Thermostats*

Various Types and Methods of Application

By W. N. Ray, M. A., and J. Reilly, M. A., D.Sc.

CHANGE of temperature affects the values of most physical and chemical constants. In many cases the effect is a large one, as, for example, with the electrical conductivities of solutions and rates of chemical reactions. It is therefore important in such cases to carry out the determinations at a fixed temperature, and to record the temperature at which each value of the constant was obtained. A change of temperature of 0.001°C . will alter the density of most liquids by about one in the sixth place; so that if densities are to be measured with this degree of accuracy the temperature must be maintained constant to 0.001°C . throughout the determination. Constancy to this extent is the best that can be obtained at present, and is only possible at temperatures within a few degrees of the room temperature, and preferably above it. An examination of the literature of such a subject as the electrical conductivities of solutions shows that results are recorded in various cases for 15°C ., 18°C ., 20°C ., and 25°C .; when values are given for two or three of these temperatures there is less objection to raise, but in many cases results are shown for one temperature only, and there is no agreement as to what this temperature should be. Since we are able to obtain most accurate temperature regulation when the temperature is a few degrees above the room temperature it would clearly be of great advantage to fix a standard thermostat temperature so that it would always satisfy this requirement; there are few laboratories in Europe where the temperature remains below 15°C . throughout the year, while in many tropical laboratories the average room temperature is nearer 30°C . The adoption of a uniform thermostat temperature of 25°C . in Europe and 35°C . in tropical countries with determination at both temperatures when possible would be of considerable value.

Thermostats for these temperatures consist of large baths of water or other liquid which are kept well stirred, while the temperature is regulated by gas or electrical heating controlled by some form of thermo-regulator. The advantage probably is with electrical heating as far as regulation of temperature is concerned.

It is often useful to have a rough instrument, especially in commercial laboratories. A metal capsule containing liquid, the expansion of which moves the top of the capsule and thence, either mechanically or electrically, cuts off the source of heat, furnishes one example, while a bimetallic strip which bends on heating gives another which can also be used at temperatures besides these in common use. Ostwald considers that spirals made from a band of two metals of as different expansibilities as possible rolled together might be suitable even for sensitive thermo-regulators, especially if connected with an electro-magnetic regulator.

One form of thermostat which has proved very satisfactory in practice consists of a tank of copper 60 cm. long by 40 cm. broad and 40 cm. deep and therefore holding nearly 100 litres of water. To prevent as far as possible loss of heat by radiation and so reduce the effect of variation in the external temperature, the sides are usually lagged with a layer about 3 cm. thick of some such non-conductor as slag wool.

No thermo-regulator is really satisfactory in a room whose temperature varies considerably. No lagging device will adequately compensate for external variations. If a thermostat is in an underground cellar of fairly constant temperature and free from draughts, lagging may be a positive disadvantage, as when the temperature of the bath is on the high side it takes all the longer to cool. In working fairly near the air temperature there is not much chance of the bath falling much below the required temperature, in which case only would the lagging come in useful. Also for high temperature thermostats, *e. g.*, for microscopical preparations, it is usually more important that the temperature does not exceed a certain amount, in which case lagging would be a disadvantage. Thus, while efficient lagging of the bath is often very useful it is difficult to generalize about its utility.

At the top of the two longer sides are plate-glass windows 15 cm. high and 60 cm. long to enable readings to be taken of objects completely immersed; the glass is sometimes cemented in position, but is better fixed by means of a metal frame fastened with screws to the metal tank, and with a layer of sheet rubber on each side of the edge of the glass, between the latter and the metal; such joints are water-tight, and the glass is more easily replaced when necessary.

When gas heating is used the bottom must, of course,

be left unlagged; with electrical heating it can be protected in the same way as the sides. A constant level of the type used on water-baths may be employed, and should be adjusted so as to keep the level about 3 cm. from the top of the thermostat; at ordinary temperatures it is hardly necessary; it is sufficient to add some water every four or five days. A small drain-cock in one corner of the bottom is very useful for cleaning and emptying purposes. A less convenient but considerably cheaper arrangement can be made of a copper tank enclosed in a wooden case with a second wooden case, allowing a space of 2 or 3 cm. between the two; this space is filled with sawdust, cork, or other convenient insulator.

