a new elastic compound of greater specific gravity and consequently of less bulk, nitric acid gas.—But there are other cases of mixtures of elastic fluids, some of which have been mentioned, where no signs of chemical affinity are discoverable; in regard to such this hypothesis fails equally with the other two. We must therefore have recourse to another.

4. *The particles of one elastic fluid may possess no repulsive or attractive power, or be perfectly inelastic with regard to the particles of another: and consequently the mutual action of the fluids be subject to the laws of inelastic bodies.*

According to this hypothesis if *m* measures of *A* be mixed with *n* measures of *B*, the two will occupy $m+n$ measures of space. The particles of A meeting with no repulsion from those of B further than that repulsion which as obstacles in the way they may exert, would instantly recede from each other as far as possible in their circumstances, and consequently arrange themselves just the same as in a void space; their density, considered abstractedly, becoming $\frac{m}{m+n}$, (that of the compound being supposed unity). In like manner the particles of B must recede from each other, till they become of the density $\frac{n}{m+n}$; thus the two gases become rarefied to such degree that their united forces only amount to the pressure of the atmosphere.—Here the particles of one fluid not pressing at all upon those of the other, the consideration of specific gravity does not enter. That part of the atmospheric pressure which the fluid A sustains, will be $\frac{m}{m+n}$; and the remainder, $\frac{n}{m+n}$, is the part that the fluid B sustains. The weight or pressure upon any one particle of any fluid mixture of this sort will arise solely from the particles of its own kind.

It is scarcely necessary, I think, to insist upon the application of this hypothesis to the solution of all our difficulties respecting the constitution of mixed gases where no chemical union ensues.

That moment we admit it every difficulty vanishes, and every fact appears a simple and immediate consequence of it. The atmosphere, or to speak more properly the compound of atmospheres, may exist together in the most intimate mixture, without any regard to their specific gravities, and without any pressure upon one another. Oxygenous gas, azotic gas, hydrogenous gas, carbonic acid gas, aqueous vapour, and probably several other elastic fluids may exist in company under any pressure and in any temperature, whilst each of them, however paradoxical it may appear, occupies the whole space allotted for them all. For, the space with them all in it, is little more comparatively than a vacuum; such is the great tenuity of all elastic fluids.

I shall now proceed to make a few observations on that collected mas of elastic fluids constituting our atmosphere, the principal of which are the *azotic* atmosphere, the *oxygenous* atmosphere, the *aqueous vapour* atmosphere, the *carbonic acid* atmosphere and the *hydrogenous* atmosphere.

Before the modern discoveries in chemistry, the atmosphere was considered as *one* simple elastic fluid, *sui generis*, containing in it, by some means or other, certain foreign substances not essentially but accidentally mixed with it. Lavoisier taught us there were *two* essentially distinguishable fluids to be found in it, and certain other substances accidentally or chemically combined with them; it now appears there are at least *four* distinct elastic fluids found in every portion of atmospheric air subject to examination. And these, for aught that appears, are totally independent one of another; so much that if any one of them was wholly withdrawn from the surface of the earth, the rest would not at all be affected by the circumstance, either in their density or situation; or if an atmosphere of another kind were added to them, they would still retain their respective stations and densities, provided that added had no chemical affinity for any one of them in the common temperature.

The *azotic* atmosphere is by far the largest and densest of them all: it supports the mercury in the barometer at a medium nearly 21. 2 inches: it is the same in quantity all over the surface of the earth; because not condensible into a liquid form at any temperature found there.

The *oxygenous* atmosphere is the next in quantity; its pressure on the surface of the earth amounts to about 7. 8 inches at a medium; it is the same nearly in quantity every where, because it preserves its elasticity in all observable temperatures.

The *aqueous vapour* atmosphere is variable in quantity according to temperature; in the torrid zone its pressure on the surface of the earth is equal to the force of ,6 and from that to one inch of mercury. In these parts it rarely amounts to a pressuse of ,6, but I have frequently observed it above half an inch in summer; in winter it is sometimes so low as to be of no more force than ,1 of an inch of mercury, or even half a tenth, in this latitude, and consequently much less where the cold is more severe.* This want of equilibrium in the aqueous vapour atmosphere is a principal cause of that constant inundation of it into the temperate and frigid zones, where it be comes in part condensed in its progress by the cold, like the vapour of distillation in the worm of a refrigeratory, and supplies the earth with rain and dew.

The *carbonic acid* atmosphere has not perhaps been accurately ascertained in quantity; it is found every where in a small proportion, not being condensible into a liquid by the usual degree of cold; its pressure may probably amount to half an inch of mercury.

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* The means of ascertaining its quantity or pressure will be given hereafter.

The *hydrogenous* atmosphere is so small in quantity as scarcely to be at all appreciable; yet, as various processes on the surface of the earth disengage this gas, and as it mixes with all the other gases constituting the atmosphere without combining with any, or rising above them, we ought to find a proper *hydrogenous* atmosphere. Perhaps we have got no tests for ascertaining very small quantities of it.

Lavoisier describes the atmosphere to be "a compound of all the fluids which are susceptible of the vaporous or permanently elastic state in the usual temperature, and *under the common pressure*." This last limitation should be omitted; he seems moreover to conceive that atmospheric pressure is the cause why water retains its liquid form at the common temperature: this notion is certainly wrong; were every atmosphere, except that of aqueous vapour, instantly annihilated, little addition would be made to the aqueous atmosphere, because it already exists in every place, almost entirely up to what the temperature will admit; the evaporation of water would be essentially the same in that case as it is at present; only the full effect would take place in less time. In short this notion of pressure preventing the evaporation of liquids, which seems to have been taken as an axiom by modern philosophers, has been the cause of more error and perplexity perhaps than any other ungrounded opinion.

Lavoisier thought that in the higher regions of the atmosphere a stratum of inflammable fluid exists in which the aurora borealis and other fiery appearances are produced; this opinion is plausible enough; but that fluid cannot be hydrogenous gas, because its particles are not repulsive of those of the other atmospheric gases, as appears by its intimate and almost instantaneous diffusion amongst them.

There may be gases in the higher regions of which we have not the principles below, the whole stock of matter being spent in their formation; and being constituted of particles repulsive of those of the atmosphere, according to the first or second hypothesis, and of less specific gravity than the other gases, they must float upon the surface of the common atmosphere, and consequently for ever elude the investigation of philosophy. He observes that even *metallic* substances may be found within the regions of the atmosphere: I have myself shewn, in my Meteorological Essays, page 180, that a fluid possessing *magnetic* properties constantly holds a place in the higher regions of the atmosphere, and which therefore we cannot help considering of a *ferruginous* quality; but it will probably ever be beyond the reach of philosophical research to ascertain the nature of so subtile and distant a fluid.

ESSAY II.

On the Force of Steam or Vapour from Water and various other Liquids, both in a Vacuum and in Air.

SECTION I.

On Vapour in Vacuo.

The term *steam* or *vapour* is equally applied to those elastic fluids which, by cold and pressure of certain known degrees, are reduced wholly or in part into a liquid state. Such are the elastic fluids arising from water, alkohol, ether, ammonia, mercury, &c. Other elastic fluids that cannot be reduced, or rather that have not yet been reduced, into a liquid state by the united agency of those two powers, are commonly denominated *gases.* There can scarcely be a doubt entertained respecting the reducibility of of all elastic fluids of whatever kind into liquids; and we ought not to despair of effecting it in low temperatures and by strong pressure exerted upon the unmixed gases. However unessential the distinction between the gases and vapours may be in a chemical sense, their *mechanical* action is very different. By increasing the quantity of any gas in a given space the force of it is proportionally increased; but increasing the quantity of any liquid in a given space does not at all affect the force of the vapour arising from it. On the other hand, by increasing the temperature of any gas a proportionate increase of elasticity ensues; but when the temperature of a liquid is increased, the force of vapour from it is increased with amazing rapidity, the increments of elasticity forming a kind of geometrical progression, to the arithmetical increments of heat.—Thus, the ratio of the elastic force of atmospheric air of 32° to that at 212°, is nearly as 5 : 7; but the ratio of the force of aqueous vapour proceeding from water of 32° and 212°, is as 1 : 150 nearly.

The object of the present essay is to determine the utmost force that certain vapours, as that from water, can exert at different temperatures. The importance hitherto attached to this enquiry has arisen chiefly from the consideration of steam as a mechanical agent; and this has directed the attention more especially to high temperatures. But it will appear from what follows that the progress of philosophy is more immediately interested in accurate observations on the force of steam in low temperatures. Different authors have published accounts of their experiments on the force of steam: I have on a former occasion (Meteorological Essays, page 134) given a table of forces for every 10° from 80° to 212°. The author of the article "Steam" in the Encyclopedia Britannica, has done the same from 32° to 280°: and M. Betancourt, in the "Memoirs des sçavans etrangeres" for 1790, (see Hutton's Math. Diction. page 755) has given tables on the subject, both for vapour from water and spirit of wine, also from 32° to 280°. But these two authors, having assumed the force of vapour from water of 32° to be nothing, are essentially wrong at that point and in all the lower parts of the scale; and in the higher part, or that above 212°, they determine the force too much; owing as I apprehend to a quantity of air, which being disengaged from the water by heat and mixing with the steam, increases the elasticity.—In a question of such moment it seemed therefore desirable to obtain greater accuracy.

