Citation:

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Physics. — „*On a 5-cellar quadrant-electrometer and on the measurement of the intensity of electric currents made with it.*" By Prof. H. HAGA.

During the last years I was repeatedly obliged to measure with accuracy the intensity of a constant current of about tèn ampere.

From the many methods which might be used, I chose that by which the difference of potential is measured between the ends of a known resistance, inserted in the circuit. As this method is exceedingly simple, capable of measuring currents of greatly different intensities with an accuracy of $^1/_{10}$ percent, it seems desirable to me to draw the attention to this method.

A good quadrant-electrometer is required. In 1893 HIMSTEDT[1]) described a 4-cellar quadrant-electrometer; the needles were suspended by a silvered fibre of quartz; the damping was obtained, by hanging two vertical magnets at the lower end of the small rod which bears the needles, the poles to opposite sides, so that they could move within an annular space in a piece of copper. The magnets not forming a *perfect* astatic system, a small directing force was left, because of which HIMSTEDT was obliged to make the whole apparatus moveable round a vertical axis.

It seemed to me that this difficulty might be avoided, by reversing the HIMSTEDT method of damping, that is to say by hanging a hollow copper cylinder movable in a magnetic field[2]). A 5-cellar quadrant-electrometer with this damping was constructed in the physical laboratory at Groninghen. The principal part of this apparatus is represented by fig. 1; the brass cylinder round the quadrants and the cylindric case round the mirror are removed.

The base of the instrument is a brass plate five mm. thick on three levelling screws; the four quadrants are placed on the plate, insulated by glass columns; one of them may be moved micrometrically. The terminals are attached under the plate, in order to protect them from dust as much as possible. They are perfectly insulated from the plate by ebonite, glass and shellac.

The whole apparatus for damping also is attached to the underside of the plate; it consists of a circular magnet three cm. high (fig. 2), provided with the armaments *a* and *b*; in the latter notches have been filed, in which the poles of the magnet fit closely;

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1) Wied. Ann. Bd. 50, p. 752, 1893.

2) Beiblätter, Bd. 19, p. 896, 1895.

Fig. 1.

