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the chemical cycle may be slight at first and by approximation all the considerations remain of force for this short period, also for a part of a reflex-apparatus, but after a longer period atrophy necessarily sets in. As soon, however, as the chemical cycle is no longer complete, the reflex-apparatus will be in a changed state after each stimulation. This interrupts the regularity of the phenomena.

Some botanists have tried to introduce into botanical physiology the notion of a reflex-apparatus built up by a concatenation of cells. There is here, however, no question of a differentiated reflex-apparatus, and a great many investigations have proved, that the same cell which receives the stimulus serves at the same time as transformer. Evidently the whole cycle of metabolism takes place in a single cell. It is therefore more accurate to consider the cell as a physiological unit for plants and probably also for the lowest animals.

In a second paper I hope to discuss the law according to which the transition of the system of the products of assimilation to the products of dissimilation takes place and the results which ensue from this for the reflex-apparatus.

**Physiology.** — "*The principle of entropy in physiology.*" By Dr. J. W. LANGELAAN. 2nd part (Communicated by Prof. T. PLACE).

In this paper I shall try to discuss the law according to which the system of the products of assimilation passes over into that of the products of dissimilation. Our knowledge of the nature of these two systems is very limited. We scarcely know, which are the principal components originally present and which are the later appearing. The equations of condition existing between these components, are also only partly known to us as regards their form and their number. The number of independent variable components is therefore not known to us. The only thing we know with certainty is that we have to deal with condensed systems.

When the application of thermodynamics in its simplest form is correct, the same law will hold true for the transition of the system of the products of assimilation to that of the products of dissimilation as that according to which two condensed systems pass into one another.

Supported by a considerable experimental material VAN 'T HOFF has applied here the following formula [1]):

[1]) VAN 'T HOFF. Vorlesungen IIes Heft 1898 p. 175.

$$dE = q \frac{dT}{T}$$

In this formula $T$ represents the absolute temperature, $E$ the quantity of energy, transformed in consequence of the transition of the two systems into each other, and $q$ a quantity of heat. If this transition is accompanied by chemical changes, then $q$ is the quantity of heat which can be developed in maximo, per unity of mass, by this transition.

As far as the present investigations reach this formula seems independent of the number of the component substances and independent of the configuration of the two systems which pass into one another. The form into which the chemical energy is transformed, is determined by the nature of the transformer.

VAN 'T HOFF himself considers this formula as the expression ot the second principal law of the mechanical theory of heat [1]). From this point of view its generality is clear, but it is no less clear that we have here an application of the law of entropy far beyond the limits for which the deduction of CLAUSIUS holds. In its application this formula has been chiefly restricted to approximately reversible processes in systems characterized by a point of transition. Therefore the limits within which this formula can be applied are not to be determined for the present.

If the transitions are quite or partly irreversible, the sign of inequality takes the place of the sign of equality. This makes the formula assume its more general form:

$$dE \leqq q \frac{dT}{T}$$

If this transition takes place in consequence of variations of pressure, the same relation exists approximately between the quantity of transformed energy and the variation of pressure for the interval over which this change can take place.

If on a receptive-organ of a reflex-apparatus a continuous stimulus acts, this stimulus will cause a change in the variables which determine the state of the chemical system. In consequence of these variations a displacement of equilibrium takes place. Equilibrium in the reflex-apparatus is only possible, when throughout the chemical system the pressure, the temperature and the thermodynamic potential for each of the independent variable components is uniform. Under influence, therefore, of the strain applied on a part of the system

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[1]) VAN 'T HOFF. l c. pag. 174.

the whole system must pass into a changed state of equilibrium. If the other circumstances remain unchanged, the new state of equilibrium will be determined by the stimulus measured in physical units [1]). The real relation between the stimulus measured in physical measure and the change in the system not being known, we must for the present represent it by an implicite function. The same holds good for the quantity of transformed energy, as we generally measure only part of it in our experiments.

