crease the sensibility and permit the use of moving-coil galvanometers of reasonably attainable behavior, it is necessary to keep down the total resistance of the potentiometer. This causes the contact resistances of the adjustable parts, such as the dials, to become of importance, and a very exact and somewhat complicated mechanical construction is required to eliminate this source of error. It appears to be practically necessary, in designing a potentiometer, to choose between some contact resistance or some thermal E.M.F.

For rapid work, it is desirable that the potentiometer circuit be so designed that the standard cell may be checked up without disturbing the potentiometer circuit, and similarly it is advantageous to be able to change the range of the potentiometer without disturbing the regulating rheostats or rechecking the standard cell. Sometimes, also, the final figure in E.M.F. is obtained from the galvanometer deflection, in which case it is convenient to make provision for a constant galvanometer sensibility for all E.M.F.'s, which may be effected by auxiliary resistances in the galvanometer circuit.

A very important matter is that of insulation, or the prevention of leaks from one part of the potentiometer circuit to another (internal leakage) and from the outside to or from this circuit (external leakage). The former becomes less important with low-resistance potentiometers. The latter effect becomes particularly menacing when the thermocouple is immersed in an electrically heated furnace. It can be overcome by interposing wire-connected equipotential shields made of metal between the measuring system and all external sources of E.M.F., or by reversal of the heating or other suspected circuit and taking the mean of the potentiometer readings.

Most of the potentiometers in use are, in part at least, slide-wire instruments, but for the very highest accuracy it is advisable to use the more costly dial construction throughout. As we shall see, potentiometers suitable for the thermoelectric or resistance measurement of temperature may now be obtained, provided with five dials and reading accurately to 0.1 microvolt, or to considerably better than any thermocouple can be depended upon at high temperatures.

An inconstant battery is troublesome, and in exact work it is necessary to pay particular attention to this point in addition to frequently checking against the standard cell. Accumulators of considerable volume, or several so connected as to give a minimum change of E.M.F. with time, should be used; and it is well, since so little current is taken from the battery, to have it constantly closed through its potentiometer circuit. The battery may also be advantageously inclosed and packed to obviate temperature changes which may cause fluctuations in its E.M.F. of sufficient magnitude to be troublesome in work of high precision.

Some care has to be exercised in the choice or design of the galvanometer to be used with precision potentiometers. For work to 0.1° C. with platinum thermocouples, it is necessary to have an appreciable deflection for 1 microvolt with the galvanometer in circuit, and the design should be such that the deflection is aperiodic when the galvanometer is used with a given potentiometer. For rapid work, as in taking cooling curves, the period of the galvanometer should be kept down; and if, besides, the last increment of E.M.F. is to be measured by the galvanometer swing, it is desirable to have a period of not over five seconds. These requirements, combined with freedom from thermoelectric effects, are very severe for the swinging-coil type of galvanometer and can be met only by the more skillful constructors of such instruments.

Types of Thermocouple Potentiometer. — The Cambridge thermocouple potentiometer, similar in design to that of Harker, is an instrument designed for measuring E.M.F.'s of 30 millivolts or less. By estimation, microvolts may be read, corresponding to about 0.1° at 1000° C. with Pt-Rh couples. The circuits of this potentiometer are shown diagrammatically in Fig. 36. The total resistance in the circuit is arranged to give a fall of potential of about 1 volt per 50 ohms, and the resistances B.C. (about 42.5 ω) and S.C. (about 51 ω) are adjusted to give a fall of potential from *M* to *N* on the slide wire *ss* equal to the E.M.F. of a cadmium cell *C*.

