with methylalcohol. This minimum is not present in the higher concentrations but at the larger dilutions it becomes more and more evident. This minimum is found precisely in the neighbourhood of those dilutions ($v = 22$ and higher) at which LOBRY DE BRUYN and STEGER and LULOFS have worked in the experiments referred to above and the amount of water in the alcohol is also the same as that for which these investigators have found the maximum of reaction velocity, namely in 60 to 80 per cent alcohol. There is therefore parallelism between the two phenomena; for methyl alcohol + water + sodium a maximum of the reaction velocity corresponds with a minimum of conductivity.

The experiments are being continued up to pure H_2O and also extended to mixtures of ethyl- and methylalcohol.

Amsterdam, June 1903. Org. Chem. Lab. University.

Physiology. — *The string galvanometer and the human electrocardiogram.* By Professor W. EINTHOVEN. (Physiological laboratory at Leyden.)

In the Bosscha-celebration volume of the "Archives Néerlandaises" [1]) the principle of a new galvanometer was mentioned and the theory of the instrument dealt with. The practical usefulness of the instrument especially for electrophysiological measurements may be judged from what follows.

It may be remembered that the instrument consists principally of a silvered quartz thread which is stretched like a string in a strong magnetic field. When an electric current is passed through the thread, this latter deflects perpendicularly to the direction of the magnetic lines of force and the amount of the deflection can directly be measured by means of a microscope with an eye-piece micrometer.

What is the sensitiveness that can be obtained in this manner?

Since the above-mentioned publication a number of material improvements have been made in the instrument by which it is possible, for instance, to give a very feeble tension to the string, now a quartz thread 2.4 μ thick, with a resistance of 10 000 Ohms. If the tension is so regulated that a deflection takes place in from 10 to 15 seconds depending on its amount, every millimetre of the displacement of the image of the string corresponds to a current of 10^{-11} Amp. when a 660-fold magnification is used. As under these circumstances a

1) W. EINTHOVEN. Un nouveau galvanomètre. Archives Néerlandaises des sciences exactes et naturelles. Sér. II. Tome VI. p. 625. 1901.

displacement of 0,1 mm. is still noticeable, as will appear from the discussion of the plates, currents of 10^{-12} Amp. can consequently be detected.

As far as is known to the writer, no other galvanometer is capable of demonstrating with certainty such feeble currents. In practical work the string galvanometer must consequently be placed on a line with the most sensitive galvanometers of other construction and must be distinguished from so-called oscillographs which only react on much stronger currents.

The force which deflects the string in a field of 20 000 C. G. S. with a current of 10^{-12} Amp. is very small and works out for a length of 12.5 cm. at 2.5×10^{-11} grammes i. e. four times less than one ten millionth part of a milligramme.

By giving the string a greater tension its movements become quicker but its deflections for equal currents less. It is easy to give the string exactly such a tension that a current of given intensity causes a predetermined deflection, as may appear from the photograms of the two accompanying plates. These photograms were obtained in the same way as the formerly described capillary-electrometric curves [1]).

The 660-fold enlarged image of the middle part of the string is projected on a slit, perpendicular to the image. Before the slit a cylindrical lens is placed, the axis of which is parallel to it; behind it a sensitive plate is moved in the direction of the image of the string. While the movements of the string are thus registered, at the same time a system of coordinates is projected on the sensitive plate by the excellent method of GARTEN [2]). Of these coordinates the horizontal lines are obtained by mounting a glass millimetre-scale close before the sensitive plate so that the sharp shadows of the scale-divisions fall on the plate, while the vertical lines owe their origin to a uniformly rotating spoked disc which intermittently intercepts the light falling on the slit. The distance of the vertical as well as of the horizontal lines has in our photograms been taken about one millimetre, every fifth line being somewhat thicker. This latter peculiarity can easily be introduced into the coordinate system by drawing every fifth line in the glass millimetre-scale before the sensitive plate slightly thicker and by also making every fifth spoke of the rotating disc somewhat broader.

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1) See various essays in "PFLÜGER's Arch. f. d. gesammte Physiol." and in "Onderzoekingen physiol. laborat. Leyden." 2nd series.

