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In This Issue

John Parker, Editor

WESTON ELECTRICAL INSTRUMENT CORP.,
614 Frelinghuysen Avenue,
Newark 5, N. J., U. S. A.

WESTON'S CADMIUM CELL

A True Standard of Comparison

This is a general article on the Weston Cadmium Cell in that it deals with the chemical and physical aspects of the cell. A subsequent article will deal more with the application and uses of such cells.

DOES the year of 1908 have any significance to you? Perhaps not, but it did to Dr. Edward Weston, as in that year the London International Electrical Congress recommended that the cadmium type of voltaic cell as discovered by Dr. Weston be adopted as the primary reference standard of voltage with a provisional value of 1.0184 international volts at 20 C.

Dr. Weston had invented the cadmium cell and obtained German Pat. 75,194 and British Pat. 22,482 in 1892, and U. S. Pat. 494,827 in 1893. This cell, in the unsaturated form, was produced in quantity in Germany by the European branch of the Weston Company from 1893 until the beginning of World War I and had become recognized throughout the technical world as a standard for the volt. In the saturated form it was reproducible, stable and practical as a primary standard of comparison. In the unsaturated form it had an extremely low temperature coefficient and was transportable by normal means.

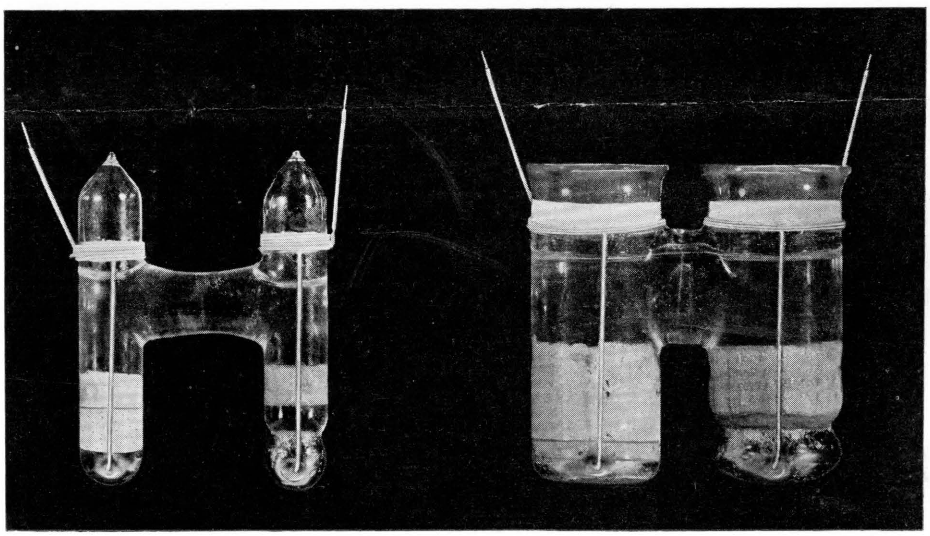


Figure 1—(Left) Model 3, Type 4 Standard Cell—(Right) Model 3, Type 1 Element as used in the Weston Model 4 Standard Cell

But let's go back a little and see just what this "cell" actually is. Figure 1 shows it to consist of an H-tube of glass filled with simple chemicals. In one leg we find mercury, mercurous sulphate paste, a septum, and a cork retainer. In the other leg we find an amalgam of cadmium and mercury together with another septum and cork retainer. Connecting the legs of the "H" is a cadmium sulphate solution. Add a platinum wire terminal to the bottom of each leg, and all the elements are there to form a cell. However, like so many fine mechanisms, it takes more than the mere parts to produce a satisfactory device. In the manufacture of a standard cell more work is performed before the ingredients are put together in the cell, than there is in the assembly of the cell proper.

Figure 2—Cabinet used for Crystallizing Cadmium Sulphate

Purest Chemicals Used

Cell manufacture really begins with the purchase of the purest chemicals commercially available, usually of cp or reagent grade. The mercury is purchased in sealed containers of triple distilled quality. Then begins a long, involved and time consuming process of repurification.

The mercury is redistilled three more times in Hulett type stills which have an arrangement for removing the oxidized impurities. The last 15% of the mercury in the stills is never used. That which passes over in the stills is kept in scrupulously clean glass bottles.

Mercurous sulphate is made by an electrolytic process using mercury and sulphuric acid with current passing through the solution which is constantly agitated in a light-proof chamber. After being precipitated as mercurous sulphate it is washed with distilled sulphuric acid and stored in bottles previously cleaned with redistilled water.

Cadmium amalgam is prepared by washing the bar cadmium in sulphuric acid, weighing, and then alloying it with an exact proportionate amount of mercury.

