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XV. New experimental Researches on some of the leading Doctrines of Caloric; particularly on the Relation between the Elasticity, Temperature, and latent Heat of different Vapours; and on thermometric Admeasurement and Capacity.
By ANDREW URE, M.D.

[Continued from p. 44.]

TABLE I.

The elastic Force of the Vapour of Water in Inches of Mercury.

Temp.	Force.	Temp.	Force.	Temp.	Force.	Temp.	Force.	Temp.	Force.	Temp.	Force.
24°	0.170	115°	2.820	195°	21.100	242°	53.600	270	86.300	295.6	130.400
32	0.200	120	3.300	200	23.600	245	56.340	271.2	88.000	295	129.000
40	0.250	125	3.830	205	25.900	245.8	57.100	273.7	91.200	297.1	133.900
50	0.360	130	4.366	210	28.880	248.5	60.400	275	93.480	298.8	137.400
55	0.416	135	5.070	212	30.000	250	61.900	275.7	94.600	300	139.700
60	0.516	140	5.770	216.6	33.400	251.6	63.500	277.9	97.800	300.6	140.900
65	0.630	145	6.600	220	35.540	254.5	66.700	279.5	101.600	302	144.300
70	0.726	150	7.530	221.6	36.700	255	67.250	280	101.900	303.8	147.700
75	0.860	155	8.500	225	39.110	257.5	69.800	281.8	104.400	305	150.560
80	1.040	160	9.600	226.3	40.100	260	72.300	283.8	107.700	306.8	154.400
85	1.170	165	10.800	230	43.100	260.4	72.800	285.2	112.200	308	157.700
90	1.360	170	12.050	230.5	43.500	262.8	75.900	287.2	114.800	310	161.900
95	1.640	175	13.550	234.5	46.800	264.9	77.900	289	118.200	311.4	164.800
100	1.860	180	15.160	235	47.220	265	78.040	290	120.150	312	167.000
105	2.100	185	16.900	238.5	50.300	267	81.900	292.3	123.100	Another exp.	
110	2.456	190	19.000	240	51.700	269	84.900	294	126.700	312°	165.5

The apparatus employed in obtaining these results, has the peculiar advantage over all others, that the mercurial column is never heated. It is the concurrent opinion of all chemical philosophers, that caloric travels downwards in liquids with extreme slowness and difficulty. Indeed, Count Rumford's experiments led him to infer that heat could not descend in fluids at all.

It is evident that in my constructions, figures 1, 2, and 3, only that small portion of quicksilver, within the vessels A, B, and C, will be affected by the heat, but the measuring column is beyond the reach of its influence.

A surprising accordance will be perceived between my numbers, and those given by Mr. Dalton between 32° and 212°, though mine were obtained with a different modification of apparatus. Above the boiling point, where the table of Mr. Dalton is deduced from calculation, the accordance soon ceases. But as my apparatus and mode of using it were precisely the same as in the former part of the range, my results, if entitled to confidence in the one case, must be so in the other. At 280° Beancourt's number and mine are not much different, the former

being 105 inches, the latter 102. Being perfectly convinced, by repeating the experiments in different circumstances, that Mr. Dalton's ratio of progression, though apparently accommodated to the intervals between 32° and 212° , could not serve for the higher ranges*, I endeavoured to discover a simple rule of more general application. It is above 212° , indeed, that for the purposes of art, the knowledge of the force of steam is required.

I first tried the differential method, so useful for determining the distant links of a concatenated series.

Without doing much violence to the above numbers, the forces corresponding to 100° , 110° , 120° , 130° , 140° , and 150° , may be written in a series of which the 5th order of differences = 0. Then if d' d'' d''' d^{iv} d^v , represent the first terms, in the first, second, third, fourth, and fifth order of differences, the n th term of the series is

$$a + \frac{n-1}{n-1} \cdot d' + \frac{n-2}{n-1} \cdot \frac{n-2}{2} d'' + \frac{n-2}{n-1} \cdot \frac{n-2}{2} \cdot \frac{n-3}{3} \cdot d''' + \frac{n-2}{n-1} \cdot \frac{n-2}{2} \cdot \frac{n-3}{3} \cdot \frac{n-4}{4} \cdot d^{iv} + \&c.$$

In the above series for steam, $d' = 0.65$, $d'' = 0.19$, $d''' = 0.04$, $d^{iv} = 0.01$, $d^v = 0$. $a = 1.92$.

Example 1st. To determine the 8th term in the series, or the elastic force at 8×10 , above 90° , (the first term 100° being included) or at 170° .

