objections or perhaps better his feelings of discomfort. It is clear that the main difficulty lies in the explanation of the time-dependent processes in statistical physics. In fact, the fundamental problem is always to reconcile the reversible laws of mechancis with the apparent irreversibility of most of the phenomena which occur in nature. With regard to the theory of the properties of matter in equilibrium, there is in practice no difference of opinion. There are different ways of interpreting and justifying the canonical ensemble. But they all lead to the same general method for calculating the thermodynamic properties of a system, when the molecular constitution and the laws of interaction between the molecules are known. Of course this general method can not usually be carried out because of the great mathematical difficulties. And it is therefore perhaps not *quite* sure whether all the equilibrium properties can in principle be explained in this fashion. There is, for instance, the question of the existence of different phases of the same substance and the corresponding problem of the phase transitions, like condensation and melting. There are only the beginnings of an understanding of the liquid state. And so one can go on; the strict theory of all these matters, starting from first principles, is still lacking, although several interesting attempts have been made. Tolman does not consider these questions. Their critical discussion would doubtless have increased the book beyond all measure. They should have perhaps been mentioned at least, because they are (or better should be) essential applications of the general methods, describing the properties of systems in the equilibrium state.

However, as said before, the main difficulties lie in the explanation of the phenomena in systems *not* in the equilibrium state. And the first problem is to show that the equilibrium state, as described by the canonical ensemble, is always reached in time. This is what the x-theorem tries to do, and it is here that the differences of opinion occur. One has to distinguish between the original H-theorem of Boltzmann, which only holds for ideal gases, and the generalized H-theorem of Gibbs, which deals with the ensemble for an arbitrary system. The proofs for these two theorems have quite a different character. For gases one can actually write down an expression for the rate of change of the function H, so that one not only shows that the equilibrium state is always reached in time, but one has also an idea how long it will take. One can estimate the relaxation time. In the background, so to speak, there is also the exact theory of the transport phenomena (heat conduction, diffusion, etc.), which gives a satisfactory explanation of at least some of the non-equilibrium phenomena in gases. The situation is quite different for other systems, as in the cases of liquids and solids. Even if one is convinced by Gibbs's proof that the equilibrium state is always reached in time—and the analysis of Tolman has made the proof really quite convincing—still one has no way of estimating the relaxation time. As a result, there does not exist a strict theory, say, for the viscosity of a liquid, and in the reviewer's opinion this is *not* only due to mathematical difficulties, but it is even not clear how to formulate the problem mathematically, supposing always that the molecular constitution of the liquid and the interaction laws between the molecules are known.

This is really the main reason why the reviewer feels dissatisfied with the treatment of Gibbs and Tolman. Ehrenfest used to say that the book of Gibbs was too "smooth"; that it gave too much the impression that all problems in statistical physics were in principle solved when one could believe the classical mechanics. And the same kind of impression may be gotten from Tolman's book. This, of course, does not detract from its value. But it is the reason why the reviewer has tried to emphasize the questions which still remain open. Statistical physics has been rather neglected by the theoretical physicists, and only the simple problems have really been solved.

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# SPECIAL ARTICLES

## THE AUTONOMIC BASIS OF EMOTION[1]

CANNON[2] has stressed the significance of the sympathetico-adrenal discharge in emotion in a number of important papers. He attributes less significance to discharges via the parasympathetic system, although he admits that under conditions of great fear signs of parasympathetic discharge may be present together with the well-known sympathetico-adrenal syndrome. This latter phenomenon he explains by a lack of "orderliness of central arrangement" so that the "opposed innervations no longer discharge reciprocally but simultaneously and then the stronger member of the pair prevails." Several authors (Kling,[3] Bekhterev,[4] Bergmann[5] and others) have shown that, at least in the

[1] Aided by a grant from the John and Mary R. Markle Foundation.

[2] W. B. Cannon, "Bodily Changes in Pain, Hunger, Fear and Rage," New York, 1929; and "The Wisdom of the Body," New York, 1939.

[3] C. Kling, *Psychological Review*, 40: 368, 1933.

[4] V. M. Bekhterev, "Feelings and Emotions." Edited by M. L. Reymert, Clark University Press 1928, p. 270.

[5] G. Von Bergmann, Funktionelle Pathologie, Berlin, 1936.

human, vagal discharges frequently accompany emotional processes.

