in B is greater than that in A, and the voltage across the furnace is reduced on contact being made, the voltage change produced by the operation of the relay will cause the mercury to overshoot the contact point, thereby reducing the sensitivity of the relay.

In practice, satisfactory regulation may be obtained with the mercury level in B, 6 to 10 mms. higher than that in A,

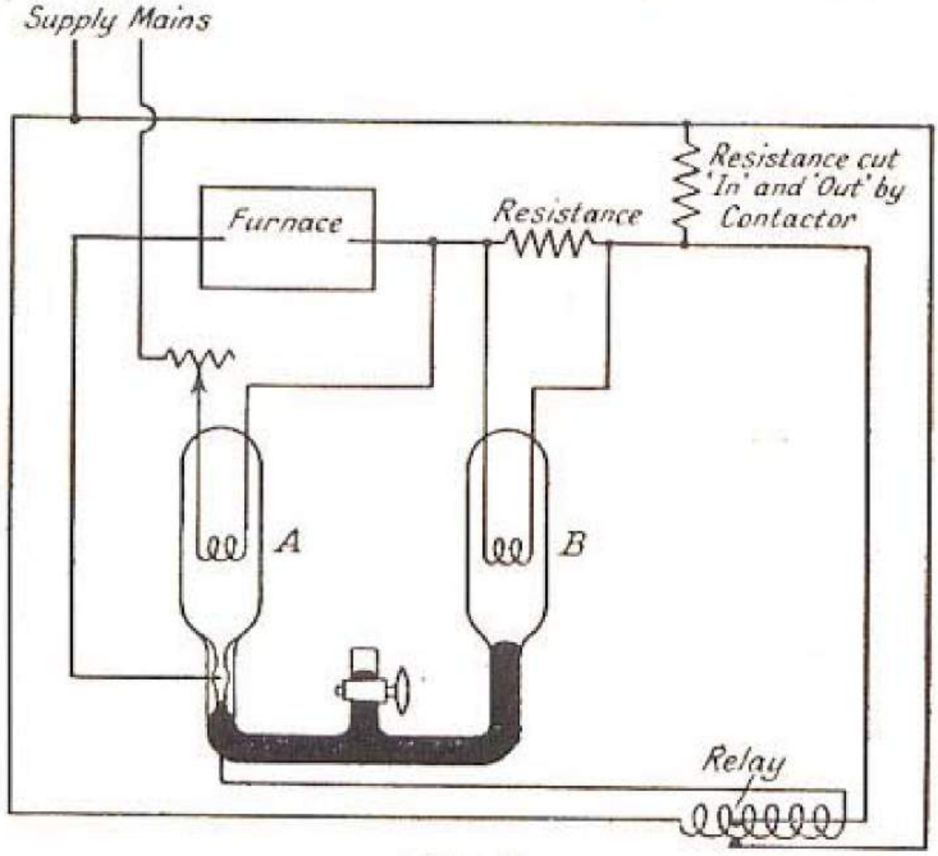


FIG. 42b.

at the moment of contact. The bulbs are so arranged that there is a small quantity of mercury in the bottom of the bulb when contact is made, thus confining pressure adjustments of the manometer to the contact limb. A valve relay is inserted in the circuit thereby reducing the current at the contacts to a fraction of a milliampere. By this method, regulation of $\pm$ 0·5% in the resistance of the heating element is obtained.

Resistance of Salts.—It has been already pointed out that salts and oxides have a negative coefficient of resistance generally the resistance decreases rapidly as the melting point temperature is approached. Since this change is constant over long periods, this method finds wide application in the control of solder pots, tempering baths and aluminium melting pots, the temperature remaining constant to $\pm$ 3° for 500° C.

When the pot is cold the resistance is high, but, with increase of temperature of the solder, the resistance of the salt which is generally contained in a steel tube, decreases, but will not permit sufficient current to operate a relay until a temperature of 400° C. is reached. When this state is attained the relay operates a switch which cuts off the main current. The auxiliary current will still continue to flow through the resistance till the temperature of the solder has fallen and the resistance has increased, permitting only a very small current

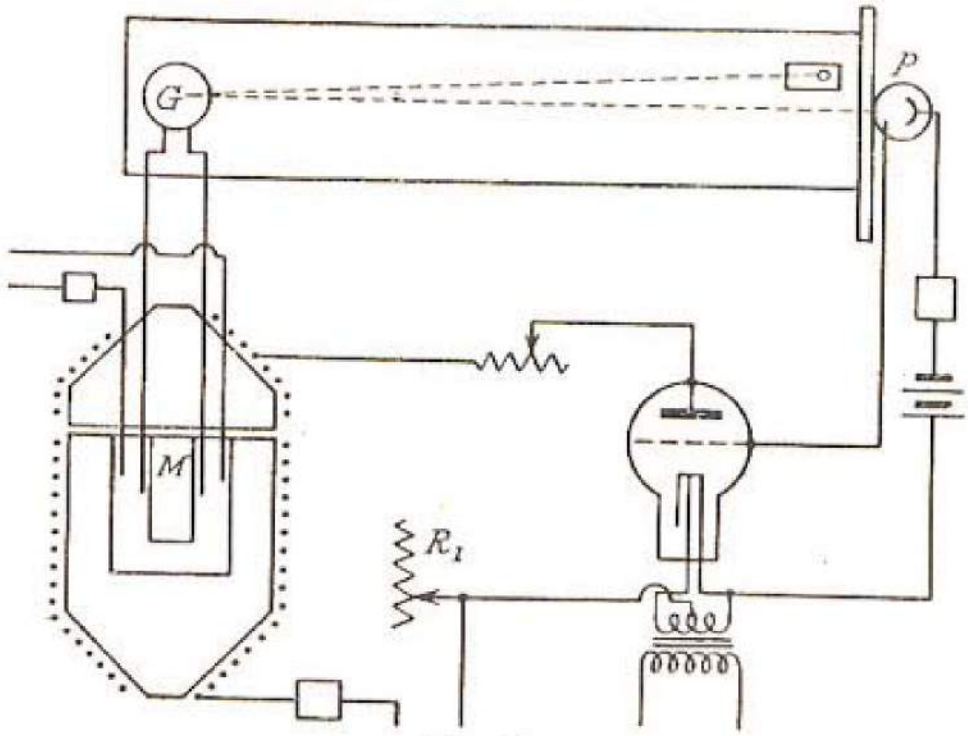


Fig. 43.

to pass. The relay consequently returns to its original position and remains set for the next operation.

Anderson[1] developed the following method for maintaining a quantity of zinc at its melting point over long periods, by surrounding it with a bath of the same metal automatically maintained in two-phase equilibrium through the abrupt change in resistivity attending isothermal fusion. Use is made of the fact that at the melting point the specific resistance of molten pure metal is about twice that of the solid metal at the same temperature. Thus, if contacts are immersed in the metal and a steady direct current passed through it, the voltage drop across these potential contact will be proportional to the quantity of metal liquified. This variation in potential

[1] *Rev. Sci. Instr.*, 1, 764. 1930.

is used therefore to control the furnace heating. The latter consists of a copper casting wound with nichrome wire, and M, the zinc bath contained in an alundum cup. Tungsten potential contacts are connected to a Moll galvanometer G (Fig. 43), of voltage sensitivity 5×10^{-6} the light from the atter being deflected to the photo-electric cell P.

Tungsten current contacts are also immersed in the bath, a 2 volt accumulator being inserted in the circuit. Heating current enters the furnace through a parallel circuit composed of an adjustable resistance R_1 and the plate circuit of a rectifier valve. In operation, full current passes through the furnace until the resistance of the bath falls, and the spot of light on the photo-cell moves away, and the bias on the rectifier valve is increased so that the discharge is extinguished. To minimise oxidation of the zinc at bath surface, a stream of nitrogen is introduced through the furnace cover, or alternately a blanket of graphite covers the molten metal. A galvanometer deflection of 3 mm. is sufficient to operate the photo-cell.

Fig. 44.

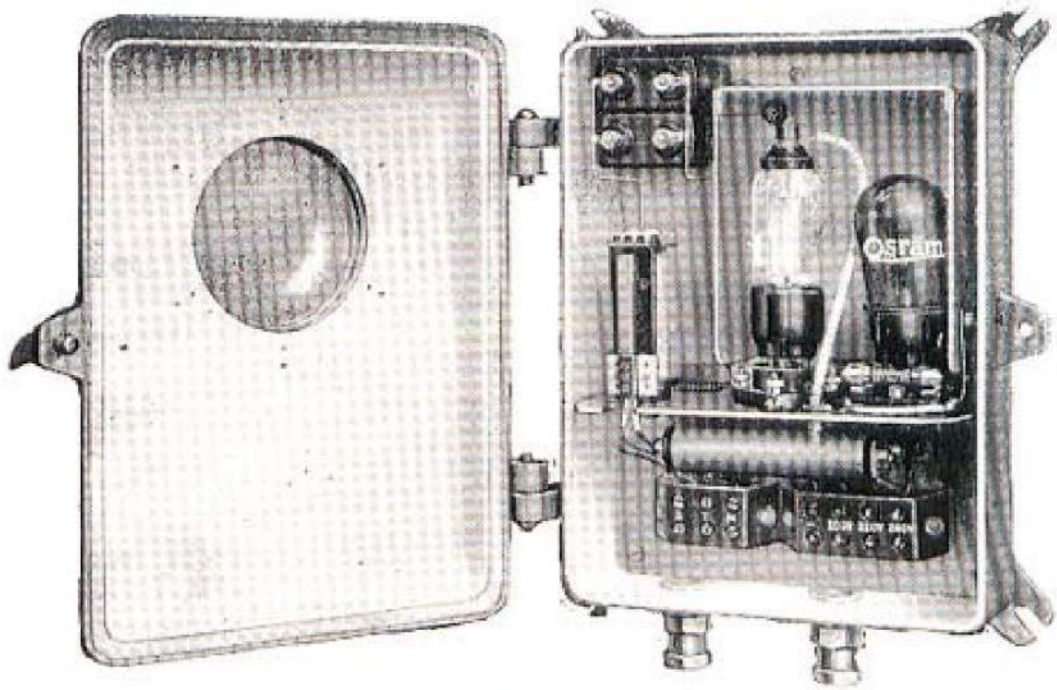


Fig. 47.

[To face page 64.

CHAPTER VII

TEMPERATURE CONTROL UTILISING THE PHOTO-ELECTRIC EFFECT

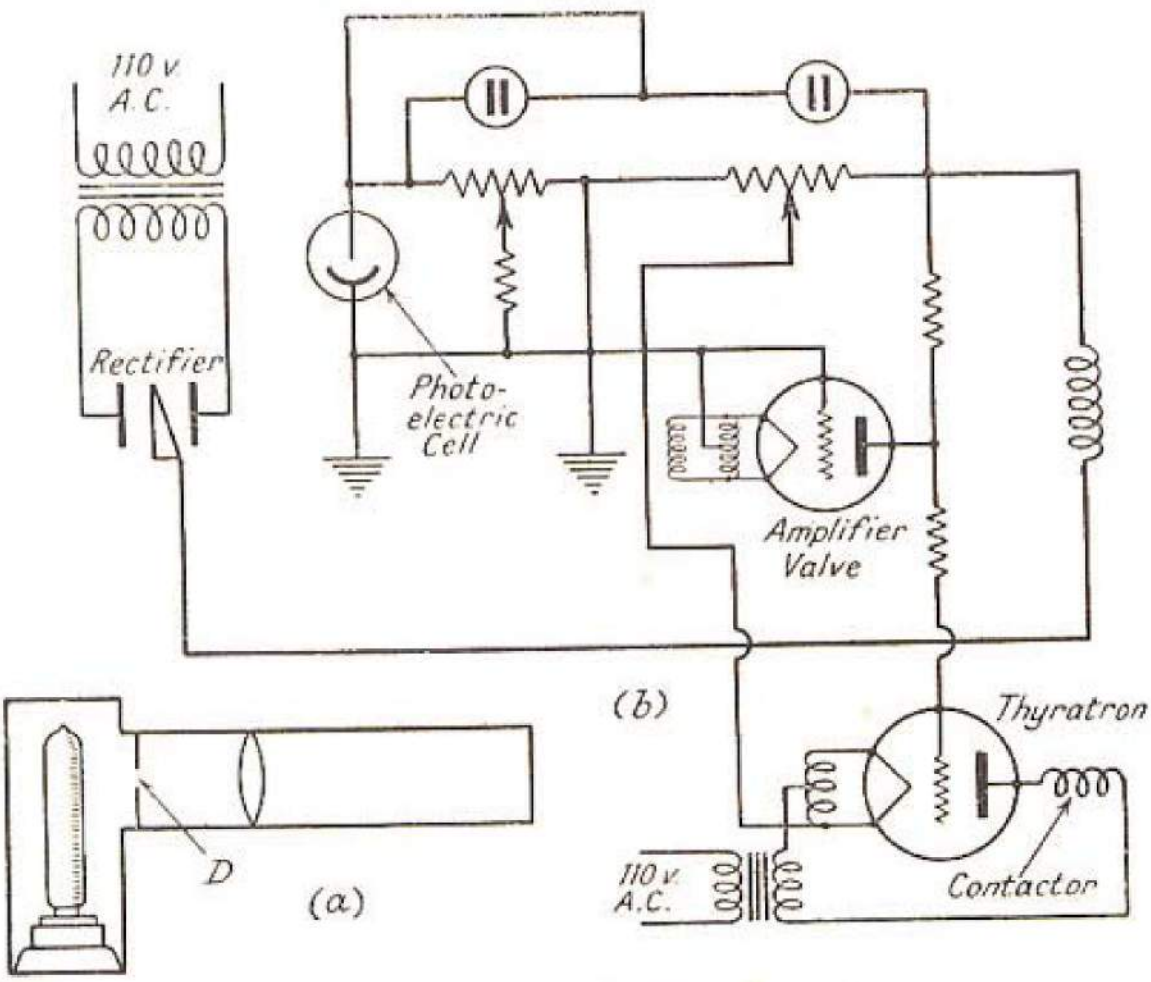
PHOTO-ELECTRIC cells make use of the fact that when a voltage is applied between suitably prepared electrodes situated within a glass envelope evacuated or gas-filled, no current passes when the cell is dark, since the path between the electrodes is practically an insulator. When, however, light is allowed to fall on the cathode, an electron emission takes place, the primary current produced being proportional to the illumination. This current may be amplified by an external amplifying arrangement and used for control purposes of auxiliary apparatus.

The cell (Fig. 44), consists of an anode in the shape of a rectangular wire grid supported by a glass pinch, and connected to the anode and grid pins of a valve base. The cathode consists of a V shaped plate of oxidised silver, coated with an extremely thin film of caesium, thus forming the light sensitive surface from which electron emission takes place. The cathode is connected to a screw terminal at the top of the glass envelope. The latter may be either evacuated and is then known as the " vacuum type " or gas-filled.

These light sensitive cells may be obtained with various type electrodes, so that the appropriate cell may be employed for the particular wavelength of light used. For temperature control work, the caesium-silver vacuum type is most suitable. The following table gives details of such cells and the purpose for which they may be employed.

TABLE 6.

Nature of cathode.	Purpose for which used.
Potassium (mass layer) gas filled.	Detection and measurement of radiation in the blue end of the visible spectrum in the range 4,000–5,000 A.U.
Caesium-silver oxide, Vac. type.	Measurements in the longer wave lengths of the visible spectrum and the near infra red.



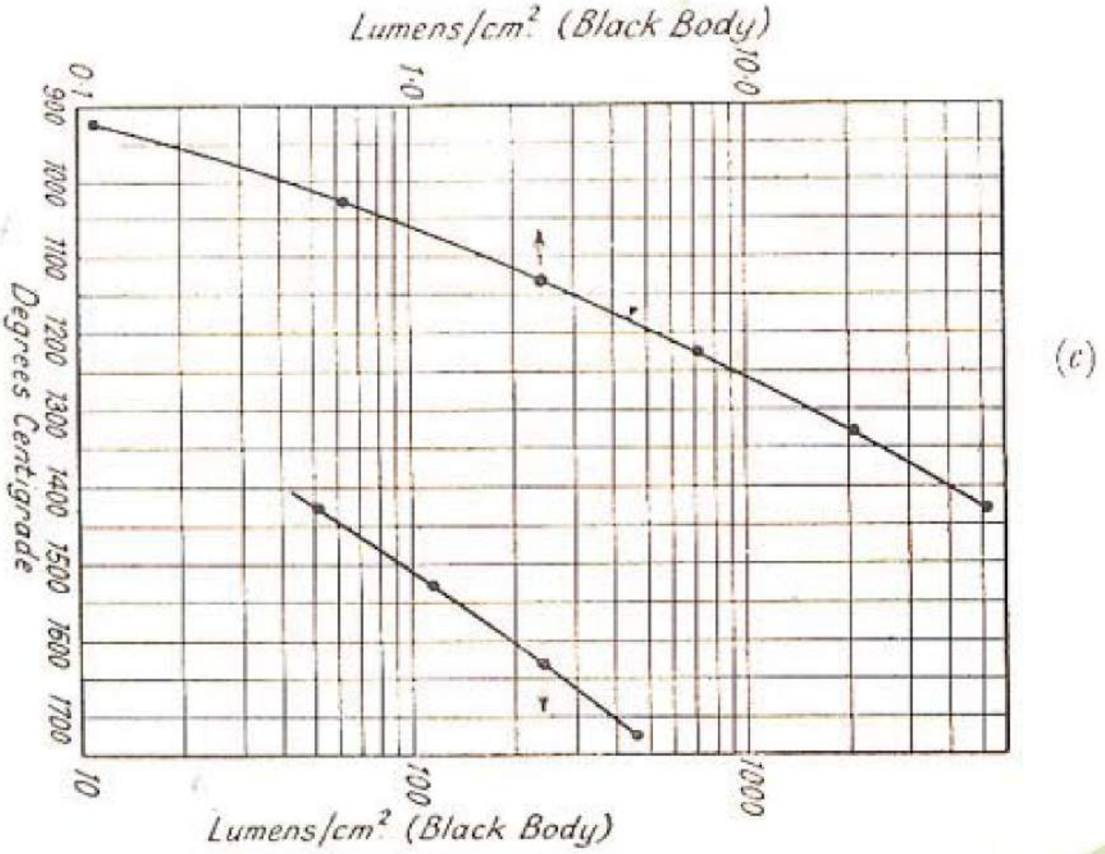


Fig. 45a–b.

(c) Variation of light flux with temperature.

Nature of cathode.	Purpose for which used.
Potassium-silver oxide, vacuum.	Measurement of illumination and applications demanding some sensitivity throughout the whole visible spectrum.
Sodium-gas filled. . .	Detection and measurement of ultra violet rays in the spectral range 3,000–4,000 A.U.
Cadmium-gas filled. . .	Detection and measurement of ultra violet rays in spectral range 2,500–3,000 A.U.

If light from an incandescent body is allowed to fall on a photo-electric cell, a current will flow which is proportional to the light flux. If the temperature of a body changes, its brightness also changes, so that the photo-electric current can be used as a measure of temperature. This current, being of a small order, can be suitably amplified and employed to control auxiliary controlling devices. Koller[1] has therefore developed a method using the light radiation given out by an electric furnace to control, by means of a photo-electric cell, the temperature of the furnace.

In order that the photo-electric current may be a true measure of the temperature it is essential that the area of the hot body "covered" by the cell shall always be the same. This is accomplished by focussing an image of the furnace wall in the plane of a diaphragm *D* (Fig. 45*a*), placed in front of the cell, and allowing only the centre portion of the image to pass to the cell. In order to prevent extraneous light from impinging on the cathode, a long tube containing a diaphragm and lens, with the interior blackened, is attached to the main body of the cell housing, the whole being conveniently mounted on a bracket about 1 metre from the furnace.