2) DR. SIEGFRIED GARTEN. Ueber rhythmische elektrische Vorgänge im quergestreiften Skeletmuskel. Abhandl. der Königl. Sächs. Gesellsch. der Wissensch. zu Leipzig. Mathem. phys. Classe, Bd. 26, No. 5. S. 331. 1901.

The first photogram, fig. 1 plate I represents the deflections of the string when currents of 1,2 and 3×10^{-9} Amp. are successively passed through the galvanometer. In the coordinate system a length of 1 mm. of the abscissae has a value of 0.1 second, an ordinate of 1 mm. representing 10^{-10} Amp. Although the image of the string has considerable breadth and has no perfectly sharp outlines — as must be expected with a magnification of 660 times — yet its displacement in the coordinate system can easily be determined with an accuracy of 0.1 mm. For if one of the margins of the image before and after the deflection is observed, observation with the unaided eye or with a magnifying-glass will show that the deflection differs from the tabulated amount by less than 0.1 mm. Hence the currents are measured in the photogram with an accuracy of 10^{-11} Amp.

One notices that the deflections are accurately proportional to the intensity of the current, that they are dead-beat and that they are accomplished in 1 to 2 seconds according to their magnitude. The strong damping must be ascribed to the resistance of the air, for during the registering of the curves a resistance of one Megohm was put into the galvanometer circuit by which the ordinary electromagnetic damping was almost entirely suppressed.

If the tension of the string is made ten times less, the galvanometer becomes ten times more sensitive and, as stated above, currents of 10^{-12} Amp. may still be observed. But with this greater sensitiveness the deflections are no longer proportional to the current and the movements of the string are difficult to record, as the quartz thread no longer moves exactly in a plane. Yet the instrument can still be used then for direct observation with the microscope.

Figure 2 plate I shows that the deflections to the right and to the left — in the figure corresponding to upward and downward deflections, are equal. The velocity of the sensitive plate has remained the same so that again an abscissa of one millimetre corresponds to a time of 0.1 second. But the tension of the string is 200 times stronger so that one millimetre of the ordinates represents 2×10^{-8} Amp. A current of 4×10^{-7} Amp. is alternately sent in opposite directions through the galvanometer and hence causes deviations of 20 mm. to the right and also to the left. It is easy to ascertain that these deviations are equal to each other up to 0.1 millimetre.

The movement of the string is very quick so that during the deflection the string can only cast a feeble shadow on the sensitive plate. The ascending and descending nearly vertical lines which in the original negative are still visible as very thin streaks have become invisible in the reproduced photogram.

In fig. 3 plate I a movement of the string is represented when a current of 3×10^{-8} Amp. is suddenly made and broken. The sensitive plate has been moved along with a tenfold velocity and the string has ten times more tension than in fig. 1, consequently one mm. absc. = 0.01 second and one mm. ord. = 10^{-9} Amp. The galvanometer circuit contains again one Megohm so that the same causes of damping exist as in fig. 1. The movement is still dead-beat, but on account of the 10 times greater force on the string it is 10 times quicker, as can easily be ascertained by comparing the great descending curve of fig. 1 with one of the curves of fig. 3 or better still by superposing diapositives of the curves of both figures. They will then be seen to cover each other exactly and since in one figure the velocity of the moving plate is ten times greater than in the other, the deflection of the string must in one case take place ten times more quickly than in the other. At the same time the resistance of the air is proved in our case to increase proportionally to the velocity of the string itself.

In recording the curves of fig. 4 and 5 of plate I the velocity of the moving plate has been increased to 250 mm. per sec. so that 1 mm. of the abscissae is 0.004 sec. The plate at first moves slowly and reaches the mentioned velocity only when it has travelled through a distance of 4 or 5 centimetres, whereas the spokes of the rotating disc always cast their shadows on the plate accurately every 0.004 second. Hence the coordinate system is in the first sixth part of the photogram compressed in the direction of the abscissae.

In fig. 4 one mm. ord. = 2×10^{-8} Amp., while in fig. 5 one mm. ord. = 3×10^{-8} Amp. These two figures together show us the limit-value of the sensitiveness for which the movement of the string is still dead-beat. In fig. 4 a current of 4×10^{-7} Amp., in fig. 5 a current of 6×10^{-7} Amp. has been transmitted through the galvanometer and interrupted. One sees that the deflection in fig. 4 is still dead-beat and is completed in about 0.009 sec., whereas in fig. 5 the motion begins to become oscillatory and for a single oscillation takes 0.006 sec. The sensitiveness with which the motion of the string is on the border between aperiodic and oscillatory motion is consequently such that a deflection of one millimetre corresponds to a current between 2 and 3×10^{-8} Amp.

