THE STANDARD ELECTRICAL CELL—ITS USE AND ITS PRACTICAL VALUE.

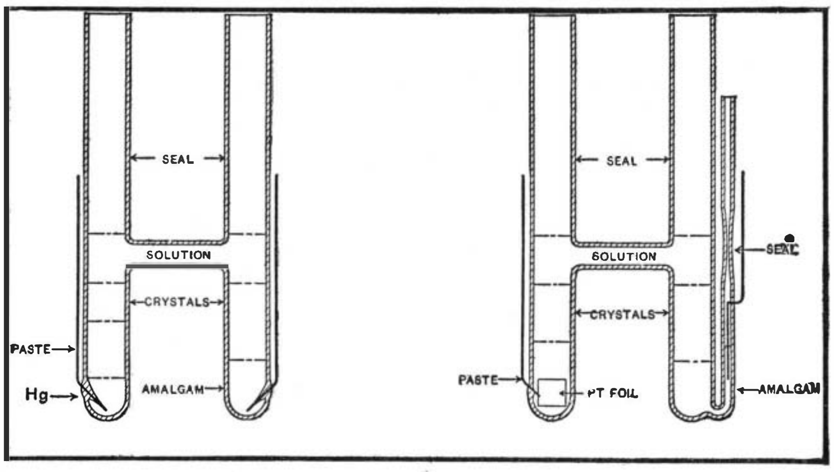
BY HERBERT T. WADE.

One of the most important lines of research in the field of electricity in recent years has had to do with the study of the standard cell, from which is obtained a certain definite and constant electromotive force. Indeed, the standard cell practically underlies all measurements of electromotive force or difference of potential, and its study and investigation have interested workers at the great national physical laboratories, especially since the Clark cell was adopted as the standard of electromotive force in the definition of the volt by the Chicago Electrical Congress of 1893. To-day not only methods and results are compared by these national laboratories and bureaus, but the very cells themselves are interchanged, and a surprising degree of uniformity obtained on their comparison. Now the standard cell in electrical measurements has the same function that a standard measure such as a scale or gage has in the shop, and it must be used in the fundamental testing of a direct-reading voltmeter, and in other forms of laboratory work where accuracy in electrical measurement is essential. While there are electrical units on the absolute system logically derived and inter-related, and such practical units as the ampere, volt, and ohm, yet it is just as difficult to reproduce and apply these units as it would be an inch or foot without recourse to some concrete standard.

To realize the fundamental definitions, and then to construct standards, is a task requiring the most refined physical work; but once the units are realized or known in terms of certain standards which may be reproduced readily and used in the laboratory, accuracy of measurement follows without difficulty. The standard cell enables us to define the volt as one of the fundamental units in addition to its general utility for electrical testing. Various physicists and the investigators at the U. S. National Bureau of Standards have made a careful study of various types of these cells, and it is their opinion that the standard cell has preponderating advantages over the coulometer as a fundamental standard. However, aside from this matter of defining the fundamental unit, the present condition of the standard cell and its construction and testing present much that is of interest.

The first standard cell, or rather a constant cell in terms of which electromotive force was measured, was the Daniell cell, where zinc in a porous jar containing zinc-sulphate solution served as the anode, while the cathode was copper in a solution of copper sulphate. This cell was and is very useful as a constant source of current, as in telegraphy, having an E. M. F. of about 1.1 volts, but as a standard it was supplanted by the Clark cell, devised by Latimer Clark in 1872.

