XVII.—*On the Weight of Aqueous Vapour which is condensed on a Cold Surface, under given conditions.* By JAMES DALMAHOY, Esq.

(Read 3d March 1851.)

In the accompanying tables are contained the results of some experiments respecting the rate at which aqueous vapour condenses on a cold surface.

These results are not so consistent as could be desired, but having been obtained by a definite and carefully-conducted process, they may claim at least to be received as approximately true.

In planning the experiments, it was assumed that $c = m(f'' - f''')$, where c is the weight of moisture which is condensed on a surface of given area in a given time; f'' the tension of vapour at the dew-point; f''' its tension at the temperature of the condensing surface; m a coefficient varying with the velocity of the current of air.

It was found, however, in the course of the experiments, that the coefficient m was not constant for calm air, as was at first supposed. The results under this state of the air indicated that the formula should be changed to $c = M(t - t''')(f'' - f''')$, in which t is the temperature of the air; t''' the temperature of the condensing surface; M a constant coefficient; and f'' , f''' , and c have their former values.

The object of the experiments in connection with these formulæ was to determine the values of the coefficients m and M from those of their equivalent expressions $\frac{c}{f'' - f'''}$ and $\frac{c}{(t - t''')(f'' - f''')}$.

As it would have been difficult, if not impossible, to have kept the condensing surface steadily at any low temperature except that of melting ice, the value of f''' throughout the experiment was equal to 0.2 inch, the tension of vapour at 32° Fahr.

In each experiment, therefore, there were only two things to be determined, namely, f'' the tension of vapour at the dew-point, and c the weight of condensed moisture.

The value of f'' was deduced by means of Dr APJOHN'S formula, from the indications of the wet and dry bulb thermometers. The data and results connected with this quantity will be found in Table I., from the fifth to the eighth column inclusive. The instruments used were two standard thermometers, made by Messrs ADIE and SON, of Edinburgh.

The value of c was ascertained by a simple process, which, however, as the success of the experiments entirely depended on it, must be described in detail.

The aqueous vapour was condensed on the inner surface of a nearly cylindrical copper vessel, the depth of which was 0·5 of an inch ; the diameter at the bottom 3 inches, the diameter at the mouth 3·075 inches ; consequently the inner area was equal to 11·8 square inches. This vessel had a thin copper lid, the catch of which adhered to the inner surface, and so did not interfere with the thorough removal of moisture from the outer surface.

The temperature of the condensing surface, it has been already remarked, was uniformly 32° Fahr. . This temperature was maintained by filling with pounded ice a cylindrical copper box, and burying in it the condensing vessel, all except its upper edge, which was made to fit into, and slightly project above, a circular opening in the top of the box.

The following are the steps of the process by which the weight of the moisture condensed on the cold surface was ascertained.

The condensing vessel and its lid were first carefully dried and then weighed in a balance, which was sensible to ·01 of a grain, when each scale was loaded with 800 grains. The vessel, with its lid closely applied, was now placed among ice, as before described, and allowed to cool for about five minutes. The lid was then removed, and the condensing surface exposed either to a current of air of known velocity, or to calm air. After the exact interval of five minutes the lid was replaced, and the vessel was taken out from among the ice ; its temperature was then raised above the dew-point by the heat of the hand, while its outer surface was carefully dried. Lastly, it was again weighed, and the excess of this above the former result was equal to the weight of moisture which had been condensed.

The results thus obtained will be found in Table I., from column twelfth to column seventeenth inclusive.

It appears from column twelfth, that when the air was calm, and the mouth of the condensing vessel was directed upwards, the quantity of condensed vapour was so small and variable as to render it probable that, under this arrangement, there would have been no sensible condensation at all, had it not been for those irregular currents, which are known to prevail even in air apparently calm.

Column thirteenth shews that when the air was calm, and the mouth of the vessel was turned downwards, much more vapour was condensed than when the mouth was upwards. This was evidently the effect of a current produced by contact of the warm air with the cold condensing surface, and which, for obvious reasons, could not take place when the mouth of the vessel was directed upwards. The effect of this current on the rate of condensation seemed to vary nearly as $t - t'''$, at least it would be difficult, except on this assumption, to reconcile the four last with the preceding results in the column.