My method is this: I take a barometer tube perfectly dry, and fill it with mercury just boiled, marking the place where it is stationary; then having graduated the tube into inches and tenths by means of a file, I pour a little water (or any other liquid the subject of experiment) into it, so as to moisten the whole inside; after this I again pour in mercury, and, carefully inverting the tube, exclude all air: the barometer by standing some time exhibits a portion of water, &c. of $\frac{1}{8}$ or $\frac{1}{10}$ of an inch upon the top of the mercurial column; because being lighter it ascends by the side of the tube; which may now be inclined and the mercury will rise to the top manifesting a perfect vacuum from air. I next take a cylindrical glass tube open at both ends, of 2 inches diameter and 14 inches in length; to each end of which a cork is adapted, perforated in the middle so as to admit the barometer tube to be pushed through and to be held fast by them; the upper cork is fixed two or three inches below the top of the tube and is $\frac{1}{2}$ cut away so as to admit water, &c. to pass by; its service being merely to keep the tube steady. Things being thus circumstanced, water of any temperature may be poured into the wide tube, and thus made to surround the upper part or vacuum of the barometer, and the effect of temperature in the production of vapour within can be observed from the depression of the mercurial column. In this way I have had water as high as 155° surrounding the vacuum: but as the higher temperatures might endanger a glass apparatus; instead of it I used the following:—

Having procured a tin tube of 4 inches in diameter and 2 feet long, with a circular plate of the same soldered to one end having a round hole in the centre, like the tube of a reflecting telescope, I got another smaller tube of the same length soldered into the larger, so as to be in the axis or centre of it: the small tube was open at both ends, and on this construction water could be poured into the large vessel to fill it, whilst the central tube was exposed to its temperature. Into this central tube I could insert the upper half of a syphon barometer, and fix it by a cork, the top of the narrow tube also being corked: thus the effect of any temperature under 212° could be ascertained, the depression of the mercurial column being known by the ascent in the exterior leg of the syphon.

The force of vapour from water, between 80 and 212° may also be determined by means of an air-pump; and the results exactly agree with those determined as above. Take a Florence flask half filled with hot water, into which insert the bulb of a thermometer; then cover the whole with a receiver on one of the pump plates, and place a barometer gage on the other: the air being slowly exhausted, mark both the thermometer and barometer at the moment ebullition commences, and the height of the barometer gage will denote the force of vapour from water of the observed temperature. This method may also be used for other liquids. It may be proper to observe the various thermometers used in these experiments were duly adjusted to a good standard one.

After repeated experiments by all these methods, and a careful comparison of the results, I was enabled to digest the following table of the force of steam from water in all the temperatures from 32° to 212°.

Two important enquiries still remained: the first, to determine the force of steam from water above 212° and below 32°; the second, to determine the comparative forces of vapour from other liquids. These enquiries seemed independent of each other; notwithstanding which I found them in reality connected.

Upon examination of the numbers in the table within the limits just mentioned, there appears something like a geometrical progression in the forces of vapour; the ratio however, instead of being constant, is a gradually diminishing one: thus, the force at 32° = ,200 inch.

—— at 122° = 3. 500 $\left.\begin{array}{r} 17.\ 50 \\ 8.\ 57 \end{array}\right\}$ Ratios

212° = 30. 000

If we divide these ratios, according to observation, they will stand thus:

Force at	32° =	,200 inch.		
			4. 550	
	77° =	,910		
			3. 846	
	122° =	3. 500		Ratios
			3. 214	
	167° =	11. 250		
			2. 666	
	212° =	30. 000		

If we divide these again, they become;

Force at	32° =	,200 inch.		
			2. 17	
	54°½ =	,435		
			2, 09	
	77° =	,910		
			2. 00	
	99°½ =	1. 820		
			1. 92	
	122° =	3. 500		Ratios
			1. 84	
	144°½ =	6. 450		
			1. 75	
	167° =	11. 250		
			1. 67	
	189°½ =	18. 800		
			1. 59	
	212° =	30. 000		

By another division we obtain the ratios for every 11°¼ of temperature from 32° to 212° as under:

Force at	32° =	,200 inch.		
			1. 485	
	43¼ =	,297		
			1. 465	
	54½ =	,435		
			1. 45	
	65¾ =	,630		
			1. 44	
	77 =	,910		
			1. 43	
	88¼ =	1. 290		
			1. 41	
	99½ =	1. 820		
			1. 40	
	110¾ =	2. 540		
			1. 38	
	122 =	3. 500		Ratios
			1. 36	
	133¼ =	4. 760		
			1. 35	
	144½ =	6. 450		
			1. 33	
	155¾ =	8. 550		
			1. 32	
	167 =	11. 250		
			1. 30	
	178¼ =	14. 600		
			1. 29	
	189½ =	18. 800		
			1. 27	
	200¾ =	24. 000		
			1. 25	
	212 =	30. 000		

Thus it appears that a ratio having a uniform decrease nearly takes place; and we may therefore extend the table of forces at both extremes, without the aid of experiment, to a considerable distance. Thus, assuming the ratios for each interval of 11°¼ below 32° to be, 1. 500, 1. 515, 1. 530, 1. 545, &c. and for each interval above 212° to be 1. 235, 1. 220, 1. 205, 1. 190, 1. 175, 1. 160, 1. 145, 1. 130, &c. we can extend the table many intervals of temperature, and determine all the intermediate degrees by interpolation. This method may be relied upon as a near approximation; however it does not supersede the expediency of determination by experiment; though that is much more difficult above 212°, and below 32°, than in the intermediate degrees: because it is dfficult to procure a steady heat above 212°; and below 32° the variation of force becomes so small as to elude minute discrimination. It will appear from what follows that the extension of the table by this method above 212° is in all probability accurate, or very nearly so, for 100° or more.

TABLE

Of the Force of Vapour from Water in every temperature from that of the congelation of Mercury, or 40° below zero of Fahrenheit, to 325°.

Temperature. °	Force of Vap. in inches of Mercury.	Temperature. °	Force of Vap. in inches of Mercury.	Temperature. °	Force of Vap. in inches of Mercury.
-40	,013	15	,108	34	,214
-30	,020	16	,112	35	,221
-20	,030	17	,116	36	,229
-10	,043	18	,120	37	,237
		19	,124	38	,245
0	,064	20	,129	39	,254
1	,066	21	,134	40	,263
2	,068	22	,139	41	,273
3	,071	23	,144	42	,283
4	,074	24	,150	43	,294
5	,076	25	,156	44	,305
6	,079	26	,162	45	,316
7	,082	27	,168	46	,328
8	,085	28	,174	47	,339
9	,087	29	,180	48	,351
10	,090	30	,186	49	,363
11	,093	31	,193	50	,375
12	,096			51	,388
13	,100	32	,200	52	,401
14	,104	33	,207	53	,415

TABLE CONTINUED.

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap in inches of Mercury	Temperature.	Force of Vap. in inches of Mercury.
54°	,429	82°	1. 07	110°	2. 53
55	,443	83	1. 10	111	2. 60
56	,458	84	1. 14	112	2. 68
57	,474	85	1. 17	113	2. 76
58	,490	86	1. 21	114	2. 84
59	,507	87	1. 24	115	2. 92
60	,524	88	1. 28	116	3, 00
61	,542	89	1. 32	117	3. 08
62	,560	90	1. 36	118	3. 16
63	,578	91	1. 40	119	3. 25
64	,597	92	1. 44	120	3. 33
65	,616	93	1. 48	121	3. 42
66	,635	94	1. 53	122	3. 50
67	,655	95	1. 58	123	3. 59
68	,676	96	1. 63	124	3. 69
69	,698	97	1. 68	125	3. 79
70	,721	98	1. 74	126	3. 89
71	,745	99	1. 80	127	4. 00
72	,770	100	1. 86	128	4. 11
73	,796	101	1. 92	129	4. 22
74	,823	102	1. 98	130	4. 34
75	,851	103	2. 04	131	4. 47
76	,880	104	2. 11	132	4. 60
77	,910	105	2. 18	133	4. 73
78	,940	106	2. 25	134	4. 86
79	,971	107	2. 32	135	5. 00
80	1. 00	108	2. 39	136	5. 14
81	1. 04	109	2. 46	137	5. 29

TABLE CONTINUED.