For the thermostat to be efficient, vigorous stirring is essential; good results have been obtained by using a bar passing lengthways along the bottom of the bath, and carrying six small paddles 5 cm. by 4 cm., and attached to a short arm which passes through a hole drilled in the bar and is held in position by a thumb-screw. The bar runs in vulcanite or metal bushes, which are secured to brass rods so as to be capable of vertical adjustment by means of clips fastened at the top of the bath; the height of the bar is adjusted so that the paddles just clear the bottom.

It is perhaps conducive to quieter running to have the bushes fastened to the sides of the bath near the bottom, especially since the vertical adjustment is rarely used after the initial setting. The stirrer is driven either by means of grooved pulleys and a belt or by means of toothed wheels and a chain. In either case it is advisable to use large pulleys or wheels. Twisted tape makes a satisfactory belt which will last for months. A deep groove on the pulleys prevents the belt from slipping off, while the use of large pulleys stops belt-slip under a heavy load. With toothed wheels the teeth should be cut and not pin teeth, since the latter wear out quickly. Chains of the kind used in pianolas are used, but these stretch after a time, and then make a considerable noise as they slip on to the teeth; for this reason the use of belts is preferable in spite of the greater chance of breakage. The upper pulley is fixed by clips to the edge of the bath, and so can be moved along to take up the slack in the belt. The spindle of this pulley is connected by a spring coupling to a one-tenth horse-power motor fitted with worm reduction gear. Instead of the spring coupling, a pulley and a belt drive may be used, while the worm reduction gear may be replaced by the back wheel of a bicycle, the axle of the wheel being clamped firmly into a heavy retort stand. One belt passes from the motor round the rim of the wheel, while the other passes round that part of the hub between the chain-wheel and the spokes. The speed of the motor is regulated by means of a lamp resistance, or in the case of an alternating current by the use of a choking coil, so that the paddles make about 100 revolutions per minute. Small paddles with rapid stirring are found to be most effective.

The efficiency of various types of gas thermo-regulator has been investigated by Lowry (*Jour. Chem. Soc.*, 1905, T., 1030). He found that with a large regulator of the Ostwald type containing about 250 cc. of a 30 per cent solution of calcium chloride, the temperature of the bath showed periodic variations amounting to 0.05°C . in amplitude, and having a period of twenty minutes. Variations of the gas pressure affected the mean temperature of the bath to a large extent, but the effect is less with more sensitive regulators. A drop in the temperature of the room was found to increase the amplitude of the temperature variations.

Lowry designed two types of regulator which gave much more satisfactory results; the bulb of one was a fluted cylinder, while that of the other was a spiral. The constants of the best example of each type were as follows:—

	Fluted	Spiral
Dimensions.....	8 x 2 ins.	8 x 6 x 1 ins.
Volume.....	150 cc.	500 cc.
Movement of mercury 1 mm. for 0.017°C .		0.006°C .
Amplitude.....	0.010°C .	0.008°C .
Period.....	7 mins.	2 mins.

With both these regulators, after the initial period, the flame merely trembled and the temperature showed no marked oscillations. When gas heating is used the best results are obtained with a low and steady gas pressure; about 3 cm. of water is a convenient gas pressure to use, and this can be readily attained by the use of the gas pressure regulator described by Joseph (*Journ.*

