

## On Delicate Thermometers

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XXXI. *On Delicate Thermometers.* By SPENCER UMFREVILLE PICKERING, M.A., *Professor of Chemistry at Bedford College\**.

SOME months ago I had the honour of bringing before the notice of this Society (*antè*, p. 8) the fact that with very delicate thermometers the temperature registered was never exactly the same when the column had risen to the point of rest as when it had fallen to it. The investigation was made by placing the instrument in a large calorimeter of water, removing the bulb at intervals, cooling or heating it slightly, and then replacing it and observing the reading. About eight separate observations were made in order to determine the difference between the falling and rising readings at any particular point on the stem; and throughout the observations the instrument was tapped continuously on the upper end † to overcome the inertia of the mercury in the tube. The difference which was noticed was explained at the time by the bulb not being of precisely the same shape while the mercury was being forced upwards through the fine tube as when it was being dragged downwards; nevertheless there were several points which rendered such an explanation not altogether satisfactory. One out of the two instruments examined (No. 62839) gave differences proportional to the height of the column in the tube; in the other (No. 63616) no such proportionality was noticed: moreover, the instrument which showed this defect to the greatest extent (63616) was the one which had the smallest and strongest bulb. I was subsequently indebted to Lord Rayleigh for a suggestion that these differences should be attributed to the capillarity of the tubes acting on the expansibility of the bulbs, and not to the action of the bulbs only, and thus the differences observed between the behaviour of the two instruments might easily be accounted for by slight differences in the shape or size of the bore at various points. In order to test the validity of such an explanation, which at first sight appeared highly probable, other experiments were performed

\* Read April 23, 1887.

† I now employ a clockwork tapping apparatus for this purpose.

with these instruments, taking care to make all the observations at exactly the same temperature, removing some of the mercury into the upper chamber, so as to make the different points on the scale correspond to the same Centigrade temperature. The somewhat bulky details of the experiments may here be omitted, and the general results only given. Table I. contains these results; those which were obtained originally, and have been given in the previous

TABLE I.

Thermometer No. '39.							
Scale-Reading .....	465	457*	270*	162	142*	mm.	
Difference in falling and rising readings. }	0.5	.46*	.27*	.17	.15*	mm.	
Relative capacity of tube at the point taken .....	46.1	46.1	45	45.6	45.6		
Thermometer No. '616.							
Scale-Reading .....	562	458	458*	289	154	142	140* mm.
Difference in falling and rising readings. }	0.73	.42	.96*	.78	.67	.62	.91* mm.
Relative capacity of tube at the point taken .....	40.3	40	40	39.3	40.1	40.1	40.1

communication, are marked by an asterisk; and any small discrepancies observed between them and the fresh experiments may be attributed to differences in the actual temperature of the observations, the recent experiments only being strictly comparable with each other, having all been performed at  $10^{\circ} \cdot 5$  C. The readings and the differences are expressed here in mm. of the column, instead of cm. (or scale-degrees) as in the former communication.

To whichever thermometer we confine our attention, it is perfectly obvious that the magnitude of the differences bears no relation to the size of the bore. Taking the original experiments with '39, the difference as judged by the size of the bore should be least at 457, and greatest at 270, and of intermediate value at 142 mm.; whereas they are found to be greatest at 457 and least at 142 mm. Again, with No. '616, the differences should be greatest at 289, and least at 562 mm.; whereas they are practically equal at these two points, and greater (taking the later experiments only) than at any other points. It may be objected, however, that the capacity of the tube at these points, as given by the length

of a comparatively long (2 cm.) thread of mercury in that position, affords but a very rough, and perhaps quite erroneous, measure of the diameter of the tube at the particular point in question. As a crucial test, therefore, it was determined to alter the bulb of one of the instruments. This was done with Thermometer '39. The capacity of the bulb was reduced to half its former value, so as to hold 18 instead of 36 grams of mercury; and a determination of the coefficients of expansion of the two bulbs under pressure (given in column 6 of Table II.) shows that what may be termed the apparent expansion, or the effect of pressure on the height of the mercury in the tube, was thereby reduced to nearly half its former value, from  $\cdot 042$  to  $\cdot 025$  mm. per mm. of mercury-pressure, so that the differences in the readings with falling and rising columns should have been diminished in that proportion, if it depended on the expansion of the bulb by pressure; but on examination it was found that this difference was even greater now than it had been previously—at 270 mm. it amounted to  $\cdot 59$  instead of  $\cdot 27$  mm., and at 457 mm. it was  $\cdot 39$  instead of  $\cdot 46$  mm. (col. 7 of Table II.). Another thermometer (No. '83) was then examined in a similar manner. Originally it exhibited no difference whatever in the falling and rising readings; but when the bulb was altered, without increasing the coefficient of apparent expansion to any considerable extent (from  $\cdot 011$  to  $\cdot 015$ ), a small though unmistakable difference in the readings was observed (No. '83 B in the table). This second bulb was then removed, and a third and smaller one substituted for it (No. '83 C), by which the coefficient of apparent expansion was reduced by one half its former value; but, instead of the differences being diminished, they were actually increased, although no accurate measure could be made of them, for the column of mercury in the tube kept breaking off when the instrument was tapped. It was evident, therefore, that the cause of these differences in the readings did not lie in the bulbs of the instruments, but in the stems, that each time the instrument was opened and air admitted into the stem, the defect was increased, till the tube eventually became entirely ruined. The moisture and gases present in the air, no doubt, affect the glass and adhere so strongly to it that the heating to which the stem is sub-

TABLE II.

