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125 YEARS OF OHM'S LAW

Did Ohm state Ohm's Law? Henry Berring, our Educational Director, writes about it below, picking up the argument from one of his instrument conferences on a recent educational lecture tour. We hope it will be as interesting to our readers as it has been to our own Engineering Staff.—THE EDITOR.

THE question of Ohm's Law came up one hot afternoon last fall, down in Tennessee, when we were in the company of a group of T.V.A. engineers. Did any of us really know Ohm's Law? We looked at each other puzzled and a bit chagrined. Granted, we had been out of school longer than we cared to admit, but. . . .

Did Ohm state Ohm's Law? He had neither ampere nor volt nor ohm. He had no instruments as we know them. Then what did he really state?

It was all good engineering argument, and we felt challenged. Through the courtesy of Dr. Adolf Scheibe of the Physikalisch Technische Bundesanstalt at Braunschweig, Germany, we obtained a microfilm copy of Ohm's treatise of 1827 as published in Dr. E. Lommel's book of Ohm's collected works (Gesammelte Abhandlungen von G. S. Ohm, Johann Ambrosius Barth, Leipzig, 1892).

Ohm's Paper

There it was — Georg Simon Ohm's original paper "The Galvanic Chain, Mathematically Treated," generally regarded as the first statement of the electrical relationship now known as Ohm's Law. It is only fitting that we here commemorate the 125th anniversary of Ohm's paper.

It is a lengthy document, some forty book pages in the long-winded style of early 19th Century writing. A complete rendition would have been unwieldy. We had to limit our translation to a few excerpts, but in these we have tried to preserve Ohm's colorful language. These parts appear in italics.

We hope our readers will enjoy this glimpse of the past and will derive from it an answer to the riddle of Ohm's original law.

Problems and Difficulties

Already in the preface to Ohm's paper we note the bitterness of frustration of the scientist who labored without recognition and adequate remuneration because his work was ahead of his time. Ohm's studies must have seemed farfetched and impractical at a time when electricity had no place in the consciousness of most people.

But it is really the paper itself which discloses the enormity of the problem. Without reliable means of generating electric power and, at best, producing only minute amounts under almost uncontrollable conditions, without any of our modern means of discrimination and measurement—yes, even without most of our mathematical tools of description and analysis, how was it possible to find law and order in the contradictory evidence of the electrical phenomena then known?

In 1827, the cause-and-effect relationship of what we call voltage and current was not yet fully understood. Ohm clearly perceived it and labored to make it clear in the minds of his readers; but he had none of our accustomed and ac-

In This Issue

John Parker, Editor
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cepted terms and definitions to back him up. His thesis, therefore, is a struggle with the limitations of language as much as those of equipment suitable to prove his point.

Ohm's experimental evidence was meager, indeed. *The aim of this paper is to derive, as a conclusive relationship, from a few principles, mostly available from experience, the meaning of those electrical phenomena which are caused by the mutual contact between two or several bodies and which are understood by the term galvanic.* Considering the task of studying electrical laws from the feeble effects of contact potentials, without a semblance of modern instrumentation, the expression *mostly available from experience* is almost heroic.

Ohm's Three Basic Laws

Three laws, one of which expresses the spread of electricity within a single body, the second one the manner of the dispersion of electricity into the surrounding air, and the third one the emergence of electricity at the point of contact of two heterogeneous bodies, form the foundation of this entire treatise and at once contain all that has no claim of complete proof.

Indeed, it must have seemed a hopeless task to furnish *complete proof* of so elusive a phenomenon as *the spread of electricity.*

As to the first of the three laws, Ohm assumes that electricity transmits itself only from one *body element* to the nearest adjoining one and not immediately to one more remote. Ohm knew little of the mechanism of conduction which to us is still complex enough to occupy the full time of scores of solid-state physicists. Yet, he reasoned that *according to the science of thermodynamics, the transfer of heat between two body elements is taken as being proportional to the temperature difference between them;* similarly, the amount of *electric transfer* must be proportional to the difference between *the electrical forces residing in the two elements.* Any remote effect would necessitate the assumption of inverse square law relationships. These would complicate the *generality, simplicity and clarity* which Ohm claims for his *chosen method.*

