SOME CALORIMETRIC APPARATUS.

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EXPERIMENTAL developments are often analogous to the progress of organic evolution. New structures and processes are derived from those already in use, even where an independent departure would be more appropriate, and features, once adopted, tend to continue long after the original reasons for them have ceased to exist. In calorimetry, the simple forms of apparatus which were suited to the early approximate methods have been applied to more exacting work by means of elaborate corrections and precautions, sometimes extending to the control of the observing room for hours previous to the actual observation, yet without attaining more than moderate accuracy. Several investigators have recently introduced new types of apparatus, with complete inclosure of the calorimeter, which are not only more accurate but on the whole simpler. Further developments and devices, largely inspired by this new departure, have issued in rapid succession from various laboratories. In two former papers of this series¹ there has been described a system in which definiteness of conditions was carried further by a modification of the calorimeter cover, and by attention to evaporation and the errors connected with stirring. Considerable simplification of calculation and an increase in thermometric accuracy are also secured. The present papers deal with the apparatus actually used, and the accuracy attained.

The apparatus was designed, and has been used, for the determination of specific heats, especially at high temperatures, by dropping bodies from heaters into the calorimeters.

1. *The Two Calorimeters.*—The two calorimeters are shown in

¹PHYS. REV., 31, 545 and 562, 1910. References to these will be by page number simply, since they virtually form one article with the present papers.

section in Fig. 1. *A* holds 1.5, *B*, 3.8, liters. In the case of each the form was chosen mainly with reference to satisfactory stirring.

The type represented by *B*, with central inner tube, has the widest and shortest possible path for the water, and, therefore, presumably, the smallest heat production for stirring of given effectiveness.¹ In some respects it would be more satisfactory if symmetrical, but this would require some kind of gearing to run the stirrer, since a shaft coming centrally through the top is usually out of the

Fig. 1.

(One sixth actual size.) Calorimeters *A* and *B*, vertical section; *A'* and *B'*, horizontal section. Features: Cover in contact with the water; prevention of evaporation; wide passages for water in circulating; absence of dead spaces. *W*, water level. The position of the crucible is shown by the dotted lines. Capacity, *A*, 1,500 c.c.; *B*, 3,800 c.c.

question. The inclined tube avoids this difficulty and gives almost all the advantages of the symmetrical form, yet with simple stirring arrangements. By inclining the whole calorimeter the circulation would become more nearly symmetrical; this arrangement seems almost necessary in adapting the type to smaller sizes. The propellers are removable. If the partition in *A* is removable, the whole interior is easily reached in cleaning. For the same reason the inner tube in *B* should be supported from the bottom, or made removable if possible.

¹Cf. page 576.

The stirring of *A* has been shown¹ to be satisfactory. When *B* is stirred so as to have lags of about the same value, the heat produced is only .6 as much as with *A*, in spite of the greater size. The cooling factor for small temperature differences is .0027 for *A*, .0017 for *B*.

The light (17-gram) floating cover, originally used with calorimeter *A*, and described three years ago, has been given up for reasons stated on page 574. The present cover (70 grams—the same one is used for both calorimeters) touches the water, but rests on a ground joint. The annular space under the cover permits the water to vary somewhat in amount without either overflowing or failing to wet the cover; while the weight of the cover prevents it from being floated out of place when the water is high. An approximate preliminary adjustment of the amount of water is of course necessary, and is very easily obtained. Evaporation through the (dry) joint is about 7 mg. an hour, which is not likely to produce appreciable error unless the extra space in the chamber is very small. An oil seal gives very little trouble, and has been used where maximum accuracy was desired. A still more satisfactory arrangement seems possible.

2. *The Jacket*.—Complete inclosure of the calorimeter chamber, quick opening and closing, and thorough circulation without much heating, were the main requirements. In Fig. 2 the jacket is shown in section and also in top view, partly open. Water is held up in the two halves of the cover, and in the upper section of the chamber wall, by atmospheric pressure. On leaving the propeller the water divides and passes across through the three upper passages, and then returns through the lower space. Its circulation is directed by the partitions, *P* and *Q*, of which *Q* runs nearly the whole length of the tank outside the chamber, as shown by the dotted line. The chamber is opened by moving the covers aside; their downturned ends then move in the troughs left at the ends of the tank. The covers slide upon the stout rod *T*. The pulley for the calorimeter stirrer, and the whole jacket stirrer, are borne on one half cover. This half is clamped firmly in place during an observation; shoving aside the other fully exposes the calorimeter opening.

