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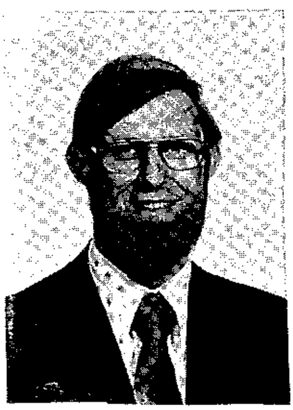

Harry Cook received his B.Sc. and M.Sc. degrees from the University of British Columbia and his Ph.D. in zoology from the Free University in Amsterdam. He taught biology at Trinity Christian College in Illinois for eight years and joined the Dordt biology department last September. His research interest is the physiology of migratory fishes.

"We wish to suggest a structure for the salt of deoxyribose nucleic acid (DNA). This structure has novel features which are of considerable biological interest."[1] With these words Watson and Crick open the article in *Nature* in which they propose a description of the three-dimensional structure of DNA. Although their suggested structure is based mainly on the observations of others, there are few scientific theories that have had as much impact as this one on the field of biology. Crick suggests in another article that "From every point of view biology is getting nearer and nearer to the molecular level. Here in the realm of heredity we now find ourselves dealing with polymers, and reducing the decisive controls of life to a matter of the precise order in which monomers are arranged in a giant molecule."[2]

Crick here implies that biology is, or will be, reducible to physico-chemical theories. This type of reductionism is a modern equivalent of the mechanistic views that have been held by some biologists throughout the history of the discipline. Nordenskiöld, in his comprehensive book on the history of biology, cited the ironic example of La Mattrie (1709-1751), who wrote a book entitled *L'Homme Machine (Man, the Machine),* but who died after eating

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an enormous amount of truffles.[3]

In modern biology the term "reductionism" is now in wide use. Munson has described reduction in biology as follows:

> Reduction . . . is the explanation of a theory or set of laws of one discipline in terms of a theory or set of laws belonging to some other discipline. . . . Reduction is achieved when the reduced theory can be logically derived from the reducing theory—when a biological theory can be derived from a physical one. . . .
>
> [The] terms of the biological theory must be connected . . . with the terms of the physical theory. Thus such biological terms as "gene" and "hormone" must be connected with such chemical terms as "DNA" and "indole-3-acetic acid."
>
> The connection between the two different kinds of terms cannot be arbitrary of course. It has to be discovered by empirical research, for example, that hormones are chemical substances with certain molecular structures.[4]

If this translation of biology into chemical terms were complete, would biology lose its autonomy as a science? I shall come back to these definitions of reduction. First, however, I shall examine some developments in molecular genetics that will form a basis for our discussion of reductionism in modern biology.

DNA—the Double Helix

Discovery of the structure and functions of DNA epitomizes what molecular biologists have been able to accomplish in their quest to explain cellular and other biological functions in physico-chemical terms. DNA has been shown to be the key to understanding the chemical basis of inheritance and cellular specificity. For this reason, I shall look at the history and functions of DNA in some detail.

Although DNA was extracted from cells as early as 1870, its function as the bearer of hereditary information was not established until much later. The British physician F. Griffith found that bacteria from a non-virulent (i.e., non-infective) strain of the pneumococcus could be transformed to virulence by remnants of virulent pneumococci in the culture medium.[5] In 1944, Avery and co-workers showed the transforming substance to be DNA.[6]

Support for a hereditary role of DNA

also came from the field of virology. Viruses have been shown to act very much like a hereditary substance in the cells that they infect. Hershey and Chase showed in 1952[7] that virus particles shed their protein coat when they infect, so that only a DNA "core" enters the bacteria that these viruses infect. Thus, the role of DNA as the cell's hereditary substance was strongly supported by experiments on bacteria.

The three-dimensional structure and configuration of DNA, as described by Watson and Crick in 1953, was immediately hailed as a scientific discovery of the first order.[8] It was this discovery that has strongly stimulated reductionistic theorizing in biology.

DNA has two roles in the cell, both of which are closely related to heredity. The first of these, the autocatalytic function, can also be called self-replication. In this process the two polynucleotide strands of the double helix unwind. Each of these strands then serves as a template for the ordered synthesis of its own complementary daughter strand. In the 1953 *Nature* article, Watson and Crick themselves suggest the possibility of replication in an interesting understatement: "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material." This "possible copying mechanism" was worked out in more detail in a subsequent article in *Nature*.[9] The replication of DNA is the basis for continuity of cell characteristics through cell divisions, through generations of organisms, and within species.

The second function of DNA, the heterocatalytic one, is no less important, for DNA directs the protein synthesis of the cell. This has often been called the "central dogma" of biology. This second function of DNA involves the transcription of "information" (relating to protein synthesis) by the DNA molecule into messenger RNA, and the translation of this information into the amino acid sequence of a protein. This "central dogma" has often been represented as

DNA⟶ RNA⟶ protein.