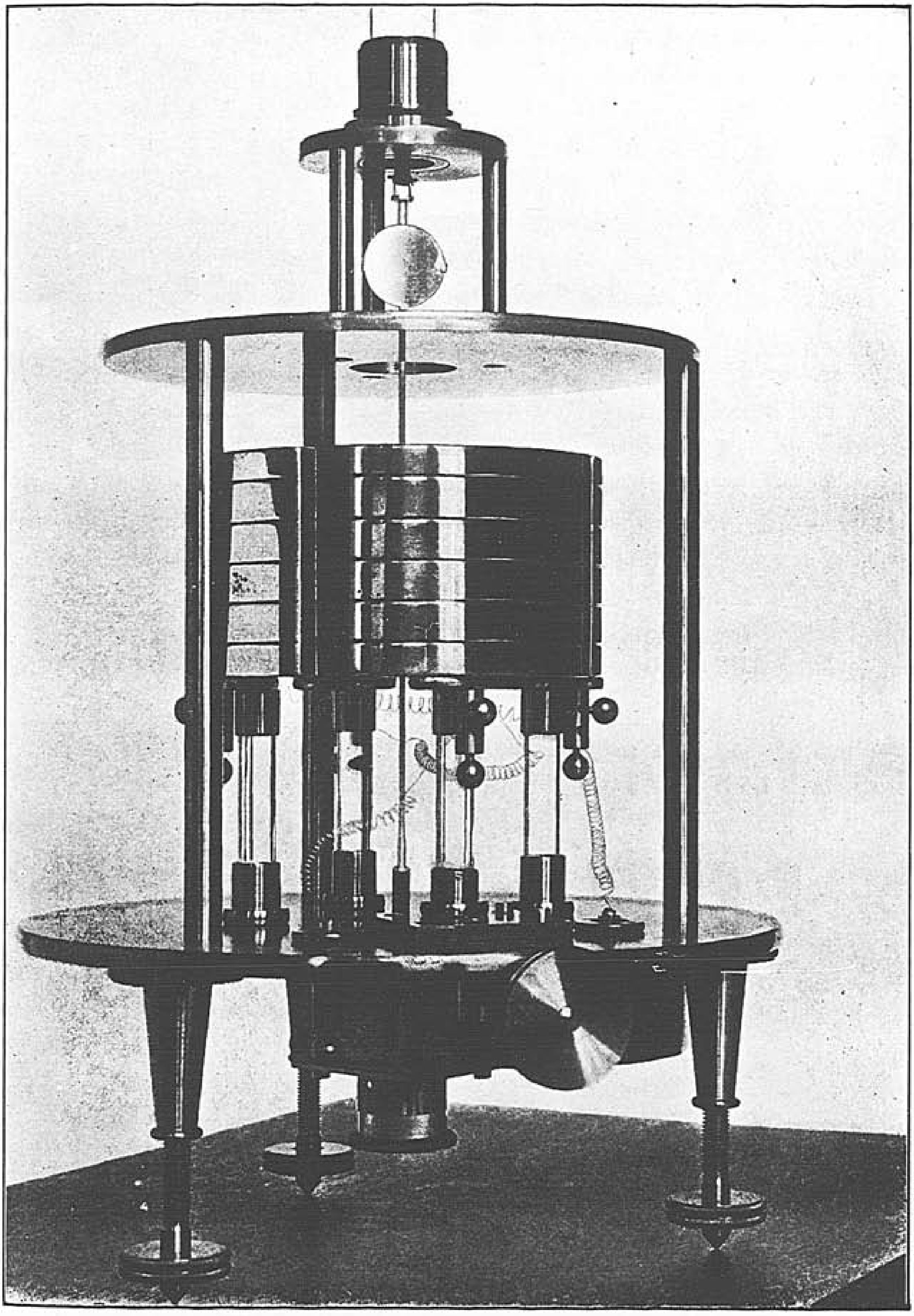
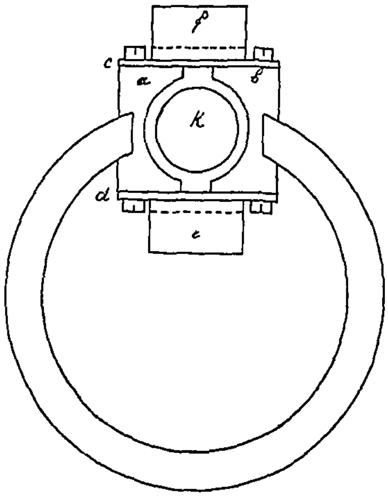


Fig. 2, 1/2 of the real size.



two brass plates *c* and *d* unite the armaments and the magnet, so that they form one whole. Another pair of brass plates *e* and *f* are bent under a right angle, the vertical parts are soldered to *c* and *d*; the horizontal parts serve to attach the apparatus to the under side of the plate. Also the under sides of the armaments are covered by a brass plate, in which a copper tube is soldered, in which the iron core *k* fits closely (fig. 1 and 2). The hollow copper cylinder can move in the annular space between the outer part of the iron core and the inner part of the armaments *a* and *b*; in the middle of the plate is a hole as large as the space between the armaments, so that a small aluminium tube may be slid over the lower end of the aluminium rod, to which the needles are attached. The tube bears an ebonite rod, which is screwed on the lid of the hollow cylinder. In this way the cylinder is suspended exactly in the centre of the magnetic field, the currents of air being excluded by the brass plates round the armaments.

Moreover the apparatus bears a torsionhead and an arrangement to move the needles in a vertical direction without their being discharged. The length of the suspending fibre is 17 cm.; the distance between the lower and the upper plate is 13.5 cm.

As to the sensitiveness of the electrometer, it depends on the suspending fibre to a great extent. With a silvered quartz fibre of 55 μ diameter a CLARK-cell caused a deviation of 760 mm. by reversal, the needles being charged at 180 volt; distance of the scale 2 M. In about half a minute the position of equilibrium was reached after three oscillations.

