On the Determination of the Heat-Capacity of a Thermometer

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large and ρ_2 small. The first of these conditions is always, the second is never, fulfilled in practice. The reason of this is obvious, viz. that the efficiency would be reduced by diminishing the resistance of the shunt. The maximum efficiency is given by the formula

$$\eta = (\sqrt{\rho_2} - \sqrt{R_m}) / (\sqrt{\rho_2} + \sqrt{R_m}),$$

which diminishes with ρ_2 . It is interesting therefore to note that a high shunt-resistance is not in itself conducive to good self-regulation; and that, within the bounds of Dr. Frölich's condition, there are still opportunities for choice by which improvements in the efficiency and regulation may be effected. Probably in practice the last adjustments will be best made by some system of experiment like that described by Dr. Frölich. The theory given above will, however, enable much to be done by a few preliminary calculations.

Since I read the paper, Prof. Silvanus Thompson has called my attention to the question as to whether my formulæ indicate the advantage of back winding in the case when a constant external current is desired. Dr. Frölich has constructed a machine on this principle, to which he was led by theory. To discuss this question fully would require an investigation of the problem when B is negative; but it may be remarked that in a case such as that discussed above, when a large value of B is desirable, it may be increased in the case of the Long-Shunt Machine (B_4) by taking s_2 negative and $< s_1$.

XVII. *On the Determination of the Heat-Capacity of a Thermometer.* By J. W. CLARK, Assistant Professor of Physics in University College, Liverpool*.

I. IN the determination of specific heats a correction should be made for that part of the thermometer which is immersed in the water of the calorimeter, as its specific heat is not the same as that of an equal volume of water. Very often this correction is reduced to a mere estimation on

* Read April 25, 1885.

account of the unknown weights of glass and mercury which constitute the immersed portion of the thermometer.

When two metals of known specific gravity are fused together, and the volume of the resulting alloy is the sum of the volumes of its two constituents, it is only necessary to know the specific gravity and volume of the piece of alloy to calculate the exact volumes of the metals comprising it. Similarly, by determining the specific gravity and volume of the thermometer, the volume of mercury which it contains can be at once determined from

$$V_1 = \frac{V(S - S_2)}{S_1 - S_2}; \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where V_1 is the required volume of mercury in the thermometer,
 V the volume of the thermometer,
 S the specific gravity of the thermometer,
 S_2 " " " thermometer-glass,
 S_1 " " of Hg.

The mean value of several very closely agreeing determinations of the specific gravity of different specimens of thermometer-glass is 3·199 for lead-glass and 2·512 for soda-glass. Should it not be known of which sort of glass the thermometer consists, it may be readily ascertained by slowly introducing the upper extremity of the instrument into the reducing-flame of a blowpipe:—Soda-glass yields a yellow flame, but lead-glass blackens, from the reduction of the oxide of lead which it contains. It may be assumed that thermometers made on the continent consist of soda-glass; those made in England are usually constructed of lead-glass.

The total volume of the thermometer (V) is obtained from its weight in air and in water.

The volume of mercury contained in the thermometer having been found by (1), the volume of that part of the thermometer which is immersed in the water of the calorimeter has next to be determined. This latter volume, less the contained volume of mercury, is the immersed volume of glass.

The total immersed volume (V_3) of the thermometer is best found from the weight (W) of the thermometer in air, and its weight (W_1) when dipped in water to the same depth as it

dipped into the water of the calorimeter ; then

$$V_3 = W_{\text{grm.}} - W_1^{\text{grm.}} \quad . \quad . \quad . \quad (2)$$

But, if the bulb be cylindrical and of the same diameter as the stem, this volume may be calculated from the measured length and diameter of the immersed portion ; for if of an irregular shape it may be found by plunging it into a burette graduated in cubic centimetres and partly filled with water ; but in both cases with a less satisfactory result than is given by (2).

The volume of the *glass* of the thermometer (V_2) immersed in the water of the calorimeter is then

$$V_2 = V_3 - V_1.$$

These volumes of glass and mercury are converted into their corresponding weights, using the mean specific gravities of lead- and soda-glass already given. The sum of the products of the weight of the immersed glass and its specific heat, and of the weight of the mercury and its specific heat, is the required water-value of the part of the thermometer dipping into the water in the calorimeter.