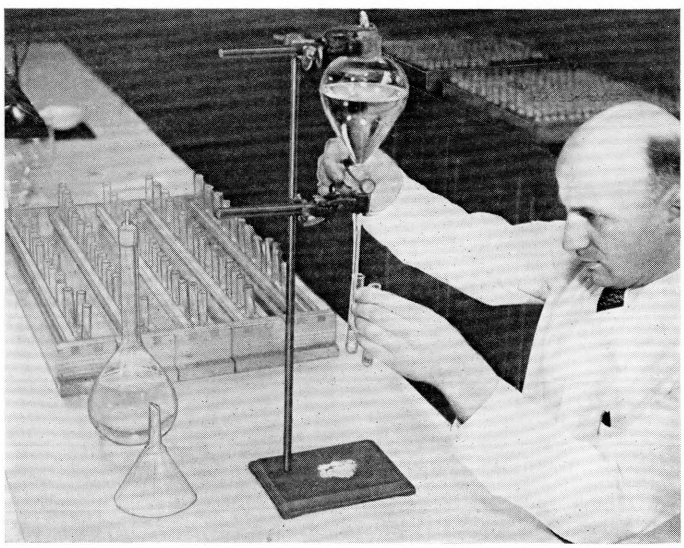


Figure 3—Filling Cells with Cadmium Sulphate Solution

The cadmium sulphate is purchased as reagent grade. It is dissolved in redistilled water and later crystallized out in trays as shown in Figure 2. This process is repeated three times, each time removing any impurities by draining off any slight residue that may rise to the surface and by using only completely formed crystals. Finally the crystals are redissolved in double distilled water. Sufficient additional redistilled water is then added to provide the degree of saturation desired.

The above is a very brief review of the processes involved and only indicates the high lights as far as the actual procedure and degree of care and cleanliness is concerned. Nothing has been said about boiling the cork stoppers, washing the H-tube with plain and then distilled water, and a final rinse in redistilled water, and many other procedures necessary to produce the final degree of purity, cleanliness and resulting accuracy.

Sealing the Cell

The electrode elements and the electrolyte are precision weighed or measured, and then together with the corks and linen diaphragms are put in the cell. Figure 3 shows the filling of the cells with the cadmium sulphate solution. Then comes the final operation, sealing off the tops of the H-tube. This may be done either with cork stoppers and wax as in the Model 4, or by glass sealing as in the Model 3 Type 4 (See

Figure 1). In the glass sealing method, see Figure 4, a torch, a steady hand, and long experience is necessary.

The Normal and Standard Cells

Having been sealed off, the cell is now mechanically completed. It then requires a period of aging with records of its emf and resistance being taken weekly over a period of months. See Figure 5. These data are taken by comparing the new cell emf with that of a bank or "normal" cells maintained in special controlled temperature chambers. These banks of cells, of which there are four, one of which was at the Bureau of Standards at the time of writing this article, each contains a group of cells which are transported by hand to the Bureau of Standards every six months for direct comparison with their bank which constitutes the lawful unit for determining the "volt" within the United States. The volt was redefined by international agreement in 1910 as $\frac{1}{1.01830}$ of the voltage of a Weston Normal (saturated) Cell at 20 C and adopted by the U. S. National Bureau of Standards in 1911. To avoid confusion between the saturated and the unsaturated type of cell it was agreed to call the international reference type of saturated cell a "Normal" cell, and the unsaturated portable type a "Standard" cell. Hence, today there are the Weston Normal Cells found usually only at the Bureau of Standards and in a few precision laboratories, while the Weston Standard Cells used with potentiometers are found in laboratories all over the world. The Weston bank of saturated cells compares favorably in size and quality with those maintained at the Bureau and is one of the largest banks of its kind.

