behavior, no matter how long he is trained, and thus there is no evidence for the psychologist to use as a basis for the inference that "consciousness" finally disappears. (2) If the subject is instructed to report not upon his movements but upon the stimuli which are presented unchanged from trial to trial, his report will either be accurate from the beginning of learning or it will increase in accuracy with training. There is no evidence that the subject will drop from accuracy to inaccuracy or from report to no report with overtraining, unless factors like fatigue are introduced.

These experiments, limited and inadequate as they are, nevertheless point the way toward future work which will more fully describe the relation between the subject's report and his degree of training in some specific response. I have said nothing in this discussion about such abnormal phenomena as dissociated personalities and automatic writing, because the theory of "lapsed consciousness" is a *general* theory of the relation of "consciousness" to learning. Experiment would undoubtedly confirm what anecdote has reported, to wit, the existence of some forms of behavior which were once reportable by the subject but which have ceased to be so as a result of some process of reorganization within the individual. This specific field of application for the theory would undoubtedly well reward the investigator bold enough and careful enough to till it!

For the present we have arrived at a general conclusion concerning the stimulus-neural control of behavior during and after learning to the effect that once stimuli and responses have been connected no amount of overtraining, under constant experimental conditions, will result in a necessary shift of the stimulus-neural control. This is the conclusion which would have been anticipated by investigators had they not been under the influence of the two psychological theories which we have discussed, one that "consciousness" lapses when the automatic stage of performance is reached and the other that the stimulus control of perfected serial action is proprioceptive in kind. If and to the extent that a shift in stimulus control occurs, the causal factors will probably be found to lie in the greater constancy of one form of stimulation or in its greater prepotency rather than in a general law that such a shift is inevitable and generally to be expected.

THE BIOLOGY OF HEAVY WATER

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As soon as it was found possible to prepare, with any desired degree of purity,[1] a new kind of water in which ordinary hydrogen, H^1, is replaced by its heavy isotope, H^2, it was interesting to ascertain what effect this heavy water would have upon living organisms. Several months ago the experiments were interrupted, and since there may be no immediate opportunity of resuming them it seems best to publish the somewhat sporadic results so far obtained.

On account of the very small amount of pure $H^2{}_2O$ available it was necessary to begin with small organisms. The first experiments dealt with the germination of tobacco seeds and a part of the results have already been published.[2] These seeds, which in ordinary water infallibly germinated within two days at 25° C., did not germinate at all in pure $H^2{}_2O$, as far as could be seen macroscopically. On the other hand, in water containing 50 per cent. $H^2{}_2O$ the seeds all germinated and developed about half as fast as in ordinary water. Later this experiment was carried on for one month, and although the development continued to be slow, the seedlings appeared to be perfectly healthy and normal.

The tobacco seeds which had remained three weeks in pure $H^2{}_2O$ without germinating, were then placed in ordinary water. At first it appeared that their power of germination had been completely destroyed, but after a week half of the seeds began to sprout, although in an abnormal way. The sprouts were extremely thin, and this sickly growth came to an end after a few weeks. There was no possibility of toxic impurities in the heavy water, as it had been very carefully distilled in a high vacuum at a temperature in the neighborhood of the freezing point. There is a remote possibility that some hostile organisms had been favored by the treatment with heavy water, but while this might conceivably explain the unhealthy growth of the seedlings, it could hardly account for the fact that one half the seeds did not germinate at all.

I believe that this whole phenomenon can best be explained by assuming that when the heavy water first began to permeate the seeds, it produced, together with the "bound water" already in the seeds, a medium in which germination could begin, but that as soon as the total water within the seed reached a

[1] Lewis, *Jour. Am. Chem. Soc.*, 55: 1297, 1933; Lewis and Macdonald, *Jour. Chem. Phys.*, 1: 341, 1933; Lewis and Macdonald, *Jour. Am. Chem. Soc.*, 55: 3057, 1933.

[2] Lewis, *Jour. Am. Chem. Soc.*, 55: 3503, 1933.

high concentration in heavy hydrogen, the process of germination was stopped. It seems reasonable to believe that it was this inhibition of the process of germination, once begun, that proved lethal, immediately to some, and ultimately to all of the seeds. If this assumption is correct, it should be possible to saturate seeds with heavy water without destroying their power to germinate. If seeds which germinate only at a higher temperature were soaked in pure $H^2{}_2O$ at about the freezing point, then kept in this medium for several weeks and finally washed for some time, at the freezing point, in ordinary water, their power to germinate might prove to be undiminished.