Temperature. °	Force of Vap: in inches of Mercury.	Temperature. °	Force of Vap. in inches of Mercury.	Temperature. °	Force of Vap. in inches of Mercury.
138	5. 44	166	10. 96	194	20. 77
139	5. 59	167	11. 25	195	21. 22
140	5. 74	168	11. 54	196	21. 68
141	5. 90	169	11. 83	197	22. 13
142	6. 05	170	12. 13	198	22. 69
143	6. 21	171	12. 43	199	23. 16
144	6. 37	172	12. 73	200	23. 64
145	6. 53	173	13. 02	201	24. 12
146	6. 70	174	13. 32	202	24. 61
147	6. 87	175	13. 62	203	25. 10
148	7. 05	176	13. 92	204	25. 61
149	7. 23	177	14. 22	205	26. 13
150	7. 42	178	14. 52	206	26. 66
151	7. 61	179	14. 83	207	27. 20
152	7. 81	180	15. 15	208	27. 74
153	8. 01	181	15. 50	209	28. 29
154	8. 20	182	15. 86	210	28. 84
155	8. 40	183	16. 23	211	29. 41
156	8. 60	184	16. 61	212	30. 00
157	8. 81	185	17. 00		
158	9. 02	186	17. 40	213	30. 60
159	9. 24	187	17. 80	214	31. 21
160	9. 46	188	18. 20	215	31. 83
161	9. 68	189	18. 60	216	32. 46
162	9. 91	190	19. 00	217	33. 09
163	10. 15	191	19. 42	218	33. 72
164	10. 41	192	19. 86	219	34. 35
165	10. 68	193	20. 32	220	34. 99

TABLE CONTINUED.

Temperature. °	Force of Vap in inches of Mercury.	Temperature. °	Force of Vap. in inches of Mercury.	Temperature. °	Force of Vap. in inches of Mercury.
221	35. 63	249	57. 31	277	85. 47
222	36. 25	250	58. 21	278	86. 50
223	36. 88	251	59. 12	279	87. 63
224	37. 53	252	60. 05	280	88. 75
225	38. 20	253	61. 00	281	89. 87
226	38. 89	254	61. 92	282	90. 99
227	39. 59	255	62. 85	283	92. 11
228	40. 30	256	63. 76	284	93. 23
229	41. 02	257	64. 82	285	94. 35
230	41. 75	258	65. 78	286	95. 48
231	42. 49	259	66. 75	287	96. 64
232	43. 24	260	67. 73	288	97. 80
233	44. 00	261	68. 72	289	98. 96
234	44. 78	262	69. 72	290	100. 12
235	45. 58	263	70. 73	291	101. 28
236	46. 39	264	71. 74	292	102. 45
237	47. 20	265	72. 76	293	103. 63
238	48. 02	266	73. 77	294	104. 80
239	48. 84	267	74. 79	295	105. 97
240	49. 67	268	75. 80	296	107. 14
241	50. 50	269	76. 82	297	108. 31
242	51. 34	270	77. 85	298	109. 48
243	52. 18	271	78. 89	299	110. 64
244	53. 03	272	79. 94	300	111. 81
245	53. 88	273	80. 98	301	112. 98
246	54. 68	274	82. 01	302	114. 15
247	55. 54	275	83. 13	303	115. 32
248	56. 42	276	84. 35	304	116. 50

TABLE CONTINUED.

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
°		°		°	
305	117. 68	312	125. 85	319	133. 86
306	118. 86	313	127. 00	320	135. 00
307	120. 03	314	128. 15	321	136. 14
308	121. 20	315	129. 29	322	137. 28
309	122, 37	316	130. 43	323	138. 42
310	123. 53	317	131. 57	324	139. 56
311	124. 69	318	132. 72	325	140. 70

On Vapour from Ether, &c.

We come now to the consideration of vapour from other liquids. Some liquids are known to be more evaporable than water; as, liquid ammonia, ether, spirit of wine, &c. others less; as, quicksilver, sulphuric acid, liquid muriate of lime, solution of potash, &c. and it appears that the force of vapour from each in a vacuum is proportionate to its evaporability. M. Betancourt maintains that the force of vapour from spirit of wine is in a constant ratio to that from water at all temperatures; namely, as 7 to 3 nearly. My first experiments with spirits of wine led me to adopt this conclusion, and naturally suggested that the force of vapour from any other liquid would bear a constant ratio to that of water. The principle however is not true, either with regard to spirit of wine or any other liquid. Experiments made upon six different liquids agree in establishing this as a general law; namely, *that the variation of the force of vapour from all liquids is the same for the same variation of temperature, reckoning from vapour of any given force:* thus, assuming a force equal to 30 inches of mercury as the standard, it being the force of vapour from any liquid boiling in the open air, we find *aqueous* vapour loses half its force by a diminution of 30° of temperature; so does the vapour of any other liquid lose half its force by diminishing its temperature 30° below that in which it boils; and the like for any other increment or decrement of heat. This being the case, it becomes unnecessary to give distinct tables of the force of vapour from different liquids, as one and the same table is sufficient for all.—But it will be proper to relate the experiments on which this conclusion rests.

Experiments on Sulphuric Ether.

The ether I used boiled in the open air at 102°.—I filled a barometer tube with mercury, moistened by agitation in ether. After a few minutes a portion of ether rose to the top of the mercurial column, and the height of the column became stationary. When the whole had acquired the temperature of the air in the room, 62°, the mercury stood at 17. 00 inches, the barometer at the same time being 29. 75. Hence the force of vapour from ether at 62° is equal to 12. 75 inches of mercury, which accords with the force of aqueous vapour at 172°, temperatures which are 40° from the respective boiling points of the liquids. By subsequent observations I found the forces of the vapour from ether in all the different temperatures from 32° to 102° exactly corresponded with the forces of aqueous vapour of the like range, namely from 142° to 212°: the vapour from ether depresses the mercury about 6 inches in the temperature of 32°.

Finding that ether *below* the point of ebullition agreed with water below the said point, I naturally concluded that ether *above* the point would give the same force of vapour as water above it; and in this I was not disappointed; for, upon trial it appeared that what I had inferred only from analogical reasoning respecting the force of aqueous vapour above the boiling point, actually happened with that from ether above the said point. And ether is a much better subject for experiment in this case than water, because it does not require so high a temperature.

I took a barometer tube of 45 inches in length, and having sealed it hermetically at one end, bent it into a syphon shape, making the legs parallel, the one that was close being 9 inches long, and the other 36. Then conveyed two or three drops of ether to the end of the closed leg, and filled the rest of the tube with mercury, except about 10 inches at the open end. This done, I immersed the whole of the short leg containing the ether into a tall glass containing hot water; the ether thus exposed to a heat above the temperature at which it boils, produced a vapour more powerful than the atmosphere, so as to overcome its pressure and raise a column of mercury besides, of greater or less length according to the temperature of the water. When the water was at 147° the vapour raised a column of 35 inches of mercury, when the atmospheric pressure was 29. 75: so that vapour from ether of 147° is equivalent to a pressure of 64. 75 inches of mercury; agreeing with the force of aqueous vapour of 257°, according to the preceding estimation: in both cases the temperatures are 45° above the respective points of ebullition. In all the temperatures betwixt 102 and 147° the forces of ethereal vapour corresponded with those of aqueous vapour, as per table, betwixt 212° and 257°. I could not reasonably doubt of the equality continuing in higher temperatures; bnt the force increases so fast with the increase of heat, that one cannot extend the experiments much farther without tubes of very inconvenient lengths. Being desirous however to determine the force of the ethereal vapour experimentally up as high as 212°, I contrived to effect it as follows:—Took a syphon tube such as described above, only not quite so long, and filled it in the manner above mentioned, with ether and mercury, leaving about ten inches at the top of the tube vacant; then having graduated that part into equal portions of capacity, and dried it from ether, I drew out the end of the tube to a capillary bore, cooled it again so as to suffer the internal atmospheric air to be of the proper density, and suddenly sealed the tube hermetically, thus inclosing air of a known force in the graduated portion of the tube. Then, putting that part of the tube containing ether into boiling water, vapour was formed which forced the mercurial column upwards and condensed the confined air, till at length an equilibrium took place. In this way I found 8. 25 parts of atmospheric air of the force 29. 5 were condensed into 2. 00, at the same time a perpendicular column of 16 inches of mercury in addition pressed upon the vapour. Now the force of elastic fluids being inversely as the space, we have 2. 00 : 29. 5 :: 8. 25 : 121. 67 inches = the force of the air within; to which adding 16 inches, we obtain 137. 67 = the whole force sustained by the vapour, measured in inches of mercury. The force of aqueous vapour, at the same distance beyond the boiling point, or 322°, is equal to 137. 28, per table. Thus it appears that in every part of the scale on which experiments have been made, the same law of force is observable with the vapour of ether as of water.

Experiments on Spirit of Wine.

