these effects are closely related with the theory of the solid state, which is yet in its infancy. The charging was believed to be a result of the exchange of *atomic* or *molecular ions* to fill up holes, or to remove excess ions, resulting from holes in the lattices from its surface. Surface films of gases on metals are in some cases in the ionic state, which complicates the picture.

Charging by friction of such complex organic substances as cats' fur, ebonite, sealing wax and glass has its obvious explanation in the possible rupture of long chain polar molecules such as those of fatty acids, etc., which through linkage of polar groups at one end with the contacting surface result in the rupture of the molecules and electrical separations. Again the rupture of strained piezo-electric crystals, or rupture by mechanical means, during pressure induced polarization of other substances could lead to electrification.[1] This whole set of phenomena requires much more work, with care to eliminate the actions of other well-known mechanisms, before it is understood.

(5) The action of the rapid diffusion of electronic carriers causing local separations in space in gases, which can be increased by mechanical means, is too well known to require discussion. There are many examples of such phenomena which do not require discussion here since they do not often confuse results of other static separation studies.

However, it should be considered that where electrical fields by polarization cause segregations of charges in droplets or solids in which mechanical rupture along an axis normal to the field can separate the polarized charge segregations, can not be ignored in all these investigations. Thus it could be possible that Chapman's[7] heavy charges on drops produced by atomization of various polarizable liquids may have been caused by the presence of unsuspected fields in the neighborhood of his atomizer. Such an effect of charge segregation with mechanical effects of falling drops in the presence of ions in the air has been invoked by C. T. R. Wilson[12] to explain thunderstorm electrification. The mechanism proposed certainly gives charged droplets. Whether it accounts for most of the electrification in thunder clouds is yet another question. A paper by J. Frenkel[13] which indicates a third mechanism in the electrification of clouds by mechanical forces has just been received by the writer. In this preferential condensation on negatively charged water nuclei of minute size causes charge segregation by gravitational forces. Its highly suggestive character merits study even if it does not apply to the turbulent regime of thunderstorm generation.

In any case, enough has been said to indicate the need for caution and discrimination in the study of static phenomena as influenced by these causes. It is clear that static electrification is caused by at least five different basic mechanisms, or perhaps six, if we include breaking of pressure or field polarized groups. The realization of this and the considerations of the influence of any of these mechanisms on observed phenomena it is hoped will alert investigators to the possibilities involved and assist in clarifying future and past studies.

13 J. Frenkel, *Jour. of Phys., USSR*, 8: 285, 1944.

THE BIOCHEMISTRY OF MUSCLE TRAINING[1]

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OUR researches on the biochemistry of muscle training began with our studies of the metabolism and role of creatine in muscle. This work[2] showed that during training the creatine in muscle increased. This observation signified to us the possibility that creatine plays a definite functional role in muscle. An investigation[3] of the creatine content of divers muscle from many fish demonstrated that muscles which were permanently, that is naturally trained, contain more creatine than muscles that work but little; for example, the muscles of the lateral fins of shark, ruff, etc., contain more creatine than the dorsal (spinal) muscles. These findings permitted the conclusion that during artificial and natural training muscle becomes rich in creatine. Further experiments[4,5,6,7,8,9,10,11] showed that muscles in which the work capacity has been increased by training possessed also higher levels of phosphocreatine, carnosine,

1 Presented at Stanford University, Biology Seminar, May 31, 1945.

2 A. V. Palladin and D. Z. Ferdman, *Z. physiol. Chem.*, 174: 284, 1928.

3 A. V. Palladin and I. D. Ochrimenko, *Ukranian Biochem. Jour.*, 12: 1938.

4 B. M. Koldaev and R. Gelman, *Ukrainian Biochem. Jour.*, 9: 35, 1936.

5 B. M. Koldaev, *Ukrainian Biochem. Jour.*, 10: 4, 1937.

6 M. F. Mereginski, *Ukrainian Biochem. Jour.*, 9: 25, 1936.

7 A. V. Palladin, *Am. Jour. Physiol.*, 90: 1929.

8 A. V. Palladin, *Jour. Physiol. U.S.S.R.*, 19: 287, 1935.

9 A. V. Palladin, *Advances in Biology* (Russian), 7: 3, 1937.

10 A. V. Palladin, *Ukrainian Biochem. Jour.*, 17: 7, 1941.

11 D. Z. Ferdman and O. Y. Feinshmidt, *Z. physiol. Chem.*, 183: 261, 1929.

phosphatides, free cholesterol, sodium, calcium and magnesium. On the other hand, it was found[12] that in trained muscle, fatiguing work does not raise the lactic acid content to the extent observed in untrained muscle. This led us to conclude that as a result of training the conditions for oxidation of lactic acid and its resynthesis to glycogen are altered. Following upon these findings, a systematic investigation of the effects of muscle training on the oxidation and synthetic processes within muscle was undertaken.