In its original form the Clark cell consisted of a test tube containing a mercury electrode covered with a paste made of mercurious sulphate, zinc-sulphate crystals, and solution, while above to form the second electrode was a rod of zinc in a saturated zinc-sulphate solution, and in contact with an excess of zinc-sulphate crystals. With an E. M. F. taken as 1.434 volts at 15 deg. C. the Clark cell found wide usefulness, and various improvements in the materials and form of construction resulted, especially the evolution of the H-type containing vessel and the substitution of zinc amalgam for the zinc rod, due to Lord Rayleigh. In 1893 the Chicago Electrical Congress adopted the Clark cell as a standard of electromotive force; and while international specifications for its construction never were prepared, yet in the United States and in other countries legal specifications for making the cells were promulgated, and the E. M. F. was started at 1.434 volts at 15 deg. C. In the United States type a glass vessel in the shape of an inverted Y was prescribed, in one limb of which was pure mercury, and in the other an amalgam of zinc and mercury. On the mercury was a layer of mercury and zinc-sulphate paste, above which, as well as above the zinc amalgam, was a layer of neutral zinc-sulphate crystals, and over all was a solution of zinc sulphate. Somewhat different types of construction were adopted in different countries, and in Germany the value of 1.4328 volts was adopted for the E. M. F., which is nearer correct than the United States legal value. Mention here should be made of the Weston cell, brought out in 1892, which since has been widely used and studied both independently and in connection with the Clark cell. In the Weston cell, cadmium and cadmium sulphate replace the zinc and zinc sulphate of the Clark cell, and the change of the E. M. F. with temperature is so small as to be practically negligible. For this and other points of advantage the Weston cell with its E. M. F. of 1.1025 volts immediately found a place in the testing laboratory.



Figs. 1 and 2.—Sectional views of standard cells.

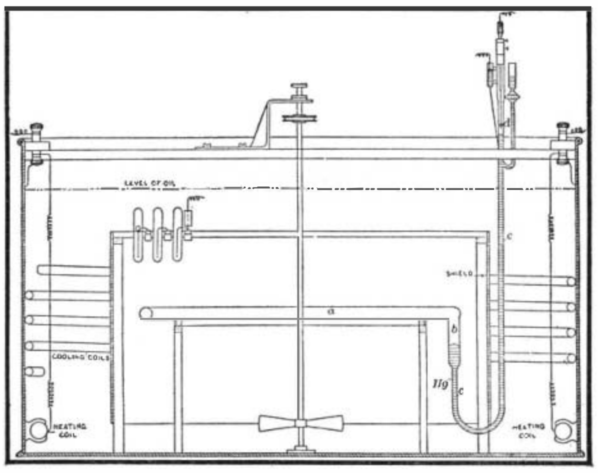


Fig. 3.—Sectional view of comparing bath.

Now, while both of these cells could be made with ordinarily "chemically pure" materials of sufficient accuracy for most ordinary work, yet their permanence and durability, as well as the limits of accuracy and reproducibility, became a matter for investigation, and this has continued with all the refinements possible in modern physical work. The purity of the chemicals used has been determined beyond question, and electrolytic and other methods have been used to obtain materials of absolute purity and uniformity, even the size of the grain of the mercurious sulphate having received attention.

The form of cell now made by the United States National Bureau of Standards is shown in the accompanying illustration, Fig. 1, a half-size diagram. The size does not affect the E. M. F. of the cell, but it does determine its polarization and its power to assume quickly the temperature of its surroundings. The lead wires are of platinum sealed into the tube, and within are coated with a thin layer of glass to nearly the end. Cracking at the point of sealing has always been a weak point with the Clark cell, and this arrangement reduces the danger, though the form of vessel serves equally well for the Clark and Weston cells.

The Reichsanstalt, or German Imperial Testing Laboratory, recommends the form shown in Fig. 2, in which the platinum terminal of the amalgam limb is sealed into a side tube, into which the amalgam is sucked up while still liquid. In a portable type of cell a piece of amalgamated platinum foil, as shown in Fig. 2, at the bottom of the left limb is welded to the platinum lead wire and replaces the mercury. This type also has been extensively used by the Bureau of Standards. The preparation of the chemicals and the construction of these cells involves the most painstaking care and the following of most detailed directions, and of equal importance is their testing. In the Clark cell especially the variation of the E. M. F. with temperature requires special temperature-regulating apparatus, which enables the temperature of the oil bath in which the cells are placed to be maintained constant to within 0.01 deg. C. This is installed in a basement room of the Bureau of Standards, where the temperature for the greater part of the year can be controlled automatically within 1 deg. or 2 deg. The illustration and diagram show the arrangement of the comparing baths and the regulating device which controls the temperature. The various cells to be tested are immersed in the kerosene baths, and their E. M. F. is measured by the potentiometer method, using a very accurate potentiometer of 10,000 ohms resistance and a sensitive galvanometer, so that a difference of 0.00001 volt is plainly indicated on the scale. In this arrangement a storage battery arranged across the terminals of the potentiometer provides a constant fall of potential. Now, by adjusting the coils of the potentiometer, points can be found where there is no deflection of the galvanometer, showing that the fall of potential of the standard cell is the same as that over a certain proportional part of the resistance of the potentiometer. Both Clark and Weston cells thus were checked against each other; and as a result of a large number of experiments and observations, it was found that taking care that the mercurious sulphate was pure, the remaining material of requisite quality could be obtained readily, so that both types of cells are reproducible to within 2 or 3 parts in 100,000. These cells properly constructed gen-

