

T H E

# AMERICAN JOURNAL OF SCIENCE

[ F O U R T H   S E R I E S . ]

---

ART. XIX.—*A Universal Switch for Thermoelement Work and Other Potential Measurements*; by WALTER P. WHITE.

THE switch here described is used to simplify the manipulations required in making simultaneous measurements with different electrical instruments, especially thermoelements or other sources of electromotive force. The type is more effective, thermoelectrically, than any other known to me, is more convenient to manipulate, is easier to take apart, inspect, or clean, and has a distinctive advantage in the ease with which it can be constructed. Similar switches have been used in our laboratory for the following purposes, among others: (1) In melting point determinations, to measure the temperature at one or two points in the furnace cavity as well as in the charge, thus permitting a better regulation of the furnace temperature, an allowance for its fluctuations, and a closer estimate of the thermal magnitudes involved;\* (2) in work on heat conduction, to avoid certain errors by measuring the temperature at several points instead of one, and to measure both gradient and temperature rate without elaborate duplication of apparatus; (3) in calorimetry, to measure, besides the calorimeter temperature itself, various temperature differences, upon which the corrections depend, or which, though ordinarily not necessary, and hence not likely to be observed unless observing is easy, may be of the highest diagnostic value if unexpected errors appear; (4) in specific heat work, to make measurements upon both furnace and calorimeter; (5) in some other kinds of determinations, to measure electrical energy along with the calorimetric temperatures; (6) in calibrations and comparisons of many sorts, whether of thermoelements, resist-

\* Cf. *Melting Point Methods at High Temperatures*, Walter P. White, this Journal, xxviii, 478, 482-88, 1909; Zs. anorg. Chem., lxi, 337, 342-50, 1911.

ances, voltages, or currents, to permit the different measurements to be alternated with a rapidity that greatly increases precision and also to allow necessary or desirable auxiliary measurements to be made in many cases.

For many of these purposes a double potentiometer, or something equivalent, is almost necessary. Such potentiometers are now readily obtainable and at a low cost;\* the exchanging switch here described may therefore be said to complete the provision of a satisfactory outfit for all such kinds of work.†

In determinations such as those just mentioned, it is of course often possible to get along with but one electrical measuring instrument, and in many cases a procedure which permits this has been developed, so that the use of more than one seems strange, if not over complicated. This situation, however, may be regarded as the legacy from a régime of crude or restricted apparatus, for as a rule the procedure with only one electrical measuring instrument is obviously and seriously disadvantageous.‡

In mere convenience also, aside from the value of the results, a switch like the present will in a few years more than pay for its installation.

Of course, all these considerations gain in weight as the construction of the switch becomes easier, and it is partly on account of its ease of construction that the present switch has seemed to deserve a separate description. The mechanical parts of our own took about 13 hours to make, including experiments and mistakes; this corresponds to a cost of about \$10.00 for the whole switch, since the cost of materials is practically nil.§

\* Potentiometers for Thermoelectric Measurements, Especially in Calorimetry, Walter P. White, *J. Am. Chem. Soc.*, xxxvi, 1874-5, 1914.

† The arrangement of knife switches shown on page 1878 of the same paper has been used, modified for 14 thermoelements, with complete satisfaction for about a year, but it took longer to install, is not so simple in operation, and is harder to overhaul than the one described in the present paper. If the mechanical arrangements of the switch here described had been thought of a little earlier, it would have been used instead. For work with a single potentiometer and a few thermoelements (say, 4 or less) the knife-switch type is probably preferable.

‡ For instance, Hüttner and Tammann describe a calorimetric method wherein, in order to avoid a second thermometer in the furnace, they make, regarding the furnace temperature, an assumption palpably contrary to fact, as Plato has shown (*Zs. anorg. Chem.* xlv, 721, 1906). And Plato, in his turn, though he did use a second thermometer for his own admirable work, nevertheless, in trying to formulate a method which demands but one, was compelled to make another assumption, also erroneous, regarding furnace temperature (namely, that there is no difference between the temperature of a cooling furnace and that of a charge within it.) In several calorimetric methods, also, precision and convenience have often been sacrificed by the lack of suitable provision for determining the temperature difference between jacket and calorimeter.

§ Of course this estimate might not apply in the case of a factory-made switch.