The last four columns exhibit the results of experiments, in which the condensing surface was exposed to an artificial current of air.

The current was produced by means of a common fire-blower, and the velo-

city of it was regulated by the number of revolutions made by the handle of the instrument in the course of ten seconds. The results correspond respectively to 5, 10, 18, and 25 of these revolutions, or on a rough estimate to actual velocities of 4·12, 8·24, 14·8, and 20·6 feet per second.

With such an instrument it was difficult to maintain a rapid current at a uniform rate, and hence, probably, the reason why the results due to five and ten revolutions of the handle are less discordant than those corresponding to eighteen and twenty-five revolutions.

The second table contains the values of $M = \frac{c}{(t-t''')(f''-f''')}$ and of $m = \frac{c}{f''-f'''}$, the former corresponding to the experiments in the thirteenth column, and the latter to the experiments in the fourteenth, fifteenth, sixteenth, and seventeenth columns of the first table. The results in column twelfth, for reasons which will be obvious from the remarks on that column, are omitted in the second table.

Taking the mean of the numbers in each column of this table, and changing the unit of surface from 11·8 to 100 square inches, and the unit of time from five minutes to one minute, it appears that the value of M for calm air is 0·12, and that the values of m for velocities of 4·12, 8·24, 14·8, and 20·6 feet per second are respectively 18·3, 26·5, 39·7, and 44·6.

These results may be useful in various meteorological investigations; but at present it is proposed to apply them only to one question connected with the theory of rain.

The admirable observations of Professor PHILLIPS and Mr GRAY, published in the Reports* of the British Association, shew that at York there fell in the course of three years, into a rain-gauge placed on the ground, 65·430 inches of rain: into a gauge placed at the height of 43·7 feet, 52·169 inches; and into a gauge at the height of 213 feet, 38·972 inches.

Professor PHILLIPS has proposed, in explanation of these anomalous results, an hypothesis which may be thus enunciated. As rain falls from a considerable height in the atmosphere, its temperature is less than that of the dew-point of the vapour through which it passes in the course of its descent; and this gives rise to a continuous deposition of moisture on the surface of each rain-drop sufficient, in the aggregate, to account for the difference between the quantities of rain received in the higher and lower gauges.

This ingenious explanation has been so ably advocated by its proposer, and by other highly competent judges, that it is not without hesitation I venture to object to it, on the ground that the rate of condensation which it assumes, when compared with the rate deduced from experiment, is too great.

I shall now endeavour to offer some proof in support of this conclusion.

* Vol. ii., p. 401; vol. iii., p. 560; vol. iv., p. 171.

At York, during the winter quarters of the years 1832–33, 1833–34, 1834–35, a rain-gauge placed on the ground received 17·32 inches of rain, and a similar gauge placed at the height of 43·7 feet received only 12·17 inches of rain.

In this case, according to the hypothesis, a rain-drop, while falling through the height of 43·7 feet condensed on its surface a quantity of moisture, the weight of which was to the weight of the drop, before the condensation began, in the ratio of ·42 to 1.

In order to make a fair comparison between this assumed rate of condensation and the rate deduced from experiment, it would be necessary to know the mean temperature of the rain, the mean temperature of the dew-point, the mean size of the drops of rain, and the velocity of their fall.

But as the available data are not sufficient to furnish mean values of these quantities, it is necessary, in order to obviate any objection on this ground to the proposed mode of comparison, to assume for the temperature of the rain, the temperature of the dew-point, and the size of the rain-drops, values the most favourable to the hypothesis which the case admits of.

First, therefore, we are sure that in assuming the temperature of the rain to be 32°, we ascribe to the condensing surface the greatest cold compatible with its being a surface of fluid water.

Again, since the mean temperature of the air during the winter months of the three years of observation was 36°·3, and the mean range of temperature was equal to 8·6 degrees, it follows that the mean maximum temperature of the air was $36\cdot3 + \frac{8\cdot6}{2} = 40\cdot6$. The temperature of the dew-point, therefore, cannot possibly be assumed as having been higher than 40°·6.