By boiling a small portion of the spirit I used (about one cubic inch) in a phial, the thermometer stood at 179° at the commencement; but by continuing the ebullition it acquired a greater heat. The reason is, the most evaporable part of the spirit flies off during the process of heating, and the rest being a weaker compound, requires a stronger heat. The true point of ebullition, I believe, was nearly 175°.—The force of the vapour from this spirit at the temperature of 212°, I found both by an open syphon tube and one hermetically sealed with atmospheric air upon the mercurial column, as with ether, to be equal to 58½ inches of mercury. This rather exceeds the force of aqueous vapour at an equal distance from the boiling point; but it is no more than may be attributed to unavoidable little errors in such experiments. In a barometer tube the spirituous vapour at 60°, over the mercury, depresses the column about 1. 4 or 1. 5 inches; which is something less than the due proportion ; one cause of this may be the evaporability of spirits, which in operating on small quantities, quickly dissipates part of their strength.

Experiments on Liquid Ammonia.

Liquid ammonia or volatile alkali, the specific gravity of which was .9474, boiled near 140°; in the barometer a small quantity depressed the mercury 4. 3 inches in the temperature of 60°. In higher temperatures it did not produce a proportional depression ; because the most volatile part of the compound, expanding in the vacuum of the barometer, leaves the rest more watery, and consequently its vapour must be weaker ; especially when the portion used is confined to a drop or two.

Muriate of Lime.

Put a portion of liquid muriate of lime over the column of mercury in a barometer. The boiling point of the muriate was found by experiment to be 230°. At 55° the depression was ,22 of an inch :

at 65°—.30
— 70°—.40
— 95°—.90

all which nearly agree with the forces of aqueous vapour 18° below the respective temperatures.

Mercury and Sulphuric Acid.

Mercury boils by my thermometer at 660°, and sulphuric acid of the specific gravity 1. 83, boils at 590°. It is very difficult to determine the precise force of vapour from these liquids in any temperature under 212°; because at such great distance from the boiling point the vapour is so weak as to be in effect almost imperceptible. Following the general law, the vapours of these fluids ought to be of the force .1, mercury at 460°, and sulphuric acid at 390°.—Col. Roi makes the expansion of 30 inches mercury by 180° of heat = .5969 or .5651; and in a barometer the expansion in the same circumstances is .5117; the differences are .0852 and .0534 which should measure the effective force of mercurial vapour of 212°, nearly. This is in all probability too much; as it is next to impossible to free any liquid entirely from air; and if *any* air enter the vacuum, it unites its force to that of the mercurial vapour.

That the force of vapour from sulphuric acid, in low temperatures, is exceedingly small, will appear from the ensuing section.

SECTION II.

On Vapour in Air.

The experiments under this head were made with manometers, or straight tubes of different lengths, hermetically sealed at one end, of $\frac{1}{15}$ inch internal diameter, and their capacities divided into equal portions. A drop or two of the liquid, the subject of experiment, was conveyed to the bottom or sealed end of the tube; the internal surface was then dried by a wire and thread, and atmospheric, (or any other air) was admitted into the tube, upon which a column of mercury was suspended of $\frac{1}{10}$ of an inch, or of 30 inches, less or more, according to the nature of the experiment. By immersing the end of the manometer, containing the air thus circumstanced, into a tall glass vessel containing water of any temperature, the effect of the vapour in expanding the air could be perceived. It was first indeed necessary to determine the increase air unaffected by any liquid (except mercury) would obtain by increase of temperature: that was done, as will be particularly shewn in the next essay. The expansion of all elastic fluids, it seems probable, is alike or nearly so, in like circumstances; 1000 parts of any elastic fluid expands nearly in a uniform manner into 1370 or 1380 parts by 180° of heat.

It will be unnecessary to repeat in detail the numerous experiments made on the various liquids in all temperatures from 32° to 212°; as the results of all agree in one general rule or principle, which is this: let 1 represent the space occupied by any kind of air of a given temperature and free from moisture; $p =$ the given pressure upon it, in inches of mercury; $f =$ the force of vapour from any liquid in that temperature, in vacuo; then, the liquid being admitted to the air, an expansion ensues, and the space occupied by the air becomes immediately, or in a short time $= 1 + \frac{f}{p-f}$; or which is the same thing, $= \frac{p}{p-f}$.

Thus in water for instance:

Let $p = 30$ inches,
$f = 15$ inches, to the given temp. 180°.

Then, $\frac{p}{p-f} = \frac{30}{30-15} = 2$, for the space; or the air becomes of twice the bulk.

If the temperature be 203°, $f = 25$, and the space becomes 6 times as large as at first.

If $p = 60$ inches
$f = 30$ inches to the given temperature

212°; then the space $= \frac{60}{60-30} = 2$; or water under the pressure of 60 inches of mercury, and at the temperature of 212°, produces vapour which just doubles the volume of air.

If ether be the instance: let the temperature be equal 70°; then $f = 15$; and suppose $p = 30$; in this case the colume of air is doubled; that is, ether of 70° being admitted to any portion of air, doubles its bulk.

The expansion of hydrogenous gas and atmospheric air by the vapour of water is the same for every temperature.

Sulphuric acid does not expand atmospheric air to any sensible amount by the heat of boiling water.

The theory of these facts is evident upon the principles laid down in the former essay: for instance; let it be required to explain the experiment with water of 212° under a pressure of 60 inches. Here the air was condensed into the space 1 by the pressure of 60 inches; but being exposed to water of 212° a vapour arose from it equal in force to 30 inches; the air therefore expanded till its force also became = to 30 inches, which was effected by doubling its volume: then the vapour pressing with 30 inches force and the air also with 30 inches force, the two together support the pressure of 60 inches and the equilibrium continues.—In short, in all cases the vapour arises to a certain force, according to temperature, and the air adjusts the equilibrium, by expanding or contracting as may be required.

The notion of a chemical affinity subsisting between the gases and vapours of different kinds, cannot at all be reconciled to these phenomena. To suppose that all the different gases have the same affinity for water might indeed be admitted if we could not explain the phenomena without it; but to go further, and suppose that water combines with every gas to the same amount as its vapour in vacuo; or in other words, that the elasticity of the compound should be exactly the same as if the two were separate, is certainly going far to serve an hypothesis.

Besides, we must on this ground suppose that all the gases have the same force of affinity for any given vapour; a supposition that cannot be admitted as having any analogy to other established laws of chemical affinity.

ESSAY III.

On Evaporation.

When a liquid is exposed to the air, it becomes gradually dissipated in it: the process by which this effect is produced, we call *evaporation.*

Many philosophers concur in the theory of chemical solution: atmospheric air, it is said, has an affinity for water; it is a menstruum in which water is soluble to a certain degree. It is allowed notwithstanding by all, that each liquid is convertible into an elastic vapour in vacuo, which can subsist independently in any temperature; but as the utmost forces of these vapours are inferior to the pressure of the atmosphere in ordinary temperatures, they are supposed to be incapable of existing in it in the same way as they do in a torricellian vacuum: hence the notion of affinity is induced.—According to this theory of evaporation, atmospheric air (and every other species of air for aught that appears) dissolves water, alkohol, ether, acids, and even metals. Water below 212° is chemically combined with the gases; above 212° it assumes a new form, and becomes a distinct elastic fluid, called *steam*: whether water first chemically combined with air, and then heated above 212°, is detached from the air or remains with it, the advocates of the theory have not determined.—This theory has always been considered as complex and attended with difficulties; so much that M. Pictet and others have rejected it, and adopted that which admits of distinct elastic vapours in the atmosphere at all temperatures, uncombined with either of the principal constituent gases; as being much more simple and easy of explication than the other; though they do not remove the grand objection to it, arising from atmospheric pressure. It has however been made to appear in these essays, I presume, that the objection to it from pressure, is itself founded upon an ungrounded hypothesis.

Leaving the theory of evaporation for the present, we shall proceed to the experiments.

The following positions have been established by others, and need therefore only to be mentioned here.

1. Some fluids evaporate much more quickly than others.

2. The quantity evaporated is in direct proportion to the surface exposed, all other circumstances alike.

3. An increase of temperature in the liquid is attended with an increase of evaporation, not directly proportionable.

4. Evaporation is greater where there is a stream of air than where the air is stagnant.

5. Evaporation from water is greater the less

the humidity previously existing in the atmosphere, all other circumstances the same.

The objects in view in this essay, are,

1. To determine the precise effect that a variation of temperature has upon the quantity evaporated.

2. To determine the ratio of evaporability of different fluids.

3. To find a rule by which the quantity and effect of previous humidity in the air may be ascertained.

4. From these and other facts to obtain a true theory of evaporation.

On the Evaporation of Water at 212°.

I took a small cylindrical vessel of tin, its diameter 3¼ and depth 2½ inches; and having fixed three pieces of wire to equidistant points of the circumference, they were fastened together at the top and the extremities bent into a hook, by which the vessel might be suspended from the end of a balance, &c. This done, the vessel was nearly filled with water, which was then made to boil over a small red fire in different circumstances: it was held in the hand and removed nearer to or further from the fire, so as to be kept just at the point of ebullition. In this state the vessel and water were weighed true to a grain, and the instant of time noted by a watch; then kept as above at 212° for ten minutes or more and again weighed: and the loss of water by evaporation, per minute, was thus ascertained. The experiments were repeated several times in the same as well as in different circumstances; and the results in no instance differed materially when obtained in the same circumstances.