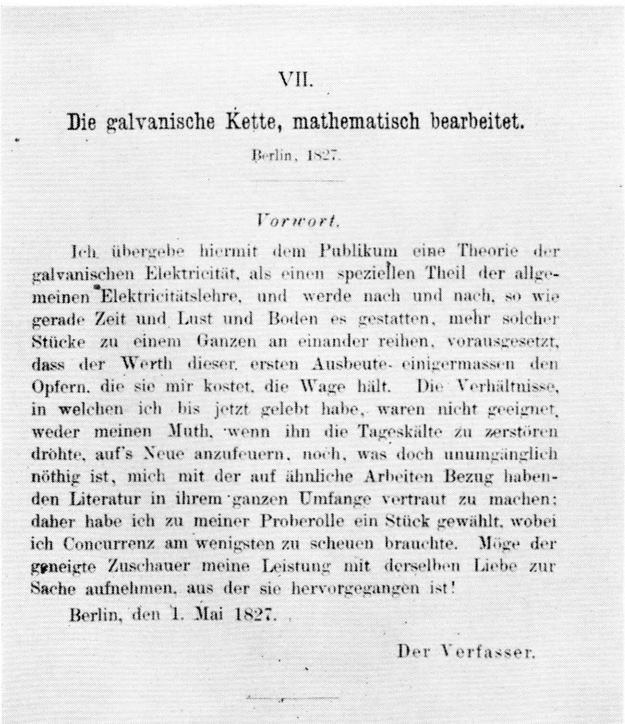
As to the dispersion of electricity into the air, Ohm reasons that *in galvanic events the influence of the air can almost always be neglected.*

The manner in which *electricity emerges at the point of contact between different bodies* is described as follows: *When different bodies are in contact with each other they maintain, at the place of contact, continuously one and the same difference of their electroscopic forces.*

From these laws, treating electricity like a liquid and limiting its flow *in one dimension only* without variation in time and without chemical effects, Ohm then develops his famous proportionalities. He admits the over-simplification of the problem but argues that these simplified conditions are those favored by the *nature and shape generally given to galvanic apparatus.*

Keeping the Problem Within Bounds

Ohm must have been plagued by the unexplored complexities of electrolysis and emphatically rules out all chemical effects of electricity.



VII.

Die galvanische Kette, mathematisch bearbeitet.

Berlin, 1827.

Vorwort.

Ich übergebe hiermit dem Publikum eine Theorie der galvanischen Elektricität, als einen speziellen Theil der allgemeinen Elektricitätslehre, und werde nach und nach, so wie gerade Zeit und Lust und Boden es gestatten, mehr solcher Stücke zu einem Ganzen an einander reihen, vorausgesetzt, dass der Werth dieser ersten Ausbeute einigermassen den Opfern, die sie mir kostet, die Wage hält. Die Verhältnisse, in welchen ich bis jetzt gelebt habe, waren nicht geeignet, weder meinen Muth, wenn ihn die Tageskälte zu zerstören drohte, auf's Neue anzufeuern, noch, was doch unumgänglich nöthig ist, mich mit der auf ähnliche Arbeiten Bezug habenden Literatur in ihrem ganzen Umfange vertraut zu machen; daher habe ich zu meiner Proberolle ein Stück gewählt, wobei ich Concurrenz am wenigsten zu scheuen brauchte. Möge der geneigte Zuschauer meine Leistung mit derselben Liebe zur Sache aufnehmen, aus der sie hervorgegangen ist!

Berlin, den 1. Mai 1827.

Der Verfasser.

Preface to Ohm's Paper. Original.

VII

The Galvanic Chain, Mathematically Treated

Berlin, 1827

Preface

I am herewith submitting to the public a theory of the galvanic electricity, as a special part of the general science of electricity, and will gradually, as time and mood and conditions happen to permit, join more such fragments to each other to form a complete whole, provided that the value of this first yield will, in some degree, balance the sacrifices which it is costing me. The conditions under which I have lived until now have not been conducive, either to lending new fire to my spirit when the cold of the day threatened to destroy it or, what is really an indispensable necessity, to making myself conversant to its full extent with the literature relating to similar studies; therefore I have selected for this specimen a part in respect to which I needed least to fear competition. May the benevolent reader accept my work with the same love of the subject from which it grew!

Berlin, May 1, 1827.

THE AUTHOR

Preface to Ohm's Paper. Translation.