If we now apply the before-mentioned formula to the transition of the system of the products of assimilation to that of the products of dissimilation, we find for a reflex-apparatus:

$$\Delta F(E) \leqq K \frac{\Delta \varphi(R)}{\varphi(R)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I)}$$

In this formula the quantity of transformed energy is represented by $F(E)$ and the value of the stimulus in physical units by $R$. For a reflex-apparatus with passive resistances, as it only occurs in nature, only the sign of inequality has sense.

As in our experiments of stimulation never one single receptive organ is stimulated, but always a great number, we must summate the above expression between 0 and $n$, $n$ being the number of stimulated elements.

$$\Sigma \Delta F(E) \leqq K \Sigma \frac{\Delta \varphi(R)}{\varphi R}$$

If we do not understand by $\Delta \varphi(R)$ the change as it really occurs in a certain receptive-organ, but the average change, we may write:

$$\Sigma \Delta \varphi(R) = n \Delta \varphi(R)$$

As the number of stimulated receptive-organs is always a function of the extent of the stimulated area, we are led to introduce, as HELMHOLTZ did [2]), this quantity in the formula of stimulation. The representation of the effect of stimulation as a sum has no sense, as it is shown by the researches of RAMÓN Y CAJAL [3]) and many others, how great the number of connections is between the afferent and the efferent nerves. In the second place this decomposition has no sense as by its construction the transformer is to be considered as a whole. By introducing a new proportionality constant the above formula goes over in:

[1]) The way by which this changed state is reached, however, is not determined by the stimulus, and this enables us to determine or modify by external circumstances the distribution of the transformed energy over different forms.

[2]) HELMHOLTZ Handb. physiol. Optik. 1896. p. 409.

[3]) RAMÓN Y CAJAL. Nuevo Concepto de la Histologia de los Centros nerviosos 1893.

$$\Delta F(E) \leqq C \frac{\Delta \varphi(R)}{\varphi(R)} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (Ia)$$

In this formula $F(E)$ represents the total quantity of transformed energy and $R$ again the stimulus in physical units. The transition of the system of the products of assimilation to that of the products of dissimilation does not depend on the intactness of the reflex-apparatus, but takes place as long as the tissue is alive. The given formula is therefore the representation of a general law of metabolism.

The special forms under which this formula has been brought in physiology and experimental psychology, may be all derived from the more general formula by means of the same method. The function which occurs in the right-hand side of the equation must be very complicated and it is therefore improbable, that we shall soon be able to put an explicite function in its place. This function has been generally developed into a series by means of the theorem of MACLAURIN. The term at which the series is interrupted in connection with the value of the coefficients determine the degree of approximation. The formula obtained in this way is naturally a formula of interpolation.

The implicite function occurring in the left-hand side of the equation, cannot be treated in this way. This function is always decomposed in a sum of several terms agreeing with the number of forms into which the chemical energy of the system is transformed.

If we apply this to formula ($Ia$), it goes over in:

$$\Delta E_1 + \Delta E_2 + \Delta E_3 + \ldots \leqq C \frac{c_1 \Delta R + 2c_2 R \Delta R + 3c_3 R^2 \Delta R + \ldots + \Sigma(c\varepsilon)}{c_0 + c_1 R + c_2 R^2 + c_3 R^3 + \ldots .}$$

In this formula the quantities which occur in $\Sigma(c\varepsilon)$ are very small and have the property to approach to zero in the limit at the same time with $\Delta R$. According to the first principal law $\Sigma(\Delta E)$ will always be equal to the total quantity of transformed energy.

When we, as a first approximation, break off the series in which $\varphi(R)$ is developed at the first powers of $R$ and put at the same time $c_0 = 0$, the general interpolation formula assumes the following form:

$$\Delta E_1 + \Delta E_2 + \Delta E_3 + \ldots . \leqq C \frac{\Delta R + \varepsilon}{R}$$

The introduction of the special value $c_0 = 0$ means physiologically that we neglect the existence of the threshold value. Under these circumstances the simplified interpolation formula will only apply to a perfectly isolated reflex-apparatus without passive resistances. Under these circumstances, however, the sign of inequality has no sense. If, moreover, we neglect for the small interval for which the formula holds, the variations of the quantities $E_2$, $E_3$ etc. with regard to the variation of $E_1$ and also neglect the very small quantity $\varepsilon$, the formula goes over in the very special interpolation formula which we know as the expression of the law of FECHNER:

$$\Delta E = C \frac{\Delta R}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (II)$$

When applying this formula to physiological problems we generally do not measure the energy quantity $E$ itself, but another quantity which (at least by approximation) is connected with that quantity by a linear relation.