As the total weight which the fibre had to bear, was 20 grams (the hollow copper cylinder weighed 10 grams), a quartzfibre of 24 μ may also be used, through which the deviation would be increased more than 16 times. The period, however, would be increased to four times its former value.

If this very great sensibility is not necessary, a platinum wire [1]) annealed in a candle-flame is to be preferred because of its

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[1]) HALLWACHS. Wied. Ann. Bd. 55, p. 170, 1895.

greater convenience in use. The elastic hysteresis [1]) moreover is not to be perceived, as is proved by the observations mentioned below. The WOLLASTON wire of 25 μ, supplied by HERÄUS can bear but 4 grams, a platinum wire of 50 μ more than 30 grams; most of the later measurements have been made with this platinum wire. The time of oscillation ($^1/_2$ period) is about 12 sec., and as the damping was so regulated that the needles were in rest after three oscillations, the observation could already be made after 36 sec.

In order to be able to regulate the damping, the hollow copper cylinder is so long thinned and shortened, till (the whole iron core being in its copper tube) the movement is aperiodic. By moving the core downward, the required damping may be obtained. Every wire has of course its own hollow copper cylinder which fits it best.

In using the quadrant-electrometer the charging-battery is of great importance. If measurements are to be made only for a short time, a ZAMBONI pile or a battery of water-cells, consisting of small test tubes filled with water, in which copper and zinc rods have been put, is sufficient. If the charging-battery, however, must be kept ready for use for some months, these arrangements do not suffice any more; nor have I succeeded in reaching this by replacing the water by paste of plaster or by gelatine with carbol. I was very much satisfied with 300 LECLANCHÉ-cells, supplied by P. J. KIPP AND SONS, J. W. GILTAY successor. In the following measurements the positive pole of this battery was connected with the needles, the negative one with the earth.

Table I contains the comparison of six CLARK-cells, constructed according to the instructions given by KAHLE in Wied. Ann. Bd. 51, p. 203, 1894, with a normal CLARK-cell furnished by R. FUESS, at Steglitz near Berlin and tested by the Physikalisch-Technische Reichsanstalt. This cell is called N, while the cells, here constructed are marked A, B, C, D, E and F.

The negative pole of the cells remained connected with the earth, the positive one with one of the pairs of the quadrants, while the other pair of quadrants was kept on zero potential, the position of equilibrium was determined. By reversal these two connections were interchanged and this was continued till five observations were made.

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[1]) GERMAN: Elastische Nachwirkung.

TABLE I.

February 11th 1897.

Needles charged by 300 Leclanché cells; distance of the scale two metres.

Clark cell.	Observed position of equilibrium.		Deviation.	
N. 18°.0	787.8 787.8 787.8	188.1 188.1	**599.7**	
A. 18°.3	788.0 788.0 788.0	188.1 188 2		**599.8^{5}**
B. 18°.2	787.2 787.0 787.1	187.2 187.2		**599.9**
N.	787.3 787.1 787.1	187.4 187.3	**599.8**	
B. 18°.2	787.1 787.1 787.1	187.3 187.4		**599.7^{5}**
A.	788.1 788.1	188.2 188.3 188.3		**599.8**
N.	788.2 788.1 788.0	188.3^{5} 188.2^{5}	**599.8**	
C. 18°.0	785.9 785.9	186.0 185.9 185.9		**600.0**
D. 18°.0	784.9^{5} 784.9^{5} 785.0^{5}	184.8 185.0		**600.1**

Clark cell.	Observed position of equilibrium.		Deviation.	
N.	785.2^{5} 785.2	185.1 185.1 185.1	**600.1**	
D. 18°.0	785.1 785.2 785.3	185.1 185.1		**600.1**
C. 18°.0	785.6 785.5 785.4	185.2 185.1		**600.3^{5}**
N.	790.9 790.7 790.8	191.1 191.1	**599.7**	
E. 18°.1	791.1 791.0 791.0	191.6 191.6		**599.4**
F.	792.5 792.5	193.2 193.1 193.1		**599.4**
N.	792.7 792.5	193.0 193 1 193.2	**599.5**	
F. 18°.2	792.4 792.6	192.9 193.1 193.2		**599.4**
E. 18°.1	791.1 791.3 791.2	191.9^{5} 192.0^{5}		**599.2**
N. 18°.0	791.9 791.7 791.7	192.0 192.0	**599.8**	