He has *neither time nor means* to subject these conditions to the *accurate test against experience* but hopes that *good-hearted men* may some day devote themselves to these problems. To them he recommends the subject *with the warmth of a father who, not blinded by puppy love, is satisfied to point at the free, clear eyes through which his child innocently looks at the wicked world.*

The paper is richly studded with such jewels of language. *A theory which lays claim to the name of an imperishable, fruitful one must not, I presume, express its noble birth by vain rhetorical flourish but always by giving real proof of its kinship to the spirit which animates nature through expressions simple and complete, without any blocks and tackles of language. . . .*

Ohm's Ring-Shaped Conductor

Ohm then discusses a uniform, homogeneous ring in which *an inequality of the electrical conditions* occurs between two immediately adjoining, radial cross sections. This disturbance he calls a tension. If the tension prevails, *the expansive force of the electricity* will bring about a flow of electricity so that each particle of matter, *body element,* receives as much as it surrenders so that its *electrical condition does not change.* Within a space of time so short *that it usually escapes our senses,* a condition *most closely resembling an equilibrium* will establish itself all around the ring except for the sudden jump in tension at the point of origin. Ohm then imagines the ring-shaped conductor opened up and stretched out, whereupon he represents it by the abscissa in a system of rectangular co-ordinates. In this graph, the ordinate represents the *electrical strength* or *electroscopic force* at any point of the conductor. By erecting verticals on the abscissa, making their lengths proportional to these electroscopic forces and connecting the end points, the electrostatic condition can be plotted for the entire length of the conductor.

For any length of conductor of constant cross section and conductivity, Ohm plots this function as a straight line. No experimental evidence is cited for this simple behavior of electricity. It is founded on the logic of Ohm's reasoning.

Conduction as a Function of the Conductor

Ohm's first principle permits *electric transfer* only between adjoining particles of matter, and only in proportion to the difference in the electrical forces between them. His second principle forbids more than a negligible amount of electricity to escape into the surrounding medium. All cross sections of a homogeneous conductor must therefore receive and surrender, per unit time, equal amounts of electricity. To do this, they all must be subjected to equal portions of the total electrical force or tension. Hence, the distribution of this tension over a homogeneous conductor must be a straight-line function of distance.

From this and the proportionalities of his graph, Ohm draws further conclusions. If there is only one and the same *electric transfer* through all cross sections, a constriction by which the cross section is locally reduced must nevertheless transmit the same amount of electricity per unit time as all other parts of the conductor. In the constricted portion, each particle of matter must therefore transmit as much more electricity per unit time as the cross section is reduced in relation to the rest.

The constriction need not be one of dimension but may have to do with the reduced ability of the material of a portion of the conductor to transfer electricity. Ohm calls this ability of materials their "*conductivity*," apparently the first use of this term.

Whether the constriction be dimensional or due to reduced conductivity of the material, each particle associated with it must transmit electricity more quickly than any particle in regular parts of the conductor so that *each cross section surrenders as much electricity to one side as it receives from the other.* To cause this increased speed of transfer, the difference in electrical tension between adjoining particles must be increased in the same measure. Hence, sections of conductor of reduced cross section or conductivity must be allotted greater portions of the over-all tension; the slope of Ohm's straight line is increased.

The slope of the line of electrical force in Ohm's graph is inversely proportional to the product of cross section and conductivity. For a given cross section and a given conductivity, the slope is inversely proportional to the length of the conductor. If a conductor is formed of several sections, these proportionalities hold separately for each section.

In a galvanic chain composed of two heterogeneous, prismatic parts there takes place, in respect to its electrical condition, at each point of excitation, a sudden jump, which constitutes the tension existing there; and from one end of each part to the other [there is] *a gradual and uniform transfer, and the slopes of the two transfers are inversely proportional to the products of conductivity and cross section of each part.*

The same is then developed for a chain of three or more sections. What we call current is called *the amount of electric transfer.* This, Ohm recognizes, must be the same, per unit time, in any cross section of a conductor, because *each cross section receives as much as it surrenders.* Therefore all cross sections and conductivities of a chain jointly determine the flow of current, the sum of all tensions being the over-all tension which we would call voltage. In each uniform section, the *electric transfer* is proportional to the tension at the ends and the product of cross section and conductivity.

All this and much more Ohm reads from his graph without recourse to measurement.

The Reduced Length

In Ohm's terminology, the length of a homogeneous portion of a conductor divided by the product of conductivity and cross section is called *the reduced length* of the conductor. Using this term and, for the first time in his paper, the word "Strom," meaning current, Ohm makes this fundamental statement:

The amount of current in a galvanic chain is directly proportional to the sum of all tensions and inversely *proportional to the total reduced length of the chain.*

This is as close as Ohm came to "Ohm's Law." It is the essence of Ohm's interpretation of his graph. It is not Ohm's Law in the terms of our time. But we know it to be a correct pronouncement which logically leads to Ohm's Law.

Conclusions

Remarkable are the conclusions which Ohm draws from this simple relationship. He correctly states the laws of parallel connection, anticipating Kirchhoff's rules. He also explains how conductivity can be measured.

