Apart from philosophical questions, however, it seems to me the realization that it is possible to exemplify on a large scale such things as our capriciously disintegrating radio-active material, which may serve as the nucleus of a superstitious religion, or may equally well serve as a most excellent gambling device, can not fail to get under the skin of the man in the street. This objectifies in the most striking way the limitations of the human intellect, and I believe that the greatest changes in our mental outlook will come as a consequence of the realization of just these human limitations—we had thought the human reason capable of conquering all things, we now find it subject to very definite limitations. We can definitely conjure up physical situations in which the human reason is powerless to satisfy itself, but must passively be content to accept phenomena as they occur, which constitutes in fact a reversion to the mental attitude of primitive man, which is purely receptive. What is more, the strictly scientific attitude recognizes no escape from the situation, but it must be accepted as inherent in the nature of things, and no way out attempted by such inventions, material or conceptual, as primitive man makes.

The realization of human mental limitations will, I believe, have the greatest effect, and the process of adjustment will be slowest, in such non-scientific activities as philosophy, religion, as already suggested, and very probably education, for some just apprehension of the possibilities of the human intellect should be imparted in any satisfactory educational program. The adjustment in scientific activity I believe will be made more rapidly, and in fact it is possible to see even now in what the adjustment will consist.

A formulation of the purpose of scientific activity which appeals to me as rather exhaustive is the understanding, prediction and control of events. It might be thought that the discovery that there are aspects of nature which are not understandable, predictable or controllable would work havoc with this scientific program. But the way out is already obvious. If it is true that there are certain aspects of nature which are neither controllable or predictable, then the obvious course is to avoid these aspects of nature. This may sound like a flippant suggestion, but the matter is really to a large extent in our own power. We have seen that although single small-scale events are unpredictable, the statistical average of large numbers of them is highly regular and predictable. The obvious course of action, then, whenever we want to be sure of the result, is to so arrange the apparatus or machine as to respond only to statistical averages, and not to function like a Geiger counter in response to single small-scale happenings. If it should prove that the large-scale behavior of biological organisms is unpredictable, then we shall take pains never to depend on the behavior of a single such organism whenever we have to be sure of our results, but this is hardly more than we do already.

The situation with regard to *understanding* small-scale events will probably take a little more adjustment, because it involves giving up an ideal which we had set ourselves. But even here the adjustment can hardly take more than one generation, and in science generations are short. Analysis will show, I believe, that what we call understanding consists in picking out from a situation elements with which we are already familiar. The difficulty in the present situation is that we are not familiar with systems in which individual events occur with no close connection with past events, so that naturally we are confused and seek for a hidden connection. But as our familiarity increases and the strangeness gradually wears off, we shall come to feel that it is natural and proper that small-scale events show only statistical regularities, and we shall come to be satisfied with our understanding of a situation when we have analyzed it sufficiently to show, if we are dealing with large numbers, the statistical regularities to be expected, or, if we are dealing with small numbers, the corresponding capricious variations. In fact, a number of the younger generation have already achieved this degree of emancipation, and the rest of us, by deliberate effort, may hope to attain it.

PALEONTOLOGY VERSUS DEVRIESIANISM AND GENETICS IN THE FACTORS OF THE EVOLUTION PROBLEM[1]

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THIS is a study in what may be called *progressive or adaptive heredity;* it is the second of a series of communications I plan to give to the National Academy on the factors of evolution; as implied in the title, this study is directly opposed to all accidental, discontinuous or mutational hypotheses of the causes of the bio-mechanical evolution of the germ plasm.

Last year I summarized results obtained through

[1] Address before the National Academy of Sciences, Washington, April 28, 1931.

twenty years of research on the evolution of the Titanotheres, a family which evolved during an estimated period of twelve million years, from an animal about a foot in height to the gigantic "thunder-beast" or Brontothere stage. This year I add results obtained from twenty-one years of research on the evolution of the Proboscideans, namely, the mastodonts and elephants, an order which may be traced over twenty million years, from present estimates of Tertiary time, beginning with animals about two feet in height and rising to animals over thirteen feet in height.