In the tracing of fig. 4 and 5 only an insignificant resistance is put into the galvanometer circuit so that here besides the viscosity of the air also the ordinary electromagnetic damping checks the motion.

Now some particulars may be mentioned referring to the 5 photograms of plate 1 in common.

In order to obtain the image of the string equally sharp in all parts of the visual field, the string must move in a plane perpendicular to the optical axis of the projecting microscope. A displacement of the string of 0.5 μ in the direction of the optical axis suffices to cause a noticeable indistinctness of the image with the magnification used. The photograms show that such a displacement does not take place.

The great constancy of the zero point and the equality of the deflections deserve notice and also — which is especially important for practical work with the instrument in electro-physiological measurements — the possibility of accurately fixing beforehand the sensitiveness of the instrument. The unaided eye can already observe in nearly all the figures of plate I that this can be done successfully with an error of less than 0.1 mm. for deflections of 30 or 40 mm., i.e. with an error of less than 2.5 or 3 per thousand. Only fig. 5 shows a real deficiency of about 0.1 mm. which some greater care might have avoided.

It is hardly necessary to point out that the galvanometer is not affected by variations in the surrounding magnetic field. Moreover it is not to any extent affected by tremors of the floor. It stands on the same stone pillar on which a large tin disc with spokes is rapidly rotated by an electromotor. This electromotor is only at a few centimetres' distance from the galvanometer, while another motor, coupled with a heavy fly-wheel, for moving the sensitive plate, is clamped to the same pillar at a somewhat greater distance. Yet no trace of mechanical vibrations appears in the photograms.

The first electro-physiological investigation made with the string galvanometer was one concerning the shape of the human electrocardiogram discovered by AUG. D. WALLER [1]). Until now this could only be obtained by means of the capillary electrometer. But the curve traced by that instrument gives, when superficially observed, a quite erroneous idea of the changes of potential differences actually occurring during the registering. In order to know these they have to be calculated from the shape of the recorded curve and the properties of the capillary used. This leads to the construction of a new curve, the form of which is the correct expression of the actual variations of potential.

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1) AUGUSTUS D. WALLER. On the electromotive changes, connected with the beat of the mammalian heart and of the human heart in particular. Philosoph. Transactions of the Royal Society of London, vol. 180 (1899), B, pp. 169—194.

An example may explain this [1]).

The following fig. 1 represents the curve traced for the electro-cardiogram of Mr. v. D. W. when the current was derived from

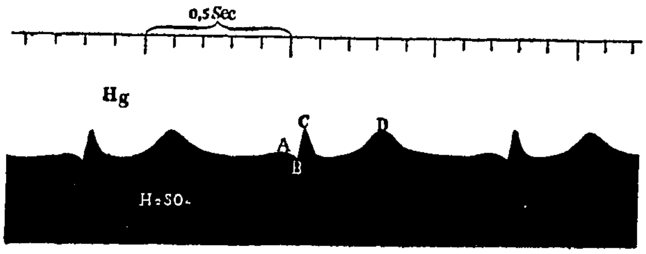


Fig. 1.

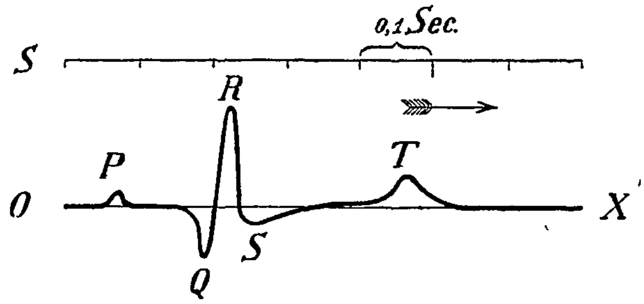


Fig. 2.

the right and left hands, whereas fig. 2 is the constructed curve. The differences are obvious. Especially the tops *C* and *D* in the registered curve should be compared with the corresponding tops *R* and *T* in the secondary curve which latter alone truly represents the ratio of the heights of the tops.