When substituting parts of a chain by others without changing the total tension or the amount of the current, the actual lengths of the parts of equal cross section are proportional to their conductivities. . . . [This] *relationship can be used to determine conductivities.*

Although all of Ohm's reasoning is founded on the electrostatic function of the electroscope, he correctly predicts the current measuring instrument. Referring to a coil of wire as a *multiplier*—because its effect upon a compass needle is a multiple of that of a single, straight conductor—he proves that its effect upon the compass needle is *independent of the reduced length of the chain.* This, of course, means that the deflection of the needle is a measure of the current in the conductor, regardless of its resistance.

Space does not permit to do justice to the full extent and purport of Ohm's paper. It is a remarkable, visionary document. Even though it does not contain Ohm's Law in our language and its conclusions were drawn from ingenious assumptions rather than tests, it is no doubt one of the foundations of our electrical science and the art of electrical measurement.

E. N.—No. 90 —*H. Berring.*

INDICATING INSTRUMENTS FOR USE UNDER SEVERE CONDITIONS

The following paper was recently presented in Washington, D. C., by F. X. Lamb, Chief Engineer. It is printed here as the first disclosure of the Weston approach to the problem of rugged instruments for our Armed Forces.—THE EDITOR.

AS WORLD WAR II progressed through the years 1942, 43, 44 and 45, and in particular those later years when the military action was primarily in the Pacific areas, it became more and more evident that much of the equipment being furnished to our fighting men was not suitable for use under the extremes of climatic and other conditions being encountered. Electronic apparatus in particular was reported as failing badly in an over-all sense.

Although instruments on electronic gear were by far not the worst offenders, nevertheless there were failures and they did contribute to the over-all picture. This resulted in the military calling first for fungus proofing and later for sealed instruments.

These were steps in the right direction, but not sufficient so that the problem could be considered as solved. Instruments were still adversely affected by the extremes of temperature, rough handling, vibration and shock encountered in military service.

The next step was for the military to decide upon a preferred means of protecting instruments from the affects of high shock. Experimental work was carried on over a period of several years and the design approach established. This work centered about instrument designs using an internal metal deck imbedded in rubber and to which the mechanism (magnet, pole pieces, moving element, etc.) was attached. Shock received by the outer housing is effectively reduced by the shock-mounting means and only a portion of it is transmitted to the mechanism. The mechanism in turn had to be redesigned to withstand the shock it receives. The instrument housing (case, window, connection studs) in turn required redevelopment to provide the necessary strength and to incorporate a sealing means so the complete instrument would be sealed, rugged, capable of being manufactured in quantity and still a good electrical indicating instrument. In the effort to meet all the other requirements, it still had to be kept in mind that the device was to be an electrical indicating instrument with a pointer, a moving coil, springs, etc., all to result in a balanced design permitting the usual accuracy in the order of 2 per cent of full scale value.

Toward the end of 1950, Weston accepted a contract requiring the design and development of a complete line of 2½″ and 3½″ flange diameter panel instruments. These included 34 different items of d-c, a-c and rf, self-contained voltmeters, ammeters, thermal instruments, some with uniform scales, a-c and rf scales, and some with expanded scales.

In considering the over-all task, thoughts were first focused on the housing, the window, the zero corrector and terminal studs. These had to be resolved before effective work could be done on internal parts to be mounted within and surrounded by them.

The first consideration was whether the sealing would be by solder means or other methods. As a company, we hold no brief for any single method of sealing but feel that each has its merit and should be employed where most beneficial and in keeping with the requirements. After due consideration and some experimental work, it was decided that the solder-sealed glass-to-metal approach had too many shortcomings for this application. Windows cut from plastics were considered, tried and ruled out. Glass with rubber gaskets had merit but fell short of the mark for the $2\frac{1}{2}''$ and $3\frac{1}{2}''$-size instruments. Finally, after a long series of tests, a plastic window of heat-resistant material was developed which met the requirements more fully than the other methods considered and tested. The window is a two-level structure having a perpendicular reinforcement around the periphery of the viewing area and extending into the body of the housing where it overlaps the internal rubber which extends up from the shock mount.

