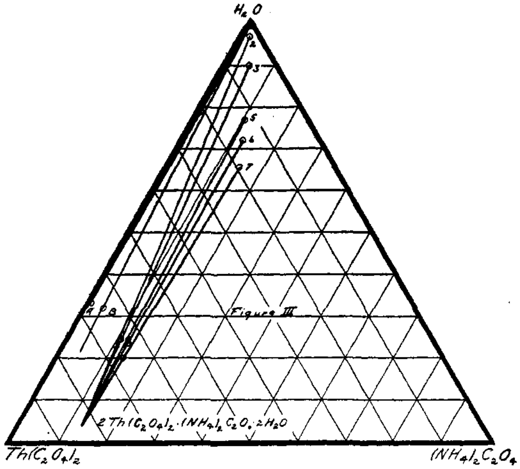

sible from the mother liquor by pressing between filter papers in a screw press. The pressed sample was quickly transferred to a weighing bottle and thoroughly mixed.

The thorium oxide and C_2O_3 contents were then determined.

The data are given in Table III and plotted in Fig. 3.

It will be seen that lines joining the points of the corresponding liquid and solid phases meet at a common point, expressed by the formula $2Th(C_2O_4)_2.(NH_4)_2C_2O_4.2H_2O$. This does not entirely agree with the results obtained by O. Hauser, since he finds three molecules of water present. However, the authors give the formula as obtained by the triangular diagram, and not from the analysis of the pure compound.

That portion of the curve in Fig. 1 represented by the line *AB* shows the solubility of thorium oxalate in ammonium oxalate. *B* and *C* are evidently transition points and the solid phase occurring in any bottles coming between these points should consist of the normal compound, $2Th(C_2O_4)_2.(NH_4)_2C_2O_4.7H_2O$, as described by Brauner. From point *C* in Fig. 1 to point *D* in Fig. 2, there exists, as the solid phase, the compound shown in the triangular diagram. From *D* to *A* in Fig. 2, the solid phase consists of thorium oxalate. Lines joining the corresponding points, representing the liquid and solid phases, do not meet.

This work indicates that at 25° there are only two ammonium thoroxalates.

DURHAM, N. H.

THERMOELEMENT INSTALLATIONS, ESPECIALLY FOR CALORIMETRY.

BY WALTER P. WHITE.

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For maximum precision in calorimetry, electrical thermometers are essential, and they are often considered to be also the most convenient. Among them the least exacting, the most accurate for small intervals, and the freest from sources of error is the multiple thermoelement when used with a small temperature difference between its two ends. With it the relative precision required in the electrical measurement is ordinarily from a hundredth to a thousandth of that needed with the resistance thermometer for the same thermometric precision. It is, accordingly, sometimes nearly indispensable, often the most convenient, and very seldom appreciably less advantageous than other types.

The thermoelement has been employed in this way for a number of years in calorimetric methods of great delicacy though of somewhat restricted scope, but the newer and more widely applicable thermoelement technic has scarcely been used in chemical work as yet, and appears accordingly to be rather unfamiliar to chemists. It has therefore seemed best, in presenting some recent modifications, to attempt also a rather complete account of the thermoelectric procedure, beginning in the present paper with the fundamental methods and apparatus, and following with descriptions of the thermoelement and of its application to the calorimeter. The methods and arrangements to be described are also in large part advantageous for precision thermoelement work in other subjects besides calorimetry.