Dynamically the Proboscideans are very strong where the Titanotheres are weak, namely, in the evolution of the grinding teeth and of the pair of superior incisive tusks around which the entire life history of these animals centers.

As previously pointed out we can not comprehend the hereditary germ plasm without intensive research on the bio-mechanical evolution of form concurrent with research and experiment in biophysics and biochemistry. Bio-mechanical adaptation has this advantage, that it can be weighed and measured in fossil bones and teeth over periods of millions of years. We can also clearly distinguish between organs and organisms which are *static* and those which are *dynamic* or in the state of movement. One part of an organ may be in rapid evolution while a contiguous part may be standing absolutely still, as brilliantly illustrated in the discovery of the shovel-tusker mastodonts in Central Asia and in Nebraska. The detection of these relatively static or dynamic conditions, of arrest or of motion, of acceleration or retardation, is denied to all biophysical and biochemical experimentalists working on living organisms. For example, the fruit fly, *Drosophila,* is probably a completely static organism. The same we know to be true of members of the mouse family, which stopped evolving at least a million years ago; it is probably true of the guinea pig family.

Physical or chemical disturbance of the inconceivably delicate and minute hereditary mechanism produces anomalies and sports which may be hereditary but can not set in evolutionary motion either an organ or an organism.

So far as we can see in paleontology, continued hard work along the lines of maximum resistance is essential to setting an organ in evolutionary motion or acceleration. Parts of organs which do the hardest work evolve most rapidly, because the universal distinction of the bio-mechanism in contrast to the inorganic mechanism is that it develops both in the individual and in the race in the line of maximum resistance, for example, the upper and lower grinders of the elephant. Under this condition it is most dynamic; it becomes static when the resistance diminishes; it retrogresses when the resistance disappears.

This contrast between static and dynamic organisms and organs extends even into the most minute subdivisions of organs as in the microscope composition of the enamel of the gigantic tusks and grinding teeth of the Proboscideans, all the rest of the animal (excepting the proboscis) remaining *static.* The most refined analysis of the tusk enamel by polarized light reveals this universal principle of adaptive reaction to lines of maximum resistance.

The modes of bio-mechanical evolution were first perceived by the Greek anatomists who discovered seven principles. Shortly before the time of Darwin two more principles were added through researches in embryology; altogether nine bio-mechanical principles were known to Charles Darwin. A summary of the fourteen factors at present known is as follows:

Bio-mechanical Principles

Known to Lamarck, Darwin and Spencer

A. *Discovered through Human and Comparative Anatomy, Palaeomorphs*

1. Bio-mechanical progression, hypertrophy
2. Bio-mechanical retrogression, atrophy
3. Bio-mechanical compensation, metatrophy
4. Bio-mechanical economy, eutrophy
5. Bio-mechanical change of proportion, allometry, metatrophy
6. Bio-mechanical co-adaptation, coordination, correlation, through interaction
7. Bio-mechanical auto-adaptation, through principles 1–6.

B. *Discovered through Embryology*

8. Bio-mechanical acceleration of organs into earlier growth stages
9. Bio-mechanical retardation of organs into later growth stages

Unknown to Lamarck, Darwin and Spencer

C. *Discovered through Paleontology, Neomorphs*

10. Bio-mechanical germinal rectigradation, in the origin of new structures and organs
11. Bio-mechanical germinal pre-determination, in the origin of new structures and organs
12. Bio-mechanical phylogenetic acceleration, in the evolution of new structures and organs
13. Bio-mechanical phylogenetic retardation, in the evolution of new structures and organs
14. Bio-mechanical germinal potentiality, in the origin of new structures and organs

The remaining five bio-mechanical principles have been discovered through paleontology since Darwin's time. Neither Darwin nor Huxley had the least knowledge of the bio-mechanical factors of evolution as they have been revealed in paleontology.