Chem. Soc. Proc., 1914). The gas from the main enters through a thin walled rubber tube, which passes between a fixed bar and the hinged bar of a telegraph sounder. The thin rubber tube is connected by means of a T-piece to a large bottle, and to the side tube of a filter-flask which contains some 40 per cent sulphuric acid. The neck of the filter-flask is closed by a rubber stopper with two holes; through the smaller hole passes a glass tube with a platinum wire sealed at the end and containing some mercury; the platinum wire dips into the acid and so makes contact with it. The other hole carries an open tube 1 cm. in diameter, with the lower end dipping into the acid; in this tube is placed the other contact made adjustable by passing it through a large cork resting on the top of the open tube. The telegraph sounder is in series with these two mercury contacts and with a battery giving about 6 volts. When the gas pressure in the apparatus rises, the acid is forced up in the wide tube and so completes the circuit; the electro-magnet then comes into operation and pinches the rubber tube, cutting off the gas supply as long as the pressure remains high. A lead weight placed on the bar of the sounder is an advantage in reducing the amplitude of the pressure oscillations. The large bottle takes up small variations of pressure, and from here the gas passes to the thermo-regulator, a T-piece serving to connect in a water manometer which indicates the gas pressure. When the apparatus is properly adjusted the fluctuations of pressure are less than a mm., even when the gas pressure in the main is as high as 25 cm. of water.

For long runs it is very advisable to further purify the gas by washing through either silver nitrate or a mercury salt (if a bubbler is used a large "capacity" must follow) or other washing medium, otherwise the surface or the mercury in the regulator soon becomes too dirty to be really good.

Many different types of thermo-regulator have been devised. Field (*Journ. Am. Chem. Soc.*, 1914, xxxvi., 72) describes one which depends on the change in vapor pressure of ether, and which was capable of maintaining a bath of 350 liters at 30°C . with an accuracy of 0.01°C . to 0.005°C . for several days at a time. This form is not so sensitive as the toluene regulator described below, but it has the advantage of adapting itself to change of temperature of the bath with great rapidity, and therefore may prove useful when large or sudden changes in the external temperature are unavoidable. The apparatus consists of a U-tube closed at one end, having a threeway stopcock at the bend and a stopcock at the open end of the tube. Two platinum wires are fused in the open side of the tube. Dried ether and air are confined in the closed side of the tube by a column of mercury, and the increase of vapor pressure of the ether causes the mercury to make contact with the upper platinum wire, and so to shut off part of the heating circuit by means of a relay. The regulator is adjusted by the addition or removal of mercury, the air in the open arm is replaced by carbon dioxide and the tap is closed. Mercury is then poured above the tap and a rubber stopper is inserted. The three-way cock is also closed by a rubber tube and a pinchcock.

The Lowry pattern thermo-regulator is one of the most satisfactory; this, as mentioned above, is made in two forms: one a spiral closed at the upper end and connected at the lower with a narrow vertical tube rising out of the thermostat; the other consists of a series of flattened bulbs one above the other; the top bulb is sealed to a narrow tube, one end of which passes to the bottom of the lowest bulb, and the other projects above the water. The object of these particular forms is to expose as large a surface as possible, so that the liquid in the regulator will follow the small changes in the temperature of the bath with as small a lag as possible. The narrow tube which projects above the surface is expanded to about 1 cm. in diameter, and has a side tube sealed on; the top of the wide tube is closed with a rubber stopper carrying an angle tube drawn out to a fine capillary; the end of the capillary is cut off or ground square, and passes down into the narrow tube. The angle tube and the side tube of the regulator are connected by an H-tube with a glass tap in the middle which acts as a by-pass. The upper tube of the H is connected to the gas pressure regulator and the lower tube to a micro burner, such as is used in the apparatus for the electrolytic detection of arsenic. The by-pass is adjusted so that the gas which passes this way is almost sufficient to maintain the temperature of the bath at the required value; very little gas then passes

