Physiology. — *"The principle of entropy in physiology."* By Dr. J. W. LANGELAAN. 3rd part. (Communicated by Prof. T. PLACE).

All investigations made with the intention of testing the law of FECHNER at the experiment, have proved, that this law is only satisfied within a small interval and within that interval only by approximation.

In order to find out the causes of these deviations, I have tried to deduce the law of FECHNER (considered as a physiological law) from a general physical principle. It has appeared from this deduction that this formula rests on very special premises, and that the circumstances assumed in these premises, are never realized in nature.

In a series of experiments I have tried to fulfil as accurately as possible the conditions required by this law according to its deduction. To this purpose the spinal cord of a frog [1]) was cut between the cranium and first vertebra; then the whole frog, with exception of the hind leg which was used for the experiment, was wrapped up in wads and fastened to a glass rod. The leg hung down in a wide vessel which could contain about 600 ccm. of fluid. In the sole of the foot a hook was put and a horsehair was attached to this hook, which passed outside through a very small opening in the bottom of the vessel. This horsehair was fixed to the arm of a length-recorder.

The small opening through which the hair passed was filled up with vaseline, this prevented almost perfectly the fluid to drip out, while the friction experienced by the horsehair was very slight. By suspending a weight to the length-recorder the leg was charged with 15 grams. Then the vessel was filled with 350 ccm. of water, and the leg immersed till the knee. To the stand bearing the glass and the frog, a clamp was fixed bearing a burette. This burette contained a solution of oxalic acid in distilled water. By opening the tap this solution flowed into the water in which the leg hung. A bent stirrer always kept in slow motion (but which did not touch the leg), caused the acid to be thoroughly mixed with the fluid. Then so much acid was slowly added to the liquid till the leg began to contract. The vertical motion of the leg, three times magnified, was registered on a slowly rotating cylindre by the length-recorder. In order to prevent too large excursions, the length-recorder struck against a piece of cork, so that the contraction in the beginning took place isotonically, at the end isometrically.

After the leg had returned to rest, we waited about 5 minutes and

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1) Small male specimens of Rana esculenta proved to be the most suitable for the experiment.

then again so much acid was added, till a new group of reflex-contractions appeared. In these experiments the acid in the burette contained 40 grams of oxalic acid per liter solution. As a measure of the stimulus in physical units the concentration of the solution, in which the leg was immersed, was chosen. The concentration is defined as the proportion between the quantities of oxalic acid and water, while as the unity of weight the molecular weight was chosen (126 for oxalic acid, 18 for water).

The result of the experiments was given in a table in the following way. The first column gives the concentration of the solution in the vessel, just at the moment the leg begins to show a group of reflex-contractions. The second column contains the increment, which the concentration in the vessel must undergo to produce again a set of reflex-contractions. The third column gives the relation between this quantity and the absolute value of the concentration at the moment that the reflex-contractions appear. This column contains therefore the quotient of WEBER.

Let us now consider in how far this experiment satisfies the conditions put by the formula. The researches of ECKHARD, KOSCHEWNIKOFF, C. MEYER and SHERRINGTON have proved, that the same spinal segments which innervate the skin of the hind leg, supply also the muscles of the leg with nerves. If we have cut the spinal cord at the upper end and have therefore annulled the influence of the higher centra, we have in the hind leg a segmental primary reflex-apparatus. The receptive organs of this reflex-apparatus lay in the skin, while the muscle forms the transformer. Adopting the simple law of distribution, I record only the mechanical effect. In this respect the experiment fulfils the required conditions.

