THE NATURE AND CAUSATION OF THE GALVANIC PHENOMENON

PART I

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THE NATURE OF THE GALVANIC PHENOMENON

I

The purpose of our present paper is to establish rigidly the fact of the presence of galvanometric deflections under the influence of psycho-physiological processes and to investigate the nature, causation and conditions under which such deflections become manifested. It is by no means an easy matter to disentangle the conditions, physical, physiological and psychological, under which galvanic deflections appear, when an organism becomes subject to external or internal stimulations. Even when the galvanic deflections due to stimulations are established still the nature and causation seem to be beyond our grasp as the factors are numerous, the conditions complicated and the whole subject of the psycho-physiological galvanic deflections appears to be intricate and shrouded in obscurity. Investigators of the subject have declared it to be a

difficult one and have been unable, except for a few conjectures, to trace scientifically by means of experimentation the cause of the 'galvanic phenomenon.' We think that our investigation will not only establish the fact of the galvanic phenomenon free from all artefacts, but will also clear the subject of all its inherent obscurities and help to disclose its nature and causation. If may be well to add that the present study is a continuation of the work carried out by Sidis and Kalmus and published in THE PSYCHOLOGICAL REVIEW for September and January, 1908, 1909.

II

Tarchanov is regarded as one of the first investigators who discovered the interesting fact that psychic states give rise to galvanometric deflections. According to Tarchanov all psychic processes, sensory, emotional and even purely ideational, as imagination and calculation, are accompanied by galvanometric variations. He observed large galvanometric deflections apparently brought about not only by sensory stimulations, actual affective states and emotions, but also by the mere memory and representation of such states. Intellectual processes, ideas, images, logical reasoning, memories are sufficient to affect the mirror-galvanometer and give rise to marked deflections. As a result of his investigation, published in a brief preliminary communication, he conjectures that the deflections be due to secretory changes going on in the epidermis. He is inclined to think that psychic activities affect the secretions of the skin which in their turn produce the marked deflections

observed in the mirror-galvanometer. Tarchanov has not followed up his preliminary communication with a detailed study of the phenomena.

Ch. Féré[2] may also be regarded as one of the pioneers who pointed out the presence of galvanic changes under the influence of emotional states. According to this investigator the changes are due to variations of bodily resistance; in other words, Féré seems to think that emotional states lower the electrical resistance of the body. This assumption of lowering of bodily resistance has been uncritically accepted by many investigators. It is accepted even by those who otherwise follow Tarchanov and assume the alleged factor of skin secretions. It is assumed that the galvanic deflections are due to lowering electrical resistance through the agency of skin secretions produced by psychic activities. The cause of the phenomenon is still regarded as unknown. We shall point out that the sole cause of the obscure factor of resistance is a faulty reasoning and a deficient technique.

A number of investigators such as Sticker,[3] Sommer,[4] Sommer and Fürstenau,[5] Veraguth,[6] Jung,[7] Binswanger[8] and others have advanced various views as to the possible causation of what has become known in psychopathological literature as the 'galvanic phenomenon.' Sticker rejects Tarchanov's hypothesis of skin effects and action of sudorific glands as the cause of the observed galvanometric deflections under the influence of psychic states. He advances the hypothesis of circulation,—the galvanic phenomenon is the effect of circulatory changes in the capillary blood vessels, changes induced psychic states in general and by

emotional states in particular. In this respect Sticker agrees with the French investigators who unhesitatingly assume the hypothesis of circulation. The galvanometric perturbations are supposed to be the effect of circulatory disturbances which somehow lower the peripheral and bodily resistance. R. Vigoroux[9] and later A. Vigoroux[10] experimenting on clinical cases reject the view that the lowering of resistance is due to skin secretions; the electrical perturbations are ascribed by them to variations of resistance of blood circulation especially of the capillary blood vessels, variations of electrical resistance in some unknown way, probably by an increase or decrease of the concentration of the blood, brought about by the influence of mental states, especially by emotions.

Recently C. G. Jung, of Zurich, and his collaborators, Peterson[11] and Ricksher,[12] have carried out a series of experiments on a number of sane and insane persons. They confirm the presence of the so-called 'galvanic phenomenon' accompanying the various mental states under observation. They find galvanometric perturbations in different forms of mental states. Jung regards the galvanometer as a valuable instrument in the study, analysis and discovery of so-called 'suppressed complexes' otherwise revealed by the so-called 'psycho-analytic method.' Some of the followers of the German school hail the galvanic test as a method in the study of psychopathic diseases in general and of hysterical affections in particular. Even criminology, it is claimed, may derive some benefit from the galvanic test, inasmuch as certain classes of criminals may be detected by means of the galvanic phenomenon.

Jung and his collaborators have not contributed anything to causation of the galvanic phenomenon, but they are inclined to accept Tarchanov's hypothesis that the galvanometric perturbations are the effect of skin secretions. According to the Zürich investigators mental activities with their accompanying affective states give rise to secretions of the sudorific glands with a consequent lowering of electrical resistance which is the cause of the observed galvanometric perturbations. This conclusion is but a plausible conjecture. They think however that it is quite probable that a number of other factors concur in the causation of the galvanic phenomenon, such as circulatory changes, changes of the central nervous system and especially changes produced by mental activities and their affective states in the sympathetic nervous system. To quote from Jung, “If one applies to a subject tactile, optic or acoustic irritations of a certain strength the galvanometer will indicate an increase in the amount of the current, *i. e.,* a lowering of the electrical resistance of the body."[13] In another place Jung and Peterson, change in resistance is brought about either by saturation of the epidermis with sweat or by simple filling of the sweat-gland canals or perhaps also by an intracellular stimulation or all of these factors may be associated. The path for the centrifugal stimulation in the sweat-gland system would seem to the sympathetic nervous system. These conclusions, the authors go on to say, "are based on facts at present to hand and are by no means felt as conclusive. On the contrary there are features presented which are as yet quite inexplicable as, for instance, the gradual diminution of the current in long experiments to a most complete extinction, when our ordinary experience

teaches that resistance should be much reduced and the passing current larger and stronger. This may possibly be due to gradual cooling of the skin in contact with the cold copper plates."[14] As we shall see further on these investigators are on a false track, their puzzles and contradictions can be easily solved.

Again Ricksher and Jung write: "The sweat glands seemed to have more influence than any other part in the reduction of the resistance. If the sweat glands were stimulated there would be thousands of liquid connections between the electrodes and tissues and the resistance would be much lowered. Experiments were made by placing the electrodes on different parts of the body and it was found that the reduction in resistance was most marked in those places where the sweat glands were the most numerous. It is well known that sensory stimuli and emotions influence the various organs and glands, heart, lungs, sweat glands, etc. Heat and cold also influence the phenomenon, heat causing a reduction and cold an increase in the resistance. In view of these facts the action of the sweat glands seems to be the most plausible explanation of the changes in resistance."[15]

It will be seen from our work that the Zürich school, when discussing the causation of the 'galvanic phenomenon,' has become inextricably entangled in a maze of factors which have but indirect relation to galvanometric deflections under investigation.

Veraguth has been working assiduously and patiently for number of years on what he designates 'the psycho-physical galvanic reflex.' He eliminates circulation and he rightly excludes skin effects as causes of the 'reflex,' but

he does not arrive at any definite conclusion as to the cause of the galvanic deflections under the influence of sensory and emotional processes. Veraguth thinks that his 'galvanic reflex' is due to variations of body-conductivity or 'Variation des Leitungswiderstandes des Körpers.' He thinks this phenomenon somewhat different from that described by Tarchanov and others. To quote from Veraguth:

"Das psychogalvanische Reflex-phänomen besteht in einer Intensitätsvariation eines elektrischen Stromes der bei der Versuchsanordenung mindestens teilweise aus einer körperfremden in der Stromkreis eingescholteten Stromquelle entstammt. Es spielt deshalb bei diese Anordnung die Variation des Leitungswiderstandes des Körpers gegen diesen exogenen Strom einer Rolle bei der Variation der Stromintensitäts.

Die Variation geschiet im Sinne der Abnahme der Stromintensität wenn die V.P. im Zustand der Ruhe längere Zeit in der itromkette eigescholtet bleibt. Durch diese Thatsache stellt sich ie 'Ruhekurve' im Gegensatz zu den gewohnliche bisherige Erfahrungen über anfangliche Variationen des Körperleitungswiderstandes gegen einen durchfliessenden elektrischen Strom.

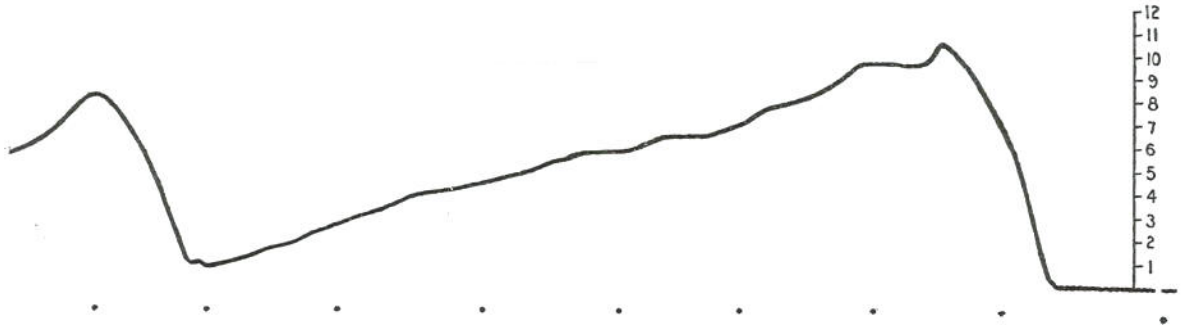
Die Variation veläuft im einen der Intensitäts-zunahme wenn die V.P. Reizen ausgesetzet wird.

Das Moment der Gefühlsbetonung allein ist es nicht das die Stärke der galv. Reaction bedingt; es kommt auch bei den höheren psychischen Reizen.

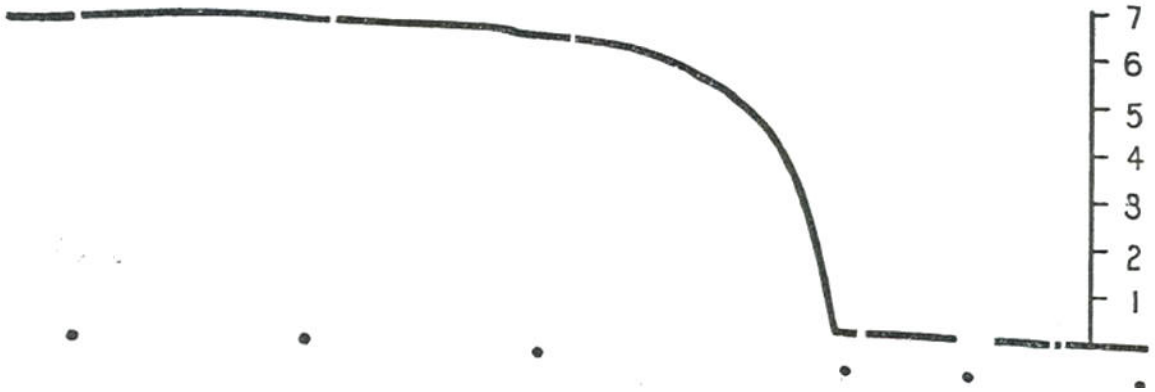
Das galv. Reflexphänomen ist also ein Indicator für Gefühlsbetonung und Actualität des psychischen Reizes.

Uncontrollierbare Variabilitäten des Widerstandes in dem Stromkreisteile ausserhalb des V.P. sind ausgeschlossen; die Tatsache der Variabilität des Leitungswiderstandes des menschlichen Körpers gegen durchfliessenden Strom ist bekannt. Mit ihr haben wir also bei unseren Experimenten mit Körperfremden durchfliessenden Strom zurechnen. Nun zeigt sich aber bezüglich dieses Leitungswiderstand ein auffalender Unterschied zwischen den obigen Resultaten und der'gewöhnlichen Erfahrungen aus der Elektrodiagnostik: bei unseren Experimenten nimmt wenn keine Reize eintreten die Stromstarke stätig ab, nicht, wie wir gewohnt sind zu beobachten del' Widerstand."[16]

Veraguth's 'phenomenon' is an artefact. The 'Ruhecurve' which he regards as almost paradoxical is an artefact. The gradual diminution of the deflection, when no stimulations are given, is due to involuntary gradual relaxation of the grip the nickel-plated electrodes used by him in his experiments. This can be shown by the following photographic curves (read right to left):[17]

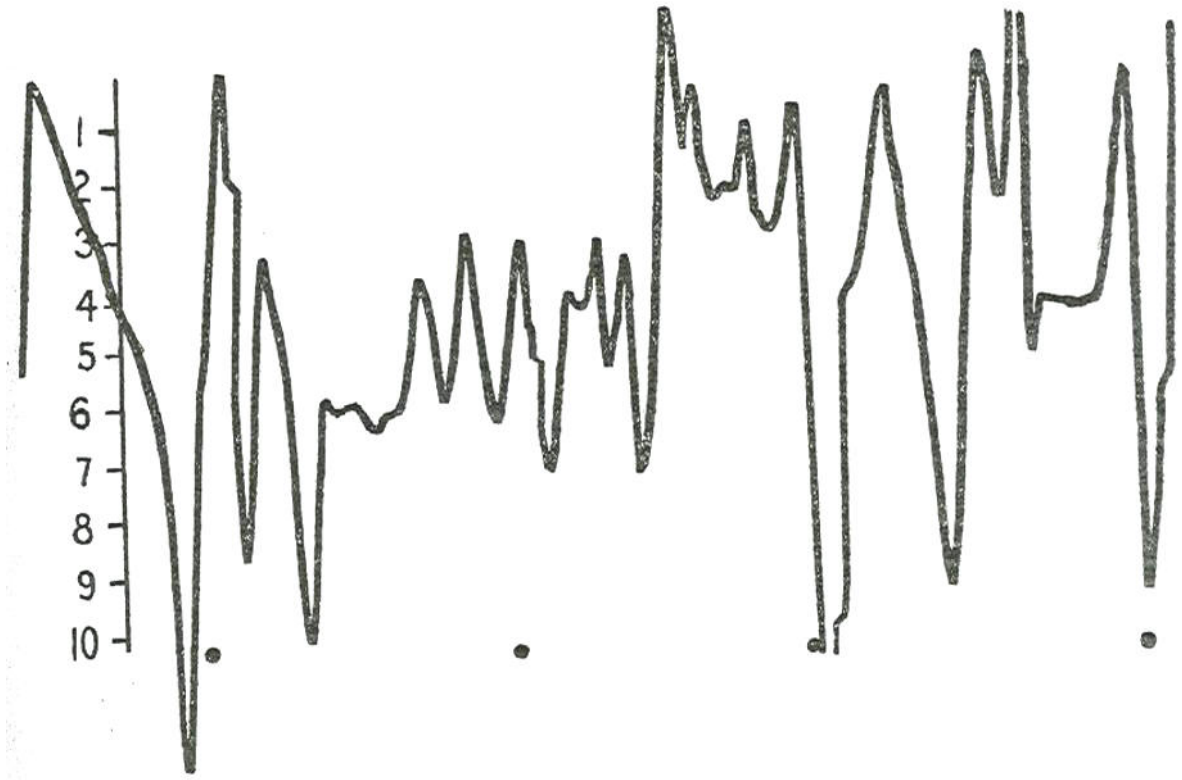


CURVE 1. Two cells in circuit; also shunt, nickel electrodes held by subject in each hand. Hands relax slowly. The curve slopes gradually. Intervals are indicated by the points under the curves and show minutes. Scale on curves is in centimeters; normal is zero.