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through the regulator, with the result that the amplitude of the temperature oscillations is small and the mercury is not so readily fouled by sulphur in the gas. (If the gas contains much sulphur it should be passed through a soda-lime tube). The liquid used in the regulator should have a large coefficient of expansion and a low density and specific heat; toluene is very generally used. The regulator is filled in the following manner:—The toluene is first distilled, and is then repeatedly shaken with mercury to remove sulphur compounds, so that a clean mercury surface left in contact with the toluene will remain clean. The end of the regulator is closed with a stopper carrying a glass tube with a tap in it, and the side tube is connected by way of a tap to the water-pump. The regulator is exhausted and the tap is closed; the regulator is then inverted, the tube placed under toluene, and the tap opened so that some of the toluene enters; the tube is then again exhausted and some more toluene admitted. This operation is repeated several times until the apparatus is full; mercury is then added so as to nearly half fill the lower bulb, and the excess of toluene is removed. The regulator is then placed in the bath at the right temperature, and mercury is added or removed by a capillary tube. The final adjustment is made by replacing the rubber stopper and raising or lowering the capillary tube. A side tube is sometimes added containing a space filled with mercury into which projects a metal screw passing through a threaded hole in a round steel nut cemented on to the end of the tube; by turning the screw the position of the mercury can be very quickly adjusted so as to give the required temperature; the arrangement does not commend itself for very accurate work, and is likely to lead to small chance variations of adjustment which might not be noticed until too late. Two thermometers are required, one a sub-standard reading from -10° to 50° C., each degree being sub-divided into tenths, so that temperatures can be obtained accurately to $1/100^{\circ}$ C. and estimated by means of a microscope to $1/500^{\circ}$ C., and a Beckmann thermometer. The two thermometers are fixed in the bath so that the points on the scales corresponding to the required temperature of the bath are as near to the surface of the water as is consistent with convenience of reading. The temperature of the bath is then adjusted to that required as indicated by the sub-standard thermometer, the readings being made with the aid of a small microscope and the necessary corrections being applied. The temperature on the Beckmann thermometer is then read, and in future the bath is always adjusted to correspond to a fixed point on the Beckmann thermometer; the latter adjustment can always be made correct to 0.001° C., although the actual value of the temperature is not known to the same degree of accuracy. In general, it is more important to get a steady temperature than to aim at any definite reading.

Whitaker's modification of thermo-regulators for gas consists in cutting off the gas by the mercury just at the top of a capillary tube, which rises from the bulb. A little well is ground at the top of the capillary, the angles of the bottom being as low (*i. e.*, as nearly horizontal) as is compatible with ensuring that the mercury will trickle back every time. The cut-off tube must approach very near indeed to the bottom of the well (say one-sixteenth up). The end of this is ground off internally at an angle estimated to be approximately tangential to the mercury globule where it touches it, thus disturbing and deforming it as little as possible. Ostwald lays great importance on the shape of the end of the inlet pipe. He considers it better to cut off the tube at right angles to the axis, so that it is shut off by a very small rise of the mercury and opened again by a corresponding small fall. Mane and Marquis have devised a simple and easily regulated thermostat (*Comptes Rendus*, 1903, cxxxvi., 614). Their instrument maintains a constant temperature to within two or three hundredths of a degree. It is composed of a cylindrical enamelled iron vessel of 15 litres capacity filled with distilled water. The vessel is placed inside a vessel of slightly larger dimensions, and the space between is filled with sawdust. The bath is heated electrically by means of a platinum wire, and the current regulated with the aid of a rheostat. The agitator is worked by a small electric motor. The constant temperature is maintained by means of a thermo-regulator consisting of a large glass cylinder filled with acetone or other liquid. The liquid selected should have a sufficiently large coefficient of expansion to give the apparatus a suitable sensitivity. The expansion of the liquid causes the level of a mercury column to vary in the proximity of a platinum point. The current necessary to establish an electric circuit for the make and break is furnished by an auxiliary pile. It acts as a relay which connects the heating current.