The electrical arrangements figured here are those appropriate to a four-dial combination potentiometer, with eight connections for various "unknowns," but can easily be modified for other methods of potential measurement. The type of contact used is not suitable for resistance measurements of the highest precision, unless by methods which eliminate the resistance of the contacts. Several features of the arrangement could well be used for resistance measurements, but we have had no occasion to develop any apparatus for such.

The leading features of the switch are the following:

1. The contacts are made between strips of thin sheet copper. This arrangement probably gives as small parasitic electromotive forces as any known, and is evidently among the first also in ease of construction.

2. Sheet celluloid\* is used exclusively for insulation, laid over wood where solidity is necessary. This also makes for very low cost of construction, by saving the time needed to work hard rubber. The copper strips are held in place by tacking celluloid strips over them (keeping the tacks away from the copper) or bending the copper over the edges of the celluloid, using shallow notches in the edges of the celluloid, or slits or holes through it, to keep the copper located. Further details on this point seem unnecessary.

3. The contacts are made by pressure alone.† Hence when the pressure is released the moving parts will return to their resting positions if light springs are provided for the purpose. It is sufficient, therefore, in devising any scheme of connections, to arrange for exerting pressure at several points, and this enables an exceedingly convenient system of connections to be very easily obtained.

4. The convenient system of connections in the present case is obtained as follows: A straight wooden rod, when pressed in, presses against the "unknown" (say the thermoelement) contact, closing that. At the same time, a pin, projecting sidewise from the rod, pushes a frame which carries the auxiliary (usually the potentiometer) contacts. A turn of the rod makes the pin strike a different frame, giving a different

\* Celluloid does not enjoy the best reputation as an insulator, but I found in two samples of sheet celluloid 0.3<sup>mm</sup> thick, one over 5 years old, in damp weather, a resistance certainly exceeding 600 megohms between tightly pressed metal conductors of 7<sup>sq</sup> cm area. Only in air of extreme saturation have I observed detectible surface leakage with it. Of course thin hard rubber can be used like the celluloid, and even with hard rubber bars the switch can not be considered elaborate in view of what it can do.

† The question has often been raised whether pressure, with practically no friction, would give a reliable contact. In five years' experience I have uniformly found that it does, with the surfaces cleaned certainly not oftener than once in three months. The pressure was several hundred grams on each contact surface of about 6 × 20<sup>mm</sup>, but less would probably have answered.

auxiliary. The rod, when pushed in, is locked by an iron bar. It first raises the bar, unlocking any other rod that may have been in. Hence, finally, to get a connection for any thermo-element (or other "unknown") along with its auxiliary, we have only to push the rod for that thermoelement, paying no attention to the auxiliary or to any previously connected thermo-element; and the auxiliary can be instantly changed for any thermoelement by rotating the rod between the thumb and finger.

*Detailed Description.*

The base is a shallow wooden box, 5<sup>cm</sup> high inside, and with other dimensions as shown in fig. 2. Pins (cut from wire brads

FIG. 1.

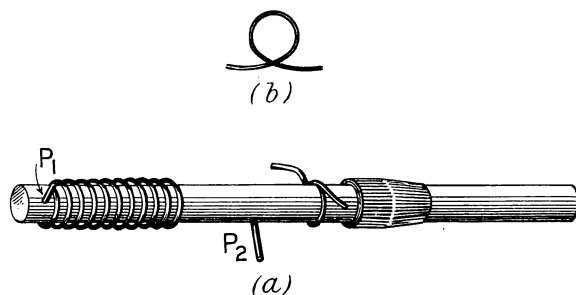


FIG. 1. Operating rod and its orienting collar. 0.4 full size.

about 3<sup>mm</sup> in diameter) project from it at suitable places to serve for attaching the other parts of the switch. Grooves 1.7<sup>cm</sup> deep in front and back hold and guide the rod of the lower auxiliary-connecting frame. The floor and sides project 13<sup>cm</sup> beyond the back.

The *operating rods* (fig. 1) are pieces of 1/2 inch (12<sup>mm</sup>) birch dowel 18<sup>cm</sup> long. The brass sleeve is turned from tubing 1.8<sup>mm</sup> thick, fitting the rod rather closely. It is pinned in place. The coiled spring is for returning the bar when it is unlocked; the pin, P<sub>1</sub>, is to hold the spring. The pin, P<sub>2</sub>, is to move one of the two auxiliary connecting frames. The wire collar (shown separate in fig. 1b) is to prevent the rod from rotating except when purposely turned by the operator. The rod then turns within the rather tight-fitting collar. The collar can never turn far, since the projecting ends would then strike the flat surface of the lower auxiliary frame. Hence the rod, when turned so as to make its pin engage either auxiliary frame, stays so till pressure enough is applied to turn it within the collar.