Further, as Sir JOHN LESLIE states that the diameters of the drops of rain vary from ·04 to ·25 of an inch; and as it is more favourable to the hypothesis to suppose them small than great, it is proposed to assume that the diameter of each drop was only ·05 of an inch. The weight of a drop of rain of this magnitude is ·0165 of a grain, and the area of its surface is equal to ·00786 of a square inch.

Lastly, since a drop of rain having its diameter equal to ·05 of an inch would soon attain its terminal velocity, it may be assumed that the drops fell with an uniform velocity of 14·6 feet per second, and consequently occupied $\frac{43\cdot7}{14\cdot6} = 3$ seconds in falling through the height of 43·7 feet.

It now remains to ascertain what rate of condensation is deducible from these data, as compared with the rate assumed by the hypothesis.

In order to do this, let $f'' = \cdot27$, the tension of vapour at 40°·6; $f''' = \cdot2$, the tension at 32°; $m = 39\cdot7$, the coefficient due to a current of air having a velocity of 14·8 feet per second, which is nearly the same as the terminal velocity with which the drops of rain have been supposed to fall.

Next, let these values be substituted in the formula $c = m(f'' - f''')$, which then becomes $c = 39 \cdot 7 (\cdot 27 - \cdot 2) = 2 \cdot 779$ grains.

But as c represents the weight of moisture which would be condensed on a surface of 100 square inches in 60 seconds, and we require to know the quantity which would be condensed on a surface equal to $\cdot 00786$ of a square inch in the lapse of three seconds, it will be necessary, in order to obtain this latter result, to multiply $2 \cdot 779$ grains, the value of c , by $\frac{\cdot 00786}{100} \times \frac{3}{60}$, which gives $\cdot 000011$ of a grain as the weight of moisture condensed on the surface of the rain-drop, while falling through 43·7 feet.

Now, as the original weight of the drop was $\cdot 0165$ of a grain, it follows that the weight of moisture condensed on the drop was to the weight of the drop itself in the ratio of $\cdot 000011$ to $\cdot 0165$, that is, in the ratio of $\cdot 00066$ to 1.

But, as was before shewn, the hypothesis assumes the ratio of these quantities to be that of $\cdot 42$ to 1.

Hence, unless there be some fallacy in the mode of arriving at the conclusion, the rate of condensation assumed by the hypothesis is $\frac{\cdot 42}{\cdot 00066} = 635$ times greater than the rate deduced from experiment.

TABLE I.