From these observations we deduce:

N.	599,8	*N.*	599,9	*N.*	599,7
A	599,8	*C*	600,2	*E*	599,3
B	599,8	*D*	600,1	*F*	599,4

The difference of deviation, caused by *N*, must in my opinion, be ascribed to the influence of temperature, in consequence of which the potential of the charging battery was changed. If greater accuracy is desired, it is necessary to keep the temperature of the charging battery and of the CLARK cell constant; in these experiments the CLARK cells were placed in glass vessels filled with paraffine oil, and care was taken that the temperature could not differ much during the night preceding the experiments.

From this series of observations is seen: 1°. that with this platinum wire the elastic hysteresis may be quite neglected and 2°. that with one observation a difference of potential of 1,4 volt may be measured to at least $^1/_{10}$ percent.

Another great advantage of this method is that the CLARK cell does not yield a current.

If, without examining in how far the deviation of the electrometer and the difference of potential are proportional, we wish to measure the intensity of an electric current, the resistance must be chosen in such a way, that at its ends the difference of potential is nearly equal to that of a CLARK cell, and this must be compared with a CLARK cell. So a resistance of 0.14 ohm is required for currents of about ten ampere; this resistance must be constructed in such a way that the current cannot cause great differences of temperature; therefore ten German Silver wires of $^1/_2$ mm. diameter and about $^1/_2$ M. long were arranged in parallel and placed in a large basin filled with paraffine oil; because of the small temperature coefficient it is sufficient to know the temperature to within three degrees without making a mistake greater than $^1/_{10}$ percent. The resistance itself was determined in the usual way with the WHEATSTONE bridge. Many measurements of the intensity of currents have been made and ampere-meters have been tested with this resistance [1]).

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[1]) That it is necessary to test ampere-meters repeatedly is proved by the fact, that on an ampere-meter of CARPENTIER a current of 10 ampere was marked in

March '95	with	12	amp.
January '96	〃	13,5	〃
March '97	〃	14	〃
October '97	〃	16	〃

Evidently the magnet has been losing its strength continually.

As it is, however, of importance to be able to use the same resistance for currents of different intensity, it was investigated, in how far the deviation of the electrometer and the difference of potential between the pairs of quadrants are proportional.

To this purpose the current of two accumulators was conducted through a resistance of 1050 ohm, viz. 400 + 300 + 200 + 100 + 100 + 30 + 20 ohm of a tested rheostat. By means of the side plugs the difference of potential could be measured between 500, 400, 300, 200 and 100 ohm, in doing which the plug on one end was always connected with the earth.

In order to eliminate the difference of the indication of the instrument between the positive and the negative potential of the same absolute value, the current was led in both directions through the resistance; the two Clark-cells *A* and *B* were placed together in one cylindric glass vessel, filled with paraffine oil; the negative pole of *A* and the positive pole of *B* were continually in connection with the earth and the others by turns with the electrometer.

The following table contains the observed positions of equilibrium and the deviations, the smaller values of the deviation caused by 1 Clark compared with those of table I are to be ascribed to the gradual weakening of the charging battery; measured with an electrometer of Braun the 300 Leclanché cells had no more than 320 volt. Distance of the scale was 2 meters.

TABLE II.

May 5th 1898. $t = 15^\circ.1$.

Observed position of equilibrium.			Deviation.
Clark B —	283 0 283.0	781 1	**498.1**
15°.1			
Clark A +	781.6 781 6	284.8	**496.8**
500 Ohm	203.8 203.8	866 0	**662.2**
	866 3 866 3	206.4	**659.9**

Observed position of equilibrium.			Deviation.
400 Ohm	798.2 798 0	269 7	**528.4**
	267 6 267 5	797 5	**529.9^{5}**
300 Ohm	331.1 331.3	728 2	**397.0**
	728 8 728.8	332.7	**396.1**
500 Ohm	866.2 866 2	206.3	**659.9**
200 Ohm	660 2 659.8	396 0	**264.0**
	395 1 395.1	659 1	**264.0**
100 Ohm	458 9 459 1	590.9	**131.9**
	591.1 591 1	459 5	**131.6**
500 Ohm	866.1 866.1	206.3	**659.8**
Clark B —	282.0 282 2	780 6	**498.5**
Clark A +	781.2 781.2	284.2	**497.0**

The observation of the difference of potential at the ends of the resistance of 500 ohm has been repeated a few times for one of the two directions to find out, whether the intensity of the current has changed during the experiment; it appears that it has remained perfectly constant.