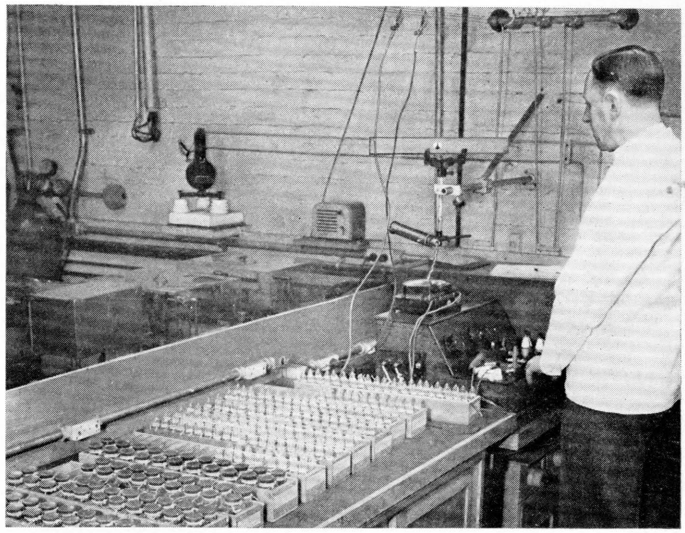


Figure 5 — Checking the EMF and Resistance of the Cell

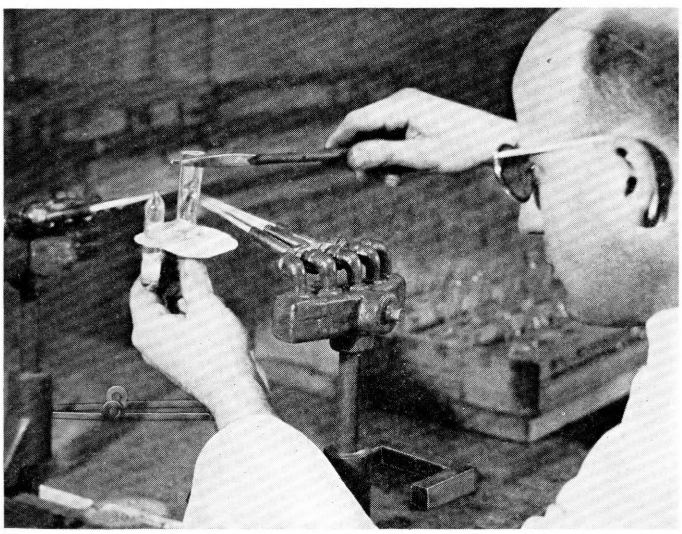


Figure 4 — Glass Sealing Method

Potentiometer Automatically Restandardized

The Model 4 Standard Cell uses an H-tube having a diameter of 25 mm (1 inch); its voltage is nominally 1.01865 and its resistance is nominally 125 ohms. The companion cell is the Model 3 Type 4 which is smaller, being $12\frac{1}{2}$ mm (0.5 inch) in diameter. It has the same nominal voltage of 1.01865 but a nominal resistance of 500 ohms because of its smaller size. This cell is produced in relatively large quantity, and is generally employed in potentiometric recorders where it is used to automatically restandardize the potentiometer, usually every 15 minutes. This continues for years without any attention, the cell faithfully serving its purpose. Standard cells, although little publicized, are really the standards of comparison for voltage when precision is required, and on their accuracy depends the final accuracy of the potentiometers with which they are used. In that manner too, the accuracy of practically all precision indicating and recording instruments is maintained as they in turn are invariably standardized by potentiometric means.

E. N.—No. 9 —*F. X. Lamb*

WESTON VACUUM TYPE THERMOELEMENT

THE measurement of alternating currents at frequencies above 100,000 cycles per second is not readily made with electromagnetic type of instruments without considerable error because of the inductance and distributed capacity inherent in these instruments. Sometimes the large power required to make these instruments operate may be objectionable making it necessary to go to another form of instrument. The thermocouple type of instrument is ideally suited for the measurement of currents at frequencies higher than is possible with the electromagnetic type instruments.

The measurement of very small alternating or radio-frequency currents is possible with a vacuum type thermoelement (vacuum thermocouple), as used in the Weston thermo-milliammeters and voltmeters. The vacuum thermoelements, used in these instruments, are manufactured in the Weston Plant under careful and exacting methods. See Figure 1.

The current to be measured flows through a conductor, called a heater, and raises the temperature of the heater as a function of the current. A thermocouple, of two carefully selected dissimilar metals, has its hot junction attached to the heater and its cold end connected to the stem leads which connect to the d-c millivoltmeter.

The small amount of heat developed from as little as 2 milliwatts makes it necessary to place the heater and thermocouple in a highly evacuated bulb. The extremely low pressure (high vacuum) effectively minimizes the cooling of the heater by convection air currents, and at the temperatures the heater is operated, losses due to radiation are negligible. From Figure 2, it is evident that for maximum output the pressure must be less than 0.0001 millimeter of mercury (0.1 micron). Weston vacuum thermoelements are evacuated to a pressure of less than 0.00001 millimeter of mercury (0.01 micron), well in the leveled off portion of the curve.

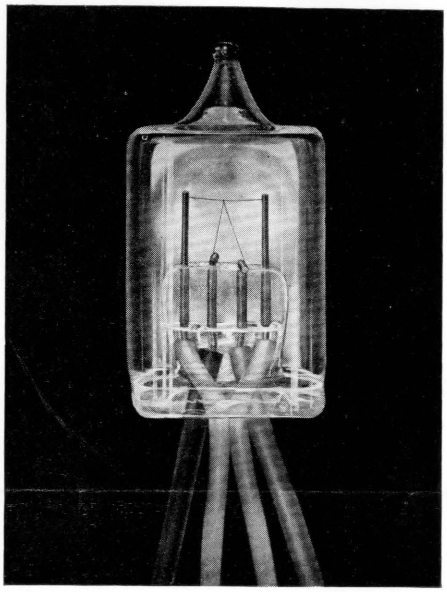


Figure 1—The Vacuum Thermoelement as used in Weston Thermo-Milliammeters and Voltmeters

Reducing the effects of cooling by convection and radiation to a negligible amount, the problem is confined to the condition where the heat developed is dissipated through the heater and thermocouple to the terminals.