1. The Thermoelectric Methods in General.

The salient features of the thermoelectric methods here presented are: (*a*) The temperature to be measured acts on the thermoelement, which is simply a slender, flexible bundle of fine, insulated wires, easily enclosed in a variety of ways, and, when once enclosed, detrimentally affected only by very severe treatment. No heat is produced in it. (*b*) The electrical quantity (electromotive force) furnished by this thermoelement is about proportional to the temperature interval, and, therefore, the relative precision required for measuring it is extraordinarily low, as already mentioned. (*c*) The electromotive force is measured with a potentiometer. (*d*) The system shares the general advantage of all potential methods, namely, it possesses an almost complete indifference to contact resistance, and thereby avoids one of the most troublesome and insidious sources of error in electrical work. (*e*) One consequence of this property is that the reading of different temperatures or electrical quantities during the same experiment is especially easy with the thermoelectric installation. (*f*) The thermoelement measures, primarily, only differences of temperature, hence some body of definite thermal condition must be provided to control the end not in the calorimeter. This provision, though it affords the means of simplifying the electrical measurement (as already pointed out), is also an inconvenience.

2. The Relative Precision Required.

The coils of the potentiometer must, in the nature of things, evidently be *calibrated* with as great relative precision as is to be obtained in the temperature determinations. This of course applies only to the coils of the highest valued decade used in any particular determination.

Potentiometer coils are ordinarily *adjusted* with a precision of from 1 per mille to 0.1 per mille. Hence corrections to the higher valued coils will often be necessary in working to 0.1 per mille, but will disappear entirely when the precision is less, or the instrument is very well adjusted. These corrections will be small and invariable; no coil corrections for temperature will ever be needed.

If the standard cell by which the potentiometer is regulated is a saturated cadmium cell, its electromotive force will vary 0.0001 for every 2° change in temperature, and a small temperature correction may be needed in very accurate work. The temperature correction of a Weston cell will be quite negligible.

The corrections required are therefore less than are usual with either a mercury thermometer or an electrical resistance thermometer.

3. The Absolute Precision Required.

The absolute precision required is the subject of most of the misconception which may exist regarding the thermoelectric system. Much potentiometer work is of such a character that for it a precision of 10 microvolts is remarkably good. With respect to this work, and to the corresponding apparatus, methods, and habits of thought, the precision of one-tenth of a microvolt, here recommended for thermoelectric work, is apt to appear extreme. The truth is, however, that this degree of precision has been selected not because it is indispensable, but because it has been found to be easily attainable in daily work, under any but the worst conditions.

A thermoelement of 24 copper-constantan couples, which may be only 5 mm. in diameter when enclosed, and will then seldom have more than 120 ohms resistance, is easily made and very convenient, and may be taken as the standard size for calorimetry. With it an *electrical* precision of 0.1 microvolt means a *thermometric* precision of 0.0001°. An electrical precision of 0.1 microvolt, therefore, is better than will usually be required for calorimetry, though 1.0 microvolt will be required in any case where the precision of electrical methods is needed at all. In *high temperature work* with platinum thermoelements a microvolt is usually the smallest quantity read, but it is sometimes very desirable in laboratory work at high temperatures to be able to read closer. In what follows here the precision in view will be 0.1 microvolt, as being easily attainable and often desirable or necessary. This precision, although greater than that used in some kinds of potentiometer work, is really low considering the thermometric precision obtained with it; it is only about half the microvolt precision commonly used to get a thermometric precision of 0.0001° with some of the best resistance thermometers.

4. The Instrumental Arrangements Needed to Give the Desirable Absolute Precision.

A precision of 0.1 microvolt, even though it is easily maintained, will of course require apparatus of greater effectiveness than is needed for reading to 10 microvolts. The galvanometer must evidently be more sensitive, though the sensitiveness needed is not extreme.

Secondly, the potentiometer, though it may be simpler and less expensive than the types most commonly used to-day, must be different from them, having greater precision, though its range may be less.

Finally, there must be one feature which is not found at all in potentiometer systems devoted to coarser measurements, but which is found in some form in Wheatstone bridges and other electrical installations of high precision; this is an arrangement for eliminating the effect of parasitic electromotive forces due to slight irregularities of temperature in various parts of the galvanometer circuit. Attempts have been made to avoid these in thermoelectric work by substituting copper for other metals at a few points in the galvanometer circuit and taking great care as to the room temperature, but such a procedure is laborious, and a vain thing for safety. The effect of the parasitics, however, can be eliminated from nearly all the circuit with ease and certainty by a suitable eliminating switch.