The interpretation of the mechanical effect is very difficult as the new state of equilibrium is not reached at once, but only after oscillating round this new state. It is therefore hard to say what part of the total effect must be considered as the quantity ΔE of the formula. Fig. I is the reproduction of a typical tracing. After the reflex-apparatus is in perfect rest, the tap of the burette is opened at the moment indicated in the curve by a couple of vertical small lines on the base line and oxalic acid is slowly added under continuous stirring. At the moment that the first contraction appears, the tap of the burette is closed and no more acid is added. At this moment the increase of concentration amounted to 3.2×10^{-5} the initial concentration being 15.9×10^{-5}. The curve represents the mechanical effect, following upon this increase of the concentration of the acid in the vessel. This effect consists of a group of great contractions, followed by some smaller ones of decreasing size. If we should be at first inclined to consider this group of large contractions as the mechanical effect corresponding to the quantity ΔE of the formula, this conception offers many difficulties when the mechanical effect assumes a form as is represented by the curve which is reproduced by fig. II. In consequence of a small increase of concentration we do not see a definite effect appear, not even partly defined, but the reflex-apparatus comes in rythmical contraction. Where in the first case the resistances in the chemical system are such that the oscillations rapidly die away, and the new state is reached after a few oscillations, these resistances in the second case are so small, that once the equilibrium disturbed, the system remains oscillating round its new state of equilibrium. This oscillation documents itself as a rythmical mechanical effect. If the rate of decay of these oscillations is very small, these rythmical

TABLE I. (Fig. V).

No 4. (12 9. 01.)

Conc.	Δ Conc.	$\frac{\Delta \text{ Conc.}}{\text{Conc.}}$
$0\ 0 \times 10^{-5}$		
	$10\ 1 \times 10^{-5}$	
10 1		
	2 8	0.218
12 9		
	3 4	0 209
16.3		
	4 0	0 196
20 3		
	4.1	0.167
24.4		
	4.3	0.150
28.7		
	4 9	0.147
33.6		
	4 8	0.123
38.4		
	10.7	0.218
49.1		
	20.8	0.298
69.9		
	10.7	0.133
80.6		

Section of the medulla 10 A.M.
beginning of the experiment 11 15 A.M.
Temp. 13 5 C.

TABLE II. (Fig. VI.)

No 35. (25. 12. 01)

Conc.	Δ Conc.	$\frac{\Delta \text{ Conc.}}{\text{Conc}}$
0.0×10^{-5}		
	$26\ 6 \times 10^{-5}$	
26 6		
	5 0	0 158
31.6		
	2 9	0.086?
34 5		
	3.2	0 085
37 7		
	2 3	0.058
40 0		
	2 0	0 047
42 0		
	1 6	0 037
43.6		
	2 7	0.059
46 3		
	3 5	0 069
49.8		
	5.4	0 098
55.2		
	10 8	0.164
66 0		
	19 3	0 226
85.3		

Section of the medulla 10.35 A M.
beginning of the experiment 12.40 P.M
Temp. 13 C.

contractions can last for several hours and often with great regularity [1]). Under these circumstances, however, ΔE is no more a determined quantity and the experiment cannot fulfil the condition of the formula, that ΔE be a constant quantity in the successive determinations. If we only use those experiments, in which the resistances are pretty considerable, and the new state of equilibrium is reached after a few oscillations, ΔE fulfils the condition, that it represents a small quantity in successive determinations. The experiment does not allow another more definite conception of this quantity.

By the addition of acid from the burette to the liquid in which the leg is immerged, the level of the liquid rises, and the stimulated surface increases. So the experiment does not fulfil the condition of the formula in this respect either.

TABLE III.

No 21. (7. 12. 01.)

Conc.	Δ Conc.	Δ Conc. / Conc
0.0×10^{-5}		
	3.6×10^{-5}	
3.6		
	1 7	0.327
5.3		
	1.4	0.203
6 7		
	2.1	0.236
8.8		
	3.6	0.292
12 4		
	6.3	0.339
18.7		
	10.5	0.359
29 2		
	12.4	0.297
41.6		
	8.7	0.173
50.3		
	26.0	0.271
76.3		

Section of the medulla 10.15 A.M.
beginning of the experiment 12.56 P.M.
Temp. 15 C.

TABLE IV. (Fig VII.)

No. 14. (21. 9. 01.)