Here $n=8$

$$\begin{aligned} a + \frac{n-1}{n-1} \cdot d' &= 1.92 + 4.55 = 6.47 \\ \frac{n-1}{n-1} \cdot \frac{n-2}{2} \cdot d'' &= 4.08 \\ \frac{n-1}{n-1} \cdot \frac{n-2}{2} \cdot \frac{n-3}{3} \cdot d''' &= 1.40 \\ \frac{n-1}{n-1} \cdot \frac{n-2}{2} \cdot \frac{n-3}{3} \cdot \frac{n-4}{4} \cdot d^{iv} &= \frac{0.35}{12.30} \end{aligned}$$

Observation gives 12.05, forming a good accordance.

Example 2. Required the 10th term, or $n=10$. For 190° F.

$$\begin{aligned} a + \frac{n-1}{n-1} \cdot d' &= 7.77 \\ \frac{n-1}{n-1} \cdot \frac{n-2}{2} \cdot d'' &= 6.84 \\ \frac{n-1}{n-1} \cdot \frac{n-2}{2} \cdot \frac{n-3}{3} \cdot d''' &= 3.36 \\ \frac{n-1}{n-1} \cdot \frac{n-2}{2} \cdot \frac{n-3}{3} \cdot \frac{n-4}{4} \cdot d^{iv} &= \frac{1.26}{19.23} \end{aligned}$$

At 190° experiment makes it 19.00, still coinciding nearly.

* Dr. Young remarks on Dalton's ratio, "It is certain that this cannot be the law of nature, since about 394° the elasticity would become uniform, and then decrease, if the law be true."—Young's Natural Philosophy, 4to, vol. ii. p. 398.

By the same equation we find the 20th term or for 290° to be $124\cdot28$; while experiment gives $120\cdot15$, showing a difference of $4\cdot13$ inches. At a higher point the error becomes greater. We here see that a geometrical series may coincide apparently through a considerable range with experiment, and yet be inaccurate when further extended.

Dissatisfied, therefore, with this approximation, I prosecuted the inquiry, and had the happiness to discover a very simple and beautiful ratio, which will actually apply through an extensive scale of temperature, and is incomparably easier in practice than the preceding rule. The elastic force at $212^{\circ}=30$ inches being divided by $1\cdot23$, will give the force for 10° below; this quotient divided by $1\cdot24$, will give that for 10° lower; and so on progressively. To obtain the forces above 212° , we have merely to multiply 30 by the ratio $1\cdot23$, for the force at 222° ; this product by $1\cdot22$ for that at 232° , and thus for each successive interval of 10° above the boiling point.

Thus $30 \times 1\cdot23 = F_{222^{\circ}}$. $30 \times 123 \times 1\cdot22 = F_{232^{\circ}}$, using F to denote the force at any temperature n , according to the notation of Laplace.

By departing from the point of 210° F., we shall obtain results equally accurate, but more convenient for comparison with the experimental table. The following numbers exhibit the correspondence of this ratio with actual observation.

TABLE II.
Observed Elasticity of aqueous Vapour compared with the Ratios.

Temp.	Calcul. Force.	Exper.	Temp.	Calcul. Force.	Exper.	DALTON	BETANC.	ROBISON.
210°	28·9	28·9	210°	28·9	28·9	28·84	28·8	28·65
200	23·5	23·6	220	35·54	35·54	34·99		35·80
190	19·0	19·0	230	43·36	43·10	41·75	45·5	44·70
180	15·2	15·16	240	52·46	51·70	49·67		54·90
170	12·07	12·05	250	62·95	61·90	58·21		66·80
160	9·50	9·60	260	74·91	72·30	67·73	80·17	80·30
150	7·42	7·58	270	88·39	86·30	77·85		94·10
140	5·75	5·77	280	103·41	101·90	88·75	105·12	105·90
130	4·42	4·36	290	119·95	120·15	100·12		
120	3·37	3·33	300	137·94	139·70	111·81		
110	2·55	2·45	310	157·25	161·30	123·53		
100	1·92	1·86	320	177·70		135·00		
90	1·43	1·36						
80	1·06	1·01						
70	0·77	0·726				Temp.	BETANC.	ROBISON.
60	0·56	0·516				32°	0·0	0·0
50	0·40	0·36				50		0·12
40	0·28	0·25				80	0·81	0·82
30	0·20	0·19				100	1·65	1·60
20	0·14	0·14				120	2·95	3·00
10	0·098					140	5·00	5·15
0	0·068					160	9·00	8·65
						180	14·00	14·05
						200	22·50	22·62

The rule on which the preceding table is formed, may be expressed in a manner better fitted to give *directly* the elastic force corresponding to any given temperature moderately distant from 212°. It becomes also more accurate.

Let r = the mean ratio between 210° and the given temperature; n = the number of terms (each of 10°) distant from 210°; F = the elastic force of steam in inches of mercury.

Then, Log. of $F = \text{Log. } 28.9 \pm n. \text{ Log. } r$; the positive sign being used above, the negative below 210°.