The *frame for the operating rods* (F, fig. 2) is a rectangular frame made of 4 wooden strips about 20<sup>mm</sup> square, with holes

giving a very easy fit for the operating rods. It is held in place by slipping over two vertical pins in the base, and can be lifted off at any time. It carries the locking bar, which is a piece of strap iron 2<sup>mm</sup> thick and 12<sup>mm</sup> wide, bent as shown and pivoted by two steel pins,  $P_3$ , clamped to the top of the frame. In fig. 2*a*, this bar is shown holding the second operating rod forward, by means of its brass sleeve, while the rod in its turn holds forward the lower auxiliary-connecting frame  $X_2$ . The back of the operating rod frame is fastened to the sides with screws, since it must be removed in order to take out any of the rods.

The *thermoelement leads* are copper strips 0.1<sup>mm</sup> thick and 6<sup>mm</sup> in width, which enter through a wide crack left below the back of the base, are fastened (with celluloid insulation, of course) to the wooden strip, E (figs. 2*b* and 3) and then rise vertically, supported by a celluloid strip 8<sup>cm</sup> high, over whose top their extreme ends are bent as a fastening. The celluloid is cut down from the top to the bar, so as to form a series of tongues, 24<sup>mm</sup> broad, each carrying a pair of leads. These leads are separated 6<sup>mm</sup>, or 12<sup>mm</sup> between centers. They run up on the back, or farther side, of the celluloid.\*

To make contact, when the switch is in use, a celluloid tongue is bent back by one of the operating rods, and so presses the copper leads against the *thermoelement bus bars*. This is a wooden support 20<sup>mm</sup> square, carrying on top a copper strip with teeth 6<sup>mm</sup> wide, and 24<sup>mm</sup> apart between centers, projecting down over the first (or near) face, and another strip below with alternating teeth projecting upward. The teeth of course stand opposite the thermoelement leads. From these two toothed strips the electrical connections run to the eliminating switch (not a part of this switch) and thence to galvanometer, potentiometer, etc., in part through the auxiliary bus bars soon to be described. The two pieces of copper are insulated and held in place by sheet celluloid, as already explained. The operating rods do not directly touch the vertical celluloid tongues but press against the obtuse apexes of the broad flat wooden wedges, W, shown in figs. 2, 3. These wedges are 1<sup>cm</sup> thick, 2<sup>cm</sup> wide and about 3.5<sup>cm</sup>

\* One form of leakage shielding, hitherto not described, but sometimes desirable, is relatively easy with this arrangement of terminals. (For general principles and methods of leakage shielding, see: Leakage Prevention by Shielding, Especially in Potentiometer Systems, Walter P. White, J. Am. Chem. Soc., xxxvi, 2011, 1914). If one thermoelement is in a furnace, or anywhere where shielding is incomplete, and is to remain there while readings of maximum precision are made on another thermoelement, a troublesome leakage current may enter the measuring system by leaking from the disconnected end of the furnace thermoelement at the switch, since insulation alone cannot, as a rule, be relied upon to protect a sensitive thermoelectric system from leakage from power circuits. The remedy is to arrange so that all the pairs of thermoelement leads, when disconnected, are separated from each other within the switch by a shield. To this end, each pair has a separate celluloid strip, and these strips are separated from the wooden parts by two metal plates which are connected to the external shield, are carefully insulated from the rest of the switch, and may even be further isolated, beyond the insulation, by a branch of the internal shield.

FIG. 2a.