Conc.	Δ Conc.	Δ Conc. / Conc.
0.0×10^{-5}		
	15.9×10^{-5}	
15.9		
	3.2	0.168
19.1		
	4.5	0.192
23 6		
	7.3	0.235
30.9		
	8 0	0.207
38.9		
	4.3	0.098
43 2		
	3 8	0.082
47.0		
	19.9	0.297
66.9		
	27.6	0.292
94.5		
	16.8	0.151
111.3		
	15.3	0.121
126.6		

Section of the medulla 10 P.M. 20. 9.
beginning of the exper. 12.1 P.M. 21.9
Temp. 16.5 C.

1) It seems to me that the heart is in this condition, and it would be worth while to repeat many experiments from the physiology of the heart on this rythmically acting reflex-apparatus.

Similar experiments as described by me, were performed by WINKLER and VAN WAYENBURG some years before. The method followed by them, which slightly deviated from mine, enabled them to extend the experiment only over a small interval of variation of concentration. They concluded for this small interval, that the reflex-apparatus of the frog follows the law of FECHNER [1]). In the experiments communicated by them slight deviations from this law proved to occur and it was with the purpose of learning something about these deviations, that I repeated these experiments extended over a greater interval. Table I, II, III and IV represent four of these experiments. If we take R as the value of the stimulus in physical measure (i. e. the concentration of the solution of the acid in which the leg is immerged) and if we take ΔR as the value of the increment of this stimulus which is required to call forth a change in the system, the quotient $\frac{\Delta R}{R}$ is not constant, but in general a function of R.

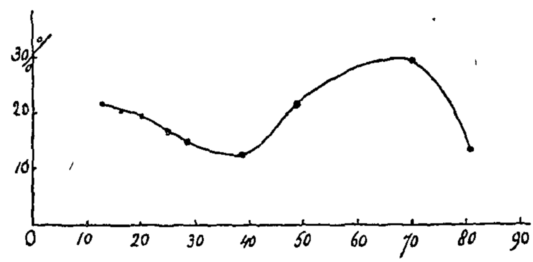


Fig. V (table I, exper. 4).

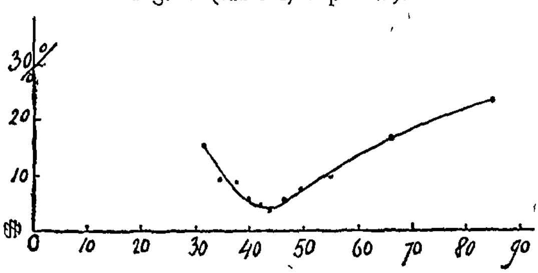


Fig. VI (table II, exper. 35).

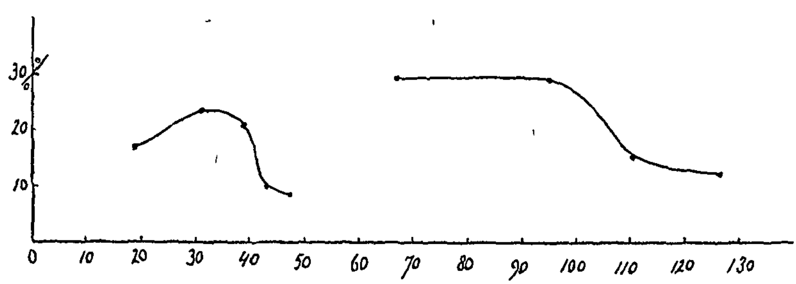


Fig. VII (table IV, exper. 14).

1) VAN WAYENBURG, Dissertation 1897. pag. 117.

Fig. V, VI, and VII are the graphical representation of Table I, II and IV. In this graphical representation I have considered the amount of water as constant (10^5 unities of weight) and put as abscissae the number of solved unities of weight of the acid. The relative increases of the concentration, in percents, have been chosen as ordinates. The points, representing successive determinations, are connected by a curve. The graphical representation of the result of the experiment by a continuous curve is only an approximation, remaining in the same course of thoughts as that, which has led us to represent the phenomenon analytically by a continuous function.