In order to make this formula which applies only for a very small increase of the stimulus, available for a greater interval, FECHNER has summated this expression over a larger interval. When executing this summation he neglected the small quantity $\varepsilon$ and replaced in this way the summation by an integration. This gives formula (II) the following form:

$$E = C \, lgn \, R + C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (III)$$

If this summation shall be correct, the same thing must take place from moment to moment. For the left-hand side of the equation this involves the special law, according to which the distribution of the transformed energy over its different forms is independent of the value of the increment of the stimulus. As the state of the system, the other circumstances remaining unchanged, is determined by the value of this increment, we can express this law also as follows: the distribution of the transformed energy over its different forms is independent of the state of the transformer. It is clear that this simple law of distribution, which we might call the law of the constant proportions, can only be correct by approximation. By means of ergographical investigations LEHMANN [1]) has tried to deduce this same law, for the contracting muscle, from the first principal law. This however, is only possible by means of the second principal law, which is itself a law of distribution. The summation of the energy quantities is beyond doubt.

For the right-hand side of the equation this summation involves that $C$ be constant throughout the interval over which the summation is extended. This constant contains the constant $K$ of formule (I). The value of this constant is determined by the nature of the transformer. Accordingly the summation involves this law: the

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[1]) LEHMANN, Körperl. Aüss. psych. Zustände, 1901. p. 191.

nature of the transformer is not changed in consequence of the stimulation. The elastic after-phenomena in muscles show most clearly, that also this law which we might call the law of the invariability of the transformer, holds only by approximation. Led by my own experiments I hope to demonstrate, that besides these small continuous variations the constant $K$ can also show discontinuities. In consequence of these two laws of approximation involved in the summation, the interpolation formula of FECHNER is only applicable for a limited interval, within which no discontinuities occur.

The method used by FECHNER for the determination of the constant of integration which occurs in formula (III), is erroneous for physiological systems, as it is based on the existence of a threshold value, while the formula, in virtue of its deduction, premises an ideal reflex-apparatus. In accordance with its sense this formula of interpolation has proved to be of general application in physiology. To confirm this I shall only refer to the investigations of DEWAR and M'KENDRICK [1]), of WALLER [2]), of WINKLER and VAN WAYENBURG [3]), of LANGELAAN [4]) and so many others. Also botanists have found it applicable, as appears from the experiments of PFEFFER [5]), MASSART [6]), VAN RYSSELBERGHE [7]).

The apparent uniformity of the natural phenomena to which this formula leads, is not founded on the nature of these phenomena, but is due to the character of interpolation formula of this form.

Experimental psychology which has discovered this interpolation formula through the investigations of WEBER and FECHNER, substituted the value of the sensation for $E$ in formula (III). If we consider the physiological law as being given first and the conformity with the psychological law as not accidental, then we may say that experimental psychology extended the simple law of distribution also to that quantity, whose variation appears to our consciousness as a change in our sensation.

Looked upon from this point of view, FECHNER has come in contradiction with his theory, which explained the logarithmical relation from the form of the distribution law. For the case that this psy-

1) Trans. Roy. Soc. Edinb. 1876, vol. 27. p. 141.

2) BRAIN, 1895, vol. 18. p. 200.

3) VAN WAYENBURG, Dissertatie. 1897.

4) Archiv f. Physiol. 1901. p. 106.

5) PFEFFER, Unters. Bot. Inst. Tübingen, 1884, 1ter Bd. 3tes Heft, p. 395.

6) MASSART, Bull. Acad. roy. Belgique, 1888. 3me Série T. 16, p. 590.

