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CONTENTS

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PHYSICAL INDETERMINISM AND VITAL ACTION

Science and philosophy, but especially science, have found great difficulty in reconciling the apparent indeterminism of many vital manifestations, particularly voluntary action, with the strict determinism of physical science. The traditional problem of freedom, with all its vast implications, is the classical expression of this difficulty. One characteristic aspect of this problem seems peculiarly significant, especially when considered in relation to the present state of discussion on the foundations of physical science. This is the qualified nature of freedom as expressed in external action; there is always a large element of restriction or external determination. No one has claimed that vital indetermination is complete, although Bergson speaks of the living organism as exhibiting a maximum of indetermination.[1] To take a simple illustration: the evidence for levitation is doubtful; even its most accomplished exponent would hesitate to launch himself from the edge of a cliff, however firmly he might be convinced of the freedom and efficacy of his own will. And he would continue to rely daily on the mechanical dependability and physically determined regularity of his own bodily organism. I allude to this inconsistency with no merely satirical intention, but simply in order to define as clearly as possible a crucial aspect of the problem. It is undeniable that the organism is subject to rigid physical determination in a large part of its activities; it seems equally undeniable that it is free in others; the difficulty is to decide where determinism ends and indeterminism begins. Intuition gives an overwhelming impression of freedom in voluntary action. Yet analysis, in tracing down the sources of such action, seems always to reinstate determinism; it shows the will to be motivated; motives have their natural origins; actions not consciously motivated either are habitual and referable to past motivation, or are instinctive and determined by heredity. In either case we seem to have a mechanistic determination. Physiology finds in the organism a nexus of physico-chemical determination differing from that in non-living nature only in its complexity; in fact the organism can be shown to depend for its survival on the constancy and stability of its proc-

[1] "Creative Evolution," English translation, Chapter 2; cf. e.g., p. 126.

esses, *i.e.*, on their strict physical determination. Although voluntary action effects mechanical change and seems free, the "energy balance-sheet" of a man shows no conflict with the law of conservation, indicating that there is no creation of energy within the organism. It might be held that the will can direct energy even if unable to create it; but since by Newton's first law force is required to change the direction of a motion as well as to initiate it, we must conclude that a system unable to create energy would be equally unable to direct it arbitrarily. Classical physics thus seems definitely incompatible with the idea of freedom; accordingly scientific men—and somewhat curiously biologists in larger proportion than physicists—have commonly regarded freedom as a delusion. In so doing they may have created more difficulties than they have resolved; certainly the inner conviction of freedom has not been abolished in the minds of most thinking men. But if we accept freedom as a fact, we are bound to consider whether at least a certain measure of physical indeterminism may not also be a fact. Such a residue of indeterminism, if it could be shown to exist, would conceivably explain the indeterminism or inner freedom seen in voluntary action; the evidence for its existence thus becomes a matter of great biological and philosophical interest.

When we inquire into the special physical peculiarities of living as distinguished from non-living systems we are struck by the fact that in the former the determining and controlling events are invariably on an extremely small scale.[1a] The microscope is the chief instrument of biological investigation. In this respect biological phenomena are at the opposite pole from astronomical phenomena. In the latter the possibility of exact prediction attains its maximum; in vital phenomena, on the other hand, prediction is possible only within certain limits; variability seems inherent; indeed in the highest manifestations of life prediction is not possible at all. It is especially such manifestations that we call "free." Such considerations suggest the question: do events cease to be predictable and become free when their spatio-temporal scale becomes sufficiently small? At least we must regard it not as a coincidence but as highly significant that the only region where physical science gives evidence of experimental indetermination, *i.e.*, of externally uncontrolled or individual action, is in the field of ultramicroscopic phenomena. At present quantum phenomena are the subject of debate as to the universality of the rule of unequivocal physical determination.[2] Even on the relatively large scale of Brownian movement any single configuration of a group of particles is as possible as any other, although the different configurations differ in probability. In other words, a given special configuration or grouping is determined by conditions of probability rather than by definitely assignable physical causation. It is well known that Maxwell and Boltzmann have ascribed a purely statistical significance to the second law of thermodynamics; and Svedberg's observations on Brownian movement, confirming the theoretical deductions of Einstein and Smoluchowski, have shown experimentally that within a sufficiently small space and time the second law does not necessarily hold.[3] It follows that the regularity of macroscopic phenomena, in which determinism is for all practical purposes complete and trustworthy, is in reality a statistical regularity.[4] We are not justified in ascribing a similar regularity to single events in the ultramicroscopic field. To a given macroscopic arrangement or condition any one of an infinite number of detailed microscopic configurations may correspond. Our microscopic picture of the world is not complete, but it already seems clear that many of the physical laws with which we are familiar in the realm of macroscopic phenomena cease to apply on the scale where events are determined by quantum relations or by the "chance" fluctuations of molecular movement. Ultramicroscopic phenomena thus give evidence of an ultimate indetermination (defining determination in the usual physical sense of quantitative specification of conditions), *i.e.*, of control by individual action rather than by statistical or mass action.[5] The laws relating to such action—assuming such laws to exist —are as yet imperfectly known, but they are certainly entirely different from physical laws as hitherto understood.