If the law of FECHNER was satisfied, the line representing graphically the quotient $\frac{\Delta R}{R}$ as function of R, would be a straight one. But instead the experiment furnishes a curved line. In order to elucidate the form of this curve further, fig. V is given, which is the graphical representation of an experiment, where the first descending branch is determined by as large a number of observations as is possible. Fig. VI shows a reduction in the extent of the first descending branch and this enables us to determine the ascending branch by a greater number of observations. In the experiment represented by fig. VII this reduction of the first descending branch is so considerable, that it no more appears in the experiment; this makes it possible to determine the top of the ascending branch and the descending branch following on it. The whole course of the second descending branch cannot be given, as always a discontinuity occurs at a point which seems to be near a second minimum. After this discontinuity a new period sets in, and as far as it is possible to follow this new period, it appears to be considerably greater, whereas the oscillation which the value of the quotient $\frac{\Delta R}{R}$ shows in this period, seems to be relatively smaller. For a skin-muscle reflex-apparatus the quotient $\frac{\Delta R}{R}$ must therefore be considered as a periodic function of R. If we inquire what is the signification of this discontinuity, it seems that only those variables, which are the representation of the independently variable components of the chemical system, can be able to show discontinuities. This brings about a change in the nature of the system and this must be attended by a discontinuous variation of the quantity R, which occurs in formula I of the second communication. The experiment communicated by MASSART [1]) seems

1) Bull. Acad. royale de Belgique 3me Série, T. 16, 1888, pag. 590.

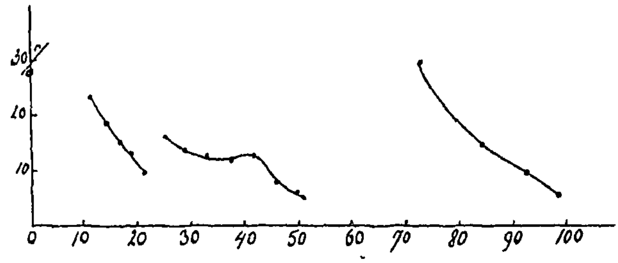


Fig. VIII (table V, exper. 25).

TABLE V. (Fig. VIII.)

No. 25. (11. 12. 01.)

Conc.	Δ Conc.	Δ Conc. / Conc.
0.0×10^{-5}	8.8×10^{-5}	
8.8	2.7	0.232
11.5	2.7	0.187
14.2	2.6	0.156
16.8	2.4	0.129
19.2	2.0	0.093
21 2	4 0	0.160
25.2	4.0	0.136
29.2	4.1	0.123
33.3	4.5	0.120
37.8	4.3	0.123
42.1	3.8	0.079
45.9	3.0	0.061
48 9	2 5	0.050
51 4	21.0	0.289
72.4	11 8	0.141
84 2	' .1	0.097
93.3	5.0	0.051
98 3		

Section of the medulla 8.30 A.M.
beginning of the experiment 12.5 P.M.
Temp. 13 C.

to show the same phenomenon. Another phenomenon, which sometimes occurred in my experiments, was the dividing of a period into several parts. Fig. VIII (table V) is the graphical representation of such an experiment.

As far as my experiments go, this small discontinuity can appear at every moment in a given period, followed by the outset of a new period.

If we compare these results obtained by the primary reflex-apparatus with those of experimental psychology, they appear to concord in many points. As appears from the critical summary of FOUCAULT [1]) also there a variable quantity showing a minimum is found for the quotient $\frac{\Delta R}{R}$ in most cases. The shape of the curve representing the quotient $\frac{\Delta R}{R}$ as function of R, makes us suppose, that the experimental psychology has seen only part of a large period. By the dividing of a period into several parts, the quotient $\frac{\Delta R}{R}$ seems to show multiple minima and this occurs also in some experiments of the experimental psychology. Hence there is agreement in these respects between the results of the psychological and the physiological experiment.