For electrical heating the apparatus can be arranged

conveniently thus: The bath, stirring gear, and thermometers remain as before; as heaters two hot-point immersion heaters are used capable of taking 2 or 3 amperes at 100 volts; one of these replaces the by-pass in the gas-heated arrangement, the other is operated by the thermo-regulator. The former is connected to the mains with a choking coil or lamps in series to regulate the current, so that by itself this heater will keep the temperature just below the required value; instead of the heaters, carbon filament lamps may be used. The Lowry thermo-regulator has a thick platinum wire sealed into the bottom, making contact with the mercury inside. The other contact is a platinum wire mounted on a thin brass rod on which a screw thread is cut, and with a head having a milled edge at the top; the screw moves through a nut cemented into the top of the regulator and provides an easy method of adjustment. The side tube of the regulator is closed with cotton-wool. The regulator is in series with two storage cells, a 2,000 ohm sliding rheostat, and a Post Office standard relay; a current of a few milli-amperes is sufficient to work the relays, but to prevent sparking with consequent injury to the contacts a condenser of 0.5 microfarads is connected in parallel with the relay terminals; the condenser may be replaced by a pair of aluminum plates insulated by glass tubing and held together by two rubber bands; the plates are about 8 cm. by 10 cm., and are immersed in a beaker of distilled water (Browning and Symons, *Trans. Faraday Soc.*, 1915, xi., 60). The second heater is connected in series with the mains, a lamp resistance, and the relay, the contacts being again shunted with a condenser. When the temperature rises contact is made in the regulator; the current from the storage cells then operates the relay, breaking the contact in the heating circuit; when the temperature falls, the current in the relay ceases, the spring in the relay then pulls the arm back, and again makes the heating current.

Either of the above thermostats will keep the temperature steady to 0.001° C. for weeks, while for longer periods they can be relied upon to 0.002° C. For some purposes it is necessary to use a thermostat adjusted to some temperature between zero and the room temperature; the heating arrangements of the ordinary thermostat can then be replaced by a coil of thin walled copper tubing carried round the walls of the thermostat near the top; ice water is passed through the coil, and the temperature is controlled by a thermo-regulator working a relay which cuts off the supply of ice water by pinching a thin walled rubber tube (Browning and Symons, *Journ. Soc. Chem. Ind.*, 1914, 33), somewhat in the same manner as in the gas pressure regulator described above. The top of the thermostat may be covered with plate-glass cut in three strips for convenience in removing. Greater accuracy than 0.01° C. cannot be obtained at these temperatures. Morgan (*Journ. Am. Chem. Soc.*, 1911, xxxiii., 334) devised an arrangement for maintaining a small thermostat at any desired temperature between 0.1° C. and 90° C. to a few hundredths of a degree. The regulator has a U-shape, one arm of the U being 3 cm. in diameter and 15 cm. long, and closed by a tap with a funnel above it. A platinum wire is sealed in this side, and bends vertically down so as to reach a point about 1 cm. above that at which the tube narrows. The bend of the U-tube is a capillary of 0.75 mm. diameter; about 6 cm. above the bend this expands to a diameter of 4 mm., which continues to the top of the tube; to the end of the tube is fixed by means of a thumbscrew a threaded collar with a binding screw. A threaded brass rod 2 mm. in diameter passes through the collar and terminates in a short stout platinum wire. Mercury is added to within 3 cm. of the top of the capillary, and then purified toluene is poured in to fill the larger side tube. The stopcock is left open while the temperature of the bath is roughly adjusted to the required value, and is then closed, the final adjustment being made by means of the threaded brass rod. The two wires from the regulator are connected to a 2-volt cell and a relay which will operate so as either to make or break the current in the main circuit. The connection in a P. O. standard relay can be made so as to produce either result. The main circuit may consist of D. C. current from the mains passing through a 32 C. P. lamp, and an electro magnet arranged like the telegraph sounder, except that the brass bar is prolonged and has a weight of several kilograms, attached to it, so that when no current passes the weight causes the other end of the bar to press upward against a metal stop. Between the latter and the bar passes a thin walled rubber tube which is compressed so that no water can flow through it. The bath has an overflow so as to keep the water-level constant, and ice water or hot water from a reservoir giving a pressure head of 40 to 50 cm. passes into the bath through the rubber tube. At temperatures below that of the room the electric circuit is arranged so as to cut off the current and allow ice water to flow when the expan-

