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Physiology. — *"Upon the simultaneous registration of electric phenomena by means of two or more galvanometers, and upon its application to electro-cardiography."* By W. EINTHOVEN, F. L. BERGANSIUS, and J. BIJTEL.

(Communicated in the meeting of May 29, 1915).

For a long time the need has been felt of a simultaneous registration of electric phenomena by means of two, or three galvanometers. This is evident from the experiments made by BULL, GARTEN, HOFFMAN, LEWIS, WILLIAMS, and others.

Speaking generally, three methods may be distinguished:

A. That in which two galvanometers are placed side by side. Each of the instruments is illuminated by a separate lamp, while the rays which proceed from the projection-oculars form two fields of illumination one beside the other on the horizontal slit, behind which the photographic plate is moved in a vertical direction.

The time-registration can be obtained by a single spoke-disc, the number of spokes of which may be 10, or a multiple of ten. The disc must be placed in such a position that its centre falls in the line, which, running about parallel with the slit, connects the optical axes of the two galvanometers. This can easily be done with great accuracy, so that no greater error need occur than say 0,01 part of the distance which divides one spoke from another. Care must also be taken that by a suitable placing of the lenses the images of the spokes on the slit are sharply defined.

B. Another method consists in stretching two strings across the same magnetic field. The Cambridge Scientific Instrument Comp. provides a double string-holder on their model of galvanometer, in which two strings are held at a distance of 0.5 mm. from each other.

If a strong magnification were used with this arrangement without any further arrangements the images in the field of projection would fall so far apart that the apparatus would be useless in practice. With a magnification of 600, the images of the strings would lie 30 cm. apart. To avoid this difficulty, the rays which are directed upon the slit by the projection-ocular, are changed in direction by a pair of achromatic prisms in such a manner, that the images of the strings come to lie at a convenient distance from one another upon the slit. A rectangular screen, placed at some distance in front of the slit, divides the two fields formed by the prisms, and forms a fine line of shadow upon the sensitive plate.

C. The third method of combination of galvanometers may perhaps be called the most elegant, but it demands a very careful adjustment. The principle of this method is that the two galvanometers are placed one behind the other, with the optical axes falling in the same line.

Midway between the projection-objective of the first galvanometer and the illumination-objective of the second a combination of lenses is introduced which may be compared to a double ocular, and which the firm of CARL ZEISS have been kind enough to construct at our request. This system is placed at such a distance from the two above mentioned objectives, that the spherical and chromatic aberrations of the image are compensated as well as possible.

The string which is nearest to the lamp is first projected in the new ZEISS-system, a second time in the optical field of the second string; a third time in the projection-ocular, and finally a fourth time upon the sensitive plate.

Although great demands are made upon the optical apparatus in order to insure sharpness in this fourth image, yet the curves show that the method leads to very satisfactory results. The images are so sharp and full of contrast, that it is sometimes almost impossible to distinguish between the image of the first and that of the second string. This may be seen for instance in the curves in the thesis of Dr. BATTAERD, in which heart sounds and E.K.G. were simultaneously registered by the method in question.

In applying the method of simultaneous registration to electrocardiography special precautions must be taken. In this paper we discuss the use of three galvanometers at once.

If an E.K.G. is made with only one derivation, regulating the sensitivity of the galvanometer in the usual way, each centimetre of an ordinate of the curve represents a potential difference of 1 millivolt, and this potential difference would actually exist between the places of derivation, if these were *not* connected to the galvanometer.

If the body is connected to a second galvanometer, the deflections of the first will be diminished, and this will be increasingly the case in proportion as the second galvanometer possesses less resistance. By a third connection the results are again reduced, and the question therefore arises: How is the sensitivity of the three galvanometers to be regulated, so that they will simultaneously inscribe curves which will fulfil the conditions required: The centimetres of the ordinates must always represent the millivolts of the potential oscillations which occur between two points of derivation of a body, when the body itself is still free from all connections.

As long as only one galvanometer is connected to the body, at the sudden application of e millivolts in the circuit the image of the string must be deflected by e cms. If there are three galvanometers connected to the body at the same time, by the application of e millivolts the deflection must be more than e cms. In a particular case with the simultaneous derivations I, II, and III, we will call the deflections required E_1, E_2, and E_3. These deflections can be calculated by means of the laws of distribution of currents from the potential difference e applied each time, the resistances of the body l_1, l_2 and l_3, and the galvanometer resistances g_1, g_2, and g_3.

The result may be obtained in the simplest and at the same time most practical way, by using the method of the equilateral triangle. [1]

In this model of the human body the resistances of the body in the three derivations are equal. If l_1, l_2, and l_3 really differ from one another, they can be made equal by means of rheostats, or in the adjustments a mean resistance $l = \frac{l_1 + l_2 + l_3}{3}$ may be used. In almost all cases this last method which is simpler in practice, is amply accurate enough.