Direct evidence of physical indetermination or freedom is thus to be sought primarily in the behavior of individual particles in the ultramicroscopic field; derivatively, however, we may expect to find it in processes of a larger scale, *provided* these processes are in some way controlled by the ultramicroscopic events. Now vital processes appear to be processes

[1a] *I.e.*, small relatively to the scale of human sense-perception and adjustment.

[2] *Cf.* P. Jordan: "Philosophical Foundations of Quantum Theory," *Nature*, 1927, vol. 119, p. 566.

[3] *Cf.* T. Svedberg: "Colloid Chemistry," New York, 1924, pp. 118 *seq.* "It is obvious that in microscopic systems fluctuations of entropy occur" (p. 120).

[4] See the recent interesting book of Professor C. E. Guye, "Physico-chemical Evolution," New York, 1926.

[5] *Cf.* F. G. Donnan: "Concerning the Application of Thermodynamics to the Phenomena of Life," *Journ. Gen. Physiology*, 1926, Vol. 8, p. 685: also *Scientia*, 1918, vol. 24 (2), p. 281.

of just this kind. Living systems are peculiar among the systems of nature in that their characteristic behavior is determined primarily by internal activities of a microscopic or ultramicroscopic kind; as a rule it is only secondarily, as a result of the characteristic "irritability" of living matter, that events in the external world affect the vital processes. This peculiarity is an incident of the special type of physico-chemical constitution characteristic of living protoplasm. Without attempting to characterize the protoplasmic system completely, I would here call particular attention to certain features which are especially relevant to the present discussion. Both the structure and the activity of the system are expressions of its specific chemical activity or metabolism, *i.e.,* of the continual chemical interaction of its component molecules; the synthetic production of new and complex compounds is an especially characteristic feature. This complexity (*e.g.,* of proteins) is itself important, because it implies large molecular weights; and the element of indetermination, in the above-defined sense, is greater (for a given mass of material) when the molecules are large than when they are small, since they are then fewer in number and there is less chance (in the statistical sense) of an individual action being rendered ineffective as a consequence of the law of large numbers. Individual molecular action may thus become an important factor in the determination of processes in the system.[6] This, put briefly, appears to be the essential difference between a living organism, considered as a purely physico-chemical system, and a machine of the usual macroscopic construction.

With regard to the general nature of the conditions determining the special activities of the two types of system, the essential contrast is that between an inner or ultramicroscopic determination of action and an external or mechanistic determination. The ultimate living units (biophores, genes or other physiological units) are characteristically minute, of dimensions corresponding to those in which the range of Brownian movement may be of decisive importance in the momentary behavior of the system. It is thus conceivable that under certain circumstances a single localized extreme oscillation, determined by conditions that can only be described as individual, may form the occasion of a change, *i.e.,* may initiate a process, which will determine the activity of the whole system.

How is it possible that an event on such a minute scale can affect the total activity of a system of microscopic or even of macroscopic dimensions, such as a cell or a larger organism? Are not the chances that its effect will be internally compensated by similar oppositely directed effects the same as in any non-living system? To understand the conditions we must recall what is implied in the general property of *irritability,* universally characteristic of living matter. The response to any stimulus implies the transmission of an activating influence from the localized site of stimulation throughout the larger functional area concerned in the response. In other words, the protoplasmic system is characterized by a highly developed power of transmission. Its irritability is inseparable from such transmissivity, and it is this latter property that renders possible the kind of centralized control under consideration. In general, protoplasmic activities are controlled by processes of a spreading kind, which as such necessarily involve amplification. It thus becomes possible for an activity initiated locally in the ultramicroscopic field of the cell or organism to spread to surrounding areas and in so doing to become indefinitely magnified in extent so as to involve the macroscopic field and determine the activities in the latter. Just as the pattern described by the fluctuations of a minute electric current in a telephone system may be reproduced by thermionic amplification in all of its original details but on a vastly larger scale, so the process corresponding to some local activity in the ultramicroscopic field of the living system (*e.g.,* in certain molecules of the nerve cells) may by a spreading action be reproduced—whether in a literal or a representative sense—over a much larger area and express itself in the macroscopic activity of the whole system.