Date and Hour.	No. of Experiment.	Duration of Experiment—minutes.	Barometer.	Temperature of the air during Experiment.	Indication of moist-bulb thermometer.	Temperature of the dew-point.	Tension of vapour at the dew-point.	Difference between the tension of vapour at the dew-point and 32°.	Difference between the temperature of the air and of the condensing surface.	Weight of the copper vessel when dry.	Difference between the weight of the copper vessel before and after the condensation of moisture.						REMARKS.
											In calm air, mouth of vessel upwards.	In calm air, mouth of vessel downwards.	In a current of 28 miles per hour, or 4·12 feet per 1".	5·6 miles per hour, or 8·24 feet per 1".	10 miles per hour, or 14·8 feet per 1".	14 miles per hour, or 20·6 feet per 1".	
1849. Dec. 15,	...	...	29·468	...	...	...	...	...	...	Grains.	...	...	...	...	...	...	
11 17 A.M.,	1	5	...	51·0	47·9	44·7	·312	·112	...	803·90†	...	...	...	...	...	2·60	
11 42 ...	2	5	...	51·5	47·9	44·2	·306	·106	...	803·89	...	...	...	...	...	2·62	
12 13 P.M.,	3	5	...	51·5	48·2	44·8	·313	·113	...	803·89	...	...	...	...	...	2·88	
12 39 ...	4	5	...	51·4	48·1	44·7	·312	·112	...	803·88	...	...	...	...	...	2·35	
1 10 ...	5	5	...	51·5	48·2	44·8	·313	·113	...	803·87	...	...	...	...	...	2·36	
1 35 ...	6	5	...	51·4	48·3	45·2	·316	·116	...	803·87	...	...	...	...	...	2·78	
1 58 ...	7	5	...	51·5	48·3	45·1	·316	·116	...	803·86	...	...	...	...	...	2·81	
2 24 ...	8	5	...	51·4	48·1	44·7	·312	·112	...	803·85	...	...	...	...	2·51	...	
2 48 ...	9	5	...	51·4	48·3	45·2	·316	·116	...	803·85	...	...	...	...	2·53	...	
3 13 ...	10	5	...	51·4	48·3	45·2	·316	·116	...	803·84†	...	...	...	...	2·56	...	
1849. Dec. 17,	...	...	29·168	...	...	...	...	...	...	...	...	...	...	...	...	...	
10 44 A.M.,	11	10	...	52·4	49·5	46·7	·334	·134	...	803·78†	0·05	...	...	...	...	...	
11 34 ...	12	5	...	52·4	49·5	46·7	·334	·134	20·4	803·77	...	0·23	...	...	...	...	
11 58 ...	13	5	...	52·8	49·9	47·2	·338	·138	20·8	803·76	...	0·17	...	...	...	...	
12 29 P.M.,	14	5	...	53·5	50·1	46·9	·336	·136	21·5	803·76	...	0·22	...	...	...	...	
12 48 ...	15	5	...	53·1	50·1	47·3	·340	·140	21·1	803·75	...	0·21	...	...	...	...	
1 10 ...	16	5	...	53·0	50·0	47·2	·339	·139	...	803·74	0·06	...	...	...	...	...	
1 32 ...	17	5	...	52·9	50·1	47·5	·343	·143	...	803·73	...	...	1·60	...	...	...	
1 55 ...	18	5	...	52·9	50·1	47·5	·343	·143	...	803·72	...	...	1·65	...	...	...	
2 15 ...	19	5	...	52·7	49·9	47·2	·339	·139	...	803·72	...	...	1·28	...	...	...	
2 38 ...	20	5	...	52·5	49·7	47·1	·338	·138	...	803·71	...	...	1·32	...	...	...	
3 11 ...	21	5	...	52·6	49·7	46·9	·336	·136	...	803·70	...	...	1·27	...	...	...	
1850. Feb. 1,	...	...	29·122	...	...	...	...	...	...	...	...	...	...	...	...	...	The greatness of the result in experiment 34 was probably owing to an imperceptible current.
11 40 A.M.,	22	5	...	50·1	47·4	44·6	·311	·111	...	803·70†	...	...	1·07	...	...	...	
12 5 P.M.,	23	5	...	50·0	47·4	44·8	·312	·112	...	803·69	...	...	1·27	...	...	...	
12 30 ...	24	5	...	50·0	47·6	45·1	·316	·116	...	803·69	...	...	1·27	...	...	...	
1 0 ...	25	5	...	50·2	47·5	44·7	·312	·112	...	803·68	...	...	...	...	2·82	...	
1 24 ...	26	5	...	50·4	47·4	44·4	·308	·108	...	803·67	...	...	...	...	2·49	...	
1 44 ...	27	5	...	50·1	47·4	44·6	·311	·111	...	803·67	...	...	...	...	2·94	...	
2 8 ...	28	5	...	49·9	47·4	44·9	·313	·113	...	803·66	...	...	...	...	2·83	...	