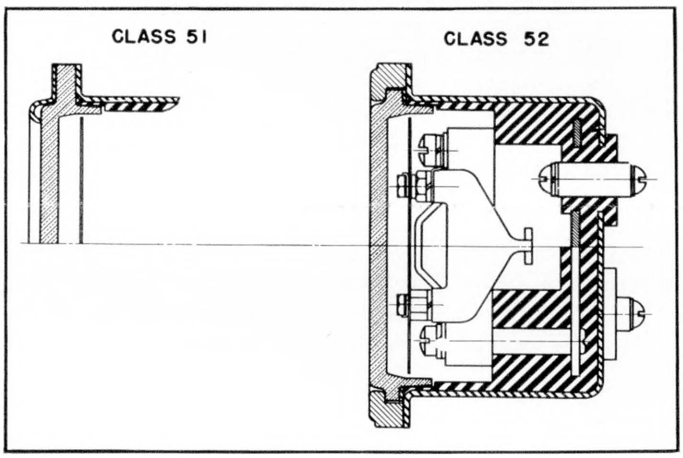


Figure 1—Sectional view of 2½″ and 3½″ d-c instruments. Class 51 is shown for comparison.

Being of tough plastic, the window easily withstands the drop test ($\frac{1}{4}$-lb. steel cylinder, free falling, through 8 inches). It also permits a zero corrector using a restrained gasket under pressure as the sealing means. The advisability of having a zero corrector is sufficiently well established not to require elaboration. Suffice it to say that an instrument is no more accurate than the ability with which it can be set to zero.

The next step was to determine the best means for bringing the electrical circuit through the housing. Numerous ways and means were considered, including glass insulators of the soldered sleeve type, those employing compression gaskets, and those of the fused glass bead type. Having had actual experience over the past years with all of these types, we knew rather definitely of their limitations. Some could be sealed and most could be treated to withstand the dielectric test. None, however, were in the rugged category. The terminal means eventually selected was simple, straightforward in design, and positive in its seal. The terminals are of $\frac{1}{4}''$ brass stock imbedded into and bonded to the internal rubber shock mount during the molding process. This results in a seal which is tough, sure, and of ample and adequate size. It is suitable for self-contained ammeters, both d-c and rf, to 20 amperes and possibly more. Its low electrical loss and high thermal conductivity are beneficial. The resulting dielectric test voltages possible are considerably above the requirements. This is also true of electrical leakage resistance before and after moisture tests. By happenstance more than intent, the housing design permits the addition of one or more additional modified terminals, should that be necessary.

The shock mount into which the mechanism deck is molded is of specification compounded rubber, tested to insure defined resilience and absence of characteristics which would adversely affect the component parts.

The Alnico V magnet is of "U" shape with soft iron pole pieces soldered thereto before machining.

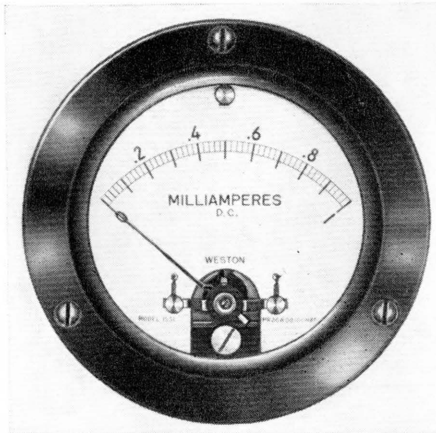


Figure 2—Head-on view of the 3½″ d-c instrument.

This insures permanent positioning of the pole pieces and other related parts.

The pivot and jewel design is exceedingly important, especially where vibration, tumbling or shock is severe, as these two parts are subject to wear, to rust-forming oxidation which can cause excessive stickiness, to blunting of the pivot tip, and to pitting or cracking of the jewel. For this purpose, a non-rusting alloy having excellent wear characteristics is used in conjunction with borosilicate glass jewels. To protect the pivot tip as well as the jewel proper under severe shock, the jewels are of the spring backed, limited motion type so arranged that when the moving coil and its pivot presses against the jewel, it (the jewel) recedes into the jewel screw until a shoulder on the pivot nut comes in contact with a shoulder on the jewel screw. With

Figure 3—Rear view of 2½″ and 3½″ d-c instrument.

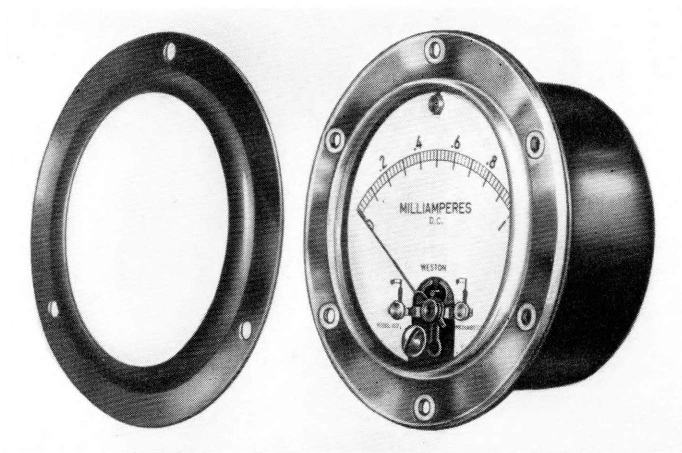


Figure 4—Edge lighted (Class 51) 2½" and 3½" d-c instrument with bezel removed.