7) VAN RYSSELBERGHE, Extrait Mém. couronnés. Acad. R. de Belgique, T. LVIII.

chophysiological law of distribution might be really represented by a logarithmic function, we should be led to formulae of interpolation as have been proposed by PLATEAU, BRENTANO, FULLERTON and CATTELL.

If we want to make the formula of interpolation applicable to a greater interval and in this way account to a certain extent for the deviations from the law of FECHNER, we must break off the series in which $\varphi(R)$ was developed at a higher power of $R$. If we break off this series at the second powers of $R$ and introduce the approximations already mentioned, a formula is obtained which accounts for the deviations of the law of FECHNER at the under limit. This formula is identical with the formula, which VON HELMHOLTZ [1]) has found for it. If we break off the series at the third powers of $R$, a formula is formed which is analagous to that of VON HELMHOLTZ [2]) and which, like the former, partly accounts for the deviations at the upper limit.

As yet we have only considered states of equilibrium. In this way we obtained the simplification that our considerations were independent of the time as a factor.

The laws which determine the transition from one state of equilibrium to another, are very complicated, because the new state of equilibrium is not reached at once, but after some oscillations round this new state. As the physiological systems show passive resistances the laws of the oscillating systems in a resisting medium will apply here. HERING [3]) has come to the same conclusion, and has rightly applied this idea to the physiology of the heart. These oscillations are of general occurrence and the clinic furnishes several examples of it.

In a third communication I hope to elucidate some of these points of view led by my own experiments.

Conclusions.

1. For the higher animals the reflex-arc is the morphological unit within which the cycle of metabolism takes place. For plants and probably also for the lowest animals this is the cell.

2. Between the system of the products of assimilation and that of the products of dissimilation exists a stable equilibrium.

3. The cyclical metabolic process is partly irreversible.

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[1]) HELMHOLTZ l. c. p. 411 the reduced formula of form 2 f.

[2]) HELMHOLTZ l. c. p. 413 form. 3.

[3]) HERING. Lotos. Neue Folge IX Bd. 1889, p. 69.

4. Threshold value and refractory period are complex quantities which originate in the imperfect isolation of the reflex-arc from the surrounding medium and in the passive resistances of the chemical system.

5· Augmentation and summation of the effect of stimulation are the consequence of not compensated changes (in the sense of CLAUSIUS).

6. The form which expresses the law of WEBER-FECHNER is a formula of interpolation deduced from the principle of entropy.

**Dynamics.** — H. A. LORENTZ. "*Some considerations on the principles of dynamics, in connexion with* HERTZ'S "*Prinzipien der Mechanik*".

In his last work HERTZ has founded the whole science of dynamics on a single fundamental principle, which by the simplicity of its form recalls NEWTON'S first law of motion, being expressed in the words that a material system moves with constant velocity in a path of least curvature ("geradeste Bahn"). By means of the hypothesis that in many cases the bodies whose motion is studied are connected to an invisible material system, moving with them, and by the aid of a terminology akin to that of more-dimensional geometry, HERTZ was able to show that all natural motions that may be described by the rules of dynamics in their usual form, may be made to fall under his law.

From a physical point of view it is of the utmost interest to examine in how far the hypothesis of a hidden system, connected with the visible and tangible bodies, leads to a clear and satisfactory view of natural phenomena, a question which demands scrupulous examination and on which physicists may in many cases disagree. On the contrary, it seems hardly possible to doubt the great advantage in conciseness and clearness of expression that is gained by the mathematical form HERTZ has chosen for his statements. I have therefore thought it advisable to consider in how far these advantages still exist, if, leaving aside the hypothesis of hidden motions, and without departing from the general use in dynamical investigations, one considers the motion of a system as governed by "forces" in the usual sense of the word.

In what follows there is much that may also be found in the book of HERTZ. This seemed necessary in order to present the subject in a connected form.

As to the authors who have, before HERTZ, published similar investigations, I need only mention BELTRAMI, LIPSCHITZ and DARBOUX.