A battery composed of plates 10 inches long and $\frac{1}{2}$ an inch wide gives a current of 0·122 ampère at first starting, but as polarisation takes place, after five minutes, only 0·079 ampère. The cost of a battery of this size is 0·40 fr. (4*d.* about), it remains in action for six days without the renewal of the sodium. Batteries of larger dimensions, as for example 10 inches long and $1\frac{5}{8}$ inches wide, last four weeks, because the action is chiefly on the edges of the sodium plate, and the broader the plate the longer the sodium lasts without renewal.

X. "On the Electro-chemical Equivalent of Silver, and on the Absolute Electromotive Force of Clark Cells." By LORD RAYLEIGH, D.C.L., F.R.S., and Mrs. H. SIDGWICK. Received June 18, 1884.

(Abstract.)

The paper contains a record of a long series of experiments, extending over nearly two years.

The measurement of the electric currents is direct, not depending upon a knowledge of the force of terrestrial magnetism. Three horizontal coils are traversed in succession by the electric current. Of these two of large diameter are fixed, and at a distance apart equal to the radius of either. Symmetrically between them a smaller coil is suspended in the balance. When the current passes, the suspended coil is pressed down, or lifted up, according to the connexions, and the observations relate to the double force called into operation when the direction of the current in the fixed coils is *reversed*. In a paper read before the British Association at Southampton it was shown that this construction presents special advantages, and in particular that the calculation of the result does not require an accurate knowledge of the radii of the coils, but only of the *ratio* of the radii of the small and large coils. In this way one of the principal difficulties, the measurement of the small coil, is evaded.

The ratio of the radii is found by the electrical method of Bosscha. A large and small coil being adjusted so as to be concentric and coaxal, a very small magnet with attached mirror is suspended at the common centre. The two circuits are connected electrically in parallel, and resistance is added to one of them until no effect upon the suspended magnet follows a reversal of the battery current. The ratio of the resistances, to be found immediately by comparison with standards, is the ratio of the galvanometer constants of the two coils, and from this the ratio of the radii may be obtained by the introduction of small corrections relating to the finite dimensions of the

sections. Full particulars are given of the procedure adopted in the reduction of the method to practice.

The insulation of the small coil, which was wound upon a ring of ebonite, was carefully tested with the induction balance after the manner recommended by Graham Bell. The first attempt at winding it proved a failure, several turns being short-circuited; and we are of opinion that no coil of fine wire can be thoroughly depended upon which has not been tested by some such method.

The calculation of the constant of the current weighing apparatus is best made with the aid of elliptic functions. Both for our own purposes and in order to facilitate the use of the method by others, we have calculated a table of the function

$$\sin\gamma\,\{2F_\gamma-(1+\sec^2\gamma\,E_\gamma\},$$

(see "Maxwell's Electricity," 2nd edition, § 701), for values of γ ranging from 55° to 70°.

For determining the electro-chemical equivalent of silver, the current passes also through silver voltameters. The solution of nitrate, or of chlorate, is contained in a platinum basin which serves as the kathode. The anode is a flat piece of fine silver sheet, wrapped in filter-paper, and suspended by platinum wire at the top of the liquid. The duration of the current is determined by a chronometer, and allowance is made for the small loss of time (about one-tenth second), incurred at each reversal of the current in the fixed coils of the measuring apparatus.

In the preliminary notice of March, 1884, the troubles into which we were led by the use of acetate of silver were referred to. With pure nitrate the manipulations present no particular difficulty. We were equally successful with chlorate, prepared for us by Mr. Scott; and the comparison of the results with nitrate and chlorate verify Faraday's law to a high degree of accuracy.

In the reduction of the current weighings, we found it necessary to time all the observations, and to plot the readings obtained in the two positions of the reversing key as separate curves. The difference of ordinates then represents the double electromagnetic force, as it would have been found were it possible to take both observations simultaneously. What we require for comparison with the mean rate of silver deposit is the mean square root of the difference of weighings, and is easily obtained when once the curves are constructed. Apart from errors relating to the constant of the apparatus, the mean value of a tolerably steady current of half an hour's duration should be obtainable to about $\frac{1}{10000}$. In our experiments, the whole change of weight on reversal was about 1 grm., and each single observation was correct to half a milligram. In the passage from

the attraction to the current, the error is halved by the extraction of the square root.

The currents actually employed were about $\frac{1}{3}$ ampère. Much more powerful currents could not be passed for the necessary time through the suspended coil without risk of undue heating. Had it been desirable to use stronger currents, it would, of course, have been possible to do so by the use of thicker wire. With given grooves to be filled up, the ratio of the electromagnetic attraction to the heat developed is independent of the gauge of the wire; and the only further modification required would be the multiplication of the fine copper wires by which the flexible connexions are made.