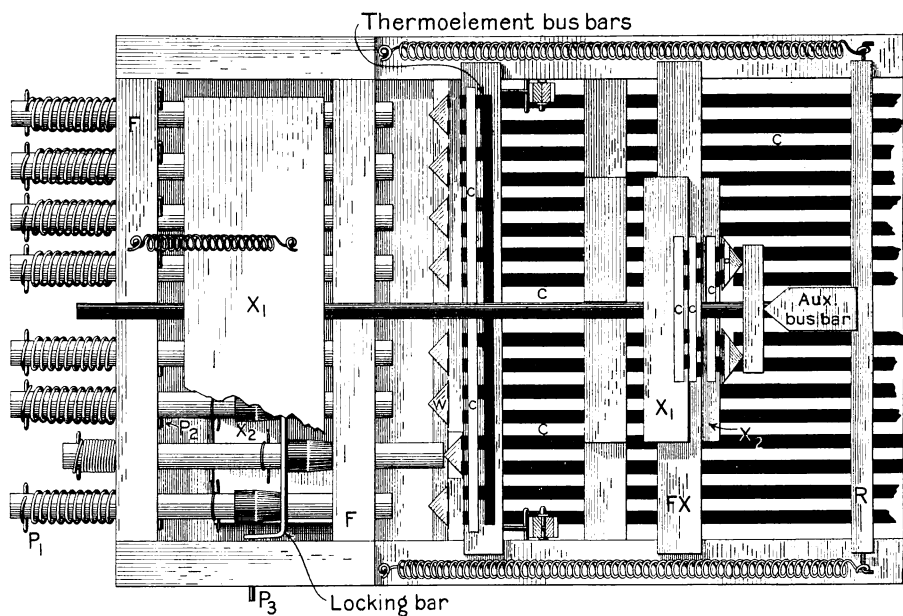


FIG. 2b.

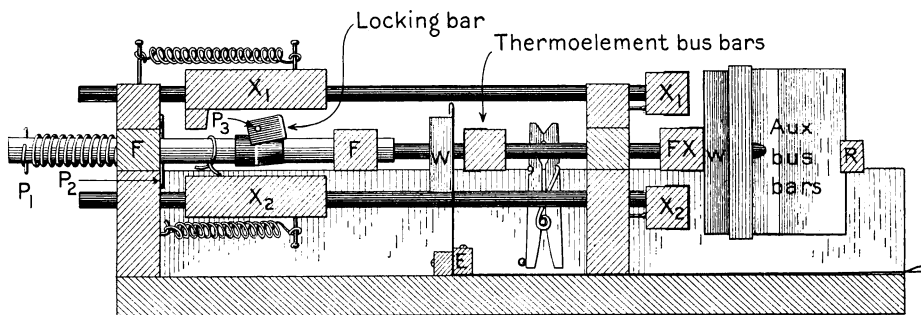


FIG. 2, a and b. Top view and section of the whole switch. In the view, above, the second pair of thermoelement lead terminals and the lower auxiliary-connecting frame,  $X_2$ , are pushed back (to the right) by an operating rod, and thus put in circuit. In the section below, the fixed auxiliary-connecting frame,  $FX$ , is making contact, but the circuit is open at the thermoelement terminals. Scale,  $\frac{1}{16}$  full size.

Copper strips are shown full black; other metal and wood, shaded; celluloid insulation,  $C$ , clear white. The lettering is otherwise explained in the text.

high. They are fastened to the celluloid tongues by small-headed pins above and below the level of the bus bar. Their function is to insure that the pressure of the operating pin shall be shared by both copper strips. These bus bars are so located that when any operating pin is pushed in and locked, the bars are pushed back 2<sup>mm</sup>, straining one or both of two stiff springs. Suitable springs are obtained by mounting two spring clothespins at the places shown in figs. 2*a* and *b*, and in the manner shown in fig. 3, so that they are opened when the bus bars are pushed back. The

FIG. 3.

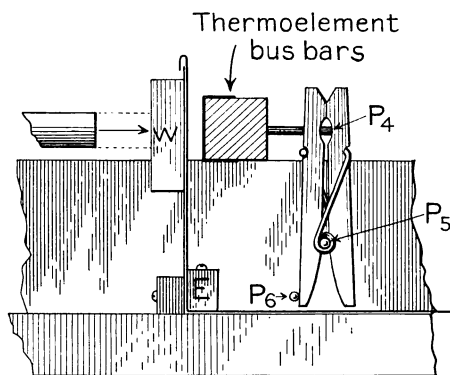


FIG. 3. Detail of thermoelement connecting system from fig. 2, *b*. The pin  $P_4$  is tight in the bus bar support, and passes very loosely through one side of the clothespin, to press against the other side. It prevents the clothespin from sliding off the horizontal steel pins  $P_5$  and  $P_6$ . By pushing the bus bars to the left the clothespin can be removed. Scale,  $\cdot 4$  full size.

strip of wood *E*, carrying the thermoelement leads, is so located that the leads, when released, are 6<sup>mm</sup> from the bus bars.