It was shown by W. N. Goodwin, Jr.* that if no thermocouple is attached to the heater, the temperature elevation (t_o) above that of the terminals would be

$$t_o = \frac{v^2}{8k\rho},$$

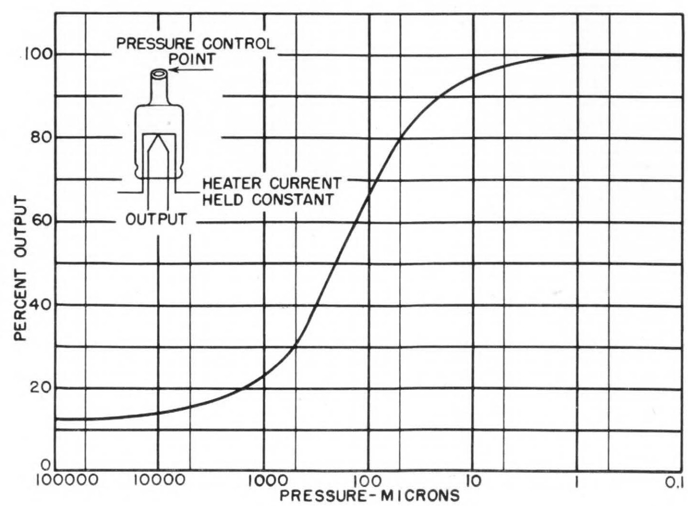
where, *v=voltage drop across the heated conductor, k=thermal conductivity and ρ=electric resistivity of the heated conductor.* But attaching a thermocouple to the heater causes a depression of the temperature distribution curve of the heater, symmetrical with respect to the hot junction, as shown in Figure 3, and the temperature at the junction (t_c) will approximate

$$t_c = \frac{1}{1+\frac{R}{r_c}} \times \frac{v^2}{8k\rho},$$

where, *r_c=resistance of the thermocouple* and *R=resistance of heater.*

The heater material should have the highest possible melting point, lowest possible temperature coefficient of resistance and lowest product of $k\rho$. The resistance of the couple depends upon the meter resistance, and its thermal and electrical constants. Further, only non-magnetic alloy material should be used for the heater, of a size which will keep the a-c resistance about the same as the d-c

Figure 2 — Pressure versus Output of Weston Vacuum Thermoelement



*"The Compensated Thermocouple Ammeter" by W. N. Goodwin, Jr., Trans. A.I.E.E., Vol. 55, P. 23, 1936.

resistance, so as to keep the output, in turn, reasonably correct at frequencies as high as 100 megacycles. To keep the error, due to skin effect, down to 3½ percent at 100 megacycles, the heater diameter should not be

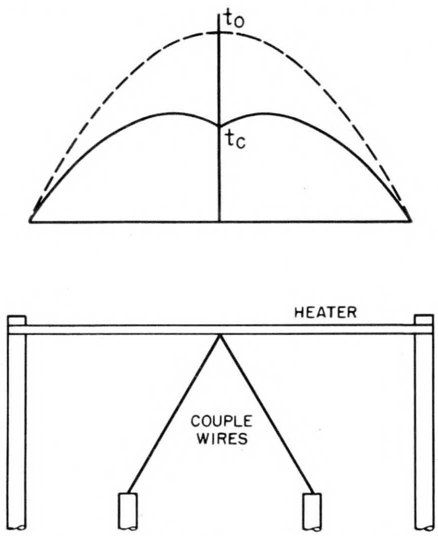


Figure 3—Diagram of Temperature Distribution of Heating Conductor

greater than 0.0036 inch for platinum alloys of resistivity of 30×10^{-6} ohms/cm³.

The thermocouple, as used in Weston vacuum thermoelement, has a resistance of 6 ohms for ranges up to 25 milliamperes and 3 ohms above 25 milliamperes. The thermocouple produces 5 millivolts, on open circuit, when rated current (+0—10%) is flowing through the heater. This output is obtained with a temperature difference of only about 80 degrees centigrade between the hot and cold end, equivalent to approximately 63 microvolts per degree centigrade.

The Aging Current

The operating temperature of the heater is kept moderate so that neither the heater nor thermocouple will be damaged at overloads as high as 3 times normal current. Weston vacuum thermoelements can operate safely at twice normal current with some overload factor. Heaters are made of platinum alloys or non-magnetic nickel alloys having a high melting point for ranges of 5 milliamperes and up, while carbon is used for the lower ranges. At twice normal current the junction temperature is approximately 320 degrees centigrade, far below the melting point of the heater material used. Further, all vacuum thermoelements are aged by passing a current for a definite time through the heater until it is a glowing red filament. This aging current is equivalent to about 90 percent of the burnout current.

Once the aging is completed, the thermoelement performance is remarkably stable, even at twice normal current. Tests show that at twice normal heater current for a length of 3000 hours the vacuum thermoelement showed no change in its output. One of the original vacuum thermoelements has been on life test and has been operating continuously for over 10,000 hours at twice normal current without any evidence of change.

