lower end is estimated only a little too low, the depression becomes too small and hence the mercury height read too large.

This systematic error amounts only to $\frac{1}{16000}$ of the pressure measured and moreover will only have any influence at pressures above 32 atm. (for then only the tubes of the second system are used). By reading the real height of the menisci perhaps even this slight deviation might be prevented.

Physics. — J. C. SCHALKWIJK: "*Precise Isothermals.* III. *A water-jacket of constant ordinary temperature.*" (Communication N°. 70, (continued) from the Physical Laboratory at Leiden, by Prof. H. KAMERLINGH ONNES).

§ 1. *The necessity of having at disposal a current of water at a constant temperature.* In consideration of the small heat conductivity of gases and the great thickness of the walls of piezometer tubes, used in my experiments (comp. Communication N°. 50 of prof. H. KAMERLINGH ONNES, June 24th 1899) it is desirable to take care that the temperature of the surrounding water cannot vary more than some hundredths of a degree per hour, and that it can be accurately adjusted at the desired value and be kept almost constant during 5 hours. This offers however many difficulties; for the bath must be more than 80 c. m. high, and we must be able to read accurately the marks over the whole length of the tube, which excludes coating the bath with a badly conducting substance as a protection. Hence there will be a continual large loss of heat from the surface of the bath. The distance of the piezometertube from the glass wall must be very small with a view to the refraction of the rays emerging from the water, as we must be able to read very accurately the difference in the height of the mercury in the piezometer tube C_1 (comp. the plate Proceedings June 24th 1899) and in the measuring glass P [1]); therefore 6 c. m. was taken as

[1]) A means used by Dr. N. QUINT (comp. his thesis for the doctorate 1900, p. 15 and fig. 5) cannot be used in our case. He placed the observation-tube in a rectangular basin containing about 40 liters of water and kept up a constant temperature by means of two liquid-resistances (saturated ammonium chloride) carrying an alternating current, an exterior krüppin resistance to be regulated by hand and rotating bladed wheel. Moreover in accurate determinations of isothermals, the measurements proper occupy each time about three hours and as therefore many readings have to be made, the regulation of the krüppin-resistance would cause an undesirable interruption of the series of observations.

diameter of the jacket. Hence as soon as the temperature is some degrees higher than the temperature of the room, — and such a difference is sure to occur in the course of the year, if we want to adjust at a definite temperature within the limits of the temperature of the room — the cooling will become considerable[1]).

Most of the thermostates used allow an accurate regulation only at a small loss of heat, moreover on account of the given dimensions of the bath and because the bottom cannot be heated (for instance by a gas flame), only electrical heating could be applied. In a narrow high jacket it is very difficult to apply heat by means of an electrically heated spiral wire without damaging the illumination of the observation tube, for that tube must remain visible over a length of 54 c. m. and strong local heating must be avoided as it would not be easy to distribute the heat equally by moderate stirring. Therefore ROTHE's method [2]), followed in the Physikalisch-Technische Reichsanstalt, could not be used. Thus there only remains heating by means of an alternating current, either the bath itself [3]), or separate heating tubes filled with a liquid [4]). But both methods are only fit for large baths, as the regulation of the alternating current[5]) with a sufficient degree of accuracy in the case of small baths with a rapid loss of heat offers difficulties.

So we are obliged to continually replace the slightly cooled water by new water at the exact temperature and therefore to connect the *observation bath* with a *heating bath.* CADY [6]) brings about a circulation by means of a rapidly rotating funnel, in the bath itself, of which means we could not avail ourselves owing to the narrow bore of the vessels. For heating microscope stages convection currents are used [7]) which however gives a much too weak and un-reliable circulation in this case.

For the arrangement used by me the adjustments at every tem-

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1) In order to avoid a possible error resulting from the uncertainty in the co-efficient of dilatation, all measurements for the isotherm at an ordinary temperature are made at the same temperature.

2) Ein Thermostat mit elektrischer Heizvorrichtung fur Temperaturen bis 500°. Zeitschr. f. Instr. 1899.

3) DUANE and LORY (Am. Journ. of Sc. (4) 9. p. 179, 1900) use a solution of common salt of 160 liters and send through it an alternating current of 110 Volts.

4) Compare the footnote on QUINT's method.

5) Done automatically by DUANE and LORY, by QUINT with the hand.

6) CADY, Journ. of Phys. Chem. 2, pag. 242, 1898.

7) VAN RIJN, Mech Zeitung 1899. FRESENIUS' Zeitschr. 99, p. 96.

perature [1]) above the highest occurring temperature of the water supply are made by admitting a regular current of water of constant temperature.