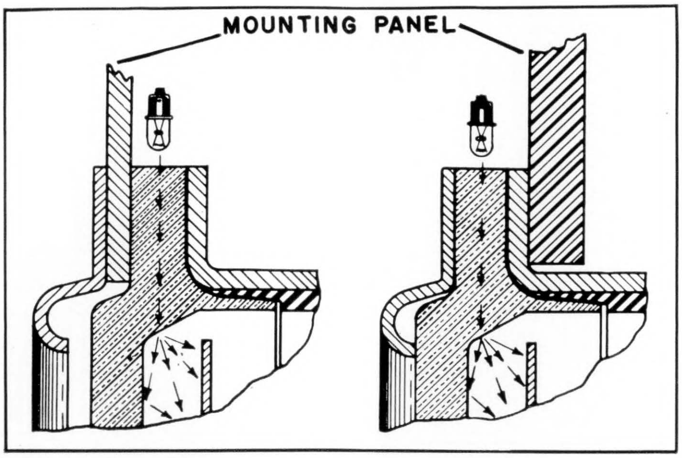


Figure 5—Details of edge lighting means showing the relative position of mounting panel.

this design, the pivot and jewel are fully protected as neither can be subjected to forces beyond a safe design point determined by the spring rate of the back-up spring behind the jewel.

An additional advantage of the above design is that the pivot to jewel clearance settings can be kept to a desirable minimum without fear of "binding in jewel." It has been proven that even with zero clearance, there will be no binding as in an ordinary instrument, because of the calibrated small pressure of the spring backing of the jewel.

The case shell is of steel about twice the gauge of regular steel cases. This was found to be necessary and advisable since military instruments are usually mounted directly to metal panels and must withstand the full force of all shock received. Tests run on experimental and commercially available cases showed that unless the flange was strong, it would give way at the radius. With the extra thick case, no deformation took place even under severe 2,000 ft-lb hammer blows on the Navy high shock machine (10-T-2145-L Bu. Ships). Further, no windows flew out, cracked or chipped.

Lance-shaped, tubular, heat-treated aluminum pointers are used for maximum strength. The springs are of beryllium copper.

An interesting feature of the basic window design is that it permits the use of two forms of bezel rings. In one form (Figures 1, 2 and 3), an aluminum bezel ring is used to compress a confined gasket and thereby provide watertightness. In another form (Figures 4, 5 and 6), a stainless steel bezel ring is used with the flange of the plastic window extending outward to the edge of the case. This permits excellent edge lighting of the instrument dial.

When back-of-panel lighting is to be used, the instrument may be fitted behind the panel while the bezel ring is mounted on the front of the panel. Instruments so mounted have a conventional appearance and can be illuminated without any important change structurally or mounting wise. The bulbs, being external to the instrument, are readily replaceable and not injurious to the instrument. Further, they do not increase the temperature of the instrument, as would internal illumination.

Mounting bolts and nuts are of stainless steel to complete the design. No additional reinforcement rings or skirts are necessary.

Voltmeters are self-contained to 300 volts, ammeters can be self-contained to 30 amp d-c, and to 20 amp rf.

In summary, it can be said that a complete line of panel instruments has been developed to meet military requirements. New ideas, new concepts and new techniques were employed. The results are gratifying.

E. N.—No. 91 —*F. X. Lamb.*

This paper was presented as a part of the afternoon session on May 6 of the Symposium on Quality in Electronic Components, held in the Auditorium of the Department of the Interior in Washington, D. C., and sponsored by the AIEE, IRE, RTMA, and the Bureau of Standards. The paper will also be published in the proceedings of the Symposium.