CURVE II. Two cells in circuit, also shunt. Nickel-plated electrodes. When precaution is taken to have constant pressure on electrodes (no involuntary relaxation of grip) the curve is constant and shows no slope. Rhythmical breaks in the curves show minute intervals.

CURVE III. Two cells and shunt in circuit. Electrodes put on hands passively so that the pressure of electrodes on hands was constant. There is no fall, but one continuous line with no deflections present.



CURVE IV. No cells and no shunt in circuit. The curve shows galvanometric variations due to variations of pressure and of changes of involuntary grip. The maximum variation is more than 12 cm.

Sommer's attitude towards the galvanic phenomenon is rather negative. He ascribes the galvanic deflections to contact-effects between the skin and the electrodes, also to changes in the resistance of the epidermis. An involuntary increase or decrease of pressure on the electrodes would change the points of contact and skin-resistance thus giving rise to galvanometric variations. It is clear that Sommer does not regard the galvanic phenomenon as the effect of processes taking place in the organism itself. The galvanic perturbations according to Somme are rather of a purely physical character and depend on the extent of surface-contact and changes of skin-resistance Sommer's work must certainly be taken into consideration before one can establish a definite relation between psycho-

physiological processes and galvanometric deflections. The usual method of most investigators, namely, the employment of metal electrodes on which the palms of the hands rest, may lend itself to such an interpretation and therefore the galvanic reaction is really not established until that objection is obviated. Jung and Ricksher do not meet Sommer's objections when they say: "That the changes in resistance are not due to changes in contact, such as pressure on the electrodes, is shown by the fact that when the hands are immersed in water which acts as a connection to the electrodes the changes in resistance still occur. Pressure and involuntary movements give entirely different deflections than that which we are accustomed to obtain as the result of an affective stimulus."[18] This rejoinder is not valid as we shall see further on when we discuss the various artefacts to be avoided in order to establish the galvanic reaction.

Binswanger in his extensive study of the galvanic phenomenon does not differ in his technique from that generally employed by Jung and his collaborators with whom he also agrees in his conclusions as to the nature and causation of the galvanic phenomenon. He agrees with Tarchanov that the cause of the galvanic phenomenon is the secretions of the skin "Es scheint mir in Uebereinstimmung mit Tarchanoff und trotz der Ausführpngen Stickers das es sich hier im wesentlichen um Sekretionströme der Haut (Schweissdriissen) handelt."[19]

In a series of experiments Sidis and Kalmus[20] have affirmed the fact of the 'galvanic phenomenon' in relation to certain psycho-physiological states and have shown by

various experiments that contact effects as well as skin changes and circulatory disturbances can be fully excluded as the causes of the phenomenon under investigation. Moreover, the same investigators have demonstrated that what may be called the galvanic reaction has nothing to do with lowered resistance, whether bodily or cutaneous, produced by psycho-physiological processes; they have proven that resistance can be excluded, that the phenomenon is entirely a function of an electromotive force brought about by the action of the psycho-physiological processes set up by various external or internal sensory stimulations. To quote from the original contribution: "Our experiments go to prove that the causation of the galvanometric phenomena cannot be referred to skin resistance, nor can it be referred to variations in temperature, nor to circulatory changes with possible changes in the concentration of the body-fluids. Since the electrical resistance of a given body depends on two factors—temperature and concentration—the elimination of factors in the present case excludes body-resistance as the cause of the deflections. Our experiments therefore prove unmistakably that the galvanic phenomena due to mental and physiological processes cannot be referred to variations in resistance, whether of skin or of body. Resistance being excluded the galvanometric deflections can only be due to variations in the electromotive force of the body."[21] Our present work has in various ways amply corroborated the same conclusion and has definitely determined the actual cause of the observed galvanometric deflections concomitant with some psycho-physiological processes.

III

From the history of the subject we may now pass to a discussion of the technique of the experiments. The usual technique of most of the investigators is very simple. In connection with a D'Arsonval galvanometer one or two cells are introduced into a circuit terminating in two metal electrodes, zinc, copper, or steel in case of hypodermic needles. The galvanometer, being shunted, the subject places himself across the electrodes usually putting one hand palm downwards on each of the electrodes, thus closing the circuit.

Jung describes his apparatus as follows: "The author (Dr. Veraguth) conducts a current of low tension (about two volts) through the human body, the places of entrance and exit of the current being the palms. He introduces into the circuit the current a Deprez-D'Arsonval galvanometer of high sensibility and also a shunt for lowering the oscillations of the mirror. I add to the scale a movable slide with a visiere. The slide pushed forward by the hand always follows the moving mirror reflex. To the slide is fastened a cord leading to a so-called ergograph-writer which marks the movements of the slide on a kymographic tambour fitted with endless paper upon which the curves are drawn by a pen point. For measuring the time one may use a 'Jacquet chronograph' and for indicating the moment of irritation (stimulation?) an ordinary electronic marker."[22] In their more detailed study Jung and Peterson give the following account of the apparatus employed by them: "The mirror galvanometer of Deprez-D' Arsonval; a translucent celluloid scale divided into millimeters and centimeters with a lamp upon it; a movable indicator sliding on the

scale and connected by a device of Dr. Jung with a recording pen writing upon the kymograph; a rheostat to reduce the current when necessary; and one, sometimes two, Bunsen cells. The electrodes generally used are large copper plates upon which the palms of the hands rest comfortably or upon which the soles of the feet may be placed."[23] Ricksher and Jung used the same apparatus with 'brass plates as electrodes upon which the person places his hands and completes the circuit.'

It will be observed that most of the investigators used electrodes, generally metal ones, without any precautions as to the traps encountered and to the artefacts produced. To avoid all those pitfalls and thus establish the galvanic reflex on a sure basis of facts Sidis and Kalmus employed the following technique:

"In a series with a battery was a sensitive galvanometer across which the subject placed himself, thus closing the circuit. The battery was a single cell giving a constant electromotive force of about 1 volt which was sometimes replaced by a thermo-element giving only a few millivolts, and sometimes entirely removed from the circuit. The galvanometer was of the suspended coil, D'Arsonval type and of extreme sensitiveness. The deflections were read by means of a beam of light deflected from a mirror attached to the moving coil of the instrument, to telescope with a scale. A deflection of 1 cm. on the scale corresponded to less than 10^{-9} ampere through the instrument. This extreme sensitiveness was too great for many of our early experiments so that a resistance *R* which could be varied to reduce the sensitiveness to any desired degree, was shunted around the galvanometer.

"The electrodes were glass vessels of about 4 liters capacity nearly filled with a strong electrolyte, as for instance a concentrated solution of NaCl. Into these vessels large copper electrodes of about 500 cm.^{2} area were permanently placed. The circuit was completed by placing the hands, feet, etc., one into each electrode solution.

"The galvanometric deflections may be due to changes in the resistance at the electrodes brought about by such purely physical causes as motion or muscular contractions of the hand, stirring of the electrode fluid or similar incidental secondary effects. In order to eliminate the possibility of such effects it was necessary to devise such electrodes that the current through the circuit should, within very wide limits, be independent of the position of the hands. The possible sources of error at this point which would change the effective surface of the hands are twofold—(1) due to the variation of the liquid level at the wrist, and (2) due to movements of the hand as a whole. The following device was used to overcome those difficulties. The wrist was covered with shellac for a length of several inches, so that the liquid-surface of the electrode was always in contact with shellac. The shellac was covered by a layer of paraffin, though a moderate coating of shellac alone was such a good insulator that the electrode resistance became independent of the height of liquid on the wrist. In addition to this the hand was put in splints in such a manner that only a small fraction of the skin was covered, so that no appreciable muscular contraction of the phalanges could take place (the same skin-area being washed by the liquid electrodes). If now a stimulus was given which aroused

an emotion or definite affective state in the subject, a marked galvanometric deflection was observed."

After excluding resistance, both of skin and body, circulation, skin secretions Sidis and Kalmus give, as the result of their investigations, the following summary: *"Our experiments thus clearly point to the fact that active physiological, sensory and emotional processes, with the exception of ideational ones, initiated in a living organism bring about electromotive forces with consequent galvanometric deflections."*[24]

In our own technique we at first closely followed that of Sidis and Kalmus with the only difference that our subjects were not human beings, but rabbits and frogs. In the course however of adaptation of the technique to the special conditions of experimentation as well as in our efforts to eliminate complicating factors and have the results free from artefacts the technique has become substantially modified. We shall give an account of these important modifications as we proceed with the exposition of the results of our investigation.

IV

Before however we give an account of our technique and its gradual modification in its adaptation to the needs of the experiments in hand, it is well to give a brief review and possibly a short discussion of the main artefacts to which this work is subject. In carrying on experiments on such an intricate problem where the factors, physical, physiological and psychological, are so numerous and complex special care must be taken to

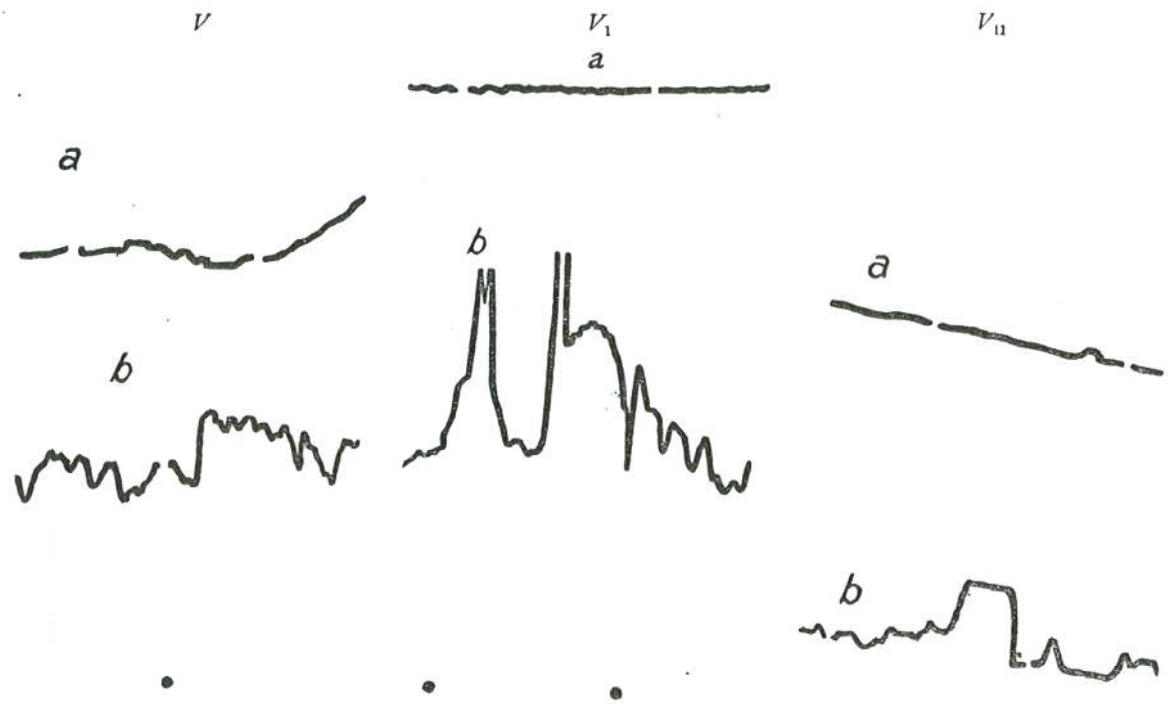
avoid the artefacts which are sure to creep in and vitiate results. The first requirement in such work is simplification of the technique so as not to introduce conditions which are apt to complicate matters and obscure the possible solution of the problem. The conclusion arrived at by Sidis and Kalmus, differing widely from that arrived at by earlier investigators, namely, that the galvanic phenomenon is not due to resistance, whether of skin or of body, but to an electromotive force, helped us materially in the simplification of the conditions of the experiments, a simplification which those investigators have, afterwards adopted in the course of their work. This simplification consists in the discarding of the electric batteries introduced into the circuit. The introduction of electric cel1s is apt to mislead the investigator from the very start, inasmuch as he is unconsciously led to postulate that the resultant galvanometric deflections are due to resistance. He assumes that the only electromotive force present is the one derived from the cells and which is therefore constant. Since the strength of the current *C* is = *E/R* and as *E* or the *E.M.F.* of the cells is constant the variations of the current *C* which give rise to the deflections of galvanometer must necessarily be due to variations of *R,* that is, of resistance. Since resistance *R* consists of two elements (1) resistance r_1 of the physical system, cells, electrodes and galvanometer, and (2) resistance r_2 of the body; since again resistance r_1 is constant, it necessarily follows that galvanometric deflections are due to variations of resistance of the elements or tissues of the body. It is this faulty technique of using cells from which the E.M.F. is supposed to be derived and passed through the body of the test-person

that has given rise to the unproved assumption that the variations of the current which produce the galvanometric deflections are due to lowering of bodily or tissue-resistance.