The cell current is amplified by a resistance coupled amplifier, the necessary direct current being obtained from a rectifier built into the set. In the described apparatus the amplifier current passes through a high resistance and the drop across the latter is impressed between the grid and filament of a thyratron valve. Thus, as soon as this exceeds a predetermined value, or the temperature exceeds a predetermined point, the rectifier operates and cuts off the main current. Immediately the furnace temperature falls below the specified

[1] *Ind. & Eng. Chem.*, 23, 1379. 1931.

limit, the photo-cell current decreases, and the main current is switched on by means of the thyratron. A suitable circuit for this form of control is shown in Fig. 45*b*, while that in Fig. 45*c* gives variation of light flux with temperature curves. This method, which maintains a temperature of 1,500° C. to within ± 10° C. possesses the advantage that it can be applied to high temperatures or atmospheres which would have a deleterious effect on thermo-couples or resistance

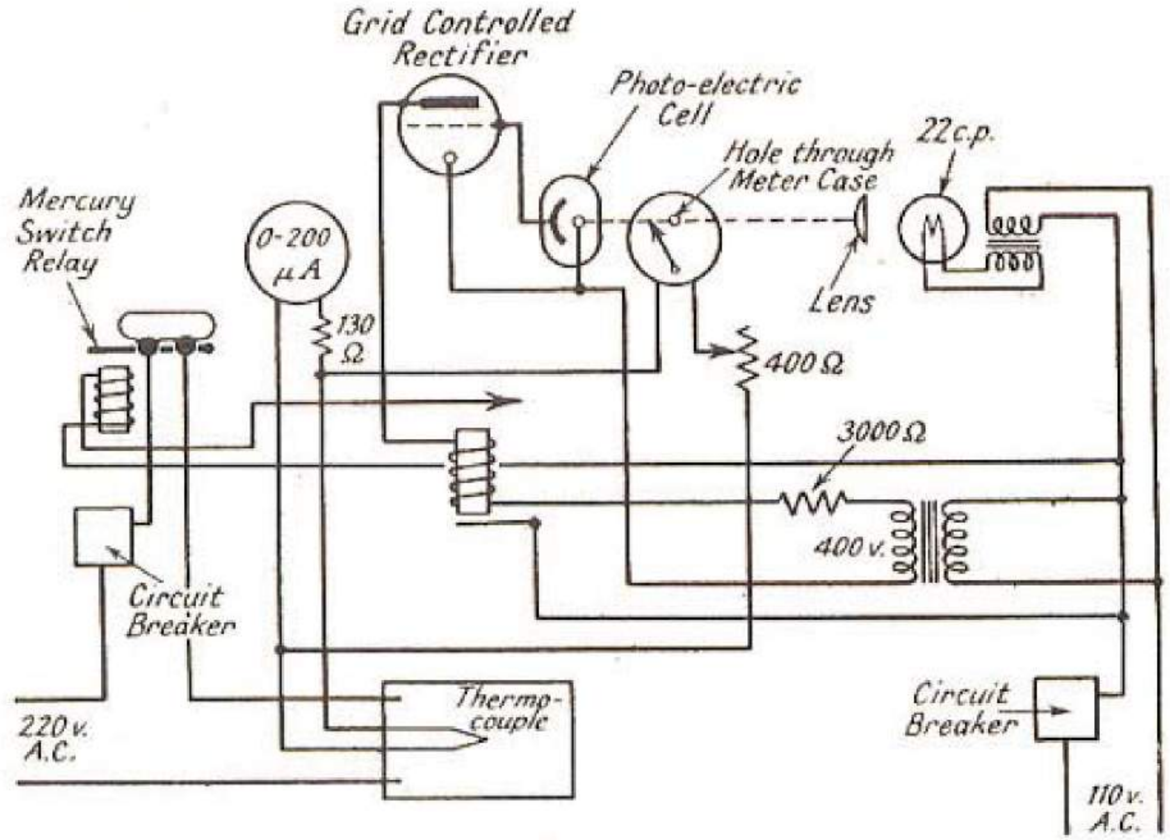


Fig. 46.

thermometers, while the whole equipment can be situated at some considerable distance from the furnace under control.

Koechel's Millivoltmeter Method.—A novel and interesting method of controlling the temperature of a filament coating oven has been described by Koechel.[1] In the oven was installed a thermo-couple, the free ends of which were connected to a millivoltmeter (Fig. 46). The latter was mounted with a suitable light source focussed on the mid-portion of the instrument scale, while placed directly behind the meter was the cell, situated within a light-proof compartment. A hole was drilled in the centre of the scale, and a corresponding hole, in a direct line with the former, in the

[1] *Electronics*, p. 170. 1932.

meter case. This enables rays of light to pass through the meter to the cathode of cell.

This hole was arranged in such a position that when the needle read in the exact centre of the scale the aperture was closed and no light could pass through to the cell. The latter was connected to a grid controlled rectifier and an associated relay system so arranged that it would connect or disconnect the line voltage to the oven under control. The sequence of the operation is such that, when the temperature of the oven is below any selected value, the meter pointer is on the lower half of the scale. Under these conditions the rays of light reach the cell, and, by operating the relay connects the main current to the oven. This condition exists until such a time that the oven temperature rises to a point equivalent to the centre portion of the scale. Under such conditions the aperture of the meter is covered by the pointer. When this occurs light is cut off from the cell, and actuates the relay thereby cutting off the current from the oven. The pointer moves with decrease in temperature and, after uncovering the aperture permits light to pass, the cycle of operations is again repeated. A calibrated meter in series with temperature meter permits setting of the latter, so that it will read at the exact centre of the scale for any temperature setting ; the dial therefore controlling this rheostat can therefore be conveniently calibrated in temperature values. Thus when the dial is set for any particular value, it means that the voltmeter will indicate at the centre of the scale when the oven reaches that temperature and therefore covers the aperture. With a focused light source of 21 c.p. and a photo-cell of sensitivity $30\mu a$ per lumen, using a $\frac{1}{16}$th inch aperture in the case of the Weston 301 meter, it is possible to maintain oven temperatures values within $\pm 0{\cdot}5\%$ of the range being used. For industrial purposes the photo-cell and amplifier are often accommodated in separate housings, especially when employed for control purposes in engineering works. When, however, the usage is not severe, the form of mounting shown in Fig. 47 is employed, the light required to operate the cell passing through the window in the casing.

CHAPTER VIII

THERMO-ELECTRIC CURRENT CONTROL

In 1828, Seebeck discovered that when the junction of two dissimilar metals was heated an electromotive force was generated, the magnitude depending on the two metals employed (Fig. 48). A serious disability, however, arises with their usage, since, on exposure of the metal elements to high temperatures rapid oxidation and deterioration takes place. In practice, the metals are in wire form having two dissimilar ends welded or soldered together; various combinations

Fig. 48.

A=Hot junction. *B*=Indicating instrument.
C=Copper leads. *D*=Cold junction.

have been employed such as copper-constantin, iron-constantin or silver-constantin. When used above 300° C. copper-constantin junctions rapidly deteriorate even when the wires are of heavy section. Iron-constantin may be employed for temperatures up to 800° C., but it is found that, after prolonged exposure to high temperatures, parasitic currents often develop. Previously, iron-nickel was largely used, but this has been replaced by nickel-chromium and nickel-aluminium. The former consists of 90% Ni, 10% Cr., and the latter 98% Al, 2% Ni, with traces of Si and Mn. This is sometimes known under the trade name of "Chromel-Alumel"; the presence of small traces of silicon and manganese are essential since it is found that although pure nickel-aluminium alloy stands well at high temperatures, it becomes very brittle at lower temperatures. This wire may be used continuously for ranges about 1,100° C., but, for good service, wire of ample gauge should be employed.

In 1886, Le Chatelier introduced the platinum-platinum-rhodium element, having 10% rhodium, for working in the neighbourhood of 1,500° C., but care must be taken to protect the elements from reducing gases, silicon or metallic vapours.

Platinum-platinum-iridium may be used for temperatures up to 1,000° C. Although it is possible under certain conditions when working at moderately high temperatures for the elements to be used unprotected it is often an advantage to protect them by placing within a suitable shield. These may be in the form of beads or cylindrical tubes ; some typical protection tubes manufactured by the Morgan Crucible Co., of Battersea,

FIG. 49.

London, are shown in Fig. 49. Porcelain may be used up to 1,400° C. provided the surface is glazed ; fused silica up to 1,000° C. provided the atmosphere is free from alkalies ; while alundum will withstand 1,500° C., but since this material is porous a glaze coating should be applied.

The thermo-electric electromotive force will depend on the combination of the junction, and the following table shows the e.m.f. obtainable with various metals coupled to platinum.[1]

[1] See *Jour. Bur. of Standards* (RP 767), 14, 239. 1935. Ibid (RP 768), 14, 247. 1935.

TABLE 7.

Metal.	Microvolts per °C.
Chromel (90% Ni, 10% Cr.)	33
Nichrome	19·3
Copper	15·4
Iron	13
Platinum-Rhodium (Pl. 90%. 10% Rh.)	9·5
Platinum	0
Alumel	− 8·3
Nickel Silver (15% Ni)	−12
Nickel Silver (25% Ni)	−22
Nickel	−22
Constantin	−41
Copel (45% Ni, 55% Cu)	−45

Thermocouple Construction.—Two methods of construction are available depending on whether the couple is constructed in wire or rod form. In the former case, the wires are passed through glass or porcelain beads or tubes, one pair of ends being carefully cleaned and "tinned," and then soldered or welded together. The twisted end should not be unduly

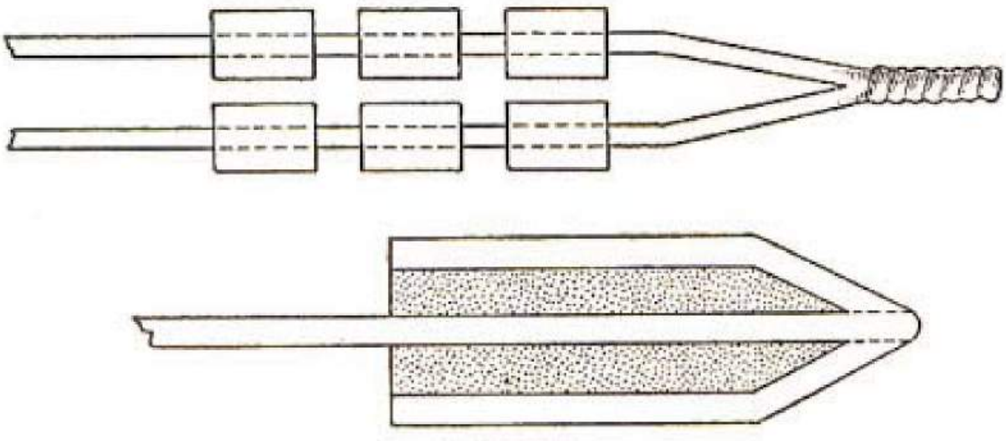


FIG. 50.

long, while the remaining ends are connected to a suitable terminal block (Fig. 50). In the case of the rod and tube type, the rod of one material is fitted into another tube having a closed end of the other material, the interspace being filled with asbestos or porcelain. At the couple end, the tube is reduced in diameter, and the actual joint should finally be welded.

In welding chromel-alumel couples it will be found that the alumel melts first; accordingly this should be placed in the cooler part of the flame until the chromel begins to flow. When both wires are in this condition, the couple should be rotated in the flame until both metals run together. The extension leads of base metal couples are usually made of the same material as that of the thermo-junction wires. In the case of platinum-rhodium couples, however, a copper lead is connected to the platinum-rhodium wire, and a copper-nickel lead to the platinum wire.

Temperature Control by Thermocouples.—A precision method developed by C. W. La Pierre[1] for the control of an

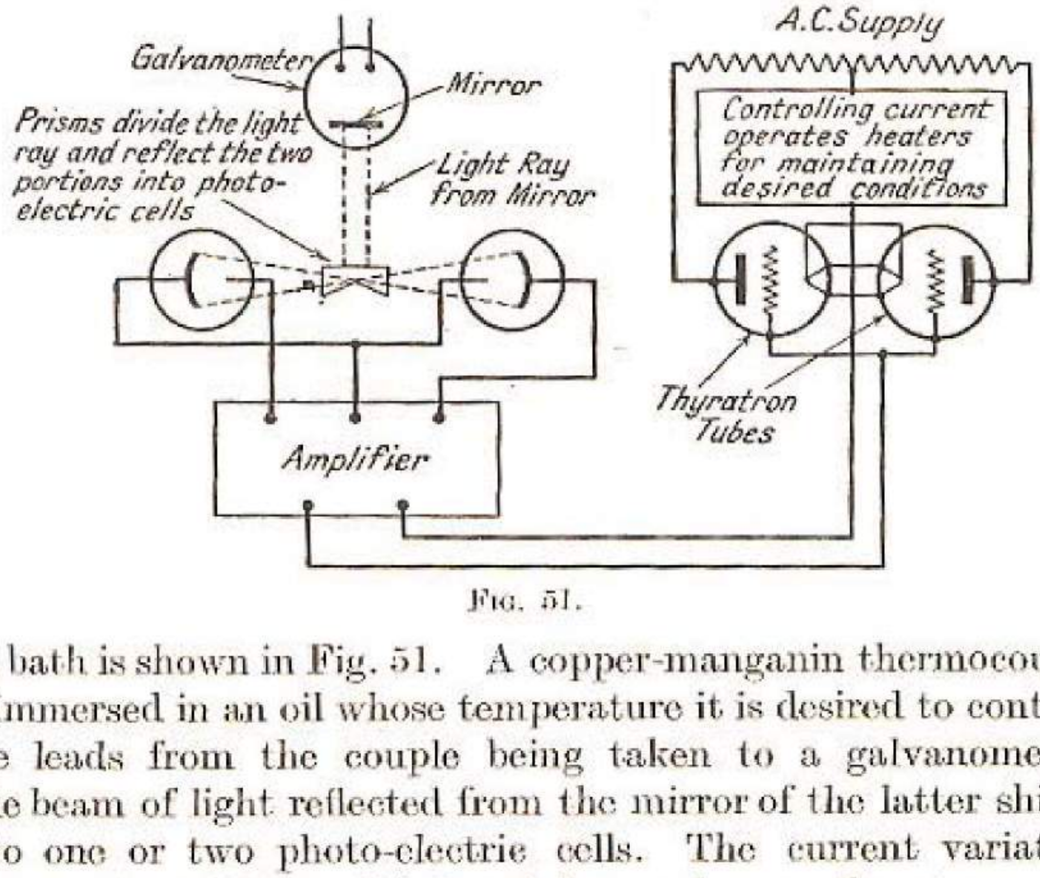


FIG. 51.

oil bath is shown in Fig. 51. A copper-manganin thermocouple is immersed in an oil whose temperature it is desired to control, the leads from the couple being taken to a galvanometer. The beam of light reflected from the mirror of the latter shines into one or two photo-electric cells. The current variation thus produced is amplified and imposed on a thyratron controlled circuit, which, in turn, changes the current in the heating coil circuit. For industrial control the arrangement is modified and the circuit shown in Fig. 52 employed. The thermocouple chosen for the temperature range is suitably protected before insertion in the furnace, and the leads connected to an amplifier. The thermocouple after comparison with a standard e.m.f. set for the required temperature influences a thyratron through the medium of an amplifier, which polarises the choke in the connection circuit of the windings. The choke, according to the state of magnetisation, admits more current to the furnace

[1] *Gen. Elec. Review*, July, 1932.

windings until the two e.m.f.s are once again balanced, and the furnace attains the desired temperature.

An interesting method of control developed by the Cambridge Instrument Co., employs a differential thermocouple T_1, T_2, situated at the extremity of a delicate galvanometer pointer arm. A small electrically heated coil *H* (Fig. 53), known as the heater, is mounted on the movable arm *B*, which is controlled by means of a removable handle set in the top of the case. This enables the instrument to be set at the desired controlled

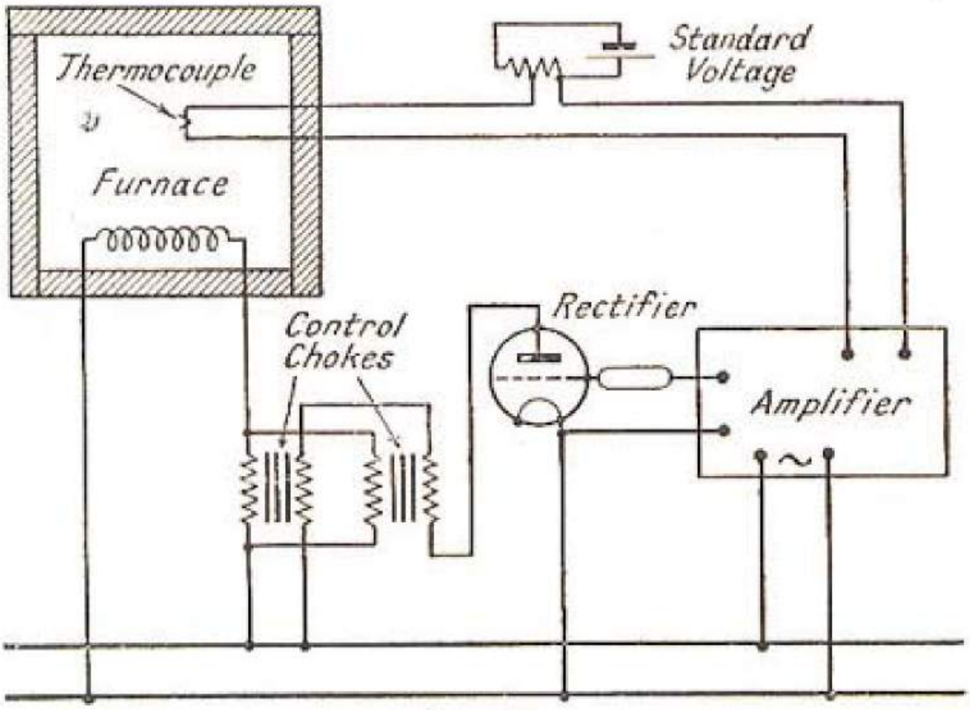


FIG. 52.

temperature, an index *I* being provided to indicate the setting on the graduated scale on the front of the case. When this temperature has been nearly attained the couple T_1 is brought opposite to the heater, and an electromotive force is set up which tends for the moment to throw the relay arm away from the contact which it will eventually close. Further increase in the temperature being controlled results in the thermocouple T_2 being brought nearer the heater, where it eventually arrives. The electromotive force then generated actuates the relay which closes an electrical circuit, which in turn directly controls the supply current to the furnace.

It is possible by employing different settings of the heater and regulator that temperatures at any point between the upper or lower limits of the scale may be controlled. To prevent any possibility of the regulator failing to function, owing to an interruption in the supply of current to the heater, a safety device is provided, whereby the supply of heat to the apparatus is automatically shut off if the heater circuit should be broken. Such an apparatus can control temperatures up to 800° C. to within ± 0·3 per cent.

Control of Furnace Temperatures.—Adcock[1] arranged for the control of furnace temperatures by placing the e.m.f.'s

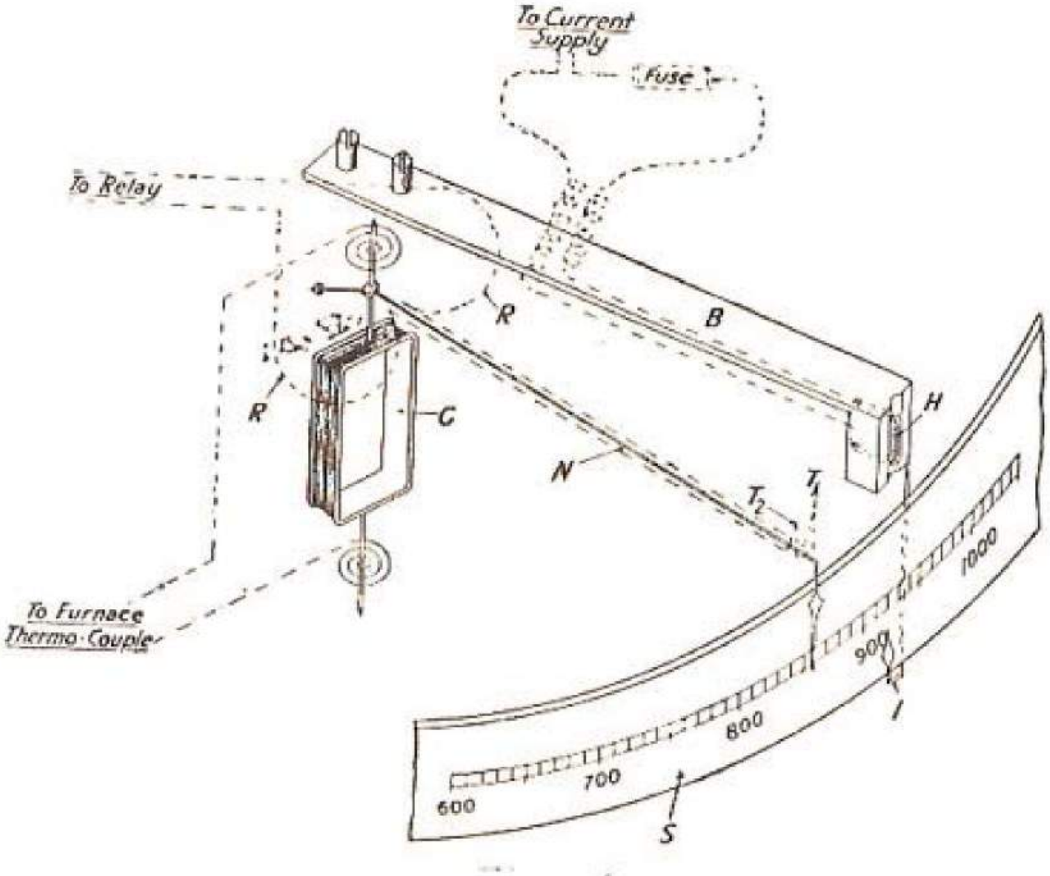


FIG. 53.

of two thermocouples in opposition, the residual e.m.f. producing the galvanometer deflection. The light from the galvanometer mirror was allowed to fall on the cathode of a photo-electric cell, thereby producing a small current in the circuit connected to a thyratron. The latter controls a small electric motor which is mechanically coupled to an adjustable resistance. This resistance is in series with the furnace windings, and, on operation of the thyratron controlled motor, less or additional resistance is inserted into the furnace circuit, thereby controlling the temperature. The set-up is shown diagrammatically in Fig. 54. The electromotive force opposing

[1] *Jour. Sci. Instr.*, 12, 286. 1935.

that of the furnace junction was maintained by means of a potential divider, consisting of 26 turns of wire, wound as a spaced helix on an insulated cylinder some 2 inches diameter and 8 inches long. The wire was an alloy containing 12% rhodium-platinum, since this does not readily tarnish and develops only a slight thermal e.m.f. against copper. Contact is made by a spring tipped with gold, and suitably tracked with

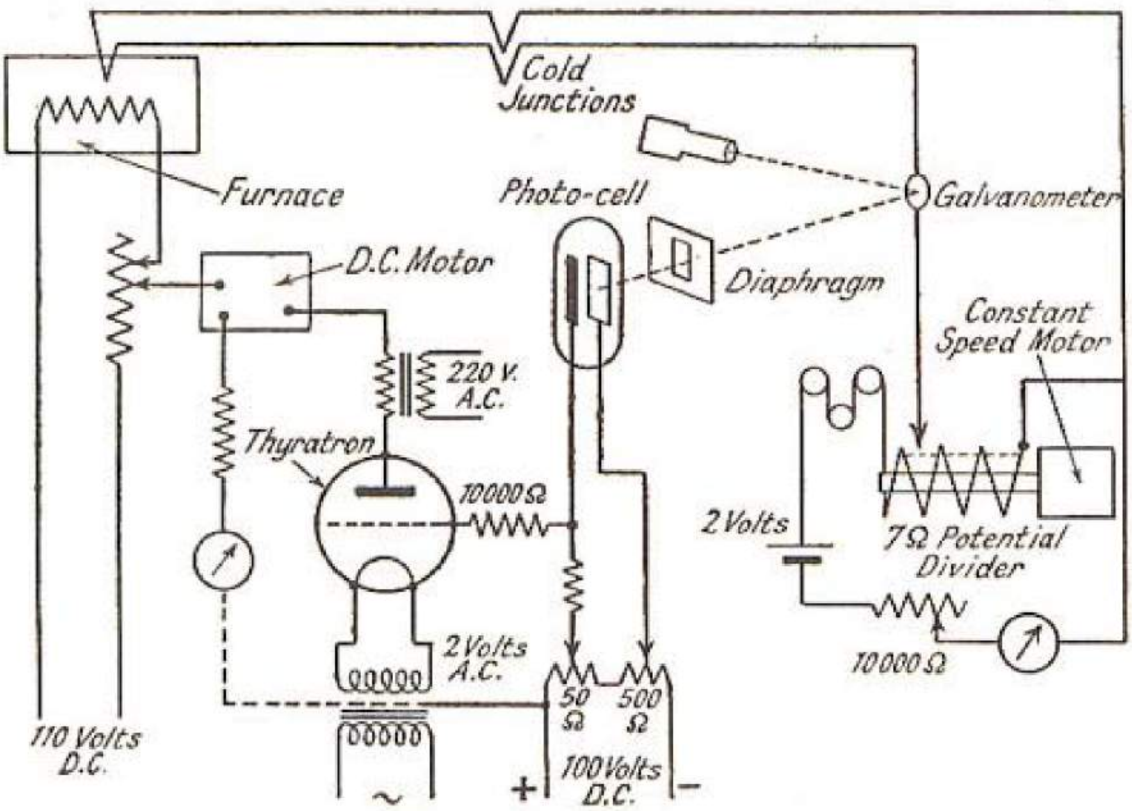


FIG. 54.

the turns of the helix ; the speed of rotation being 5 turns per hour.