Or by common arithmetic, multiply or divide 28.9, according as the temperature is above or below 210°, by the mean ratio, involved to a power denoted by the number of terms. The product or quotient is the tension required.

Example 1st. The temperature is 140°. What is the corresponding elasticity of the vapour from water heated to that point?

140° is 7 terms of 10° each *under* 210°; 1.26 is the mean ratio $= \frac{1.23+1.29}{2}$; and, consequently, $r=1.26$; $n=7$.

$$\text{Log. } 28.9 = 1.46090$$

$$\text{Log. } 1.26 \times 7 = 0.10037 \times 7 = -0.70259$$

$$0.75831, \text{ which is}$$

the logarithm of .. .. 5.732 inches.

Experiment gives .. .. 5.77, difference .04, inconsiderable.

Example 2. What is the tension of steam at the temperature of 290°?

$$r = \frac{1.23+1.16}{2} = 1.195 \quad n=8$$

$$\text{Log. } 28.9 = 1.46090$$

$$8 \text{ Log. } r = 8 \times 0.07737 = +0.61896$$

$$\text{Log. of } 120.02 \text{ inches } 2.07986$$

At 290° by experiment = 120.15.

Example 3. Temperature 250°. Force of steam in contact with water?

$$r = \frac{1.23+1.20}{2} = 1.215 \quad n=4$$

$$\text{Log. } 28.9 = 1.46090$$

$$4 \text{ Log. } r = 4 \times 0.08458 = +0.33832$$

$$\text{Log. of } 62.98 \quad 1.79922$$

At 250° Experiment 61.90

At these high heats, it is very possible that the experiment may be in error by one inch, which is the whole difference here. About half a degree of Fahrenheit misnoted, would give this deviation.

Such a correspondence, therefore, of observation with the calculated

culated results, shows that we have found a rule of perfect accuracy for all purposes of engineering, &c. If I am asked whether this formula coincides at every link with the chain of nature, I freely acknowledge, that I do not imagine it strictly so to do. But still it affords approximations such, that within moderate limits, I cannot tell whether to place more confidence in them, or in those found by experiment. It has moreover the rare advantage of being extremely simple, and level to the capacity of all practical men.

In Biot's excellent work above quoted, where many of the hitherto vague disquisitions of physical science have been happily brought within the pale of geometry, this celebrated philosopher has deduced, from Mr. Dalton's experiments on the force of steam, a general formula for determining its elasticity at any temperature.

In investigating this formula, he represents the decrease of the logarithms of the elastic forces by a series of terms of the form $an + bn^2 + cn^3$; a b c being constant coefficients.

$$\text{Thus, Log. } F_n = \text{Log. } 30 + an + bn^2 + cn^3.$$

It is unnecessary to employ powers of n higher than the cube, because their coefficients would be insensible, as the calculation will show. To determine the coefficients a b c , he makes use of the elastic forces, observed at the temperatures on the centigrade scale of 100° , 75° , 50° , and 25° ; whence result these conditions,

$$\begin{array}{ll} n=0 & F = 30.00 \text{ inches} \\ n=25 & F_{25} = 11.25 \\ n=50 & F_{50} = 3.50 \\ n=75 & F_{75} = 0.910 \end{array}$$

Substituting these conditions in the above general formula, and bearing in mind that the logarithm of a fraction is equal to the logarithm of the numerator minus the logarithm of the denominator, we have the three following equations of conditions.

$$\begin{array}{l} -0.4259687 = 25. a + 625 b + 15625 c. \\ -0.9330519 = 50. a + 2500 b + 125000 c. \\ -1.5180799 = 75. a + 5625 b + 421875 c. \end{array}$$

Doubling the first, and subtracting it from the second, a disappears; trebling it, and subtracting it from the third, a also disappears. Then dividing each of the resulting equations by the coefficient of b , we have

$$\begin{array}{l} -0.00006489160 = b + 75 c. \\ -0.00006404635 = b + 100 c. \end{array}$$

Subtracting the one of these from the other, b will disappear; and dividing it by the coefficient of c , we shall have c . Next,
by

by substituting the value of c in one of these equations, we get b . Lastly, putting b and c in one of the two first equations, we have a . Thus we find

$$\begin{aligned} a &= -0.01537419550 \\ b &= -0.00006742735 \\ c &= +0.00000003381 \end{aligned}$$

Whence the whole formula $\text{Log. } F_n = \text{Log. } 30 + an + bn^2 + cn^3$ is completely determined, and may serve for calculating F_n , relative to any proposed value of n .

If we make, for example, $n=100$, we shall have the elastic force at 100 degrees below the boiling point, or at the temperature of melting ice. We thus obtain

$$\text{Log. } F_n = 1.4771213 - 2.1778831 = -0.7007618.$$

Or employing negative indices in order to make use of the ordinary logarithmic tables,

$$\text{Log. } F_n = 1.2992382, \text{ whence}$$

$$F_n = 0.19917 \text{ inches; and observation}$$

gives us 0.200.