The two *movable auxiliary-connecting frames*,  $X_1$  and  $X_2$ , fig. 2, are intended to make connection with the appropriate auxiliary apparatus (usually, potentiometer dials) when any one of the thermoelements (or other "unknowns") is connected. Each is made with a 5/16 inch (8<sup>mm</sup>) mild steel rod 28<sup>cm</sup> long, driven with a very tight fit through two strips of wood, one 20<sup>mm</sup> square and 12<sup>cm</sup> long, the other 6.5<sup>cm</sup> wide, 20<sup>cm</sup> long and 18<sup>mm</sup> thick. The square strip carries 4 copper strips (fastened and insulated by celluloid, as usual) which are connected to a set of 4 potentiometer switches. The broader strip of wood is pressed by the pins  $P_2$  of the operating rods. The steel rod does not pass through the wood midway of its thickness. In the lower frame, the top of the broad strip must be 12<sup>mm</sup> below the center line of the operating pins, while the top of the 20<sup>mm</sup> strip must be 17<sup>mm</sup> below. Hence the steel rod is 5<sup>mm</sup> lower in the broad bar than in the narrow one. In the upper frame, the broad strip must be

20<sup>mm</sup> above the center line, in order to clear the locking bar; hence the iron rod is 3<sup>mm</sup> nearer the bottom in this strip than in the 20<sup>mm</sup> strip.

Between the back ends of the upper and lower auxiliary connecting frames is the *fixed auxiliary-connecting frame* FX (fig. 2) which is merely a single square wooden strip provided with 4 insulated copper strips like the others. Like the rod frame it is held in place by two steel pins in the base, and can be lifted off at any time.

Contact with the auxiliary-connecting frames is made by the *auxiliary bus bars* (fig. 2). This arrangement consists of two broad wedges, 8<sup>cm</sup> long, borne on a wooden cross-piece, which rocks on the wedge-shaped front of another flat piece of wood. The two wedges carry (with suitable insulation) 4 strips of copper, opposite to those on the frames, and running to the battery and galvanometer terminals to which the potentiometer switches are to be connected. The whole is pressed forward by the rod, R, which is pulled by two long springs. The object of the two wedges and rocking cross-piece is, of course, to divide the pressure equally among the 4 contacts. The combination is fastened together as follows: Through the cross-piece, opposite the apex of each of the 3 wedges, are bored 2 holes, large enough to be an easy fit for a small nail. Each hole is then counterbored nearly through so as to take the head of the nail easily. The nails are then driven through into the wedges, far enough to hold these in place but still permit the slight rocking motion required. Pressure against the wedges of course causes no wear or other injury to the holes.

When the movable auxiliary-connecting frames are out of action, the contact strips on them are about 4<sup>mm</sup> to the front (left, in the figure) from those on the *fixed* auxiliary-connecting frame, so that this frame receives the pressure of the bus bars, and is thereby connected in. When either of the movable frames is pushed in, it pushes the bus bar away from the stationary frame, breaking that connection at the same time as it establishes its own. Thus with 2 movable frames three sets of connections are possible. When the moving frame reaches the bus bars two sets of connections are joined parallel for an instant, but this does no harm in the case of a potentiometer. If in any case this momentary paralleling of connections should be deemed undesirable, it could be avoided by a different, probably slightly less convenient, arrangement of the contacts. The bus bars must be moved about 3<sup>mm</sup> to clear the stationary frame freely, and after that 8<sup>mm</sup> further while the thermoelement contact is being established. The springs must be long enough so that this motion of 11<sup>mm</sup> will not greatly increase the pressure exerted.

The operating rods move 10<sup>mm</sup> before engaging the movable auxiliary-connecting frames. Hence these frames, at rest, are 10<sup>mm</sup> from the resting position of the impelling pins, P<sub>1</sub>, of the operating rods. This 10<sup>mm</sup> of motion is used to raise the locking



bar, *b*, and break the previous connection before the coming connection begins to be made. The rods then carry the frame 15<sup>mm</sup> further. Of this, 4<sup>mm</sup> brings the frame to the auxiliary bus bars, and then comes the 11<sup>mm</sup> just described. The travel of the operating rod thus performs three operations, each of which must be finished before the next begins: (1) releasing the previous connection, thus opening the circuit; (2) making the proper contact with the auxiliary bus bars, thus putting into action the proper set of potentiometer switches (or other auxiliaries); (3) closing the circuit as it puts in the desired thermoelement, or other unknown.