It is clear, if we make no assumptions, that in the formula *E/R* the variations may take place either in *E,* or in *R,* or in both. In other words, the unbiased experimenter realizes at the start that he deals here with electromotive forces and resistances which either alone, or both, may participate in the causation of the observed galvanometric deflections. While therefore it is a fundamental fallacy, a *petitio principii* as it is termed in logic, to make at the outset the unwarranted assumption of ascribing the galvanic effects to variations of only one of the factors, namely, resistance, it is on the other hand a serious error of technique to use cells in the circuit and thus complicate unnecessarily the conditions of the experiment. The introduction of more elements, of cells and shunts, brings in more electrodes and resistances into the circuit and thus only helps complicate and obscure the investigation of an intricate subject. We must remember that the first requirement of an experimental work is not complication, but elimination and simplification.

If we examine more closely the conditions of experimentation of the various investigators, we find that one of the most serious artefacts results from the employment of metal electrodes, such as copper, zinc, nickel, brass and steel in direct contact with the fluids of the palmar surfaces of the Calomel-mercury electrodes present similar artefacts on account of the impurities giving rise to currents with sudden and often ceaseless

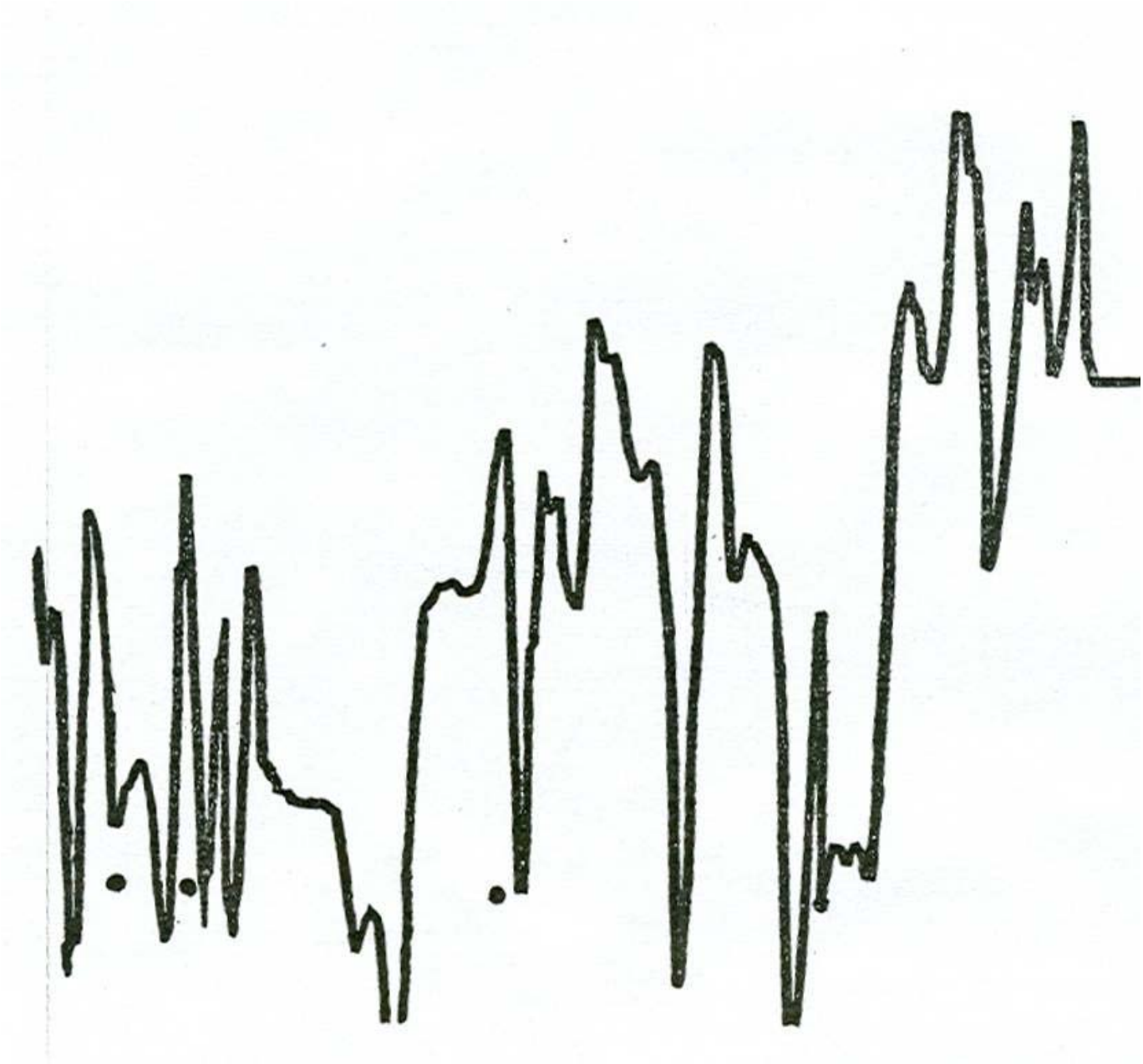
fluctuations of the mirror-galvanometer thus causing extensive artefacts seriously impairing the value of the results. One cannot help realizing the full force of Sommer's objections that under such conditions numerous variations of contact are brought about, variations which in themselves are amply sufficient to account for the observed galvanometric perturbations. The results are at any rate vitiated and totally obscured. Under such conditions of experimentation galvanometric deflections cannot possibly be correlated with psycho-physiological changes. It can also be shown that in the use of metal electrodes the galvanometric deflections obtained when the hands are placed on the electrodes differ widely from those obtained when the same electrodes are put (passively) on the hands (see Curves V, V_1, V_{11}).



CURVE V. *V*: (a) Copper electrodes; no cells and no shunt in circuit. The electrodes were put on the hand passively so that there was no alteration due to active pressure. (b) Copper electrodes under same conditions of circuit. Hands put *actively* on the copper electrodes. V_1: Show passive (a) and active (b) pressure of platinum electrodes. V_{11}: Show passive (a) and active (b) pressure of tinfoil electrodes.

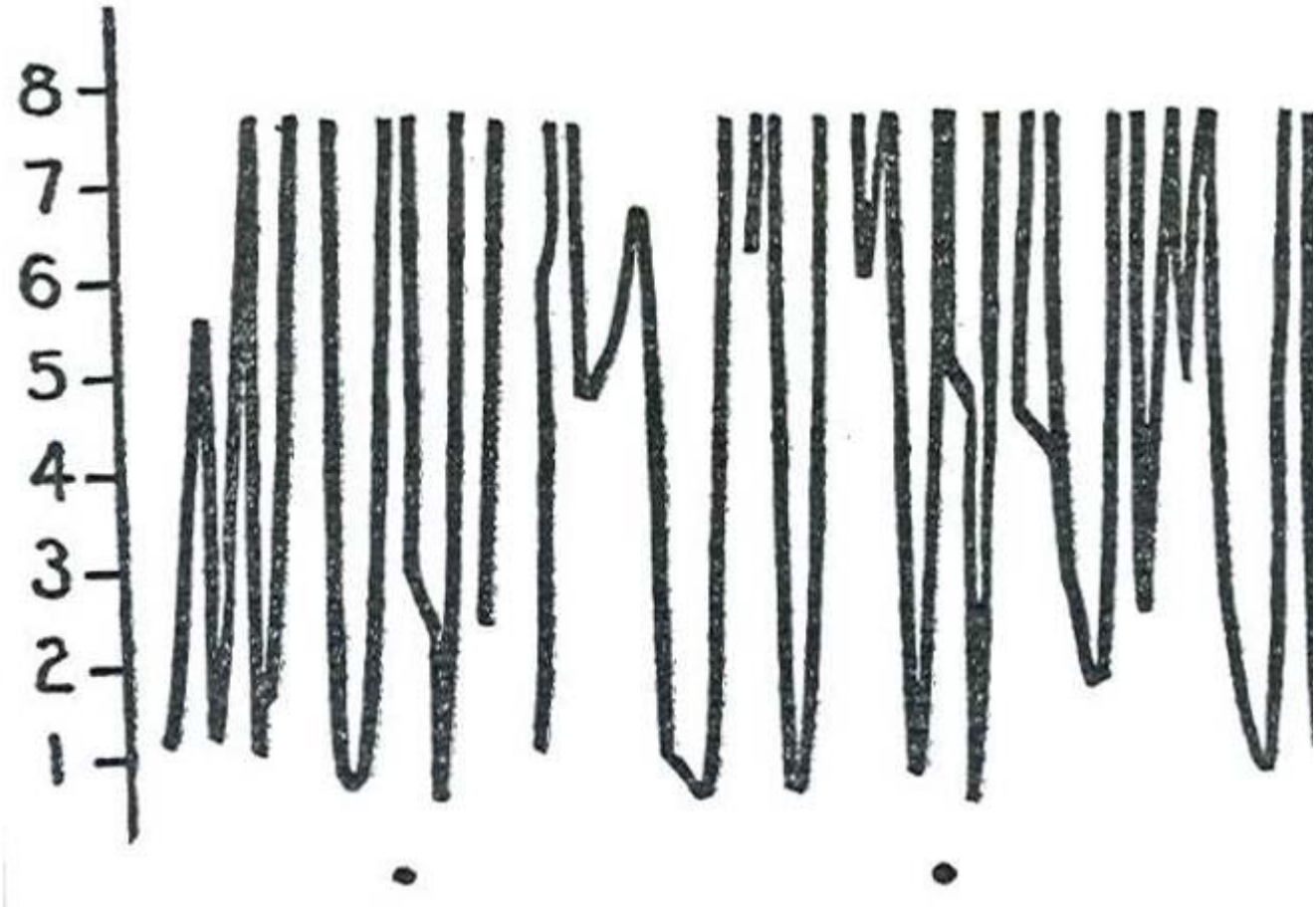
An important source of error is the employment of polarizable electrodes. The physical currents induced by polarization give rise to so many electrical variations and consequent galvanometric deflections as to destroy the scientific value of the results. The fluids of the palmar or of the skin surfaces in contact with the polarizable metal electrodes initiate a number of currents which ceaselessly give rise to large sudden deflections of the mirror-galvanometer. In cases where we have all those conditions combined, namely, increased or decreased surfacecontact and pressure accompanied with changes of polarization we can realize how unreliable and untrustworthy the final results are. The current view that the galvanometric deflections are due to skin-effects is quite in accord with the artefacts of the experiments, since under such conditions the main galvanometric deflections do occur under the various influence of skin-effects. As long as the experiments are conducted under such conditions and are beset with such serious artefacts not only is it vain to expect a correct view of its causation, but even the very fact of the correlation of psycho-physiological processes galvanometric deflections cannot be established with any degree of certainty. The claim of Jung and his collaborators that “when the hands are immersed in water which acts as a connection the changes still occur" is in itself beset with many errors. In the first place, if the liquid is put in two different vessels, the liquid must be of the same concentration and of the same temperature, otherwise we get deflections due to difference of temperature and concentration; then again the least change of level of the liquid will change the level at which the electrodes are washed which will produce new currents. At the same time the change of level of the

liquid will change the area of the skin washed and will once more initiate currents. Then, again, the wires and metal plates become polarized and additional currents supervene. The artefacts are here so numerous that to obtain any results is almost hopeless. Sidis and Kalmus, who worked with liquid electrodes had to contend with all those difficulties and could only circumvent and overcome them with constant vigilance for artefacts and painstaking precautions, such as the careful use of pure or distilled water of the same temperature, the use of shellac and paraffin as well as splints for the hands. The following photographic curves will give one a clear idea of the ceaseless play of currents and hence of the artefacts met with in the use of polarizable metal electrodes or of liquid electrodes when the necessary precautions are not taken.



CURVE VI. Brass electrodes without cells. Electrodes held in the hands. Maximum deflection is more than 14 cm.

CURVE VII. Copper electrodes (plates) in two vessels filled with water. Hands inserted into the vessels. Two cells and shunt in circuit.



CURVE VIII. Same condition of liquid electrodes but without cells and shunt in circuit. Disturbances of level of liquid and slight restlessness of hands. Maximum

deflection is more than 8 cm.

When working with hypodermic electrodes the effects of polarization should be specially taken into consideration. Steel or iron being impure becomes easily affected chemically, thus giving rise to currents with large variable galvanometric deflections. The following photographic curves obtained with steel electrodes inserted into the skin of a rabbit's abdomen bring out clearly the effects of polarization:

CURVE IX. Steel electrodes inserted under skin of abdomen of rabbit. No cells, no shunt. Maximum deflection about 3 cm.

It becomes clear from what we have said how cautious one has to be and with what numerous difficulties one has to cope in the investigation of this subject. Considering then the difficulties and numerous artefacts we had to contend with it may be of interest to point out the development of our technique. As we have already mentioned the fact our work links on to that of Sidis and Kalmus and naturally our technique was the same as theirs. These investigators started with the usual procedure, common to all earlier investigators, of introducing cells into the circuit. Unlike, however, other investigators, they did not start with the tacit assumption

of regarding the observed galvanometric deflections as due to variations of the factor of resistance alone. They were on the lookout for variations both of electromotive forces and resistance. Since the trend of their experimentation was clearly in the direction of electromotive forces and towards the total elimination of resistance as a factor in the galvanic perturbations, they finally in their later experiments completely dispensed with the cells and superimposed electromotive forces derived from outside sources and worked with the electromotive forces manifested by the organism under the influence of external stimulations. Such a procedure is essential as it deals directly with the phenomena under investigation. We followed the same procedure and discarded the cells. The physical system of the circuit was thus greatly simplified.