The arrangement shown in Fig. 55 was employed by Scott and Brickwedde[1] to control the temperature of a calorimeter. In this X is to be maintained at the same temperature as Y, and inserted into X and Y respectively are the thermocouples which are attached to a sensitive galvanometer. The mirror of the latter instrument forms an image on the screen K, placed in front of the photo-electric cell C. The position of the lamp, screen and scale are so adjusted with respect to the galvanomenter, that when X is at the same temperature as T, no current flows through the galvanometer, and the reflected lamp image is focused on the edge of the screen K. When the

[1] *Jour. Bur. of Standards* (R.P. 284), 6, 401. 1931.

temperature of X changes from that of Y, the image moves across the edge on to the screen or photo-cell, depending on the direction of temperature change. Since the photo-electric current is too small to operate a relay, they are amplified by a valve, the relay R being connected in the plate circuit of the valve. In practice the photo-electric cell current is made to vary the grid potential by connecting the grid between a photo-cell and a resistance of 40 megohms (Z). The relay opens or closes a

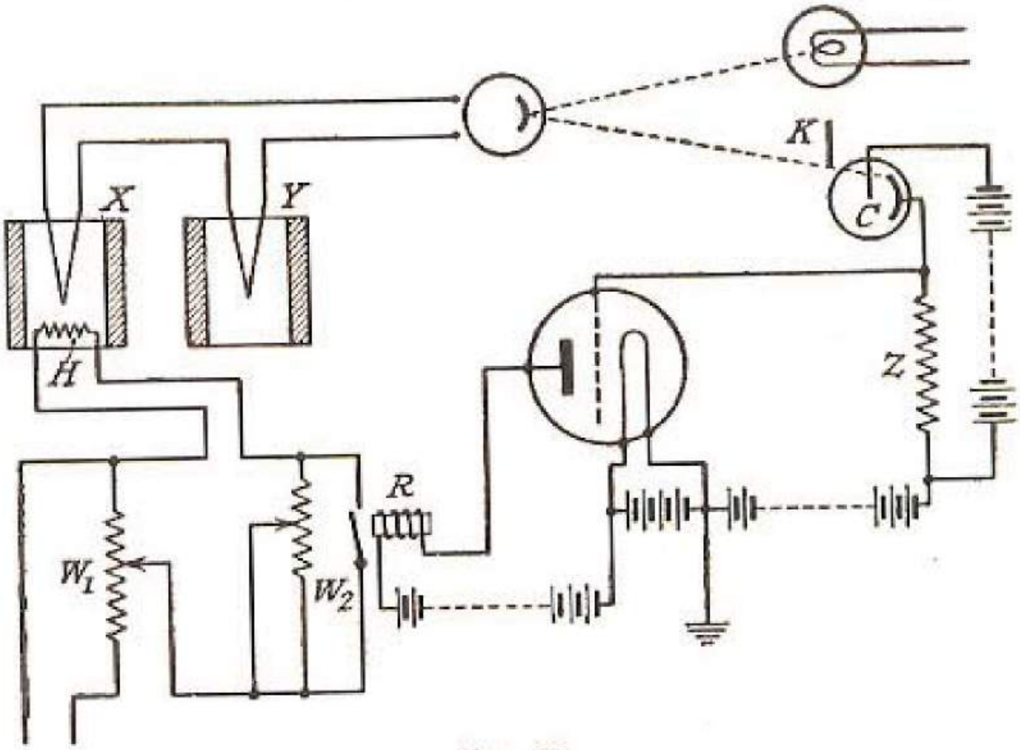


FIG. 55.

shunt circuit across the resistance W_2 connected in series with the heater H. The current through the latter is varied by W_1, while that for the thermostat is controlled by W_2.

It will be appreciated that if the number of junctions were increased and connected in series, such an arrangement would give rise to greater e.m.f., viz., for a given temperature difference between the junctions the e.m.f. will be n times that of a single couple. Such an arrangement is known as a thermopile, and consists of a number of bars, alternately of bismuth and antimony, about 2 cms. long, forming a number of couples in series. They are insulated from each other along their lengths by thin mica strips, and arranged so that the junctions form the opposite faces of a small cube. One of these faces is covered with lamp-black so as to readily absorb any radiant heat energy that falls upon it ; the other set of junctions is kept bright so as to be non-absorbent, and is further protected from temperature change by a brass cap. The whole is then mounted in a convenient holder, and to enable the collecting surface to absorb as much energy as possible, a metal open-ended cone is fitted over it, the wide end being towards the energy source.

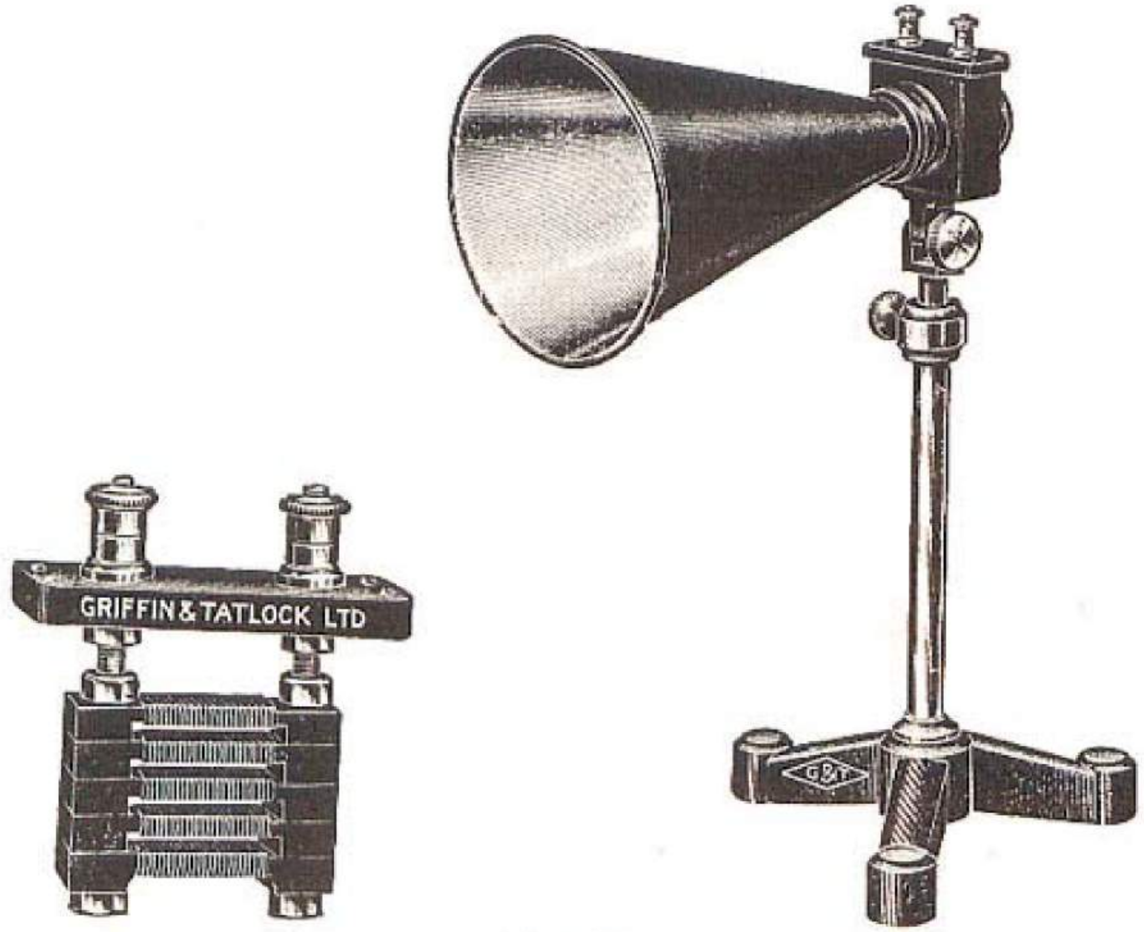


FIG. 56.

A commercial form is shown in Fig. 56 ; the materials of the couples may vary depending on the required sensitivity of the instrument. An industrial application of this instrument as developed by the Cambridge Instrument Co., is given in Fig. 57 where the heat radiated by a callendar roller is absorbed by the thermopile, and is used in conjunction with the apparatus described on page 75 to control its temperature.

The Cold Junction.—Since the electromotive force generated by a thermocouple depends upon the difference in temperature between the hot and cold junctions in the thermo-electric circuit, any variations in the temperature of the cold junction will affect the output of the junction. In order therefore that the cold junction may be maintained at constant temperatures, some form of control must be employed in order to maintain this temperature constant. A very simple method is to employ a thermos flask filled with oil, the vessel being surrounded by a heat insulating material. A thermometer, by which the temperature of the cold junction may be determined,

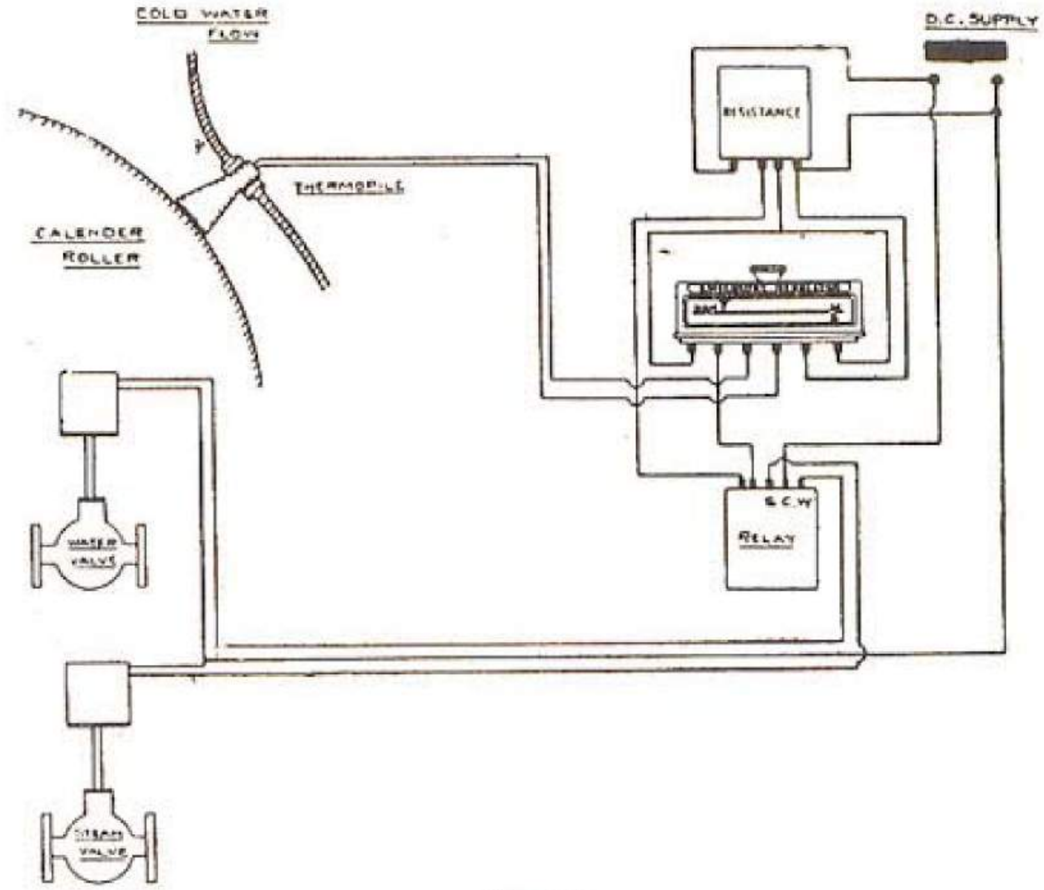


Fig. 57.

may be inserted through a cork in the neck of the flask. Another method is to control the temperature by burying the junction several feet in the soil. The temperature under such conditions can be maintained reasonably constant, especially if the junction is buried under a floor of a building rather than in the open. The junction may be enclosed in a $\frac{5}{8}$ inch diameter steel sheath pointed at its lower end, the thermocouple leads being connected to a suitable head fixed at the top of the tube.

CHAPTER IX

TEMPERATURE CONTROL AS APPLIED TO SCIENTIFIC INSTRUMENTS

THE application of temperature control has taken place in almost every branch of experimental science, for whenever precise and accurate measurement is desirable, temperature fluctuation must be minimised as much as possible. The method of control employed will vary with individual requirements both of the experimental problem and equipment, but the following descriptions of the form of control used in various branches of work may be taken as typical examples. When used in connection with spectrometers, refractometers, polarimeters and microscopes, the arrangement consists of some form of circulating cell, fitted so as to enclose the vital parts of the instrument. Not only is it essential that the instrument itself should be maintained at constant temperature, but also the liquids which are being used in the experimental work.

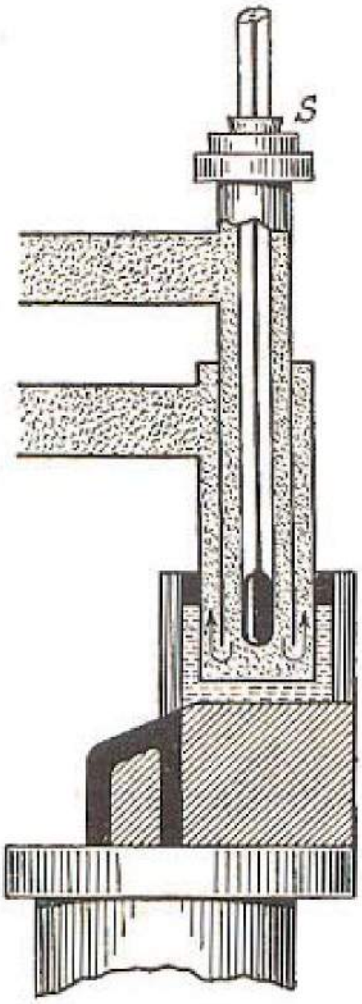


FIG. 58.

Refractometer Temperature Control.—The simplest form of control is that used on the Pulfrisch refractometer as shown in Fig. 58. It consists of a glass prism surrounded by a metal box, through which water circulates. After passing round the prism, the water enters the heating chamber *S*, and thus controls the temperature of the cell liquid, finally passing to the thermostat waste pipe. To maintain the prism at the desired temperature, the heating chamber is lowered into the cell liquid, and, after stable temperature conditions have been obtained, observations may be taken. For the purpose of ascertaining the liquid temperature, a thermometer is fitted into *S*. It should be noted that when the temperature of the experiment is not excessive, the cell may be attached to the prism by means of vaseline, but in the event of high temperatures being employed Krönig's cement may be used. This is prepared by melting 1 part of white wax with 4 parts colophony, and applied with the aid of a heated glass tube or rod.

It is sometimes required that the controlled temperature with this instrument shall be in the neighbourhood of −20° C.,

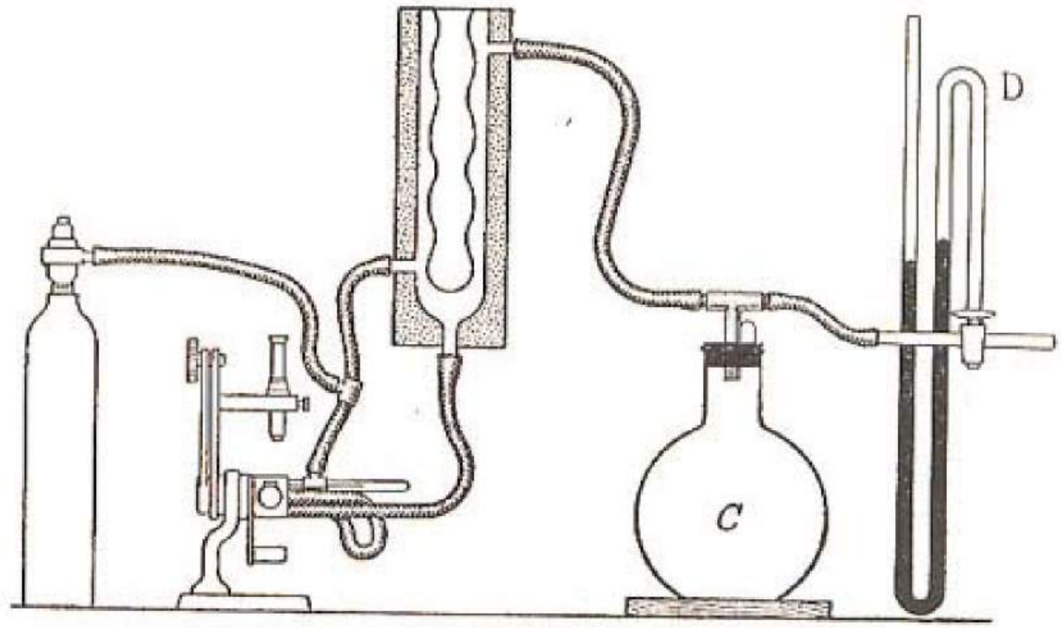


FIG. 59.

or even less. An arrangement due to Grose[1] is shown diagrammatically in Fig. 59, which is self explanatory. Efficient cooling to any desired temperature may be obtained by boiling any appropriate liquid such as isobutane (−10° C.), methyl ether (−25° C.), and propane for −42° C., but finer temperature measurements may be obtained by changing the total pressure of the system by means of *C* and *D*. After the refractometer has been filled with a sufficient quantity of cooling liquid, a thermo-syphon effect is produced and very efficient cooling with a steady temperature is attained. When working below −25° C. a calibrated thermocouple is inserted in place of the usual thermometer. The prisms are covered with a section from a microscope slide to avoid frosting, and are held *in situ* by a little vaseline. A few kernels of calcium chloride are inserted into the enclosed space and attached to the sides with vaseline. At a temperature between −30° C.

[1] *Jour. Amer. Chem. Soc.*, 59, 2739. 1937.

and $-50°$ C. it is necessary to wipe the glasses to keep them clear.

The disadvantage of this instrument lies in the fact that it can only be employed when a comparatively large amount of liquid whose refractive index is desired, is available. The Abbé refractometer does not suffer in this respect, since very small amounts are all that is necessary for accurate measurement. While the design of the instrument is different from the former one, temperature regulation is, nevertheless, accomplished in a similar manner as shown in Fig. 60. Suitable metal boxes are arranged for water circulation, such that they surround the glass blocks. The temperature is indicated by the usual thermometer, which should be screwed into position before any attempt is made to circulate the water. It is always advisable to arrange that thermometers record the temperature of the circulating water, both on entering and leaving the apparatus.