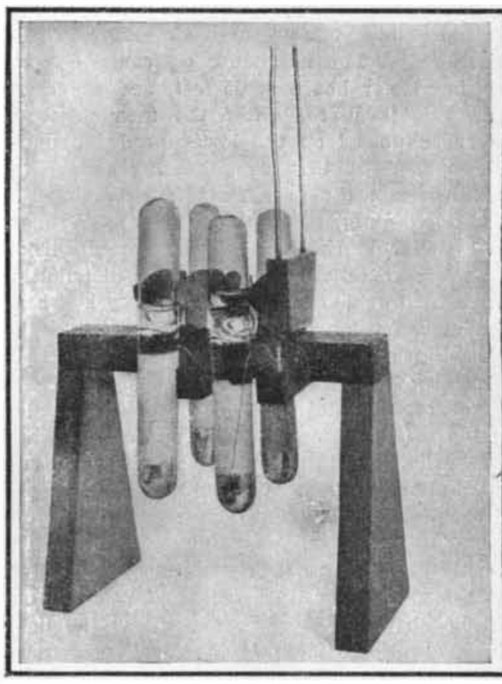


Fig. 4.—Cells, showing traveling contacts and method of mounting.

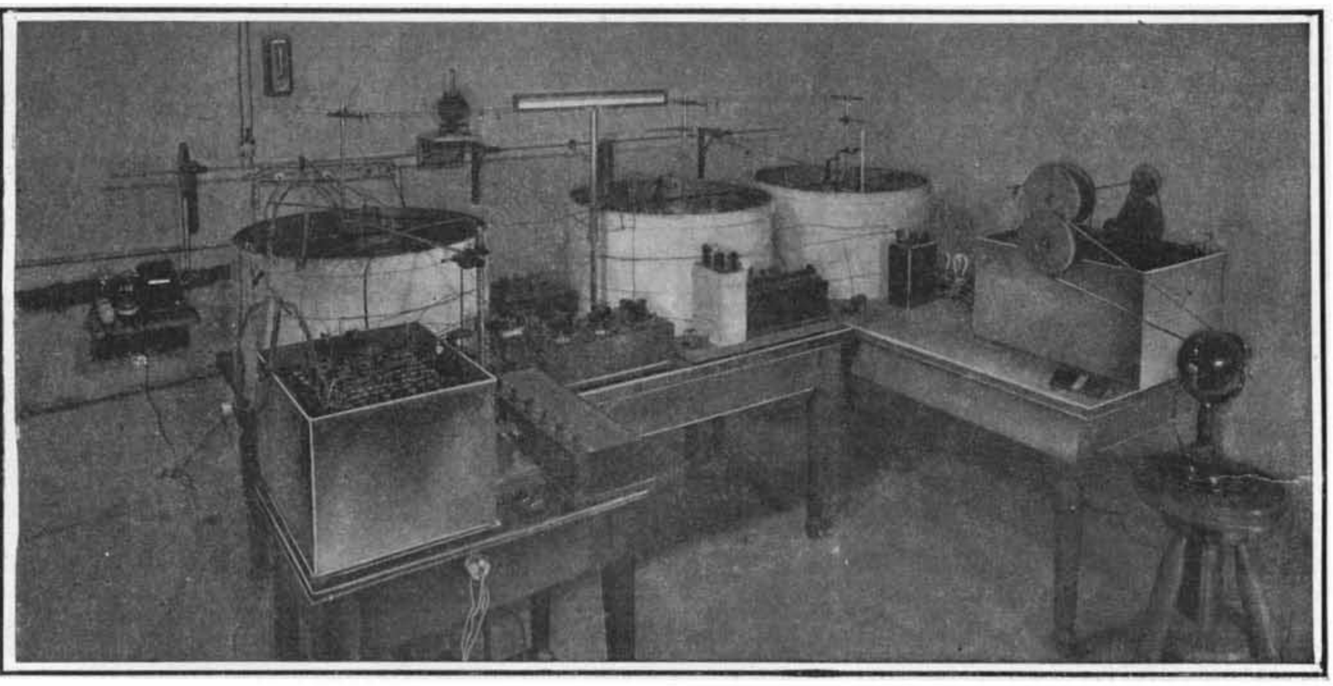


Fig. 5.—Laboratory for studying standard cells.

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erally reach a constant value within a few days, and their E. M. F. can be depended on within the above limits for at least a year.

The investigators at Washington have studied not only their own cells made in various ways, but also those of other investigators, particularly those of the Reichsanstalt, the National Physical Laboratory of Great Britain, and the Laboratoire Centrale d'Electricité, comparison with the cells of these institutions having been made both in Europe and in Washington. The conclusion was reached that standard cells could be set up by different investigators which will agree to within a few parts in 100,000, and that they can be constructed and carried considerable distances even on shipboard if ordinary precautions are observed.

In the present condition of the standard cell, the national laboratories can secure the desired accuracy and reproducibility, and this extending in turn to the secondary standards must have its effect on electrical measurements. If it is not feasible for the national laboratories and bureaus to construct these standard cells for ordinary testing or manufacturing laboratories, it has been suggested that they might supply the materials of the requisite purity, and thus obtain substantial harmony, as the mere following of the specifications is not difficult, while testing and certification by the Bureau would be a sufficient guarantee of accuracy. The Weston cell, which undoubtedly will be selected as an international standard of E. M. F. at the coming congress, though possibly without a legal numerical definition of its voltage to supplant the Clark cell of the present definition, has now been demonstrated as a convenient standard and one easily reproducible with exactness. It is for these reasons that many physicists, especially those in America, wish that the volt as defined by the standard cell should form with the ohm the two fundamental electrical units.

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THE GUAYULE RUBBER INDUSTRY.

(Concluded from page 24.)

are said to own or control 3,000,000 acres of guayule lands, and there are other large interests besides these.