Thirteen determinations of the ratio of the square root of the double attraction of the coils to the rate of silver deposit gave numbers ranging from 2413·7 to 2415·5, mean 2414·45; whence, after introduction of the constant of the apparatus, the value of the electrochemical equivalent in C.G.S. measure is found to be—

$$\cdot0111794.$$

In terms of practical units, we have as the quantity of silver in grams deposited per ampère per hour—

$$4\cdot0246.$$

With use of this number, it is now easy to determine by the deposit of silver currents up to $1\frac{1}{2}$ ampère. For currents of greater power it is necessary either to increase the size of the (3-inch) platinum basins serving as voltameters, or to dispose several such in multiple arc. For ordinary practical purposes, many of the precautions which we thought it necessary to adopt may be dispensed with. The deposits, after a few rinsings with distilled water, may be left to soak for an hour, and then, after a further rinsing, dried off over a spirit lamp. In an hour's time, the basin may be weighed correctly to a few tenths of a milligram. With regard to the materials, it is sufficient to use for the anodes a sheet of ordinary fine silver (such as is sold at 5*s*. per ounce), and a 15 or 30 per cent. solution of nitrate. It is hoped that this method may come into general use for the verification of current-measuring instruments, whose indications depend upon the constancy of springs, or of steel magnets. Silver presents so many advantages as compared with copper, that its greater cost should not stand in the way of its adoption, more especially as there need be no great waste of material.

In view of the importance of obtaining a convenient standard of electromotive force, a prolonged examination has been made of a number of Clark cells. Of these two patterns have been used, the first constructed according to the directions of Clark himself and of Alder Wright, with some simplifications; the second, called for

brevity the H-cell, in which the solid zinc is replaced by a fluid amalgam. The amalgam and the pure mercury, forming the metallic electrodes, are placed at the bottom of two small test-tubes standing vertically. The electric connexion is made by platinum wires sealed through the bottoms, and the communication between the two vertical tubes is through a lateral horizontal branch sealed into them. The cell is filled with sulphate of zinc solution above the level of the horizontal branch, and can then be closed with corks. This form of cell lends itself conveniently to experiment, as by withdrawing the corks it is easy to observe the effect of stirring or of various additions.

A large number of cells have been compared for more than eight months, and have behaved very satisfactorily. The results are sometimes anomalous for the first two or three weeks, but the values finally attained are in our experience extremely close together.

The comparisons are made by the method of compensation. The *difference* of electromotive force of the cells to be compared is compensated by a known fraction of the electromotive force of other cells, the value of which is then expressed in terms of one of the Clarks. There would be no difficulty in obtaining still greater sensitiveness, but it is useless to take readings closer than to $\frac{1}{10000}$.

The Clark cells possess the immense practical advantage (as compared, for instance, with Daniell's) of standing always ready for use, but the objection is sometimes expressed that they polarise greatly on the passage of the smallest currents. Our experience has been in the opposite direction, and has shown that moderate short-circuiting is actually advantageous in the case of cells newly set up. When old cells, which have reached their permanent condition, are allowed to make $\frac{1}{1000}$ ampère for a quarter of an hour, the disturbance thus occasioned passes off in about half an hour to within a few ten-thousandths, and on the next day there is no indication of any residual effect.

The absolute determinations of the E.M.F. of Clark's cells were made by compensation with the difference of potentials at the terminals of a known resistance traversed by a known current. The details of the method, which offers no special difficulty, are given in the paper. Of thirteen values, found on different days between October, 1883, and April, 1884, with the current measuring apparatus, the highest is 1·4552 and the lowest 1·4531. This number expresses the E.M.F. of a certain cell at 15° in terms of B.A. volts. To get the E.M.F. in true volts, the mean number (1·4542) must be multiplied by the number expressing the B.A. unit of resistance in absolute measure. If 1 B.A. = ·9867 ohm, E.M.F. of Clark = 1·435 volt.

The value of the H-cells would be a few ten-thousandths higher.

Apparatus capable of giving original determinations of the intensities of currents not being generally available, we have shown with

examples how by the use of the silver voltameter the E.M.F. of any cell can be found without much difficulty, and with scarcely any special appliances.

XI. "Preliminary Note on the Constant of Electromagnetic Rotation of Light in Bisulphide of Carbon." By Lord Rayleigh, D.C.L. Received June 18, 1884.

In connexion with other work upon current measurement by Mrs. Sidgwick and myself, we have endeavoured to determine the value of this constant, so as to decide between the very discrepant results arrived at by Gordon* and by H. Becquerel.† The method adopted by us was so far similar to that of Gordon that the tube of bisulphide of carbon was placed inside a helix, but the value of the current traversing the helix was determined in a different manner without reference to terrestrial magnetism.

The light employed was that emitted by sodium. When it is remembered that the effect would vary about two parts per thousand in passing from one sodium line to the other, the importance of definiteness in this respect will be obvious.

The number of turns in the helix is 3684, and the insulation was submitted to severe tests.

In carrying out the measurements the principal difficulty encountered was from optical disturbance arising from the communication of heat from the helix to the bisulphide. Not only does the mean temperature of the bisulphide rise somewhat rapidly during a series of experiments, but on account of the tendency of the warmer parts to find their way to the top of the tube, the light is sensibly diverted from its proper course. It is believed that by a modification of the apparatus about to be tried, this source of embarrassment will be materially checked.

The plane of polarisation was determined in some experiments by a Nicol read in two positions, and in others by a double image prism read in four positions. The adjustment of the match between the two parts of the field presented by the half-shade apparatus was facilitated by a device that may be found useful. In addition to the principal helix, the tube was embraced by an auxiliary coil of insulated wire, through which could be led the current from a Leclanché cell. This current was controlled by a reversing key under the hand of the observer, who was thus able to *rock* the plane of polarisation backwards and forwards through a small angle about

* "Phil. Trans.," 1877.

† "Ann. d. Chim.," 1882.