¹Cf. page 575.

The pulley is connected to the propeller shaft of the calorimeter by a small fiber rod. This separable pulley removes from the calorim-

Fig. 2A.

(One sixth actual size.) Calorimeter jacket, giving complete inclosure by a single body of water, with free circulation of the water, and readily opened. Vertical section (empty).

Fig. 2B.

Top view, opened to show the calorimeter (dotted lines) within. *T*, rod on which the top slides in opening. *S*, pulley which operates the calorimeter stirrer. *θ*, groove for passage of thermoelectric thermometer. *W*, water level.

eter the heat produced in the bearing, keeps the condition of the bearing constant in spite of temperature changes in the calorimeter,

and avoids running a belt into the chamber. Some metal workers may find difficulty in soldering the whole apparatus together, but this difficulty will disappear if the calorimeter chamber and the upper passage next it are made in a separate piece, and then fastened in place. The outer wall then becomes a simple rectangular box. The partitions are merely to guide the circulation, so tight soldering is needed only on the covers, the chamber, the upper inclosure around it, and the outside tank.

In an earlier jacket¹ the water entered and left the single cover by two downward projecting tubes on the same side, and the cover rotated about one of these to open the chamber. The advantages of the newer form are the wider and shorter path for the circulating water, and the ability to open the chamber freely and at the same time have thermometers, stirrers, etc., inserted in the calorimeter from above through the stationary part of the cover. The older form is preferable where it is desirable to expose the whole calorimeter quickly.

3. *The Crucible*.—A platinum crucible was necessary to hold the loose lumps of material generally employed, and was also used, as already pointed out,² to eliminate the errors due to *all* the heat losses in transferring from the furnace to the calorimeter. This was done by making determinations on the crucible alone, and taking for the effect of the substance investigated the difference between these results and those when the crucible was loaded. The crucible is shown in section in Fig. 3; the bail, of platinum wire, is for suspension; the reëntrant tube for the thermoelement fits very loosely around the porcelain insulating jacket tube, and so drops promptly away from it at the proper time. Some tests seemed to show that if the sides of the porcelain jacket were partly ground away for 2 cm. from the end, so as to expose the thermoelement to direct radiation from the crucible, the thermoelement

¹Represented in simplified form in Amer. Jour. Sci., 28, 337, 1909.

²Amer. Jour. Sci., 28, 336, 1909. T. W. Richards and F. G. Jackson have since laid considerable emphasis on the improvement introduced into calorimetry by this method of "adiabatic transfer." (Z. für physik. Chem., 70, 426, 1909.) The first one to use and report it appears to have been N. Stücker (Sitzber. kais. Akad. Wiss., Wien, Math.-nat. Klasse, 114, 658, 1905), who mentions it as a means of eliminating radiation losses.

lag was diminished, and furnace regulation thus favored, but the equilibrium temperature was not altered.

In the earlier determinations, explosions of steam during cooling in the calorimeter blew most of the charge out of the crucible, and in one case projected some of it out of the calorimeter altogether. Although emptying a granular charge out into the free water circulation shortens the time for attaining temperature equilibrium, and may be recommended for that purpose, in the present case it was thought undesirable, for the charge needed re-weighing, which necessitated a heating and rather tedious cooling. With the present locking cover shown in the figure, the silicate charges only lose from 2 to 6 mg. at each cooling. More determinations can be thus made in a day, as a weighing once a day is now sufficient, for which the cooling may be done over night.

4. *The Furnace.* — The high temperature furnace is of the type first used in this laboratory,¹ with internal platinum winding. This feature not only permits the attainment of a higher tem-

Fig. 3.

(One sixth actual size.) Platinum-wound furnace, used from 500° to 1500°. *P*, partitions to shield against the cooling effect of the ends of the furnace; *SS*, swinging shield; *L*, latch for dropping out the furnace bottom; *MM*, heavy wires for the dropping current. *T*, thermoelement.

¹Day and Allen, *PHYS. REV.*, 19, 177, 1904; Day and Clement, *Amer. Jour. Sci.*, 26, 411, 1908. See also *Amer. Jour. Sci.*, 28, 474, 1909.

perature, but at lower temperatures also has the decided advantage, not so often noted, of diminishing the lag between coil and chamber, and so increasing the quickness and the exactness with which a constant temperature may be reached and maintained. The furnace is 32 cm. high by 20 cm. in diameter; internal cavity, 4.8 cm. diameter.