§ 2. *The reduction of the variation of temperature in flowing water.* The arrangement for obtaining flowing water at constant temperature by VAN ELDIK in Communication N°. 39 (Proceedings May 29th '97 p. 22 and fig. IV) has served as my starting point. The disadvantage of using large quantities of water does not matter much in my arrangements as the same water is used to move the stirring apparatus. Important modifications had to be introduced into VAN ELDIK's arrangement because it only reduced the variations in the temperature to 0.1 deg. C, and this is insufficient for my purpose (comp. § 1).

The most important of these modifications is the construction of a large well packed *mixing bath*, containing over 84 liters of water. The water streams into this from a smaller heating bath of $\frac{1}{6}$ the capacity and is mixed with the larger quantity and well stirred; if now in the heating bath the temperature is only allowed to vary within given limits, this variation is reduced in the mixing bath to one sixth of its value [2]). Moreover a more reliable thermoregulator was constructed to regulate the temperature of the heating bath.

The apparatus is shown on the annexed plate. The tube K conducts a little more water than is needed to the overflow A, the superfluous water flowing away by the tube L. From the funnel B the water runs to the heating bath D, to the mixing bath F and through the indiarubber tube G_1 to the observation bath H, whence it is conducted by the outlet-tube I. The difference of level amounted to 75 c. m., and 800 c.c. of water ran through per minute. The connecting tubes E and G_1 are protected from cooling by a coating of pure wool; the mixing vessel is surrounded by a second vessel and the space between the two is filled with pure wool. The cover of the inner vessel is provided with 4 openings M, N, O and P; thermometers are passed through corks in M and N, O and P are pro-

[1]) For the investigation of the Isothermal of hydrogen at ordinary temperature I have chosen 20° C.

[2]) It would have been even better if the heating bath had been smaller and the mixing bath larger; but as apparatus of the description mentioned was at hand no change has been made in the ratio.

vided with loose glass covers; the whole is covered by a double layer of felt.

In order to be able to properly mix the water in the heating bath and in the mixing bath the stirrers Q and R have been made, each provided with six blades [1]). In order to prevent a general rotation of the water which would delay the perfect mixture, vertical baffle plates T have been fixed vertically to the inner wall of each vessel. At their upper ends the axes Q and R are provided with grooved discs U and V, connected by a string consisting of a spirally wound wire. The axis R also carries a disc W, connected by a similar string with the small disc X on the axis of the watermotor Y [2]). In order to prevent strain in the apparatus the axes are connected by strong iron bands Z; while the axis of the motor is supported by the tube a which also serves as oil-reservoir [3]). The water from the water supply streams through the motor to the overflow A.

Stirring is also necessary in order to obtain an equal temperature in the observing bath. For this purpose two brass rings e, are connected by means of three glass rods, and moved by a chord f over a pully (see Plate Comm. N⁰. 50). In order to assist the mixing by convection the water is admitted at g and runs off above at I.

§ 3. *The Xylene-thermo-regulator*. The only important thing left was to construct a suitable regulator for the heating bath. The known regulators of GOUY [4]), DOLEZALEK, GUMLICH [5]) and others, which work electromagnetically, seemed less suitable, since there the regulating flame is repeatedly extinguished and with a view to the large quantity of heat required, this cannot but give rise to too great variations of temperature. I thought it therefore better to return to liquid regulators, as with these small gradual variations could be

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[1]) The plane of these blades is bent at an angle of 45° as shown in the figure for a pair of blades S; they are bent so that in rotating alternate blades move the water upwards and downwards.

[2]) The motor consists of a box Y; at a distance of $\frac{1}{4}$ of the circumference two parallel tubes b and c are fixed. Above these tubes a horizontal plate is fastened to the axis, provided with vertical blades at angles of 45° with the radius, so that they are placed crossly before c and straight before b.

[3]) To facilitate taking the apparatus to pieces the axes Q and R have been cut through; and the parts are fixed to the connecting tube by means of pins d.

[4]) GOUY, Journ. de Phys. (3) 6, p. 479, 1897.

[5]) GUMLICH, Ueber einen Thermoregulator für ein weites Temperaturgebiet. Zeitschr. für Instr. 1898.

produced in the supply of gas. As E. BOSE [1]) has also demonstrated, the *chief requirement for this is a large volume with an extensive surface* and well conducting walls, while the liquid must have a large coefficient of expansion α, small coefficient of compressibility β and a small specific heat and must be forced up in a rather narrow tube. As an additional requirement might be mentioned the regulation of the exterior pressure of gas by means of a manostate, as used by SMITS [2]) or by TRAUBE and PINCUSSOHN [3]) but as for my apparatus the regulation of the gas supply was sufficient, I could neglect this.