To illustrate the case in a somewhat more concrete manner: a human action, appearing entirely spontaneous and voluntary (free) to both actor and observer, would, if analyzed physiologically, exhibit itself as a succession of mechanistically determined events in all of its macroscopically observable details. Its special *quale* would, if traced down into the finest possible detail, finally appear as dependent upon certain ultramicroscopic events in the nerve cells. What should especially be noted is that when these events were finally reached in the analysis no further definite physical determination could be assigned. The events might in fact not be physically determined —in the sense in which classical physics defines determination—but be examples of indeterminism, *i.e.,* of "free" or externally uncontrolled individual action. Regarding the conditions of such action science has little to say at present. The difference between mechanist and vitalist would then narrow down to the question of how far the *initiatory* process was physically determined or "free." No one would dispute that the macroscopic processes were unequivocally determined or mechanistic; but the inner determina-

[6] *Cf.* the calculation in Donnan's recent paper, *loc. cit.* (1926).

tion in the ultramicroscopic field might quite properly be called free. The question of what physical meaning could be assigned to the term freedom would then arise. Briefly, an internal or individual rather than an external determination would seem to be the essential character implied.

The distinction we are emphasizing is essentially that between the conditions determining macroscopic processes, which according to Maxwell and Boltzmann are determined statistically, and those determining single ultramicroscopic events where individual determination prevails. A smoothing-off or obliteration of inner detail is inevitable in effects controlled by mass action, which as observed represent the sum or integration of numerous fluctuating minutiæ. The relation between a smoothed curve and the distribution of the points showing the individual data is a relation of a similar kind. The inner processes which acting as an assemblage or collectively produce a certain mechanical or other effect might, individually considered, be free. Compare the analogous case of the curves representing the frequency distributions of human voluntary acts like suicide; predictions made on the basis of such curves are reliable if the number of individual cases is sufficient, and the behavior of such a population might seem mechanically determined.[6a] For an essentially similar reason physical determination in the macroscopic realm appears unequivocal and freedom entirely absent. If, however, we consider a system in which single individually determined or "free" ultramicroscopic events—whether Brownian movements, quantum phenomena or something still more ultimate—are in some way enabled to control effectively the macroscopic events in the system, the latter would also appear (to that degree) to be externally uncontrolled or free.

It seems highly probable that the conditions in living organisms are actually of this type. Evidently an inner control of the kind imagined would be possible only in a system with highly developed transmissive properties. The living organism is, however, just such a system. Experimentally it is easy to show that an event of microscopic extent and duration, *e.g.*, a properly localized electric shock or a pinprick, may determine the activity of the whole system. Consider also the relation between the retinal processes and the activities which they control. Such large physiological effects depend, as just indicated, upon the peculiar type of transmission characteristic of living matter—spreading of chemical influence associated with amplification. The degree of the spreading and of the resulting amplification (which may be intensive as well as extensive) is limited only by the distribution of the tracts or surfaces over which the spreading can take place and by the nature of the physiological mechanisms which are thus activated. In higher animals and man these transmitting tracts are represented mainly by the minute and extensive ramifications of the nervous system, which control muscular and other action. In the single nervous element or cell the transmissive process appears to consist essentially in a chemical and structural alteration of the interfacial films at the protoplasmic phase-boundaries. Transmission of chemical influence to a distance by means of the local electrical effects resulting from the alteration of interfacial films is well known in inorganic chemistry—the case of passive iron and similar systems—and shows many close analogies with protoplasmic transmission.[7] Incidentally it may be pointed out, as a special condition favoring indetermination (independence of mass action) in systems having this type of transmission, that these films may be monomolecular in thickness; the local ultramicroscopic surface-area where the activity is initiated thus contains fewer molecules than would be the case if the molecules were distributed in three dimensions, and the chance that a single large fluctuation may become effective is correspondingly increased.