5. The Eliminating Switch.

The essentials in the operation of one form of eliminating switch are: (*a*) To remove from the galvanometer circuit the main electromotive forces, namely, those of the battery and of the thermoelement, leaving the parasitics alone in the circuit; (*b*) to eliminate the deflection due to the parasitics by moving the telescope or scale (by a "slow motion" of course) so that the galvanometer reading is zero; (*c*) to return the principal electromotive forces and read directly the *additional* deflection produced by them.

An admirable instrument for making this adjustment is a common 2-way, 2-pole copper knife switch. Fig. 1 shows the method of connection. In the figure the knives are thrown to the left for the adjustment

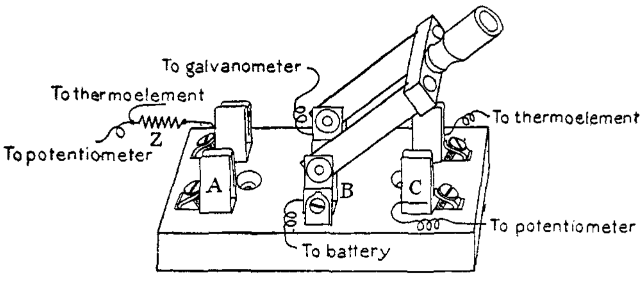

Fig 1.—Knife switch arranged to eliminate parasitic electromotive forces.

and to the right for the reading. Z is a resistance, to be explained presently.

The simple connections required can, of course, be secured in numberless ways,[1] but for low cost, minimum of attention required, and minimum probability of accident or trouble in working, there appears to be nothing equal to the knife switch.

The convenience of the knife switch can also be still further increased if the ordinary knife is replaced by one of twice the length, whose two ends make an obtuse angle with each other, as in Fig. 9 of the following paper in this series. The throw of the switch then requires a much shorter and simpler motion, and can be made by means of a pull rod, as in Fig. 9. From this latter fact follow several advantages: the switches can be protected by a box, through whose side the pull rods pass; a number of switches can be worked from almost the same point, immediately under the operator's hand; and the motion of several switches can be made nearly or quite simultaneous. This is an especial advantage in potentiometer work; illustrations of it will be given in Figs. 8 and 11 of the following paper. Switches of this modified pattern can be obtained from the manufacturers at about 40 cents extra cost each, for small orders.

In throwing the eliminating switch, it is essential that the thermoelement circuit should open before the battery circuit, and close after it, or else there may be a very large galvanometer deflection which would generally spoil the adjustment. This requirement is easily met by filing off a little from the edge of the knife on the thermoelement side of the switch.

The opening of the battery circuit when the switch is thrown removes the corresponding electromotive force without materially changing the galvanometer circuit, but the electromotive force of the thermoelement cannot be removed without disconnecting the thermoelement itself. But the deflection due to the parasitics will not remain the same unless the resistance of the circuit is the same. Hence during the adjustment a coil must be inserted, approximately equal in resistance to the missing thermoelement. This is Z of Fig. 1. If the maximum parasitic force is 4 microvolts (a rather large value) and the precision is to be to 0.1 microvolt, the parasitic currents evidently must not be changed as much as one-fortieth in the adjustment, and the galvanometer circuit resistance must therefore remain as constant as that. A constancy of 1% in the resistance is twice what is needed, and so gives a satisfactory margin of safety. Hence it will be sufficient if the resistance of the thermoelement does not differ from that of the coil Z, by more than 1% of the resistance of the whole circuit, that is, by more than from 2 to 10 ohms, as the case

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[1] See, for instance, "Potentiometer Installation, Especially for Thermoelectric and High Temperature Work." *Phys. Rev.*, **25**, 344 (1907).

may be. This degree of equality is, of course, very easily secured, and the necessity for it is in any case no objection to this method of elimination, since it is also usually desirable in order to maintain proper galvanometer sensitiveness[1] where several thermoelements are in use. The thermoelements with their leads must then be made equal to each other in resistance, and hence might as well also be made equal to *Z*.