Moreover, we decided to work on animals instead of test-persons who are by no means favorable subjects for experimentation. Animals present us with great scope for experimentation, for surgical operations, for the injection of various drugs and thus to afford opportunities for the study of the causation of the galvanic phenomenon and allow the exclusion of the various complicating factors not concerned in its production.

Now in our experiments with animals, rabbits and frogs, we found that the technique of Sidis and Kalmus had to be further modified. In the first place the liquid electrodes with shellac, paraffin and splints proved inadequate as the hairy legs of the rabbit did not quite lend themselves to such manipulations. Shaving the hair was not satisfactory, taking it off chemically produced an undesirable inflammation unfavorable to the purpose of

our experiments. Besides, the liquid-electrodes proved unsatisfactory as it was difficult to restrain the rabbit from agitating the liquid and sometimes spilling the contents of the vessels, thus changing the levels of the liquid with its consequent large galvanometric deflections. The technique was defective, because we had not only to watch the deflections, but also the rabbit, the fluid, the vessels and the wires. Another objection to liquid-electrodes is the fact that they do not eliminate skin-effects which, as it has been demonstrated, are not concerned in the causation of the galvanic reaction. We were therefore forced to give up liquid-electrodes and in order to eliminate the skin, we had to fall back on hypodermic electrodes. This procedure not only considerably simplified the conditions of experimentation, but it also, at one stroke, so to say, greatly simplified our problem, since we thus got rid of the factors of pressure, increased and decreased contact-area and of all the disturbances that might be ascribed to the action of the sudorific or sebaceous glands. The simultaneous simplification of method and problem was too important not to take advantage of. Hypodermic electrodes were clearly indicated by the conditions and nature of our work.

It is however one thing to find that hypodermic electrodes are indicated and it is quite another matter to find the proper kind of electrodes. We found 'that copper, iron, steel, nickel, brass, had to be rejected, because of the ease of polarization giving rise to variable currents with consequent variations of galvanometric deflections (see Curves VI, VII, VIII).

It was found that platinum is sufficiently pure so as

not to become polarized and is therefore well adapted to our purpose. When using hypodermic platinum-electrodes, the galvanometer was found to remain steady as can be seen from the following photographic curve:

CURVE X. Platinum electrodes in abdomen of rabbit. No stimulation; rabbit quiet. No cells; no shunt.

This steadiness of the galvanometer is of the utmost importance, because it gives us a steady zero-reading, while in the case of other investigators there is no steady zero-reading, since their galvanometer keeps on ceaselessly varying, thus making the results uncertain and even destroying their value.

Platinum hypodermic electrodes were used by us throughout our work. Our technique thus far was extremely simple: a D'Arsonval type of galvanometer with scale divided into millimeters, platinum hypodermic electrodes and a key for closing and opening the circuit.

Focal distance of mirror to lamp is one meter.

Sensibility is 225 megohms.

Period is 9.5 seconds.

The sensibility is given in the number of megohms resistance through which one volt will give a deflection of

one millimeter at one meter distance. The period is the time of swing from the maximum deflection to zero.

We found it requisite to take photographic records of the galvanometric deflections. We shall give a detailed description the apparatus and its complete outfit in its proper place.

V

The animal was put on an animal board and kept quiet, while the hypodermic electrodes were inserted into the body, usually well under the skin or through a muscle. We may now pass to the experiments. We quote a few experiments selected from our laboratory notes:

Experiment I.—Live rabbit; hypodermic platinum-electrodes inside of thigh.

Galvanometric zero reading before closure of circuit	24 cm
Galvanometric reading after closure of circuit	27
Deflection gradually diminishes and in 4.5 minutes returns to	24
Circuit open	24
Circuit closed	24

Opening and closing the circuit did not change the galvanometric zero reading.

Circuit closed, galvanometric zero reading	24 cm
Stimulus, pinch, galvanometric reading	23.95
	23.90
	23.85
	23.80
Galvanometer returns to	23.85
	23.90
	23.95
	24

Experiment II.—Same live rabbit; hypodermic platinumelectrodes inside of forelegs.

Galvanometric zero reading before closure	24 cm
After insertion of electrodes and closure of circuit galvanometric reading	27
After a period of 4 minutes galvanometric reading	24
Galvanometer stationary at	24
Stimulus, sharp snap on nose; galvanometric deflection	24.10
	24.20
	24.30
	24.40
	24.50
Galvanometer returns to	24.40
	24.30
	24.20
	24.10
	24

Experiment III.

Galvanometric reading; circuit open	24 cm
Galvanometric reading; circuit closed	24
Stimulus, series of sharp snaps on nose; galvanometric reading ...	24.10
	24.20
	24.30
	24.40
	24.80

Galvanometer then returned to its original zero reading.

Another series of sharp snaps given to the nose after rabbit had rest brought galvanometer reading to	24.80
A further series of snaps did not increase galvanometer deflection;	24.80

galvanometer reading remained stationary at .....
After a few minutes galvanometer returned to original zero 24

Experiment IV.—New fresh rabbit. Hypodermic electrodes inserted in forelegs.

Zero reading; circuit open 24
Galvanometric reading; circuit closed went up to 27
Galvanometer returned and remained stationary at 24
Stimulus, prick; galvanometric deflection 24.10
24.20
24.30
24.40
24.50
24.60
25
Galvanometer gradually returns to original zero 24
A series of prick-stimuli given immediately after gave galvanometer deflection ..... 24.10.
24.20
24.30
More stimulation gave no further deflection .....
Galvanometer gradually returns to 24

We must mention here one important point. Every time the platinum electrodes were taken out to be inserted again, whether in a new fresh animal or into the same animal, they were sterilized on a flame and thus purified from extraneous matter. This was the procedure in all our experiments.

To return to our work:

Experiment V.—New fresh, live rabbit.

Circuit open; galvanometric reading ..... 24 cm

Circuit closed; galvanometric reading	27
After a few minutes galvanometric reading	24
Ammonia applied to rabbit	24.10
(Rabbit moved slightly.)	(24.20)
(Rabbit moved slightly.)	(24.20)
Galvanometer returns to	24
Ether given to rabbit	24.10
	24.20
	24.30
	24.40
	24.50
Galvanometer returns to	24
Ether continued	24.10
	24.20
	24.30
	24.40
	24.50
Galvanometer began to return to	24.40
	24.30
At this stage rabbit moved, galvanometric deflection	24.40
	24.50
	24.60
	24.70
Galvanometer returned to	24.20
Rabbit moved, galvanometric deflection to	24.50
Galvanometer returns to	24
Every time rabbit moves; galvanometric deflection rises to	24.50
Then returns to	24
Rabbit moves again; galvanometric deflection to	24.50
Rabbit quiet; galvanometer returns to	24
Rabbit completely narcotized; galvanometric reading	24
Stimulations, such as pricks, snaps, ammonia, produce no effect; galvanometer remains unaltered; galvanometer at zero reading	24

When rabbit came out of narcotic state the galvanometric deflections under various stimulations were the same as before narcotization:

Galvanometric zero-reading, circuit open	24 cm
Galvanometric zero-reading, circuit closed	24
Stimulus, prick	24.10
	24.20
	24.30
	24.40
Galvanometer then returned to	24

Out of the many experiments carried out on frogs we take one series as typical of many others.

Experiment VI.—Live frog. Platinum electrodes inserted into each thigh.

Circuit open, galvanometric reading	24 cm
Circuit closed, galvanometric reading	24.40
After a few minutes, galvanometric reading	24
Closed and opened circuit several times, galvanometer at	24
Abdomen hit a few times, galvanometer reading to	24.05
	24.10
	24.15
	24.20
Galvanometer then returned to zero-reading	24
Frog struggled; galvanometric deflection to	24.90
	24.80
	24.70
	24.60
Galvanotneter then returned to	24
Hitting abdomen sharply a few times; galvanometer reading to	25
Galvanometer returned to	24
Burn (frog struggled); galvanometer reading to	23.60
Returned to	24
Acetic acid (stimulus); galvanometer reading to	24.50
Returned to	24
Alcohol injected into mouth of frog; galvanometer reading to	23.90
	24.80
	24.70
Galvanometer returned to	24

Experiment VIII.

Strychnine injected into lymph-sac of frog; from zero reading 24
24.05
24.10
Galvanometer returned to 24

Galvanometer at 24
Stimulus, pinch leg 23.95
23.90
23.85
23.80
Galvanometer returned to 24

Galvanometer at 24
Stimulus pinch (frog struggled violently) 25
26
27
28
29
30
31
31.50
Galvanometer gradually returned to 24

After strychnine took effect stimulation began to give large galvanometric deflections.

Stimulus, tapping abdomen slightly, from zero ..... 24 cm
Galvanometric reading 24.90
24.80
24.70
24.50

Even tapping the board produced deflections ranging from 24 to 23.70, to 24.20 and back to 24 cm.

Tapping the abdomen of frog sharply, from zero-reading 24
Galvanometric deflection 23
22
21

20
19
18.90
Galvanometer back to 24

Frog in convulsions; galvanometer keeps on oscillating from zero-reading 24 cm. to 23.80, to 24, 24.10, to 24.20 and again to 24 cm.

The summary of our experiments with various frogs runs in our note-book as follows; "Frog motionless on board, no deflection. Every time frog moves, galvanometric deflection observed. The extent of the deflection appears to be proportionate to the amount of movement. Alcohol poured on the head of the frog; reaction violent, movements very extensive, large galvanometric deflections. Strychnine 3 drops administered to frog hypodermically. At first frog was quiet, no galvanometric perturbations. Afterwards frog in convulsions, galvanometric deflections amount to 10 centimeters."

The experiments in both species of animals, rabbits and frogs, give us practically the same results. Of course, should expect to find that in animals so widely different as the rabbit and the frog the extent of the galvanometric deflection would differ under the influence of external stimulations.

At this stage of our work the experiments prove conclusively the following propositions:

1. Every sensory stimulation is accompanied by a corresponding galvanometric deflection.

2. Motor reactions intensify the galvanic phenomenon giving rise to a more extensive deflection.

3. Motor activity is by itself sufficient to give rise to large galvanometric variations, as found in the rabbit and more especially in the frog poisoned by strychnine.

4. The hypodermic electrodes, excluding the effects of epidermis, show that the galvanic perturbations due to external sensory stimulations are not the resultant of skin-effects. In other words, the skin is not concerned in the manifestation the galvanic reaction.

This conclusion will be established more rigidly by a different set of experiments.

The galvanic reaction being established by our experiments the question may be raised as to whether our experiments give us an insight into the nature of the galvanic phenomenon. Are the galvanometric deflections correlative with psycho-physiological changes induced by external sensory stimulations due to variations of resistance, lowered resistance, or are the deflections due to an electromotive force initiated in the organism itself by the action of psycho-physiological processes. We may say that our experiments prove conclusively that the galvanometric phenomenon is not due to changes of electrical resistance, but to the action of a newly generated electromotive force.

If we scrutinize our experiments more closely, we find that, when the circuit is open, that is, when there is no current, the galvanometric zero-reading is 24 cm. On the insertion of the hypodermic platinum electrodes and closure of circuit there is an initial galvanometric

deflection which indicates the presence of a current. This current is due to the slight injury of the tissues produced by the insertion of the electrodes and also due to difference in temperature. After a period of four or five minutes the current subsides and the galvanometer returns to its original zero-reading when the circuit is open and no current is flowing trough the system. If we now open and close the circuit, the galvanometric reading remains unchanged at the original zeroreading. In other words, there is no current on opening or closing of circuit. If now, with circuit closed and galvanometric reading at its zero-reading, we prick, pinch, burn, or stimulate the animal in various other ways, we get a galvanometric deflections which can only be brought about by the generation of an electromotive force. It is clear that no change of resistance without an electromotive force can possibly bring about a galvanometric deflection. *Hence our experiments prove conclusively that the galvanometric deflections are not due to changes of resistance, but to electromotive forces.* Since the hypodermic platinum electrodes exclude the effects of contact, pressure and skin, it is obvious that the galvanic phenomenon can only be due to an electromotive force initiated in the organism itself by the psycho-physiological processes under the influence of external stimulations.

Part II

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[1] Tarchanov, 'Ueber die galvanische Erscheinungen,' *Pfl. Arch.,* 1890.

[2] Ch. Féré, *Comptes ren. de Soc. de Biologie,* Jan.-March, 1888.

[3] Sticker, 'Ueber Versuche einer objectiven Darstellung von Sensibilitäts,' *Wien. klin. Rundschau,* 1897.

[4] Sommer, Beiträge, Wien, 1902.
[5] Sommer und Fürstenau, 'Die electrische Vorgänge,' *Kl. f. Psych. U. N. Kr.,* B. I, H. 3, 1906.
[6] Veraguth, 'Das psycho-galvanische Reflex-Phaenomenon,' *Monat. für Psychiatrie und Neurologie,* B. 21, 1906.
[7] Jung, 'On Psychophysical Relations,' *J. of Abn. Psych.,* Feb., 1907.
[8] Binswanger, 'Ueber das Verhalten des psychogalvanischen Phänonena,' *J. für Psychologie und Neurologie,* B. 10, 1908.
[9] R. Vigoroux, 'Sur la Résistance électrique,' *Le Progréss Medical,* Jan. 21-Feb. 4, 1888.
[10] A. Vigoroux, 'Etude sur la Résistance électrique,' 1890.
[11] Peterson and Jung, 'Psychophysical Investigations,' *Brain,* V., 30, 1907.
[12] Ricksher and Jung, 'Investigations on the Galvanic Phenomenon,' *J. of Abn. Psych.,* Vol. II, 5, 1908.
[13] *Op. cit.*
[14] *Op. cit.*
[15] *Op. cit.*
[16] *Op. cit.*
[17] The curves should be read from right to left.
[18] *Op. cit.*
[19] *Op. cit.*
[20] Sidis and Kalmus, 'A Study of Galvanometric Deflections Due to Psycho-Physiological Processes,' PSYCHOL. REVIEW, Sept., 1908; Jan., 1909.
[21] *Op. cit.*
[22] *Op. cit.*
[23] *Op. cit.*
[24] *Op. cit.*

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THE NATURE AND CAUSATION OF THE GALVANIC PHENOMENON

PART II

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AND
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Psychological Review, 1910, 17, 98-146.