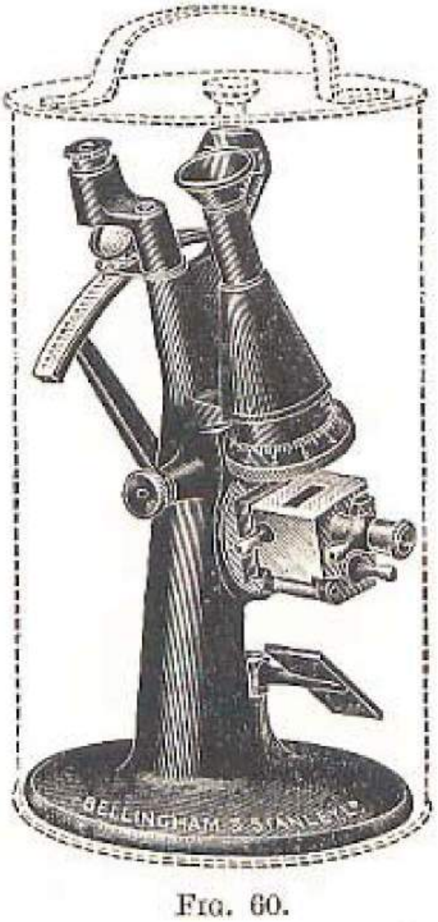


FIG. 60.

The previously described instruments are used solely for the measurement of refractive indices, but where the rotary power of liquids or solutions are required, polarimeters are employed. This instrument naturally is of different optical design and construction from the refractometer, but, nevertheless, the same method of temperature control is adopted, namely, circulating a previously heated liquid through the apparatus. The liquid, whose rotary power is desired, is contained in a glass cylinder placed horizontally between the relevant optical parts of the refractometer. This cylinder, however, is arranged in such a manner that it is surrounded by a cylindrical metal or glass jacket,[1] having specially fitted end pieces to enable the tube to be readily filled or emptied, yet maintaining it liquid tight when in position. Two tubes are also fitted to the jacket serving as

[1] *Trans. Far. Soc.*, 9, 193. 1913.

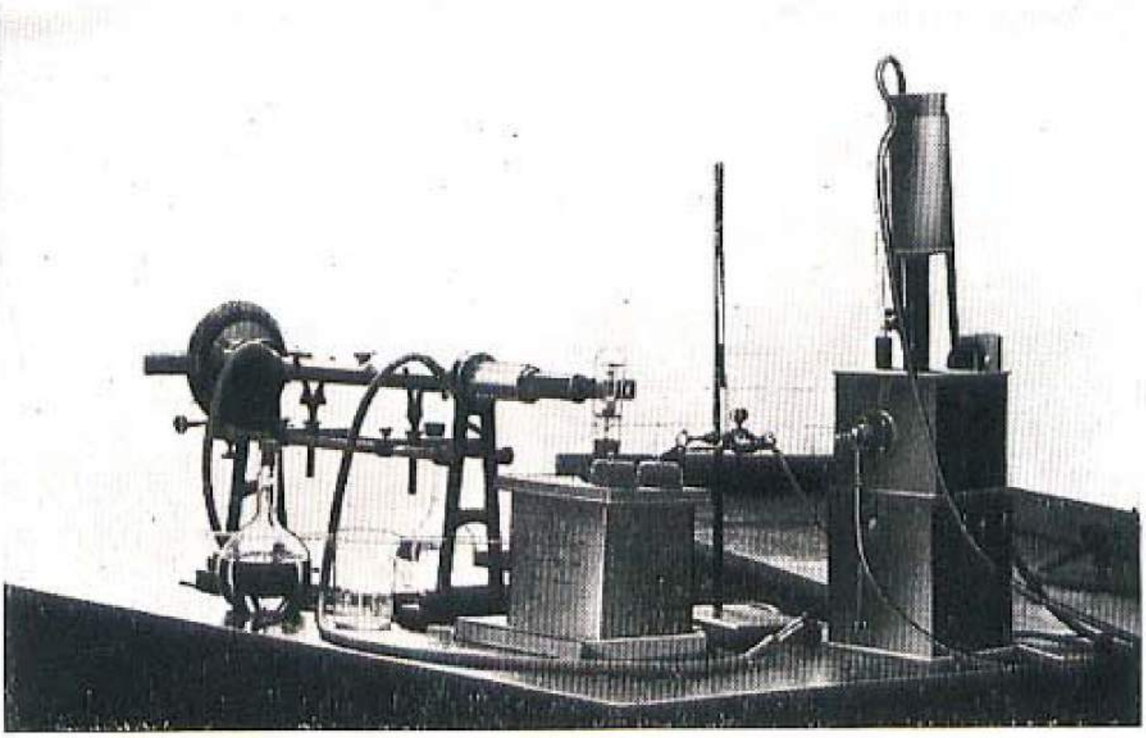


Fig. 61.

[To face page 23.

an exit and entrance tubes for the circulating liquid. A typical set-up of such apparatus is seen in Fig. 61; the apparatus on the extreme right being used for the temperature control of the liquid.

It might be anticipated that in experimental work conducted at room temperature, water supplied direct from the water-main after passing through a constant level device would be quite suitable for control purposes at that temperature. In actual practice, however, accurate temperature control within fine limits becomes impossible by this method, largely due to the fact that the comparative variations in the surroundings are too large, making some form of control not only desirable but essential.

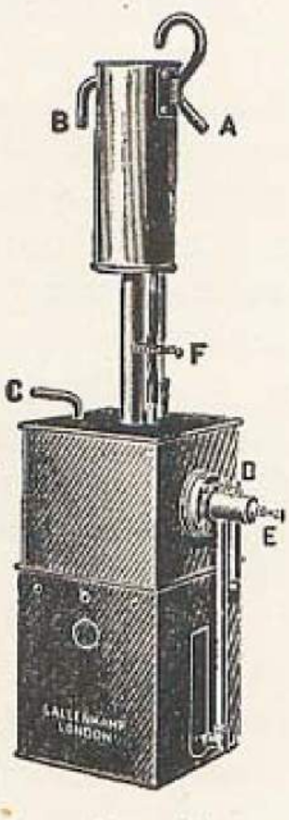


FIG. 62.

This auxiliary apparatus for ordinary or elevated temperatures consists of two parts; one part being a device whereby the temperature is maintained within the desired limits and range, the other a device for maintaining constant water level. A convenient form of this type of apparatus is made by Gallenkamp (London), being of the capsule regulation type; the assembly being shown in Fig. 62. The tube *A* is connected directly with the water supply, while *B* serves as a waste pipe. This ensures that a constant head of water is available at the given temperature. The reservoir contains a copper spiral, and is filled with water to about 1 inch from the top; *C* is connected by rubber tubing to the instrument in which constant temperature is desired. If no provision has been made for the direct measurement of the temperature of the latter, a glass T piece containing a thermometer should be inserted between *C* and the inlet pipe and as near the instrument as possible. The flow of water may be regulated by means of the screw clip *F*, while the gas supply is connected to the pipe situated below the screw *E*. The temperature is regulated as follows: The screw *E* is rotated to the left until the spring inside feels quite loose. By this means the capsule is allowed to expand and shut off the main gas supply, but allows just sufficient through the by-pass to keep the burner alight.

To increase the temperature of the water, and therefore the gas pressure, the screw *E* is turned to the right until the flame reaches the maximum height. Any regulation necessary for the by-pass burner may be made by the screw *D*. The temperature control should be obtained by adjusting the screws *D* and *E* until the correct temperature is attained. It should be noted that the smallest turn of the screw *E* will alter the temperature so that when near the desired temperature this screw should be carefully rotated.

Spectrometers and Spectrographs.—The first attempt to arrange temperature control for spectrometers was made by Perkins,[1] but recent work by Taylor and King,[2] and also Martin[3] provides a much more convenient and modern method of accomplishing this control. In order to avoid the expense of optical flats required for a thermostatically controlled heating chamber, which only encloses the prism, a design was developed which permitted the whole spectrometer to be enclosed, allowing only the collimator and the eyepieces to project through the sides of the thermostat chamber. Heating was carried out by means of two nichrome wire grids situated in front of two small electric fans placed within the chamber. The control unit connected to a relay, was mounted in the path of the air received from the fans. The unit shunted in or out a ballast resistance so that the rates of heating and cooling were about equal. The temperature of the apparatus was read by a thermometer inserted through the roof of the chamber, the bulb of the instrument being in direct contact with the glass prism situated on the spectrometer table. A spring on a shaft driven by the fan belt continually tapped the thermostat control and so prevented any sticking of the contacts. An arrangement of sliding doors or curtains was fitted to seal effectively the openings in the chamber necessary for the rotation of the spectrometer arm. With this arrangement the temperature was usually constant to 1/10th° C. the range being from air temperature to 65° C.

Shaw[5] when designing an ultra-violet stellar spectrograph employed a much more elaborate method of control than that described, the arrangement being shown in Fig. 63. The collimator, prism and camera were housed within a light steel

[1] *Jour. Chem. Soc.*, p. 288. 1892. [2] *Jour. Amer. Chem. Soc.*, p. 894. 1911.
[3] *Jour. Opt. Soc. Amer.*, 23, 308. 1933. [4] *Proc. Roy. Soc.* (A), p. 704. 1926.
[5] *Jour. Opt. Soc. Amer.*, 26, 273. 1936.

housing, in the top and bottom of which holes were cut, slightly larger in diameter than that of the fan blades employed to circulate the heated air. The fans were fastened to a steel spindle passing through the chamber, one end of which was further extended without the case, so that it could be coupled to a small electric motor for driving purposes. The inner case was then surrounded by the constant temperature case, which was constructed as a single unit except for one removable

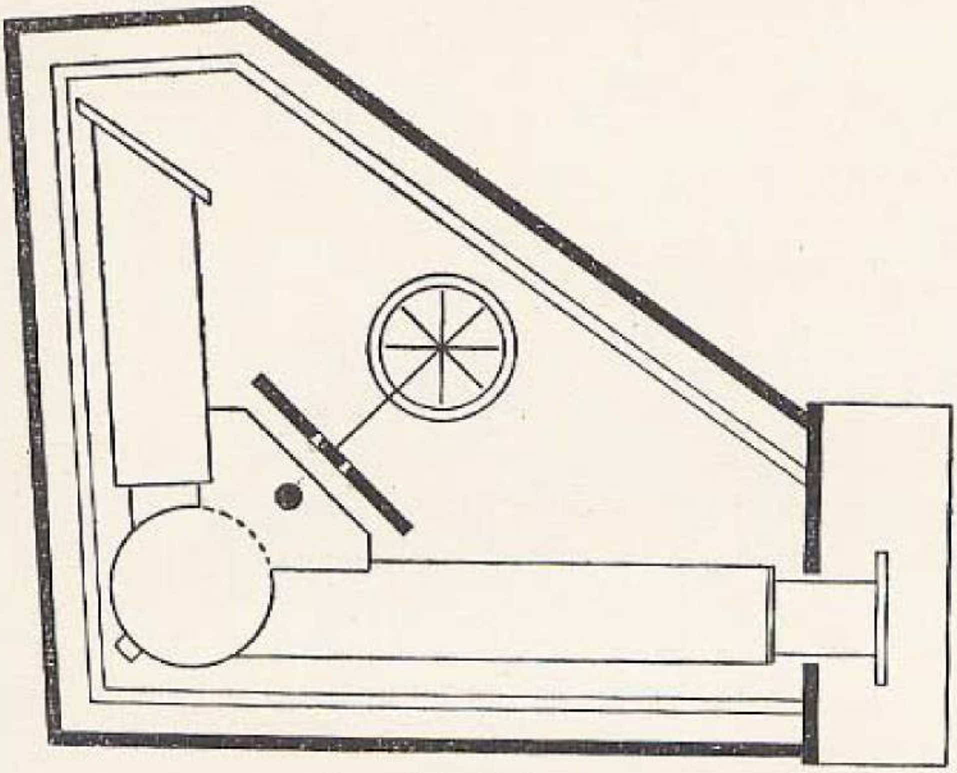


FIG. 63.

wall. The latter was made of insulite, a wood fibre board having very good thermal insulation properties, and covered with thick aluminium sheeting. The bi-metallic thermostat unit, the heaters and switches are arranged on this movable side, the heaters being of the flat grid form supported on porcelain insulators on the inside of the case. Flexible leads are employed to make the essential connections. In order that the air in the inner chamber housing the instrument shall have no temperature pockets or gradients, the fans are rotated very slowly for a considerable period before any readings are taken in order to obtain equilibrium. The temperatures as before are measured by means of a very accurate thermometer inserted through the housing and projecting through the outer case.

Microscope Stage Control.—For the control of microscope stage temperature, a commercial form of apparatus as shown in Fig. 64 is typical. The heating and cooling stage on which the specimens are mounted for examination is arranged so that carbonic acid may be circulated or the requisite amount of heat supplied by the internal heater unit. The latter is connected to the main supply via a resistance lamp, while the thermostatic control screw is fitted to the edge of the stage

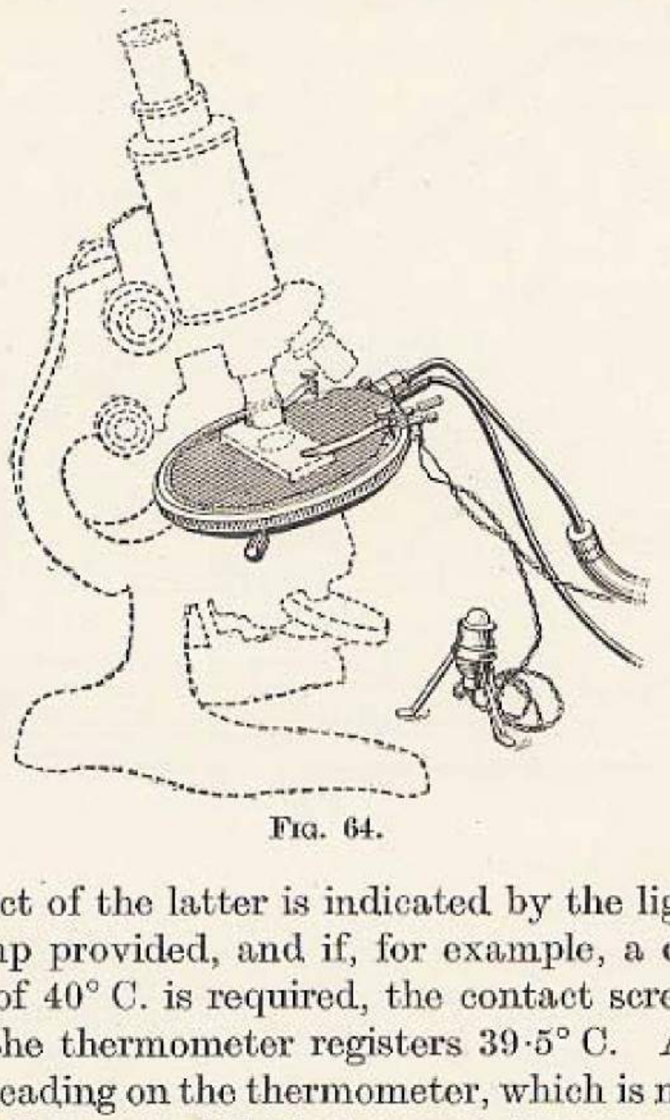


FIG. 64.

itself. Contact of the latter is indicated by the lighting of the signalling lamp provided, and if, for example, a desired stage temperature of 40° C. is required, the contact screw should be eased when the thermometer registers 39·5° C. After a short interval, the reading on the thermometer, which is mounted concentrically on the stage of the instrument, is again observed, and the setting of the regulator screw readjusted until the desired temperature is attained. The room temperature must be kept as constant as possible and the apparatus must be protected from draughts. Cooling may be effected by means of additional equipment in connection with the carbonic acid.

Mason and Rochow[1] have described a very useful arrangement for temperature control of a microscope stage, and

[1] *Ind. & Eng. Chem.*, 6, 367. 1934.

although the temperature may be as low as $-25°$ C. it may be maintained to within 0·1%. The cold stage *S* (Fig. 65), is made from a piece of aluminium $70 \times 100 \times 10$ mm., the upper surface of the plate being channelled and a second plate 3 mm. thick fastened to it, using a lead foil gasket *G*. An opening 19 mm. diameter is provided for the specimen and is recessed to take 25 mm. diameter windows. The channel thus formed

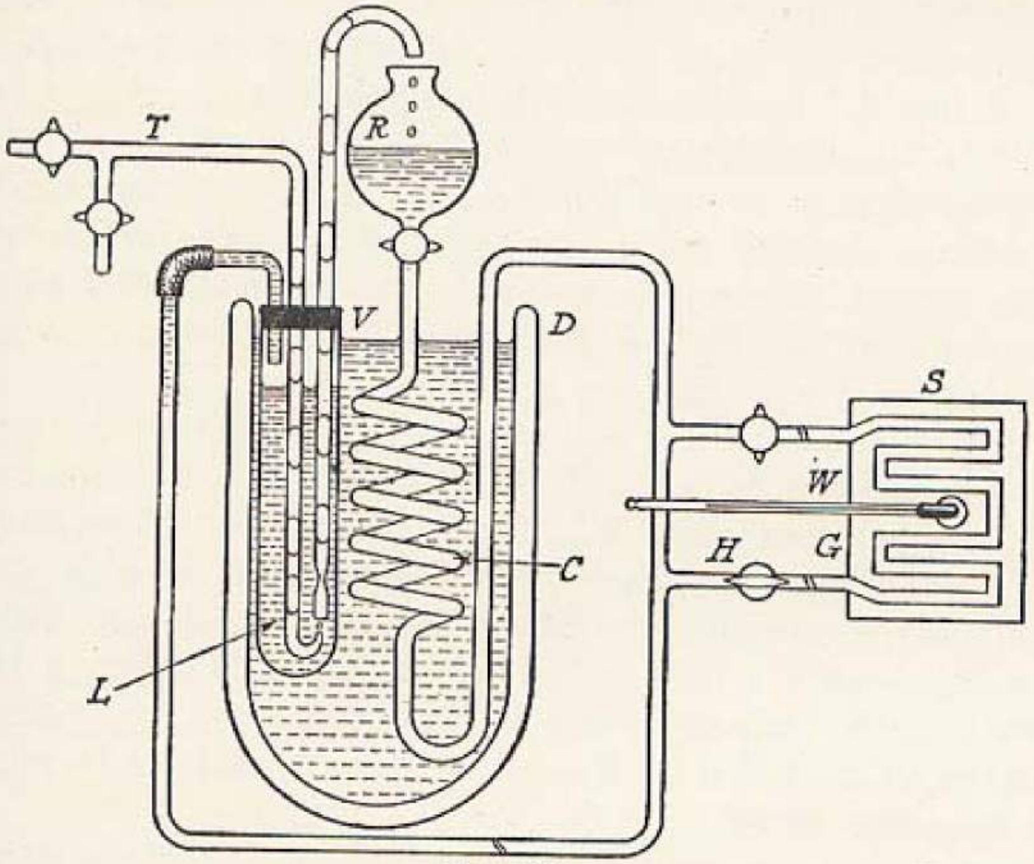


Fig. 65.

constitutes a circulating path for the freezing liquid ; a hole at *W* being provided for the insertion of the thermometer. The liquid is circulated by means of dry air passing into the air lift *L*, where the liquid from the cooling system is forced up into the reservoir *R*. From the latter the liquid flows into the cooling coil *C*, and thence to the cold stage *CS*, and through *H* to return to the air lift. The latter is constructed as follows : One end of a 6 mm. glass tube is bent into a curved nozzle with a 2 mm. opening. Another tube is drawn out 10 mm. from the end into a neck about 25 mm. long and 3·5 mm. diameter. The bent nozzle is inserted into the second tube at the lower end of its constriction. These are then passed through a cork and inserted into the vessel *V* which contains the liquid to be circulated. The cork also contains the two air lift tubes and another for the return line; finally, the whole should be effectively waxed to prevent air leakage.

The air admitted from a low pressure air line passed through a U-tube containing calcium chloride to the T-tube fitted with a stopcock. The T tube serves both as a safety valve for any liquid which may be sucked back if the pressure fails, and also as a means of draining the apparatus by applying air pressure at the top of the reservoir *R*. The latter is arranged about 50 cm. above the stage so as to provide a static head for the flow of liquid. In operation, air is admitted through the bent nozzle to the constricted tube at such a rate so as to cause alternate slugs of air and liquid to rise in the delivery tube to the funnel through which air escapes through the inserted thistle funnel. From the reservoir the liquid flows into the circulating coil of copper tubing 6·5 mm. diameter, wound into a spiral 4 cm. diameter and 16 cm. long. Both the coil and the air lift assembly are immersed in a cooling bath contained in a Dewar flask *D*. The cooling bath consists of acetone and solid carbon dioxide. The temperature is controlled chiefly by regulating the relative proportions of circulating liquid passing through the stage, and the shunt *H* which is across the outlet and inlet tubes, cocks being fitted in both tubes for this purpose. The assembly may be conveniently mounted on a wooden baseboard and held in position by means of a large iron stand.

The following are typical examples taken from the electrical branch of scientific work, one involving the measurement of the electronic charge and temperature control for use with a crystal oscillator. For the former, Laby and Hopper[1] found that it was necessary to maintain the temperature of the air in which the oil drop moved, uniform and constant and such that it has no motion due to convection.

