LXIV. The maintenance of constant pressures and temperatures

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mental test ; but in the meantime we give no further indication of the reasoning by which it has been arrived at, nor of the way in which our equations would be modified, preferring to leave the investigation in a perfectly rigid form as it now stands, rather than to introduce any assumption which might appear problematical, even although such an introduction would both add weight to our theory, and might explain, from the velocity *in space* of a place at midnight being greater than at midday, the cause of the solar-diurnal magnetic variation.

LXIV. *The Maintenance of Constant Pressures and Temperatures.* By FREDERICK D. BROWN, B.Sc.*

[Plate XIII.]

THE great majority of the results obtained from physical experiments vary with the temperature at which the observations are made. The measurements of the density of a substance, for example, of its refractive index, of its electric conductivity, of its elasticity, of the maximum tension, and of the latent heat of its vapour, all require that the temperature should not vary during the observations. Hitherto many of these measurements have been confined to temperatures differing little from that of the atmosphere; such temperatures are easily maintained constant by means of a bath of water or other liquid; but when we try to make observations at higher temperatures, the means at our disposal fail us, and we find that, except at certain points (such as 100°), we cannot keep up the same temperature long enough to make at leisure accurate readings of our instruments.

Many attempts have been made to obviate this difficulty, but, as it seems to me, without complete success. The ordinary method has been to use a large quantity of water or other liquid, and to keep it in continual agitation; above 50°, however, the temperature of such a bath is rarely, or never, rigorously constant, while the inconvenience and waste of time incurred in heating the large mass of liquid to the required point are by no means to be neglected.

In order to keep such a bath at a constant temperature, a large number of gas-regulators have been invented. In most of these a small vessel containing mercury or air is placed in the bath, and arrangements are made by which the gas-supply is partially shut off when the mercury expands beyond a certain point. Probably the most sensitive form of this kind of apparatus is that recently described by M. Benoit to the French

* Communicated by the Physical Society.

Physical Society. Here a small closed vessel containing methyl acetate is placed in the water the temperature of which is to be maintained constant; this vessel communicates with a manometer containing mercury; and as the vapour-tension of the methyl acetate increases, the mercury in the manometer rises, obstructing the flow of gas to the burner in the usual way.

I have applied this form of thermostat to a bath of water used for heating a long column of mercury. The water is contained in a vertical copper cylinder 42 inches in length by 6 in diameter; the cylinder is packed with felt on the outside, and contains within it a second smaller and shorter one open at both ends, and extending to within about 2 inches of the top and bottom. By means of a suitable mechanical arrangement, the water is made to flow continuously down the space between the two cylinders and up the inner cylinder; the upper and lower portions of the bath are thus kept at exactly the same temperature. The water is heated by allowing it to circulate through a copper coil placed over a gas-burner. Even when the small vessel of the thermostat is filled with ether, the tension of which varies much more for a given variation of temperature than does that of methyl acetate, the temperature is subject to fluctuations of as much as $0^{\circ}\cdot 1$, and this independently of the change which necessarily occurs when the pressure of the gas is altered.

Gas-regulators are employed perhaps more successfully where the gas-flame can be applied directly underneath the bath; for the rise of temperature in the water then follows more rapidly upon the increase of the flame, the flow of gas is sooner checked by the mercury, and the tendency to allow too much heat to be communicated to the water is thereby lessened. Still better results are obtained if the thermostat be applied to an outer jacket of water surrounding the bath in which the observations are made. Both these conditions, however, are generally very difficult to carry out where large quantities of water are of necessity used. Even when all these precautions are taken, a constant temperature, in the true meaning of the words, is not attained. For a further discussion of the defects of this form of thermostat see Laspeyres*.

The only practicable way of attaining the object in view appears to be afforded by the fact that the vapour emitted by a boiling liquid does not vary in temperature, provided that there is no variation either in the composition of the liquid or in the pressure to which it is subjected. Taking their stand on this consideration; Laspeyres (*loc. cit.*) and Sprengel

* Pogg. *Ann.* clii. p. 132.

(Journ. Chem. Soc. 1873, p. 458) suggested the use of mixtures of sulphuric acid and water of different strengths; which, if the vapour given off is condensed and returned to the mass, boil constantly at certain given temperatures: here the constant temperature is afforded by the liquid and not by the vapour, which is less hot; hence, if the liquid tends to become superheated, fluctuations in temperature will infallibly occur. The great objection to this method is that, when a series of temperatures is required (as, for instance, in the comparison of thermometers), great inconvenience and loss of time is incurred by having frequently to replace the liquid in the apparatus by another containing a different proportion of sulphuric acid or other substance.

A series of temperatures can be obtained with one liquid only, if the pressure under which it boils be varied. This method, simple as it appears, is beset with considerable mechanical difficulties, to surmount which the apparatus described below has been constructed.