There are several other effective methods of eliminating the effects of the parasitic forces, but the one just described appears on the whole to be preferable, at any rate for precision not very much greater than 0.1 microvolt.[2]

6. "Neutral" Contacts and Connections.

The arrangement and procedure just described effectively eliminate parasitic troubles in the galvanometer and the potentiometer; it is also necessary that the switch itself, and the leads from it to the thermoele-

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[1] For reading to *one-hundredth* microvolt with a 4 microvolt parasitic force, a constancy of resistance to about 0.001 of the total would be desirable, and to maintain this with various thermoelements might be troublesome, particularly if the total resistance had to be low, in order to gain sufficient sensitiveness. Hence in such a case there is more reason for preferring one of the methods of elimination, described in the following foot-note, which dispenses with the resistance Z. But it should be noted that to attempt to eliminate any parasitic effect to 1/400 of its value is a very unpromising task, so that readings to 0.01 microvolt will generally be accompanied by precautions against the occurrence of any parasitics approaching 4 microvolts in value, and in that case the resistance adjustment might still be preferable.

[2] (*a*) It is possible to record and apply a correction instead of adjusting the scale, but this is more laborious, complicates the record, and unless one is very systematic about it, may be a source of mistake. The correction must be applied to every accurate reading, while the adjustment, once made, is good for from one to ten minutes. (*b*) Instead of the deflection produced, the electromotive force itself may be compensated, by means of a device which is really a little potentiometer, made of a battery, a high resistance, and a very small variable resistance (A. D. Palmer, *Phys. Rev.*, 21, 72 (1905), and several other writers). This method, however, is not valid unless either (1) the resistance is kept constant, or (2) the galvanometer is first made to read zero on open circuit. But (1) with resistance adjusted to be constant this method is more complicated than the movable scale, without any countervailing advantage, while (2) in the other case it requires two adjustments, of which the one on open circuit is very tedious with moving coil galvanometers. The method, however, might still be worth while in very delicate measurements, especially if, as is likely to occur with them, the galvanometer was of the Broca type, which is damped on open circuit. (*c*) Another method of eliminating the effect of the parasitics is to reverse simultaneously both the battery and the thermoelement, by means of two commutators operated together, when half the algebraic sum of the two deflections obtained is the true deflection. Here the resistance is bound to be constant without any special arrangements, but this, as has been stated, is practically no advantage for precision not greater than to 0.1 microvolt, since constant resistance is needed also to give constant galvanometer sensitiveness; on the other hand, the method carries to an even greater degree the complexities of record and other defects which result from recording the zero reading, and this disadvantage, it is evident, is especially great in reading varying electromotive forces.

ment, be "*neutral*," that is, free from parasitic thermal electromotive forces. Thermoelectromotive forces are necessarily absent where no temperature difference exists, a condition which is often secured in switches by immersing them wholly in oil. This troublesome precaution, however, is quite unnecessary in working to 0.1 microvolt. Both the switch and the thermoelement leads can very easily be made sufficiently neutral, under all temperature conditions ordinarily occurring, by taking advantage of the uniformity and homogeneity now characteristic of the ordinary commercial copper sold for electrical purposes.[1]