It was shown recently by ourselves[6] that the inhalation of low oxygen as well as the administraiton of metrazol produces in rats definite signs of a simultaneous vago-insulin and sympathetico-adrenal discharge. The predominance of the sympathetico-adrenal system explains the fact that in normal animals anoxia and metrazol cause a rise in the blood sugar. After elimination of the sympathetico-adrenal system these factors lead to a characteristic hypoglycemia. If, however, the vagi are cut below the diaphragm this hypoglycemic effect is absent. These experiments make it probable that conditions such as sham rage and rage which in the normal cat lead to marked discharges over the sympathetico-adrenal system may in animals in which the effects on this system have been eliminated reveal discharges over the vagus, leading to an increased secretion of insulin. Such experiments seem to be of great interest not only for the theory of emotion but also as a contribution to the still disputed problem in how far the vagus contributes to insulin secretion under physiological conditions.

In the first group of experiments the well-known syndrome of sham rage was produced by stimulating the left mamillary body of the hypothalamus in lightly narcotized cats by means of faradic currents. The Horsley-Clarke sterotaxic instrument was used in these experiments. Such a stimulation leads regularly to an increase in blood sugar due to sympathetico-adrenal discharge (Karplus and Kreidl,[7] Ranson[8] and collaborators). If the adrenals are eliminated and the liver is denervated, such stimulation, although still accompanied by the marked sympathetic signs of sham rage, is accompanied by a reversible fall in blood sugar. If, however, the experiment is repeated in such animals after the vagi had been cut the result of stimulation is now a slight rise in blood sugar which is much weaker than that observed in animals with the sympathetico-adrenal system intact. It seems highly probable that this latter rise is due to a secretion of sympathin (*cf.* Partington[9]). The fall in blood sugar observed in the first part of the experiment must be attributed to an increased secretion of insulin mediated by the vagi.

These experiments are confirmed in a second group of experiments in which the spinal cord was sectioned below the sixth cervical segment, and hypothalamic stimulation was carried out eighteen hours later. Here again it was found that sham rage produced hypoglycemia when the vagi were intact, but a slight delayed rise in blood sugar occurred on hypothalamic stimulation after vagotomy.

Another group of experiments was conducted on cats in which again the spinal cord was sectioned at the sixth cervical segment in order to eliminate the effect of central sympathetic discharges on the sympathetico-adrenal system. When such cats were confronted with a barking dog, whereby a typical rage reaction was elicited, the blood sugar fell in spite of marked signs of rage such as pupillary dilatation, increased respiration, unsheathing of the claws, etc. If, however, the experiment was repeated after the vagi had been cut below the diaphragm the result of the rage reaction was now a slight increase in blood sugar. Whether this increase is due to sympathin or to some stimulation of the hypophysis remains to be investigated. The experiments have clearly proven that the natural emotional process of rage as well as sham rage induced by hypothalamic stimulation lead to a simultaneous discharge over the vago-insulin and sympathetico-adrenal system.[10] It is obvious that it will be very important to study the evidence of such vago-insulin action under conditions of emotional disturbances.

SUMMARY

(1) It is shown that hypothalamic stimulation in cats, with faradic currents eliciting the syndrome of sham rage, produces after the elimination of the sympathetico-adrenal system a hypoglycemia when the vagi are intact. After bilateral vagotomy the stimulation results in a slight and delayed rise in blood sugar.

(2) If in cats in which, due to a sectioning of the spinal cord at the sixth cervical segment, the effect of central discharges on the sympathetico-adrenal system is eliminated, a rage response is elicited by a barking dog it produces a fall in blood sugar. The sectioning of the vagi below the diaphragm abolishes this reaction.

From these experiments it is concluded that the normal emotional process as well as the sham rage reaction is characterized by a simultaneous discharge over the vago-insulin and sympathetico-adrenal system. The latter predominates in the normal animal and masks the effects on the former.

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[6] E. Gellhorn, paper read at Cincinnati meeting of the American Psychiatric Association, May, 1940.

[7] J. P. Karplus and A. Kreidl, *Arch. ges. Physiol.*, 135: 401, 1910.

[8] S. W. Ranson and H. W. Magoun, *Ergebn. Physiol.*, 41: 56, 1939.

[9] P. P. Partington, *Amer. Jour. Physiol.*, 117: 55, 1936.

[10] It is interesting to note that Harris and Ingle (*Am. Jour. Physiol.*, 120: 420, 1937) observed in adrenalectomized rats a fall in blood sugar under conditions of fright which evoked a hyperglycemic effect in the control animals. These authors failed, however, to see the significance of their findings and the role of the vagus in insulin secretion. They attribute their results to an artefact.