Since the process involves glass work and a number of techniques somewhat foreign to ordinary instrument practice, a special department handles this particular work. The various glass components are made in this department from glass tubing on specially designed machines some of which are shown in the figures. The final sealing of the bulb to the base, evacuating and testing is also done in this department.

In Figure 4, the thermoelement base is being flared from short

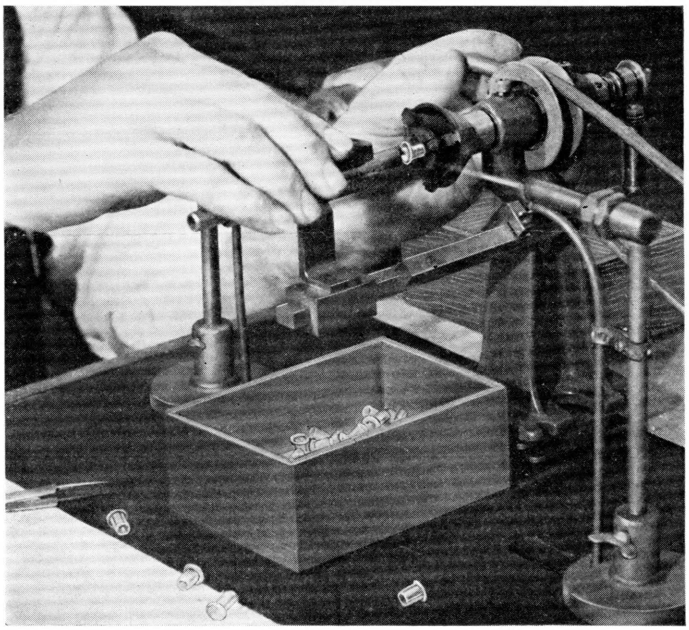


Figure 4—Flaring Thermoelement Base from short lengths of Lead Glass Tubing

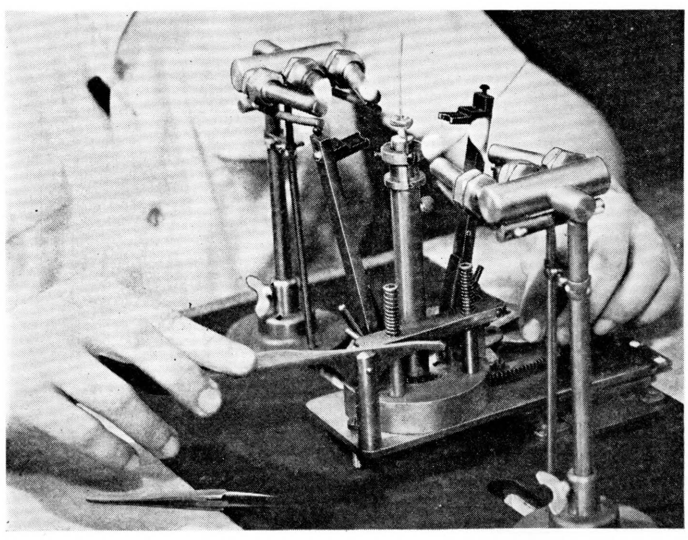


Figure 5—Sealing Special Leads in the Glass

lengths of lead glass tubing. This flare is necessary as this will be fused to the bulb later. Figure 5 shows the sealing of special leads which are inserted in the flared base and sealed in the glass, making vacuum tight joints. At this point, the moment the base is removed from the machine it must be annealed at a temperature of about 430 C and gradually allowed to cool to room temperature in a specially designed annealing machine.

The heater and thermocouple wires are now welded to the base lead wires. The welding of these wires must be done under exacting conditions because some of the wires are as small as 0.0004 inch in diameter. Special welding devices were developed to weld these small wires which are as small as 1/10 the diameter of a human hair. There are as many as six welds on each thermoelement base.

While the bases are being welded, the glass bulbs are formed from thin walled glass tubing, Figure 6. A length of lime glass tubing is permitted to turn on the four rollers with a flame directed at the center. After the tubing is softened, a pair of rollers is pressed down on the soft tubing to form the two bulbs shown in the holder next to the machine. The formed tubing is annealed in a controlled oven whose temperature is raised to 525 degrees centigrade and then allowed to cool to room temperature.

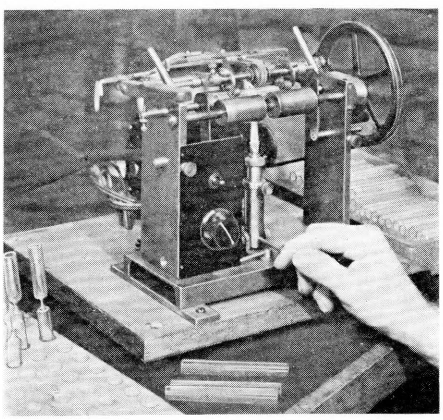


Figure 6—Forming the Glass Bulbs from Glass Tubing

The formed tubing is cut in half making two bulbs. The halves are cut to proper length after which a small diameter tube is fastened to the smaller diameter of the bulb for evacuating.