There is, first, no danger of trouble along any single uninterrupted length of copper wire. Second, the very slight differences in thermoelectric quality which may possibly exist between wire and terminal are rendered harmless by the fact that these may all easily be made to occur in pairs, in each of which the two members are close together (and therefore always at the same temperature), and so connected that the exceedingly minute thermal forces either oppose each other or (in the eliminating switch) are substituted one for the other. And finally, the presence of thermal forces in the contact surfaces can be very easily prevented by appropriate methods of construction. These forces, whose existence is perhaps not universally recognized, are due to the fact that wherever two pieces of the same metal come together, whether soldered or not, the material right at the contact surface is thermoelectrically decidedly different from the rest. As long as the two metals on each side of this thin layer are at the same temperature, no trouble whatever results, but appreciable thermal forces are produced if there is a temperature gradient through the contact layer. A very effective way to prevent the formation of such a gradient in a temporary contact is to make the contact occur between two thin flat strips of metal, which will evidently come immediately to a common temperature, if the contact is good. A knife switch is excellent in this respect, but a still more effectively neutral contact is obtained by means of a very thin strip of copper, pulled into a spring clothes-pin, which serves as a clamp to maintain pressure on the contact. Cables or wires terminated by such contacts (Fig. 2), which are made to grasp other thin strips of copper, can be thoroughly recommended for the connection between the thermo-element and the eliminating switch, being rapid, adaptable, exceedingly cheap, and thermoelectrically unexcelled.

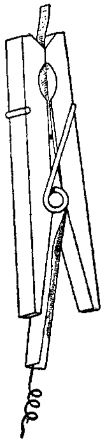
Fig. 2.—Quick, movable, neutral (or "anti-thermoelectric") contact.

This type of contact, by the way, really has a very wide range of profita-

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[1] For data as to this, see "The Thermoelement as a Precision Thermometer," *Phys. Rev.*, 31, 149 (1910).

ble use. I have used them for miscellaneous connections, instead of plugs in resistance boxes, as commutators, etc. (by suitable arrangements of several copper strips), and for several years as regular potentiometer switches. They really excel binding posts for most purposes and plugs for many, both on account of their quickness and because the spring insures that they will not spontaneously become loose, but as switches they are a little less convenient than some other arrangements, and are recommended mainly by their low cost and ease of installation.

Where two pieces of copper are *soldered* together, the same general condition obtains as in a temporary contact; that is, there is a thin intervening layer which must be free from temperature gradient. If one of the members is a wire, the equalizing effect of the broad contact is no longer fully obtained, hence it may be well to bring the two conductors to the same temperature before they reach the contact, which is done by putting them close together with thermal but not electrical contact (Wenner). In the clothes-pin contacts, this means merely folding the flat copper strip together over a part of the wire from which the original insulation has *not* been removed (Fig. 2), or, in the case of a more massive terminal, winding the insulated wire around it and cementing with some electrically insulating varnish, such as shellac.[1] As far as I know, this precaution has not been observed to be necessary except when the terminal is rather massive, and therefore apt to differ considerably in temperature from the air, but it is so very easy to take that it is best employed for high precision, and by all means in the eliminating switch of Fig. 1, which ought to be quite above suspicion.

The elimination of parasitic electromotive forces by means of the eliminating switch is very complete, and is dependent only on the effective neutrality of the switch itself, which should therefore be carefully tested as a prelude to any work of precision. The test is easily and quickly made, after the leads have been soldered to the switch, and before these have been permanently connected to the other apparatus. The leads from the two end clips (Fig. 1) are connected together to one terminal of a galvanometer, the lead from the center post to the other terminal; a difference of temperature is produced between the end clips (by holding one awhile between thumb and finger, for instance); the change of deflection caused by throwing over the switch is then observed.

Tests have been made here on four lots of switches, one of unknown make, the others, catalog numbers 710 and 980 of the Trumbull Electric

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[1] The wires should of course be as fine as is convenient. For the outer connections, where some strength is required, anything not larger than 22 cable (7 strands of 0.25 mm. diameter each) is unobjectionable, though for the stationary *neutral* connections much finer wire (0.2 mm. or less) had better be used, since its use entails no inconvenience.

Company. The contact clips were bent-up copper strips (Fig. 3), a form perhaps more likely than machined contacts to resemble the knife in quality of metal. With one clip heated by holding an incandescent light against it for several minutes the first deflection on throw-over was 0.5 microvolt, falling in 5 seconds to 0.1 microvolt, which lasted somewhat longer. Other similar tests gave comparable results.