In transferring the crucible to the calorimeter, the middle of the furnace bottom is first dropped away, and then, as soon after as possible, the crucible is dropped by an electrical arrangement.

The furnace (Fig. 3) is mounted on a stout iron plate, 5 mm. thick, with a 5 mm. heat-insulating air space between. An opening 5.5 cm. in diameter is cut through the furnace bottom and plate. This is closed by a plug of fire-clay, borne on a movable iron plate 10 cm. square. This is held up against the large plate by the latch *L* in such a way, readily intelligible from the figure, that a quick pull on the latch causes the plug to fall without tipping. Upon the plug, and inside the furnace chamber, is a pedestal, made up of three fire-clay partitions 6 mm. thick, each faced on both sides (except next the crucible) with reflecting discs of platinum foil, and supported by a light frame made by grinding away as much as possible from a thin porcelain tube 4 cm. in diameter. The pedestal has two functions. It protects the crucible from the cooling effect of the furnace bottom, and so makes for uniformity of temperature; and it supports the crucible during the hour or more necessary to reach and establish a constant and uniform temperature. Platinum is very soft at high temperatures, and the fine wires, which support the crucible for the interval of one second which elapses between the fall of the pedestal and that of the crucible, would have to be undesirably large if they were to hold for any length of time. At the higher temperatures the uppermost partition is apt to stick to the bottom of the crucible, hence it is tied by platinum wire to the plate below, whose weight is enough to pull it away. Above the crucible another platinum covered shielding partition is suspended. The crucible is fastened by fine wires to the larger wires, *MM*. The drop is made by melting the fine wires electrically, securing both quickness and simplicity of manipulation. This arrangement, borrowed from J. A. Harker,¹ has needed modification

¹J. A. Harker, *Phil. Mag.*, 10, 430, 1905.

at the higher temperatures used in our work, first by the addition of the supporting pedestal, as already explained, second by precautions against the formation of an arc between the large wires as the small ones melt. Some arcing is necessary, for *both* sections of the fine wire must be melted; hence the current must not stop when the first goes. By using two separate, vertical, fine wires as far apart as possible, good results were usually obtained. The two small arcs first formed were then pulled out by the fall of the crucible. But at 1300° and over, where arcing is easier, and the fine wires have to be relatively heavy, even this method often fails. A better arrangement, therefore, will be reported later.

5. *The Swinging Shield*.—When the pedestal falls from the furnace it is caught in a light wooden box. This box, which can turn on a vertical pivot, is immediately swung aside by the observer's hand; the single quick motion performs the following operations: It carries the pedestal out of the way, shuts off the furnace current, pushes a temporary cover off from the calorimeter, and closes the circuit which drops the crucible. Immediately returned to its place, the box shields the calorimeter from the direct heat of the furnace, after an exposure of only a second for the drop. The heat radiated to the calorimeter is, at 1500° , 0.5 calorie per second, or 1/50,000 the quantity of heat then measured; hence a doubling of the interval would produce no appreciable error.

6. *The Splash Cover*.—The water which is thrown out of the calorimeter as the crucible enters it causes no error, for the weighing is done after the heat determination is finished. The slight resulting heat loss is one of the things eliminated by dropping the crucible alone. But even a very small amount of water falling on the outside of the calorimeter and evaporating there will generally cause a very serious error. The water raised by the splash, therefore, is confined by a removable upward extension of the calorimeter wall in the form of a heavy brass collar 11 cm. high, which presses a rubber gasket against the top of the calorimeter. The few drops which get over the top of this tube are caught by a metal pan. This splash cover is put in place some time before the drop, and is removed by hand immediately after it. The crucible and jacket are then covered for the first time. The method used to

compute the cooling correction (see page 547) permits this rapid and convenient procedure to be employed without disadvantage.