The auxiliary bus bars make contact sometimes near their top, and sometimes below, yet they must remain vertical. To secure this a 5/16 (8<sup>mm</sup>) steel rod is driven tight into the back piece, and runs forward, through a very long bearing. This bearing is formed by a hole in the stationary auxiliary-connecting bar, and one in the front bar of the operating rod frame. The steel rod passes without touching through larger holes in the bus bar cross-piece, in the thermoelement bus bar support, and in the back of the operating rod frame. It must of course be withdrawn (taking away the bus bars) before lifting off any of the structures through which it passes.

To make room for this rod, and for the rods of the movable auxiliary-connecting frames, which are in line with it, above and below, an interval of 40<sup>mm</sup> is left between centers of the two innermost copper connections of all the sets.

The rod of the upper auxiliary-connecting frame slides in grooves in other blocks, one of which, 20<sup>mm</sup> high, is permanently nailed upon the front of the operating rod frame; while the other, 40<sup>mm</sup> high, is fastened by two steel pins to the back of the base so as to be removable. This block also has a hole for the rod of the auxiliary bus bars.

The indispensable eliminating switch\* is not included in the present description. At present we are using a triple knife switch as already described,† but we have also used with success something similar to a pair of operating rods, arranged so that each makes the necessary three contacts, instead of two.

For making the necessary electrical connections the various copper strips are left long enough to be clamped together, thus making a system without a single soldered joint, but wires can also be introduced without detriment.

Less cleaning will be needed if the contact surfaces are silver plated. The parasitic thermoelectric forces developed at the contacts are then about three times those for clean bare copper, but are still ordinarily quite negligible in working to tenths of microvolts. The amount of cleaning needed by unplated copper, however, is less than is given to most dial switches. But if corrosive

\* Thermoelement Installations, Especially for Calorimetry. Walter P. White, J. Am. Chem. Soc., xxxvi, 1859, 1914.

† Thermoelement Installations, etc., loc. cit., p. 1859.

gases (except chlorine) are likely to be abundant, gold plating might be very desirable.

In order to provide for 16 connections it would be best to have two operating rod frames, one on top of the other, two thermoelement bus bars, and one more auxiliary-connecting frame.

The auxiliary-connecting frames together constitute the "master switch" for the potentiometer used. If this is a combination potentiometer\* another arrangement has considerable advantages, though details have not yet been worked out. For it everything resembling a master switch is omitted, and the 4 potentiometer dials are replaced by 40 strips of copper, arranged in parallel lines running from the operator, clamped by a series of wooden strips, insulated with celluloid as in the switch. Above and at right angles to these are several, perhaps 4, sets of contact makers, each consisting of 4 contact pieces sliding on a stout bar, or pair of bars, and performing the functions of the arms of 4 dial switches. Each auxiliary-connecting frame, when pushed back, depresses one of the contact-making bars by means of a suitable connecting mechanism, thus putting into action the particular dial setting made upon that particular bar. This arrangement gives a quadruple potentiometer more easily and cheaply than by a series of dials, and is also more nearly neutral; though it is not quite so completely neutral as a Diesselhorst-Wölff potentiometer.†

#### *Summary.*

A switch combination is described, intended to promote rapidity (and, therefore, often accuracy also) in making comprehensive and varied measurements with potentiometers. The type is characterized by the use of contacts between thin copper strips, which is, thermoelectrically, perhaps the best contact obtainable. A new mechanical arrangement greatly promotes convenience and flexibility in operation. Other schemes make construction and overhauling extraordinarily easy.

Geophysical Laboratory,  
Carnegie Institution of Washington, Jan. 25, 1916.

\* Potentiometers for Thermoelectric Measurements, etc., loc. cit., page 1874.

† Diesselhorst, *Instrumentenkunde*, xxxiii, 1, 1908; Potentiometers for Thermoelectric Measurements, etc., loc. cit., pp. 1871-73.