In all our experiments designed to study the effects of training on muscle metabolism, training was produced in the following manner: The skin over one extremity was shaved and to it an electrode attached to an induction apparatus was applied. The flow of current was interrupted by a metronome. This resulted in rhythmic contraction of the muscles, which were stimulated ten to fifteen minutes twice per day, and continued over a period of fifteen days. As a result of this training the work capacity of the muscles was increased, and simultaneously an increase in the glycogen and creatine content presented a biochemical index of training.

The effects of training and of fatiguing work on oxidation processes of the muscles were studied by estimation of the oxidized and reduced forms of glutathione,[13] of catalase,[14] of the ability to reduce methylene blue,[15] of the oxidation-reduction potential,[16] and of the respiratory activity.[17,18] We found that the concentration of catalase, the reduction capacity for methylene blue (Thunberg method), and the concentration of ascorbic acid[4] were increased in trained muscles. By application of the Warburg technique in the respiration studies, it was found by Sorenyi that training considerably increased the respiration of muscles. The cyanide-resistant portion of respiration increased on the average to a level fifteen times greater than the cyanide-sensitive portion.[19] From these results we concluded that the higher work capacity of the muscle required a higher proportion of the respiratory process not inhibited by cyanide. In fact, cardiac muscle, which has the highest work capacity of all, has a respiratory activity which is least inhibited by cyanide. Under training, the flavine content of the muscle increases[18]; correspondingly the cardiac muscle is conspicuously high in flavine as shown by Sorenyi and Tchepinova. Experiments on various muscles of many animals have shown that the greater the work capacity of muscle, the lower is the proportion of its total respiration which is inhibited by cyanide and the greater is its flavine content.

Training not only increases the respiratory processes of muscle, but also increases aerobic and anaerobic glycolysis.[18] In this connection it is assumed that in trained muscle following the onset of fatigue, the lack of accumulation of lactic acid is not the result of increased carbohydrate resynthesis, but is due rather to the fact that, following training, oxidation and glycolysis are not increased in the same proportion. Attempts to identify the dehydrogenating agents which determine the changes in reduction capacity of muscle showed an increase in succinodehydrogenase and α-glycerophosphate dehydrogenase activity.[20]

Training also improves the conditions for synthetic processes, a fact demonstrated by Koldaev.[21] He found that in a fatigued, preliminarily trained muscle, the capacity of the muscle substance to synthesize phosphate esters is lowered to a much smaller degree than in a muscle similarly fatigued but untrained. Hence we have concluded that training not only raises the work capacity of muscle, but improves the conditions therein which are more favorable for oxidation reduction and synthetic processes.[10] On the other hand, fatiguing work reduces the latter set of conditions.

Alterations in the metabolic processes following fatiguing work are not simply localized in muscle. Under these conditions processes independent of muscle metabolism also undergo change; for example, changes occur in the ability of the organ to oxidize phenol and in the synthesis of its detoxication product. This we established by studying the effect of phenol injected into a rabbit both under resting conditions and under conditions of fatigue.[22]

On the basis of our experiments the following conclusions may be reached: If muscle subjected to preliminary training is worked to the point of fatigue, oxidation processes are disrupted to only a slight degree in comparison with the normal; the decrease induced by fatiguing work in untrained muscle is much greater. Hence a trained muscle does not reach the point of fatigue as rapidly as an untrained muscle and is capable of greater work. The fact that training results in a more favorable milieu for synthetic processes puts a trained muscle on a more favorable basis than an untrained one, in so far as capacity for intensive, prolonged work is concerned.

12 A. V. Palladin, L. I. Palladina and E. Perzova, *Biochem. Z.*, 236: 268, 1931.

13 A. V. Palladin, *Ukrainian Biochem. Jour.*, 7: 1, 1933.

14 A. V. Palladin and e. Rashba, *Jour. Physiol. U.S.S.R.*, 21: 507, 1936.

15 A. V. Palladin and A. Kashpur, *Jour. Physiol. U.S.S.R.*, 7: 4, 1935.

16 R. Tchagovetz, *Ukrainian Biochem. Jour.*, 9: 1936.

17 E. T. Sorenyi, *Ukrainian Biochem. Jour.*, 9: 2, 1936.

18 E. T. Sorenyi and O. P. Tchepinova, *Ukrainian Biochem. Jour.*, 9: 3, 4, 1936; 10: 4, 1937.

19 *Idem, Ukrainian Biochem. Jour.*, 11: 3, 1938.