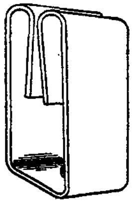

Fig. 3.—Contact clip of Fig. 1, in detail.

There appears, therefore, no doubt that under reasonable conditions these switches would never show a permanent parasitic force approaching 0.1 microvolt. To make certainty still more certain, however, it seems worth while to shield from drafts, as can be easily and simply done by an inverted box, perhaps using pull rods to work the switches, which in that case should have the longer bent knives mentioned above.

The substitute coil *Z* should of course also be thoroughly neutral. To make it so, the ends of the manganin coil are joined to very fine copper terminals, the junctions are brought as close together as possible and so wrapped or enclosed as to shield them from uneven temperatures without.

7. The Galvanometer.

The work here in view demands from the galvanometer nothing extraordinary or special. The period need not be less than 5 seconds; the necessary external resistance will not be more than from 60 to 300 ohms, depending mainly on the thermoelement used; the sensitiveness, for reading to 0.1 microvolt, should be 1 mm. per microvolt at 2 meters distance, that is, one scale division should correspond to a microvolt, and tenths should be easily estimated. Moving coil galvanometers of greater sensitiveness than this are now regularly catalogued, while at least two concerns furnish galvanometers whose efficiency is over twenty times that just stated.[1] This prescription, however, supposes a steady support for the galvanometer. Vibration of the building may lower the *effective* sensitiveness to one-fifth of its proper value, and may thus diminish the number of moving coil instruments available for a precision of 0.1 microvolt. But some of them would evidently still suffice, while a less precision than 0.1 microvolt suffices in most cases. Of course, galvanometer difficulties are not an affair of the thermoelement alone, but affect it rather less, if anything, than they do the resistance thermometer.[2]

[1] One of these is a moderate-priced instrument of the Cambridge Instrument Company, with a period of only 2.8 sec., a circuit resistance nearly 300 ohms, and a sensitiveness of *four* millimeters per microvolt at 1 meter. (For thermoelectric work with this instrument the resistance should be increased at the expense of the unnecessarily short period or of the sensitiveness, which would usually be excessive.) The other is a *special* galvanometer of the Leeds and Northrup Co.

[2] Because the microvolt sensitiveness of the resistance thermometer, as ordinarily used, is less, and the required galvanometer sensitiveness, therefore, greater than with the thermoelement.

If the type of galvanometer available more than meets requirements, convenience dictates that some of the extra efficiency, at least, should lie in the direction of high resistance, for this makes the circuit less sensitive to changes of resistance, and hence diminishes the care and attention needed to secure the constant galvanometer sensitiveness which permits rapid observing. Little gain comes from having the sensitiveness much more than sufficient to permit estimating the smallest unit which is to be recorded. A satisfactory combination is: microvolt sensitiveness, 0.5 (that is, 0.5 mm. at 1 meter—the same as 1 mm. at 2 meters); period 3 to 4 seconds: resistance as high as possible up to 1000 or 1200 ohms. The makers of galvanometers can advise regarding the attainment of the most satisfactory performance in any particular case.[1]

Many galvanometer installations could easily be given higher effective sensitiveness by the use of a more powerful telescope. In most cases, also, the sensitiveness can be nearly doubled simply by putting the scale much farther from the mirror than the telescope is—a device presumably well known, but surprisingly little used.

For high temperature work and in other cases where a precision of only a microvolt is counted sufficient, the galvanometer may be less sensitive, and therefore cheaper and a little less delicate to handle, but in such work high resistance and shortness of period are often more important than in calorimetry.

