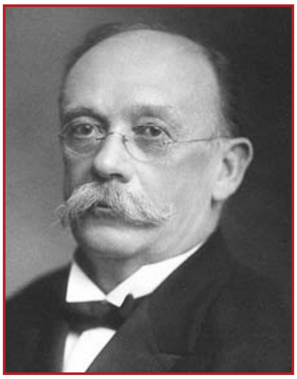
ECS Classics

Weston, the Weston Cell, and the Volt

by Petr Vanýsek

The measurement of electromotive force, potential, or voltage difference has been central to measurements ever since the concept of potential in electricity was first understood. The definition of the volt changed a few times throughout the course of history and at one point it was even based on electrochemistry, on the so-called Clark cell. The international volt was defined in 1893 as 1/1.434 electromotive force of the Clark cell. This definition lasted until 1908. The Clark cells used zinc or zinc amalgam for the anode and mercury in a saturated aqueous solution of zinc sulfate for a cathode, with a paste of mercurous sulfate as a depolarizer. The cell design had a drawback in a rather significant temperature coefficient and also suffered corrosion problems, which were caused by platinum wires that were alloying with the zinc amalgam in the glass envelope. In 1908 the definition based on the Clark cell was supplanted by a definition based on the international ohm and international ampere (through Ohm's law). Neither definition was of much practical use in helping to calibrate the precise Poggendorff compensation potentiometer. The standard for the use in the Poggendorff apparatus became a cell known as the Weston cell, named after its inventor Edward Weston, who came up with its design in 1893. This cell was adopted as the International Standard for EMF used from 1911 until 1990.

Weston—The Man



Edward G. Weston

Edward G. Weston (1850-1936) was born May 9th in the town of Oswestry, Shropshire (England) and was brought up in Wales. He studied medicine and later developed an interest in chemistry while also serving an apprenticeship to a local physician. After receiving the medical diploma in 1870 he set off for New York City, where he found a job not in medicine but in the electroplating industry. The first company where he worked went out of business and for a while he had a short career as a photographer. (It is perhaps worth noting here that Edward Weston of the Weston cell fame should not be confused with Edward (Henry) Weston (1886-1958) a prominent American photographer.) In 1872, E. G. Weston and George G. Harris formed the Harris & Weston Electroplating company and there he patented a nickel-plating anode in 1875 and developed his first dynamo for electroplating based on his understanding of the need for reliable power sources for electroplating. From New York City and the electroplating enterprise he moved on to Newark, New Jersey, where he founded The Weston Dynamo Electric Machine Company and in 1876 he patented a design for a DC generator.

Sharing much of the same enthusiasm as Acheson (ECS Classics, *Interface,* **26**(1) 36-39), Edison, or Swann (ECS Classics, *Interface,* **23**(4) 38-40), Weston was also interested in lighting equipment. His company, among others, won the contract to illuminate the new Brooklyn Bridge. His carbon based light bulb filament made from Tamidine (reduced nitrocellulose) was used until tungsten was introduced.

Weston was, since his first introduction to electrochemistry in electroplating, well aware of the need to reliably measure electrical parameters. Because of this interest, in 1887 he established a laboratory making devices for measuring electrical parameters. In the process he developed two important alloys, constantan and manganin, with virtually zero temperature coefficients, making them suitable for calibration resistors. In 1888 he developed a portable instrument to accurately measure current, the basis for a voltmeter, ammeter, and wattmeter. Then, in 1893, he developed the practical "Weston Standard Cell," that was used for almost a century to calibrate electrical measuring instruments. His company, Weston Instruments, produced world famous voltmeters, ammeters, wattmeters, high-frequency meters, electric meters (watt-hour meters), and current/potential transformers and transducers. In 1928-29 Weston and his son Edward Faraday Weston (1878-1971) were experimenting with light film exposure meters for photography based on a photoelectric cell also produced by the Weston company. Eventually, these selenium-based meters became very useful and highly appreciated tools in film photography (Fig. 1). While the quality of the Weston light meter was undisputed, one has to wonder how much visibility the meters gained thanks to the market of photography books by Edward (Henry) Weston and vice versa, as both the meters and the books were advertised in 1960s side by side in *Modern Photography* magazine

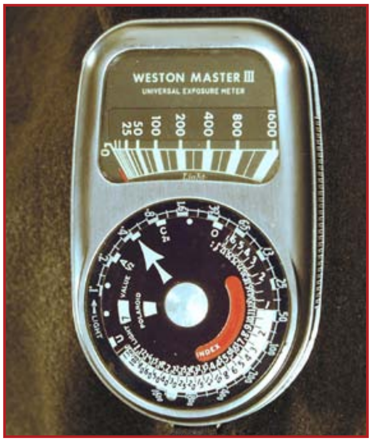


Fig. 1. *The Master III photography exposure meter (circa 1956-1959) produced by the Weston Company (photo author).*

Weston[1] did not make his mark on electrochemistry just by his standard cell. He was also a charter member of ECS. In 1928 he invested $25,000 in a trust of ECS to support and advance education in electrochemistry. In eight decades this fund supported over three hundred summer fellowship recipients.