20 O. P. Tchepinova, *Ukrainian Biochem. Jour.*, 14: 2, 1939; 32: 1940.

21 B. M. Koldaev, *Ukrainian Biochem. Jour.*, 7: 4, 1935.

22 A. V. Palladin and L. I. Palladina, *Ukrainian Biochem. Jour.*, 7: 1, 1934.

It was of interest to determine whether the biochemical changes produced by training and fatigue were dependent only upon the degree of training and extent of work or whether other factors were of significance. Previous experiments had suggested the importance of nutritional factors. Experiments were therefore undertaken to elucidate the influence of diet on the metabolic changes produced by training. We started by studying the effects of a vitamin C-free diet. Experiments carried out at the Institute of Biochemistry showed[9] that fatiguing work raised the lactic acid content of the muscle of normal guinea pigs by an average of 28 per cent., and that of scorbutic guinea pigs on a vitamin C-free diet by 48 per cent. That is, work of similar intensity resulted in greater changes in the lactic acid metabolism in scorbutic guinea pigs than in normal. Concurrently, it was shown that muscle work in trained guinea pigs on a normal diet did not result in an accumulation of lactic acid, but in scorbutic guinea pigs which were trained, similar work always resulted in a considerable accumulation of lactic acid. In scorbutic animals, training does not result in an improvement of the synthetic processes of muscle. These observations supplemented the results of experiments in which the effects of a vitamin C-free diet on the reductive capacity of trained and fatigued muscle was studied.[6] Experiments showed that the lack of vitamin C resulted in a more rapid onset of fatigue and that training under such adverse nutritional conditions had less effect on the ultimate work capacity of such a muscle.

Similar results were obtained on pigeons fed on a thiamin-free diet. Preliminary training did not produce the favorable effects on oxidation reduction processes as resulted in the case of birds fed on a high thiamin diet.[10] Similarly, in pigeons on a thiamin-free diet muscle work resulted in a considerable accumulation of lactic acid, both in trained and untrained animals. Pigeons on the normal diet, but previously trained, when subjected to similar conditions of work did not show an accumulation of lactic acid in muscle. It is to be concluded, therefore, that deficiencies of ascorbic acid and thiamin affect the biochemical processes of muscle produced by training or by fatigue.

Diets were next investigated which were not vitamin free but which were acid or alkaline—normal in all respects except for the predominance of inorganic anions in some and in organic cations in others. On the basis of our experiments with phenol under fatiguing work and with various diets, we found[13] that work on an acid diet interrupted to a lesser degree the oxidation of phenol than synthesis of its detoxication product, but it interrupted these processes to a greater degree when on an alkaline diet. While the general applicability of these findings to all oxidation processes is not to be inferred, they none the less provide a foundation for the concept that the synthetic and oxidative-reductive processes in muscle, as altered by fatiguing work, may be further varied by the alkaline- or acid-forming nature of the diet. Similar results were obtained in studies of the metabolic processes of muscle tissue. The experiments of Guly show[23] that training does not have the same effect on the reduction capacity of rabbit muscle on both alkaline and acid diets. Training to a greater degree improved the oxidation-synthetic processes of rabbit muscle on an acid-forming diet than on an alkaline-forming diet. In the same way, fatiguing work inhibits glycolysis to a great extent, alters the permeability of cell membranes and upsets the water balance of rabbits on an alkaline diet more than in the case of those maintained on a diet of acid-forming substances.[24] All our experiments[10] thus show that the dietary ingredients in respect to quantity of vitamins and preponderance of inorganic anions or cations have a great influence on muscle metabolism, *viz.*, on changes in carbohydrate metabolism, in oxidative and synthetic processes brought about by training and fatigue in muscle and on the work capacity of muscle. These observations bring forth for further elucidation an important theoretical and practical problem—whether by varying the diet it is possible to make the muscle more receptive for training, for more rapidly increasing its work capacity or for delaying the onset of fatigue.

OBITUARY

GEORGE DAVID BIRKHOFF

MIDDAY on Sunday, November 12, 1944, George Birkhoff and his wife were preparing to go over to their son Garrett's. He was ready a quarter to half hour before time to leave and took the occasion to lie down. It was not that he felt badly, but incident to a minor illness in the preceding spring he had been advised to take it a bit easier now he was sixty and in particular to lie down a little while in the middle of the day whenever possible—as so many good doctors advise so many older patients—and being the conscientious person he was, wishing to do the right thing by his doctor, his family, his university and his science, he took that particular opportunity, as he had taken others, to follow the advice. A little later when his wife went to get him to go, he was dead.

23 N. F. Guly, *Ukrainian Biochem. Jour.*, 9: 2, 1936.
24 *Ibid.*, 11: 3, 1938.