With regard to the mechanical effect I have pointed out, that this is greatly dependent on the rate of decay of the oscillations of the system. The rapidity of this decay is determined by the passive resistances in the chemical system. If these passive resistances are slight, a small increase of R will be sufficient to call forth a change in the system. Therefore the value of the quotient $\frac{\Delta R}{R}$, which is a measure of the value of these passive resistances, will determine the rapidity of the decay of these oscillations.

In correspondence with this the experiment shows that the height and the number of the elevations in every successive determination increases with decrease of the value of the quotient $\frac{\Delta R}{R}$. Fig. III (table II) observation 2, 3, 4, 5 shows this clearly. At the 5[th] observation the resistances are so slight, that the system continues to oscillate for several seconds. Observation 8 and 10 show this same phenomenon at a higher value of R, in the same series of observations. If we compare, however, observation 8 with observation 5, in which two observations the value of the quotient $\frac{\Delta R}{R}$ is almost the same, and

1) M. FOUCAULT. La psychophysique, 1901.

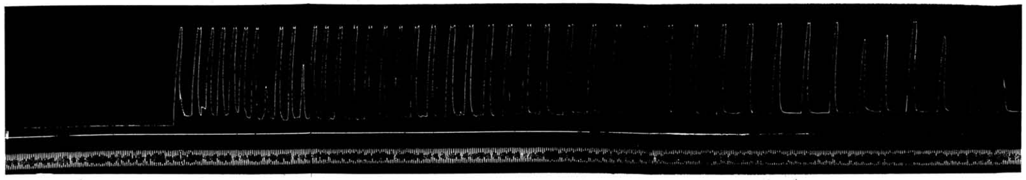
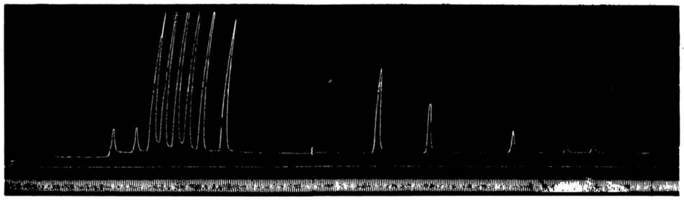


Fig. II. (Exp, N⁰. 24.) Tuningfork 2 vibrations per second.

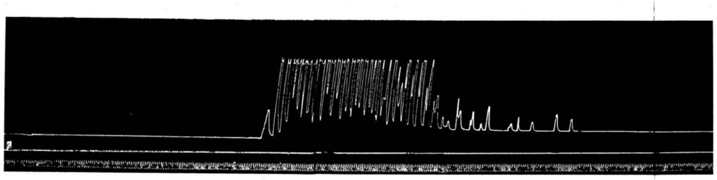


$\frac{\Delta R}{R} = 0.168$

$R = 19.1 \times 10^{-5}$

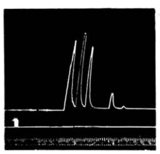
Fig. I. (Exp. N⁰. 14.) Tuningfork 2 vibrations per sec nd.

1



$R = 26.6 \times 10^{-5}$

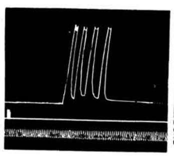
2



$R = 31.6 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.158$

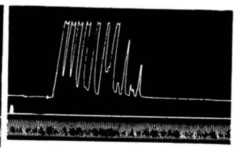
3



$R = 34.5 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.086?$

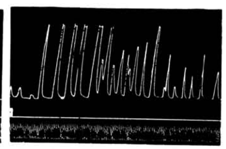
4



$R = 37.7 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.085$

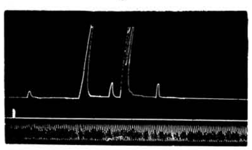
5



$R = 40.0 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.058$

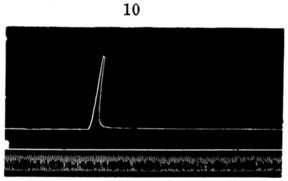
8



$R = 46.3 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.059$

10



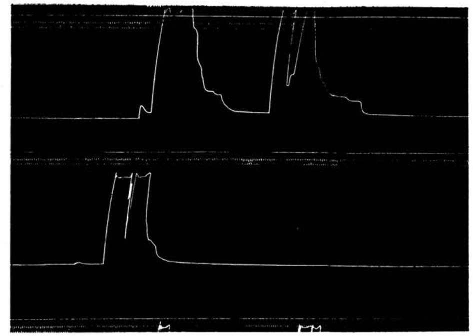
$R = 55.2 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.098$

Fig. III. (Exp. N⁰. 35.) Tuningfork 2 vibrations per second.