At first sight it would seem that, if the vessel containing the steam be connected with a large closed vessel serving as air-reservoir, all that is necessary is to rarefy or compress the air in the reservoir to the required extent, and to allow the liquid to boil undisturbed. But the steam-bath is necessarily large; and the reservoir therefore must be large also. Now the reservoir must not only be strong enough to stand a vacuum inside it, but must also be capable of supporting an interior pressure of at least 50 lbs. on the square inch; such a reservoir is not only cumbrous and expensive, but dangerous. Further, any change of temperature in the room alters the pressure inside this reservoir; it must therefore be placed in a cistern of water, which is a second objection. The great obstacle to the employment of this method, however, is the difficulty of preventing leakage even with the greatest possible care. In endeavouring to stop leaks I expended so much time that I gave up the reservoir, and determined to construct an apparatus for maintaining a constant pressure in a given vessel even when it leaked.

Lothar Meyer (*Ann. Chem. Pharm.* vol. clxv. p. 303) had already devised an apparatus of this kind, adapted chiefly to fractional distillation under reduced pressure. It consists essentially of two vertical tubes, A B and C D (fig. 1, Pl. XIII.), connected at the upper part by the lateral tubes E and F; at B an india-rubber tube connects A B with the tube K, which slides up and down the board to which the whole is fixed; at the top of A B is a tube H which is connected with an air-pump; the top of C D is provided with a cork, through which a narrow tube S S passes nearly to the bottom of C D; finally, the lateral tube *k* is

connected with the apparatus X, in which a constant pressure is kept up. Sufficient mercury is poured into R to fill A B up to the lower end of H when R is about half full; C D is also filled with mercury, which is let out by the tap M until the column P S above the lower end of S S is equal to the difference between the required pressure and that of the atmosphere. If now the air-pump be set to work, a partial vacuum will be created in X and in the tubes A B and C D, the mercury will rise in A B until it touches the lower end of H; R is then placed in such a position that the vertical distance between the lower end of H and the surface of the mercury in R is equal to P S. It is now evident that when the desired pressure is reached the mercury will close up the orifice of H, thus stopping the withdrawal of air; while if the pressure is less than that required, more air will enter through the tube S S and bubble up through the mercury, and thus a more or less constant pressure will be maintained in X.

This apparatus suffers from two defects: first, the splashing of the mercury as it is sucked up H and then falls down again, together with the bubbling of air up C D, renders the pressure in X slightly variable; secondly, it is only adapted for pressures less than that of the atmosphere.

Meyer's instrument has very recently been modified by Dr. Otto Schumann and by W. Stadel and E. Hahn (*Ann. Chem. Pharm.* vol. cxcv. p. 218); the new form, although capable of regulating pressures above an atmosphere, apparently with tolerable accuracy, has a very limited range.

The apparatus for maintaining constant pressures, which I now wish to bring to the notice of the Society, consists of a manometer connected with which is an automatic arrangement for governing the supply of air. The manometer (fig. 2) consists of a tube A B having the form and dimensions shown in the figure; the lateral tube C is connected with the vessel X, in which a constant pressure is to be kept up; the tube D is connected with an air-pump or other contrivance for rarefying and compressing air. The upper end of the tube A B is closed by an india-rubber stopper, or, better, by a metal cap, through which the rod E_1 passes air-tight; this rod is tipped with platinum at its lower end. The lower end of A B is joined by means of india-rubber tube to the tube F, of which the upper part has the same diameter as that of A B; this tube is fitted with another cap and iron rod E_2 similar to the first; but the cap does not fit air-tight. The piece of wood which carries F moves along the scale S S in a groove in the board to which the whole is fixed. Lastly, the two rods E_1 , E_2 are furnished with binding-screws for copper wire, while a third binding-

screw K is connected with a small piece of steel tube interposed between the end of A B and the india-rubber tube. This third connexion with the mercury contained in the manometer may of course be made by means of a third (insulated) rod passing down to the bottom of the wider part of A B or F.

To fill and adjust the manometer, the tube F is raised to the same level as A, and mercury is poured in until it just reaches the wide cylindrical portions of A and F; the rods E_1 , E_2 are then moved until the point of E_1 just touches the surface of the mercury, while that of E_2 is a fraction of a millimetre above it.

Suppose now that F be lowered n millims. and the air-pump be set to work to pump air out at D; further, that K be connected with one pole P of a battery, and the rods E_1 , E_2 with the other pole N; then it is evident that as long as the pressure in A, and consequently in X, is greater than $H-n$ (where H = the barometric pressure), the current will pass through the circuit P K E_2 N, whereas when the pressure is less than $H-n$ the current will pass along P K E_1 N. Similarly, if F be raised n millims. above A and the pump be made to compress air into A, as long as the pressure is less than $H+n$, the current will pass along P K E_1 N; but when the pressure becomes greater than $H+n$, the current will pass along P K E_2 N. In order to economize space, the tube A B is widened out at B; and when it is intended to obtain a pressure greater than H , the rod E_1 is replaced by a long one reaching down to B; this, of course, is equivalent to lowering A or raising F nearly the whole length of the scale S S. In the further description I shall only consider the case in which F is lower than A—that is, when a pressure less than H is required; the alteration needed for higher pressures will readily suggest itself.