THE CAUSATION OF THE GALVANIC PHENOMENON

VI

The problem of the causation of the galvanic phenomenon is highly complex. The physiological processes concerned in phenomenon may be secretory, coming from skin or other glandular organs; may be circulatory, due to the blood vessels or lymphatics; may be due to intestinal changes, such as peristalsis; may be nervous, due to the action of the central or sympathetic nervous. system, or may be due to tissue-metabolism and activities taking place in the organism, or all of them may participate in the production of the galvanometric deflections brought about by various sensory stimulations. It is by no means easy to disentangle such an intricate mesh of factors. At one stage in our work the experiments seemed to indicate as if peristalsis, with its complex metabolic processes, were concerned in the phenomenon. Thus when the hypodermic platinum electrodes were

inserted into the legs or the chest, the initial maximum deflection was about 3 centimeters, the initial deflection when electrodes were inserted in the abdomen was far larger, often amounting to more than 50 centimeters, the ray occasionally getting off the scale. Moreover, constant rapid galvanometric oscillations were present, oscillations not observed when electrodes were inserted in any other place than abdomen. To give a few of our experiments:

Experiment I.—Live rabbit.

Galvanometer zero, circuit open ..... 24 cm
Platinum electrodes in abdomen. Galvanometric deflection off scale returned to 50 and then gradually return ing to .....
Deflection to 17; oscillating between 16 and 17.

Experiment II.—Live rabbit.

Circuit open, galvanometer zero ..... 24 cm
Platinum electrodes in abdomen; circuit closed, off scale, galvanometer to 3, returning rapidly to 7, 8, 9, 10, II, to 16, 17, and kept on oscillating between 16 and 17.

Experiment III.—Live rabbit (new).

Circuit open, galvanometer zero
Platinum electrodes in abdomen. Circuit closed; deflection to 4 cm., then gradually returns to original galvanometer zero .....

Galvanometer keeps on oscillating between 24 and 25 with an occasional large deflection of more than 50 centimeters ascribed to a possible 'rapid transit' of food in the intestinal tract.

An autopsy, however, of the rabbit showed that the intestinal tract was injured in many places by the electrodes giving rise a number of points of hemorrhage. The results therefore were pure artefacts produced by demarcation-currents or currents of injury having little or nothing to do with the galvanic phenomenon.

Experiment IV.—Live rabbit.

Galvanometer zero ..... 24 cm.

Platinum electrodes in abdomen, electrodes put so that they would produce no scratches, perforations and points of hemorrhage. Under such conditions the galvanometric deflection when circuit is closed: 26 - 24.50 - 24 cm. One fact, however, was of great interest from our standpoint and that was the relatively larger extent of the deflection produced by various stimulations and motor activities of the rabbit, the deflections varying from 4 to 10 and even to 20 centimeters.

We then decided to open the abdomen and find whether there could be directly observed any relation between peristalsis and galvanometric deflections.

Experiment V.—Rabbit given three grms. of urethane. Abdomen opened; intestine exposed; rabbit put into bath of 0.8 per cent. sodium chloride solution.

Circuit open, galvanometer zero ..... 24 cm.
Platinum electrodes in sides of abdominal cavity and when circuit closed galvanometric reading 15, 20, 21, 22, 23, 24.
Rabbit struggles; galvanometer 20 and then off scale.
Galvanometer then returns to its original zero-reading 24
Galvanometer keeps on oscillating from 24 to 25 - 25.50 - 26.

Experiment VI.—After 24 hours dead rabbit in same bath. The oscillation is of the same magnitude from 1-2 centimeters. Platinum electrodes taken out of the rabbit and put in the salt solution alone; the galvanometric deflections were observed to be of the same magnitude, of 2 cm. It was evident that the deflections and oscillations were due solely to the chemical processes and electrical currents generated by them. To clinch the proof the rabbit was taken out of bath and washed with clean water and then electrodes inserted into the abdominal cavity. No further changes were observed. The oscillations then were artefacts and could certainly not be ascribed to the action of peristalsis. We were then on the wrong track. Still the fact remained that with the electrodes in the abdomen and with all the precautions against injuries and scratches which the autopsies of the rabbits showed to be absent there were undoubtedly relatively far larger deflections than when the electrodes were placed in any other part of the body.

The large abdominal galvanometric deflections which sometimes occur so sporadically gave us good cause to think that we may be here on the track of some of the important factors concerned in the causation of the galvanic phenomenon and that could only be accomplished by a more perfect method of recording the results of our experimentation. What we needed was a record of all the galvanometric deflections that had taken place,—to get, so to say, a continued history of all the changes that had taken place during a certain period. In short, what is requisite is a graphic method and the best

graphic method is to get a photographic record which has the advantage of being trustworthy, automatic and continuous. Not only should the photographic records give good continuous curves, but the curves should be for long periods. The apparatus should give us a continuous photographic record at least for a period of two hours. At the same time there should be a chronograph marking time and a marker indicating any important change or time of stimulation. The following is a description of apparatus used:

The apparatus consists of a Ludwig kymograph *K* to which is attached a system of two drums D, D_1 by means of two pulleys *P*, P_1 and belt *H*. Around the belt there is wound a belt of paper to which a length of six feet of photographic paper may be attached. The galvanometer *G* is placed on a solid table built to the wall, so that no vibrations should affect it. The source of light is *L,* a Nernst lamp, which is well covered by a box having a very small narrow vertical slit in it. The pencil of rays coming from the narrow vertical slit is reflected in mirror of the galvanometer which is placed in the focal distance from a screen *S* with a horizontal slit which reduces the reflected rays coming from the galvanometer to a point of light. This ray of light passing through the horizontal slit of the screen falls on the sensitive paper *H* attached to the belt of paper around the two drums.

For recording the time there is a time-marking device $C_1C_2C_3S_1$ which consists of an ordinary alarm clock with a prolonged second hand dipping every minute into a cup of mercury thus closing a current coming from three cells. This current is transmitted to a telegraph-sounder S_1 which marks the on the sensitive paper. By means of a

key K_1 the same current is shunted and used to indicate on the revolving sensitive paper the time of stimulation or any other important event taking place during the experiment.

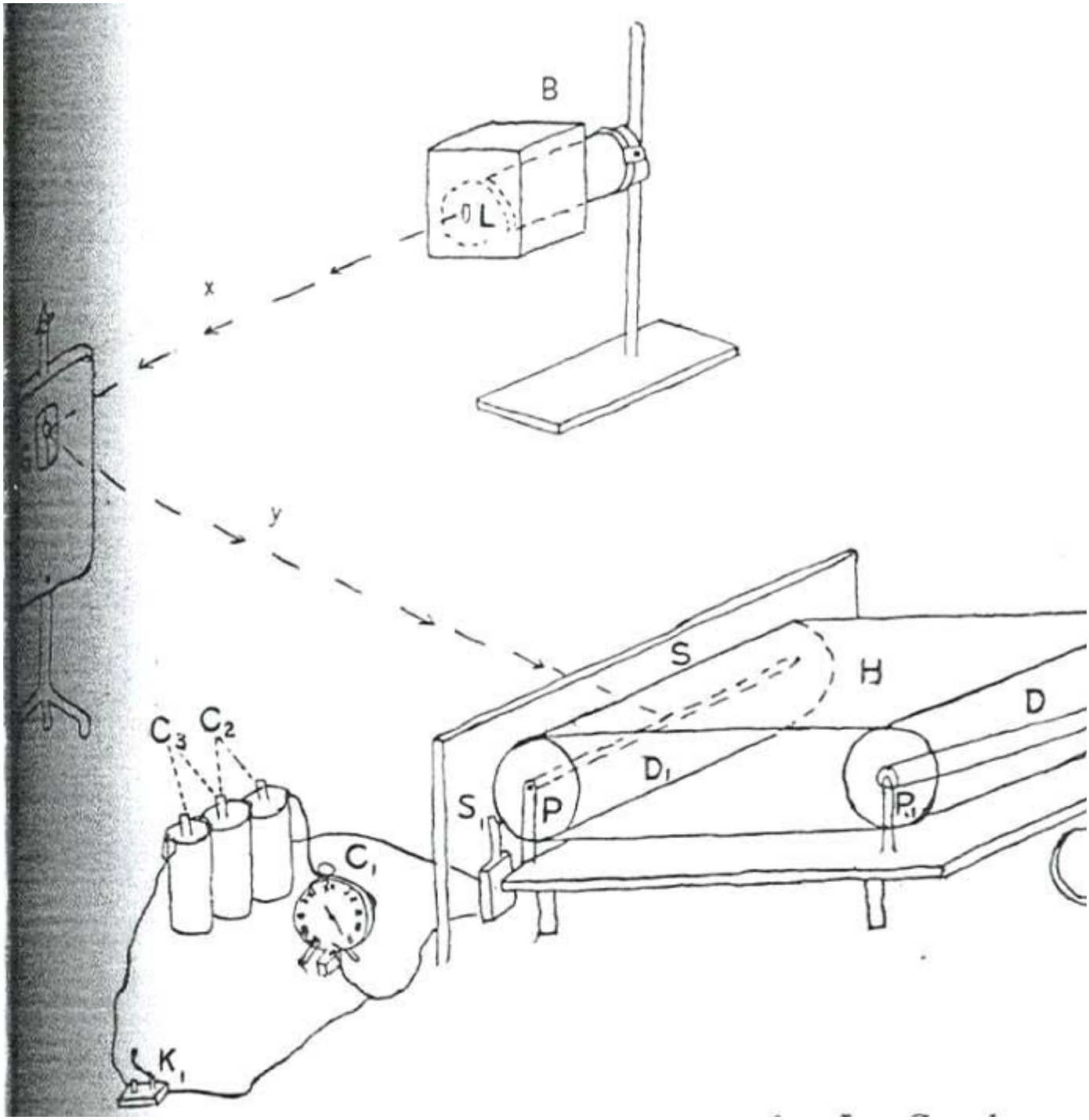


Fig 1. *L,* Nernst light; *B,* box covering *L, G*, galvanometer; *x, y,* path of light; *S,* board with horizontal slit; *D, D*$_1$, drums; *S*$_1$, telegraphic sounder; *C*$_1$, *C*$_2$, *C*$_3$, clock and cells; *K*$_1$, key; *H,* belt of paper; *P*, *P*$_1$, pulleys; *K*, kymograph.

The apparatus fulfilled all the conditions outlined above,—it gave a long and continuous record of the history of the galvanic happenings. As the photographic record was registered automatically on the sensitive paper we could turn our attention to the rabbit and watch closely any disturbances in the animal. Since the light reflex moving on the brass slit could be easily noticed in the darkened room even from a distance of several meters, it was an easy matter to watch the disturbances taking place in the animal as well as any galvanometric perturbations occurring simultaneously. The time of the disturbances was automatically recorded by the marker on the sensitive paper. The marking of the stimulations and of the changes in the animal placed each event, as it occurred, in its proper position with regard to the galvanic curve. This enabled us to correlate at a glance the disturbances in the animal with the corresponding galvanometric deflections. Armed with this technique we returned with a renewed vigor to the attack of the problem of the causation of the galvanic reaction due to psycho-physiological processes.

In order to come somewhat more closely to the main factor concerned in the production of the galvanic phenomenon it was thought that it might be well to approach the problem by subjecting to test sensitivity itself, especially the affective or the algedonic tone of it which has been demonstrated to be somehow related to the galvanic phenomenon under investigation. In modifying the sensitivity it was hoped that we might possibly be enabled to observe the simultaneous variations of some other factor more closely connected

with the various changes of the galvanic reaction.

If again peristalsis is somehow concerned in the causation of the galvanic phenomenon, the modifications of peristalsis should also affect the galvanometric perturbations or possibly that factor which is directly concerned in the causation of the galvanometric deflections.

The modifications of sensitivity, gradual decrease and even total annihilation of sensitivity and then again its gradual increase, are brought about by various anæsthetics, especially, ether and chloroform, while the modifications of peristalsis can be brought about by various purgatives such as magnesium sulphate, oleum ricini, oleum tiglii, etc.

CURVE XI. Platinum electrodes in abdomen of rabbit. First part of curve shows normal, then ether given. Marked deflections during struggle of animal. Rest of curve without deflections, result of anæsthesia. Maximum deflection is about 5 cm. No cells; no shunt.

CURVE XII. Platinum electrodes in abdomen of rabbit. First part of curve normal. Then chloroform given. Marked deflections during struggle. Rest of curve shows no deflections. Rabbit under chloroform anæsthesia. Maximum deflection is about 5

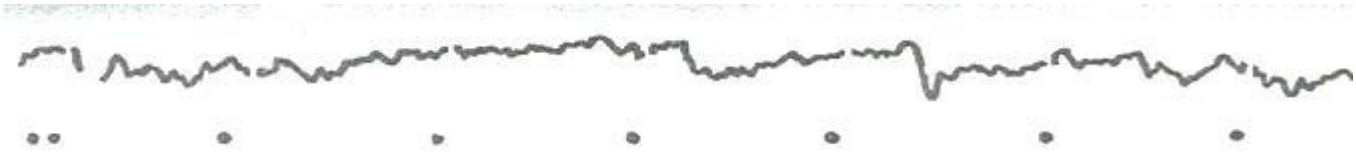
cm. No cells; no shunt.

The foregoing (Curves XI, XII) are the photographic records taken of the rabbit under the influence of chloroform and ether with or without stimulation.