5

3



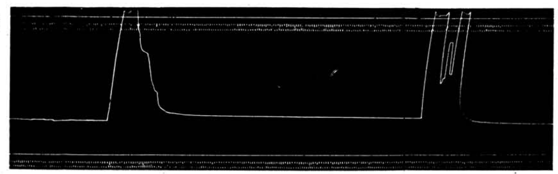
$R = 171 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.206$

$R = 96.8 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.234$

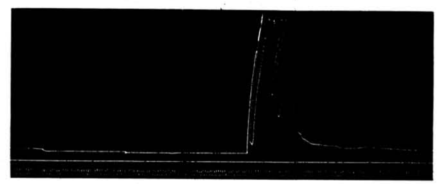
6



$R = 195.4 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.125$

10



$R = 413.9 \times 10^{-5}$

$\frac{\Delta R}{R} = 0.093$

Fig. IV. (Exp. N⁰. 50.) Tuningfork 2 vibrations per second.

also observation 10 with observations 3 and 4, it appears, that in the second place the rate of decay is dependent on the absolute value of R. Supported by these and more similar observations we may say that the rapidity of the decay of the oscillations increases with increasing value of R and with increasing value of the quotient $\frac{\Delta R}{R}$.

In this we have to keep in view, that the first observation always occupies a special place; for this observation ΔR is always very large, and though the method followed does not enable us to determine the quotient $\frac{\Delta R}{R}$ for this observation, this quotient is probably also very great. Notwithstanding this we always see that the rate of decay is very slight and from this we should have to conclude, that the influence of the absolute value of R on the rapidity of this decay is preponderant in the beginning.

The same experiments which I have described for the frog whose spinal cord is cut through, can also be performed with perfectly intact frogs. For this it is necessary to wrap up the whole animal carefully in wads with exception of the hind leg which is used for the experiment. If we take care to avoid tactile and auditory stimuli, the frog remains quiet during the experiment also under these circumstances [1]). In this case the result of the experiment is the same as that of the preceding one.

Fig. IX (table VI) is the graphical representation of an experiment.

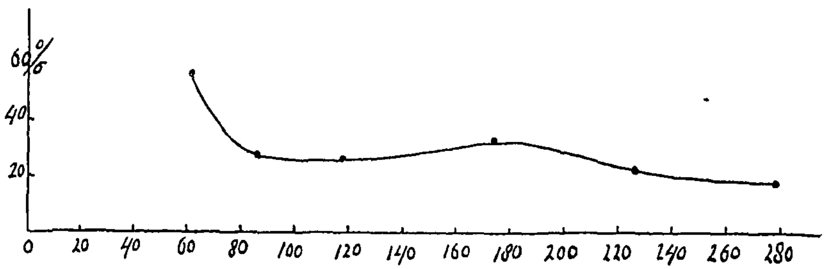


Fig. IX (Table VI, exper. 46).

If the first period is small, it is possible to see also here a part of a second period appear (Fig. X, table VII). This second period seems also greater than the first, while the oscillation, which the value of the quotient $\frac{\Delta R}{R}$ shows in this period, seems relatively to be smaller.

1) In these experiments the solution of acid in the burette contained 80 grams of oxalic acid per liter solution.

TABLE VI. (Fig. IX.)

No. 46. (18. 1. 02.)