The error is obviously insensible; and we may adopt, says M. Biot, our formula as representing the experiments of Mr. Dalton. To introduce the Fahrenheit degrees into the formula, calling them f , and counting from 212° , we have $\frac{5}{9}f = n$; and substituting this value of n in the preceding formula, we obtain

$$\begin{aligned} a &= -0.00854121972 \\ b &= -0.00002081091 \\ c &= +0.00000000580, \end{aligned}$$

whence $\text{Log. } F_f = 1.4771213 + af + bf^2 + cf^3$, f being the number of degrees of Fahrenheit, reckoning them from 212° , positive below and negative above this point of departure.

By the above formula, thus elaborately investigated by M. Biot, I have computed the elastic forces of steam at the three successive temperatures of 232° , 262° , and 312° , or 20° , 50° and 100° , above the boiling point of Fahrenheit's scale.

In the first case we have $f = -20$ and $af + bf^2 + cf^3 = 20 + 400b - 8000c$; f is negative, being above the point of departure 212° , and, consequently, the products af and cf^3 are positive, while bf^2 becomes negative.

$$\begin{aligned} 20a &= 0.170824 \\ 400b &= -0.008324 \\ 8000c &= +0.000046 \end{aligned}$$

$$\begin{aligned} &0.162546 + \text{log. } 30 \text{ or } 1.477121 \\ &1.477121 \end{aligned}$$

$$\text{Log. of } 43.62 = 1.639667$$

By

By Biot's formula therefore at 232° F. .. 43·620

My experiments .. .. 44·700

Mr. Dalton's table .. .. 43·25

Betancourt .. .. 47·20

By M. Pouillet's table at the end of Biot's 1st vol.

computed from the above formula .. 43·500

The difference between Biot and my experiments here is only 1·10 inches.

2d Example. Temperature 262° Fahr. $f = 50$

50 $a = 0·4270609$

2500 $b = -0·0520272$

125000 $c = +0·0007250$

0·3757587

Log. 30 = 1·4771213

Log. of $F_{262^\circ} = 1·8528800$ $F_{262^\circ} = 71·265$

Experiment .. 74·600

Dalton's table 69·700

Pouillet's table 70·800

Betancourt .. 82·500

The disparity between Biot's formula and experiment becomes more apparent now: it amounts to 3·335 inches.

At 266° Fahr. which corresponds to 130° centigrade, I make it from Biot's first formula 77·053, while at 130° by M. Pouillet, it is 75·68 *; difference 1·973. Finally,

At the temperature of 312°, $f = 100$

100 $a = 0·854121972$

10·000 $b = -0·208109100$

1000000 $c = +0·005800000$

0·651812872

1·477121300

Log. of $F_f = 2·128934172$ $F_f = F_{100} = 134·57$

Experiment gives 167·00

Mr. Dalton's table 125·85

The difference between experiment, and both calculations, is now excessive, and even between the two latter it amounts to nearly nine inches.

From this ample investigation, we may legitimately conclude,

* 130° centigr. gives by M. P. force of vapour = 1907·07 millimetres; of

which taking 25·4 to the English inch, we have $\frac{1907·07}{25·4} = 75·08$ as above.

that

that we ought to receive such geometrical representations with great caution. M. Biot, indeed, with a candour becoming his genius, admits these formulæ to be merely tentative approximations. The high reputation of this philosopher, and the geometrical skill here displayed, might have led the scientific world to repose confidence in his formula, within the limits of $55\frac{1}{2}$ degrees centigrade = 100 Fahr. It was therefore entitled to a deliberate examination.

It is curious to observe that my very simple formula, $\text{Log. } F = \text{Log. } 28.9 \pm n. \text{Log. } r$, gives good approximations, through a much more extensive range, than the elaborate formula of the distinguished French geometer. Even when carried so high as the 310th degree of Fahr., we have

$$\text{Log. } 28.9 + n. \log. r = 2.19810 = L, F_{100}; \text{ hence}$$

$$F_{100} = 157.8.$$

Experiment gives 161.3, a difference of only $3\frac{1}{2}$ inches at this prodigious elasticity; which may be deemed altogether unimportant in practice.

Biot's formula gives a result 31 inches, and Mr. Dalton's 40 in defect.

Of Professor Robison's higher numbers, it is merely necessary to examine the successive differences for every 10° above 212° . These are 7.2, 8.9, 10.2, 11.9, 13.5, 13.8, 11.8, and the second differences are $+1.7 + 1.3 + 1.7 + 1.6 + 0.3 - 2.0$.