The least evaporation per minute was 30 grains: this was when the fire, or lamp, was in the middle of a room, the doors and windows shut, and the air calm.

The next degree was 35 grains per minute or thereabouts: this was when the evaporating vessel was over a small fire in the usual fireplace; there being a moderate draught of air, and the room close.

A brisker fire, causing a stronger current of air up the chimney, gave from 35 to 40 grains per minute.

When the windows of the room were open, and a strong wind prevailed, the draught over the fire was proportionally increased, and the evaporation was from 40 to 45 grains per minute.

The extremes that have thus been noticed are 30 and 45 grains per minute: but were the experiment tried in the open air in high winds, I am inclined to believe from a comparison of the observations, that an evaporation of 50, 55 or even 60 grains per minute might be observed.

On the Evaporation of Water below 212°.

I have frequently tried the evaporation at all the temperatures below 212°: it would be tedious to enter into detail of all the experiments, but shall give the results at some remarkable points. In all the high temperatures I used the vessel above mentioned, keeping a thermometer in it, by which I could secure a constant heat, or at least keep it oscillating within narrow limits.

The evaporation from water of 180° was from 18 to 22 grains per minute, according to circumstances; or about $\frac{1}{2}$ of that at 212°.

At 164° it was about $\frac{1}{3}$ of the quantity at the boiling temperature; or from 10 to 16 grains per minute.

At 152° it was only $\frac{1}{4}$ of that at boiling; or from 8 to 12 grains, according to circumstances.

The temperature of 144° afford $\frac{1}{5}$ of the effect at boiling; 138° gave $\frac{1}{6}$; &c.

Having previously to these experiments determined the force of aqueous vapour at all the temperatures under 212°, I was naturally led to examine whether the quantity of water evaporated in a given time bore any proportion to the force of vapour of the same temperature, and was agreeably surprised to find that they exactly corresponded in every part of the thermometric scale: thus the forces of vapour at 212°, 180°, 164°, 152°, 144° and 138° are equal to 30, 15, 10, $7\frac{1}{2}$, 6 and 5 inches of mercury respectively, and the grains of water evaporated per minute in those temperatures were 30, 15, 10, $7\frac{1}{2}$, 6 and 5 also; or numbers proportional to these. Indeed it should be so from the established law of mechanics, that all effects are proportional to the causes producing them. The atmosphere, it should seem, obstructs the diffusion of vapour, which would otherwise be almost instantaneous, as in vacuo; but this obstruction is overcome in proportion to the force of the vapour. The obstruction however cannot arise from the *weight* of the atmosphere, as has till now been supposed; for then it would effectually prevent any vapour from arising under 212°: but it is caused by the *vis inertiæ* of the particles of air; and is similar to that which a stream of water meets with in descending amongst pebbles.

The theory of evaporation being thus manifested from experiments in high temperatures, I found that if it was to be verified by experiments in low temperatures, regard must be had to the force of vapour actually existing in the atmosphere at the time. For instance, if water of 59° were the subject, the force of vapour of that temperature is $\frac{1}{60}$ of the force at 212°, and one might expect the quantity of evaporation $\frac{1}{60}$ also; but if it should happen, as it sometimes does in summer, that an aqueous atmosphere to that amount does already exist, the evaporation, instead of being $\frac{1}{60}$ of that from boiling water, would be nothing at all. On the other hand, if the aqueous atmosphere were less than that, suppose $\frac{1}{2}$ of it, corresponding to 39° of heat, then the effective evaporating force would be $\frac{1}{120}$ of that from boiling water; in short, the evaporating force must be universally equal to that of the temperature of the water, diminished by that already existing in the atmosphere. In order to find the force of the aqueous atmosphere I usually take a tall cylindrical glass jar, dry on the outside, and fill it with cold spring water fresh from the well; if dew be immediately formed on the outside, I pour the water out, let it stand a while to increase in heat, dry the outside of the glass well with a linen cloth, and then pour the water in again; this operation is to be continued till dew ceases to be formed, and then the temperature of the water must be observed; and opposite to it in the table (page 559) will be found the force of vapour in the atmosphere. This must be done in the open air, or at a window; because the air within is generally more humid than that without. Spring water is generally about 50°, and will mostly answer the purpose the three hottest months in the year: in other seasons an artificial cold mixture is required.—The accuracy of the result obtained this way I think scarcely needs to be insisted upon. Glass, and all other hard, smooth substances I have tried, when cooled to a degree below what the surrounding aqueous vapour can support, cause it to be condensed on their surfaces into water. The degree of cold is usually from 1 to 10 below the mean heat of the 24 hours; in summer I have often observed the point as high as 58° or 59°, corresponding to ½ an inch of mercury in force, and once or twice have seen it at 62°: in changeable and windy weather it is liable to considerable fluctuation; but this is not the place to enlarge upon it.

For the purpose of observing the evaporation in atmospheric temperatures I got two light tin vessels, the one 6 inches in diameter and ½ inch deep, the other 8 inches diameter and ¼ inch deep; and made to be suspended from a balance, like the former one. When any experiment designed as a test of the theory was made, a quantity of water was put into one of these (generally the 6 inch one, which I preferred) the whole was weighed to a grain; then it was placed in an open window or other exposed situation for 10 or 15 minutes, and again weighed to ascertain the loss by evaporation; at the same time the temperature of the water was observed, the force of the aqueous atmosphere ascertained as above, and the strength of the current of air noticed. From a great variety of experiments made both in the winter and summer, and when the evaporating foice was strong and weak, I have found the results entirely conformable with the above theory. The same quantity is evaporated with the same evaporating force thus determined, whatever be the temperature of the air, as near as can be judged; but with the same evaporating force, a strong wind will double the effect produced in a still atmosphere. Thus, if the aqueous atmosphere be correspondent to 40° of temperature and the air be 60°, the evaporation is the same as if the aqueous atmosphere were at 60° of temperature and the air 72°; and in a calm air the evaporation from a vessel of 6 inches in diameter in such circumstances would be about .9 of a grain per minute, and about 1. 8 grains per minute in a very strong wind; the different intermediate quantities being regulated solely by the force of the wind.

The following table exhibits the ratios and quantity of water evaporated in each temperature, derived from the preceding theory, and confirmed by experiments, as far as they have been extended. The first column expresses the temperature; the second, the corresponding force of vapour taken from the preceding table; the other three columns give the number of grains of water that would be evaporated from a surface of 6 inches in diameter in the respective temperatures, on the supposition of there being previously no aqueous vapour in the atmosphere. These columns present the extremes and the mean of evaporation, likely to be noticed, or nearly such: for, the first is calculated upon the supposition of 35 grains loss per minute from the vessel of 3¼ inches in diameter; the second, 45 and the third 55 grains per minute.

TABLE

Shewing the force of vapour, and the full evaporating force of every degree of temperature from 20° to 85°, expressed in grains of water that would be raised per minute from a vessel of six inches in diameter, supposing there were no vapour already in the atmosphere.

Temperature. 212°	Force of Vap. inch: 30	Evaporating Force in Grains. 120	 154	 189
20°	.129	.52	.67	.82
21	.134	.54	.69	.85
22	.139	.56	.71	.88
23	.144	.58	.73	.91
24	.150	.60	.77	.94
25	.156	.62	.79	.97
26	.162	.65	.82	1. 02
27	.168	.67	.86	1. 05
28	.174	.70	.90	1. 10
29	.180	.72	.93	1. 13
30	.186	.74	.95	1. 17
31	.193	.77	.99	1. 21
32	.200	.80	1. 03	1. 26
33	.207	.83	1. 07	1. 30

TABLE CONTINUED.

Temperature.	Force of Vap. inch.	Evaporating Force in Grains.		
212°	30	120	154	189
34°	.214	.86	1. 11	1. 35
35	.221	.80	1. 14	1. 39
36	.229	.92	1. 18	1. 45
37	.237	.95	1. 22	1. 49
38	.245	.98	1. 26	1. 54
39	.254	1. 02	1. 31	1. 60
40	.263	1. 05	1. 35	1. 65
41	.273	1. 09	1. 40	1. 71
42	.283	1. 13	1. 45	1. 78
43	.294	1. 18	1. 51	1. 85
44	.305	1. 22	1. 57	1. 92
45	.316	1. 26	1. 62	1. 99
46	.327	1. 31	1. 68	2. 06
47	.339	1. 36	1. 75	2. 13
48	.351	1. 40	1. 80	2. 20
49	.363	1. 45	1. 86	2. 28
50	.375	1. 50	1. 92	2. 36
51	.388	1. 55	1. 99	2. 44
52	.401	1. 60	2. 06	2. 51
53	.415	1. 66	2. 13	2. 61
54	.429	1. 71	2. 20	2. 69
55	.443	1. 77	2. 28	2. 78
56	.458	1. 83	2. 35	2. 88
57	.474	1. 90	2. 43	2. 98
58	.490	1. 96	2. 52	3. 08
59	.507	2. 03	2. 61	3. 19
60	.524	2. 10	2. 70	3. 30
61	.542	2. 17	2. 79	3. 41

TABLE CONTINUED.

