RESISTANCE STANDARDS: THEIR MANUFACTURE
AND ADJUSTMENT.

BY ELMER G. WILLYOUNG.

[Read at the stated meeting, held November 3, 1891.]

I shall speak to you for a very brief time this evening on the subject of electrical standards of resistance. The standard of resistance is, to my mind, by far the most valuable standard with which we have to do in actual work. Considering only the quantities involved directly in Ohm's law, which are about the only quantities of any particular value or meaning to four electricians out of five, the standard of resistance is almost the *only material* standard which we can possess. The unit of current is a standard but it is a standard which only exists by definition and is not an actual tangible and physical thing, while the standard of E.M.F. which shall give an exact unit or multiple of a unit is yet to be discovered; a standard cell, to be sure, giving a definite E.M.F. at a definite temperature and whose rate of variation with temperature is accurately known, is now a comparatively easy thing to secure, but the care necessary in its use together with the decimal value of its E.M.F. are both considerably against its being rated as high, practically, as the standard of resistance. It must also be borne in mind that, having a standard of resistance, we may obtain the value of any E.M.F. by the solving of $E = CR$ where C is known from the amount of electrolytic deposition taking place in a given time out of a suitable solution; the amount of copper, silver, or other metal deposited out of such a solution in a given time by a given current being always a definite and exact one to be found in any text-book upon the subject.

The standard of resistance, as generally known, is a length of wire of one kind or another, wound upon a spool, mounted in a convenient case to protect it from injury and moisture, and having its resistance at some given tempera-

ture definitely determined; a true standard also has its rate of variation of resistance for change of temperature accurately known. Sometimes one coil is mounted up alone and sometimes many coils of different values are put up in the same mounting.

In the manufacture of standards of resistance a great many qualities are required of the resistance wire which shall be used. It should have high specific resistance, in order that the standard may not have too much bulk; it should have as small a temperature coefficient of resistance as possible, in order that its value may be easily obtained at any reasonable temperature without the making of troublesome calculations; it must not change its resistance in time; it must not be oxidizable by the air or by the medium in which it may be enclosed, since this would change the constitution and hence the resistance of the wire; and it must be of a hardness suitable for handling in manufacture and adjustment without injury. The requirement of high specific resistance immediately compels us to reject copper, iron, aluminum, silver, and all other pure metals except lead, antimony and bismuth. The softness, difficulty of working, and high temperature coefficient as well as many other reasons would throw these last three out of the account. The matter of temperature coefficient alone, in fact, would compel us to reject all pure metals since they all increase roughly about twenty-five per cent. in resistance between 0° and 100° C., except iron, which increases about forty per cent. We are, therefore, led to try alloys. Dr. Matthiessen, chairman of the sub-committee (of the Committee on Electrical Standards of the British Association), from 1862-65, having in charge the investigation of the properties of wires with reference to the selection of a suitable one to be used in the standard of resistance, decided upon by the British Association and now known as the B. A. Ohm, examined very exhaustively a large number of wires, among which were pure iron, silver, copper, thallium and other metals, and a great many alloys; he finally concluded that silver alloyed with 33.4 per cent. of platinum was the best alloy obtainable. This alloy, known as plati-

num silver, is still used by English makers; it has a specific resistance of twenty-four microhms and a per cent. variation per degree C. of $\frac{31}{100}$. In selecting this alloy we see that the requirements of high specific resistance and low temperature coefficient have both been observed, the resistance of platinum silver being about sixteen times that of copper and its temperature coefficient less than $\frac{1}{100}$ that of copper.

With reference to the constancy of resistance in wires it may be well to mention that many metals and alloys seem to alter in electrical resistance with time, or on being subjected to change of temperature. In an investigation carried on by J. Bergmann, a German electrician, in the latter part of 1889, he reports that, after raising to and maintaining at 300° C. for one hour and then cooling, the resistance of several substances changed as follows:

	<i>Per Cent.</i>
Copper decreased,	2'4
Aluminum "	5'0
Magnesium "	6'8
Zinc "	2'4
German-silver increased,	$\frac{2}{10}$

Mr. Tomlinson, a little earlier, found a somewhat similar result in the case of iron wire, which decreased in resistance about one-quarter per cent. after several heatings to 100° C., and subsequent cooling. Dr. Matthiessen, in the investigations previously alluded to, found a considerable time change in a number of the alloys and wires, which he experimented upon. It may be of interest to state here that three of the original platinum-silver coils determined by the British Association through Dr. Matthiessen and his colleagues at the time of the adoption of the B. A. Ohm were found last year, when carefully examined, to have developed an increase of resistance of about six parts in 10,000, or about $\frac{6}{1000}$ per cent., quite an appreciable amount as standards go. The committee having these last comparisons in charge suggested that this change in resistance was only temporary, and due to strains in the wire produced by lowering it to 0° C., at which temperature the measurements were made; they have, however, not yet been able to verify this idea. A time change is, however, to be noted in a large

number of metals and alloys where strains are not taking place. This time change in resistance, as Dr. Matthiessen suggested, is probably very largely due to a gradual annealing effect, as it is particularly noticeable in hard-drawn wires. It has also been observed to be in a marked degree a property of wires containing zinc and to be lacking, except to a very small extent, in wires free from zinc; here it is possible that zinc may gradually crystallize out, since it does easily crystallize, and the homogeneity of the wire thus being altered, the change in resistance may be accounted for.