2 26 ...	29	5	...	49·9	47·5	45·0	·315	·115	...	803·65	...	...	...	...	2·71	...	
2 48 ...	30	5	...	50·0	47·4	44·8	·312	·112	...	803·65	...	...	...	...	...	3·19	
3 8 ...	31	5	...	50·0	47·4	44·8	·312	·112	...	803·64	...	...	...	...	...	3·43	
3 29 ...	32	5	...	50·2	47·6	44·9	·314	·114	...	803·64	...	...	...	...	...	3·32	
3 47 ...	33	5	...	50·2	47·6	44·9	·314	·114	...	803·63†	...	...	...	...	...	3·09	
1850. Feb. 19,	...	...	29·470	...	...	...	...	...	...	...	...	...	...	...	...	...	The experiment spoiled.
10 50 A.M.,	34	5	...	54·3	50·2	46·3	·328	·128	...	803·63†	0·14	...	...	...	...	...	
11 17 ...	35	5	...	54·3	50·2	46·3	·328	·128	...	803·62	0·03	...	...	...	...	...	
11 43 ...	36	5	...	54·5	50·5	46·7	·334	·134	...	803·62	0·06	...	...	...	...	...	
12 12 P.M.,	37	5	...	54·6	50·7	47·2	·338	·138	22·6	803·61	...	0·25	...	...	...	...	
12 44 ...	38	5	...	54·5	50·4	46·5	·331	·131	22·5	803·61	...	0·26	...	...	...	...	
1 20 ...	39	5	...	54·6	50·6	46·8	·335	·135	22·6	803·60	...	0·26	...	...	...	...	
1 45 ...	40	5	...	54·6	50·6	46·8	·335	·135	...	803·60	...	...	...	2·04	...	...	
2 11 ...	41	5	...	55·1	50·8	46·7	·334	·134	...	803·59	...	...	...	1·78	...	...	
2 39 ...	42	5	...	54·8	50·8	47·2	·338	·138	...	803·59	...	...	...	2·08	...	...	
3 3 ...	43	5	...	54·7	50·6	46·7	·334	·134	...	803·58	...	...	...	1·89	...	...	
3 30 ...	44	5	...	54·6	50·6	46·8	·335	·135	...	803·57	...	...	...	1·97	...	...	
3 53 ...	45	5	...	54·5	50·6	46·9	·336	·136	...	803·57†	...	...	...	...	3·47	...	
1850. Mar. 14,	...	...	30·385	...	...	...	...	...	...	...	...	...	...	...	...	...	The condensing vessel repaired. The experiment spoiled.
10 38 A.M.,	46	5	...	56·6	51·1	45·8	·324	·124	24·6	803·56†	...	0·18	...	...	...	...	
10 59 ...	47	5	...	56·7	51·2	45·9	·325	·125	24·7	803·55	...	0·14	...	...	...	...	
11 24 ...	48	5	...	56·8	51·3	46·0	·326	·126	24·8	803·54	...	0·16	...	...	...	...	
11 44 ...	49	5	...	56·8	51·3	46·0	·326	·126	24·8	803·53	...	0·16	...	...	...	...	
12 3 P.M.,	...	...	...	...	...	...	...	...	...	803·52	...	...	...	...	...	...	
12 15 ...	50	5	...	56·8	51·3	46·0	·326	·126	...	803·51	0·06	...	...	...	...	...	
12 35 ...	51	5	...	56·8	51·5	46·5	·331	·131	...	803·49	0·07	...	...	...	...	...	
1850. Aug. 14,	...	...	29·844	...	...	...	...	...	...	803·48†	...	...	...	...	...	...	
10 19 A.M.,	...	...	...	...	...	...	...	...	...	792·40†	...	...	...	...	...	...	
10 28 ...	52	5	...	67·3	60·4	55·6	·451	·251	35·3	792·39	...	0·71	...	...	...	...	
10 52 ...	53	5	...	67·4	60·5	55·7	·452	·252	35·4	792·38	...	0·72	...	...	...	...	
11 12 ...	54	5	...	67·5	60·6	55·8	·455	·255	35·5	792·37	...	0·67	...	...	...	...	
11 37 ...	55	5	...	67·7	60·7	55·8	·455	·255	35·7	792·36	...	0·70	...	...	...	...	
11 59 ...	56	5	...	67·8	60·8	56·0	·458	·258	...	792·35	...	...	7·11	...	...	...	
12 25 P.M.,	57	5	...	67·9	60·9	56·1	·459	·259	...	792·34	...	...	3·02	...	...	...	
12 47 ...	58	5	...	68·1	61·0	56·2	·460	·260	...	792·33	...	...	3·17	...	...	...	
1 15 ...	59	5	...	68·3	61·3	56·4	·465	·265	...	792·33	...	...	3·17	...	...	...	
1 39 ...	60	5	...	68·6	61·6	56·8	·471	·271	...	792·32	...	...	...	4·98	...	...	
2 7 ...	61	5	...	68·7	61·7	57·1	·474	·274	...	792·31	...	...	...	4·39	...	...	
2 28 ...	62	5	...	68·8	61·8	57·2	·476	·276	...	792·31	...	...	...	5·07	...	...	
2 53 ...	63	5	...	69·0	61·9	57·2	·476	·276	...	792·30	...	...	...	...	7·40	...	
.....	...	...	...	...	...	...	...	...	...	792·30†	...	...	...	...	...	...	

