Logic and Law in Biology.[1]

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TEN years after the publication of the "Origin of Species," Kelvin, then Sir William Thomson, threw a bomb into the camp of the apparently victorious evolutionists. "It was quite certain," he said, "that a great mistake had been made—that British popular geology at the present time was in direct opposition to the principles of Natural Philosophy." According to the great physicist, the rate of cooling of the earth and other physical 'principles' showed that our globe could not have been in a position to support life for longer than a period of from 50 to 300 million years. In his opinion, the drafts on the bank of time demanded by those who upheld uniformitarian geology and the evolution of plants and animals could not be honoured.

Science rebuking science! It was meat and drink to the disheartened supernaturalists, the more reviving because in these days physical science was in good odour, and the new doctrine of evolution was the enemy. Huxley dealt with it in his presidential address to the Geological Society in 1869. He had no difficulty in showing that Kelvin's 'principles' were not unbending laws with universal jurisdiction, but merely combinations of observation, inference, and theory in different proportions. He took his final stand on the simple ground that as there was sufficient evidence for the orderly succession of the rocks and the orderly appearance of fossils in them, there must have been sufficient time for these processes. From this logical viewpoint he reached a remarkable result. Assume the correctness of Kelvin's calculation of the earth's rate of cooling and that yet there is sufficient evidence for evolution having taken place; why then there must be some unknown source of heat in the crust of the earth? Such a source of heat has been discovered in the radio-active elements, and from the rate of their disintegration the age of the oldest sedimentary rocks has been calculated at 1200 millions of years—a credit at the bank of time ample to meet all cheques presented by the followers of Lyell and Darwin. Twenty years later, in the course of an amusing controversy with the Duke of Argyll and a brace of bishops who had been talking about the suspension of 'lower laws' by 'higher laws,' as when a man raised a stone in his arm, he discussed the meaning of the term 'law' in science. He insisted that it was no more than the product of a mental operation upon the facts of Nature which had come under observation. It had no external existence and included no conception of causality. He took as examples the Newtonian laws of gravity and of motion and the law of constancy of mass.

At the time, Newton's laws must have seemed as securely established for the whole universe as any principle of science, and the constancy of mass through all chemical changes appeared to be a foundation of chemistry. With regard to both, Huxley insisted that they had no necessary sway. He stated the laws as to gravitation in such terms that they require not a word of alteration now that Einstein's unexpected discoveries have been made and confirmed. With regard to the constancy of mass he went even further, and said that there was no reason in our knowledge of the facts why mass should not be found to alter with the conditions. Recent physics have shown that in the atomic system the mass of the electron is a function of its rate of motion.

If, as Sir Oliver Lodge believes, the disincarnated spirit of Huxley is still in conscious existence, there must be a wry grin on what corresponds with the face of a disincarnated spirit, if Huxley imagines that I am going to claim prophetic powers for him on the grounds that he anticipated the discovery of radio-activity, made allowances for Einstein's amendments of Newton, and foresaw the gyrations of the electron. Huxley laid no claim to any faculties not within the scope and the duty of every man of science. His mental discipline comprised accurate observation, clear statement, the most rigid scrutiny of generalisations, the withholding from these generalisations of any iota of causal principle or any right to application to sets of facts different from those upon which they were based, and, above all, the declaration of ignorance in preference to the invention of imaginary principles. If, as he believed, the writ of science is to run howsoever it may be in opposition to customs, traditions, beliefs, or dogmas, there is the more need for scientific men to distinguish carefully in their pronouncements, especially to the public, between generalisations well founded on observation, probables, possibles, and hopes.

The presidential address to the British Association at Liverpool in 1870 is a conspicuous example of Huxley's methods. He described simple facts of everyday life, such as the appearance of maggots in carcases, of moulds on fruit, of vinegar eels, and so forth, explained by the ancients as due to spontaneous generation of the living companions of corruption from the corrupting but dead matter. In 1568, Redi, the Italian, covered meat with gauze, watched the blowflies, attracted by the smell of putrefaction, settling on the gauze, but noted that as the eggs could not pass through the gauze no maggots appeared in the meat. From similar experiments Redi drew the generalisation that living organisms arose in nutrient media only when the living seeds of these organisms had previously gained access to the media. The gauze of Redi has now been replaced by the far more delicate methods of bacteriologists, and the generalisation has been extended to almost every kind of living thing with which we are acquainted. But the principle remains the same; such 'causa-

[1] From the Huxley Memorial lecture delivered at the Imperial College of Science and Technology, South Kensington, on May 4.