This potentiometer is operated as follows: With *N* set at the known value of the standard cell *C*, and the key *k* thrown to *cc*, putting *C* in opposition with the storage cell *B*, the resistances R_1 and R_2 are adjusted until the galvanometer *G* shows no deflection on tapping the key. The battery *B* is then substituted for the cell *C* by throwing *k* to the side *xx* for the determination of the unknown E.M.F., *X*. The balancing of *X* against *B* is made by setting the dial, or series of millivolt coils, *MVC*, and the pointer *Q* on the slide wire *VV*, until as before the galvanometer shows no deflection on pressing the key. The value of *X* is then given directly in millivolts by adding the readings of *MVC* and *Q*. This is effected by making the dial *MVC* of 29 coils each of 0.05 ω, giving on the basis of 1 volt per 50 ohms a pressure diagram of 1 millivolt on each section. Similarly, the resistance of the wire *VV* being 0.06 ohm, the fall of potential along its length is 1.2 millivolts, or the maximum E.M.F. measurable is 30.2 millivolts. This range will take in most base-metal thermocouples as well as the usual platinum couples. In order to minimize thermal E.M.F.'s and temperature coefficients, all coils are of manganin and all connections of copper.

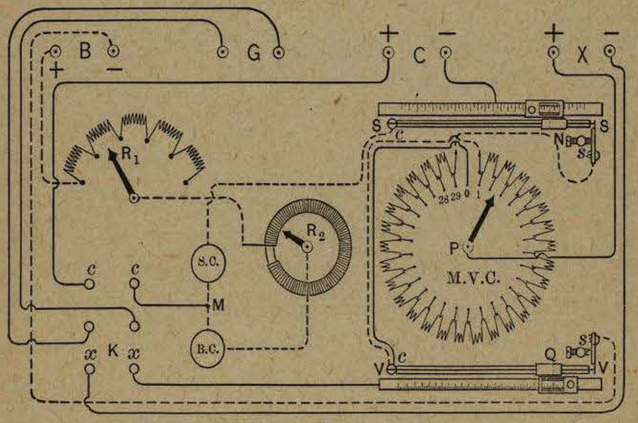

Fig. 36. Cambridge Thermocouple Potentiometer.

The Leeds and Northrup thermocouple potentiometer represents another, if somewhat similar, solution of this problem to about the same degree of accuracy. The arrangement of circuits is shown in Fig. 37. By means of the plug at *A* the range of the instrument may be increased tenfold. The heavy slide wire possesses eleven turns and permits reading to better than 1 microvolt with a suitable galvanometer. The resistance of each of the seventeen millivolt coils is 0.5 ohm, giving with the slide wire a total of about 9 ohms in the main circuit.

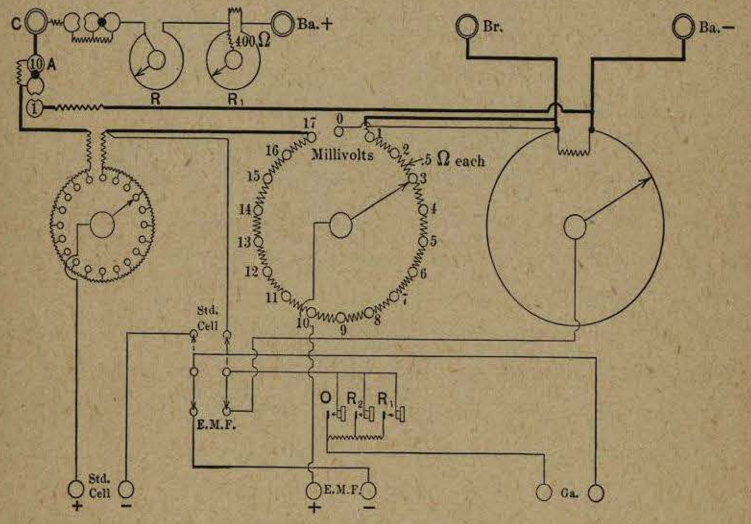

Fig. 37. Leeds and Northrup Thermocouple Potentiometer.

In both of the above instruments, settings on the standard cell may be made without disturbing the battery circuit, and the range and sensibility of either may be increased at will by suitable devices which may conveniently be built into the instruments. There are also numerous other potentiometers, such as those of Siemens and Halske, Carpentier, and Wolff, based on similar methods of operation. This type of instrument is not entirely free from internal thermoelectric forces, but these may be practically eliminated by proper reversals in the circuits.