Such striking irregularities cannot exist in the progression of nature. Betancourt's are liable to a similar censure. We may find indeed small discrepancies in the best observations at such temperatures.

§ II. *Experiments to determine the elastic Forces of the Vapours of Alcohol, Ether, Oil of Turpentine, and Petroleum or Naphtha.*

The determination of the elasticities of these vapours is a very interesting problem in chemical philosophy. It may possibly unfold the law which connects temperature and elastic energy, and it may furnish likewise some useful applications.

Mr. Dalton has examined the subject with considerable care.

My experiments were performed with the apparatus above described, and were verified by frequent repetitions. The following results were noted down during the progress of the experiments.

TABLE III.

Elastic Forces of the Vapours of Alcohol, Ether, Oil of Turpentine, and Petroleum or Naphtha.

Ether.		Alcohol sp. gr. 0.813.		Alcohol sp. gr. 0.813.		Petroleum.	
Temp.	Force of Vapour.	Temp.	Force of Vapour.	Temp.	Force of Vapour.	Temp.	Force of Vapour.
34°	6.20	32	0.40	193°·3	46.60	316°	30.00
44	8.10	40	0.56	196.3	50.10	320	31.70
54	10.30	45	0.70	200	53.00	325	34.00
64	13.00	50	0.86	206	60.10	330	36.40
74	16.10	55	1.00	210	65.00	335	38.90
84	20.00	60	1.23	214	69.30	340	41.60
94	24.70	65	1.49	216	72.20	345	44.10
104	30.00	70	1.76	220	78.50	350	46.86
		75	2.10	225	87.50	355	50.20
2nd. Ether.		80	2.45	230	94.10	360	53.30
		85	2.93	232	97.10	365	56.90
105°	30.00	90	3.40	236	103.60	370	60.70
110	32.54	95	3.90	238	106.90	372	61.90
115	35.90	100	4.50	240	111.24	375	64.00
120	39.47	105	5.20	244	118.20	Oil of Turpen.	
125	43.24	110	6.00	247	122.10		
130	47.14	115	7.10	248	126.10	Temp.	Force of Vapour.
135	51.90	120	8.10	249.7	131.40		
140	56.90	125	9.25	250	132.30	304°	30.00
145	62.10	130	10.60	252	138.60	307.6	32.60
150	67.60	135	12.15	254.3	143.70	310	33.50
155	73.60	140	13.90	258.6	151.60	315	35.20
160	80.30	145	15.95	260	155.20	320	37.06
165	86.40	150	18.00	262	161.40	322	37.80
170	92.80	155	20.30	264	166.10	326	40.20
175	99.10	160	22.60			330	42.10
180	108.30	165	25.40			336	45.00
185	116.10	170	28.30			340	47.30
190	124.80	173	30.00			343	49.40
195	133.70	178.3	33.50			347	51.70
200	142.80	180	34.73			350	53.80
205	151.30	182.3	36.40			354	56.60
210	166.00	185.3	39.90			357	58.70
		190	43.20			360	60.80
						362	62.40

Remarks on the preceding Table.

The ether of the shops as prepared by the eminent London apothecaries boils generally at 112°; but when washed with water, or redistilled, it boils at 104° or 105°. It may by rectification, however, be made to boil at a still lower temperature.

Concerning the boiling point of oil of turpentine, curious (may we say ridiculous) discrepancies exist in our systems of chemistry. Dr. Murray, for example, in the table of the scale of temperature

at

at the end of the first volume of his valuable System, last edition, places the boiling point of oil of turpentine at 560° . Mr. Dalton, vol. i. p. 39, of his new System of Chemical Philosophy, says : "Several authors have it that oil of turpentine boils at 560° . I do not know how the mistake originated, but it boils below 212° , like the rest of the essential oils." I made with much care several experiments on this point, previous to ascertaining the force of its vapour, and found its boiling point to be about 316° . When recently distilled, however, it will boil at 305° . Did it boil below, or even at 212° , as Mr. Dalton asserts, *then*, long before the included portion in the above experiments had reached the 304th degree, it would have acquired such an elasticity as to support a high column of mercury, instead of being barely *in equilibrio* with the atmospheric pressure.

Plunge a phial half filled with fresh oil of turpentine into a metal cup containing any fixed oil. Heat the cup gradually. It will be found that, at the temperature of 316° , the oil remains in steady ebullition, as indicated by a thermometer suspended in the centre of the phial. Prior to this, even at 212° , some small bubbles will be evolved, principally owing to the moisture dispersed in the pores of the oil, from the water originally mixed with the crude turpentine in its distillation. If the heat be very rapidly thrown in, while the upper surface of the oil of turpentine has the area only of a one or two ounce phial, it is possible to heat it to 360° or 370° , in apparent contradiction to the theory of latent heat ; for when a liquid boils in an open vessel, according to Dr. Black, its temperature should remain stationary. The true cause of this phenomenon is developed towards the conclusion of this memoir. The specific caloric of the vapour of the volatile oil is so small, compared to that of water, that the heat may readily be quicker introduced than the boiling process can abstract it. Concerning the boiling point of this oil, I have since inquired of a manufacturer ; and he states its boiling point at 320° . Essential oil of rosemary, when kept for some time, boils at 270° ; recent oil at 212° . To assign the cause of this difference, is foreign to our present object.