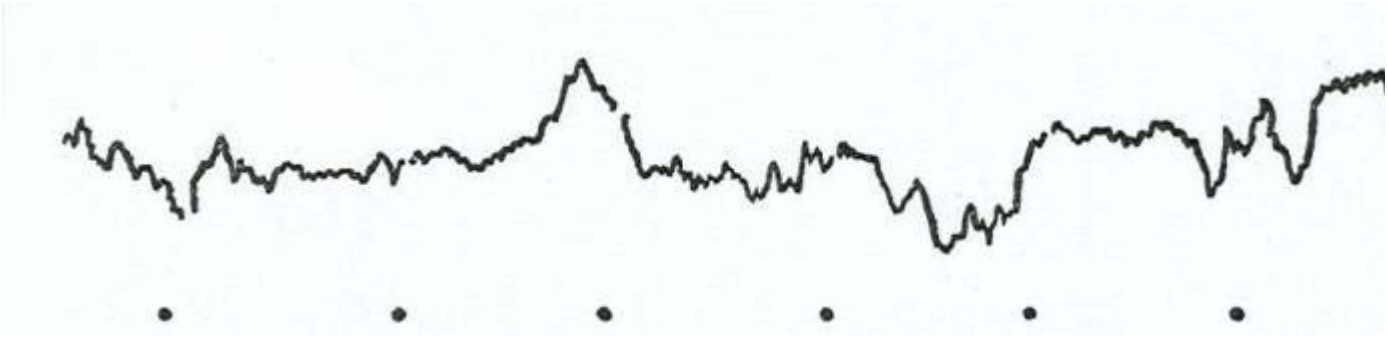
VII

An examination of the photographic records under anæsthesia, discloses the facts of large galvanometric perturbations when the anæsthetic is administered and again when the animal is passing from under the influence of the drug. Stimulations produce more or less marked deflections during the period preceding and following the state of deep narcosis. We notice one important circumstance and that is the fact, that such marked galvanometric deflections are uniformly accompanied by movements and struggles on the part of the animal. When the motor activity diminishes the galvanometric deflections decrease correspondingly and when the animal is quiet the galvanic perturbations completely disappear. The same relation is also observed in the case of the various drugs inducing peristalsis. Peristalsis accompanied by motor activity such as struggles, twitchings, shiverings, convulsions and generally by muscular contractions produce galvanometric deflections which seem to be proportionate to the extent of the observed muscular activity. Where motor activity is absent, although the action of the drug continues with its consequent peristalsis no galvanometric changes can be detected. Thus in the case of defecation which is accompanied by large contractions of the intestinal tract and general condition of straining there are large

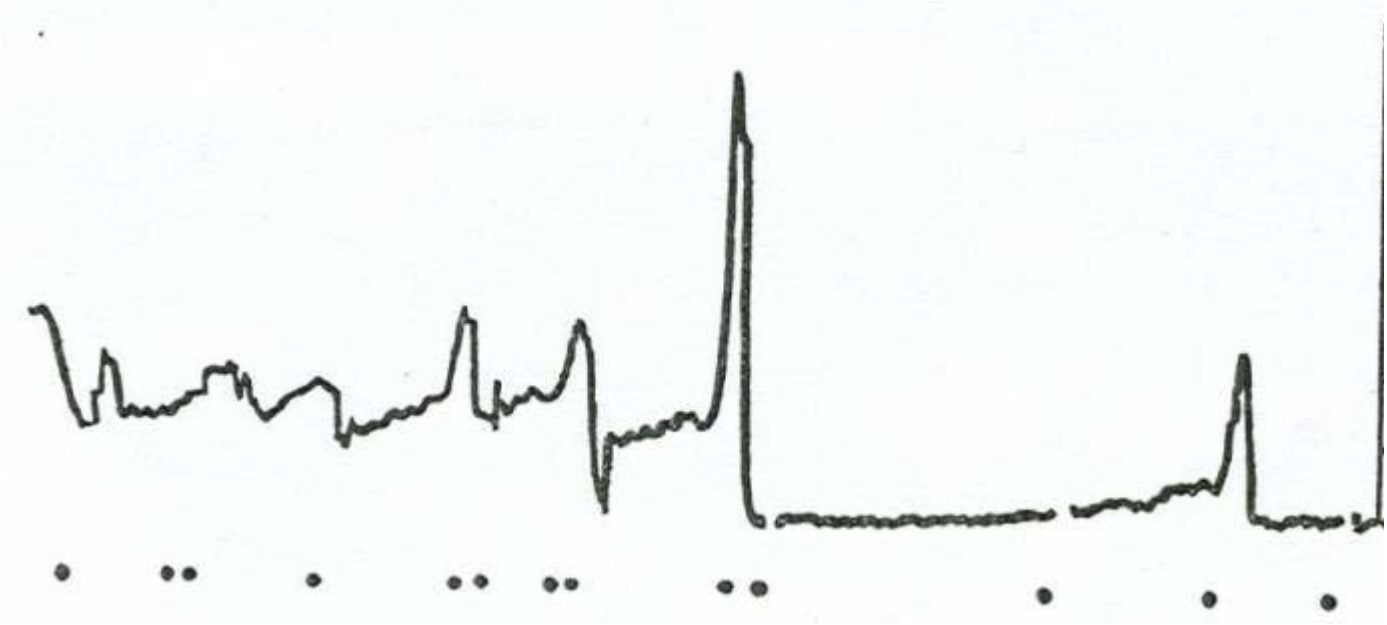
deflections, while during the intermediate periods of peristalsis, when the animal is quiet no deflections are present. This also holds true even of such cathartic drugs as aloin and croton oil. The curve of apomorphine is especially interesting from this standpoint. The injection of apomorphine into the rabbit does not produce vomiting, but causes continuous shivering and twitchings of almost all the muscles. The result is a corresponding ceaseless fluctuation of the galvanometric deflections. No less instructive is the injection of strychnine which gives rise to twitchings and convulsions with corresponding deflections of the mirror-galvanometer well brought out in the following photographic record:



CURVE XIII. Platinum electrodes in abdomen. Curve of defecation. No cells; no shunt.



CURVE. XIV. Platinum electrodes in abdomen. Curve shows deflections under apomorphine injected into rabbit. Apomorphine injected 5 mg. Maximum deflections about 5 cm. No cells; no shunt.



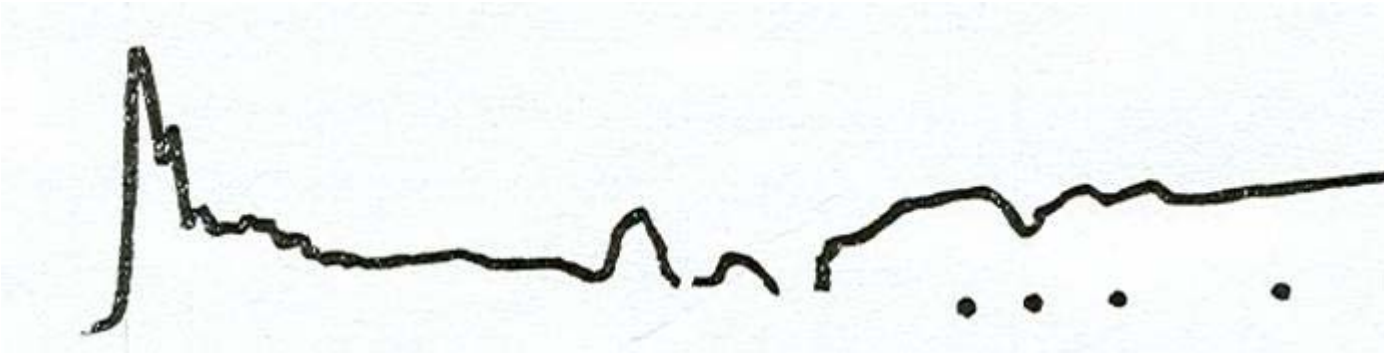
CURVE XV. Platinum electrodes in abdomen of rabbit. Injected strychnine 0.5 mg. Deflections during convulsions. Maximum deflections about 7 cm. No cells; no shunt.

The same relation holds true even in the case of the galvanometric deflections due to various stimulations. Where the stimulation is accompanied with motor reaction there the deflection is manifest, where such reaction is absent the galvanic deflection does not appear. All those facts point to the conclusion that the concomitant motor activity plays an important and possibly a predominant role in the causation of the galvanic phenomenon.

This agrees with the work of Sidis and Kalmus who have observed in their experiments that coughing, laughing, sitting, rising, bending arms and muscular activity in general give rise to marked galvanometric deflections. "From these experiments," they say, "it seems that muscular activity of those parts of the body actually forming the circuit bring about galvanometric deflections, while activity of the more remote parts are ineffective."[1] We certainly must take issue with Jung and Peterson in their claim that the galvanometric deflection due to coughing is

'psychic, that is, emotional.' The galvanometric deflection in coughing as well as in like physiological activities is entirely of muscular origin which mayor may not be accompanied by an emotion.

That the obtained galvanometric deflection during stimulation and consequent contraction of muscles in the circuit is not the effect of movement of the electrodes inserted in the tissues of the animals can be demonstrated by the experiment of moving the electrodes to which are attached insulated rubber bands. Such movements of electrodes, but with no muscular contraction, give no galvanometric deflections. This is to be seen from the following photographic records:



CURVE XVI. No cells, no shunt. Platinum electrodes in legs of rabbit. Rubber bands attached to electrodes for insulation from touch of hands. Pulling hands and moving violently electrodes produced no deflections. When however a stimulation such as prick is given, the rabbit contracts the legs and a galvanometric deflection of 33 mm. is obtained.

VIII

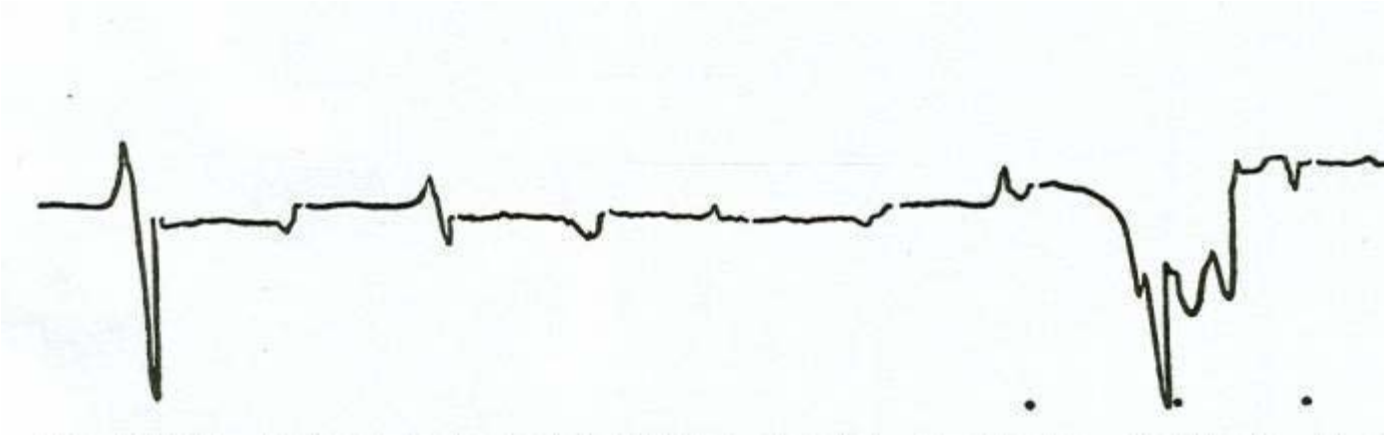
If such relation between motor activity and the galvanic phenomenon exists, it should be demonstrated, after all other possible factors are rigidly excluded, by some crucial experiments. The first crucial experiment that naturally suggests itself is to restrict the muscular activity of the

animal and see what happens to the galvanic deflections, when the animal is stimulated by pinches, pricks, sharp snaps and various other painful agencies. If muscular contraction is concerned in the causation of the galvanic phenomenon, we should find that with their diminution and total suppression the galvanic phenomenon should be correspondingly decreased and even totally abolished. With this end in view we performed the following experiment:

The hind legs of the rabbit were firmly bound so that they could not move. The circuit was closed with the platinum electrodes inserted well into the muscles of the motionless thighs. Under such conditions no stimulations however painful could call forth galvanometric deflections. In other words, with the suppression of muscular action the galvanic reaction disappears. This is clearly demonstrated by the Curve XVIa.

CURVE XVIa. Platinum electrodes into hind legs of rabbit. Legs immobilized. Rabbit stimulated every minute. No deflections. No cells; no shunt.

With the platinum electrodes in the same position one of the legs was let free to move. When the rabbit was now stimulated the leg, of course, contracted and the galvanic deflections were evident in response to each stimulation. In other words, with the reinstatement of muscular action the galvanic phenomenon once more reappeared as demonstrated by the Curve XVII.

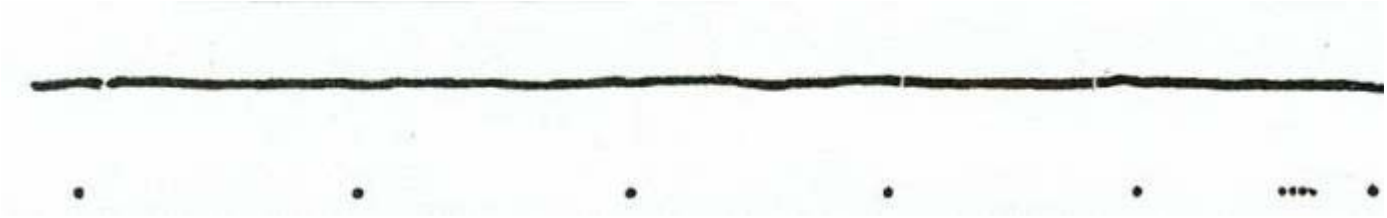


CURVE XVII. Platinum electrodes into hind legs of rabbit. One leg free. Rabbit stimulated at intervals of one minute. Deflections with each motor reaction to painful stimulation. Maximum deflections about 7 cm. No cells; no shunt.

This experiment is crucial, inasmuch as it also excludes all other possible factors, such as secretion, whether of skin or of other glands; it excludes circulation, whether of lymphatics or of blood-vessels and excludes also the action of the sympathetic and of the central nervous system. For if the galvanic phenomenon is due to any, or all of those physiological processes, the galvanic phenomenon should be present under the influence of stimulation, since those physiological processes are not arrested with the restriction of the movements of the limb.