A few inadequate experiments were then tried with micro-organisms. A set of tubes, filled alternately with ordinary water and pure $H^2{}_2O$, both containing 5 per cent. of malt sugar with small amounts of necessary inorganic salts, were inoculated with a pure yeast culture. In a similar set of tubes "shotgun" inoculations were made with traces of common dust. In both sets the marked difference between the two solutions could be seen with the naked eye. The solutions in ordinary water became cloudy, and in the second set soon became covered with mold, but the solutions in pure $H^2{}_2O$ at the end of several days remained transparent and seemed, under the microscope, to be entirely sterile. The experiments were interrupted at this point, but after two weeks mold was observed upon one of the solutions containing heavy water. This one observation can not, however, be taken as proving that organisms may develop in very high concentrations of $H^2{}_2O$. The tubes were protected from the air only by cotton plugs, and certainly there must be some interchange between the water inside and the moisture of the air.

Pacsu[3] has recently made quantitative measurements of the rate of evolution of carbon dioxide from glucose solutions containing 4 to 6 per cent. yeast in ordinary water and in $H^2{}_2O$. The rate of fermentation proved to be about ten times as great in the former as in the latter. Since the rate was highest at the beginning and diminished during the experiments, and since relatively large quantities of yeast were employed, the rate of fermentation was presumably determined, not by the growth of the organism, but by the large amount of enzyme initially present.

It must be noted that in my own experiments and in those of Pacsu the solvent was never pure $H^2{}_2O$; and even if the solvent were introduced in the pure state and there were no interchange with water on the surface of the container or with the moisture of the air, still there must be an immediate interchange of hydrogen between the solvent and, presumably, at least half of the hydrogen of the sugar. In all the experiments, therefore, at least several per cent. of ordinary water must have been present. I believe that it will be found that no organism will grow in pure $H^2{}_2O$. However, in order to make a conclusive demonstration it will be necessary to dissolve the nutrient substances in pure $H^2{}_2O$, then to evaporate to dryness and add a fresh quantity of pure $H^2{}_2O$, protecting the solution at all times from contamination by water adsorbed on the tube and by the moisture of the air.

It next seemed desirable to try higher organisms, and because of their size and docility, flatworms (*Planaria maculata*) were selected. These, when placed in water containing over 90 per cent. of $H^2{}_2O$, soon began to lose their activity and within an hour or two they had released their hold upon the containing vessel and appeared to be dead. After remaining in the heavy water for four hours they were washed and placed in ordinary water. After a lapse of several hours some of them came slowly to life and ultimately a little more than half had resumed their normal activities, but the others were dead. Since this experiment was tried, work with the same organism has been reported by Taylor, Swingle, Eyring and Frost,[4] who state that flatworms were destroyed within three hours in 92 per cent. heavy water. The same authors also studied tadpoles, small fish and a certain protozoan, all of which were reported killed by 92 per cent. heavy water in periods ranging from one to forty-eight hours. They found, however, no lethal action of water containing 30 per cent. of $H^2{}_2O$.

Finally, I wished to test the effect of heavy water upon a warm-blooded animal. For this purpose I obtained three young white mice of respectable ancestry, weighing approximately ten grams apiece, and kept them in the laboratory for several days while their normal habits were being observed. Then, after they had all been deprived of water over night, two of the mice were given ordinary water while the third was given heavy water, administered by means of a medicine dropper, with a screw clamp upon the bulb which permitted the water to be forced out slowly and steadily. In this way the mouse drank all the water administered without losing a drop. Nevertheless, the experiment was a very costly one and I regret that since it was undertaken solely to ascertain whether the heavy water would be lethal, no preparation was made for a careful clinical study of the effects produced.

The answer to the main question was decisive. During the course of three hours the mouse received,

[3] *Jour. Am. Chem. Soc.*, 56: 245, 1934.