The liquid used by me was xylene; BOSE advises the use of chloroform, for which $\frac{\beta}{\alpha} = 0.064$, specific heat $= 0.235$; xylene however is less dangerous, while $\frac{\beta}{\alpha} = 0.075$, and is in that respect almost as advantageous. The xylene is enclosed in a copper thin-walled spiral *h*, consisting of 3 layers each of 6 turns; the whole length is 12.5 meter, so that the total surface amounts to about 1950 c. m^2. and the volume to about 240 c. c.

For 1 degree increase of temperature the volume will increase by 0.235 c.c. and this causes in a tube of 2.5 m. m. bore, such as used by me, a displacement of 47 m. m. [4]). By means of the xylene a mercury column must be forced up, which will produce the regulation of the gas. As the mercury may not come into contact with the copper we have soldered on to the end of the spiral *i* (see the fig. to the left) a flanged tube *j*, provided with a screw thread and with a groove of 2 m. m. depth into which the glass tube *k* fits easily. The rest of the groove is filled with some cork rings. Round the glass tube, ground flat at the end, I have sealed a long flanged-tube *l* with a smooth rim and over this a loose nut *m* fits into the screw thread of the tube *j*. If the nut is screwed up the glass tube compresses the cork-packing and the closure is perfectly tight, and the xylene does not wet the sealing-wax. Unto the glass tube *k* is sealed the reservoir *n* and to this a narrow bent glass tube and reservoir *o* while above this the narrow tube *p* of 2.5 m. m. bore projects beyond the heating bath and there joins the wide tube *q*.

[1]) BOSE, Leistungsfahigkeit und Konstruktionsprinzipien von Präzisionsthermostaten mit selbstthätiger Reguliering. Mech.-Zeit. 1899.

[2]) SMITS, Manostat. Zeitschr. für phys. Chem. 33, p. 39, 1900.

[3]) TRAUBE und PINCUSSOHN, Ein einfacher Thermostat und Druckregulator. Mech. Zeit. 1897.

[4]) If the temperature remains constant displacement of 1 m. m. is brought about by a variation of 22 c. m. of mercury pressure.

At the lowest temperature that we can expect[1]) the mercury stands at the lower end of the reservoir *o* and at the upper end of the reservoir *n*; at the highest temperature[2]) the mercury must remain in the lower end of the reservoir *n*. It may be easily seen on the plate how the regulator controls the flame. The narrow glass tube *t* is drawn out at its lower end until the bore is less than 2 m. m., then it is ground flat and after this ground at a slant, so that we obtain a lengthened opening. This end of the tube *t* is placed at the narrow opening of the tube *p*; a slight increase of temperature is sufficient to diminish the supply of gas perceptibly but gradually.

In order to fill the regulator the tube *q* was closed at its higher end by means of an india-rubber stopper and carefully exhausted through the side-tube *r* ending in a point which was broken off under xylene. The india-rubber stopper is removed, the spiral is immersed in a bath of over 25° C. and mercury is poured into it. The xylene bubbles through the mercury and is removed; then the bath is slowly cooled to the desired temperature, in my case 20° C, taking care that always sufficient mercury remains; by means of a narrow glass tube as siphon, small quantities of mercury may be removed for adjustment to different temperatures.

This regulator would also be insufficient, if the regulating flame had to be used to heat all the water streaming through as in the case of VAN ELDIK; its only purpose however is to serve as a *regulating flame*, while a constant flame *v* must warm the water to a little below the temperature desired. In order to avoid heating of the mixing bath from the side it is protected by an asbestos plate *z*.

§ 4. *Use and results.* If we want to set the apparatus working, the clip *w* is kept closed, the stirring apparatus are put in motion and we begin to slowly heat the heating bath. Then boiling water must slowly be poured through the open window *O* into the mixing bath, until the desired temperature is reached. When this temperature is almost reached in the heating bath, the dip *w* is opened. First the constant flame is regulated so, that it can heat the water to almost the desired temperature and then it is somewhat diminished: this difference must be supplied by the regulating flame, which even while burning at its highest must be *much smaller* than the *constant flame* and may *never* be extinguished.