tion' as there may be lies in the meshes of the gauze or their equivalent, not in any absolute distinction between living things and inorganic matter. To this generalisation Huxley gave the name 'biogenesis'; to the opposite conception, that of the direct origin of living from dead or inorganic matter, he gave the name 'abiogenesis.' As if foreseeing how his statement might be abused, consciously or unconsciously, he went on to say in a memorable passage that, so far from seeing in biogenesis a necessary and absolute principle, it was his expectation—belief was too strong a word in the absence of evidence—that a spectator in far-distant geological times might have seen the actual origin of living matter from inorganic matter. His prevision was necessary. In a recent book, addressed to the wide public, Sir Oliver Lodge has said that the "doctrine of biogenesis is that life could alone produce life." In another recent book, addressed to a narrower circle, Prof. Lloyd Morgan, setting out from the article on biology in the 11th edition of the "Encyclopædia Britannica," says that the authors implied that "biological events are not susceptible of interpretation in terms of physics and chemistry." The authors said nothing of the kind. They wrote, "have not been interpreted." Advocacy of the supernatural in natural science seems to confer an obliquity of vision.

My object is now to pass in rapid review some of the history of biology before Huxley and since Huxley, and to show how with a monotonous reiteration the craving for final causes has led many great biologists to extend their generalisations beyond their scope and to impose on them imaginary principles; in short, to invent gods and to place them in the machine to account for the part of the working not yet understood.

What is the order of events in the development of a new individual? Two eggs, similar in size and appearance, placed in an aquarium tank under the same conditions, grow, the one say into a mollusc and the other into a fish. In the words of Bateson, whose premature death removed from us one of the most active and productive workers in the long history of our science, "Shakespeare once existed as a speck of protoplasm not so big as a small pin's head. To this nothing was added that would not equally well have served to build up a baboon or a rat." I do not accept these crude statements without qualifications so great as to reduce them almost to nonsense, but they serve well to pose the main problem of biology, the likeness of offspring to parent. To biologists of the seventeenth and eighteenth centuries the answer was easy. Recall their pictures of the egg with the miniature of a human being coiled up within it. They believed that the process of development was the evolution or unrolling of a preformed minute adult, invisible to us only because of the imperfection of our optical appliances and the opacity of the medium. The English Harvey and some others were uneasy about this interpretation, but it was not displaced until Caspar Wolff in 1759 published the results of his observations on the development of the chick. Wolff was able to show that the germ was unformed material and that it assumed only gradually, stage by stage, the likeness of its parent.

Development is an epigenesis, the putting on of phase after phase. Wolff saw that the preformation theory was miraculous, differing, as he put it, only from ordinary miracles inasmuch as it had been performed once for all by the Creator at the beginning of the world. But having got rid of miracle in one way he introduced it in another. For he endowed his plastic organic material with a *vis essentialis*, an inherent force by which it wrought its own miracle. Wolff thus by actual observation freed biology from the chains of a preconception and set embryology on lines which have led to great advances in knowledge. But the theory he imposed on his observations has been the parent of a great brood, a whole Valhalla of false gods; hear the names of some of them: vital force, *nisus formativus*, bathmism, entelechie, creative evolution, emergent evolution, purposive striving—not one of them more than a beguiling word for ignorance.

After nearly two centuries rich in new knowledge of the observed facts of embryology, but with no important advance in theory, there came August Weismann. A skilled embryologist, he knew the successive phases of development to be a visible epigenesis and to recall at least in a general fashion the ancestral history. The fertilised egg-cell of a human being recalled the morphological grade of the protozoa, next assumed (as Huxley was the first to recognise) the appearance of the cœlenterate or two-layered creatures, then became a simple cœlomate, then a generalised chordate which might be about to become fish, flesh, or fowl, then an anthropoid stage man or ape, and only at a very late prenatal stage assumed definitely its human structure.

But Weismann found an exception to this orderly epigenetic progression. The cells which were going to become the gonad of the future adult did not wait to appear in their turn in their due order and place. They were separated, usually, if not invariably, at an extremely early stage, and preserving their individuality, were passed along through the developing embryo, occupying now one position, now another, until they reached their final place. The likeness between parent and offspring was thus shown to have a material basis and the link between ontogeny was given a local habitation and also a name, the germplasm. The daughter was only a delayed sister of her mother. Neglecting the complications due to parental crossing, the mother and daughter were products of the same germplasm.