The vapour of ether follows nearly the same rate of expansion as water, if we start from their respective boiling points. This was observed also in Mr. Dalton's experiments ; and from this single analogy, chiefly, he laid down the general law, "that the variation in the force of vapour from all liquids is the same for the same variation of temperature, reckoning from vapour of any given force."

My experiments on oil of turpentine and petroleum show the fallacy of this generalization, if we reckon the common thermometric scale a tolerably correct index of temperature ; but if,
with

with Mr. Dalton, we consider our thermometric scale, as very erroneous, then either itself is an exception to its own law, to use this paradoxical, though just expression. In consequence of his peculiar thermometric ideas, Mr. Dalton has abrogated the above law, which he had himself framed; though it is curious to observe, in some respectable treatises on chemistry, both hypotheses detailed, without indicating their mutual incompatibility. M. Biot, likewise, far from imagining that the law had been repealed for eight or nine years, proposes to judge by its provisions of the total elastic force of every vapour at 100° centigrade, to serve as the basis of the determination of their respective specific gravities at that temperature*.

My experiments show that from 105° to 167°·5 Fahrenheit, ether trebles the tension of its vapour, as water also does from 212° to 272°·7; both containing nearly, but by no means exactly, equal intervals of the Fahrenheit graduation. According to Mr. Dalton's corrected scale of temperature, we have

$$\begin{array}{rcl} 212^{\circ} \text{ Fah.} & = & 212^{\circ} \text{ Dalton.} \quad 105^{\circ} \text{ Fah.} = 119^{\circ} \text{ Dalton.} \\ 273 \text{ F.} & = & 256\cdot4 \text{ D.} \quad 167\cdot5 \text{ F.} = 176 \text{ D.} \end{array}$$

real interval = 44·4 by Dalton. By Dalton 57 = the real interval of temperature.

Thus we see, that while the interval for trebling the tension of ethereal vapour is 57°, that for aqueous vapour is only 44°·4; quantities that are to each other nearly as 100:80. Hence, according to this eminent chemist, ether must take for trebling the force of its vapour a fifth part more heat than water does.

I hope presently to be able to adduce satisfactory experimental evidence, that our thermometric indications are not at all so unequable as Mr. Dalton conceives.

Meanwhile, in examining closely the table of the vapour of ether, a beautiful analogy with that of water presented itself. The series of ratios representing the progression of the latter being lowered a single step, will accurately fit the former. At 30 inches of elasticity 1·23 was our initial number for aqueous vapour; for ethereal, it becomes 1·22; increasing or diminishing by unity each time in the second decimal figure, according as we descend or ascend by intervals of 10° of the Fahrenheit scale.

The following is a general view of the results.

* "On peut calculer par la loi de M. Dalton, quelle doit être, pour chacun d'eux, la force élastique totale de sa vapeur à la température de 100 degrés."—*Traité de Physique*, tome i. p. 393.

TABLE IV.

The observed Tension of ethereal Vapour compared with the Ratios 1·22, 1·23, &c. and 1·22, 1·21, &c.

Temp.	Quotients.	Expert.	Temp.	Product.	Expert.
104°	—	30·00	105°	—	30·0
94	24·7	24·70	115	36·6	35·9
84	20·2	20·00	125	44·3	43·24
74	16·3	16·10	135	53·4	51·9
64	13·06	13·00	145	63·6	62·1
54	10·3	10·3	155	75·4	73·6
44	8·1	8·1	165	88·2	86·4
34	6·35	6·2	175	102·0	99·1
			185	117·3	116·1
			195	134·0	133·7
			205	151·3	151·3

The numbers derived from calculation give a surprising accordance with those observed in the lower range. In the upper range, the correspondence is as good as the delicacy of the experiments at such temperatures could permit us to expect. The experiments have been presented without modification. I must own, that when first the above perfect coincidence appeared, it gave me no small pleasure, as it led me to suppose that I had discovered the hidden chain of nature.