[4] *Jour. Chem. Phys.*, 1: 751, 1933.

in three doses, a total of 0.54 g of 87 per cent. and 0.26 g of 71 per cent. heavy water, containing altogether 0.66 g of pure $H^2{}_2O$. This would be equivalent, weight for weight, to a consumption of 4 or 5 liters of heavy water by an adult human being. The mouse survived and on the following day and thereafter seemed perfectly normal. Nevertheless, during the experiment he showed marked signs of intoxication. While the control mice spent their time eating and sleeping, he did neither, but became very active, running and leaping about and spending much of the time, for some mysterious reason, in licking the glass walls of his cage. The more he drank of the heavy water the thirstier he became, and would probably have drunk much more if our supply of heavy water had not given out. The symptoms of distress that he showed seemed more pronounced after each dose but not cumulative with succeeding doses, which leads me to suspect that the heavy water was being rapidly eliminated by the mouse. This could have been ascertained if suitable preparation had been made.

When we consider all these experiments we may conclude that heavy water is never toxic to any high degree and that it is tolerated in high concentrations by lower organisms. In such cases the rate of the vital processes seems to be roughly proportional to the fraction of the total hydrogen which is H^1. When all the H^1 is replaced by H^2, growth is certainly extremely slow and is probably entirely inhibited. When we seek an explanation of these phenomena there is no question but that it is to be found in the greatly reduced rate of all physico-chemical processes when H^2 is substituted for H^1. This is seen in the lower mobility of the heavy hydrogen ion,[5] in its much lower rate of deposition at a cathode, in the diminished rate of mutarotation of sugars[6] containing heavy hydrogen, and in the fermentation experiments to which reference has been made. Professor Rollefson in this laboratory is studying a photo-chemical reaction in which $H^1{}_2$ reacts thirteen times as fast as $H^2{}_2$. Now it seems likely that in the complicated chain of processes which are necessary to growth, there are some whose rate is so enormously decreased by the substitution of H^2 for H^1 that they are practically inhibited. The inhibition of a few essential processes would inhibit all the processes which must run concurrently, or in sequence. Thus in a system containing no ordinary hydrogen vital growth would be suspended, while in one containing both H^1 and H^2 the process of growth would be approximately proportional to the fraction of the total hydrogen which is H^1.

One of the first experiments that should be tried is to grow some organism for a considerable period of time in a mixture of the two kinds of water, and then by analysis of the dried tissues to find whether the two isotopes are used in the proportion in which they exist in the water, or whether there are mechanisms which permit the preferential employment of H^1, or even in some cases of H^2. It is not inconceivable that heavy hydrogen, which exists in small amounts in all natural water, may actually be essential to some plants or animals. A supply of water almost completely freed from the heavy isotope is now being prepared for the purpose of conducting such studies.

SCIENTIFIC EVENTS

THE EMERGENCY COMMITTEE IN AID OF DISPLACED GERMAN SCHOLARS

THE Emergency Committee in Aid of Displaced German Scholars has submitted its annual report. It is pointed out that the procedure followed by the committee has been simple. Due to the response of so many universities, colleges and institutes, and due also to the limited funds at its disposal, it was found necessary to make grants in preferential order to a selected list of institutions extending from the Atlantic to the Pacific oceans. At first, grants were made for a single scholar in each institution. Later, in isolated cases, a second grant was made. Funds have been made available directly to the administrative heads of institutions.

The Emergency Committee records with satisfaction the monetary assistance received from foundations, especially the New York Foundation and the Nathan Hofheimer Foundation; from the American Jewish Joint Distribution Committee and from private sources. In its decisions the Emergency Committee has had the support of the Rockefeller Foundation, which, in accordance with its general policy, has reserved freedom of action in regard to each application from the universities. Actually the Rockefeller Foundation has contributed equally with the Emergency Committee in almost all the grants made.

As of January 1, 1934, grants have been made for placing thirty-six scholars. Their names, disciplines, previous institutions and present posts are given below.

M. Palyi, economics, Handelshochschule, Berlin, University of Chicago.

O. Szasz, mathematics, Frankfurt, Massachusetts Institute of Technology.

[5] Lewis and Doody, *Jour. Am. Chem. Soc.*, 55: 3504, 1933.

[6] Pacsu, *Jour. Am. Chem. Soc.*, 55: 5056, 1933.