In order to overcome this difficulty, a resistance thermometer was made by winding a single layer of copper wire around and in good thermal contact with the microscope condenser which forms part of the apparatus, the temperature of which it is desired to control. This coil forms one arm of a Wheatstone bridge, the other arms being manganin resistances. Any change in the temperature of the apparatus deflects the spot of light of the galvanometer connected to this bridge, which

[1] *Nature*, 143, 240. 1939.

when occurring in one direction falls on a photo-electric cell which operates a polarised relay. The latter then operates two 30 watt lamps placed on opposite sides of the instrument. The bridge is then adjusted to be balanced at a temperature a few degrees above the maximum temperature which the room attains every day. The lamps flash on and off every few seconds and maintain the external temperature of the apparatus constant to about ·002° C. The amplification of the galvanometer current by the photo-electric cell circuit is of the order 10^6.

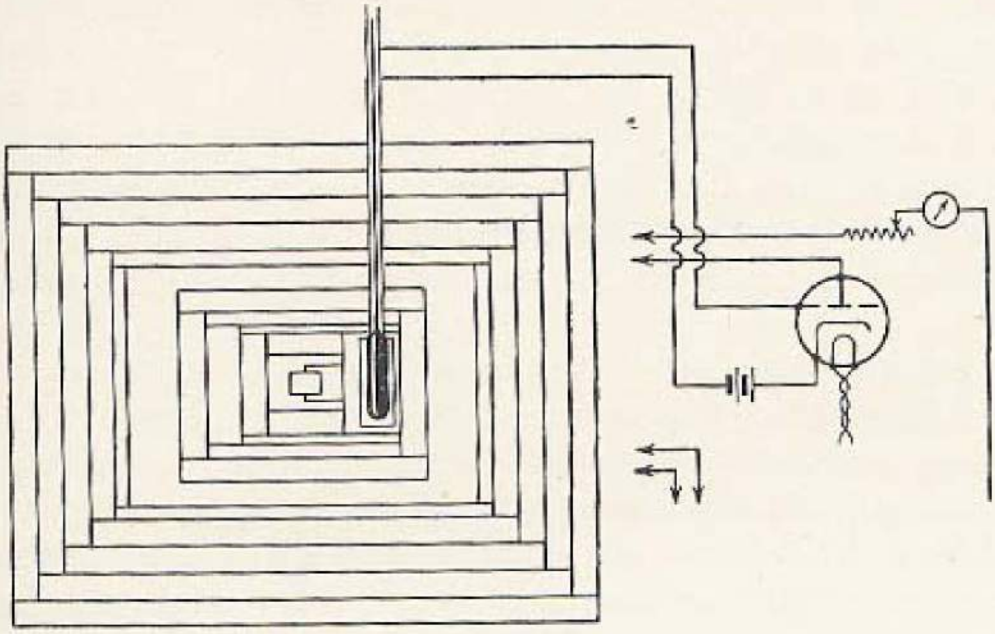


Fig. 66.

Piezo-Electric Oscillators.—A form of control employed in piezo-electric oscillators as devised by Booth and Dixon[1] is shown diagrammatically in Fig. 66. The crystal holder was mounted in a copper box of internal dimensions $6 \times 6 \times 3{\cdot}5$ cm. lined with a layer of celotex. The temperature was maintained constant by means of four heater mats, two being connected to a battery supply, and the remaining pair controlled by a contact thermometer through a mercury vapour rectifying valve. The bulb of the thermometer was fitted into a metal pocket sweated to the side of the copper box. The latter was then enclosed in a wooden box lined with a thick layer of celotex, and the whole housed in an aluminium box $28 \times 25 \times 22$ cm. lined with four layers of celotex. It was found that the outer insulation should not be less than one inch.

[1] *Jour. Inst. Elec. Eng.*, 77, 197. 1935; see also *Proc. I.R.E.*, 16, 976. 1928; *Proc. I.R.E.*, 18, 1239. 1930.

CHAPTER X

LIQUID BATHS

THE equipment required for thermostatic control consists of the sensitive heat unit, the controlled chamber, stirring apparatus and heater elements. The stirring and heater apparatus is somewhat of a different type for controlled air chambers, but many of the sensitive units previously described are applicable both to liquid and air baths. Their choice, apart from their cost, is largely determined by the materials available for their construction, and, in many cases, the auxiliary equipment desirable for their use. The sensitive heat units have already been described, and a brief account of the remaining equipment follows.

Container Design.—The design of the container will depend largely on the nature of the work in progress; the materials employed being glass or metal. The size of the container will be determined by the dimensions of the immersed apparatus, including the space occupied by the heaters, stirrers and control equipment. Whenever possible, the bath should be of generous proportions in order that it may have a large heat capacity, whereby the slight variations during the heating and cooling periods may take place in a regular manner, and sudden changes of temperature in the surroundings will not cause erratic behaviour of the control unit.

The metal largely favoured for this type of work is copper, which should be of ample gauge and strength to hold the bath liquid without undue sagging and consequent strain on the joints. The bath interior should be treated with a heat resisting enamel, while, in the case of gas heating, additional baffles should be provided between the burners and the tank bottom. For certain type work it may be advantageous to diminish the loss of heat as much as possible by polishing the exterior of the container to reduce radiation. It will be realised that liquids other than water are often employed for bath purposes, and possible chemical action with the materials of the bath should not be overlooked. Some of these are as follows :

Water	. . . . . .	0–100° C.
Kerosene	. . . . . .	0–75° C.
Lubricating Oils	. . . .	30–200° C.
Commercial vegetable oils	. .	100–300° C.

Various fused organic salts may also be employed for the range 200°–1,600° C.

Another important factor, especially in experimental work, is complete visibility. This may be arranged in various ways,

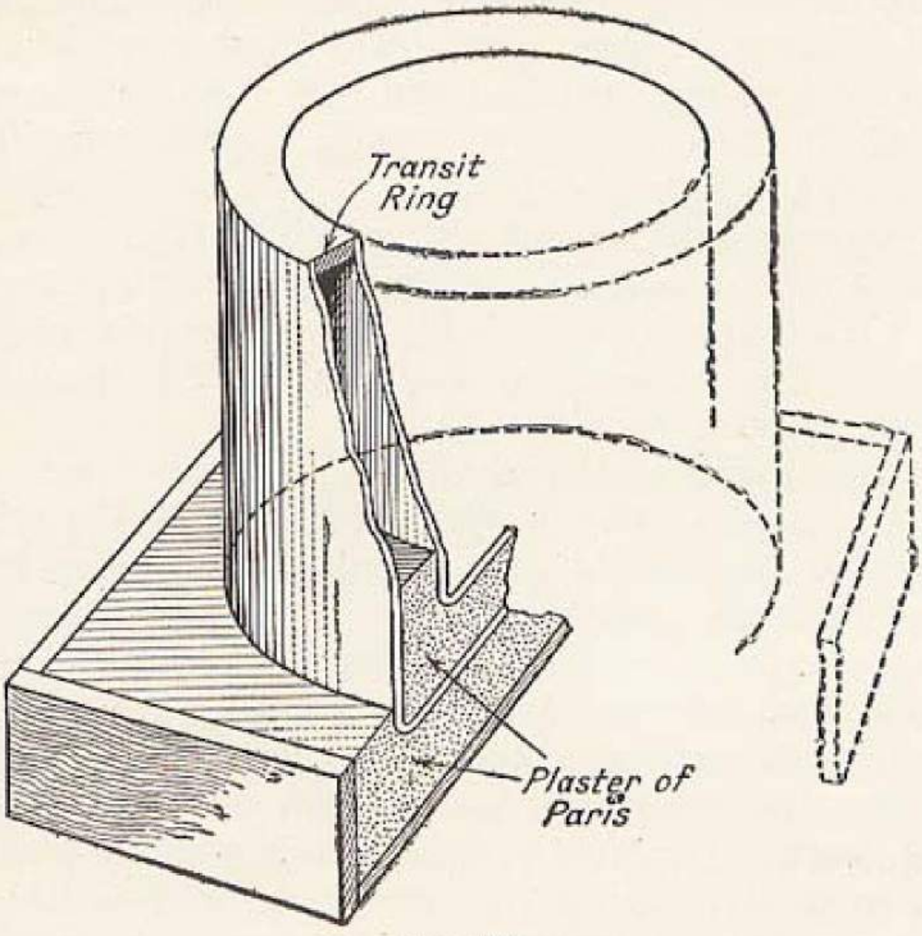


Fig. 67.

that described by Willihnganz and McGrew,[1] who employed it for temperature control of an Ostwald viscometer, being obviously of wider application. A pyrex jar, some 25 cm. diameter was inserted into a larger jar of the same material (Fig. 67), but isolated from the bottom by means of a thick Plaster of Paris ring of the same diameter as the inner vessel. The surrounding space between the pyrex jar and the large containing vessel was filled to the same height by a layer of asbestos. For the remaining portion of the jar no packing

[1] *Ind. Eng. Chem.* (Anal. Ed.), 6, 234. 1934.

material was used, the two vessels being held *in situ* by means of a circle of transit board situated at the top of the container. Finally, the apparatus was allowed to stand in a deep tray containing solid Plaster of Paris and the whole securely clamped by brass tie rods. The latter, when extended, also carried the stirring apparatus and the immersion heaters, which were capable of supplying 900 watts.

When an inspection window is desirable in the commercial form of tank, it is arranged by making one side of the vessel of channelled metal, of sufficient width to accommodate the desired thickness of sheet glass. The glass may be held in position by a paste of red lead and gold size, or litharge and glycerine. The latter, however, requires a much longer period for drying before it can be used.

Such arrangements are not always suitable, since, on occasions, it is often desirable to be able to remove the glass front of the tank completely in order to adjust the immersed apparatus. The following method enables this operation to be carried out with very little trouble.

Holes are drilled in the metal rim normally fitted to one side of the tank, so that bolts passing through the rim will just clear the edge of the glass when it is laid symmetrically over the opening. Leather washers are fitted beneath the bolt heads, which are inside the tank. A piece of rubber pressure tubing, through which is threaded a stiff copper wire, is applied to the metal rim between its edge and the bolt holes, the copper wire being bent to keep the rubber tube to the required shape. The ends of the tubing are cut to fit closely together somewhere along the upper edge. The plate glass is laid on the rubber tubing and pressed down to form a water-tight joint by means of small pieces of 4 mm. brass, 4 cm. long and 2 cm. wide. These brass pieces are drilled in the centre to be a sliding fit on the bolts and are forced down by nuts threaded on the ends of the bolts. The outer ends of the brass pieces are drilled and tapped to take 5 mm. cheese-headed screws, which bear on the metal on the tank and are adjusted to keep the brass pieces parallel to the surface of the glass. Little pads of leather are interposed between the brass pieces and the glass plate ; Fig. 68 shows the method of construction.

Stirring Methods.—In the design of liquid baths provision is made for installation of one or many heaters according to the size of the tank. Even so, the distribution of heater elements throughout the bath does not indicate that the heated liquid will be of constant temperature throughout. In practice, it will be found that this is far from the case, and if the liquid is explored with a sensitive thermometer, temperature gradients will readily be discovered. These are more pronounced in the region of heating, and, in order that this effect may be neutralised to a large extent, some method of circulating must be employed. Accordingly, baths are fitted with various types of stirrers, the design varying with the specific purpose and the size of the container.

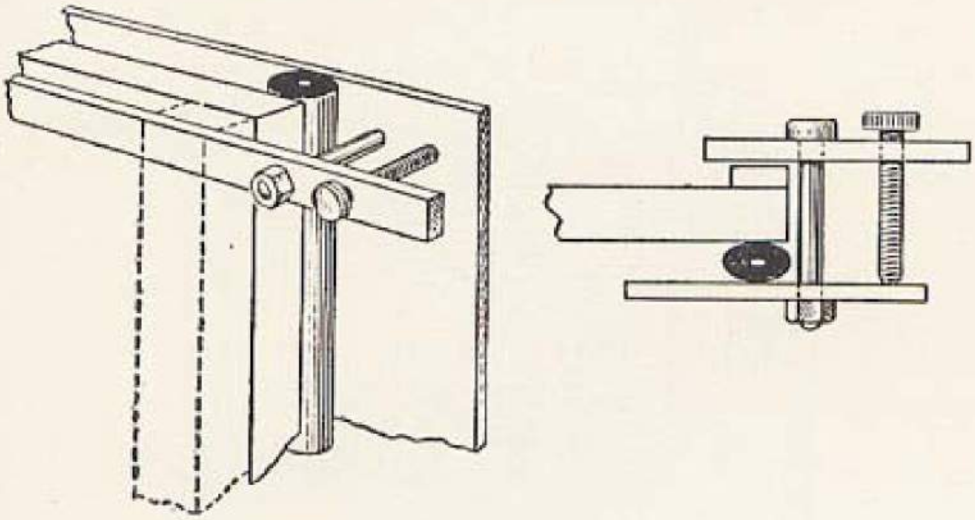


FIG. 68.

The method of stirring requires careful consideration, in order to avoid certain portions of the bath becoming stagnant through the absence of circulation, for not only must the liquid in the immediate neighbourhood of the stirrer be well mixed, but its action must effect the extreme portions of the bath. Experience indicates that such stirring is specially important during such time as the heater is supplying heat. In order that the mixing should be thorough, and to ensure that equilibrium of temperature has been obtained, the bath should be explored by a sensitive thermometer to detect any such differences. It should be remembered, however, that rapid local variations may occur, because of the lag between the occurrence of temperature change in the bath and the compensating change in the heating supply. This may, of course, be minimised by installing an efficient and most suitable form of heat control for the apparatus in use. In practice, it is possible to avoid extreme differences of temperature by the employment of a number of unit heaters, rather than concentrating the heat source at one spot. In this way the heaters tend to make the stirring effect much more rapid and efficient. Whatever the form of stirring employed the action should be such that it is just sufficient to produce wavelets or floating bubbles; violent action should at all times be avoided. Circulatory motion, however, can be assisted somewhat by the employment of different types of containing vessel, that shown in Fig. 69, proving very effective. The vessel is constructed of sheet metal, with a ∞ shaped section,

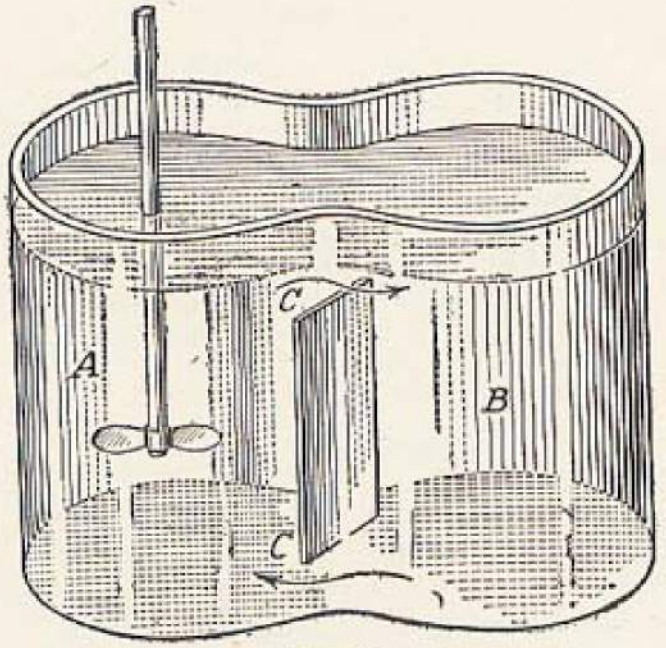


FIG. 69.

the stirrer of propeller form being contained in *A*, which is connected to the section *B* by the passage *CC*. By means of this shaped vessel and the suitably positioned partition, steady and smooth circulation of the liquid is possible, but particular care must be given to ensure that the spaces *CC* are such that restriction of the circulating liquid is not possible.

For large baths screw propellers are generally employed, which, while producing rapid circulation of liquid, will also produce ample mixing, provided a sufficient number of propellers are used. The best arrangement is to locate them so that the liquid shall be drawn from the top of the bath, pass the heating coils, then around the propeller, where it is thoroughly mixed, and finally discharged in the neighbourhood of the regulator bulb and into the bottom of the tank. In this way

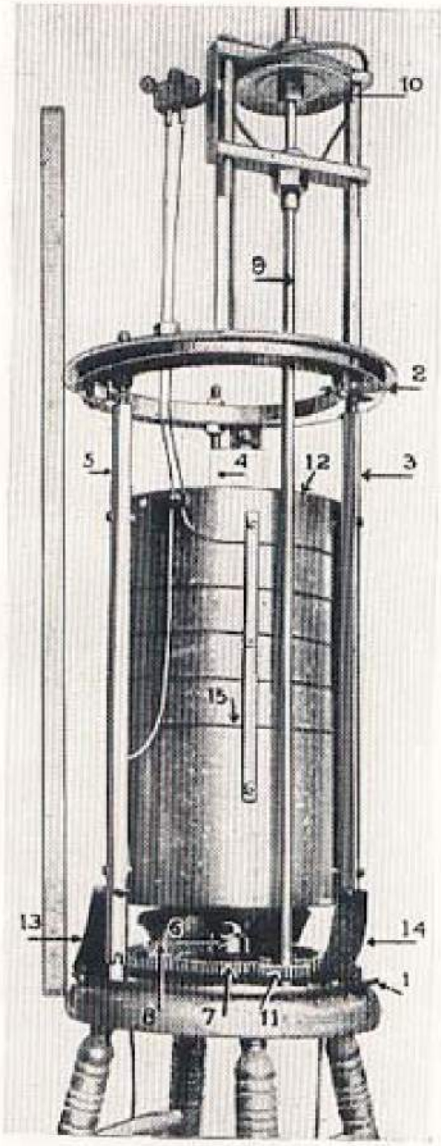


FIG. 70.

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a maximum response of temperature change is secured which is essential to precise control.

Collins[1] has described a very useful arrangement for the circulation of water in a cylindrical tank, the arrangement shown in Fig. 70 permitting the maximum space to be available for equipment. The unit was carried on an iron disc (1), and a ring (2), held apart by means of three rods. The spindle attached to the plate (1) carries a spur gear, of pitch diameter 10 inches and $\frac{1}{2}$ inch face and also an impeller (8). The latter is made of sheet iron $\frac{1}{2}$ inch thick. The drive shaft (9) is carried by three bearings, and fitted by its lower end is a pinion which drives the spur gear (7). This has a pitch diameter 2 inches and $\frac{1}{2}$ inch face. The cylinder, some 10 inches diameter and 18 inches long serves chiefly to guide the liquid in an orderly circuit. The centrifugal action of the impeller causes the liquid in the thermostat to move under some pressure and with considerable velocity into the annular space between the cylinder and the walls of the container. In order to assist this action further curved runners (13) and (14) are inserted in the most suitable position. The liquid having passed through the angular channel, spills over the top of the cylinder and flows downward through it. Fitted at the lower end of the cylinder is a stationary vane, consisting of a strip of iron 2 inches wide placed along the diameter and twisted so that its ends make an angle of 90° with each other. This twist is such that the spinning column of liquid is deflected into the impeller rather than away from it. The heater arrangement consisted of a number of turns of nichrome wire, 22 S.W.G. drawn into a steel tube and suitably insulated. It was found that good regulation was obtained when the propeller revolves at such a speed that the bath liquid passes through the tube three or four times per minute. A great advantage of this form of mixer is that the liquid is forced to the extreme and outlying parts of the bath.

Another arrangement used when large bulks of liquid have to be mixed is the paddle form of stirrer, but while mixing thoroughly the smaller portions of liquid, it does not produce a positive circulation of the liquid.

Fig. 71 shows a modification of the same idea. The vessel is arranged having two bearings diametrically opposite and

[1] *Rev. Sci. Instr.*, 10, 502. 1936.

having a rod passing through them of the shape shown in the diagram. Fixed at *B* is a suitable driving pulley, while *AA* are metal plates attached to the crank *C*. On the rotation of *B* the paddles move backwards and forwards, and also have vertical motion. Circulation can be somewhat improved by bending the ends of the metal plates as shown.

Miniature Stirrers.—The foregoing methods are specially suitable when large quantities of liquid are involved, but if the containers are of small dimensions, the design of the stirrers will have to be considerably modified.

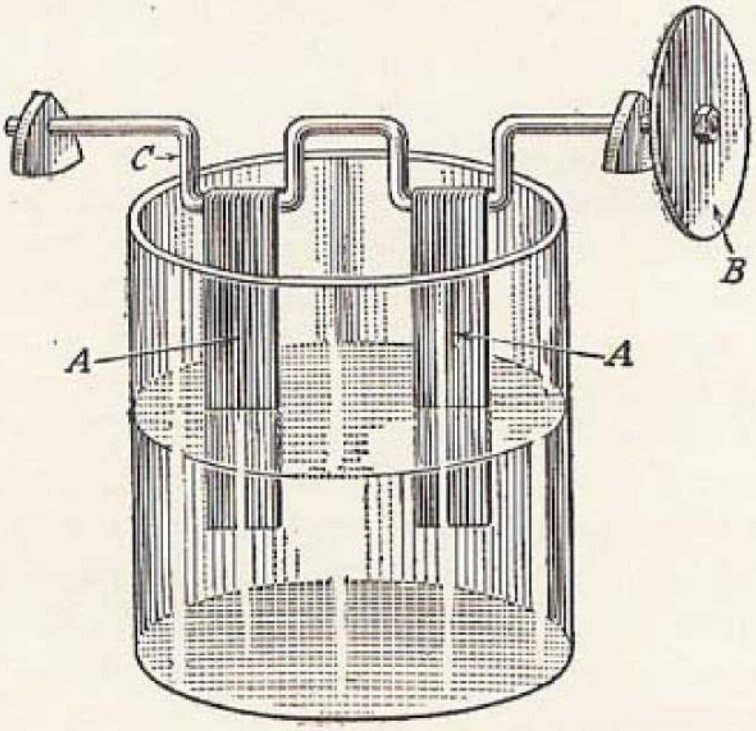

FIG. 71.