Figure 7 shows the sealing of the bulb to the base. The base and bulb are held directly in line by the holder of the sealing machine with the bulb overlapping the flare of the base. The burner flames are directed on the overlap. The holder is turned by hand until both the base and bulb fuse together, after which the assembly is removed, straightened and immediately placed in a special annealing device shown in the background of Figure 7.

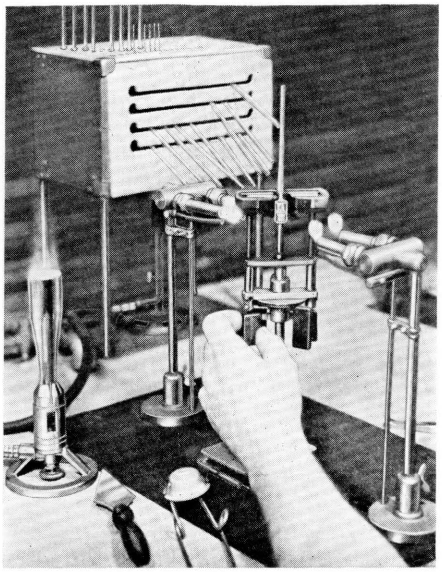


Figure 7—Sealing the Bulbs to the Base

The evacuating is shown in Figure 8. A mechanical roughing pump capable of reducing the pressure to 0.001 mm of mercury is in the back line of a two-stage oil diffusion pump which, in turn, is capable of giving an ultimate vacuum of something better than 0.00001 mm of mercury. The thermoelements are affixed to the manifold, and while they are being evacuated, an oven is placed over them for outgassing or removing any adsorbed gases from the surfaces of metal and glass of the thermoelements. While they are in position for evacuating and before the oven is placed over them, it is necessary to test each individual thermoelement for any possible hairline cracks with a spark coil shown along side of the outgassing oven.

When the evacuating time is sufficient, the oven is removed and by means of the tipping torch shown, each thermoelement is sealed off. Before sealing and removal from the line, each thermoelement is again tested by means of the spark coil.

The evacuated thermoelements are aged by passing a definite current through the heater for a specified period. They are then tested for heater resistance, couple resistance and for heater current for the required 5 millivolt output. These values are appropriately marked on the container in which the thermoelements are inserted.

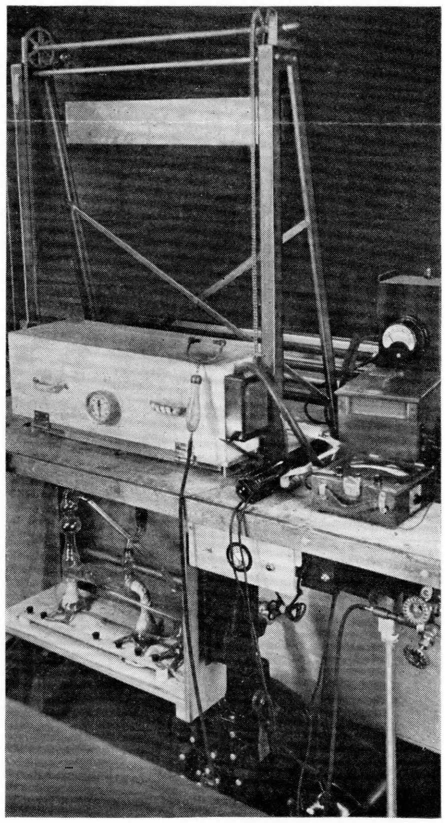


Figure 8—The Evacuating Process

The vacuum thermoelements are then placed in stock subject to the requirements for incorporation in the assembly of thermo-milliammeters and voltmeters.

E. N.—No. 10 *—M. C. Kunz*

SIMPLIFIED BRIDGE ANALYSIS

THE several equations given in the discussion entitled "The Galvanometer and the Bridge" in Vol. 1 No. 1 of these Notes are rigorous and exact. They are, however, rather complicated and usually require a considerable amount of paper work.

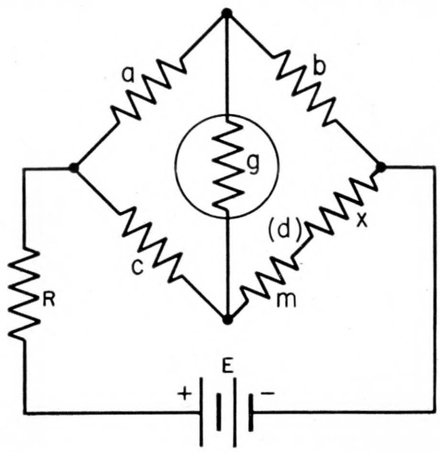


Figure 1—Bridge with Unknown Arm broken into Balanced and Unbalancing Sections

To obtain the galvanometer current within a few percent, there is a simplified method of analysis which is used occasionally and which the writer has found of much value in quickly obtaining the order of the sensitivity required in the galvanometer for a given degree of unbalance.