8. Special Conveniences of the Thermoelement System.

The very simple eliminating switch with its neutral contacts, the fairly sensitive galvanometer, and an appropriate potentiometer (to be considered later)are the three special features *required* by the auxiliary system of the precision thermoelement. That system *offers* two other features which are of great convenience, namely, facility in reading different instruments during the same observation, and facility in using large deflections of the galvanometer so as to simplify observing. Both are possible with other systems, but are especially effective with this. The reading of different instruments is somewhat dependent on the design of the potentiometer, and will be treated along with it in a following paper.

9. Deflection Reading.

One great and largely unappreciated advantage of thermoelement and potentiometer methods is the ease with which switch manipulation can be diminished, and time and errors accordingly saved, by the accurate reading of relatively large galvanometer deflections.

The relations of all-deflection, partial deflection, and null methods, are well illustrated by the case of the balance. An all-deflection instru-

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[1] Some help may also be obtained from a rather technical discussion in "Every-Day Problems of the Moving Coil Galvanometer," *Phys. Rev.*, **23**, 382 (1906).

ment is the spring balance, quick but relatively inaccurate. The null method, accurate but slow, is obtained when the beam balance is counterpoised till it reads exactly zero. The partial deflection method, intermediate in speed, but quite equal to the null in precision, is merely the ordinary practice, where the last figures of the result are read with the pointer. It requires, of course, a moderately constant sensitiveness.

In electrical measurement, the obtaining of an exact balance is usually less tedious than in weighing, and the maintenance of constant galvanometer sensitiveness is usually troublesome with the Wheatstone bridge, and also with some potentiometers, hence for electrical work of precision null methods have been extensively used. From this fact, probably, has arisen the tendency, sometimes apparent, to think of null methods as the only possible precision methods in electrical work, which has in one case resulted in the wholly unwarranted assertion that partial deflection methods are intermediate in precision as well as in speed between all deflection and null methods. In reality, partial deflection reading gives quite as much precision in electrical work as null methods do, while with appropriate potentiometers its speed and other advantages are obtained with very little inconvenience.

The partial deflection method here considered, like the best methods of weighing, has the sensitiveness not merely constant, but in some standard unit, so that the last figures of the result are read directly from the scale, and annexed to the switch reading without addition or subtraction. The proper degree of sensitiveness is obtained by proper selection of scale division length and scale distance, Fig. 4 shows a very convenient method of numbering the scale, which makes all the readings positive and yet brings the zero′ at the middle. It is obtained by adding 1000 to the negative readings as the scale is numbered.

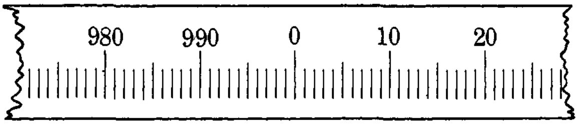

Fig. 4.—Positive scale with zero at the center, for partial deflection reading.

To maintain constant sensitiveness during any set of observations, it is only necessary to keep the galvanometer circuit resistance constant. The reason why the thermoelement system especially favors deflection reading is because the resistance of most thermoelements never varies much, and because the potentiometer can easily be made to have a constant resistance in the galvanometer circuit.[1] The very slight changes in galvanometer sensitiveness due to other causes can be corrected by

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[1] In case it does not have this, a hand regulation of the circuit resistance is easy and well worth while, except where frequent and considerable changes of the potentiometer setting are being made. See "Potentiometer Installation," *Loc. cit.*, pp. 337–340.

adjusting the circuit resistance or by varying the scale distance, as may be convenient. The sensitiveness can, of course, be adjusted or verified in a moment at any time, since it can be tested, while any nearly constant electromotive force is being read, by merely moving one of the switches and noting the resulting change of deflection.