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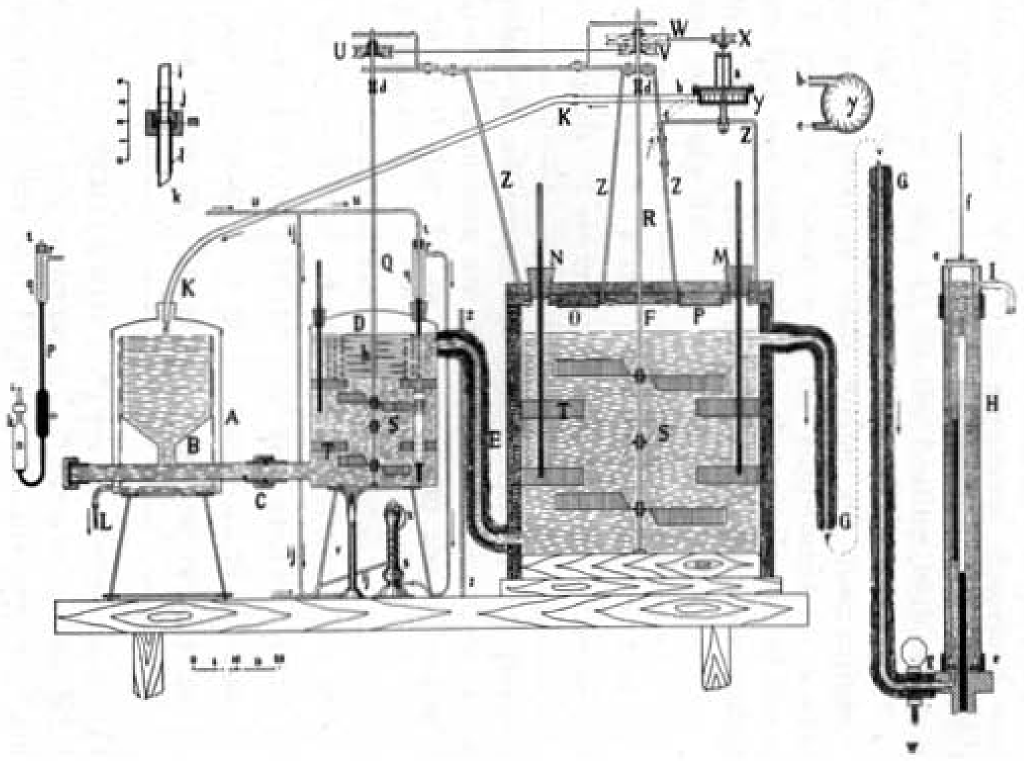
[1]) In the Phys. Lab. at Leiden rooms, when necessary, can be heated night and day; the lowest temperature may therefore be kept higher than 0° C.

[2]) Supposed to be 25° C. the isotherm is determined at 20° C.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It is obvious that changes in the temperature of the room may have a considerable influence on the constancy of the temperature in the *observing bath*: although I could not notice in the heating bath a variation of 0.1 deg., it sometimes happened with a great change in the temperature of the room that the temperature in the observing bath changed some hundredths of a degree. Therefore it is desirable to keep the temperature of the room as constant as possible.

The results obtained with the apparatus described were quite satisfactory; although under some circumstances we could observe variations of almost 0.1 deg. C. in the heating bath, they were not perceptible in the observing bath.

Here follow some readings made during my observations. In the first place I give an instance of the adjustment for a case when sufficient care had not been taken in the regulation of the constant flame, so that the regulating flame was sometimes extinguished. This happened on July 7th.

7 July	time	2.29	2 47	3 09	3.24	3.44	3.59
	temp.	19°.75	19°.77^5	19°.81	19°.80	19°.80	19°.76^5

The accuracy of adjustment is insufficient for my purpose. But if the required precautions are taken, the temperature is accurately maintained to 0.01 deg. C. as appears from the following observations on two days:

25 Aug.	time	2.48	3.09	3.28	3 48	4 07	4 26
	temp.	19°.78^5	19°.78^5	19°.78^5	19°.78^5	19° 78^5	19°.78^5
27 Aug	time	2.44	2 56	3.07	3 22	3 36	3.48
	temp.	19°.79	19°.78^5	19°.78^5	19°.78^5	19°.80	19° 79^5

Physics. — J. C. SCHALKWIJK: "*Precise Isothermals. IV. The calibration of piëzometertubes.*" (Communication N°. 70 (2nd continuation) from the Physical Laboratory at Leiden, by Prof. H. KAMERLINGH ONNES).

In this paper the method for the calibration of piëzometer tubes, mentioned in Communication N°. 50 is described more in detail [1]).

[1]) AMAGAT mentions only that he calibrated carefully, but not how and to what degree of accuracy; a source of uncertainty in the calibrations of REGNAULT is mentioned and corrected by LEDUC, who also employed constant temperature and considered the volume of the meniscus in the calibration of his bulbs; BUNSEN calibrated by admitting small measured quantities of mercury.

3*