sion in the regulator makes the current there. For higher temperatures the connections are arranged so as to break the main current, and cut off the hot water supply when the temperature causes the regulator to make the current in the relay. Thermostats to give exactly 0° C. are rather difficult to arrange. Since water just above 0° C. is less dense than that at 0° C. it is advisable to have a good supply of ice at the bottom of the tank. A false bottom of perforated zinc is therefore fitted 15 to 20 cm. above the bottom of the bath, and on this rests a rectangular perforated zinc box of such a size as to leave ample space for ice between it and the side of the bath; the box forms the actual working space, and can be fitted with a stirrer, etc. When preparing the thermostat for use crushed and washed ice is packed on the bottom to a height of 15 to 20 cm.; the false bottom is then secured in position, and on this the rectangular box; the space between the walls and the box is then packed with lumps of ice up to the top; ice water is next run in to the desired level, and finely crushed ice is put in to a depth of 2 or 3 cm. in the top of the box and a plate-glass cover placed on the whole.

For high temperature an electric furnace is described by Waidner and Burgess (*Bull. Bur. Stand.*, vi., No. 2). It consists of a resistance furnace mounted vertically, and having two separate heating coils of platinum ribbon 0.01 mm. by 2 cm. wound on porcelain tubes with the turns so spaced as to allow the establishment of a uniform temperature over a considerable length of the furnace. A separate rheostat controls the current in each circuit. Temperatures are read by means of a platinum resistance thermometer, and it is possible, by adjusting the rheostats by hand, to maintain the temperature steady to a few hundredths of a degree.

Recent Observations on the Solar Coronas

THE simple examination of the sky during the daytime nearly always exhibits the sun surrounded by a circular whitish luminescence whose diameter and whose intensity are susceptible of great variation. Leaving aside all theoretic considerations with regard to this apparition, a Zurich astronomer, M. Maurer, recently published in the *Archives des Sciences Physiques et naturelles* an account of the systematic investigation of this subject made by him since the profound atmospheric disturbance of 1912.

The exhaustive and continuous study of the solar nimbus shows that it often constitutes a veritable corona, and that it presents the simplest and most certain criterion of the purity of our atmosphere.

The first result of the observations begun by M. Maurer in 1912-13, is that the great solar nimbus attains a minimum diameter twice a year, in April-May and in August-September; at these periods it may even entirely disappear.

But the year 1916 took a very different course from spring to fall. The spring minimum was but slightly marked, and even in April the Corona had attained a diameter of 100° . Then in July and in August of the same year the nimbus had assumed, even in a blue sky, enormous dimensions approximately 140° in the middle and at the end of August; this was the mark of an optical disturbance of the atmosphere which had been revealed by other signs so early as the beginning of April.

The solar nimbus exhibit svery remarkable phases at the periods of great solar activity; with diameters of 70° - 80° and even of 100° , it is surrounded with a border of a distinct color of a tint shading from red to yellowish brown. It then gives the absolute impression of a circle of Bishop, but of markedly greater diameter. The intense apparitions of this border are accompanied without exception by notable telluric and atmospheric phenomena (polar auroras, telluric currents). It is most probable that these phenomena are to be attributed to extensive emissions by the sun of cathodic rays, conformably to the views of Birkeland. The rapid appearances and disappearances of the colored ring are incompatible with the idea of an intermittent aureole due to clouds of volcanic ashes. The explanation of the solar nimbus by the theory of diffraction presupposes the presence of particles which are extremely tenuous and very close together. These particles might be engendered by the nuclei of condensation sent to the earth by the sun in its paroxysms, and which would also exert the polar auroras.

The observations made at Davos by M. Dorno seem to reveal the existence of an intimate and regular relation between solar activity and the appearance or accentuation of the great solar corona. We have here a correlation which requires to be verified by prolonged observations made in very diverse localities and at elevated altitudes.