Weston died in Montclair, New Jersey on August 20, 1936.

The Standard Weston Cell

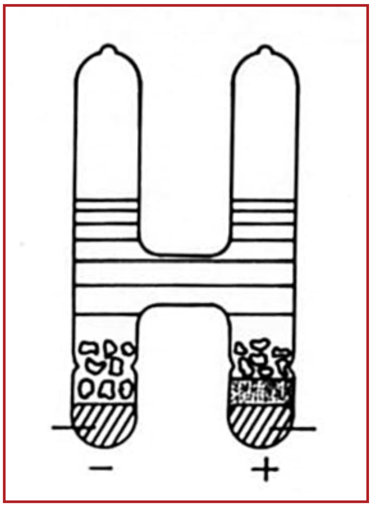


Fig. 2. *Schematics from an unpublished manuscript by the author.*

Edward Weston invented the cell in 1893. As shown in Fig. 2, the negative electrode is a 12.5 percent amalgam of cadmium with mercury and the positive electrode is pure liquid mercury. These are placed into the arms of the H-shaped glass cell to make contact with platinum contact wires that are sealed in the glass at the bottom of each leg. The diameter of the tubes of the original design was about 25 mm. Over the pure mercury of the positive electrode is placed a paste of mercurous sulfate and cadmium sulfate mixed with mercury. The electrolyte is an aqueous solution of cadmium sulfate. In the original design the solution was saturated and, to maintain saturation, crystals of cadmium sulfate were placed above the cadmium amalgam and the mercurous sulfate paste in each arm. Some air remained in the vessel and both arms were flame sealed on the top. While the cells could provide some electricity, they were never used to supply much current. They were used as standards connected to high impedance and intermittently to sensitive galvanometers through a Poggendorff compensation potentiometer. The electrochemical reactions of the cell were oxidation of cadmium on the anode and reduction of Hg_2^{2+} on the cathode.

Anode reaction (negative electrode):

$$Cd(Hg)(l) \rightarrow Cd^{2+}(aq) + 2\ e^-$$

Cathode reaction (positive electrode):

$$Hg_2SO_4(s) + 2\ e^- \rightarrow 2\ Hg(l) + SO_4^{2-}(aq)$$

A photograph illustrating an actual H-cell of a commercial Weston cell (Metra Blansko, Czechoslovakia) is shown in Fig. 3.

The nominal potential of the cell was 1.018 636 V. Achieving the nominal potential was not a simple task. The commercial mercury was cleaned in dilute nitric acid and distilled water and twice distilled in vacuo, a method adopted and practiced later by many polarographic labs.

The amalgam was in the standard descriptions chosen as 12.5 per cent, i.e., one part cadmium to seven parts of mercury. It turns out that as long as the liquid phase in the amalgam remains, the appropriate potential is maintained, thus amalgam containing 6 to 14% of cadmium is sufficient.[2]

Cadmium sulfate for use in the cell was prepared by recrystallization from water by evaporation at a somewhat elevated temperature. It should be noted that at laboratory temperatures cadmium sulfate crystallizes as a hydrate of formula $CdSO_4 \cdot 8/3\ H_2O$, an octatritohydrate. Above 74 °C the hydrate becomes $CdSO_4 \cdot H_2O$. Thus, the solid crystals placed in the saturated version of the cell above the solid/liquid mercury phases are sometimes properly labeled as $CdSO_4 \cdot 8/3\ H_2O$. The assembled cell had very stable potential, which varied only slightly with temperature. Even this variation was determined and codified between temperatures *t* 0 °C and 40 °C by an empirical formula:

$$E_t = E_{20} - 0.0000406\ (t - 20) - 0.00000095\ (t - 20)^2 + 0.00000001\ (t - 20)^3$$

Later, unsaturated cells were also used, which showed even lower temperature dependencies. However, their potential would gradually drift and they had to be periodically recalibrated.

The potential of the standard cell was originally given (E_{20}, thus at 20 °C) as 1.0183 volts, but this was in the international volt unit. On January 1, 1948 the international volt was replaced by the absolute volt,[3] which in the USA required multiplication by 1.0003300; thus, the value became, at least numerically, 1.0186360 V. An astute student should note the excessive number of significant figures. It has been subtly clarified that the original value was valid to the seventh decimal (hence 1.0183000) and hence the conversion, as given, is valid.[4] In practice, Weston cells can be made without an extreme amount of care, once the pure chemicals are available, so that they agree to 0.01 mV, thus to the fifth decimal. Thus, the practical reference value is more reasonably 1.01864 V.