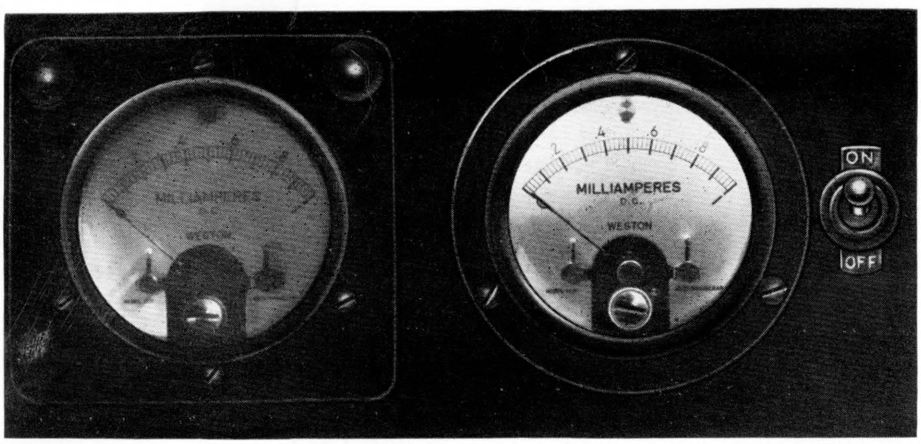


Figure 6—The above illustration shows the comparison of a non-illuminated and edge-lighted dial.

AGING OF STANDARD CELLS

Pursuant to an invitation from Dr. Hamer of the Bureau of Standards, Mr. F. X. Lamb, Chief Engineer of Weston Electrical Instrument Corporation, presented the following paper on September 21, 1951. The occasion of the presentation was a Symposium on Electrochemical Constants sponsored by the National Bureau of Standards in co-operation with the Office of Naval Research, and held in Washington, D. C., to commemorate the fiftieth anniversary of the Bureau. The full text of Mr. Lamb's paper follows.

IN COMING to Washington to speak before this group on the occasion of the 50th anniversary of the Bureau of Standards, it seemed only fitting and proper to reflect on some of the technical events which have occurred during those 50 years. In this talk I shall refer particularly to the subject of standard cells.

As is well known and recorded in history, as well as in the Patent Departments of Germany and the United States, Dr. Edward Weston invented the cadmium type cell prior to 1891 and obtained his patents in 1892. Dr. Weston actually began production of his cells in 1891 in a branch laboratory of the Weston Company in Berlin, Germany, primarily because of the availability of chemicals superior in purity, and because of the advantages gained by being close to the Reichsanstalt.

The Weston form of cell, both saturated and unsaturated, has been made without interruption over the intervening 60 years from 1891 by the Weston Corporation. In this paper, however, only the unsaturated or practical working form of cell will be considered.

Although no person living can recite from personal experience the problems attendant to the early production of cells, we know from recorded data that one of the most difficult problems was to produce cells without having available cell ingredients of required purity or knowing how to produce them commercially of the required purity. As we all know, great strides have been made in chemistry and methods of refining chemicals over the past half century. This is particularly so since World War I. Today in the United States not only are chemicals available of very high purity, but the refining procedure has been developed to the point where chemical purity is a matter of willingness, patience and cost rather than lack of knowledge.

Without any reflection except that of pride for the cells made in the early days by Dr. Weston, it can be said that present-day cells do differ somewhat from those made 50 years ago. The changes, however, are in the refinements associated with the advance of the technical frontier rather than in premise or in fundamentals.

Among the changes which have taken place during the past 50 years, resulting from the efforts of many workers in the field, might be listed the following:

1. Improved methods for the refining of the ingredients.
2. Improvement in the sealing off of cells to make them truly hermetically sealed.
3. Improvement in the thermal shielding.
4. Change from soda-lime to boro-silicate glass for the containers.
5. Improved methods of filling and retaining the ingredients within the glass containers.
6. Improvements in the housing.

While the passage of time has obscured the details of the difficulties encountered by Dr. Weston during the early days of cell manufacture, it is recorded that "considerable difficulties were overcome only after years of sustained efforts." This is borne out by the story that in the early days of cell manufacture, keen interest was always shown in the number of good cells produced as a percentage of the total. Today, cells are made with such exactness that rejects are usually restricted to mechanical failures such as glass breakage.

Notwithstanding the advances which have been made in the art of standard cell manufacture, one may ask, "Just how good are standard cells?" and "How do you as a manufacturer know since you send your product out to industry and seldom see it again?" The answer is that there are data available. Some have been accumulated and published by Vinal, Craig and Brickwedde,[1] and more recently by Vinal.[2]

Further, many cells are periodically returned to the Weston plant

Edward F. Weston Honored

An honorary doctorate of engineering was presented Edward F. Weston by the Newark College of Engineering on June 6 during the school's commencement exercises.

The presentation was made by George O. Smalley, president of the New Jersey State Board of Education. In conferring the degree on Dr. Weston, the college cited his leadership and achievement in the field of electrical engineering.

Dr. Weston also holds a degree in electrical engineering, which he obtained upon graduating from Columbia University in 1900. Former president of the Company, Dr. Weston has served as Chairman of the Board since 1945.

for recertification. These data are accumulated and subjected to analysis.