7. *The Temperature Measurements.*—The copper-constantan thermoelements used to measure the calorimeter temperature, the platinum-rhodium elements for the furnaces, and the potentiometer installation, have already been described.¹ The latter has been modified to suit the demands of the present work. The potentiometer is arranged as a double potentiometer,² that is, two separate switch settings can be made at the same time, either of which can, by a single motion of an exchanging switch, be brought into play along with the appropriate thermoelement. Other thermoelements, also, can be connected to the galvanometer alone, for direct reading of small electromotive forces. One switch setting is used to read the furnace temperature, the other, the calorimeter temperature. The difference between calorimeter and jacket is read by the galvanometer alone before the drop of the crucible, and afterward on the connection previously used for the furnace. The small differences within the furnace are, where necessary, read by direct deflection.

The whole system is fully equal to the demands of the present work. Just before the drop, four different readings are often made and recorded in half a minute. A small auxiliary potentiometer is used, in series with the main potentiometer, in order to provide an additional dial. The resulting combination enables satisfactory results to be obtained with a potentiometer originally of too small capacity for the present work.

The exchanging switch is quite different from that described in the earlier article, and is briefly referred to in the *PHYSICAL REVIEW*, Vol. 30, p. 784, 1910. Connections outside the switch are made by means of the wooden clothespin clamps described in the same article.

An electric dial, operated by impulses from a seconds pendulum, gives bell signals at appropriate intervals in each minute, and saves all necessity of looking for the time, either in reading temperatures or in dropping the crucible.

¹Constancy of Thermoelements, *PHYS. REV.*, 23, 449, 1906; Potentiometer Installation, *ibid.*, 25, 334, 1907; The Thermoelement as a Precision Thermometer, *ibid.*, 31, 135, 1910.

²*Zeitschr. f. Instr.*, 27, 218, 1907.

8. *Protection Against Leakage in the Potentiometer System.*—The system of equipotential leakage shields described in a former article¹ has been extended. It was there pointed out that when a feeble current from an outside source leaks through a measuring circuit, the only detrimental part of it is that which goes through the galvanometer, and that this part can be diminished by (1) improving insulation; (2) so arranging the circuit that the vagrant current shall tend to pass through it by a path which does not include the galvanometer; (3) interposing a metallic conductor, the shield, between the circuit and the outside E.M.F. If an external shield is complete the protection it gives is perfect. But in a hot furnace, where the air conducts, a shield, to be complete, must be a complete inclosure, and this is usually inconvenient. There will, therefore, often be a small leakage current, and it is desirable to make this leave the circuit as near the furnace as possible, in order to fulfill condition (2). Yet it is obviously disadvantageous to provide any more or better paths for the vagrant current. The difficulty is avoided by having a second, internal, shield, connected to the circuit, but insulated from the external shield. It intervenes between the external shield and the potentiometer, switch, auxiliary resistances and battery. Such a shield can easily be insulated better than most ordinary apparatus, hence by its use leakage is diminished, yet whatever leakage does occur will leave the circuit by the most desirable path. The same shield may serve for protection against leakage in the storage battery circuit of the potentiometer.² In the installation here described, it is directly under the top of the observing table, where this rests on the legs, and consists merely of four (connected) plates of metal, 10 cm. square, set on four smaller insulating discs of paraffined hard rubber, which by their situation are well protected from dust and light. The external shield for the table is the metal legs. (In many cases it might conveniently be four small metal plates between the table legs and the floor.) In order to give protection from battery leakage, the shield must separate from the galvanometer circuit all apparatus which is

¹Potentiometer Installation, *loc. cit.*, p. 340.

²*Loc. cit.*, p. 343. The present shield is merely a slight extension of the shield first used for the storage battery circuit.

near the positive potential of the battery. Hence all such apparatus rests on a metal plate, which is connected to those below the table. But no further insulation is required for this plate.

Recently, in humid summer weather, appreciable leakage was detected between the two sides of the thermoelement circuit, which differed only by .013 volt. It is impossible to shield against such leakage; the only effective defense is better insulation. Accordingly, a change was made in the installation. The exchanging switch was kept dry by inclosure in a tight, glass-topped case in which calcium chloride was placed. The leads passed out through sheaths of celluloid imbedded in paraffin, and all other exposed insulating surfaces, including the top of the potentiometer itself, were paraffined after being dried in the radiation from an incandescent light. These precautions have proved effectual in very humid weather. In some potentiometers now being constructed in the shop of the Geophysical Laboratory, provision is made for keeping them dry by an upper glass cover and the use of drying material. Such inclosure is in some ways more favorable to constancy than immersion in an oil bath, and is certainly cleaner. It seems likely to prove a valuable general method where high precision is desired along with freedom from uncertainty and troublesome precautions, especially in humid climates.