The rate of consumption of guayule is a subject of interest and importance. With several well-equipped factories in active operation working, at least a part of the time, both night and day, the inroad upon the supply is a matter demanding consideration. Although the acreage above cited seems large, the fact is that only parts, favored situations, of these large holdings actually produce the plant—the foothills especially, of limestone formation. A single factory may consume 30,000 tons of guayule shrub in a year, or approximately 100 tons a day. This may represent the growth on anywhere from 25 to 100 acres of land. The number of plants on an acre, and the weight of the individual plant, vary so much that no constant figures can be given. One may find on guayule lands a stand of from 1,000 to 2,000 plants to the acre, and the plants weigh anywhere up to 15 pounds (very large); probably the majority of the plants taken weigh dry from 1 to 4 pounds. Thus on an acre we should find from 1,000 to 8,000 pounds of the shrub. If we call the average yield two tons per acre, we may estimate the area harvested at fifty acres for one day's consumption at a large factory.

While the fact is patent that the supply of guayule is decreasing and must ultimately be exhausted, the opinions of experts place the date, some at ten, some at twenty years hence. Large factories running steadily at Parras, Torreon, Saltillo, and elsewhere, using the product of no less than 100 acres every day; the activities of the camps which the traveler may see in a dozen places in a day's journey; the bales of the shrub piled high by the siding awaiting shipment, all point to the speedily approaching day when the factories must shut down for want of material.

This menace to the business interests involved has not been overlooked or ignored. To provide a continuous crop upon which the business could depend is an idea that has appealed, not only to the members of interested corporations, but also to private landholders, who appreciated the income prospective from such an enterprise. Experiments here and there have been tried, and various opinions have taken form as to the prospect. The most notable of these experiments was that conducted at the instance of the Continental-Mexican Rubber Company, who recently established an elaborate department of investigation at Cedros, Mexico, and spent much money in forwarding the work. Although less than a year was allowed for this large task, the time sufficed to show some insuperable obstacles to the cultivation of the plant on anything like an economic scale.