REMARKS ON TABLE I.

The experiments, the results of which are contained in this table, were all consecutive. No experiment was rejected after what appeared to be a satisfactory mode of experimenting had once been adopted.

The indications of the barometer in the fourth column are reduced to 32° Fahr.

The indications of the dry and wet bulb thermometers recorded in the fifth and sixth columns, are the means of observations made during the intervals of the experiments. As the moist-bulb thermometer was observed in calm air, it was necessary to apply to its indication a subtractive correction, the amount of which was determined by ascertaining, at the end of each day's experiments, how much the moist-bulb was cooled by fanning it for a short time.

The tenth column exhibits the weight of the condensing vessel with its lid. It was found that the friction used in drying the vessel reduced its weight by about .01 of a grain at each experiment. In order to make the suitable correction on this account, the vessel was weighed at the beginning and end of each day's experiments, and the loss of weight was equally distributed over the intervening experiments. The numbers marked with a cross thus †, express the weights which were actually determined.

TABLE II.

No. of Experiment in preceding Table.	Values of M in calm air, when the con- densing surface is downwards.	Values of <i>m</i> in a cur- rent of 28 miles an hour, or 4·12 feet per 1".	Values of <i>m</i> in a cur- rent of 56 miles an hour, or 8·24 feet per 1".	Values of <i>m</i> in a cur- rent of 10 miles an hour, or 14·8 feet per 1".	Values of <i>m</i> in a cur- rent of 14 miles an hour, or 20·6 feet per 1".	REMARKS.
1	...	...	...	...	23·21	The experiments contained in the twelfth column of the first Table are omitted, as affording no definite results. The fifty-sixth experiment is also omitted, having obviously been spoiled.
2	...	...	...	...	24·72	
3	...	...	...	...	25·49	
6	...	...	...	...	23·97	
7	...	...	...	...	24·23	
8	...	...	...	22·41	...	
9	...	...	...	21·81	...	
10	...	...	...	20·07	...	
12	·084	...	...	...	...	
13	·059	...	...	...	...	
14	·075	...	...	...	...	
15	·071	...	...	...	...	
17	...	11·19	...	...	...	
18	...	11·54	...	...	...	
19	...	9·21	...	...	...	
20	...	9·56	...	...	...	
21	...	9·34	...	...	...	
22	...	9·64	...	...	...	
23	...	11·34	...	...	...	
24	...	10·95	...	...	...	
25	...	...	...	25·18	...	
26	...	...	...	23·05	...	
27	...	...	...	26·48	...	
28	...	...	...	25·04	...	
29	...	...	...	23·56	...	
30	...	...	...	...	28·47	
31	...	...	...	...	30·62	
32	...	...	...	...	29·12	
33	...	...	...	...	27·10	
37	·082	...	...	...	...	
38	·088	...	...	...	...	
39	·085	...	...	...	...	
40	...	...	15·11	...	...	
41	...	...	13·28	...	...	
42	...	...	15·07	...	...	
43	...	...	14·10	...	...	
44	...	...	14·70	...	...	
45	...	...	...	...	25·51	
46	·059	...	...	...	...	
47	·045	...	...	...	...	
48	·051	...	...	...	...	
49	·051	...	...	...	...	
52	·080	...	...	...	...	
53	·080	...	...	...	...	
54	·074	...	...	...	...	
55	·077	...	...	...	...	
57	...	11·66	...	...	...	
58	...	12·19	...	...	...	
59	...	11·96	...	...	...	
60	...	...	18·38	...	...	
61	...	...	16·02	...	...	
62	...	...	18·37	...	...	
63	...	...	...	...	26·81	
	0·07	10·78	15·63	23·45	26·30	{ The average values of M and <i>m</i> for a surface of 11·8 square inches and five minutes of time. The average values of M and <i>m</i> for a surface of 100 square inches and one minute of time.
	0·12	18·3	26·5	39·7	44·6	