9. *Averaging.*—The important temperatures are all obtained by taking the mean of several observations. A short method of averaging is employed. As the separate observations are recorded, each is subtracted from the preceding. The time required for this is almost inappreciable, since the differences are nearly constant for one set of readings. Five readings are usually made, at half minute intervals. These will yield four differences. If these differences, in order, are called *A*, *B*, *C*, *D*, it is easy to show that the arithmetical mean of the five readings differs from the middle one by $[A - D + 2(B - C)]/5$, a value which is almost never more than one unit of the last place, and can be obtained at a glance. Similar formulæ can of course be obtained for three or seven readings.

10. *Conduct of an Observation.*—While the furnace is heating, the calorimeter is filled, its temperature regulated (by ice or by an immersed incandescent light) if necessary, the ice tank is filled,

and the splash cover is put in place. When the desired furnace temperature has been reached and held long enough to heat the crucible uniformly, the thermoelement in the furnace is removed, and the accurate element used for the final measurement is inserted instead. After about three minutes, readings of the furnace temperature can be resumed, and are alternated with readings of the calorimeter temperature. As soon as constancy of temperature in the furnace is again assured, the drop is made. This requires five simple operations. At a bell signal from the clock the latch is pulled, letting the pedestal fall. Immediately after a quick glance to see if this has happened properly, the box is swung out and back, dropping the crucible. The splash cover is then removed, the calorimeter and jacket are covered, and the observer returns to the galvanometer telescope, arriving in ample time for the first reading, fifteen seconds after the drop.

During the next two or three minutes the temperature rise is rapid, and readings are made every fifteen seconds. One-minute readings then begin, and in the intervals between them the preparation for the next determination is started. The porcelain tube and crucible attachments are removed from the furnace to get cool, and the furnace is closed again to keep hot. At the end of the temperature observations, about ten minutes later, the crucible can be at once adjusted for another heating. Meanwhile the reduction of the observations has also been nearly completed.

11. *The Lead Bath.*—It was found that in the furnace described above, the absolute, and still more the relative, uniformity of temperature over the crucible is a maximum at the highest temperature measured (1500°) and decreases continuously down to 500° , where the extreme difference is about 15° . Hence for work at 300° and 500° a furnace of a different type was made, designed so as to give more uniform temperatures, and shown in section in Fig. 4. The bottom, a soft steel annular plate, is joined to the two soft steel concentric vertical tubes, *A* and *B*, by beading the metal of the tubes over the edges of the bottom. The annular space between the tubes is filled with a lead-tin alloy which is stirred by a propeller, with water-jacketed bearing. The heating coil is in three sections, at top, bottom, and sides. These are separately regulated, in ac-

cordance with the readings of differential thermoelements, so as to give a temperature uniform to 3° or 4° all over the outside. The bottom swings aside to expose the crucible for dropping. In swinging it trips a catch which releases the crucible.

Fig. 4.

(One sixth actual size.) Electric furnace, for temperatures not only constant but very uniform, from 180° to 600° . Of steel, filled with a lead and tin mixture, which is stirred, and is kept from oxidation by means of illuminating gas.

Actual measurements showed that when the bottom of the chamber was 10° warmer than the center, the resulting temperature difference on the surface of the crucible was not over 0.5° . When the bottom of the chamber was 10° cooler, the effect on the crucible was imperceptible. When equilibrium has once been established, the temperature of the bath seldom attempts to vary faster than about 1° in fifteen minutes. This bath has several times been raised to 600° .

A slow stream of illuminating gas keeps the melted metal free from oxide.

12. *The Steam Oven*.—Values of the mean specific heat up to 100° are obtained with the apparatus shown in Fig. 5. This differs from some others of its kind in that boiler and crucible chamber are combined in one vessel. It is thus simple, compact, and manageable, takes little heat, and avoids all difficulties from throttling or imperfect circulation of the steam. It is made of sheet copper, soldered with tin. When in use, it is over the calorimeter; the small flame keeps the water inside boiling just fast enough so that condensation continues in the air condenser, *K*; the asbestos board partitions *G, G*, keep the flame from interfering with the temperature either of the crucible chamber or of the calorimeter. A shield, *S*, guides the flow of the steam inside. A copper-constantan thermoelement measures the temperature of the chamber. Two hours are allowed for the charge to attain the temperature of the steam.