Since, however, cells which have been sent out and later returned can only add to data on cells after an unknown service, it seemed warranted that we at Weston obtain additional data relative to cells where the service conditions were known. To this end we have over the past many years made it a practice to select at random one or more cells for life tests from the successive groups manufactured. These cells are set aside and periodically checked. Periodically we also obtain cells from other makers for comparison purposes and test them side by side with our own. The data thus collected have heretofore been classified as confidential. Today, for the first time, these data are being disclosed and are presented herewith. The available records cover a period of 20 years and date back to 1930.

At this point it is important to state that while the data are complete and unabridged, the figures are not fully applicable to cells which would be shipped to a user. Cells having a change as great as some few of those being reported upon would normally be rejected by inspection and test run during the normal aging period of six months to one year before a cell is standardized and considered as ready for shipment. Also attention is directed to the phenomena where it is quite common for new cells to increase in emf for a short period of time after which they reverse the trend, decrease in emf at a moderate rate, then stabilize, and thereafter begin a slow drift downward which invariably continues throughout their life.

The data presented cover the life of the cells after initial standardization at about one year from the date of assembly. It is the summary of 305 standardizations made on 45 cells.

The average change of 80 microvolts per year on this group of cells compares favorably with the average change of 85 microvolts per year reported by Vinal, Craig and Brickwedde[1] and with a weighted average drift of 71 microvolts per year reported by Vinal.[2]

TABLE I

Elapsed Time Years After Initial Standardization	Average Charge Microvolts per Year All Cells
1	85
2	94
3	92
4	81
5	78
6	70
7	77
8	77
9	78
10	73
11	57
12	71
13	71
14	52
15	70

Average of all readings 80

Considering that the cells being reported on were all "as made," with no preselection, the groups from which the cells were taken represent rather excellent control and manufacture.

To assist further in evaluating the data collected from these cells, a graph is presented (Figure 1) to show both the individual values of the drift of the cells and a curve for the average value of the drift. The unbroken curve is for the average value of the drift with all values of standardization included and is in accordance with the values shown in Table I. The broken portion of the curve is obtained by omitting those observations shown at the top of the graph representing a few cells where the drift was in excess of 200 microvolts per year for the first several years. This is justifiable as previously mentioned. Further, it is worthy of mention that those cells which exhibited a drift in excess of 200 microvolts were manufactured prior to 1940.

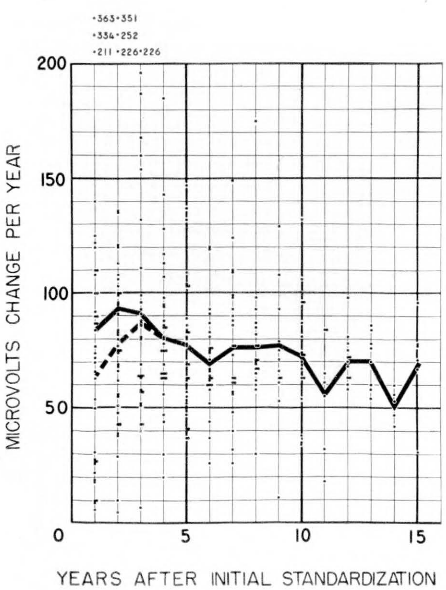


Figure 1—Graph showing voltage drift of standard cells with age.

It is hoped that the data presented will be of some use to those concerned with standard cells. If it served no other purpose, it is convincing evidence that cell quality is being maintained and that those concerned with their manufacture recognize their responsibility and are keeping faith with those who purchase their product.

The data presented are useful, however, in that they indicate that if standard cells are not mishandled, or subjected to abnormal conditions, their constancy is remarkable and the voltage drift is within relatively narrow limits. The data presented also confirm the statement that for measurements requiring great precision, for example 0.02 per cent or better, which corresponds to a 200 microvolt change, it is recommended that cells be recertified at intervals of one or two years.

In conclusion, it is only fitting to comment on the assistance rendered by the National Bureau of Standards to those of us concerned with the maintenance of precision standards. The Bureau has been of inestimable help without which it would have been impossible to carry on the work to the high degree of accuracy required for standard cell manufacture and certification.

We in these United States are indeed fortunate to have available the services of so fine an organization as that of the National Bureau of Standards. Its history over these past years has been one of service with integrity, a combination which we all value and of which those who comprise its staff may be justly proud.

[1] *Craig and Brickwedde.* Trans. Electrochem., Sec. 68, 139 (1933).
[2] *Vinal.* Primary Batteries, Wiley (1950).

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