The apparatus depicted in fig. 3 consists of a brass tap T and an electromagnetic clutch to work the tap automatically. The tap, which is shown in section in fig. 4, is placed between the tube D of the manometer (fig. 2) and the air-pump, L_1 being connected with D and L_2 with the pump. From the figure it is readily seen that when the tap is in the position drawn, and the lever fitted to the head of the key lies in the direction $a b$, air will be admitted into the manometer; if, on the other hand, the lever and key occupy the position $a' b'$, the pump will withdraw air from the manometer. The object of the clutch, therefore, is to place the tap in the first position when the pressure is too small, and in the second when it is too great. The lever $a b$ (fig. 3) terminates in two arcs which are grooved to hold a cord; these arcs are furnished with set screws S_1, S_2 , by means of which

the amount which the tap can open may be regulated. The two ends of the lever are connected by strings at S_1 S_2 to the loose pulleys P_1 P_2 of the clutch. These pulleys are made of soft iron, and run on a spindle which revolves on the centres A_1 , A_2 . Revolving with the spindle and facing P_1 and P_2 are two small electromagnets M_1 , M_2 : one end of the coils of each of these magnets is soldered to the insulated ring I_2 ; the two other ends are soldered to I_1 and I_3 respectively. The binding-screws U_1 , U_2 , U_3 are connected electrically by means of springs with these rings; U_2 is further connected with the pole N of the battery, while from U_1 and U_3 wires run to E_2 and E_1 respectively. The disposition of the wires is shown in fig. 5: it is there evident that if the mercury in the manometer touches the rod E_1 , M_2 will become magnetic; the loose pulley P_2 (fig. 3) will then tend to revolve with it, and the tap will take up the required position ab ; while if the mercury touches E_2 , M_1 will become magnetic, P_1 will revolve, and the tap will assume the position $a'b'$, in which communication is made with the air-pump. By this arrangement, therefore, the pressure in the manometer, and in whatever apparatus is connected with it, is caused to rise and fall within very small limits; with care these limits may be made to differ only about 0.25 millim.; and thus a practically constant pressure is attained.

The current required to work the magnets is no more than is furnished by a small Smee's cell; the magnets may be made to revolve with a small turbine; the air-pump may be replaced by a Bunsen water-pump; an air-pump, however, is the only convenient apparatus for *compressing* air.

It may be objected that the arrangement above described requires motive power, which is not always at hand in a laboratory. To meet this objection I endeavoured to construct a double valve to be moved to and fro by two stationary magnets; but I found that magnets of ordinary size were not powerful enough for the work, as the valve, to be of any use, must fit perfectly air-tight, even when subjected to very high pressures. I have not, however, given much attention to this point, an engine which I use for many other purposes being obviously the best source of the necessary power.

In fig. 6 is given a section of the steam- or vapour-bath which I employ for the comparison of thermometers and for the measurement of the expansion of liquids in dilatometers; it is also suitable for the direct comparison of thermometers with a standard air-thermometer. The bath is made of brass, and consists merely of a boiler B surmounted by a double tube D , D similar to those first used by Rudberg and Regnault for

the upper fixed point of thermometers; the vapour, after traversing this, passes into the U-shaped condenser C, from which the condensed liquid runs back into B down the tube E. The end H of this condenser is connected with the lateral tube C of the manometer by means of a very small lead pipe; and thus the liquid can be made to boil under any required pressure. The thermometers or other instruments are placed in the small tubes T T, which are filled with petroleum of high boiling-point. Besides water, the best liquids for generating the vapour appear to be carbon disulphide for low, and purified paraffin oil for high temperatures; the latter substance I have not hitherto used, as I have had no occasion to make observations at such temperatures. I have, however, made experiments with it in a smaller apparatus of similar form, and found that no variation of temperature took place.

The temperature obtained from these three liquids may be varied from 25° to 300° without unduly increasing the pressure.

If the temperature in the double tube D D be observed with a thermometer of which each degree is 5 millims. long, no variation can be detected, even with an extremely rigid cathetometer, provided, of course, that the barometric pressure does not alter; the variation due to this cause might, if necessary, be removed by making the cap of the tube F of the manometer fit air-tight. When great accuracy is necessary, it is not advisable to decrease the pressure below 100 millims.

In order to see whether the whole length of D D is at the same temperature, small oblique tubes similar to T were inserted, one at the top, the other at the bottom; a thermometer placed first in one and then in the other of these, gave exactly the same reading in both.

To sum up. First, with the above apparatus, viz. a manometer communicating by means of a specially constructed tap worked by a double electromagnetic clutch with a constantly working air-pump, any given pressure may be maintained for an indefinite period without varying more than 0.25 millim.; secondly, if this constant pressure be applied to a suitable vapour-bath, any given temperature between 25° and 300° may be maintained absolutely constant as long as no chemical change occurs in the liquid whence the vapour is derived.