Direct observations with a thermoelement in the middle of the charge showed that at least 90 minutes is necessary if results are to be accurate to $.1^{\circ}$. The partitions, of cork covered with tin foil, in the lower part of the chamber, protect the crucible from the cooling effect of the bottom.

13. *Dropping the Crucible from the Steam Oven.*—In dropping from the steam oven, it is possible to get rid of the splash and splash cover. To accomplish this, the crucible is lowered rapidly by a

Fig. 5.

Fig. 6.

(One sixth actual size.) Steam oven for temperature of 100° . *S*, radiation shield; *cc*, copper constantan thermoelement; *H*, chain; *GG*, asbestos guards around the flame.

Diagrammatic view illustrating the automatic method of dropping the crucible from the steam oven of Fig. 5.

cord, checked just before it strikes the water, and at once released automatically. The automatic release is performed by a pair of brass tongs with two handles, one of which closes, the other opens them. To one handle the cord is attached, to the other a chain, *H*, whose other end is fastened to the inside of the oven chamber. Hence the crucible, raised by the cord, is held firmly, but drops as soon as it is lowered enough to pull upon the chain. A constant

heat loss in the drop is furthered by also using an automatic arrangement (Fig. 6) to lower the crucible. This is hardly necessary at such low temperatures, but simplifies the manipulations, and so diminishes accidents, while the labor of installing it is the merest trifle. Its essential feature is a pendulum consisting of a heavy ball hung by a cord. This, near the middle of its swing, is restrained by another cord, *R*, and then swings about its attachment as a center. The cord which lowers the crucible is attached a little below at *D*; thus the motion of the crucible changes suddenly from a high to a low velocity as the cord, *R*, tightens; this happens just before the crucible touches the water. The pendulum is first released by the pull of a cord attached to the jacket cover, which, here taking the place of the swinging shield above described, is thrown back to make the drop. The motion of the cover is also made to release a stretched rubber band, which jerks a temporary cover away from the calorimeter. The upper cork partition in the oven chamber is attached to the chain, and leaves the chamber only when the crucible does. It protects the crucible from appreciable heat loss after the chamber is opened.

The operation of dropping, then, comprises four motions, among which confusion is very unlikely, first (at leisure) opening the chamber; second, at the clock signal, moving the cover, when the drop follows automatically, and then covering calorimeter and jacket as usual.

SUMMARY.

This paper deals with a calorimetric system in which all conditions affecting the calorimeter temperature are, as far as possible, definite and measured, and in which as a result errors once serious are made negligible, computation is often simplified, and an increase in effective thermometric accuracy can be secured. The apparatus was designed for the determination of specific heats, especially at high temperatures, by the mixtures method.

1. Two calorimeters are described, designed for effectiveness in stirring. In one of them the use of an *inclined* central tube affords a path both wide and short for the circulating water, and at the same time allows the stirrer itself to remain simple. Copper covers, carefully fitted and in contact with the water, practically eliminate evaporation, both externally and internally.

2. When in their jacket these calorimeters are surrounded above and on all sides by a single compact body of circulating water, and have, therefore, a uniform environment. The calorimeter chamber can be opened at any time without disturbing either the circulation or the connections to the calorimeter.

3. The internally-wound type of furnace commonly used in the Geophysical Laboratory, modified to permit the dropping of bodies, was used for most of the temperatures employed. At 1500° the temperature of the charge was found uniform to a small fraction of one per cent.

4. A light swinging shield under the furnace controls the exposure of the calorimeter. It performs with certainty, ease and quickness the functions often sought through a movable calorimeter or furnace.

5. Temperatures uniform and constant to 0.1° at least are obtained for the interval from 200° to 600° in an electrically heated and stirred bath of melted metal, which surrounds but does not touch the body to be heated.

6. A steam-heated oven is also used. With this a simple automatic arrangement gives uniformity of results in dropping bodies into the calorimeter.

7. This paper makes a short addition to a previous discussion of equipotential leakage shields.

8. By partly inclosing the apparatus in cases which also contain drying material, and then coating with paraffine all exposed insulating surfaces, insulation was assured, without inconvenience, under atmospheric conditions previously considered almost fatal to high accuracy in the measuring system.

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