In the first place, the slow production of seeds, and the care required in their planting, and the rearing of young plants, make the procedure unprofitable from an economic standpoint. With a possible germination rate of 10 per cent of the seed sown, the failure through one cause or another of the young seedlings to pass the initial stages of development, the ranks of the young plants again depleted by pest or parasite, the loss by accidents or in the process of transplanting, and a few subsequent vicissitudes both possible and probable, make it doubtful whether one can count on as much as 1 per cent of the seed sown to mature plants, even under the most favorable conditions. Cuttings mostly fail to grow except from portions of the roots, or stems having part of the root system in connection with them, and only under certain conditions of irrigation; even then, as in the case of seedlings, the cost of the operation exceeds its value. Irrigation is quite essential to the starting either of seeds or cuttings, and in the subsequent growth the rapidity of development depends upon the quantity of water supplied.

But the rapidity of development is in inverse ratio to the formation of rubber in the tissues. Plants grown under irrigation grow rapidly, and attain in four years a weight of six pounds or more, but the rubber content in such plants is practically *nil*, while in native desert-grown plants it is about 10 per cent of the dry weight. If, however, water is withheld, as under desert conditions, the plants grow very slowly, and it is doubtful whether a crop could be matured much under twenty years. Of course, rubber is present in desert-grown plants at an age much less than this, but it is a question at what age plants may be most profitably taken, though certainly not in less than ten years.

Reforestation by natural processes must be very slow, and as in the case of the lumber forests of the North, the second growth is never equal to the first. A guayule seed in the desert has about one chance in ten thousand of coming up, and thereafter danger from drought, disease, and accident make its hold upon life exceedingly uncertain. The only hope of prolonging the business seems to be in so harvesting the plants that the roots are left in the ground; from these new shoots will arise, and in a few years possibly yield another crop worth the taking. How long this process can be kept up profitably is at present unknown. However, the guayule rubber industry seems destined to have its day and pass out.

The above statements are issued only after much observation and experiment, the details of which are soon to be published in a book under the joint authorship of the investigators.

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A 5,000-TON TESTING MACHINE.

After the Quebec Bridge fell into the river, it was found that the special member which gave way had failed under a load far below that which theoretically it should have carried. The steel of which the bridge was built was of excellent quality, and in the compression member which doubled up under its load there was sufficient steel for the purpose, if it had only been assembled and braced together in the proper manner to develop its full strength. The engineers who built the bridge believed that the box-like form in which the plates of the bottom chord had been assembled and latticed together represented the strongest form of construction. They believed that the latticing was quite sufficient to hold the deep webs or plates of the chord in true line and prevent just that very buckling which brought about the fall of the bridge.

If we take a one inch cube of steel, of the same quality, say, as that in the Quebec Bridge, and subject it to compression in a testing machine, it will begin to give way at a certain maximum load, which represents the ultimate compressive strength of the material. If we take another piece of the same steel, one inch square and six inches long, and subject it to compression in the direction of its longer axis, failure will take place under a load less than that which was necessary to destroy the one inch cube. Similarly, if we take another specimen, one inch square but twelve inches long, there will be a still further decrease in the comparative compressive strength of the specimen. As the length of the successive bars tested increases, there will be a rapid decrease in their resistance, failure taking place, not as in the case of the cube by the actual crushing of the material, but by the bending or bowing of the specimen away from its longitudinal axis. If, however, as the length of the specimens is increased, sufficient bracing be applied to prevent their bending from the straight line, they will carry the same maximum load, or nearly so, as the first specimen measuring one inch on every side.