In treating of the vapour of alcohol, Mr. Dalton considers it as irregular in the progress of its elastic force by heat, owing to its not being a homogeneous liquid. He suspects "that the elastic force in this case is a mixture of aqueous and alcoholic vapour." I cannot see the cogency of this argument; for, if the separate bodies have a regular progression, the mixture ought not surely to be anomalous. I believe, however, that if the experiments were made with due accuracy, alcohol would be found as methodical in the elastic march of its vapour as other bodies. The following table will afford satisfactory proofs of the justness of these views. For absolute alcohol, the progression is probably as simple as that of the preceding vapours. But for alcohol, sp. gr. 0·813, which though highly rectified contains not a little water, we should expect it to result from a composition or modification of ratios. After some search on this principle, I accordingly found it. Starting from the boiling point 174°, or, for the convenience of comparison with the table, from the decade 170°, we move not by a unit, as before, but by a unit and a tenth; or the initial ratio 1·26 is affected at each step or term of

of 10° , with the number ± 0.011 , the signs being employed as in the preceding cases.

TABLE V.

Elastic Force of the Vapour of Alcohol compared with the Ratios.

Temp.	Calcu- lat.	Ob- served	Temp.	Calcu- lat.	Ob- served.	Temp.	Calcu- lat.	Ob- served.
250°	130.24	132.3	170°	28.3	28.3	90°	3.41	3.40
240	111.13	111.24	160	22.46	22.6	80	2.52	2.45
230	93.94	94.1	150	17.7	18.0	70	1.85	1.76
220	78.67	78.5	140	15.8	15.9	60	1.35	1.23
210	65.29	65.0	130	10.65	10.6	50	0.97	0.86
200	53.69	53.0	120	8.16	8.10	40	0.69	0.56
190	43.76	43.2	110	6.2	6.00	30	0.49	0.38
180	35.35	34.73	100	4.67	4.50			

$$\frac{28.3}{1.26} = 22.46 \therefore 28.3 \times \frac{1}{1.26-0.011} = 35.35$$

$$28.3 \times \frac{1}{1.26-0.011} \times \frac{1}{1.26-0.022} = 43.76 \text{ \&c.}$$

$$\frac{22.46}{1.271} = 17.7, \text{ \&c.}$$

The correspondence here exhibited between the observed and calculated elasticities is remarkable; nor does the difference ever exceed what would be produced by an error of 1° in the construction or reading off of the thermometer. This may fairly be deemed the limit of accuracy in such an experiment.

Oil of turpentine is regulated by the constant ratio 1.122, which converts any elastic force into that 10° above or below, multiplying as usual in the former, and dividing in the latter case. For petroleum the ratio is 1.14; it is also constant.

The following table exhibits a comparative view of theory and experiment.

TABLE VI.

Oil of Turpentine.			Petroleum.		
Temp.	Calculated.	Observed.	Temp.	Calculated.	Observed.
310°		33.5	320°		31.7
320	37.7	37.06	330	36.2	36.4
330	42.5	42.1	340	41.2	41.6
340	47.7	47.3	350	47.0	46.86
350	53.5	53.8	360	53.6	53.3
360	60.4	60.8	370	61.1	60.7

The whole of the preceding research is closely interwoven with a question of the first importance in chemical philosophy; what are the relative portions of temperature denoted by the graduations of our thermometric scale? Mr. Dalton regards the progressive elasticities of aqueous and ethereal vapour as affording countenance, if not support, to his thermometric innovations. He affirms, that if our instrument for the measuring heat were accommodated to his doctrine, the quantity of expansion of its mercury is as the square of the temperature from its freezing point; then “the force of steam in contact with water increases *accurately* in geometrical progression to equal increments of temperature, provided these increments are measured by a thermometer of water or mercury, the scales of which are divided by the above-mentioned law*.”

Were this position true, it would certainly bring a powerful analogy in aid of his theoretical views. We are now furnished with *data* to verify, or refute it. The following tables show the correspondence between that principle and experiment. In the table of aqueous vapour, the *first* column presents his geometrical progression of that vapour, coordinate with his equal intervals of real temperature contained in the *second*. In the *third*, are the corresponding points of the common scale, as given by Mr. Dalton. To these points the elastic forces, as determined by experiment, are placed opposite in the fourth column.

Table second, for vapour of ether, is similarly arranged; the first three columns being Mr. Dalton's; the *fourth*, the faithful transcript of observation.

“The force of the vapour of sulphuric ether,” says Mr. Dalton, “in contact with liquid ether, is a geometrical progression, having a less ratio than that of water.” “Ether, as manufactured in the large way, appears to be a very homogeneous liquid. I have purchased it in London, Edinburgh, Glasgow, and Manchester, at different times, of precisely the same quality in respect to its vapour†.” This shows that no exception can be made to my experiments on account of a supposed difference in the quality of the ether. From the mode of conducting my experiments, there remained always a quantity of liquid ether in contact with the vapour, a circumstance essential to accuracy in this research. The results were verified by frequent repetitions, and discover, in my opinion, the consistency of truth.

* New System, vol. i. p. 11.

† Ib., pp. 20, 21.