One of the simplest type is that shown in Fig. 72*a*, where a piece of glass tubing of internal bore 3–5 mm. is bent as shown, and has a hole blown at each end. The tube may be conveniently fitted to the shaft of an electric motor. The Witt stirrer (Fig. 72*b*), is an improvement on the former type, a bulb replacing the bent tube. By means of a circulatory motion, the liquid contained in the bath is drawn in through a hole at the end of the bulb, and thrown out again at the sides. If stirring is necessary in a very confined space, such as a test-tube, a number of metal rings fastened to a hole in an extended shaft will be found very useful. This stem may be projected and made to terminate in a piece of iron which is placed central relative to a magnetising coil; the latter is operated by a "flasher" connected to the mains supply.

In the Dupre type of apparatus, two glass stirrers (Fig. 73) are so arranged that the shaft of one stirrer passes through the hollow shaft of the other. Attached to the end of each shaft is a pulley for driving purposes. The mixing fans are so arranged that they are in close proximity to each other, and with the direction of fan twist in opposite directions. The rotation of the blades is in opposite directions and by

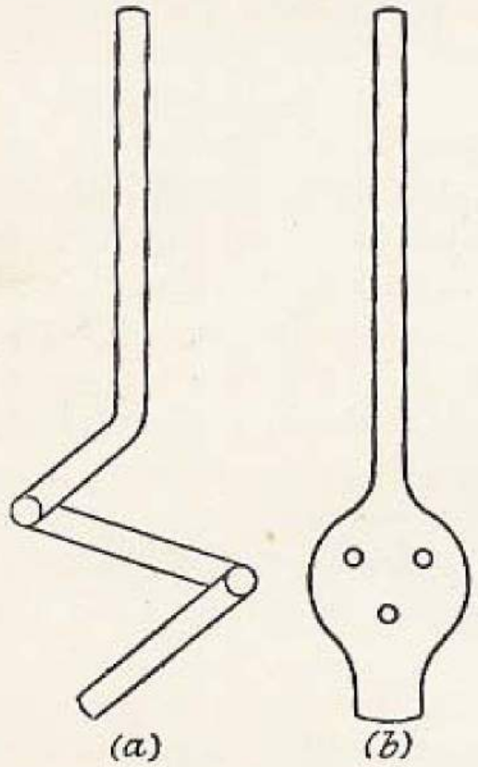

FIG. 72.

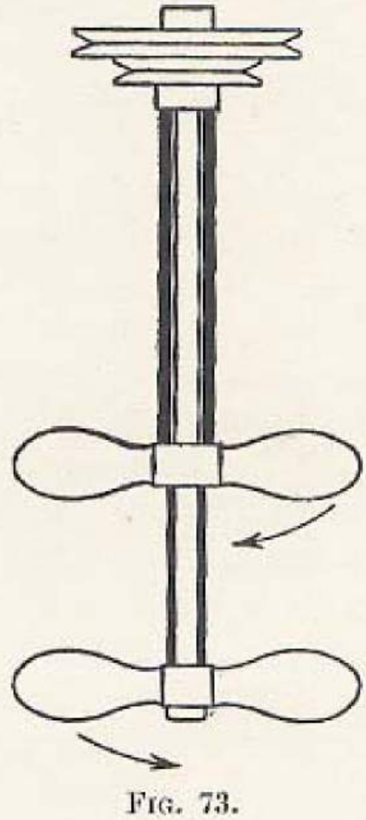

FIG. 73.

this arrangement thorough mixing is obtainable while circulatory motion is absent. In a case where the bath space was very limited, two fan blades fixed rigidly to one shaft were employed and rotated at high speeds. Unfortunately, while the circulation of bath liquid was satisfactory, the wave motion was very disturbing to the apparatus situated within the bath. By the provision of a cylinder of perforated zinc placed around the two fans as so to enclose the blades, adequate circulation was readily obtained while the wave motion was considerably damped.

A commercial stirrer of an efficient type is marketed by Griffin and Tatlock, under the name "Moritz Turbo-Stirrer," obtainable in four different types as shown in Fig. 74. These are known as agitator, emulsifier, projector and reactor stirrers, each being designed for a particular purpose. In the agitator pattern, the vane shaped blades are distributed on the periphery of a stationary crown surrounding the propeller, but while the mixing is extremely efficient, when the stirrer is operated at high speeds vertex effects are produced which may be disturbing for some type work. By the substitution of the emulsifier type this may be somewhat diminished, and is accomplished by replacing the stationary diffusing crown of the former type by another form of crown carrying a fairly large number of cylindrical studs instead of blades. In this case the liquid being thrown out by the impeller meets the studs and is divided and dispersed, or produces a greater number of streamlets which make for more efficient mixing. The reactor type consists of an impeller revolving between the stationary crown as described above, but having in addition to the blades a number of studs, which increases the possible stirring efficiency . The projector and turbo-reactor types may be suitably employed where the bath liquid is of a very viscous nature. The component parts of this mechanism may be obtained in mild steel, monel metal, brass or bronze, rubberised steel, aluminium or alloys and in bakelite. These stirrers are obtainable in sizes suitable for use in laboratories and also for large scale industrial processes.

Heat Sources.—The heat source for the baths may be either gas or electricity ; the latter finding increased application due to its cheapness and convenience in use. With gas burners, the familiar laboratory bunsen burner requires modification, the diameter of the gas inlet being far too large for this type work. A very simple method may be employed when the tank is of small dimensions (of approximately 1 cubic foot capacity and operating at normal temperatures), when the projection tube of the burner, together with the adjustable air control may be removed, so that the burner operates as a small, smoky flame. Unfortunately, with gas burners the methods of temperature control are somewhat limited, being confined to the use of pressure, expansion of liquids and solid devices. But wherever such burners are employed, metal baffles should always be fitted between the tank and flame in order to prevent deterioration of the tank bottom on heating.

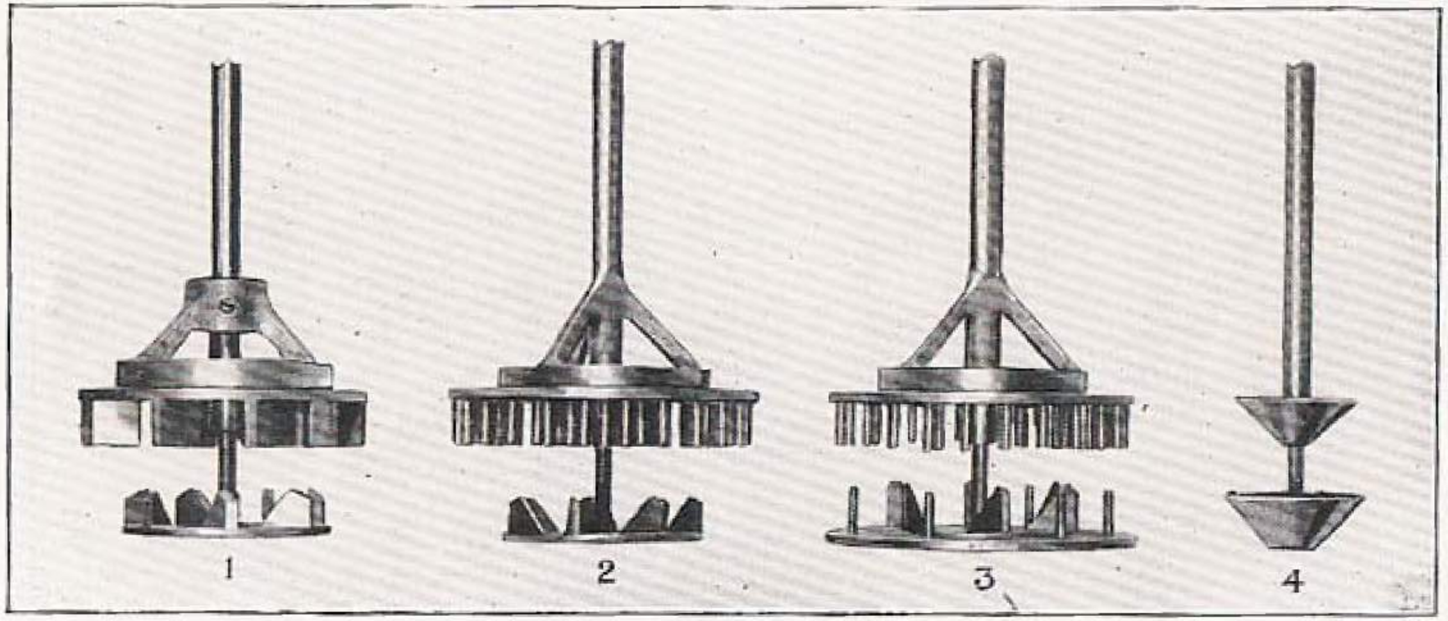

FIG. 74. MORITZ STIRRERS.

Turbo-Agitator (Fig. 1). For intimate mixing.

Turbo-Emulsifier (Fig. 2). For emulsification.

Turbo-Reactor (Fig. 3). For breaking up clotted or lumpy substances within a mass or to dissipate two immiscible liquids within one another.

Turbo-Projector (Fig. 4). For projecting liquids into a gaseous atmosphere, to increase area of contact, accelerating chemical reactions or evaporation.

[To face page 98.

Undoubtedly the use of electricity offers greater scope both in control and design than gas, and the methods are far more adaptable. One method of electrical heating employs tubular lamps, of the form employed in the early type electric radiator, but, while for this purpose they have fallen into disfavour through fragility and inefficiency, on the other hand they make excellent heaters for liquid bath purposes. When so employed, however, lead collars should be fitted to their stems to make them more stable when immersed in the circulating liquid. They are fitted with standard bayonet caps and rated at 250 watts.

Heating may also be carried out by means of resistance wire immersed in the liquids, nichrome being generally employed; leads from the wire being taken to the main electrical supply. In order to ensure long life for such an arrangement, and to avoid electrolytic corrosion at the junction of the wire and terminals, the elements are suitably encased. In the blade type immersion heaters, the heater element is in the form of nichrome tape wound on a mica frame, sandwiched between mica protecting sheets before being inserted into the case. The purpose of the latter is to prevent the elements shorting across the outer casing. The cylindrical type consists of nichrome spirals placed longitudinally in a suitable refractory, inserted in a grey cast iron frame. The mounting is then insulated in an outer case of welded copper or galvanised steel, the interspace being an aluminium and silicon alloy.

It will be appreciated that, in order to conserve bath space, "blade" type heaters should be fitted. These are obtainable in straight or circular form, fitted with patent plugs for ease of fitting, and also to ensure that the heaters are watertight. It should be realised that in order to improve control of bath temperatures, the heating elements should be evenly distributed over the bath area as much as possible. Thus, if it is desired to heat a bath of great length, it will be far more advantageous to employ a number of heaters, with the load distributed among them, than to use one large heater with the full load. This tends to accomplish a more uniform heating of the bath liquid than if one heater only was employed. When fitting blade type heaters, they should lie in an horizontal place and as near the bath bottom as is practicable. For the heating of corrosive liquids special forms of protection must be employed, and generally Vitrosil is found the most suitable. This material may be obtained from laboratory furnishers or from the Thermal Syndicate Co., who manufacture it in all sizes and shapes.

In selecting the necessary heater for this purpose a certain margin must be allowed for extreme variations both in the desired temperature of the bath and the possible temperature fluctuation of the surroundings. The heat unit employed is the B.Th.U. (British Thermal Unit) and is the amount of heat required to raise the temperature of 1 lb. of water 1° F., but if the unit weight selected be the gramme and the temperature scale the Centigrade, the heat unit is called the caloric. The latter, however, is more generally employed in scientific work. The electrical unit is the kilowatt and one unit of the latter for one hour is one kilowatt hour, also one kilowatt hour is equal to 3,412 heat units.

Thus the required number of electrical units for the heating of a mass of water is given by :

$$\frac{\text{lbs. of water} \times (\text{desired temperature} - \text{temperature of surroundings } ^\circ\text{F.})}{3{,}412}$$

By the terms of definition of the B.Th.U., 1 lb. of water requires that quantity of heat to raise its temperature 1° F., but if that quantity of heat is used to raise the temperature of 1 lb. of copper, the rise will be greater than 1° F. Similar results are obtained with other substances, and it is found that the quantity of heat so required to raise the temperature through 1° F. is proportional to its specific heat. Thus when a liquid other than water is employed for bath purposes this value must be taken into account. Accordingly the formula becomes :

$$\frac{\text{lbs. of water} \times \text{specific heat of liquid} \times (\text{desired temperature} - \text{temperature of surroundings } ^\circ\text{F.})}{3{,}412}$$

CHAPTER XI

AIR BATHS

THE design of a temperature controlled room will vary greatly with the purpose in view, and the available facilities both in respect of equipment and cost. In many cases, the chamber will be of comparatively small dimensions, involving little expense or construction. On the other hand, its size may be such as to need expensive building materials, which must have good thermal insulating properties. If an existing room within a building is available, it may frequently be adapted for this purpose with but little expense ; if the choice lies between a room well within a building or that partially exposed to external conditions, preference should be given to the former. This is advisable, since there is likely to be considerable changes in the outside temperatures and thus cause a greater dissipation of heat through the walls to the outside, than if the walls are connected to the inside of a building.

An ideal arrangement, although not often readily available, is a cellar, since the surrounding earth serves as an excellent insulator, whilst the deeper the room, the less likelihood of temperature variations caused by fluctuations in external conditions. The determinant factor generally in the design of such a chamber is primarily one of cost. The choice of material to prevent the loss of heat will depend on its thermal conductivity coupled with its cost, and it is only reasonable to suppose that efficiency in this direction will be governed by cost. Further deficiency in this direction will mean a greater amount of heat will have to be supplied to the chamber in order to maintain its temperature equilibrium. So that considering a chamber having walls of good thermal conductivity, or a wall having a thicker insulation but of poorer quality, the ultimate factor will be the cost of heating to compensate for the poor insulation. Thus a balance has to be struck between the cost of additional insulation and the cost of heating required to obviate the necessity for it.

Thermal Insulators.—The choice of materials will depend on the purpose for which it is employed ; for a large size room, brick is preferable, although wood may be utilised provided it is suitably insulated. For an already existing interior room, generally the walls need thermal insulation, and some form of air lock is essential for means of access. In the case of small chambers situated within a room, wooden or metal containers insulated thermally are sufficient. The insulation may be insulwood, cork, celotex, slag wool, expanded rubber, and for the construction of doors, Balsa wood may be employed. The latter, however, is rather soft, and in practice it is preferable to use an ordinary constructed door, with a facing of this material. Both insulwood and cork are available in panel form which makes for ease of fixing. These insulators may receive a coating of plaster if necessary after fixing, in order to enhance their appearance.

The best form of insulator to employ is, of course, a vacuum and the next best, a gas such as air in a perfectly still state. It must not be assumed however that a simple air space between two walls is a still air space, for it will be found that convection currents circulate within it, and increase the transmission of heat from one wall to the other wall. Thus in designing air controlled chambers, an endeavour should be made to reduce such heat losses to a minimum, and the function of such materials as granulated cork or expanded rubber, is to subdivide the air space, so that convection is greatly reduced. On the other hand, the presence of thermal insulation in the neighbourhood of the walls greatly reduces the transmission of heat by direct radiation.

It has been suggested that the value 0·29 B.Th.U. per square foot per hour per inch thickness for 1° F. difference of temperature between the faces may be taken as the thermal conductivity of an insulator of good quality. This value then will serve as a guide to the choice of such materials for thermal insulation.

It will be found that finely granulated cork, after baking to a dark brown colour, is a much better insulator than the raw material. Cork wool or shavings is another good insulator, but must be carefully protected from access of moisture. Slag wool or silicate of cotton may also be employed, but close packing should be avoided, since it will tend to become a relative good conductor. Sheet rubber is not very efficient, but with cellular expanded rubber, i.e. a material made up of an assembly of minute air cells bounded by membranes, excellent results are obtainable. It should be remembered that whatever selection is made, it is essential that the material shall not readily absorb moisture, since apart from its inferiority for thermal insulation, it is also liable to set up decomposition in organic substances.

Two forms of expanded rubber are available, Onazote and Rubazote, the latter being of the resilient variety, of thermal conductivity 0·19 B.Th.U. It may be obtained in a variety of forms, such as wooden faced panels, gaskets for sealing doors and windows, cylinders for pipe insulation and in sheet form. The manufacturers are the Expanded Rubber Co., Croydon. Insulwood is another useful material, being of a wood cellulose composition and made by the Patent Impermeable Millboard Co., Sunbury-on-Thames. This material may be used as a covering directly in contact with brick or woodwork, with or without a protecting coat of plaster, or may be used directly as a wall itself. It may also be used as a roof or ceiling, a covering of bitumastic or asphalt being used as a weather protection. For cementing to brick or plaster a special bonding cement, No. G5688 Line Cement, made by Messrs. Goodlass Wall & Co., Langham Street, London, should be employed. The edges of each panel should be brought into close contact and a strip of the same material should be glued either behind the joint or on the face.

If we assume that the quantity of heat flowing into the wall through one face is equal to that flowing out from the wall, none being absorbed or given up by the intervening material, the quantity of heat passing through the wall is proportional to the difference in temperature between the faces. This quantity also depends on the nature of the material of the wall, and for every material there is a value, " *K*," known as the thermal conductivity. The unit of conductivity may be defined as the number of British Thermal units which flows per hour, per square foot, per inch thickness, per 1° F. difference of temperature between the faces. This value for various materials and different methods of construction are given in Tables 8 and 9, which have been supplied through the courtesy of the Patent Impermeable Millboard Co., Sunbury-on-Thames, and this heat loss for wall area of the chamber will have to be compensated for when calculating the heater sizes for a given room.

The heat loss by conduction through a plain wall is then

$$K A t \frac{(\theta_1 - \theta_2)}{L}$$

where A = area of walls in square feet ;
K = the thermal conductivity of the material of the walls, in B.Th.U. per hour ;
θ_1 = temperature of hot face of wall in ° F. ;
θ_2 = temperature of cold face of wall in ° F. ;
L = thickness of wall in inches ;
t = time in hours.

TABLE 9.

THERMAL CONDUCTIVITY OF MATERIALS.

Material.	B.Th.U. / Sq. ft. / hour / for 1 inch thickness and for 1° F. difference in temperature.
Slab cork (naked)	0·21 to 0·41
Cork wool (packed 3·3 lb./cub. ft.)	0·21
Charcoal	0·34
Slag wool or silicate of cotton	0·29
Rubber sponge sheet	0·37
Pitch pine (across grain)	1·05
Teak (across grain)	0·81
Oak (across grain)	1·10
Deal (across grain)	0·81
Spruce (across grain)	0·70
Three-ply	0·96
Balsa wood	0·32
Glass fibre mats	0·27

Attention should also be given to the floor, especially when the building is exposed to outside weather conditions, and it should be of the greatest thickness permissible. Portland cement is the best material, and a minimum thickness of six inches should be regarded as essential. When, however, this is not possible, and a raised wooden floor is employed, some form of heat insulation is desirable ; particular attention being given to the elimination of any possible crevices due to faulty jointing. This is also applicable to floors of existing rooms, since, with the usual form of floor construction, a large air space is always present under and between the joists. Thick linoleum may be employed for this purpose, or where expense is no object, the existing floor may be covered with plywood of

TABLE 8.

Values of K—Heat transmitted in B.Th.U./square foot/hour/1° F. difference between wall faces for various materials.

Description of work or material.	Total thickness (inches).	"K"	As described with the addition of: One thickness of plaster ½"	One thickness insulwood ½"	½" plaster each side. 1" total thickness.	½" insulwood each side.	½" insulwood and ⅜" plaster.
Ordinary brick wall—sand lime bricks in cement mortar	9	1·03	·87	·41	·76	·26	·40
Cavity wall—sand lime bricks in cement mortar headers spanning cavity	9	·80	·76	·38	·66	·25	·36
4 in. Gravel concrete—4 in. breeze concrete with 2 in. cavity and galvanised iron ties . .	10	—	·46	·29	·43	·20	·27
Concrete wall—coke breeze 4, cement 1½ . .	9	—	·43	·27	·40	·20	·27
Portland stone 4, sand, 2, cement 1 . .	9	—	·58	·33	·52	·22	·33
Timber construction—¾ in. weatherboards, 1 in. rough boards, 4 in. × 2 in. studs and 1 in. lath and plaster	6	0·40	—	—	—	—	—
Ditto, but without 1 in. boards and 1 in. lath and plaster, but with 1 in. Insulwood each side	5	0·15	—	—	—	—	—

suitable thickness, and the junction between floor and the walls covered with a beading.

The presence of windows is not altogether advantageous, in fact these may be easily eliminated, since adequate illumination may be obtained by using internal lighting. For some purposes, however, observation windows are essential; they should be double-glazed with window glass, and care taken to ensure that the spaces between the glasses are air-tight. This has two advantages; it eliminates the possibility of condensation forming between the glasses, and also, the intervening air space will serve as an insulating medium.