Conc.	Δ Conc.	Δ Conc. / Conc.
0.0×10^{-5}	26.9×10^{-5}	
26.9	34.6	0.562
61.5	24.1	0 282
85.6	32.1	0.273
117.7	55.9	0.322
173.6	52.3	0.231
225.9	52.2	0.187
278.1		

Medulla intact. Beginning of the experiment 11.46 A.M Temp. 13.5 C.

TABLE VII. (Fig. X.)

No 50. (26. 1. 02.)

Conc.	Δ Conc.	Δ Conc. / Conc.
0.0×10^{-5}	29.3×10^{-5}	
29.3	44.9	0.605
74.2	22.6	0 234
96.8	39.0	0.546
135.8	35.2	0 206
171.0	24.4	0.125
195.4	53.0	0.213
248.4	71.6	0.224
320.0	55.4	0.148
375.4	38.5	0.093
413.9		

Medulla intact. Beginning of the experiment 3.0 P.M. Temp. 11.5 C.

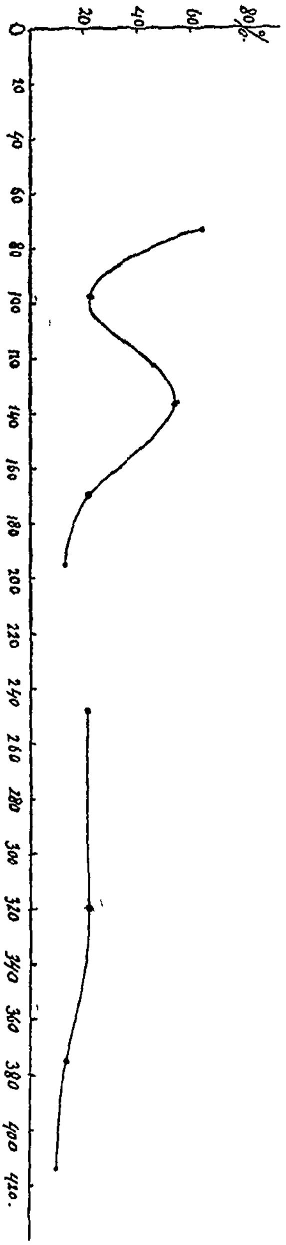


Fig. X (table VII exper. 50).

The *number of my experiments in which a second period appears*, is, however, not great. Therefore we may say also in this case, that the quotient $\frac{\Delta R}{R}$ is probably to be considered as a periodical function of R. The value of the quotient $\frac{\Delta R}{R}$, however, is in these experiments considerably greater than in the preceding experiments, while in concordance with this the rapidity of the decay of the oscillations of the system is also greater.

Figure IV (table VII) which is the reproduction of four observations from the same series, shows this clearly; the new state of equilibrium is reached after a few oscillations. If we compare observation 3, 5 and 6, the system proves to be a periodical one, at the third observation; at observation 5 and 6 the rapidity of the decay decreases with decreasing value of the quotient $\frac{\Delta R}{R}$. At the tenth observation, where the quotient $\frac{\Delta R}{R}$ shows a very low value, the rapidity of the decay is very small notwithstanding the high value of R. If we summarize these differences briefly, we conclude that in consequence of the high section of the spinal cord, the passive resistances in the chemical system of the skin-muscle reflex-apparatus considerably decrease. On account of clinical observation chiefly regarding the plantar-reflex, it seems to me, that we have to deal here with a very general phenomenon occurring always where there is a wasting of systems. In this case the rapidity of the decay of the oscillations of the system is very small in consequence of the decrease of the passive resistances in the chemical system. It is obvious that a good motor function can only exist, when the rapidity of the decay is so great, that the system is almost aperiodic. The motor disturbances, which occur in multiple sclérosis, in locomotor ataxy and many other diseases of the nervous system seems to be partly due to the decreasing resistances in the chemical system of the reflex arc.

If the system is perfectly aperiodic, then the quantity ΔE is a perfectly determined quantity. This condition must also be fulfilled by the systems, to which the experimental psychology extends its experiments; if this condition is not satisfied, then the effect is a not determined quantity as in the physiological experiment.