It is almost self-evident that the resistance of a metal or alloy is a function of its density; hence, all causes tending to change the density of the resistance metal will also tend to change its resistance. It is quite reasonable to expect, therefore, that an increase of resistance should be observed after a wire is wound upon a spool. A wire wound up on a spool not over eight times its own diameter will increase from one-half to two per cent. in resistance; a part of this increased resistance is due to the increased hardness caused on the inside of each turn, by the bending stress, and hence gradually falls away as the wire slowly anneals. For this reason, it is unsafe to send out a resistance standard as correct until several months have elapsed after winding.

Several years ago a wire was brought out in England known as "platinoid." It was said to be an alloy composed of ordinary German-silver with one or two per cent. of metallic tungsten added. It has a specific resistance of about thirty-two microhms and a temperature coefficient of $\frac{22}{100}$ per cent. per degree Centigrade. I have analyzed this several times but have never been able to detect any tungsten; two or three friends have done the same with the same result. Whether or not any tungsten is used as the wire is now made, is, therefore, not certain. During the week since reading this paper, I have been informed by an electrician that the tungsten "burns out" in the process of manufacture. The properties of this alloy are, however, about as reported. It is nearly as cheap as German-silver, and during the time over which my own

observations have extended shows no time change; at least if any change has taken place in the coils in our possession, it has been by less than $\frac{1}{100}$ per cent. The wire is hard, practically non-oxidizable and easily handled. It is now being used in all the standards sent out by Queen & Co., and proves satisfactory in every way. I have here in my hand a wire recently sent me by the Aluminum Brass and Bronze Company, of Bridgeport, Conn., and claimed by the manufacturers to have thirty-five times the resistance of copper together with an extremely small temperature coefficient, less than $\frac{1}{10}$ that of German-silver. I have not had an opportunity to test the accuracy of these statements as yet, having been too busy with other work, but hope soon to be able to do so. According to the *Electrical Engineer*, of October 21, 1891, there is also claimed for this wire a tensile strength of 70,000 to 100,000 pounds per square inch, with eighty twists in six inches, and with a lower resistance, a tensile strength up to 140,000 pounds per square inch. You see it is of a pale-rose color and looks as if it might contain considerable copper. I suspect it is a variety of manganese-copper made up of about seventy per cent. of copper and thirty per cent. of manganese, with perhaps a small percentage of nickel. Mr. Edward Weston experimented on some of these alloys a couple of years ago and found one of them to have a negative temperature coefficient; his statement to that effect was received with considerable incredulity at the time, but has since been thoroughly verified. According to Drs. Feusner and St. Lindeck, in *Zeitschrift für Instrumenten Kunde*, February, 1891, an alloy composed of seventy per cent. copper and thirty per cent. manganese had a resistance of about five times that of German-silver and a temperature coefficient of but $\frac{4}{1000}$ per cent. per degree Centigrade, while an alloy of seventy-three per cent. copper, three per cent. nickel, and twenty-four per cent. manganese had a specific resistance a little less than three times that of German-silver, and a *negative* temperature coefficient of $\frac{3}{1000}$ per cent. We see, hence, that it ought to be entirely possible to obtain a wire having a zero coefficient, *i. e.*, not changing resistance at all for change of

temperature by properly combining the constituent metals of this alloy. The obtaining of such an invariable standard is a "consummation devoutly to be wished" in electrical work as accurate work is very troublesome and tedious where long decimal coefficients have to be applied, and this becomes particularly the case where several sets of coils are used in the same investigation having different temperature coefficients. Dr. E. S. Nichols, of Cornell University, and others have made successful attempts to obtain resistances having a zero coefficient working along another line; they have taken a rod of carbon and soldered to its extremities a length of wire of some metal or alloy; since carbon decreases and wires increase their resistance with rising temperature, it is evident that by using a suitable wire and proper proportions a combination might be found which when placed in a circuit in parallel would remain of the same resistance at any temperature. The difficulty of soldering to carbon as also the care necessary in adjusting prevent, however, such resistances from becoming commercial possibilities; the carbon is also too sensitive to changes of pressure and to strains.

A strictly standard resistance is, according to the practice of the best makers, adjusted to anything within from $\frac{1}{10}$ to $\frac{1}{100}$ per cent. of absolute accuracy. A *single* coil would not be considered a "standard coil" unless it were accurate within from $\frac{1}{50}$ to $\frac{1}{100}$ per cent. absolute accuracy. To obtain this high accuracy of adjustment it is easily seen that very exact methods of measurement must be employed; should we attempt to measure an inch within this limit of error, the error could not be over $\frac{1}{10000}$ inch, an exceedingly small quantity. Various methods have been suggested and employed by different parties at different times. An apparatus designed by Prof. Fleeming Jenkin, and used somewhat by the British Association Committee in 1862, consisted of essentially, an ordinary Wheatstone's Bridge with the connection between two adjacent arms, consisting of a short, straight length of resistance wire. If, now, one galvanometer contact be on this straight wire and the other at the junction of the two opposite arms of the bridge, and S , one

of these opposite arms, be the coil to be adjusted to R , the other of the opposite arms, and the arms adjacent to the straight wire be designated C and A we will have

$$\frac{C}{A} = \frac{R}{S}$$

we now interchange R and S and have

$$\frac{C}{A} = \frac{S}{R}$$

this will demand a new position of the galvanometer contact upon the straight wire and the distance moved over on the straight wire is a measure of the difference in resistance between R and S .