It is important to note that the transmissive process itself (*e.g.*, nerve impulse), being on a relatively large scale, belongs in the class of phenomena dealt with by classical physical chemistry. Hence it is limited in its possible range of variation by thermodynamic conditions of the usual kind; correspondingly it is unequivocally regular or determined in its physical character. It is clear that the chain of processes intervening between the physically undetermined initiatory event and the large-scale organic action must themselves be rigidly determined in character and interconnection, otherwise any precise or regular control would not be possible. In fact, voluntary control is precise to a remarkable degree—as all acts of skill testify—limited only by the physical capabilities of the organism.

An example from the inorganic field, showing how large external effects may be without assignable external causes, may illustrate perhaps more clearly the general nature of the conditions. Every now and then an unexplained explosion occurs in stores of high explosives. We know from observation of Brownian movement, as well as from theoretical con-

[6a] *I.e.*, to an observer whose scale of perception did not permit discrimination of inner detail.

[7] *Cf.* my recent volume, "Protoplasmic Action and Nervous Action," University of Chicago Press, 1923, for an account of this type of transmission.

siderations of probability, that at infrequent intervals an internal molecular or particulate movement of unusual amplitude occurs. Such a movement may exceed the critical minimum below which no chemical reaction results; but if such a reaction should take place locally the whole mass would be ignited by transmission of the explosive type. Explosions due to purely spontaneous activity are thus to be expected in large masses of explosive at intervals; such intervals may be calculable, and the matter might well be tested experimentally, using known volumes of mechanically sensitive explosive kept at appropriate temperatures. A local mechanical shock will set off such a mass, and conceivably an internal particulate movement of large amplitude might have the same effect.[8] The spontaneous activation which occurs in passive iron wires kept in dilute nitric acid —with a frequency increasing with dilution, size of wire and temperature—is an example of a similar condition, also suitable for statistical investigation.

In the living organism the microscopically visible structure shows a definite correspondence with the requirements of the present view. In broad outline we seem to perceive the character of the nexus through which submicroscopic events are enabled to control microscopic and ultimately macroscopic events. It is clear from general considerations that a heterogeneous system such as protoplasm is favorable to a centralized type of control of the kind indicated.[9] Experimental studies lead to a similar conclusion. Modern genetics indicates that submicroscopic particles (genes) determine the special details of inheritance;[10] in an analogous manner minute local stimuli determine the activation of extensive physiological mechanisms, and minute areas of active growth determine the form adopted by the growing embryo. Just as submicroscopic events thus determine microscopic events, so behind or internal to the submicroscopic events we must assume a series of ultramicroscopic events reaching back by convergence into the field where the known types of physical determination are replaced by another type of determination, the special conditions of which we do not know. Apparently, however, this type contains possibilities of a kind entirely different from those with which we are familiar from our experience of large-scale phenomena. In this field events occur which appear to be free, *i.e.*, internally rather than externally determined, although we can as yet give no scientific account of the conditions of such determination.

We may now briefly consider the question: how are we to conceive the conditions of action in the remote ultramicroscopic field where physical determination, as hitherto understood, seems to fail? This field, beyond the range of the classical or deterministic physics, is now, thanks to the methods of the new physics, open (in part) to experimental investigation. One may therefore hesitate to call it the ultraphysical field—still less the metaphysical. Probably it can be characterized satisfactorily only on the basis of future research. It would seem, however, that there must be some final support or substratum of the physical to which only the term metaphysical can be applied. The question becomes: is action in this field free? and if so what is meant or implied by the term? Two possibilities suggest themselves. If by free we mean externally uncontrolled, it would appear that the ultimate local centers or units of action should be independent of one another: *i.e.*, a radical discontinuity should exist at the basis of physical reality. Something of the kind seems to be indicated by quantum phenomena. There is also the general philosophical position that the universe, considered in its totality, must be the expression of free action, since an all-inclusive whole can not be determined externally, *i.e.*, by conditions outside itself. How otherwise are we to account for its having the special and arbitrary character which it actually does have, instead of any other one of the infinity of possible alternative characters? Claude Bernard, indeed, while working actively in experimental physiology, referred the ultimate vital determination to the metaphysical world. In this world, he considered, freedom was possible, although in experimental biology he insisted on a rigid determinism.[11] What is significant is that in both of the possibilities just considered an ultimate determination other than physical is implied, but without infringing the usual types of physical determination.

It may be objected that (*e.g.*) intra-atomic phenomena are not undetermined, but are determined according to laws which are still physical laws, however different they may be from those prevailing in the macroscopic or mechanical sphere. The stability

[8] For a discussion of the chances of appreciable mechanical effects resulting from Brownian movement, *cf.* the recent book of Professor G. N. Lewis, "Anatomy of Science," Yale University Press, 1926, p. 145. Incidentally the case of levitation comes in for consideration.