With regard to the development of the individual, however, Weismann's endowment of the germplasm with a historic architecture was a return to a more subtle kind of preformation. The bricks of his imagined edifice were 'determinants,' separate particles so arranged as to be given off at precisely the time when they were required to control the development of the tissues into which they were marshalled. The initial stock of germplasm was thus disintegrated into sets of determinants with limited powers of control until each portion reached its final stage of being able to determine only one kind of cell or tissue. The plasm in these various stages of irreversible disintegration was what he called the somatoplasm. His interpretation brought into clear light the relative if not the absolute stability of the germplasm, found and stressed the material link between ontogeny and phylogeny. But his historic architecture and his determinants were imagined principles to give causal explanations of processes which were not yet understood.

Oscar Hertwig, a very able experimental embryologist, very soon showed that the stresses of the environment acting on adult and embryonic stages could overpower the control assigned to the historic architecture and compel reluctant material into forms which it would not otherwise have assumed. The irreversible disintegration of the germplasm could not account for the facts, and the accessory theories produced by Weismann and his followers were more ingenious than convincing. Hertwig's insistence on the moulding forces of the environment brought the fresh air of observation of facts into the study of embryology and opened up a new and fertile chapter. But he, too, had to invent a causal principle; the name of the god he placed in the machine was the control of the whole organism over its parts in such a fashion that they served the needs of the whole. It is a disconcerting circumstance that his deity is more powerful in the embryo than in the adult, and in the lower than in the higher organisms.

Making the large allowances necessary for the play of the environment in producing the characters of an organism, there remains much which must be assigned to the hereditary material. The Mendelian analysis of heredity and the physiological doctrine of hormones have found a material interpretation for some of the unexplained occurrences for which Weismann invented his historic architecture and Hertwig his 'control of the whole.' The brilliant experimental analysis of the Mendelians has shown that at least with regard to a certain number of characters, heredity is particulate, consisting of unit characters which may be combined in groups in various ways. There is, in short, a mechanism in heredity which is being explored, and converging advances in knowledge of the nuclear changes are finding a material seat for it. On the other hand, the rejection of the influence of the environment is leading Mendelians into fantastic extravagance. The pronouncement by Bateson, in his address as president of the British Association in Melbourne in 1914, was a return to a conception of preformation more miraculous than those of pre-scientific philosophers. Arguing from the success of Mendelian breeders in eliminating factors and their failure in their efforts to add factors, he suggested a similar limitation for Nature, and that the whole course of divergent evolution from the beginning of life to the appearance of Shakespeare had come about by the elimination of factors.

The discovery by Brown-Sequard and D'Arsonval of secretions discharged into the blood stream by glands in addition to the secretions liberated through their ducts, and their extension of this to the supposition that all organs and tissues might produce internal secretions, have been carried much further by more recent work. It has been shown that many of these secretions, called hormones, or chemical messengers, by Bayliss, Starling, and W. B. Hardy, do exist and exercise highly specialised co-ordinating functions. They form a chemical nexus independent of nerve reflexes, and so far definitely reduce the unknown field for which Hertwig invented his mysterious power of control by the whole over the part. Experiments particularly on the development of batrachian larvæ have shown that secretions produced at one stage of the development control the later stages. It may be that in hormones will be found to be the material agents by which the germplasm controls the development of the individual. But those which have been studied so far are extremely precise in their action, and I have been unable to find a trace of direct evidence for the belief so greedily imbibed by those who accept the evidence of the inheritance of acquired characters—the belief, for example, that if the plumage of a bird or the coloration of a moth becomes darker from the effect of some agent in the environment, the melanistic tissues will produce a changed hormone of such a kind that it will influence the germplasm to produce melanistic forms.

To what general issue have I led myself in this rapid review of some biological problems in the light of Huxley's canons? Definitely to the position that if we scrutinise our generalisations and do not extend them to a class of facts from which they were not derived, if we do not endow abstractions with an independent reality, we shall find no logical ground to infer the existence of any but physical events in the world of living things. I agree that the phenomena of living things have not yet been fully interpreted in terms of the inorganic. But I note that every positive addition to biological knowledge in the last century, from the identification of Mendelian factors in heredity, the artificial fertilisation of ova and the other achievements of bio-chemistry, to Sir Charles Sherrington's exploration of mammalian reflexes, has been a diminution of the residuum to which it is possible to apply vitalistic conceptions. On the other hand, Philosophy, since she was judicially separated from science, has made no positive addition to knowledge. How far our progress will go, I do not know. It may only be a phase of anthropomorphism to expect that man can ever comprehend the universe. But science must pursue the quest, and if we adhere to what is called materialism in the simplest sense of the word, we shall at least in the future, as in the past, make positive additions to knowledge.