Regnault has given the specific heat of thermometer-glass as 0·2; but for greater accuracy it would be desirable that for this value the mean specific heat of lead or of soda thermometer-glass should be substituted according to circumstances*.

The following is an illustration of the application of the method :—

Thermometer No. 2. Soda-glass.

Weight of thermometer in air . . .	= W	33·97 grm.
" " water . .		23·01 grm.
<hr/>		
Volume of thermometer . . .	= V	10·96 c. c.
<hr/>		
Specific gravity of thermometer . .	= S	3·098
Mean sp. gr. of soda-glass	= S ₂	2·512
Sp. gr. of Hg	= S ₁	13·6
<hr/>		
Volume of mercury in thermometer	= V ₁ =	$\frac{V(S - S_2)}{S_1 - S_2}$
<hr/>		
= 0·5795 c.c.		

* It may perhaps be serviceable to call attention to the *Physikalisch-Chemische Tabellen* of Landolt and Börnstein as a work which contains a most useful collection of data.

Weight of thermometer in air 33.97 gm.

Weight of thermometer with lower end im-
mersed in water to the same depth as it } 29.73
was immersed in water of calorimeter

Loss of weight=volume of immersed part } 4.24 c.c.
of thermometer

Subtract contained volume of Hg= V_1 . . . =0.5797

to get immersed volume of thermometer-glass =3.661 c.c.

Weight of this volume of thermometer-glass } 9.196 gm.
 3.661×2.512 =

Weight of contained Hg 0.5795×13.6 . . . =7.881

Water-value of immersed glass 9.324×0.2 =1.840

Water-value of immersed Hg 7.881×0.0335 =0.2639

Total water-value of the immersed part of } 2.1039
the thermometer

To test the reliability of the method, I sacrificed the thermometer by cutting off the stem at the level at which it was immersed in the water of the calorimeter, and weighed the quantities of glass and mercury: there were 9.63 and 7.64 grms. respectively, corresponding to a water-value of 2.182, *which ascribes to the above method an error of 3.7 per cent. in the required correction.* This negligible error is due to the volume of the thermometer—consisting, not only of glass and mercury, but also of the unfilled bore of the tube—and to slight deviation of the specific gravity of the thermometer-glass from the mean specific gravity used in the calculation. It may be just worth pointing out that when a fragment of the thermometer-tube is obtained from the maker with the instrument, these errors may be avoided and the *true* water-value obtained. Probably a greater error than the above is introduced into ordinary specific-heat determinations by the evaporation of the water in the calorimeter.

II. A second method for the determination of the water-value of the immersed part of a thermometer may be employed,

but it requires that the diameter of the bore of the stem be known. To determine this a fragment of the same thermometer-tube may be obtained from the maker of the instrument, or a short piece of the upper part of the thermometer may be very easily drawn-off before the blowpipe-flame, the closed end of the fragment cut off, and the diameter of the bore measured with a microscope furnished with a micrometer eye-piece and stage-micrometer. Then the weight of mercury (w), corresponding to an increase of temperature from 0° to 100° C., is given by

$$w = al \times 13.6, \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a is the area of the tube and l the length in centimetres of 100° (t°) on the scale of the thermometer.

The weight (W) of mercury in the bulb is then

$$W = \frac{w}{\alpha t^\circ} + w, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where α is the coefficient of apparent expansion of mercury in glass. For lead-glass $\alpha = 0.000155$, and for soda-glass 0.0001586 . Having thus determined the quantity of mercury, the quantity of glass may be found as in the first method. With a thermometer containing a known weight of mercury, this method gave a water-value for the immersed part of the instrument which was 3.2 per cent. in error. I place much less reliance upon this than upon the former method, as the apparent coefficient of expansion of glass varies more than its specific gravity. The first method is quick and simple, and the results so excellent, that this second method may be almost regarded as unnecessary; but should any case arise in which it is found to possess advantages over the first, it might be possible to determine the coefficient by observing the increase in length of the thermometer when heated in steam.

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