Instrument.	Mercury in bulb.	Relative capacity of tube.	Value of 1 mm. of column.	Coeff. of expansion of bulb per mm. mercury-pressure.	Alteration in height of column per mm. mercury pressure.	Difference of readings with falling and rising column.	Description of bulb.
'616.	30.5 grams	40	0.0064 C.	0.000,000,034,8	mm. 0.0303	0.42 to 0.78 mm.	Double, glass cylinder.
'39.	36.2 grams	45	0.006 C.	0.000,000,045,8	0.0424	0.15 to 0.45 mm.	Single, glass cylinder.
'39 B.	18.1 grams	45	0.012 C.	0.000,000,054,3	0.0252	0.39 to 0.59 mm.	Single, blown.
'83.	15.6 grams	100	0.038 C.	0.000,000,064,6	0.0114	Nil.	Single, blown.
'83 B.	28.5 grams	100	0.027 C.	0.000,000,041,5	0.0147	0.04 to 0.32 mm.	Single, glass cylinder.
'83 C.	19.4 grams	100	0.0304 C.	0.000,000,03	0.0075	Large.	Single, glass cylinder.
'08.	38.8 grams	76	0.0116 C.	0.000,000,030,1	0.0145	Nil.	Double, glass cylinder.
'61.	46.0 grams	72	0.0097 C.	0.000,000,033,2	0.0191	Nil.	Double, glass cylinder.
'16.	15.4 grams	100	0.0385 C.	0.000,000,035,6	0.0062	Nil.	Single, glass cylinder.

jected is quite incapable of removing it, and the interior of the tube remains coated with an elastic covering which destroys the working capabilities of the instrument. The researches of Bottomley (Proc. Roy. Soc. xxxviii. p. 158) and others on the absorption of air, and especially carbon dioxide, by glass, prove, in a striking manner, the extent to which such absorption occurs, and the persistence with which the absorbed gases are retained.

Both the delicate instruments ('39 and '616), in which the difference of the readings was first observed, had had small temporary bulbs attached for the purpose of calibration; and it therefore seemed probable that the second opening of the tube may have been the sole cause of the defects which they exhibited. To settle this question, and to ascertain whether it was possible to make instruments of such delicacy entirely free from this defect, two other thermometers were manufactured, Nos '08 and '61. The delicacy of these was somewhat less than in the former instruments, owing to the impossibility of procuring sufficiently fine tubes; the size of the bulbs, however, was increased, that of '61 containing as much as 46 grams of mercury. An estimation-figure,  $\cdot 05$  mm., represented about  $0\cdot 0005^{\circ}\text{C}$ . On examining these instruments, in the same manner as previously, it was found that they worked perfectly, the mercury registering exactly the same temperature whether the column had risen or fallen to the point of rest, equally satisfactory results being obtained whatever portion of the stem was examined. Instruments of this excessive delicacy are therefore perfectly workable; it is, however, only by observing the utmost precaution in making them that success can be obtained. The tube must on no account be opened till the last minute, when the bulb is finished and ready to be attached without a moment's delay; the bulb, as soon as it is attached, must be warmed so as to fill the tube with mercury and prevent the access of air through the upper end. If any failure occurs in the attachment of the bulb at the first trial, the stem must be rejected; a second attempt would be attended with the same results as putting on a second bulb after the instrument had been made up. When once the stem is filled with mercury, the tube may apparently be opened several times at the top without damage being done,

and the bulb itself may be made 24 hours before it is attached to the stem without being injured by exposure to air for that time.

It is a common practice of thermometer-makers to examine the bore of a tube before it is made into a thermometer by passing a thread of mercury along it, and often, indeed, the stems are divided and fully calibrated before the bulb is attached and the tube closed. From what has been ascertained as to the effect of the air on the interior of the tube, it is obvious that a tube which has been treated in such a manner will be utterly useless for any really delicate instrument.

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XXXII. *On the Effect of Pressure on Thermometer-bulbs, and on some Sources of Error in Thermometers.* By SPENCER UMFREVILLE PICKERING, M.A., *Professor of Chemistry at Bedford College\**.

THE great difficulty which exists in obtaining exact concordance between two thermometers throughout a considerable range of their scales must have been experienced by all who have had occasion to require such concordance. In the course of a series of experiments, in which the temperature-disturbance in a calorimeter was measured simultaneously with two instruments, I was much struck by the appearance of a certain amount of regularity in the difference in the results yielded by the two instruments, which, according to direct comparisons with each other through longer ranges of temperature, should have been absolutely concordant. The instruments being open in the scale and having large bulbs, I was led to seek for an explanation of these discrepancies in irregularities in the expansion of the bulbs under the pressure of the column of mercury in the tube.

The effect of pressure on a thermometer-bulb has been investigated by Egen (*Pogg. Ann.* xi. p. 283), and by Mills (*Roy. Soc. Edin.* xxix. p. 285), with the general result of showing that the expansion experienced is directly proportional to the pressure. But although the pressures employed

\* Read April 23, 1887.