The Diesselhorst potentiometer, built by O. Wolff of Berlin, is based on quite different principles from the preceding and represents an attempt to attain the highest accuracy possible in such apparatus, 0.1 microvolt being measurable with exactness. It is a five-dial instrument of very low resistance, and combines principles of construction suggested by several writers including Hausrath, White, and Diesselhorst. Thermoelectric effects in the main potentiometer circuit are eliminated by the design of the instrument, and temperature coefficient changes in the coils may be avoided by oil immersion. The effects of contact resistances are eliminated only by the excellence of construction. As constructed, this potentiometer possesses the disadvantages usually common to split-circuit instruments in which the range is altered by changing the battery current, such as requiring the adjustment of the rheostat in the battery circuit and rebalancing against the standard cell whenever the range of the instrument is changed. This is prohibitive for the rapid intercomparison of considerably different E.M.F.'s such as is often required in temperature measurements, unless sensibility is sacrificed.

White has developed a dial potentiometer suitable for thermoelectric work of high accuracy, in which, however, the last two dials are replaced by the galvanometer deflection, necessitating a construction, which has been realized, giving constant galvanometer sensibility. White has also realized a double potentiometer permitting alternate and independent measurements of two rapidly varying E.M.F.'s with all the advantages of two instruments, but with the accessories of only one.

Finally, Wenner has suggested a modification of the potentiometer circuit suitable for the measurement of low E.M.F.'s, consisting in shunting by a comparatively high resistance a part of the circuit including the potential point of a dial. By means of a double-dial switch both branch points between the shunt and the main circuit may be shifted in steps of equal resistance so as to introduce a larger or smaller resistance in the dial while keeping the resistance shunted constant.

In Fig. 38 is shown a plan for this potentiometer for use with thermocouples.

The dial contacts are all in the battery circuit, each branch of which is of comparatively high resistance, so that the resistance of the contacts and thermoelectromotive forces due to the setting of the dials have only a very small effect. The compensation circuit, on the other hand, is of low and nearly constant resistance, which makes it possible to use a galvanometer having a high voltage sensibility and permits the reading of a small unbalanced electromotive force from the deflection of the galvanometer (*G*).

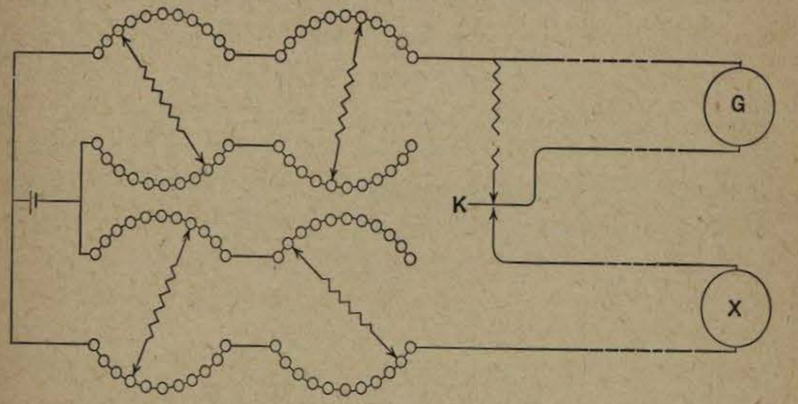

Fig. 38. Wenner's Design.

The effect of thermoelectromotive forces in the galvanometer is much reduced by keeping the circuit closed and the resistance approximately independent of the position of the galvanometer key. Under these conditions a change in the deflection of the galvanometer following a change in the position of the key (*K*) signifies an uncompensated electromotive force independent of any fairly constant electromotive force in the galvanometer.

The question of best design of precision potentiometers for use with thermocouples may be said to be in a state of flux, and no single best instrument meeting satisfactorily all the conditions imposed above has yet appeared in practical form.