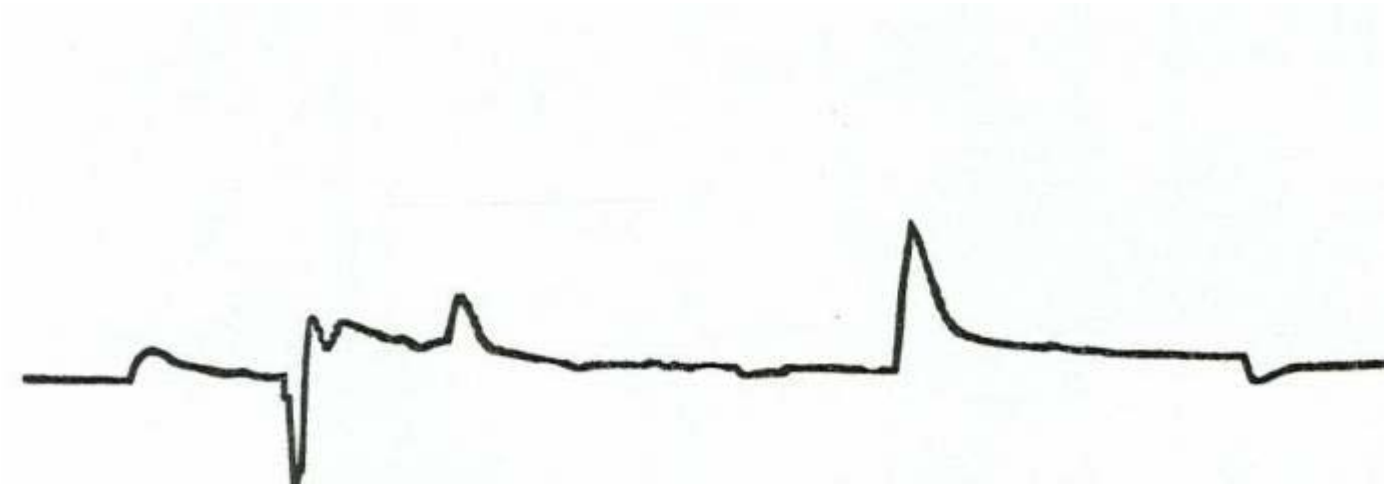
Of course, the skin-effects have practically been excluded by the whole course of our experiments, inasmuch as we worked exclusively with subcutaneous electrodes and still obtaining the galvanic deflections in response to various stimulations.

That the skin effects or secretion-currents[2] have nothing to do with the galvanic phenomenon can be further shown by the experiment that when the electrodes are inserted into the skin only, the deflections are made to disappear with the immobilization of the limbs as shown by the Curve XVIII.



CURVE XVIII. Platinum electrodes through skin of hind legs. Rabbit immobilized. Painful stimulation given at intervals of one minute; no deflections. No cells; no shunt.

In experimenting on the cat similar results are obtained. When the cat is immobilized no sensory stimulations, such as pricking or pinching, can possibly produce any galvanometric deflection. When however the movements of the animal are made somewhat freer so as to make possible muscular contractions the galvanic perturbations under the influence of sensory stimulations become manifest.



CURVE XVIIIa. Platinum electrodes in legs of strapped cat. Where the animal can react with muscular contractions to stimulations there is a deflection which diminishes and disappears with greater and even complete limitation of muscular movement.

Experiments performed on the frog exclude skin resistance and glandular skin secretion as possible factors in the causation of the galvanic phenomenon.

If the frog is put on the animal board, the platinum electrodes put into the muscles and the animal well bound and stretched out on the board so as to arrest muscular activity, the galvanic deflections due to stimulations diminish with the restriction of muscular activity and disappear with the complete arrest of muscular reaction to external stimulation. The galvanic phenomenon remains absent when the platinum electrodes are wound around the freely secreting skin of the frog, or on the inside of the skin layer, or one electrode is put on the outside and one on the inside of the skin. In all such cases, provided the muscular activity of the frog is arrested, the galvanic phenomenon is absent.

If the frog is curarized, thus abolishing the action of the muscles, but not affecting sensitivity, the platinum electrodes inserted into the muscles call forth no galvanic deflection. If the electrodes are now put into the skin or on the inside and outside of the skin layers, no sensory stimulation, however violent, can call forth the galvanic phenomenon.

That the glandular secretion has nothing whatever to do with the galvanic phenomenon can be further demonstrated by the following experiment:

The skin of the frog is easily removed from both legs leaving exposed the muscles of the legs into which the platinum electrodes are inserted. When the galvanometer is at zero and remains stationary, the animal, with legs free, is stimulated by sharp pricks or pinches, with each stimulation and concomitant muscular reaction there is a marked galvanometric deflection amounting, in some cases, to more than 20 millimeters. Under such conditions

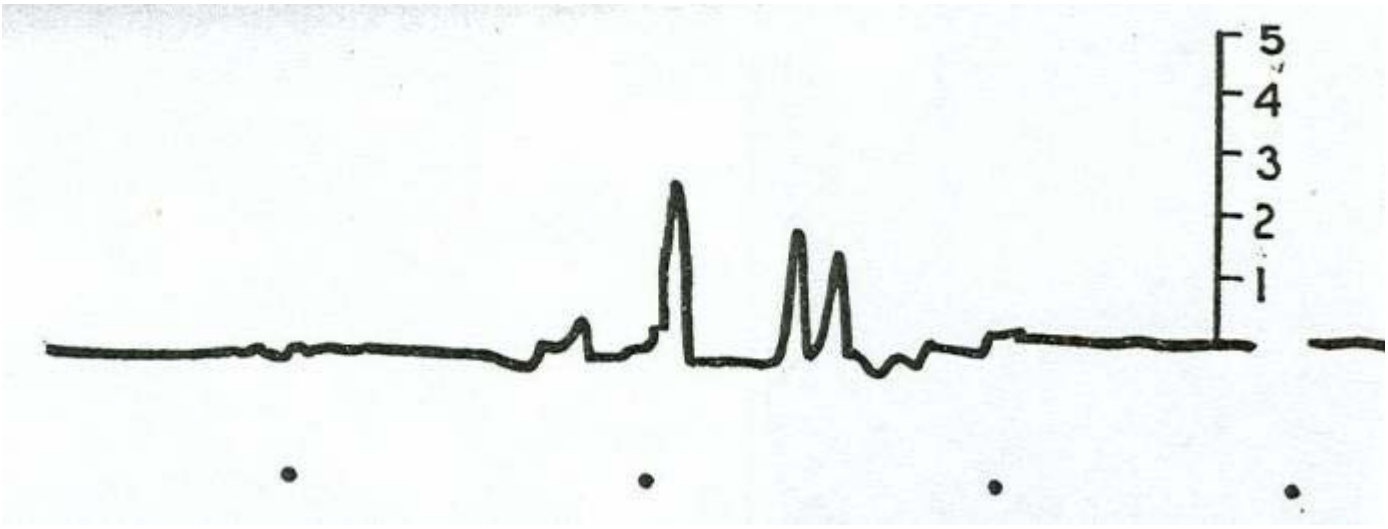
the following characteristic curve is obtained (Curve XVIIIb):

CURVE XVIlIb. Platinum electrodes inserted in legs of frogs. Legs stripped of skin. First part of curve normal. Second part shows marked galvanometric deflections under the influence of stimulations (pricks, pinches), concomitant with muscular reactions.

The brain, the spinal cord, the sympathetic nervous system as well as the action of other internal organs, such as liver and spleen, have likewise been *directly* eliminated by us. We plunged our platinum hypodermic electrodes into the tissues of those various organs and found that when muscular contractions were not present the galvanic phenomenon was invariably absent.

Similarly circulation can be directly excluded. Already Sidis and Kalmus excluded circulation as the cause of the galvanic phenomenon by the use of Esmarch bandages. In the case of animals, such as the rabbit or the frog, it is possible to exclude circulation by ligation of the arteries supplying the limbs. Under such conditions the galvanic phenomenon still persists showing that blood circulation is not among the causes of the galvanic phenomenon. The following (Curve XIX) is a photographic record of such

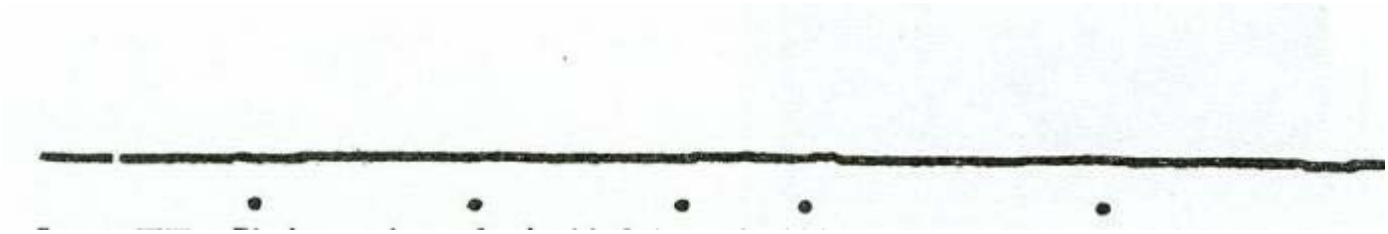
experiments:



CURVE XIX. Platinum electrodes in left hind leg of rabbit. Left femoral artery ligated. Left leg free. Rabbit stimulated at short intervals of 20 seconds. Marked deflections with each stimulation. Maximum deflection about 3 cm. No cells; no shunt.

That the galvanic reaction is entirely muscular can be still further demonstrated by the following experiment:

The sciatic nerves were cut and platinum electrodes inserted into the muscles of the legs. Under such conditions the galvanic phenomenon was absent. No stimulations, however intense and painful given in different parts of the body, could call forth the galvanic phenomenon as shown by the following photographic record: (Curve XX)



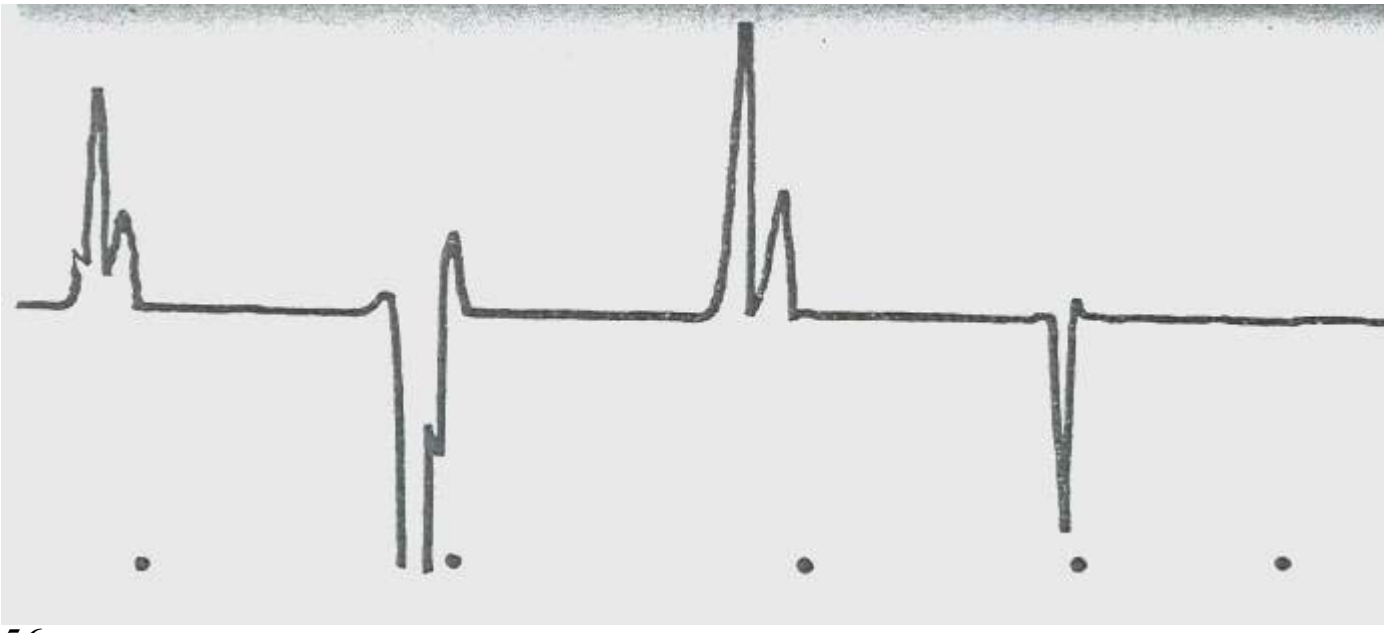
CURVE XX. Platinum electrodes in hind legs of rabbit. Nerve supply to both legs cut. Stimulation given at intervals of a minute. No deflections present. No cells; no shunt.

Similar experiments were also performed on frogs

and with the same results. With the platinum electrodes in the gastrocnemius of each leg the galvanic phenomenon invariably disappeared when the sciatic nerves were cut. The fol1owing curve (Curve XXI) is a photographic record of the experiment:

CURVE XXI. Platinum electrodes wound around gastrocnemius musc1e of frog. Sciatic nerve cut. Leg free. Frog stimulated at intervals of 20 seconds. No deflections to stimulations. No cells; no shunt.

The experiment of section of the motor nerves of the legs is also a crucial one, inasmuch as the galvanic phenomenon disappears on the paralysis of muscular activity, although all other conditions, skin secretions, circulation and sensory nerve processes remain unchanged. Moreover, it may be added that the galvanic deflections can be reinstated even under condition of paralysis of motility by passive contraction of the muscle of the leg, as demonstrated by the following photographic record: (Curve XXII).