Now, in designing steel compression members, whether in the form of columns to support the walls of buildings, or of posts or chords for steel bridges, an effort is made to so tie together the angles, plates, etc., of which they are composed, that the steel will stand a compressive stress as near as possible to that which is necessary to crush a one-inch cube of the same steel. Formulæ have been drawn up, based upon tests to destruction of built-up members of comparatively small size, which are used in designing the big compression members that are too large to be placed in any existing testing machine. All of the large bridges which have been built in this country during the past few years, including the Quebec Bridge, have been designed by these formulæ which were formerly believed to give closely accurate results. Consequently, when the failure occurred at Quebec, it is not putting the case too strongly to say that it produced positive consternation among bridge builders, not only here but throughout the whole world. And although subsequent investigation of the bridge proved that it was overweight, and that the latticing which failed was lighter and more openly distributed than in the judgment of many eminent engineers would be considered safe practice, it is still a fact that if the commonly accepted theory of latticing was correct the bridge should not have gone down. Hence there has risen a demand among bridge engineers for the construction of a machine large enough to take the biggest compression members and test them to absolute destruction. It has come to be understood that only by this means will it be possible to draw up formulæ which will be absolutely reliable in the design of compression members of unusual size.

Largely as the result of the agitation of this subject the United States Geological Survey is having built a mammoth testing machine, which will have the large capacity of 5,000 tons. This powerful plant, which forms the subject of our front page engraving, is now under construction for the Structural Materials Testing Laboratories of the Geological Survey by Olsen & Company of Philadelphia. The main purpose for which the machine is being built is the testing of large blocks of stone used for building purposes by the United States government. It was also desired to obtain data regarding the strength of columns of brick, concrete and structural steel. Originally designed to take members 25 feet in length, the machine is now being built to accommodate specimens up to 65 feet in length. It will have a total weight of over 200 tons and its height above its foundation will be 80 feet. With a view to exhibiting its great proportions our artist has shown how the machine would appear if it were erected at the corner of Broadway and Vesey Street, adjoining the southeast corner of the old Astor House, which is shown in the illustration. Although the machine has a total compression capacity of 5,000 tons, it will not be capable of crushing to destruction a chord section of the Quebec Bridge, or of the recently opened Queensboro Bridge in this city. The drawings of these two sections have been introduced into the picture merely to show their huge proportions. The Quebec Bridge section is shown adjoining St. Paul's Churchyard, and the Queensboro Bridge section is shown within the testing machine whose length is sufficient to include it.

During the present Congress a bill was introduced but failed to pass, authorizing the construction of a testing machine by A. H. Emery, who built the celebrated 400-ton testing machine at Watertown Arsenal from which such great benefits have been derived. This huge machine, which will have a capacity in compression of 11,000 tons and in tension of 5,500 tons, will be able to handle specimens one hundred feet in length. Its total length will be 153 feet; it will be 25 feet in width; its weight will be about 3,500 tons, and its cost would be $1,750,000. Had such a machine been in existence during the design and construction of the Quebec Bridge, it is safe to say that the catastrophe would never have occurred.

Returning now to the 5,000-ton Olsen machine, as herewith illustrated; the base contains a hydraulic cylinder or ram of 2,000 square inches cross-sectional area, upon which is placed the lower platform. From the four corners of the base extend four huge vertical screws, each 13½ inches in diameter and 72 feet 2 inches in length. At their upper extremities they pass through a massive upper head and are provided with four nuts which are operated simultaneously by means of gearing. The maximum clearance between the upper and lower heads is 65 feet, and the heads are each six feet square. After the member to be tested has been placed on the lower head the upper head is brought down to a snug bearing on the top of the member, and the pressure is then applied by means of a triple plunger pump connected to the main hydraulic cylinder in the base of the machine below the lower head, which, to secure an even distribution of pressure, is provided with a ball-and-socket bearing. The determination of the pressure which is being applied to the member tested is arrived at by means of a set of standard levers upon which is weighed 1/80 of the total load on the main cylinder, the reduction being secured by means of a piston and diaphragm. The weighing beam is balanced by means of an automatically operated weight, and it is provided with a device by which counterweights of one million pounds each may be successively applied. The machine will stand upon a foundation of concrete eight feet below the floor line, and the top of the machine will be about seventy-two feet above the floor. The main hydraulic cylinder is fifty inches in diameter, and each of the 13½-inch main screws will weigh over twenty tons. The contract calls for an accuracy of at least one-third of one per cent for any load over fifty tons and up to the full capacity of 5,000 tons.