We shall now try to compare the string galvanometer as a research instrument with the capillary electrometer and must first of all bear in mind that the deflections of the string galvanometer measure a current, that of the capillary electrometer an electromotive force. But it must be remarked that whenever variations in current or tension are measured, the mercury meniscus as well as the string moves. And during this movement the capillary must be charged or discharged by an *electric current*, whereas the string in the magnetic field develops an opposed *electromotive force*. Moreover, when there is a constant considerable resistance with negligeable self-induction, such as commonly occurs in electro-physiological investigations, the

[1]) See PFLÜGER's Arch. Bd. 60. 1895 and "Onderzoekingen". Physiol. Laborat. Leyden. 2nd series, vol. 2.

intensity of the current will at any moment be proportional to the active electromotive force, so that the fundamental difference between the electrometer and the galvanometer is no obstacle to a comparison of both instruments.

The string galvanometer has several advantages over the capillary electrometer. First the deflection of the string galvanometer will in many cases and especially in the case of tracing a human cardiogram be greater and quicker than the deflection of the capillary electrometer. Then the capillary electrometer is less accurate in the constancy of its indications, their proportionality to the potential differences and their equality in opposed directions.

A highly magnified image of the mercury meniscus cannot be so sharply projected as that of a fine thread and one cannot regulate the sensitiveness of the capillary electrometer to a predetermined amount. The electrical insulation of the string galvanometer is much easier than of the capillary electrometer and a phenomenon like "creeping" does not occur with the galvanometer.

In the capillary electrometer the movement of the meniscus is damped by the friction of the mercury and sulphuric acid when streaming through a narrow tube. Invisibly small traces of impurities may hinder or even entirely stop the movement of the mercury meniscus. Many a capillary had after a relatively short time to be replaced by a new one because there was a "hitch" in the movement of the meniscus. In the string galvanometer, on the other hand, we have air-damping as well as electromagnetic damping, both of which work with perfect regularity. The electromagnetic damping can moreover be varied at will by changing the intensity of the field and the resistance in the galvanometer circuit.

Plate II contains the electrocardiograms of some six persons, traced by means of the string galvanometer. In the coordinate system an absciss of one millimetre has a value of 0.04 sec., while an ordinate of one mm. represents a P.D. of 10^{-4} Volts. By choosing these round numbers the curves satisfy generally the requirements of the international committee for the unification of physiological methods.

The movement of the quartz thread, as may be seen from the normal curves at the end of each photogram, was dead-beat and very quick, so that the traced electrocardiogram is a fair representation of the oscillations in the potential difference existing between the right and left hands of the experimental person. As a rule this may be admitted for the lower tops *P*, *Q*, *S* and *T* without any noticeable error. But for the high and sharp top *R* a correction should be applied especially in photograms 8 and 9, a correction by which

8*

the extremity of the top would be shifted a little to the left and upwards. The necessary correction is small however and its amount may be approximately estimated at less than 0.2 mm. for the shifting to the left and less than one mm. for the shifting upwards.

Photogram 8 represents the electrocardiogram of the same person whose capillary-electrometric curve is shown in the text. When the registered curve of fig. 8 plate II is compared with the formerly plotted curve of fig. 2 in the text, it is evident that both curves have great similarity. The tops *P, Q, R, S,* and *T* are not only present in both curves, but have also the same relative height in both.

In the plotted curve 1 millivolt of ordinate has been made equal to 0.1 sec. of absciss, while in the galvanometer curve 1 millivolt of ordinate corresponds to 0.4 sec. of absciss. Hence the galvanometer curve is compressed in the direction of the abscissae, as a superficial inspection will reveal. Besides the galvanometer curve, on account of the gradual transitions of one top to another, gives the impression of being in its minor details a more faithful representation of nature than the plotted curve. It is obvious that of this latter curve only a limited number of points could be accurately calculated, while for the rest the calculated points had to be joined by the curve that fitted them best. But these small differences are immaterial.