Heater Design.—There are two classes of heaters available for heating purposes; radiator and convection types. The former, which are usually fitted with reflectors, dissipate their heat by radiation. Electric fires and panel heaters constructed with their elements encased in refractory materials are examples of this form of heating. The second type is the convection heater, which consists of a nichrome wire wound on a special former and enclosed in a perforated metal case. Air comes into immediate contact with the elements, which on heating set up convection currents, which by circulation warm all parts of the room. These heaters may be constructed by winding nichrome wire on a frame of solacite, uralite or hard asbestos sheeting. Commercial forms of this heater are available having wattages of 250, 500 and 1,000. A convenient position for erecting is some 18 inches from the floor, and projecting some distance from the wall, but in order to avoid temperature gradients, the positions should be carefully chosen. These gradients will, of course, be greatest in the vicinity of doors and windows, and, in order to compensate for this, heaters should be placed in these regions. For this reason, although the initial cost will be slightly increased, it is preferable to subdivide the heater system into a number of smaller units, each one being fitted with a switch. The latter will then permit the inclusion or exclusion of heaters as required. For positioning, when windows are present, a heater should be placed beneath it, and for doors, on either side of the entrance. For calculation of the required heaters, the formula on page 100 is used, the specific heat of air being 0·23, and specific gravity 0·0012. Allowance should be made for heat loss through the walls and ceiling.

It should also be remembered that when erecting the selected control unit, it is important not to fix the sensitive portion nearer than $1\frac{1}{2}$ inches to the wall. This is important since it will be found that the temperature within this area is not identically the same as that in other portions of the chamber.

In order to prevent temperature gradients, an air lock should be provided, since, though the door may only be opened on occasions for a comparatively short period, influx of cold air will be sufficient to disturb temperature equilibrium. This will be increased further if the heater system has no safe working margin, so that a long period must elapse before equilibrium

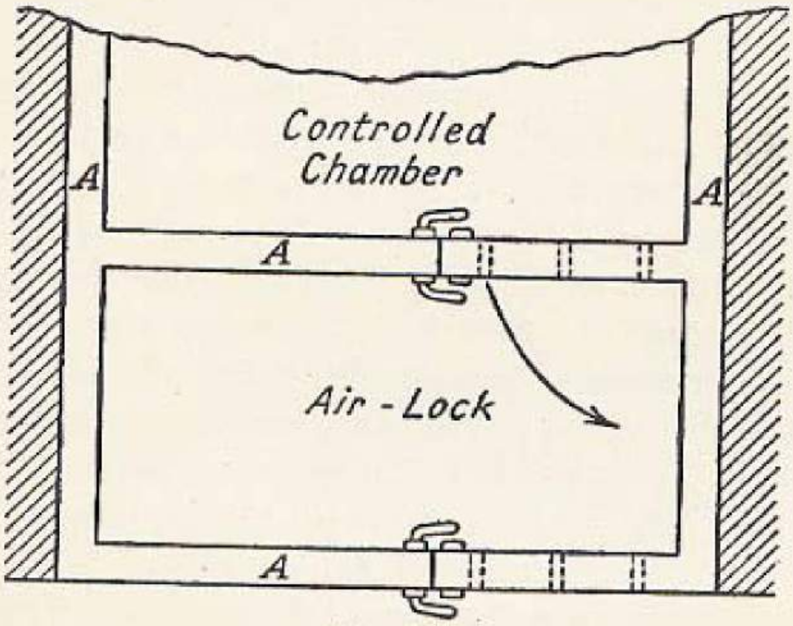

FIG. 75.
A = Heat insulation.

is once again attained. Such an arrangement to prevent the free access of cold air is shown in Fig. 75, but will have to be modified to suit individual requirements. Apart from the actual air lock, it will be a distinct advantage to arrange that the chamber door jambs are chamfered, so that it makes a very tight fit. The thorough agitation of the air is extremely important, if "stratification" or variation of temperature at different heights is to be avoided. This may be accomplished by the use of electrically driven fans, which may be one of two types, the disc or propellor form, and the centrifugal or paddle wheel type. The former consists of a set of radial blades which drive air forward on their rotation, in a direction parallel to the axis of rotation. The blades may be flat or curved and should be run at high speeds; they are employed when small pressure is required and a large amount of air has to be moved.

The centrifugal or paddle wheel type is largely employed where constant change of air is necessary, the air being extracted by means of centrifugal force. This type fan is so arranged that together with its framing it is rigidly clamped over an opening in the chamber wall, as near the ceiling as is practicable.

Ceiling fans operate at much lower speeds than the former, and in order to produce an equal agitating action the blades are constructed with a larger sweep. This, coupled with the fact that the blades are increased in number, causes the air to be kept in motion over a large area. No definite ruling can be given regarding fan fixing, since conditions vary with every type of control chamber, making it rather a matter of experiment for the determination of the best position. This may readily be found by altering the position of the fan, and exploring the various positions of the chamber by means of a sensitive thermometer. Generally, however, the best positions will be found some three-quarters the height of the room, except of course when ceiling type fans are employed, and these should be directly attached to the ceiling. When it is practicable, separate fans should be provided close to each heater in order to avoid temperature pockets.

Ventilation should also be provided, especially if the room is to be raised to more than ordinary temperatures. Many methods are available, but one of the following will be found useful and simple in construction. Small metal grids, having an area of some 9 square inches are fixed at the corners of the room, about 9 inches from the walls. On the rising of the hot air in the room, which passes through the grids, cold air is brought into circulation in the chamber. Another simple arrangement is to drill a number of holes in the bottom of the door of both the air-lock and the temperature chamber. These may be approximately 1 inch diameter. By means of simple guides or runners, a shutter may be used to close or open the ventilator as desired, thereby regulating the supply of cold air to the chamber. Commercial ventilators of this type may be readily obtained. It should be noted that when fixing the ceiling grids, the position should be so chosen that the hot air readily escapes into the atmosphere, and is not trapped by the presence of still air remaining in the neighbourhood of the grid. This may be eliminated by the provision of short chimneys fitted with cowls, which, while permitting the hot air to escape prevent cold air from entering.

Some typical temperature controlled chambers, giving their constructional details are now described. The following design is due to Deighton,[1] and consists of a room 15′×9′×8′, the walls of which are insulated by ½ inch thick celotex boarding, the floor being covered with cork lino. Double windows

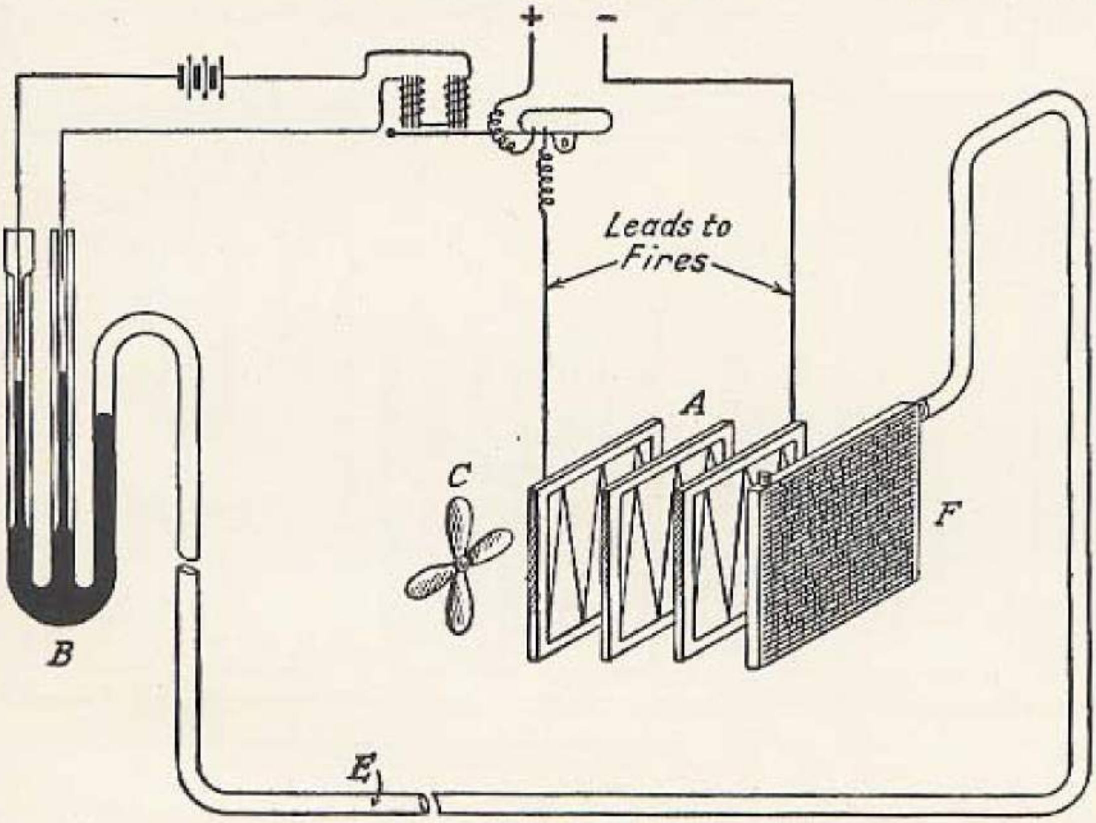

FIG. 76.

are fitted and in addition the whole window frame covered over with celtotex boarding, the door and ceiling being uninsulated. The heating was carried out by an electric fire of 2 kilowatts output, situated at one end of the chamber. This was so arranged that various heating elements could be used as required, giving 1,500, 500 or 250 watts. Further control was effected by connecting an adjustable resistance in series with the mains supply. The fires were constructed on special frames of uralite wound with coils of nichrome wire, since the heat capacity of the usual fire elements was found to be too great. This ensures that the heat capacity of the fire

[1] *Jour. Sci. Instr.*, 13, 298. 1936.

is hardly greater than that of the spirals themselves. At a short distance from the fire is placed an electric fan *C* (Fig. 76), so as to blow air through the fire elements, which are mounted vertically and parallel to each other, and about 1 inch apart. By this means, the warm air is spread over the end of the room and taken up by five electric fans and driven towards the opposite end of the room. The return flow of air is assisted by the operation of three additional fans. The thermostat unit consists of a capillary tube 2 mm. in diameter which was attached by cement to a length of "compo" tubing passing

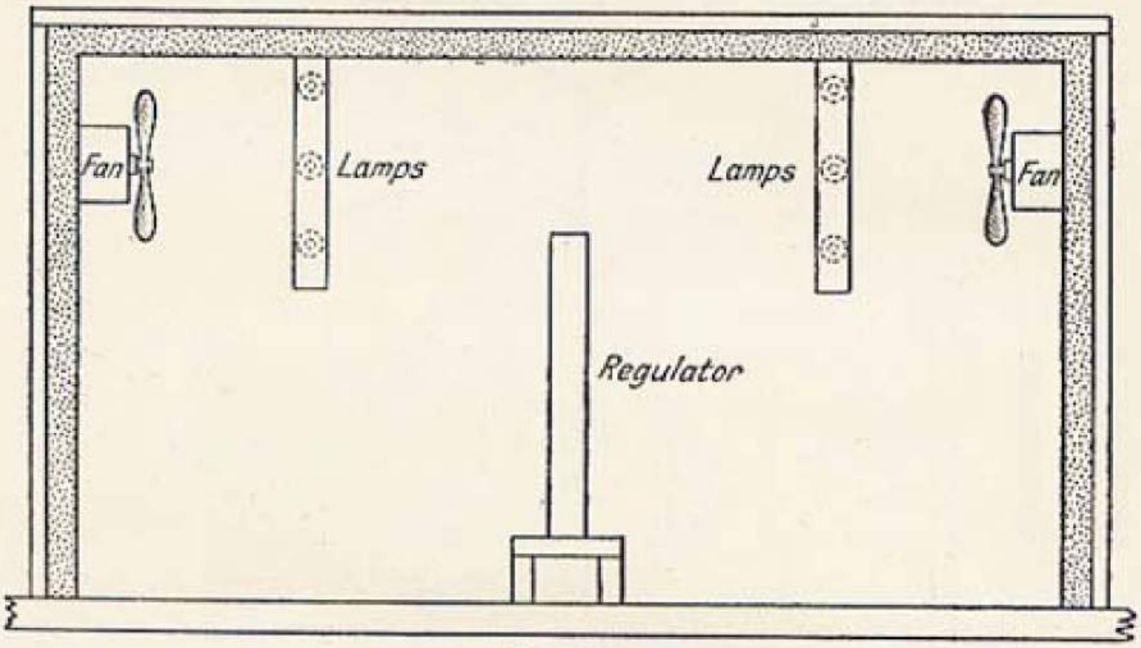

Fig. 77*a*.

from the U-tube round the walls of the room at a height of about 3 feet. After making a broad loop on the wall containing the window it finally terminated in the heat absorber *F* specially constructed of motor car radiators. The relay circuit is activated by accumulators, contact being made with the capillary tube and mercury through a nichrome wire. The make-and-break for the main current is accomplished by a rocking mercury-in-neon switch *D*, which should be capable of passing at least 10 amperes. The liquid employed in the other limb *E* of the thermostat is paraffin. Care should be taken to ensure that when filling the "compo" tubing with oil, all air bubbles are excluded before fixing the same to the capillary tube. Finally, the heat absorber *F* is filled with oil. It was found that the employment of this portion of the apparatus was a distinct advantage in obtaining more balanced temperatures, and it should be placed immediately behind the fire.

Vernon,[1] however, arranged for such a chamber to fit on the top of an ordinary laboratory cupboard, the size being approximately $8' \times 4' \times 3'$. The walls were constructed of $\frac{1}{2}$ inch matchboard, backed by a lagging of compressed cork in closely fitting blocks 2 inches thick, which were lined internally with asbestos board $\frac{1}{4}$ inch thick. The two doors

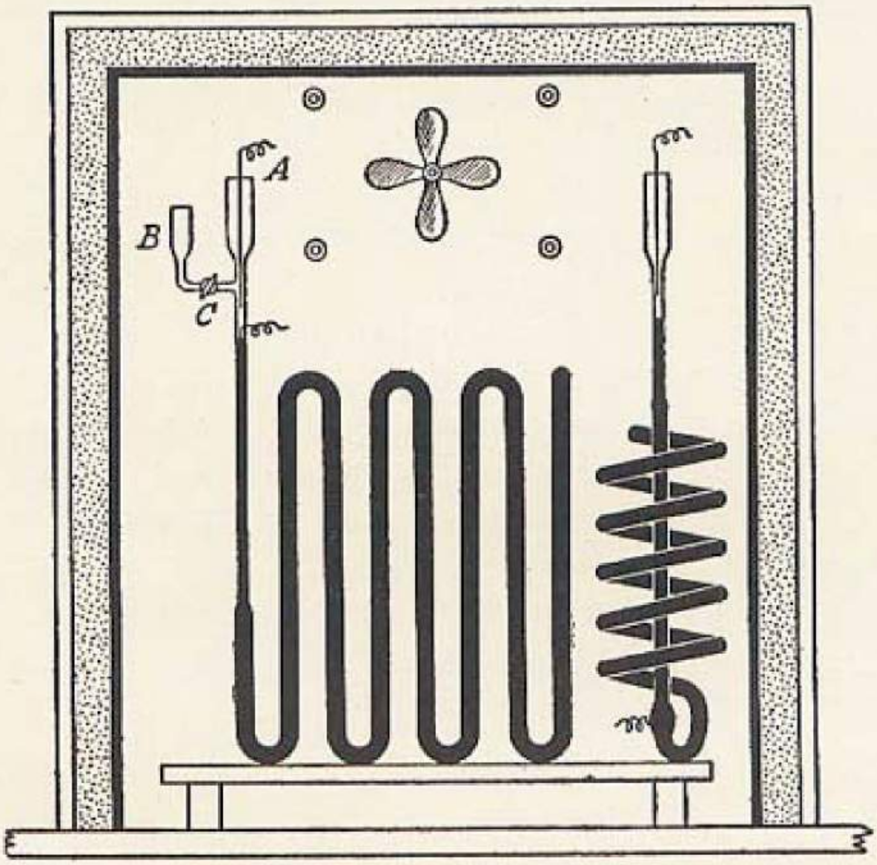

FIG. 77b.

open by sliding vertically, each being in two parts, the upper of which fits by a dovetail joint into the lower. The latter is lagged with cork, whilst the upper is fitted with two glass windows, enclosing an air gap. The top edge of the upper door is fitted with rubber flaps so that when the door is lowered the cupboard is completely closed. To facilitate ease of manipulation the doors may be held in any desired position by means of a peg engaging in a series of holes. The heating arrangements consisted of carbon filament lamps, arranged in two groups of four, each group being disposed symmetrically in a brass frame, which is suspended in front of a 14 inch four-blade fan in an appropriate position.

[1] *Trans. Far. Soc.*, 27, 241. 1931.

The fan centres are 25 inches above the level of the working floor, and the two opposing air streams, after passing over the heating lamps meet in the middle of the thermostat and pass downwards over the regulator bulbs. A portion of each stream passes through the holes H_1 or H_2 in the working floor (made of 1 inch wood) under which it returns, a portion is deflected to the side of the cupboard and returns by way of the gap between the floor and the walls.

The regulators are of the toluene type, the main one being made of $\frac{5}{8}$ inch glass tubing of length 22 feet, and is bent into a grid 20 inch long × 15 inch high, and consists of 18 vertical columns. At one end a vertical capillary tube, 1 mm. bore, is sealed, which houses the platinum contact. The subsidiary regulator is of the Lowry spiral pattern, fitted with adjustable contact at the head of the tube.

If during work it is desirable to open the door widely, an auxiliary lamp may be switched on at the appropriate end of the cupboard, in order to compensate for local cooling, and to maintain as far as possible the normal working of the system.

Fig. 77*a* is a diagrammatic view of the arrangement, while Fig. 77*b*, shows the electrical circuit; it was found that variation did not exceed ·015° C. at a controlled temperature of 25° C., even though the outside temperature varied between 15·5° and 22·5° C.

APPENDIX I

RELAYS

The amount of energy usually available in thermostatic control devices is usually very minute, and generally too small to give satisfactory operation of the current regulators. In order, therefore, that such currents may control those of greater strength, devices known as relays are employed. These may be of the semi-mechanical or entirely electrical type. By such an arrangement currents of the order of a few milliamperes are used to control a secondary circuit carrying 10 amperes or more. The former type of such control is shown in Fig. 78 and employs a metal-mercury contact, since metal-metal contacts are usually unsatisfactory with currents greater than 1 ampere. It consists of an electro-magnet, with an extended armature fitted with a counter-balance. By this means the U-shaped metal contacts may be adjusted relative to the position of the mercury surface in the contact cups. These contacts on making contact in the two separate mercury cups close the secondary circuit, the other pair of terminals being connected to the bath control device. Although heavy currents may be made or broken by this means, in practice it is found that it is not altogether a very reliable piece of apparatus.

This is largely due to the fact that open contact cups are employed, and the mercury surface rapidly becomes oxidised when in contact with air. This oxide not only increases the contact resistance, but renders renewal frequently or cleansing of the mercury essential. Various attempts have been made to minimise this defect by providing a protective film of oil, such as glycerine for the mercury, but after some period of use it will not be found to have improved the control.

In order to overcome this inherent defect, the make-and-break mechanism of relays have been developed so that contact takes place within a sealed glass envelope, and which does prevent to some extent rapid oxidation. The tubes are made of hard Jena glass or pyrex, fitted with an internal spark protection in the form of an internal trough or tube of hard glass, ceramic material or quartz. The electrodes consist of a special alloy of iron and nickel which are often platinised to minimise contact resistance. The most reliable form of switches do not break the circuit between the solid electrode and mercury, but between pools of mercury surrounding the electrodes. This also keeps down the contact resistance and prevents excessive heating at one or both electrodes in the case of high voltage or currents being employed. Such

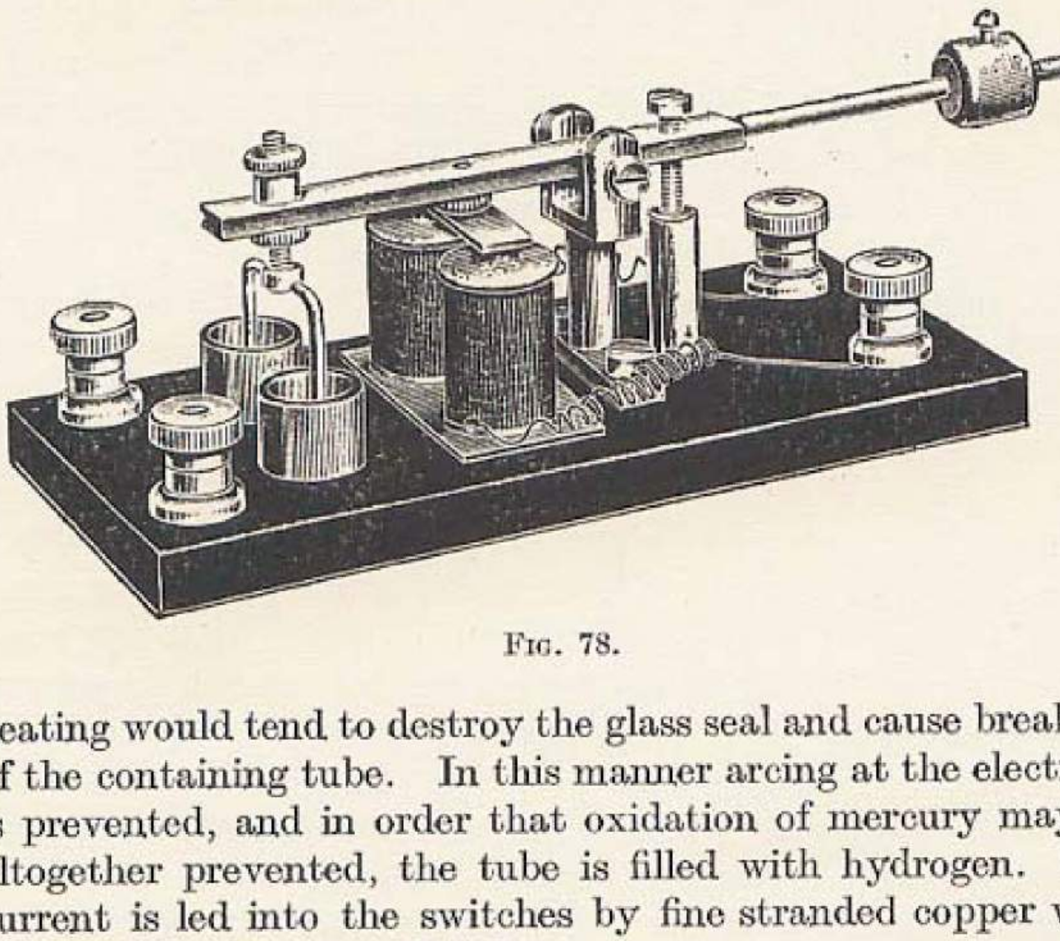

FIG. 78.

heating would tend to destroy the glass seal and cause breakage of the containing tube. In this manner arcing at the electrode is prevented, and in order that oxidation of mercury may be altogether prevented, the tube is filled with hydrogen. The current is led into the switches by fine stranded copper wire, insulated by porcelain beads.