Temperature.	Force of Vap. inch.	Evaporating Force in Grains.		
212°	30	120	150	182
62°	.560	2. 24	2. 88	3. 52
63	.578	2. 31	2. 97	3. 63
64	.597	2. 39	3. 07	3. 76
65	.616	2. 46	3. 16	3. 87
66	.635	2. 54	3. 27	3. 99
67	.655	2. 62	3. 37	4. 12
68	.676	2. 70	3. 47	4. 24
69	.698	2. 79	3. 59	4. 38
70	.721	2. 88	3. 70	4. 53
71	.745	2. 98	3. 83	4. 68
72	.770	3. 08	3. 96	4. 84
73	.796	3. 18	4. 09	5. 00
74	.823	3. 29	4. 23	5. 17
75	.851	3. 40	4. 37	5. 34
76	.880	3. 52	4. 52	5. 53
77	.910	3. 65	4. 68	5. 72
78	.940	3. 76	4. 83	5. 91
79	.971	3. 88	4. 99	6. 10
80	1. 00	4. 00	5. 14	6. 29
81	1. 04	4. 16	5. 35	6. 54
82	1. 07	4. 28	5. 50	6. 73
83	1. 10	4. 40	5. 66	6. 91
84	1. 14	4. 56	5. 86	7. 17
85	1. 17	4. 68	6. 07	7. 46

The use of this table will appear from the following problems:

PROBLEM I.

Having given the temperature at which the aqueous atmosphere begins to be condensed into water, and the temperature of the air, to find the quantity of water that would be evaporated in a minute from a vessel of 6 inches diameter.

Solution. Subtract the grains opposite to the lower temperature from those opposite to the higher one, in the first, second or third column of grains, according to the strength of the wind, and the remainder will be the quantity evaporated in a minute, under those circumstances, nearly.

Example. Let the point of condensation be 52°, the temperature of the air 65°, with a moderate breeze.

The number opposite 52° in the second column of grains is 2. 06, and that opposite 65° is 3. 16; the difference, 1. 1 grain, is the evaporation per minute.

PROBLEM II.

Having given the quantity evaporated in a minute, found by experiment, and the temperature of the air, to find the force of the aqueous atmosphere, and the point of condensation.

Solution. Subtract the observed evaporation from that opposite the given temperature in the table; and look above for the number nearest to the remainder in the same column of evaporation, opposite to which will be found the force of the aqueous atmosphere, and the point at which it begins to be condensed.

Example. Finding the evaporation from a vessel of 6 inches in diameter to be 1. 7 grain per minute with a brisk wind, air 62°; what is the weight of the aqueous atmosphere, and the temperature at which it begins to be condensed into water?

The number opposite 62° in the third column of grains is 3. 52, being the whole evaporating force at that temperature in a perfectly dry atmosphere; from which take 1. 7 grains, the real evaporating force observed, and the remainder, 1. 82, corresponds, as per table, to the force .294 inches of mercury, the weight of vapour, and to 43° of temperature*.

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* It may be proper to remind the reader that all the experiments on evaporation are understood to be made in the open air, or in a window with a current inward; also it may be observed the evaporation in a close room is much less and is besides irregular, being greater proportionably from a less surface, evidently from the stagnation of the air.

Evaporation of Spirits, Ether, &c.

If the law of evaporation above given apply to water in every part of the scale of heat, no reasonable doubt can be entertained respecting its application to other liquids. I have notwithstanding made several experiments on others, the results of which are conformable to the same law. Some of them follow:—

1. Spirit of wine.—Evaporated from a surface of 4 inches in diameter, 54 grains in 25 minutes: air 53°; aqueous atmosphere at 49°, and beginning to rain with a moderate breeze. It would proportionally have been 121 grains from a vessel of 6 inches in diameter. This gives nearly 5 grains per minute. The same spirit boiled at or near 180°.

Now from the *data*, water of 83° is equivalent in force to spirits of 53°: and it may be seen that the evaporating force of water of 83° is nearly 5 in the first and second columns of grains of the table. It seems probable that the aqueous atmosphere does not diminish the evaporation of spirits as it does that of water.

2. Ether. 1. Put a phial containing ether, and a small tin vessel of 1¾ inch diameter into a scale and balanced them exactly: then poured the ether into the evaporating vessel and put

the phial into the scale again; took out 40 grains from the opposite scale, and waited till the equilibrium was restored: this was in 8 minutes 6 seconds. The air was 50°, and the ether at first 50°; but it rapidly sunk, as was found by dipping a very small bulbed thermometer into it, to 28°. In a window with a moderate breeze.

——— 2 and 3. Repeated the experiment in the same circumstances, except the evaporating vessel, which was now porcelain, and 2½ inches diameter. Lost 40 grains in 3 minutes. Thermometer sunk from 50 to 30°. The two experiments made this way did not differ above one or two grains.

These results reduced to a vessel of 3¼ inches in diameter give

1st. Experiment, loss 17 grains per minute;
2 & 3 ——— — 22½ ———

The reason why the result in the first experiment was something less than in the other two, was evidently owing to the circumstance of its longer duration, by which the ether was the greater part of the time in a low temperature, and consequently evaporated less.—The ether used boiled at 102°. At 50° it was therefore in the capacity of water at 160°. But water at 160°, at most loses only 17 or 18 grains per minute, and less

20° below that temperature. At first view therefore it should seem that ether evaporates quicker than the general law assigns.—But it must be allowed that the temperature of the *air* has some effect upon evaporation, though it has certainly very little. Now ether in the above experiments is acted upon by a current of air of an equal or higher temperature than itself; but water of 160° is usually acted upon by air 100° lower than itself, which is every moment precipitating the vapour formed, and thus obstructing its circulation. This appears to be a sufficient cause for the small difference observed.

With respect to mercury, sulphuric acid, muriate of lime, &c. there can be no doubt but they experience a real evaporation like those above; but it must be very small in proportion as their boiling points are high. And it would be difficult to make experiments upon such of these as have an affinity for aqueous vapour; because their acquisition from the aqueous atmosphere would far exceed their loss by evaporation.

Since writing the above essay, opportunities have occurred to ascertain whether the evaporation from ice is conformable to the same law as that from water. Every one, who has tried the experiment, admits the fact that ice is evaporable.—I have lately made several observations on this subject, the results of which, as far as they go, support the conclusion that the general law of evaporation continues the same below the point of congelation as above it. All the experiments were made in the tin vessel above described of 6 inches in diameter; a quantity of water was suffered to freeze in it, so as to form a circular cake of ice; the vessel and ice were then weighed together, and exposed in the open air for a certain time, after which being again weighed, the loss was found; the force of the aqueous atmosphere was sometimes determined during the experiment by a mixture of pounded ice and salt, in the manner already described.

	Grs.	H.	Grs.		Wind.	Air.
Nov. 5. In the night lost	110 in	9	; or, .20	per m.	N.,E. brisk.	28° to 31°
—— at 10 A. M. —	25 in	$1\frac{1}{4}$	; or, .33	——	N. E. mod.	32°
—29. at 1 P. M. —	24 in	$1\frac{3}{4}$	; or, .23	——	calm.	31°
P. M. —	84 in	$9\frac{1}{4}$	; or, .15	——	——	30°
—30. in the night —	94 in	9	; or, .17	——	N. E. mod.	31°
Dec. 19. P. M. —	75 in	8	; or, .16	——	N. E. calm.	26°—28°
In the night —	33 in	11	; or, .05	——	calm.	29°
—20. A. M. —	21 in	2	; or, .175	——	W. mod.	31°

Some of these being made in the night, and of long duration, neither the temperature of the air, nor the force of the aqueous atmosphere could be fairly determined: the second experiment was made under every favourable circumstance, and the aqueous atmosphere found at 22°. By problem 2, at page 588 it would have been determined at $21\frac{1}{2}°$, using the second column of grains in the table.*

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* On the subject of evaporation it may be considered as unpardonable not to advert to De Saussure's valuable Essays on Hygrometry.