Referring to Figure 1, we have the four arms as conventionally given except that the fourth arm, *d*, is actually made up of two parts, *x* and *m*, where *x* is the value which would balance the bridge and *m* is the difference between this and the actual value.

Now, fundamentally, it is the voltage drop of the current passing through *m*, the unbalanced portion, which actuates the galvanometer through the bridge network and the evaluation of this voltage drop and its application into the galvanometer and its associated network will give the resultant galvanometer current.

In the ordinary bridge application the resistance, *R*, is usually negligible. Since the bridge is close to balance, the current through the galvanometer can be neglected in obtaining the current through *c* and *d* (or *c* plus *x* plus *m*) so that we have the simple circuit of these two arms in series across the battery, *E*. This amount of current can usually be evaluated mentally and, as an example, in Figure 2 we have typical values given and it will be noted that we are trying to determine the galvanometer current when we measure a resistor having a value of 3015 ohms with the bridge actually balanced for 3000 ohms. With a 3 volt battery and a resistance in the two lower arms of 3115 ohms, we have a trifle less than 1 milliampere flowing, or 960 microamperes by slide rule.

The drop developed by 960 microamperes or .96 ma through 15 ohms is 14.4 mv.

The next step is to discard the battery entirely and inject this value of 14.4 mv into the network in place of the 15 ohm unbalanced component, Figure 3, and, again, evaluate the result. Here we have 6000 ohms in the right hand arms plus the resistance of the galvanometer shunted by the left hand arms, 100 ohms shunted by 200 ohms, or 67 ohms. The total is 6067 ohms.

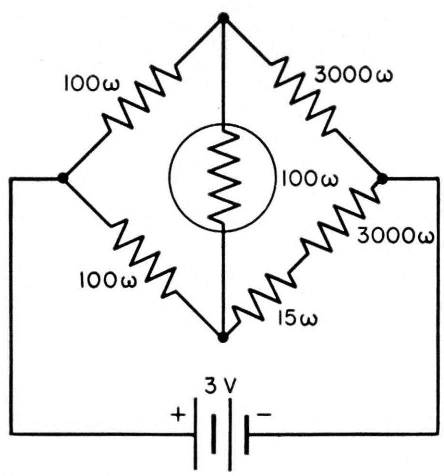


Figure 2—A Numerical Example showing the Balanced and Unbalancing portions in one Arm

14.4 mv applied to 6067 ohms results in approximately 2.5 microamperes flowing, actually, by slide rule, 2.38 microamperes.

Of this current, 2/3 will flow through the galvanometer since its resistance is 100 ohms shunted by 200 ohms; 2/3 of 2.5 microamperes is a trifle over 1.5 microamperes, or, again by slide rule, 1.57 microamperes and this is our solution.

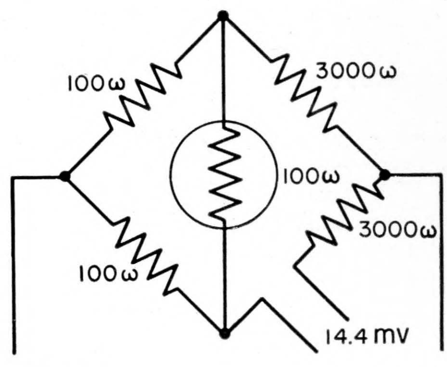


Figure 3—Bridge diagram showing the Unbalancing Resistor replaced by an Injected Voltage