The results of this experiment have been collected in table III; the two numbers between brackets represent the deviations caused by the current in its two different directions.

TABLE III.

Deviation.		Difference of potential in volt.		Intensity of the current in ampere.
		Observed.	Calculated.	
Clark B — 498.1 Clark A + 496.8	497.5			
500 Ω 662.2 659.9	661.1	1.900	1.905	0.003801
400 Ω 528.4 529.9[5]	529.2	1.524	1.524	0.003810
300 Ω 397.0 396.1	396.6	1.143	1.143	0.003811
200 Ω 264.0 264.0	264.0	0.7617	0.7615	0.003811
100 Ω 131.9 131.6	131.8	0.3806	0.3810	0.003805
Clark B — 498.5 Clark A + 497.0	497.7			

Because of the slight difference between the deviation of 1 CLARK and the difference in potential at the ends of a resistance of 400 ohm, the proportionality between the deviation and the difference of potential was assumed, from which 1.524 V. was derived; accordingly the intensity of the current was 0.003810 ampere; if we multiply this value with the value of the resistances — taking the very slight corrections into consideration — we find the „calculated" differences of potential. Under „observed" differences of potential the values have been given which are found in the supposition of proportionality between deviation and difference of potential. It will appear that this proportionality ranges within pretty wide limits. The same fact is also shown in the last column where the intensity of the current is calculated by dividing the observed difference of potential by the resistance. It is a matter of course that the deviations are reduced to angles.

If care is taken that the angle through which the needles are moving, does not exceed 7°½, (agreeing with the deviation 529 by reversal) and that the deviations do not become too small, so that the errors of the readings are less than $^1/_{1000}$ of the deviation, very different intensities may be determined with the same resistance to at least $^1/_{10}$ percent. In this case the current was weak, and it is clear, how with the quadrant-electrometer we may determine among others the constant of mirror galvanometers without any difficulty. If on the other hand we have a „Normal Widerstand" of 0.001 ohm, as it is constructed by SIEMENS and HALSKE for instance, a current of 1000 ampere may be measured with the same accuracy.

To conclude I shall point out a circumstance which may occur in some cases with such measurements, and which may cause very great mistakes, and has rendered a great many of my own experiments worthless. In this laboratory 30 accumulators are coupled in series, and different groups may be used in different rooms; in my experiments the current, which passed also through the resistance, mentioned on page 6, was taken from a group of 5 accumulators; one end of this resistance was connected with the earth, the other with the electrometer; when however in another room another group of accumulators is used at the same time and part of the circuit is in connection with the earth in that room too, or is not quite insulated, the end, connected with the electrometer may be between two points which are in connection with the earth, and the true difference of potential is not measured. A mistake of this kind is at once found when we change the direction of the current; moreover this mistake may be easily avoided by insulating the cells used.

Physical Laboratory. Groninghen.

Physics. — „*On the influence of the dimensions of the source of light in diffraction phenomena of* FRESNEL *and on the diffraction of X-rays.*" (Third communication.) By Dr. C. H. WIND (Communicated by Prof. H. HAGA).

17. In my former communications on this subject [1]), I have pointed out (cf. Arts. 10 and 16) that the theory concerning the influence of the widening of the illuminated slit, in the simple form at least in which it was given there, cannot explain the fact that, when the diffraction slit gradually narrows towards one end, the two principal maxima continue to appear as two distinct bright or (on photographic negatives) dark lines, even after the point of inter-

[1]) Versl. K. A. v. W. 5, p. 448 and 6, p. 79, 1897.