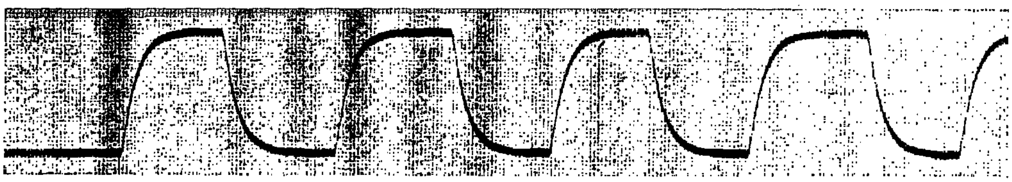
It may give some satisfaction that the results formerly obtained by means of the capillary electrometer and more or less laborious calculation and plotting have been fully confirmed in a different and simple manner by means of the new instrument. For this affords us a twofold proof, first of the validity of the theory and of the practical usefulness of the formerly followed methods and secondly of the accuracy of the new instrument itself.

The six electrocardiograms of plate II were selected among a greater number and arranged after the dimensions of the downward top *S* (see the figure in the text). In 6 and 7 the curve remains, at the spot where *S* ought to be, above the zero-line of the diastole, in 8 and 9 *S* is only small, in 10 and 11 great. The numbers 6 and 11 mark in this respect the extremes which occur in our collection of electrocardiograms, whereas N°. 8, that of Mr. v. D. W. represents a sort of norm with which the other numbers may all be easily compared.

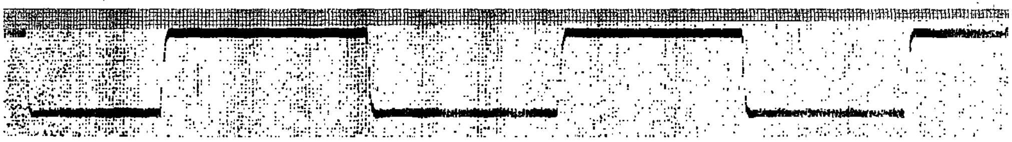
The constancy of shape of the curve for a certain person is remarkable. This shape seems even to change so little in course of time, that with some practice one may recognize many an individual by his electrocardiogram We conclude this essay with a remark on the

1.
Absc. 1 mm. = 0,1 Sec.
Ord. 1 „ = 10^{-10} Amp

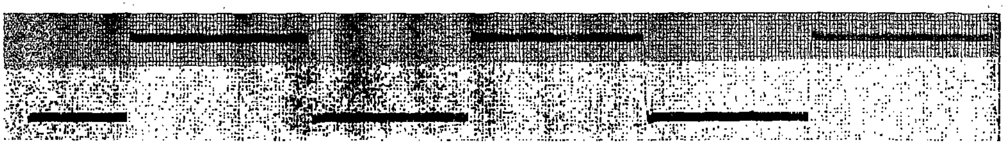
2.
Absc. 1 mm. = 0,1 Sec.
Ord. 1 „ = 2×10^{-8} Amp.