Where different thermoelements (or other apparatus in their place) are used, the necessary constancy of resistance is secured by inserting in the circuit with each a small, *neutral*, "complementary" coil, so adjusted that the combined resistance of coil and thermoelement is, to a rough approximation, the same in every case, and equal to the coil Z of the eliminating switch.[1] Since these coils help to secure not only the advantages of deflection reading, but also the most convenient method of eliminating parasitic forces, the very slight labor of making them is well worth while. As a rule, the ease and convenience which recommend this method are destroyed by an attempt to keep the galvanometer sensitiveness certainly constant to 1 per mille. It is therefore generally best to read only the last two figures of the result on the galvanometer, which calls for complementary resistances adjusted to at most 0.5% of the total galvanometer circuit resistance, that is, only to one ohm or more.

The advantages of deflection reading lie in several directions. There is first, in general, the evident gain in convenience and speed, with attendant diminution of the chances for mistakes in recording, and also, incidentally, a reduction, sometimes very important, of the number of switch dials needed in the potentiometer. Second, there are special advantages wherever, as in most thermal work, the electromotive force read is varying.

In such determinations, the only way to work the *null* method is to observe the more or less irregular times at which the scale reading passes through zero for different previous settings of the switches. A chronograph is needed for any considerable precision, and the simultaneous following of two or more differently varying temperatures, often essential and nearly always desirable in melting point and recalescence work, is difficult and confusing. When deflections are read, on the other hand, the observer, watching the scale while he gets the exact instant of reading from the ticking of his timepiece or from a bell signal, easily takes accu-

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[1] It is convenient to make the terminals of these coils consist of two flat copper strips, 3 or 4 cm. long, close together and separated by mica or celluloid, which are put in the circuit by being inserted between the line and switch terminals, as these are clamped together. A very compact, convenient, and easily constructed arrangement results if the copper strips are made to hold the coil (laid flat) between them, being held together by bending the edges of one over the other, of course with an insulating strip between. They are stamped or marked to indicate with what thermoelements they may be used. The manganin wire of the coils is connected to the terminals by means of fine copper wire, with other precautions as already described for neutral coils in connection with the description of the coil Z.

rately timed readings without the chronograph; frequent readings of different varying temperatures present no difficulties; and the equal timing of the observations greatly facilitates their subsequent treatment.

The latter point is important in calorimetry. As a rule, most of the observations in calorimetry relate to the cooling correction, and are worked up to get the average temperature for a given period of time. For the irregularly timed data given by null readings, the best method of reduction is to plot and apply a planimeter. But this graphic treatment, very properly recommended as a great saving of labor by those who have had in view the null method data, is clearly much more trouble than the simple addition which alone is required for the data obtained by deflection reading. The observer, therefore, will very soon be repaid for the slight labor needed to fit his installation for deflection reading.

The summary is combined with that of the following paper.

POTENTIOMETERS FOR THERMOELECTRIC MEASUREMENTS ESPECIALLY IN CALORIMETRY.

By Walter P. White.

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In order to be well adapted for accurate thermoelectric work, a potentiometer should show a precision of 0.1 microvolt, because this precision, as a rule, can readily be reached in the connections and galvanometer, and to fall short of it in the potentiometer involves a waste of facilities, limiting by so much the efficiency of the thermoelement. There are also other features which, though not essential, are desirable in a potentiometer for thermoelectric purposes. The range, however, may be relatively low, so that such potentiometers, in spite of their high precision, are of relatively low cost. To avoid confusion it may be well to point out that some slide-wire instruments, specially designated as "thermoelectric," have little in common with the instruments here considered, and are, in fact, peculiarly undeserving of their name on any grounds, having almost no feature which specially adapts them for thermoelectric work, and several which hinder. These potentiometers, however, like most others, are satisfactory in many cases, and particularly in high temperature measurements, where the sensitiveness, and usually the precision also, of the thermoelement, is far in excess of requirements.

1. Essentials of the Potentiometer in General.

A potentiometer is a row of resistances in series, through which a current, the "auxiliary" current, is passed from a constant battery. This current is kept constant by occasionally adjusting it so that the "drop" (potential difference) through a fixed resistance balances a standard cell. Then, since in a simple circuit the drop is proportional to the resistance,