[9] *Cf.* the discussion in Guye's "Physico-chemical Evolution," p. 136.

[10] Freundlich has considered the possibility that fluctuations in the Brownian movement of the genes may lie at the basis of mutations: *Naturwissenschaften*, 1919, Vol. 7, p. 832.

[11] *Cf.* the recent English translation of Bernard's book on "Experimental Medicine," Macmillan Co., New York, 1927.

of an atomic system in itself implies strict determinism. Our amended conclusion therefore would be that events are determined, in the sense of being subject to law, in the ultra-mechanical as well as the mechanical world, but that the conditions of this determination are fundamentally different. The term "physical indeterminism" might by some be regarded as a misnomer. We seem, however, to have reached a stage in scientific development where physical terms are acquiring unexpected meanings; the present contention would simply be that the older physical conceptions of determinism may not prove applicable to the new range of phenomena, and that the experimental facts themselves may oblige us to admit the existence of determining factors indistinguishable in essence from those which formerly we called free. This, however, is not a philosophical but a scientific paper; and my present aim is simply to indicate an objectively valid source of determination for certain fundamental vital phenomena which hitherto have proved refractory to analysis.

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MARINE BIOLOGICAL LABORATORY,
JUNE, 1927

HENRY PAUL TALBOT

THE death of Dean Henry Paul Talbot deprives the institute of the services of one of its most cherished alumni, one who devoted his life in a noteworthily unselfish way to the upbuilding of his Alma Mater. For forty years he gave the best of his brain and heart to the development of teaching and administration and to the advancement of the Massachusetts Institute of Technology as a great school of engineering and science.

Dr. Talbot graduated at the institute in 1885 and received the degree of doctor of philosophy from the University of Leipzig in 1890. He returned to the institute as an instructor and was rapidly promoted through the several grades and was finally appointed professor of analytical chemistry in 1898. He showed marked administrative ability and from 1895 was nominally in charge of the department of chemistry, although his official appointment to this post was not made until 1901. He served as chairman of the faculty from 1919 to 1921, as chairman of the administrative committee from 1920 to 1923 and as dean of students from 1921.

Dr. Talbot's training in chemistry was broad: his work as a student equipped him with the point of view of the analytical chemist; his research for his doctorate was in organic chemistry; and he devoted much attention to the study in Germany of the new physical chemistry which was being rapidly developed at that time. He was impressed with the importance of the advance of the science in this direction, and on his return from Germany he introduced at the institute a course in physical chemistry, which he taught successfully. This course was one of the first in this subject given in American universities.

When Dr. Talbot took over the instruction of the first-year students, he felt the advisability of bringing before them the more fundamental concepts of the newer chemistry. He accordingly prepared, with the assistance of Professor Arthur A. Blanchard, a text for this purpose entitled "The Electrolytic Dissociation Theory." Professor Talbot's progressive action in these two cases is typical of his attitude in educational affairs. He was the leader in the development of his department to its present efficient condition and served as chairman of committees on chemical education in the American Chemical Society and the Society for the Promotion of Engineering Education. He showed unusual interest in the teaching of high school science and was helpful in organizations devoted to the improvement of teaching in this field. He served as president of the New England Chemistry Teachers' Association and was for several years chief examiner in chemistry of the College Entrance Examination Board.

Dr. Talbot's record as a member of the American Chemical Society brought to him the honor of election as one of the five directors who determine the more important policies of the society and have full charge of its finances. He has been a member of the council since 1898; he served as associate editor of the *Journal* of the society and as chairman of the division of inorganic and physical chemistry. He also was a member of many important committees.

During the world war Dr. Talbot was appointed a member of a small committee to act in an advisory capacity to the Bureau of Mines in the work it had undertaken in correlating the chemical activities of the country to meet the problems arising from gas warfare. He was particularly helpful in presenting to the Secretary of War directly the needs of this organization, which carried on for over a year, outside of the war department, all the work on war gases.

Dr. Talbot was always interested in research. In the years following his return from Germany he published the results of several investigations in the field of inorganic and analytical chemistry. For a number of years he was chairman of the committee of the American Academy of Arts and Sciences that has charge of the C. M. Warren Fund, the income of which is devoted to aiding chemical research. In recent years the small amount of time available, after he had completed his work as a teacher and administrator, was devoted to editorial work and the writing