The galvanometer-resistances must be actually made equal to each other, by the addition of rheostat resistances to the two smallest ones. We then write $g_1 = g_2 = g_3 = g$.

If $\frac{l}{2g} = a$, the deflection required is for each of the three string images $E = e\,(1 + a)$ centimetres.

We may remark in passing that at the application of e millivolts

[1] Comp. "Ueber die Richtung und die manifeste Grösse der Potentialschwankungen im menschlichen Herzen", u. s. w. Pflüger's Archiv fur die ges. Physiologie. Bd. 150. p. 275, 1913.

in one of the galvanometer circuits all three of the string images show a deflection. If the sensitivity of the strings is properly regulated the string image into the circuit of which the potential difference is introduced will be deflected by E cms and each of the other string images by $E-e$ cms.

The following case may serve as an example. In the experimental subject *Hu* the resistances of the body are

$$l_1 = 1200 \text{ Ohms}$$
$$l_2 = 1000 \text{ ,,}$$
$$l_3 = 800 \text{ ,,}$$

from which it follows that the mean resistance is $l = 1000$ Ohms.

Two galvanometer resistances of 4400 and 4000 Ohms are raised by means of rheostats to 6200 Ohms and thus made equal to the third galvanometer resistance. We then get

$$g = 6200,\ a = \frac{l}{2g} = 0{,}08, \text{ and } E = e\,(1+a) = 1{,}08 \text{ cm.}$$

The sensitivity of each galvanometer must therefore be regulated in such a way that when in one of the circuits one millivolt is introduced, the string image that belongs to that circuit will show a deflection of 10.8 mms. The other string images will be deflected by 0.8 mms.

The curves obtained in this way show a complete agreement within the limits of observation with the formula quoted. In the measurement of a curve of complicated shape with a strongly negative peak R_{III} no deviation was found to be larger than 0.1 mm.

The simultaneous registration of the E. K. G. by three derivations has provided a new and not unwelcome proof of the accuracy with which the string galvanometer is capable of reproducing the potential oscillations of the human heart. For the direct practical proof that the formula for the three derivations is right, can only be given, when each of the three curves is accurate in itself.

It is worth mentioning, that the object can be obtained with the ordinary commercial string galvanometers. Our curves are obtained partly with the original model, partly with the double string-holder of the Cambridge model.

The method here described further opens the possibility of determining the manifest value and the direction of the potential difference in the heart itself, in an easy and certain way. If, in the measurements, one is obliged to use curves which have been registered one after the other, one often meets with difficulties. If the curves have a complicated form it is not always easy to ascertain the corresponding

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phases of a heart period that has been registered by derivation I, for instance, and of another period by derivation II or III.

Moreover, one heart contraction is not exactly like another At a superficial glance the E.K.G. of the same series, appear so similar to one another, that one would take one period for the reproduction of another, but, when measured, numerous small differences appear which impede the accurate calculation of the direction and the manifest value of the potential difference. All these difficulties disappear when the E.K.G. is registered by the three derivations simultaneously.

The method is of service not only physiologically, but also clinically. For the object of practical cardiography is not to ascertain the potential difference that exists between one hand and another, or a hand and a foot, but to obtain an insight into the working of the heart itself [1]).

Physics. — "*The magnetic susceptibility and the number of magnetons of nickel in solutions of nickelsalts.*" By P. WEISS and Miss E. D. BRUINS. (Communicated by Prof. H. A. LORENTZ.)

§ 1. The purpose of this research was to investigate, how in connection with the magnetontheory the magnetic susceptibility of nickel in solutions of nickelsalts depends on the concentration of nickel in the solution. The research was made after QUINCKE's method improved by PICCARD [2]).

Before and after every series of measurements water was measured of which the specific susceptibility or coefficient of magnetisation has of late years been determined with great accuracy after different methods.

For this coefficient SÈVE gives: $-0.725.10^{-6}$ at 22° C. [3])
PICCARD: $-0.7193.10^{-6}$ „ 20° C. [2])
DE HAAS and DRAPIER: $-0.721.10^{-6}$ „ 21° C. [4])

In the following calculations has been used the value given by PICCARD $\chi_{water\ 20^\circ C.} = -0.7193.10^{-6}$.

The coefficient of magnetisation χ_L of the solution is calculated with the formula:

1) The complete account of the above investigation will appear elsewhere.

2) Die Magnetisierungskoeffizienten des Wassers und des Sauerstoffs. Promotionsarbeit von A. PICCARD. Arch. de Genève 1913.

3) SÈVE. Paris 1912. Thèse. Ann. Chim phys. (8) 27 p. 189–244. 1912.

4) DE HAAS und DRAPIER. Annalen der Physik. Band 42. p. 673–684. 1913.