That excellent philosopher determined, by a well conceived experiment, that dry air of the temperature of 64° or 66°, imbibed aqueous vapour so as to increase its elasticity $\frac{1}{54}$ of the atmospheric pressure; and that a cubic foot of such air required 11 or 12 grains of water to produce the effect. By the table above at page 560 it appears the force of vapour at $61° = .54 = \frac{1}{54}$ of 29 .5 inches, nearly. It is probable this difference is occasioned in part at least by the want of perfect dryness in the air he operated upon, which caused the increase of elasticity to be less than otherwise.—It was, I think, unfortunate that he attached so much importance to and confidence in his hygrometer; and that he adopted the theory of chymical solution of water in air, contrary to the facts he discovered, which seemed more reconcileable to the notion of aqueous vapour being a distinct elastic fluid. Indeed he is forced to acknowledge in the 1st. chap. of his Essay on the Theory of Evaporation, that in the ordinary temperature of the atmosphere, aqueous vapour is formed in the first instance a distant elastic fluid, and *after it has been converted into an elastic fluid*, it is dissolved by the air; "Je crois qu'il ne la dissout que lorsque l'action du "feu l'a convertie en vapeur elastique." Now if it can for a moment exist independently under the pressure

ESSAY IV.

On the Expansion of Elastic Fluids by Heat.

The principal occasion of this essay is another on the same subject by Messrs. de Morveau and du Vernois in the first vol. of the Annales de Chimie. It appearing to them that the results of the experiments of De Luc, Col. Roi, de Saussure, Priestley, Vandermonde, Ber-

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of the atmosphere, why may it not continue to exist in that state?

His table of the weight of aqueous vapour in a cubic foot of air at different degrees of the thermometer, being derived from experiments with his hygrometer, except the standard one of 66° (15° Reaumur), is far from accurate; and the inaccuracy increases with the distance from the standard, which, as has been observed, appears to be nearly correct: in the higher temperatures he makes the water dissolved too little, and in the lower temperatures too much.—He says (§ 93) that the lowest he has seen the hygrometer in the open air, is 40; and that it indicated a reduction of temperature in the air amounting to 34° .7 (78° of Fahr.) was necessary in order to deposit dew. This observation alone is sufficient to render his hygrometer suspected; for, few who have attended to the formation of dew will admit the probability of so large a reduction being necessary in any climate or season: I believe it rarely requires 40° reduction in temperature in any part of the world to produce the effect.

thollet and Monge did not sufficiently accord with each other; and that it would be of importance to determine not only the whole expansion of each gas from two distant points, such as the freezing and boiling, but likewise whether that expansion be uniform in every part of the scale, they instituted a set of experiments expressly for those purposes. The result of which was, that betwixt the temperatures of 32° and 212°, the whole expansion of one gas differs much from that of another, it being in one instance about $\frac{4}{10}$ of the original, and in others more than 12 times that expansion; and that the expansion is much more for a given number of degrees in the higher than in the lower part of the scale. These conclusions were so extremely discordant with and even contradictory to those of others, that I could not but suspect some great fallacy in them, and found it in reality to be the fact: I have no doubt it arose from the want of due care to keep the apparatus and materials free from moisture.

My method of experimenting on this subject is simple, and therefore less liable to error. A straight manometer tube, such as has been mentioned, is duly divided into equal portions of capacity; it is then dried by a wire and thread, and the open end inserted through a cork into a phial containing sulphuric acid, in order that the aqueous vapour may be drawn out of the tube; this is essential if we operate in temperatures lower than that of the atmosphere, otherwise not. For want of this attention, Col. Roi, in his valuable paper in the Philos. Trans. vol. 67, has been led into some erroneous conclusions.—A small column of dry mercury is then let down to a proper point in the manometer, and it is ready for experiment with common air.

It requires some address to fill the manometer with any other gas.—I succeeded best as follows: filled the tube with dry mercury; then pushed down a wire with thread, so that when the wire was got to the end of the tube, a thick covering of thread just entered the open end, and held the mercury like a cork, so that the tube could be inverted without losing the contents; then having a glass funnel with a perforated cork over the water apparatus, containing the gas, I slipped the manometer through the hole in the cork, and putting my hand into the water under the funnel, drew the wire out of the manometer, and with it the mercury; upon which the gas entered the manometer. For carbonic acid gas, I opened the sealed end of the manometer, drew it out to a capillary bore, and forced a stream of the gas through the tube; then putting my finger on the other end, sealed it again by a blow-pipe, and let down a small column of mercury to the proper point.

When the manometer was to be exposed to a heat of 212°, I used a Florence flask, with a long glass tube corked into it, in such sort that as much of the manometer as was necessary to be exposed to the temperature might be in the tube; then water at the bottom of the flask was made to boil violently, so that a constant stream of vapour issued out of the top of the glass tube, which was found to raise the thermometer to 212°. Small specks of white paint were put upon the divisions of the manometer together with numbers which were discernible through the containing tube. For lower temperatures a deep tin vessel containing hot water was used, in which the manometer was immersed, the water being well agitated previously to each observation.

From a great many experiments made in this way on common air, and likewise upon hydrogenous gas, oxygenous and nitrous gases, and carbonic acid gas, I can assert that the conclusions of De Luc, Roi, Saussure, Berthollet, &c. are nearly accurate throughout, and that those of de Morveau and du Vernois are extremely inaccurate in the higher temperatures.

I have repeatedly found that 1000 parts of common air of the temperature 55° and common pressure, expand to 1321 parts in the manometer; to which adding 4 parts for the corresponding expansion of glass, we have 325 parts increase upon 1000 from 55° to 212°; or for 157° of the thermometric scale. As for the expansion in the intermediate degrees, which Col. Roi's experiments shew to be a *slowly diminishing* one above the temperature of 57°, but which de Morveau's on the contrary shew to be a *rapidly increasing* one in the higher part of the scale; I am obliged to allow that Col. Roi is right, though it makes in some degree against an hypothesis I have formed relative to the subject; he has certainly however made the diminution too great from 72° downwards, owing to his not perceiving that he actually *destroyed* a portion of the elastic fluid he was operating upon (aqueous vapour) in reducing its temperature so low; if his air had been previously dried by sulphuric acid, &c. he would not have found so remarkable diminution below 72°. My experiments give for 77½° above 55°, 167 parts; for the next 77½° only 158 parts: and the expansion in every part of the scale seems to be a gradually diminishing one in ascending.

The results of several experiments made upon hydrogenous gas, oxygenous gas, carbonic acid gas and nitrous gas, which were all the kinds I tried, agreed with those on common air not only in the total expansion, but in the gradual diminution of it in ascending: the small differences observed never exceeded 6 or 8 parts on the whole 325; and differences to this amount will take place in common air, when not freed from aqueous vapour, which was the situation of all my factitious gases.

Upon the whole therefore I see no sufficient reason why we may not conclude, that *all elastic fluids under the same pressure expand equally by heat*—and that *for any given expansion of mercury, the corresponding expansion of air is proportionally something less, the higher the temperature.*

This remarkable fact that all elastic fluids expand the same quantity in the same circumstances, plainly shews that the expansion depends *solely* upon heat: whereas the expansion in solid and liquid bodies seems to depend upon an adjustment of the two opposite forces of heat and chemical affinity, the one a *constant* force in the same temperature, the other a *variable* one, according to the nature of the body; hence the unequal expansion of such bodies. It seems therefore that general laws respecting the absolute quantity and the nature of heat, are more likely to be derived from elastic fluids than from other substances.

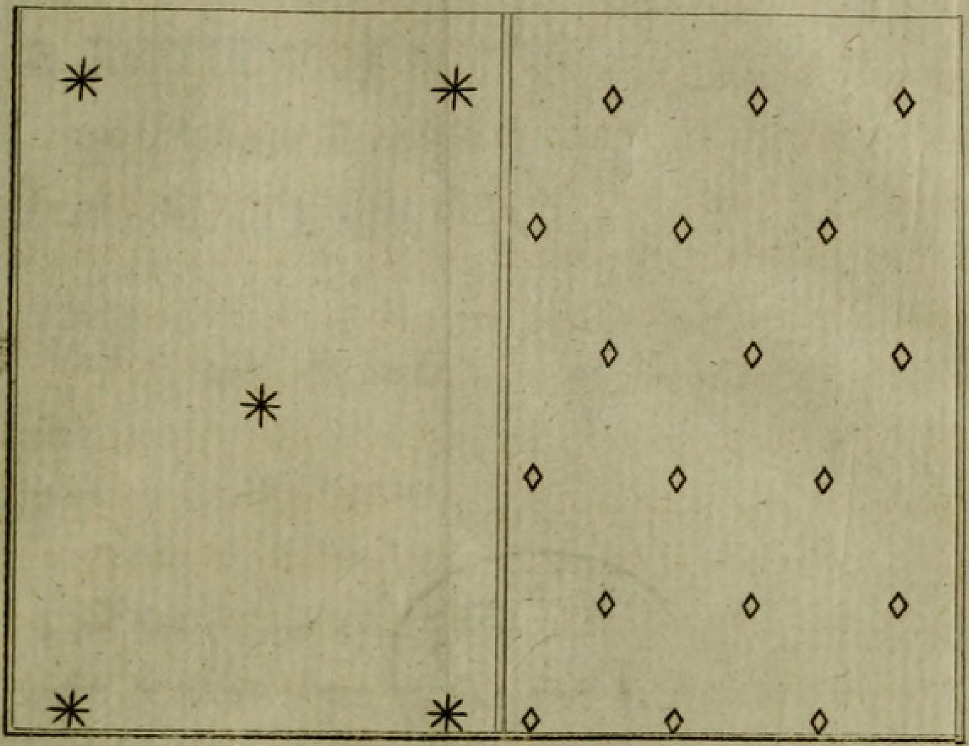
In order to explain the manner in which elastic fluids expand by heat, let us assume an hypothesis that the repulsive force of each particle is exactly proportional to the whole quantity of heat combined with it, or in other words to its temperature reckoned from the point of total privation: then, since the diameter of each particle's sphere of influence is as the cube root of the space occupied by the mass we shall have $\sqrt[3]{1000} : \sqrt[3]{1325}$ (10 : 11, nearly) : : the absolute quantity of heat in air of 55°: the absolute quantity in air of 212°. This gives the point of total privation of heat, or absolute cold, at 1547° below the point at which water freezes. Dr. Crawford (On Animal Heat, &c. page 267) deduces the said point by a method wholly different to be 1532°.—So near a coincidence is certainly more than fortuitous.