The Volt

A volt in the System International is a derived unit, defined as the difference in electric potential between two points of a conduction wire when an electric current of one ampere dissipates one watt of power between those points. While this is a rigorous definition, it does not lend itself to a very practical calibration setup. That is the reason why the Weston cell, once perfected, remained a conventional standard until 1990. Many of these cells still exist on the shelves of research labs, though they are likely not used much anymore. In 1990 the *conventional volt* was implemented using the Josephson effect. The Josephson voltage standard uses a superconductive integrated circuit operating at 4 K, driven by microwave excitation (70-96 GHz). This device generates voltage which is only dependent on the excitation frequency (and frequency/time measurement can be controlled/measured to the highest number of significant figures) and fundamental constants (the Planck constant and the charge of an electron). The stability of such a well-maintained device is one part per billion or better. As secondary standards properly designed semiconductor devices are used, such as Zener diodes or a bandgap voltage reference, which is a circuit which maintains very constant voltage at 1.2 to 1.3 V, arising from the 1.22 eV bandgap of silicon at 0 K. With such properly designed circuits implemented in modern laboratory instruments their calibration is no longer needed or even possible. When critical or desired, certification may be required instead.

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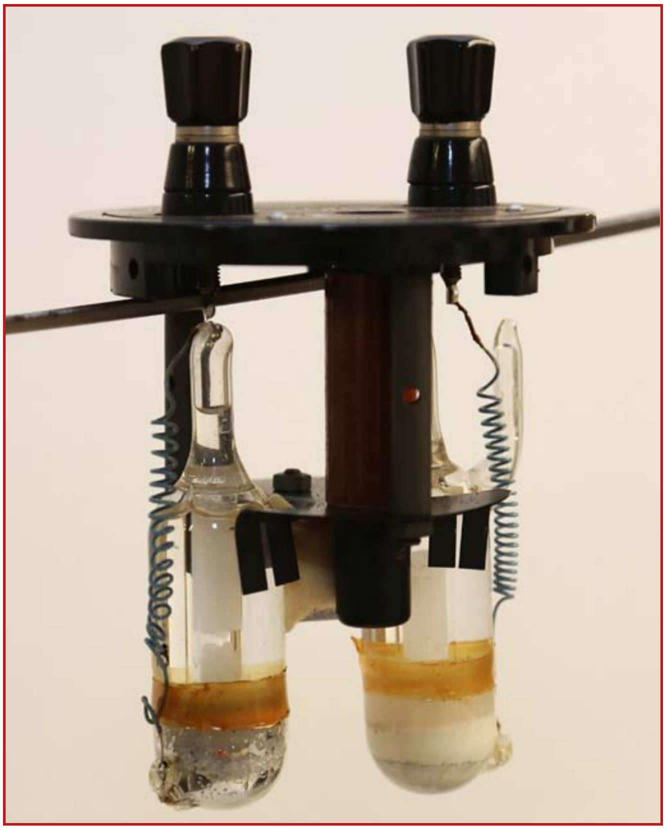

Fig. 3. *H-cell from the Metra Blansko commercial cell (photo V. Novak).*

The Weston cell was an elegant design bringing electrochemistry (albeit often in a black box, with two terminals on top and the workings not visible) to laboratories that depended on exact voltage measurement. A few such cells are shown in the accompanying pictures (Fig. 4-6), not from laboratories but provided for photographing courtesy of the Brno Technical Museum in Czech Republic (Ing. J. Pipota). The Czechoslovak instrument company Metra Blansko produced not only reliable voltmeters and multimeters, but also standard cells, for which we were able to obtain even a picture as disassembled. While the cell could be placed intermittently on its side, it had to be stored and operated in an upright position. While we may be sorry to see that this ambassador of electrochemical thermodynamics has disappeared, we cannot dismiss the practicality of internally calibrated multi-digit meters. And realistically, if the Weston cells were not replaced when they were, their mercury contents would phase them out a few years later anyway.[5]

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Fig. 4. *Cell manufactured by Weston Electrical Instrument Company—the unsaturated version (circa 1950s) (photo author).*

Fig. 5. *The standard "International Weston normal cell with saturated solution" manufactured by Metra, Czechoslovakia (1958) (photo author).*

Fig. 6. *Assorted standard cells. In the middle are two cells in one container for comparison (photo author).*

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About the Author

Petr Vanýsek grew up in Czechoslovakia, in the part of the country now known as the Czech Republic, where he received a doctorate in physical electrochemistry. His scientific career developed in the USA, where he went through the ranks of tenure track and tenured faculty at the Department of Chemistry and Biochemistry at Northern Illinois University. Now an Emeritus at NIU, he is currently working at the Faculty of Electrical Engineering and Communication of the Brno University of Technology, Czech Republic. The Czech connection enabled him to photograph the collection of the Technical Museum in Brno. Vanýsek has long involvement with ECS on a number of committees including four years as the society secretary. Presently, he is a co-editor of Interface, chair of the Europe Section, and vice-chair of Physical and Analytical Electrochemistry Division. He can be reached at pvanysek@gmail.com.

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