Suppose that C and A each have 100 inches of the same wire as the straight wire and that we have had to move over one inch in reversing R and S , then R and S agree within one per cent. Now we adjust S closer to R and substitute for C and A two new coils C' and A' each of 1,000 inches wire. If now we again adjust so as to move over one inch in reversing we are within $\frac{1}{10}$ per cent. of accuracy; and so by continually adjusting S to R we may obtain gradually closer approximations to accuracy if we, at the same time, substitute other coils for C and A . But this process is, at the best, but a cut-and-try one and exceedingly tedious. A complete description of this method and convenient apparatus will be found on p. 38, of *Reports of Electrical Standards*, published by Spon.

I have here a piece of apparatus first designed several years ago during my student days. It is a modification of an arrangement devised by Prof. S. P. Thompson, and described in *Stewart & Gee*, 2d vol., p. 160. The one I have here was first suggested to me by Prof. H. S. Carhart, of Michigan University, and has since been somewhat modified by myself. If we take an ordinary slide wire bridge having four openings for coils at the back and (the slide wire being in front) fill these spaces, beginning at the left, with coils designated P , R_1 , R_2 and Q , respectively, connect the battery from between P and R_1 to between R_2 and Q , and the galvanometer from between R_1 and R_2 to a point on

the slide wire, we have substantially the method which is known as the Carey-Foster method. Designating the resistance of copper connector at the left by r_1 and of copper connector at the right by r_2 and letting P be the resistance of unit division of the wire.

$$\frac{R_1}{R_2} = \frac{P + r_1 + X_1 \rho}{Q + r_2 + (L - X_1) \rho} \quad (1)$$

where X_1 is the reading on the bridge wire and L the total number of divisions. Reverse the position of P and Q and we have

$$\frac{R_1}{R_2} = \frac{Q + r_1 + X_2 \rho}{P + r_2 + (L - X_2) \rho} \quad (2)$$

From (1) we have

$$\frac{R_1}{R_1 + R_2} = \frac{P + r_1 + X_1 \rho}{P + Q + r_1 + r_2 + L \rho} \quad (3)$$

and from (2) we have

$$\frac{R_1}{R_1 + R_2} = \frac{Q + r_1 + X_2 \rho}{P + Q + r_1 + r_2 + L \rho} \quad (4)$$

From (3) and (4) we get

$$Q + r_1 + X_2 \rho = P + r_1 + X_1 \rho$$

$$Q - P = \rho (X_1 - X_2)$$

which is an expression independent of the resistance of the end pieces of the bridge, being merely the resistance of that portion of the wire over which we must move in obtaining our two balances. Thompson's device is merely for quickly and conveniently interchanging coils P and Q ; with it we must change the position of four copper connectors in four mercury cups; this is tedious and increases the danger of a change of temperature between the adjustments. The modification which I have here has reduced these changes to two which can be almost instantly made. With this device and a carefully calibrated bridge wire it is an extremely simple matter to attain an accuracy of $\frac{1}{100}$ per cent., while much higher percentages of accuracy may be gotten with care. Of course, in this method the coils P

and Q must be at a definitely known temperature which shall not change during the taking of the two readings; hence, the two coils are placed in well stirred water or oil baths. The other coils R and S are wound together and left in the open air as, if they change at all, they will probably change about equally and the result be of no appreciable importance. This device is also the best thing to use in determining temperature coefficients of wires; a length of wire is wound up on a spool, immersed in oil at a definite temperature and compared with a standard. The temperature of the oil is then raised and the resistance of the wire again determined; knowing the difference of temperature and the change of resistance the temperature coefficient follows.

ON THE VARIABLE ACTION OF TWO-COIL SOLENOIDS.

By WM. S. ALDRICH, Johns Hopkins University, Baltimore, Md.

[Read at the meeting of the Electrical Section, held February 2, 1892.]

The Two-coil Solenoid Electro-magnetic Mechanism produces a double-acting reciprocating movement of an iron core or plunger, when the coils are variably energized by a pulsating current, causing the induction to rise from zero to a maximum alternately in each coil. The action of the plunger under the influence of the two magnetic fields of force, other conditions being equal, will vary according to whether the two solenoids act with or against each other. The respective movements of the plunger are not only very different in each case, but the maximum pull in either direction towards the central line between the two coils is greater in the former arrangement than in the latter, as will be seen by referring to the plotted results of the experiments under these two conditions.

A preliminary experiment was made with a variable current obtained by an adjustable resistance, to determine the maximum pull, its variation, the movement of the plunger