The only objection I see to this hypothesis is, that it necessarily requires the augmentation of elastic fluids for a given quantity of heat to be greater in the higher temperatures than in the lower, because the cubes of a series of numbers in arithmetical progression differ more the larger the numbers or roots: but it has just been shewn that in fact an augmentation of a contrary kind is observed. This refers us to the consideration whether the mercurial thermometer is an accurate measure of the increments of heat; if it be, the hypothesis fails; but if equal increments of heat cause a greater expansion in mercury in the higher than in the lower temperatures, and that in a small degree, the fact noticed above instead of being an objection will corroborate the hypothesis.—Dr. Crawford determines the expansions of mercury to be very nearly in proportion to the increments of heat: M. De Luc makes them to be less for a given quantity of heat in the lower than in the higher part of the scale; and in a ratio that agrees with this hypothesis. Now as every other liquid we are acquainted with is found to expand more in the higher than in the lower temperatures; analogy is in favour of the conclusions of De Luc, that mercury does the same.

EXPLANATION OF THE PLATE.

The annexed plate is intended to illustrate the author's conception of the constitution of the atmosphere. The different marks or characters of the particles of the gases are merely arbitrary, and intended for distinction; the simple atmospheres are given nearly on their real densities, and the particles are arranged at equal distances from each other. In the compound atmosphere the same arrangement is made of each kind of particles as in the simple; but the particles of different kinds do not arrange at regular distances from each other; because it is supposed they do not repel each other.

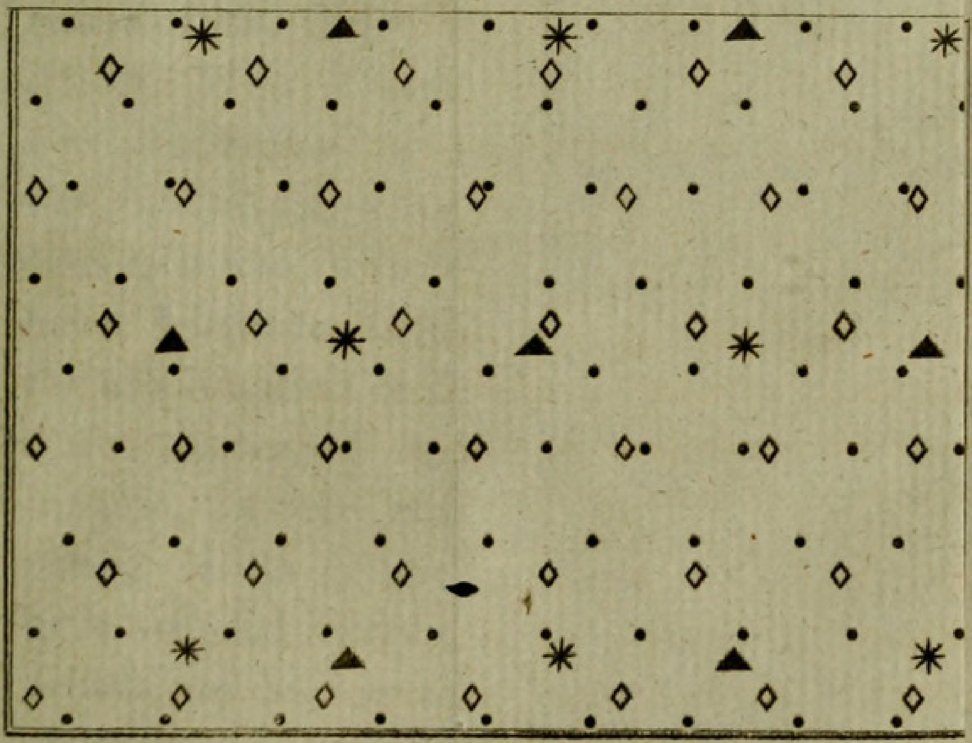
SIMPLE AT p02.



Aqueous vapour

Oxygenous gas.

COMPOUND A



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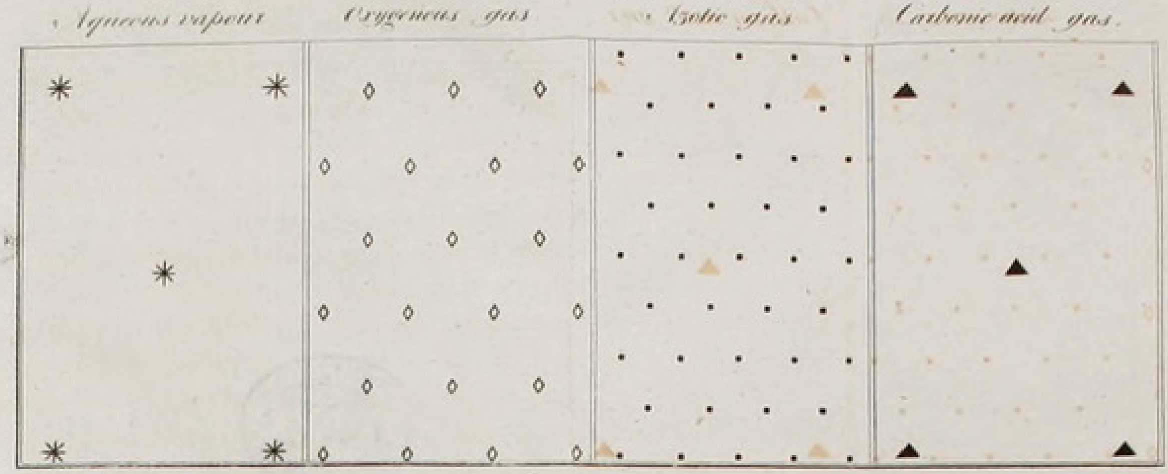
SIMPLE ATMOSPHERE'S.



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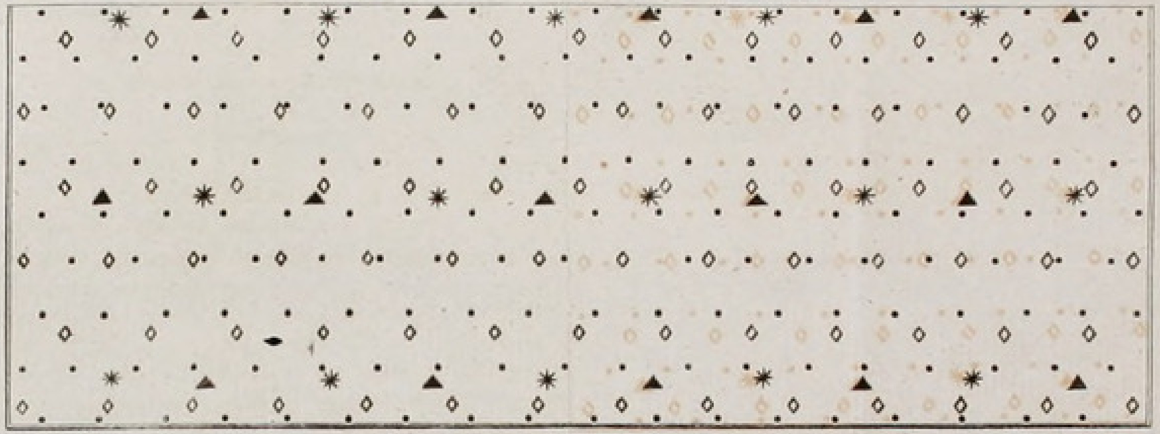

Dalton, John. 1798. "Experimental essays, on the constitution of mixed gases; on the force of steam or vapour from water and other liquids in different temperatures, both in a Torricellian vacuum and in air; on evaporation; and on the expansion of gases by heat." *Memoirs of the Literary and Philosophical Society of Manchester* 5(2), 535–602.