Conclusions as to the Origin of Species

These fourteen bio-mechanical principles not only lend no support to the Darwin-DeVries hypothesis of mutation but are directly contrary to current assumptions and hypotheses by geneticists and experimentalists that bio-mechanical adaptation can be induced by sudden changes in the genes. Whatever may be true of sudden bio-chemical adaptations a presumption from this overwhelming bio-mechanical evidence is that *both bio-chemical and bio-physical evolution is also along continuously adaptive and creative lines.*

William Bateson, founder of the genetic school, finally declared that genetics could not explain the origin of a single species. Modern paleontological research, on the other hand, reveals with absolute clearness and fullness not only how species originate bio-mechanically, but the inner interpretation of divergence in every grade of animal organization from the minute ascending mutations up to the higher points in the development of genera, families and orders.

The modes of these transmutations of form which from the same original materials produce the horse, the rhinoceros, the titanothere and the elephant are now absolutely clear, but the internal causes of these marvelous bio-mechanical transmutations of the germ plasm are far more mysterious and incomprehensible than they were in the time of Charles Darwin.

OBITUARY

ALBERT A. MICHELSON

AT one o'clock on Saturday afternoon, May 9, 1931, death came very quietly in his home in Pasadena to the most illustrious of the American physicists of our generation, at the age of seventy-eight years and five months. Six weeks earlier he had taken to his bed, after having made with his associates, Messrs. Pease and Pearson, enough observations to assure himself that his last experiment on the speed of light as measured in an evacuated pipe a mile long and three feet in diameter buried in the earth on the Irvine ranch near Santa Ana, California, was going to yield results as satisfactory as he had anticipated. This experiment had been planned for the sake of obtaining a check by a method entirely free from atmospheric effects of all kinds upon the accuracy of his next preceding determination made over a twenty-one mile stretch between California mountain peaks. He did not expect by these new experiments to exceed the accuracy previously obtained, but rather to add something to the *reliability* of the previous determination.

More than a month before his death, Mr. Michelson had known that he would never get up again, for a creeping paralysis was coming over him of which he himself was altogether conscious. His mind was quite clear until two days before the end, when a lesion occurred which brought on unconsciousness within an hour, an unconsciousness from which he never again awoke.

As one of the men who has had the most enduring and most intimate association with Mr. Michelson and his work, I esteem it a privilege to now make a few additions to my former appreciation of him and his achievement.

Under the caption, "Michelson's Economic Value," now published as Chapter VII in a volume by Scribner's entitled "Science and the New Civilization," I have attempted to appraise in broad lines the significance for our times of measurements of the highest skill and accuracy of the sort which Michelson has done and for which his name stands the world over, and I should like to refer to that appraisal and merely supplement it here by adding some details both of a scientific and of a personal sort.

Practically all Mr. Michelson's work in physics centered about determinations for increasing the precision of measurement. He has been called an extremely skilful and intelligent instrument designer, but while he was that he was much more than that, for his attention was always on the problem to be solved, not primarily on the instrument for solving it, and he was always seeking for problems incapable of solution save by improvements in the accuracy of measurement. Ten different times in the fifty-one years of his activity, extending from 1880, when at the age of twenty-eight he became the best known American physicist by virtue of his new speed-of-light measurement, up to 1931, when he died, still trying to prove the certainty of his determination and precision of that most fundamental constant, he made major outstanding advances, which I list as follows:

(1) Measurements of the speed of light, 1880–1931.

(2) Development of the Michelson interferometer, 1882, *et seq.*

(3) Ether-drift experiments, 1887–1928.

(4) The first analysis of the fine structure of spectral lines, 1894–1900.

(5) Development of the Michelson-Stratton harmonic analyzer, 1897.

(6) Development of the principle of the Echelon spectrograph, 1898.

(7) Perfection and increase in resolution of the line grating, 1902–1917.

(8) First accurate measurement of the rigidity of the earth, 1916.

(9) Development of the U. S. naval range finder, 1918.

(10) Direct interferometer measurement of the diameter of stars, 1921.