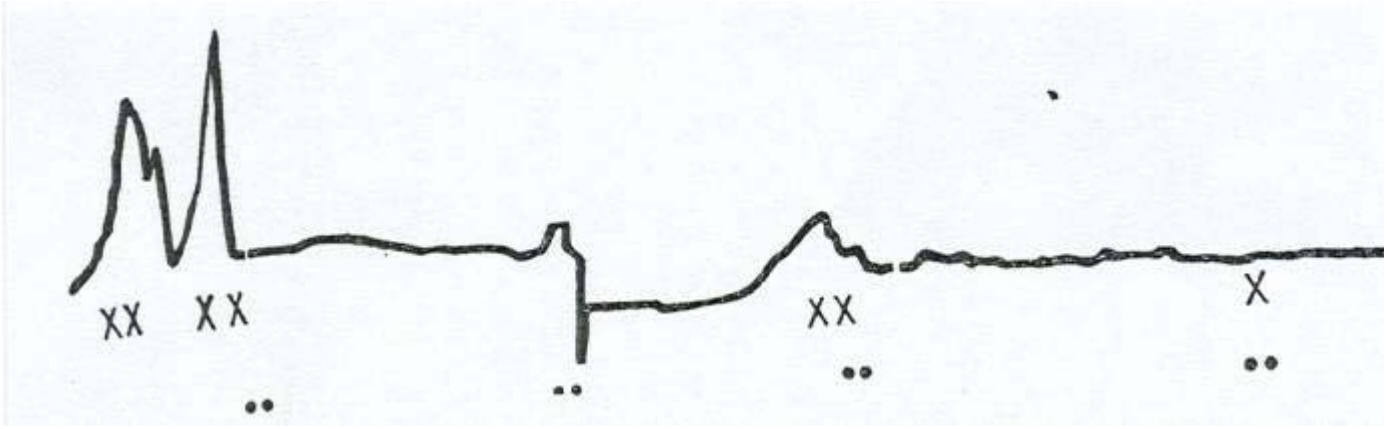


CURE XXII. Platinum electrodes in legs of rabbit. Nerve supply to leg cut off. Passive movements of legs of rabbit. With each passive movement marked deflections present. Maximum deflections about 9.5 cm. No cells; no shunt.

We can now explain the large galvanometric perturbation obtained in the case when the hypodermic electrodes are inserted into the abdominal wall. The animal in all of our experiments was tied on a board so that the extremities were naturally more limited in their movements than the abdomen, which remained free to react to painful stimulations.

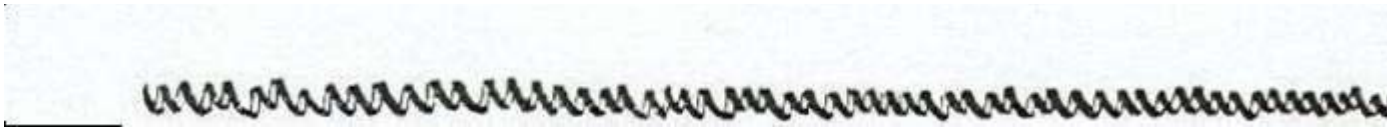
We are also in a position to account for the significant fact, present in all of our experiments, namely, that struggles, twitchings and convulsions are followed by large galvanometric deflections. For *our work proves conclusively that the galvanic reflex is a muscular phenomenon. The galvanometric deflections are due to electromotive forces liberated by muscular activity under the influence of affective and emotional states.*

Another crucial experiment is that of injection of curare. It is well known that curare only affects the striped or voluntary muscles leaving all other functions unimpaired. Now when the frog or the rabbit is injected with a dose 2 c.c. of 1 per cent solution of curare and kept alive by artificial respiration the galvanic phenomenon completely disappears. The paralysis of muscular activity causes this disappearance of the galvanic phenomenon. The following photographic record shows the results of the experiments under the influence of curare: Curve XXIII.



CURVE XXIII. Platinum electrodes in abdomen of rabbit. Rabbit given 2 C.c. of I per cent. solution of curare. Stimulation rave no deflections. Deflections are obtained by slight passive movements of legs and by tapping or rubbing abdominal walls, deflections amount to 35 mm. No cells; no shunt. (x) shows stimulation. (xx) shows passive movement of legs.

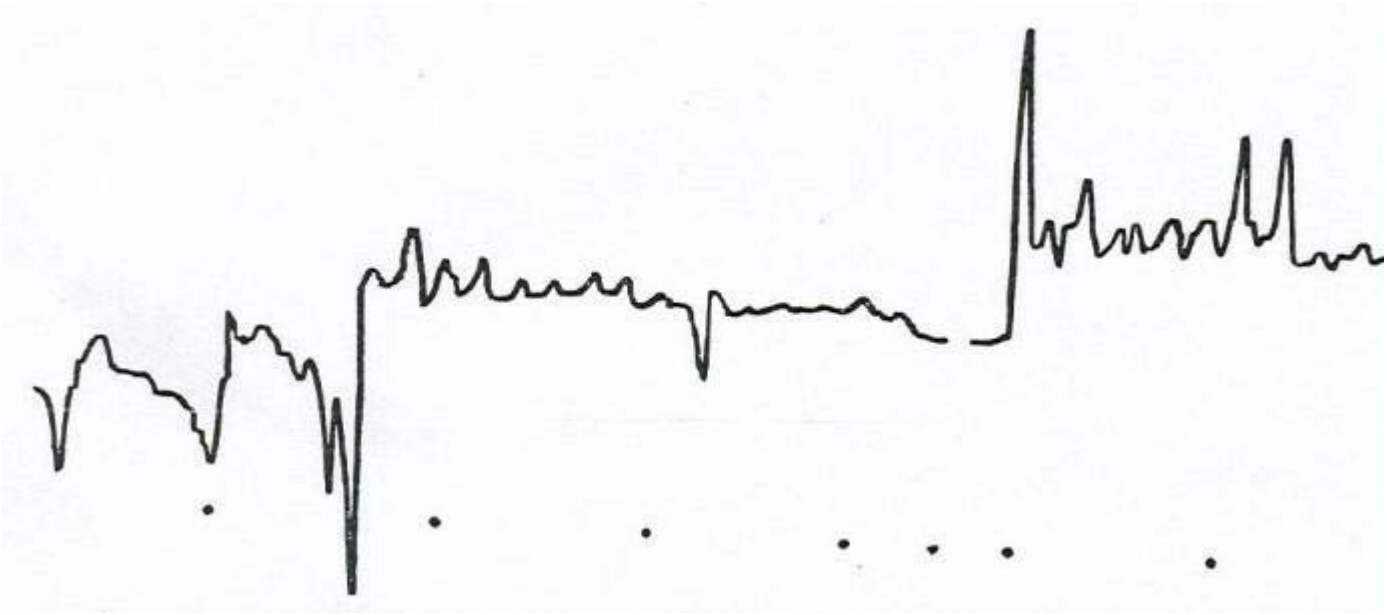
Marked rhythmical deflections are obtained from muscular contraction of heart as shown by Curve XXIV.



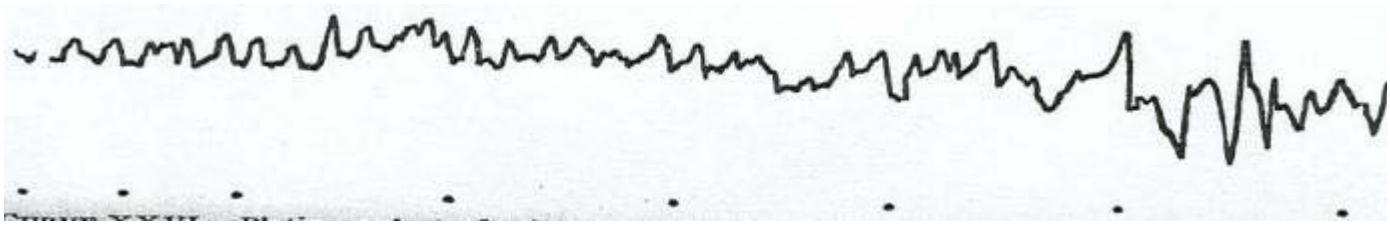
CURVE XXIV. Platinum electrodes wound around heart of rabbit. Rabbit injected with 4 C.c. of 1 per cent. solution of physostigmine. Deflections are synchronously with the contractions of the cardiac muscle. No cells; no shunt.

We can now understand the reason of the apparent paradox puzzling to Jung and Peterson when they say "there are features presented which are as yet quite inexplicable, as for instance the gradual diminution of the current in long experiments to almost complete extinction, when our ordinary experience teaches that resistance should be much reduced and the passing current larger and stronger." The reason why Jung and Peterson find the fact of ‘the gradual diminution of the current’ so 'inexplicable' is because they have totally misconceived the nature and cause of the galvanic phenomenon. In the first place, we do not deal here at all with resistance, but with

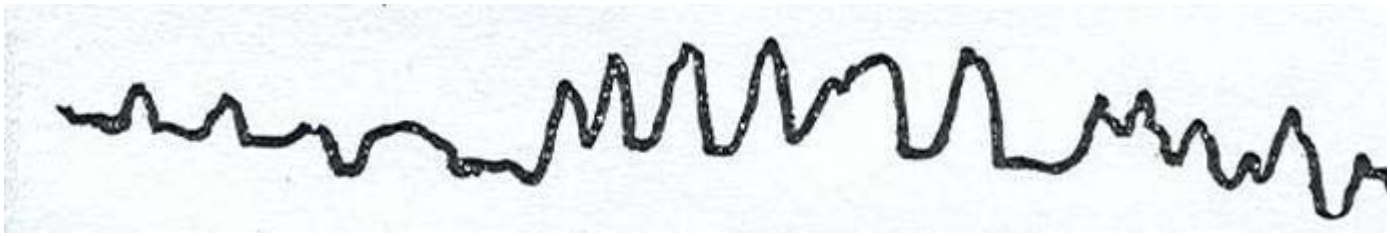
an electromotive force. In the second place, the electromotive force generated is muscular in origin. This makes 'the gradual diminution of the current in long experiments to almost complete extinction' an absolute necessity. For it is clear that an electromotive force cannot possibly become stronger and larger 'with continuous use.' That would be against all the laws of physics, With continuous use the muscles become exhausted and with the repetition of the same stimulus a lesser impression is made on the sensory nervous system calling forth a smaller and smaller muscular reaction with its accompanied diminution of electromotive force and consequent decrease of galvanometric deflection. This is demonstrated by Curves XXV, XXVI, XXVII.



CURVE XXV. Platinum electrodes in hind legs of rabbit. No cells and no shunt. Legs are free. After a normal is taken a series of stimulation of slight touches every 10 seconds is given to the leg of the rabbit. The galvanometric reaction reaches its maximum of 6.5 cm. with violent muscular reaction to subside for a period of 4 minutes, after which the galvanometric reaction once more reaches its maximum and so on.



Curve XXVI. Platinum electrodes in hind legs of rabbit. Right leg free. A series of hard pricks given to rabbit at regular intervals of 10 seconds. The galvanometric reaction gradually diminishes falling from 30 mm. to about 3 mm. No cells; no shunt.



CURVE XXVII. No cell, no shunt Platinum electrodes in legs of rabbit. Legs free. Passive movement of legs every 10 seconds, Curve shows diminution from 20 mm. to 5 mm.

We may say then that all our experiments prove incontestably that the galvanic phenomenon is due to an electromotive force which is muscular in origin.

VIII

In conclusion we may make the following summary of our results:

1. Galvanometric deflections are brought about by psycho-physiological processes (but not by purely ideational processes) under the influence of various stimulations.

2. These galvanic deflections termed by us ‘galvanic reactions' are not due to variations of resistance, whether of skin or of body.

3. The galvanic reaction is the *result of variation of electromotive*

forces produced by the psycho-physiological processes: set into activity by the agency of external or internal stimulations.

4. The causation of the galvanic reactions cannot be referred to circulation, nor can it be referred to secretory currents, whether of skin-glands or of other glandular organs.

5. The central nervous system and the sympathetic nervous system are alike excluded as factors concerned in the manifestation of the galvanic reaction.

6. *The galvanic reaction is entirely a muscular phenomenon* due to contraction, stretching, straining of the muscular fibers under the influence of various agencies, be they psychic, sensory, physiological, chemical, thermal, electrical or mechanical.

7. The galvanic reaction is chiefly brought about by the muscles within the circuit.

8. Prolonged active peristalsis gives rise to galvanic deflections which are due to the contraction of the muscles involved in the process of peristalsis.

9. The galvanic reaction diminishes and even completely disappears with the repetition of the same kind of stimulation.

10. This fall or complete disappearance of the galvanic reaction with the repetition of stimulation is usually due to a decrease of sensitivity in regard to the same repeated stimulation.

11. The fall however of the galvanic reaction may also be brought about by the action of a prolonged stimulation resulting in a gradual fatigue of the muscles in the circuit.

12. The heart-beat, like the contractions of any of the other muscles, gives rise to galvanic deflections.[3]

We are glad to thank Professor Franz Pfaff, of the Pharmacological Department of Harvard Medical School, for the many opportunities and courtesies shown us in the carrying out of this experimental work.

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[1] *Op. cit.*

[2] 'Secretion-currents' are usually ascribed to the physiological activity of the secretory glands. Our experiments, though not final, seem to point to the fact that in 'secretion-currents' we do not deal at all with physiological activities, but with purely chemical processes going on in the end-products of secretion. The chemical processes of the secreted end-products give rise to electrical currents which are regarded as secretion-currents representing the physiological activity of the glands. Such currents however may have little or nothing to do with glandular physiological activity and may be nothing but an artefact due to chemical processes going on in the decomposition of the secreted products.

If one of the platinum electrodes is put into the inner surface of the armpit rich in glands and the other platinum electrode is put on the shoulder, there is a marked galvanometric deflection. If now we take cotton and saturate it with the secretions from the armpit and then let the cotton soak in a small  beaker filled with distilled water and immerse one of the platinum electrodes tin the beaker and the other platinum electrode in another beaker with pure distilled water, *the galvanometric deflection is found to be of the same order of magnitude and in the same direction as in the experiment on the armpit and the shoulder.* The same result is obtained when the platinum electrode is applied by pressure directly to the saturated cotton. The secretion-currents here are evidently not physiological.

The subject of secretion is highly complicated and cannot be dismissed with a couple of experiments, however suggestive. We shall take up the matter in a separate study on secretion as an accompaniment of psycho-physiological activity.

[3] The clinical aspect of the galvanic reaction will be considered by us separate study.