In selecting such switches, those of ample proportions should always be chosen, since with large volume it is possible for the heat generated on operation to be dissipated rapidly.

These are obtainable from Isenthal Automatic Controls, London. It should also be remembered that the energy to be dealt with at "make" is vastly but momentarily increased owing to the production of surge currents. This is particularly so on D.C. circuits, and ample margin should be allowed for, especially when frequent switching is anticipated.

Although this form of relay, i.e. the electrical mechanical type, is largely employed, it will be appreciated that a small time-lag must therefore occur before the relay will effectively respond to each individual temperature change. This is due, of course, to the mechanical weakness of such a system, the presence of friction being one contributing cause. This defect, however, has been overcome in the valve type rectifier, the time of control being reduced to about 10–15 micro-

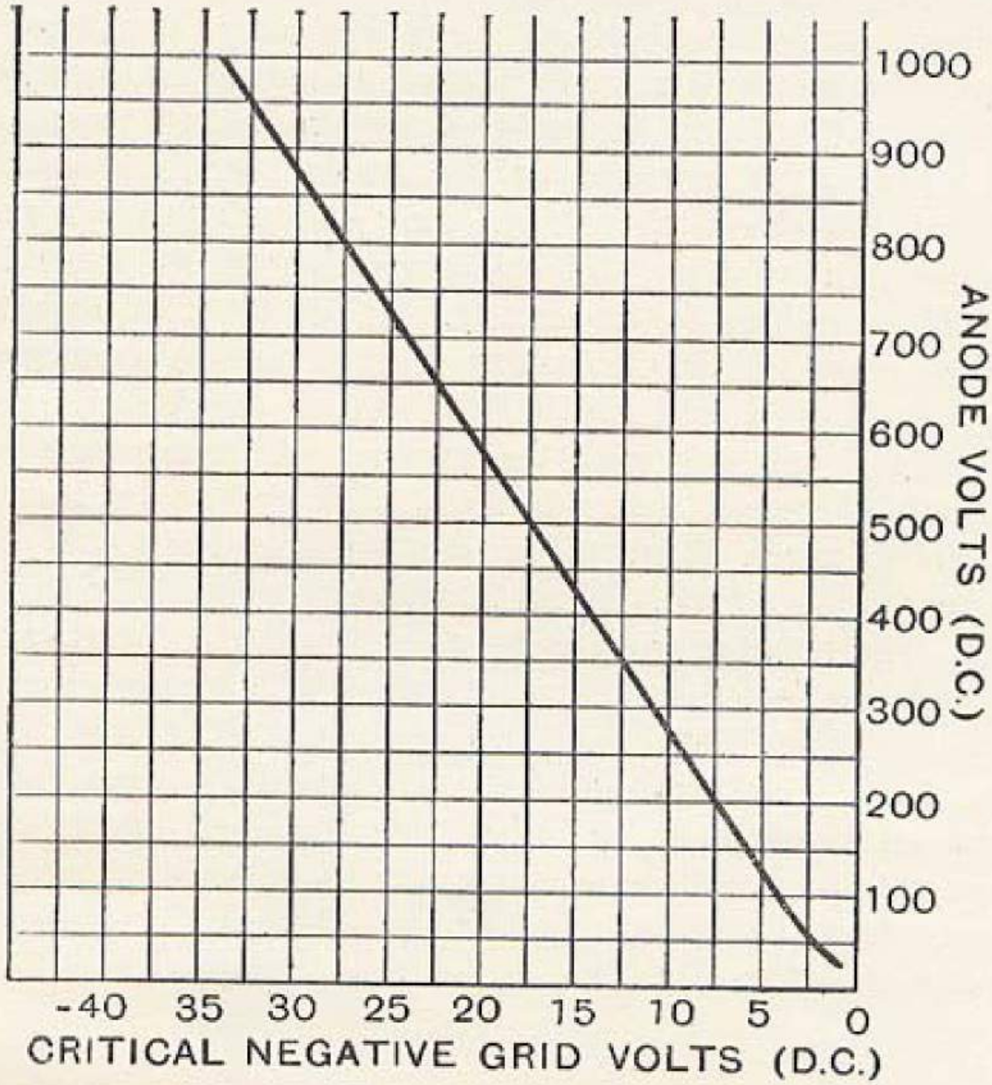

FIG. 79. GAS-FILLED RELAY. TYPICAL CHARACTERISTIC CURVE.
Filament volts 4·0, Filament current 1·3 (amperes).

seconds. This valve, known as the thyratron or grid controlled rectifier, is an electron discharge device consisting of an indirectly heated cathode, and anode and a control grid situated in a glass envelope containing mercury vapour.

Current is made to pass through the valve by the passage of electrons from the cathode to the anode by the application of a positive potential to the latter. This flow of current between the anode and cathode may be withheld, however, if a sufficiently negative bias is applied before the anode is made positive. Further, if the anode voltage is now increased, or the negative bias reduced sufficiently, a discharge will take place, and anode current will flow. This will ionise the mercury vapour, and a blue glow will be present in the bulb, and the internal voltage drop between the electrodes will be about 15 volts. The tube now acts as a simple hot cathode mercury vapour rectifier, and once ionisation has been produced, the grid will normally have no power to control the discharge. Thus for the grid to regain control, the anode voltage must be removed or the anode current stopped by breaking the circuit for a time long emough for the ions to disperse. In practice, this may require 10 to 1,000 milliseconds according to circumstances. In alternating current circuits, since the anode current falls to zero at some part in every cycle, the grid is able to control the instant in the succeeding cycle at which the current will commence again. It should be noted that when the peak voltage is less than 500 volts, argon filled valves are employed instead of the mercury vapour type. Neon also has been used for this purpose. The neon or gas-filled types have the advantage that they are unaffected by temperature while the mercury vapour tubes are somewhat critical to temperature changes. Neon tubes have considerably higher voltage drop than mercury tubes, while argon have only some 2 volts difference than mercury vapour. Circuits employing such forms of relay have already been described; while the characteristic operating graph is shown in Fig. 79.

APPENDIX II

GALVANOMETERS

THESE instruments are used for the measurement or detection of electric currents, but, in general, when employed for temperature control work, the detection of varying electric currents is of primary importance. This variation causes a movement of the instrument coil which is used to operate auxiliary

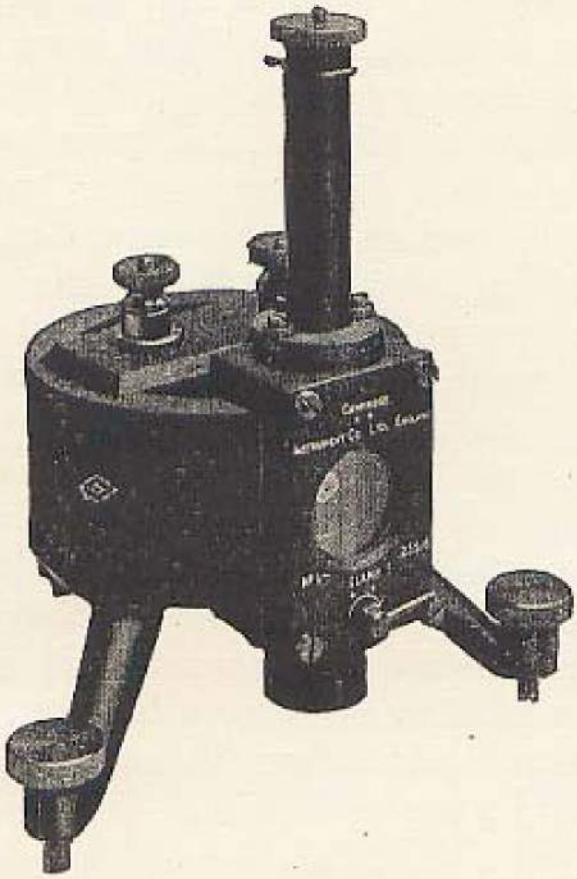

FIG. 80.

control apparatus. This instrument consists of a horse-shoe magnet having radial pole pieces, and situated between the pole pieces is a cylindrical soft iron core. In this way, the magnetic field is made radial and constant irrespective of the position of the suspended coil. The latter, usually consists of a rectangular shaped coil, having a large number of turns of fine insulated wire; the ends being taken to a suspension fibre and spiral spring respectively. It is arranged in such a manner that it may swing freely in the space between the pole pieces and the soft iron cylinder. This motion takes place on the passage of an electric current and, in order that the coil shall return to its original position on the cessation of the current, a spiral of phosphor bronze is fitted to the base of the coil. Current is led into the instrument by means of the upper suspension strip and this return spiral. When the current passes the couple rotates the coil until the opposite couple due to the twist in the upper suspension strip brings it to rest. With such an arrangement, the couple is proportional to the current, and therefore the deflection. An instrument of the reflecting type is shown in Fig. 80, and when used in conjunction with a galvanometer lamp is eminently suitable for temperature control purposes.

The resistance of a galvanometer may be high or low; and its sensitivity may be altered either by using different resistance values or by changing the suspension strips. Practical difficulties in construction and design, however, limit these values to within certain limits. In practice, however, not too high a resistance instrument should be employed.

The sensitivity of a galvanometer may be defined as the deflection in mms. produced on a scale, 1 meter away from the galvanometer mirror, by a current of 1 micro-ampere. In order to compare the performances of different instruments, a quantity, known as the "Factor of Merit," is generally stated in manufacturers' publications, and is calculated by reducing the sensitivities to the value they would have if all such instruments had unit period and resistance. For any galvanometer the Factor of Merit is:

$$\frac{100 \times D}{T^2 (R)^{2/5}}$$

where T = periodic time (undamped) in seconds,
R = galvanometer resistance in ohms,
D = deflection in mm. per micro-ampere at a scale distance of 1 metre.

The following Table gives sensitivity data of some typical instruments by various makers:

TABLE 10.

Type of Galvanometer.	Maker.	Approximate Resistance of Coil (R) ohms.	Period Undamped (T).	Mins. Deflection 100 cm. Scale. distance per			Critical Damping Resistance.	Factor of Merit (Approx.).
				Micro-Ampere (D).	Micro-Volt.	Micro-Coulomb.		
D'Arsonval .	Griffin . .	17·5	14·4	186	11·0	105	320	28·5
D'Arsonval .	Griffin . .	25·0	21·0	174	7·0	44	350	10·5
D'Arsonval .	Griffin . .	700·0	13·2	460	0·7	200	3800	20·0
Ayrton Mather .	Griffin .	10·50	5·0	79	7·8	90	80	123·3
Ayrton Mather .	Cambridge .	150·0	6·0	260	1·7	—	—	97·3
High Sensitivity	Cambridge .	15·0	15·0	300	20	126	300	45·0

APPENDIX III

THE WADE AND MERRIMAN PRESSURE MANOSTAT

It has been already intimated that when using Lambert and Clark's vapour pressure bath (Chap. III) some form of constant pressure device was essential. These workers adopted the form devised by Wade and Merriman,[1] which consisted of a U-tube *AB* (Fig. 81), the limbs being 10 mm. bore and connected at the top by a tube containing a tap *E*. This U-tube is filled with mercury, some 130 ccs. being needed, the upper end of the U-tube being connected to the evacuated system by means of the tap *E*. The centre of the lower bend of the U-tube is connected to the chamber *F* by the short capillary tube *C*, while this chamber is open to the atmosphere at the tap *G*. The capillary tube *D* of 2·4 mm–2·6 bore just dips into the mercury at *F*, ending just above the opening of *C*. The upper end of *D* is conveniently attached by means of rubber tubing to *A* just above the mercury level. When the pressure is reduced at *E* the mercury rises in *A* and *B* and falls in *F* until the lower end of *D* is uncovered, thus air can be admitted to the apparatus through *D*. When the apparatus is working a continuous stream of air and mercury bubbles passes up *D* into *A*. For use at pressures above the atmosphere the apparatus may be connected to the pressure system at *G*, while *E* is left open to the air.

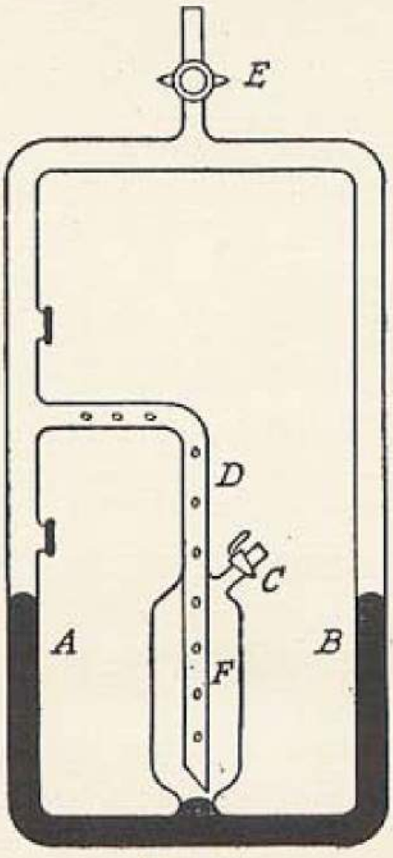

Fig. 81.

[1] *Jour. Chem. Soc.*, 99, 184. 1911.

APPENDIX IV

THERMAL CONSTANTS

Substance.	M.P. °C.	B.P. °C.	Specific Heat Cals. gm^{-1} °C.$^{-1}$ Temp. °C.		Expansion Coefficient/°C × 10^{-6}.	Thermal Conductivity Cals. cm^{-1} sec^{-1} °C.$^{-1}$.
Aluminium	658	1800	17–100	0·217	26	0·504
Chromium	1520	2200	17–100	0·110		
Copper	1083	2310	15–100	0·093	17	0·92
Iron	1530	2450	18–100	0·113	12	0·161
Lead	327	1525	20–100	0·0305		0·083
Nickel	1452	3000	15–100	0·109	13	0·142
Platinum	1773	3910	15–100	0·0322	9	0·165
Silver	960·5	1950	15–100	0·056	19	0·974
Tin	232	2270	20	0·054	23	0·155

DENSITIES

In grms. cc. at ordinary temperatures (15°–23° C.)

METALS.

Aluminium	2·70	Platinum	21·50	Brass	8·4
Copper	8·89	Rhodium	12·44	Constantin	8·88
Iron	7·86	Silver	10·5	Invar	8·0
Mercury	13·56	Tin	7·29	Manganin	8·50
Nickel	8·9	Zinc	7·1	Steel	7·8

LIQUIDS. (15° C.).

Alcohol (ethyl)	0·791
,, (methyl)	0·810
Ether	0·736
Glycerine	1·26
Paraffin Oil	0·9
Turpentine	0·87

ELECTROMOTIVE FORCE OF STANDARD CELLS

Clark . . . . ·1·433 volts.
Weston . . . . 1·0183 „

RESISTIVITY OF SOME COMMON METALS

Temperature 20° C. ; temperature coefficient at 20° C.
The values are in microhm-cms.

Metal.	Resistivity.	Temp. coeff.
Aluminium	2·82	0·0036
Brass	8·0	0·0015
Constantin	49·0	0·00001
Copper	1·72	0·0040
German silver	28·0	0·0003
Iridium	6·15	0·0037
Manganin	44·0	0·00001
Nichrome	100·0	0·0004
Nickel	7·24	0·0054
Platinoid	38·0	0·00028
Platinum	10·5	0·0037
Silver	1·62	0·0036
Steel—Invar	78·0	0·002
Steel—Mild	15·0	0·0033
Steel—Piano wire	12·0	0·0032
Tin	11·4	0·0044
Zinc	5·92	0·0035

NICKEL CHROME RESISTANCE WIRE—No. 1

Current necessary to maintain given temperature rise. Wire held straight and horizontal in air with free radiation.

Size. S.W.G.	Diam. inches.	Diam. m/m.	Resistance per 1,000 yards. Ohms.			Amperes for a temperature rise of			Weight per 1,000 yards. lbs.
			100° C.	500° C.	1,000° C.	100°	500°	1,000° C.	
16	·064	1·62	457	474	475	6·4	18·75	42·5	34·9
17	·056	1·42	597	619	621	5·3	15·50	35·1	26·7
18	·048	1·21	813	844	846	4·3	12·60	28·3	19·6
19	·040	1·01	1171	1215	1218	3·4	10·00	22·1	13·6
20	·036	0·91	1446	1500	1504	2·9	8·60	18·9	11·0
21	·032	0·81	1830	1899	1904	2·4	7·40	16·0	8·73
22	·028	0·71	2390	2480	2486	1·9	6·30	13·4	6·68
23	·024	0·60	3254	3377	3384	1·5	5·20	10·8	4·91
24	·022	0·55	3873	4019	4028	1·3	4·45	9·5	4·12
25	·020	0·50	4685	4862	4873	1·13	3·95	8·35	3·41
26	·018	0·45	5784	6000	6017	0·99	3·50	7·28	2·76
27	·0164	0·41	6970	7233	7251	0·90	3·14	6·45	2·29
28	·0148	0·37	8557	8880	8901	0·80	2·80	5·65	1·86
29	·0136	0·34	10134	10516	10541	0·75	2·55	5·06	1·57
30	·0124	0·31	12191	12651	12681	0·68	2·30	4·5	1·31
31	·0116	0·29	13931	14345	14490	0·64	2·15	4·15	1·147
32	·0108	0·27	16071	16676	16716	0·60	2·99	3·78	·994
33	·0100	0·25	18745	19452	19498	0·56	1·84	3·44	·852
34	·0092	0·23	22146	22980	23035	0·52	1·68	3·13	·721
35	·0084	0·21	26565	27566	27632	0·48	1·51	2·78	·601
36	·0076	0·19	32457	33681	33762	0·43	1·34	2·48	·492
37	·0068	0·17	40536	42063	42165	0·39	1·19	2·19	·394
38	·0060	0·15	52077	54042	54171	0·35	1·03	1·91	·306
39	·0052	0·13	69315	71928	72102	0·32	0·90	1·63	·230
40	·0048	0·12	81360	84426	84627	0·30	0·083	1·51	·196

The above data should be regarded as approximate. Melting point 1375° C. Temperature coefficient ·00010° C.

NICKEL CHROME RESISTANCE TAPE—No. 1

Current necessary to maintain given temperature rise. Wire held straight and horizontal in air with free radiation.

Size inch.	Resistance per 1,000 yards. Ohms.			Amperes for a temperature rise of			Weight per 1,000 yards. lbs.
	100° C.	500° C.	1,000° C.	100° C.	500° C.	1,000° C.	
·025 × ·002	33567	34830	34914	·61	1·41	2·92	·482
·025 × ·003	23422	24305	24363	·68	1·61	3·40	·681
·025 × ·004	15132	15703	15740	·75	2·06	4·28	1·058
·025 × ·006	9963	10339	10364	·83	2·80	5·37	1·623
·025 × ·008	7395	7672	7692	1·11	3·31	6·27	2·177
·03125 × ·003	15814	16410	16450	·71	2·09	4·53	·968
·03125 × ·004	12734	13214	13246	·92	2·52	4·83	1·289
·03125 × ·006	7358	7635	7654	1·20	3·20	6·26	2·123
·03125 × ·008	6108	6338	6368	1·23	3·67	7·28	2·652
·03125 × ·010	4481	4650	4661	1·42	4·25	8·90	3·508
·050 × ·004	7815	8109	8129	1·21	3·43	7·36	2·063
·050 × ·006	4938	5124	5136	1·63	4·56	9·55	3·181
·050 × ·008	3817	3961	3971	1·97	5·35	11·47	4·244
·050 × ·010	2812	2918	2918	2·01	5·53	12·36	5·460

The above data should be regarded as approximate. Melting point 1375° C. Temperature coefficient ·00010° C.

INDEX

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