3.
Absc. 1 mm. = 0,01 Sec.
Ord. 1 „ = 10^{-9} Amp.

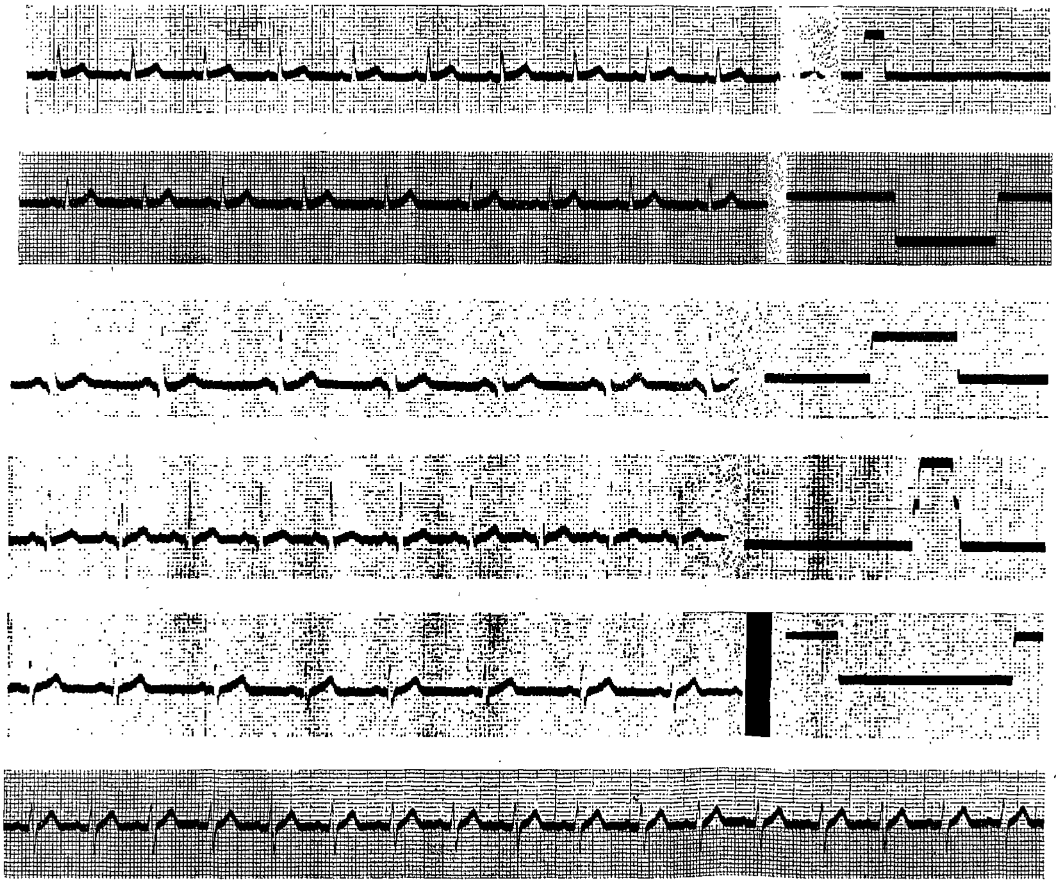


4.
Absc. 1 mm. = 0,004 Sec.
Ord. 1 „ = 2×10^{-8} Amp.



5.
Absc. 1 mm. = 0.004 Sec.
Ord. 1 „ = 3×10^{-8} Amp.

Absc. 1 mm. = 0,04 Sec. Ordin. 1 mm = 10^{-4} Volt.



6. Ad.

7. Vr.

8. v. d. W

9. Kr.

10. Be.

11. Bi.

small irregular vibrations occurring in most electrocardiograms, where they sometimes reach a height of 0,1 to 0.5 mm. and more, but are sometimes entirely absent, as e.g. in N°. 6 of Mr. AD.

These vibrations are not caused by tremors of the floor or other irregularities which should be ascribed to an insufficient technique as is easily shown by the vibrationless normal curves at the end of almost every series of electrocardiograms. Hence they must be caused by electromotive agents in the human body itself and the question arises whether they find their origin in the action of the heart or of other organs. We may expect that an investigation undertaken with this object will give a definite answer to this question.

Physics. — Dr. J. E. VERSCHAFFELT. "*Contributions to the knowledge of* VAN DER WAALS' *ψ-surface. VII. The equation of state and the ψ-surface in the immediate neighbourhood of the critical state for binary mixtures with a small proportion of one of the components.*" (part 4). Supplement N°. 6 (continued) to the Communications from the Physical Laboratory at Leyden by Prof KAMERLINGH ONNES.

(Communicated in the meeting of May 30, 1903).

17. *The α, β-diagram.*

In the previous communications the different phenomena in the neighbourhood of the critical point in substances with small proportions of one component have, according to our plan set forth at the beginning, entirely been expressed by means of the α and β and the co-efficients that can be derived from the general empirical reduced equation of state. For shortness, and to avoid the constant repetition of the same factors (comp. § 1) I have used till now, instead of the differential quotients of the general empirical reduced equation of state, the co-efficients k, where the m's (comp. form. 19) have been expressed by means of α and β, but henceforth, as the numerical values are more important I shall make use again of the differential quotients of the reduced equation of state itself, used in equation (1). It seemed important to me to completely determine by means of the numerical values of α and β the different cases which, according to the formulae found by KEESOM (Comm. N°. 75) and by me (loc. cit.), may present themselves in the relative situation of the different critical points. To illustrate this I intend to divide an α, β-diagram into fields in which there is a definite relative situation, by means