The Thermocouple Circuit. — For good working of the platinum thermocouple there are certain practical precautions to be taken, which we shall consider. Most of these remarks apply even with greater force to the base-metal couples.

Junction of the Wires. — The contacts of the different parts of the circuit should be assured in a positive manner; the best way is to *solder* them. Binding screws often work loose in time, or the metallic surfaces in contact become oxidized. The importance of this precaution varies with the conditions of the experiments; one can dispense with it for experiments that last only a few hours, because there is little chance that the contacts will become modified in so short a time; soldering is, on the contrary, indispensable in an industrial installation which may be used for months without being tested anew.

But in any case, the soldering together of the two leads of the couple is absolutely indispensable. It is quite true that the electromotive force is independent of the manner of making contact. The two wires twisted together or soldered will give at the same temperature the same electromotive force. But under the action of heat the twisted parts are soon loosened, and there result bad contacts which increase the resistance of the whole circuit. In general, this accident is not noticed until the untying is almost complete, so that one may make before this a whole series of false measurements without being warned.

The best method of soldering is the autogène junction by direct fusion of the wires of the couple; it is necessary, in order to effect this, to have oxygen at hand. One commences by twisting the two leads together for a length of about 5 mm., and they are then clamped above an oxyhydrogen blast lamp. Oxygen is admitted through the central tube, and gas through the annular space; the oxygen is allowed to flow in normal quantity, and the gas in feeble quantity, then one opens progressively the gas cock. At a certain instant one sees the extremities of the wires melt, giving off sparks; the gas is then shut off. If one waits too long, the junction will melt completely and the two wires separate. With a little practice a good junction can be made by touching together, in the oxyhydrogen blast, the two untwisted wires held in the hand.

In default of oxygen, the wires may be soldered with palladium, which can be melted by means of a blast lamp furnished with air, taking care to reduce the action of radiation. A hole is cut in a piece of charcoal in which is placed the junction of the two wires twisted together after having wound about it a wire or a small strip of palladium, and the flame of the lamp is then directed upon the junction.

In the cases in which the couple is not to be used above 1000°, and only in these cases, the soldering may be done still more simply by the use of gold; the ordinary Bunsen flame is sufficient to make this junction.

Annealing. — Before use, even with new couples which are usually hard-drawn, the wires of the couple should be rendered as homogeneous as possible by annealing them electrically. For the platinum couples of 0.6 mm. diameter, which are in common use, a current of 14 amperes usually suffices. The current is kept on until the wires glow uniformly. In the case of couples that have been used, bad spots are easily detected in this way, and should be cut out if the glowing does not remove them.

Insulation and Protection. — The two leads should be insulated from one another throughout their length. For this, use may be made in the laboratory of glass tubes or pipestems, or of thread of pure asbestos wound about the two wires, by crossing it each time between the two (Fig. 60) so as to make a double knot in the form of an eight, each of the wires passing through one of the loops of the eight. This is a convenient method of insulation for laboratory use, although ordinary asbestos is likely to contain impurities which will damage the couple. The two wires with their envelope form a small rod of considerable rigidity which is easily slipped into apparatus. With this arrangement it is impossible to go above 1200° or 1300°, at which temperature asbestos melts. The most satisfactory insulation, however, is had by means of thin tubes of hard porcelain standing 1500° C. and of Marquardt mixture, 1600°, obtained from the Royal Berlin Porcelain Works.

For industrial installations, use may be made of small fire-clay cylinders of 100 mm. in length and 10 mm. in diameter, pierced in the direction of the axis by two holes of 1 mm. diameter, through which pass the wires, or hard porcelain tubes may be used. One or another of the other forms of insulator is added in sufficient numbers. They are placed, according to the case, in an iron tube or in a porcelain tube. The porcelain tube should be employed in fixed installations in which the temperatures may exceed 800°. One may, as does Parvillée in his porcelain furnaces (Fig. 39), place the porcelain tube in the lining of the furnace in such a way that its end is flush with the inner surface of the lining. An open space of a decimeter cube is cut in the lining about this extremity of the tube. This method makes easier the establishment of temperature equilibrium without subjecting the tube to too great chances of breaking by accidental blows.