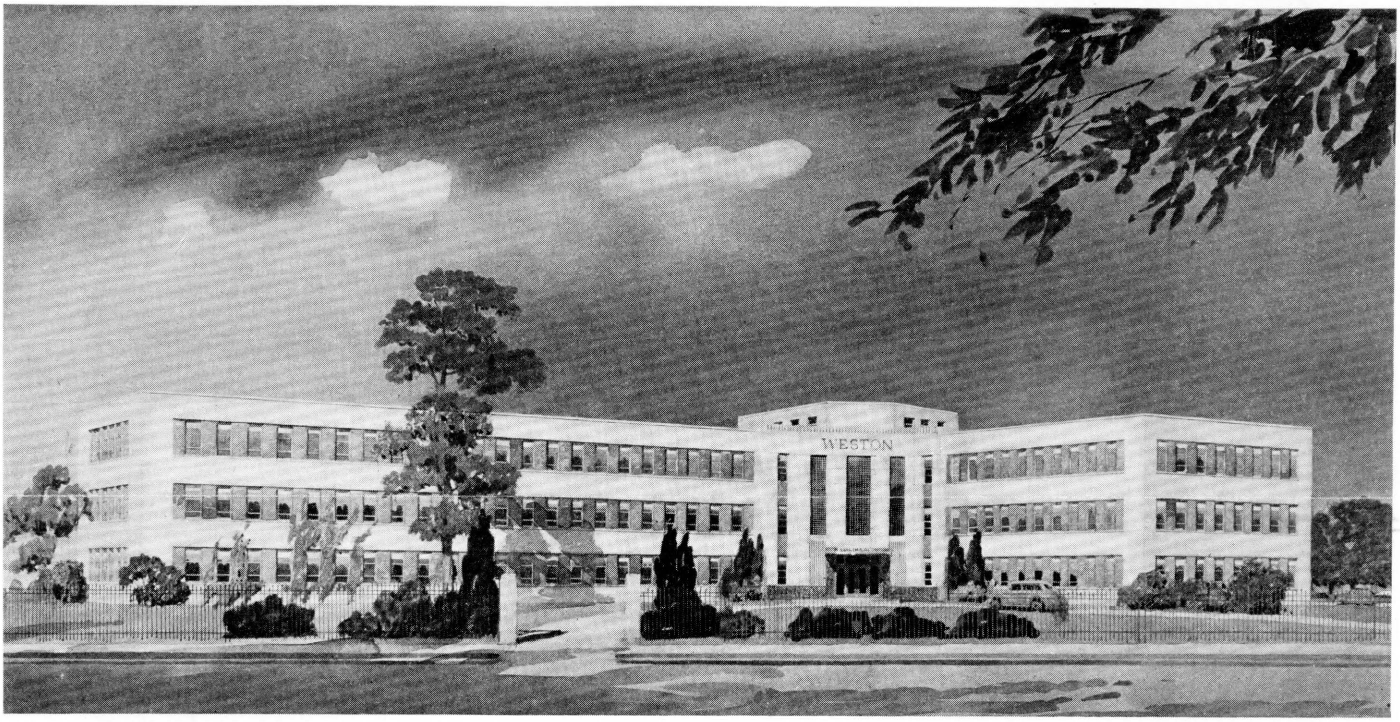
Working this out the long way through the complete equation and using equation (2) from the previously referenced article, we get a value of 1.587 microamperes, the exact value. However, for the selection of a galvanometer from an instrument room, or from a catalog if one must be purchased, this approximate method is most satisfactory. While not strictly rigorous, particularly for large unbalanced conditions, its accuracy does increase as the balance point is approached.

If the resistance under test is less than the balanced value, use a resistance in a negative sense which would secure balance. In other words, in the example given the same values would be used if arm *d* were 2985 ohms, in which case the 15 ohm value would be preceded by a negative sign, the numerical results would be the same, but the galvanometer would deflect in the opposite direction.

In the casual use of bridges in test work, the writer has found this short cut invaluable. Its publication in the past seems always to have been surrounded by involved procedures and explanations which have tended to so complicate the situation that clear understanding seemed impossible. Actually, the procedure is so straightforward that if one merely remembers to pick up the unbalanced resistance, apply the current flowing to get a millivolt drop value across it, then throw away the battery and determine the galvanometer current, one will be able to analyze bridges in a reasonably adequate manner, either mentally or with a slide rule, and to a very satifsactory degree of accuracy.

Perhaps the best way to really learn this system is to set up a few bridge diagrams with examples of typical values and analyze the results using this method and the conventional equations. A few trials will be convincing and will indicate the degree of accuracy to be obtained. Thereafter the method will be straightforward and will involve no carrying of notebooks or equations to arrive at what is ordinarily considered a rather complicated procedure.

E. N.—No. 11 —*John H. Miller*



As this edition of Engineering Notes goes to press steam shovels are busily engaged excavating for the new Weston Engineering-Administration Building pictured above.

Caxton Brown, president of the Weston Corporation, turned the first spade of turf at the ground breaking, May 13th.

In commenting on this plant expansion move, which will permit vacating of badly needed manufacturing space now occupied by engineering and administrative units, Brown said, "The relocation and enlargement of our engineering facilities have been contemplated for many years. It is now necessary to permit us to render service to the government and to industry generally during this reconversion period and in the future where electrical and electronic applications are destined to play a most important role".

Continuing Brown declared, "This ambitious project, undertaken at a time when environment in which industry must operate is so unsettled, is an indication of the faith of myself and others of management in the future of the Weston Corporation and is undertaken to permit enlarged production with its related employment both for additional workers and for those now in our employ." The new "T" shaped, three story, reinforced concrete brick-faced building will have a gross floor area of 78,620 square feet and is laid out on a 6 ft. module throughout.

Among many innovations incorporated in the plans is fluorescent lighting adjustable to conform with a movable steel partitioning arrangement.

All areas of the building will have high current bus ducts which will be centrally located overhead for heavy duty power requirements. Metal ducts and chases are to be run on sidewalls permitting connections to a variety of electrical services. Access to sewer connections will be through removable floor sections along sidewalls and through double beams at center sections.

Ventilation ducts will include provision for the installation of air conditioning at a future date.

Completion date for the new $625,000 structure has been set for the Spring of 1947.

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