TABLES VII. and VIII.

DALTON's Theory of the thermometric Scale compared with the observed Temperatures and Tensions of Vapours.

Aqueous Vapour.				Ethereal Vapour.			
DALTON's geom. Pro- gression of Elasticity.	DALTON's new Scale of Tem- perat.	FAHREN. Observed Elasticity	Observed Elasticity	DALTON's Progression of Elasticity.	DALTON's Scale.	FAHREN. Observed Elasticity	Observed Elasticity
22.7 inch.	202°	199°	23.1 in	6.1	32°	32°	5.81
30.0	212	212	30.0	9.16	52	46.6	8.67
39.5	222	225	39.11	13.77	72	62.55	12.60
52.0	232	238.6	50.3	20.65	92	79.84	18.40
69.0	242	252.6	64.5	31.0	112	98.50	27.2
91.0	252	266.8	81.5	46.54	132	118.50	37.7
120.0	262	281.2	103.5	69.88	152	139.9	56.8
158	272	296.2	131.7	104.91	172	162.4	83.3
208	282	311.5	164.8	157.5	192	186.5	118.3
				236.5	212	212°	169.0

The numbers of the first and fourth column ought evidently to agree, if the theory be just. Their differences, on the contrary, are prodigiously great. At 272° of his scale, for example, equal to 296°·2 of ours, the law of progression makes the elastic force of aqueous vapour amount to 158 inches: experiment gives 131·7; and I am confident, that the latter cannot be in error above an inch or two. Again at 262°, equivalent to 281°·2 Fahrenheit, his theory gives the force of the same vapour at 120 inches; by observation it is only 103·5. Now at this part of the scale, my result is confirmed by the concurrence of those obtained by Betancourt and Robison. I consider this demonstration complete. If we compare these very elasticities of Mr. Dalton, with the table formerly given by the same philosopher*, we shall find discordances which no ingenuity can harmonize. At that time, 225° of Fahr.=222° of the new scale, gave a force of vapour equal to 38·3; it is now 39·5. 252°·6 F. = 242° D. then coincided with an elasticity of 58·6 inches; above, it is 69. And finally, 281°·2 F.=262° D. were opposite to 90 inches; they have become here 120. And yet no new experiments on the vapour of water have been adduced, to justify such immense alterations.

It may be said, indeed, that these changes arise merely from the substitution of one hypothesis for another; but the deviations from experiment are even more remarkable, since as 282° new scale, correspond to 311°·5 Fahr., the difference amounts to 43 inches, being more than one-fourth of the total elastic force generated at that high temperature.

* Manchester Memoirs, vol. v.

When we turn our attention to ether, we find the discrepancies, if possible, less easy to reconcile. At the temperature of 212° , for example, where the old and new scales meet for the last time, the force of its vapour by the geometrical progression exceeds that found from experiment, by the enormous quantity of 67 inches and a half; amounting to two-fifths of the whole elastic force evolved.

May we venture, then, to conclude, from these multiplied comparisons, that the progressions of elasticity in vapours, taught by Mr. Dalton, are geometrical fictions, intended to quadrate with his notions concerning temperature; but not consonant with the laws or phenomena of nature?

Within a moderate compass, indeed, it is not difficult to suit the ratio of elastic force and the thermometric graduation to each other; but the prosecution of the inquiry into ranges more remote, detects the fallacy of such hypothetical adaptations. My experiments on the vapours of water, alcohol and ether, seem to show, that the ratio of tension decreases in a certain progression as the temperature augments. Were the ratios 1.23 , 1.22 , 1.21 , &c., which are seen to apply so well to aqueous vapour for a considerable range above 212° , to be adopted as representing the progressive march of nature, it would lead to the absurd conclusion, that at 240° above the boiling point, or 452° F., the further influx of caloric would occasion a diminution of elasticity in the steam. The truth however is, that at the 312^{th} degree, indications of a divergence begin to appear between the two lines of experiment and calculation, which had run for so long a space nearly parallel. The curve representing the expansive force of steam, I consider to be logarithmic, in which the ratios, as ordinates, continually diminish, without ever vanishing, or coming to an equality. The axis is an asymptote to the curve, as in the atmospherical logarithmic.

[To be continued.]

XVI. *On Wheel-Carriages and their Effects upon Roads.* By
Mr. JOHN FAREY Sen. Mineral Surveyor.

To Mr. Tilloch.

SIR, I AM glad to see the important subjects of Wheel-carriages and Roads, brought under the notice of your readers, by the communication of Mr. Benjamin Wingrove, in your last Number; wherein he recommends two important improvements; viz. to prevent or lessen the evils of *dragging waggon wheels* down the hills, and the constructing of *carriages of an uniform breadth*, so that their wheels repeatedly follow in the same tracks, and cut ruts in the

the