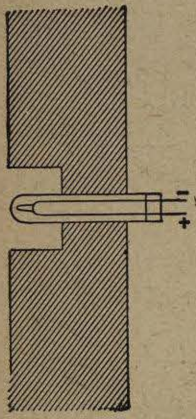

Fig. 39. Parvillée's Mounting.

The iron tube is used for temperatures not exceeding 800°, in the lead baths serving to harden steel for example, and for movable couples which are exposed to heat only during the time necessary to take the observations. In this case the junction is placed some 5 cm. beyond the insulators and the iron jacket. The wires take up the temperature within 5 seconds, and the observation can be taken before the tube becomes hot enough to be burned, even in furnaces for steel whose temperatures exceed 1600°, and before the wires have had time to be altered even in strongly reducing flames. The other extremity of the iron tube carries a wooden handle (Fig. 40) where are located, outside, the binding posts for the galvanometer leads, and inside an extra length of wire for the couple to replace portions burned or broken off. The figure shows one arrangement of this handle.

Fig. 40. Opened Wooden Handle.

In all cases in which the furnace whose temperature it is desired to measure is under a reduced pressure, suitable precautions must be taken to prevent any permanent entrance of cold air by the orifice necessary for the introduction of the tube, as well before as during an observation; otherwise one runs the chance of having inexact results.

In the case of prolonged observations in a reducing atmosphere or in contact with melted bodies, as the metals capable of altering the platinum, the couple should be protected by inclosing it in a covering impermeable to the melted metals and to vapors. For fixed installations in industrial works, use should be made of a porcelain tube, or one of iron, closed at the extremity where the junction is located; in this case the dimensions of the tube are unimportant. Quartz or porcelain tubes with an iron tube furnish oftentimes a very permanent and satisfactory sheathing. Fig. 41 shows one form of mounting for a protected couple attached to its galvanometer. For laboratory investigations it is often indispensable, on the contrary, to have around the wires a covering of as small diameter as possible If it is simply a question of protecting the couple against the action of non-volatile metals, the simplest way is to use, as did Roberts-Austen, a paste sold in England under the name of Purimachos, which serves to repair the cazettes employed in molding. We

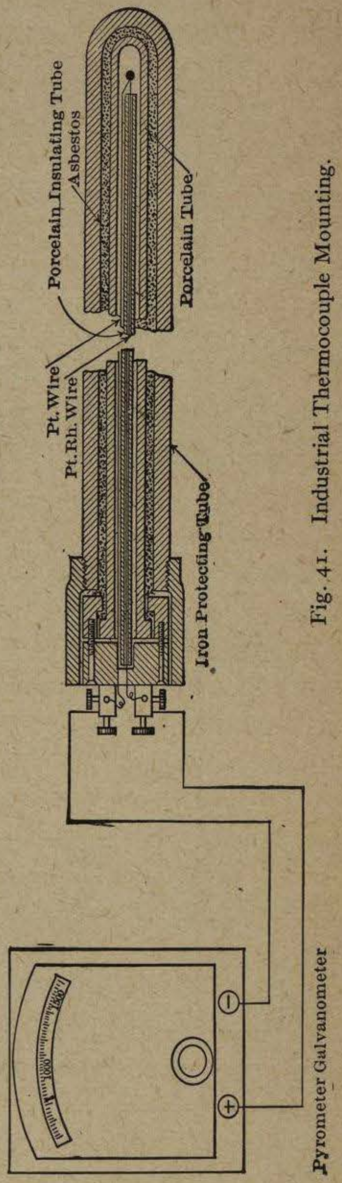

Fig. 41. Industrial Thermocouple Mounting.