The arrows indicate the one-way flow of "information."

For those who object to the term "central dogma," it may be comforting to know that the flow of information has been found to be reversed from RNA to DNA in some viruses.[10] In most cases, however, the synthesis of proteins is directed by DNA (via RNA). Because proteins are highly complex compounds that serve many functions in the cell, and also because these proteins have very specific shapes and chemical structures, they are thought to be the key to cell specificity. *How* DNA governs protein synthesis gave rise to a burst of research activity. What is the nature of the "code"? Much is now known

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about this topic. In fact, the code has been "cracked." For details on this topic many sources are available.[11]

The DNA story focussed much attention on the capabilities of molecular biology. This branch of biology has also been successful in the investigation of other areas of cell physiology.[12] We shall not discuss these findings but simply use the example of DNA and its importance in molecular genetics in our examination of reductionism in biology.

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Reductionism in Biology—A Second Look

If our earlier definition is correct, namely that reduction has been achieved when theories, laws, or terms of one field of science can be translated into theories, laws, or terms of another, "simpler" field of science, then we would have to admit that reduction of the field of classical genetics into molecular genetics has largely been achieved with the discovery of the role of DNA and the subsequent findings. The situation in other areas of biology may not be quite the same, but the trend is present there also.[13] Many would base their definition of reduction on "translation" in this way.[14] Others suggest that even if reduction is not possible in some fields of biology now, there is no reason to assume that it is therefore in theory impossible.[15]

This definition of reductionism has a philosophical aspect, for it deals with the relationship between the various disciplines. The area of philosophy that deals specifically with theories of explanation or formulation of laws is epistemology. Therefore, we can describe the above definition of reductionism as epistemological. Ayala has also identified this as one type of definition of reduction.[16]

But is reduction purely a problem of terms, language, and translation? Is it merely an epistemological problem? In other words, does a definition of reduction that is based largely on lingual criteria do justice to the question of whether biological *phenomena* are really nothing but chemical phenomena? Ayala distinguishes a second type of reductionism, namely ontological reductionism. Ontology is that branch of philosophy that deals with what we assume the structure of reality to be. In most Christian philosophies, ontology will always determine epistemology, rather than the other way around. Therefore, it seems to me that ontological assumptions are more basic than epistemological theories to the reductionism debate, even though to many philosophers of science epistemological formulations are prior to ontological ones.

Most biologists are not concerned with, or indeed aware of, either epistemological or ontological considerations in their work. This is probably the reason that Ayala distinguishes methodological reduction as a third type.[16] Most investigators worry little about theoretical considerations, once their research topics have been chosen. In fact, investigators see little effect of reductionist or antireductionist theories when they compare their research with that of another scientist doing the same type of research.[17] I have found, however, that some biologists do dismiss the investigations of others in a different field of biology as irrelevant, unscientific, or not basic. They make these types of judgments on the basis of their position in respect to reductionism, whether or not they are aware of it.

In a most interesting article, the British scientist and philosopher M. Polanyi argues that living things in one sense *are* like machines. Laws of chemistry and physics cannot explain machines completely, he feels, even though machines obey these laws: "The machine is a machine by having been built and being then controlled according to principles of engineering. The laws of physics and chemistry are indifferent to these principles; they would go on working in the fragments of the machine if it were smashed. But they serve the machine while it lasts; machines rely for their operations always on the laws of physics and chemistry.[18] Polanyi applies the same line of reasoning to argue for the uniqueness of living things: "When I say that life transcends physics and chemistry, I mean that biology cannot explain life in our age by the current workings of physical and chemical laws."[19]

I was particularly struck by Polanyi's opinion that when molecules bear biological information, as DNA does, ". . .we must refuse to regard the pattern by which DNA spreads information as part of its chemical properties."[20] "The pattern of information storage can no more be derived from the laws of physics and chemistry when engraved in an RNA molecule, than it can when inscribed on a tape or, for that matter, on the surface of a rock."[21] Like Polanyi, I feel that when a protein or nucleic acid fulfills a cellular function, it cannot be described only in chemical terms. Hence, for such substances, terms like "chemistry," "biochemistry," or "molecular biology" all have their place.[22] In this essay, all three have been used, depending on context and topic.

The biological sciences distinguish themselves from the physical sciences, in my opinion, but we cannot prove this distinction if we *assume* that it does not exist. For the Christian, this assumption is not necessary, for he is not bound to one cause or level of explanation in biology. For Polanyi, who takes an evolutionistic position with respect to origins, there may be a conflict between his evolutionistic views and his antireductionist position. Most Christians already accept the existence of design, and this design could include several levels of complexity, including the molecular and the cellular. Christians respect the integrality or wholeness that is characteristic of living things as a creational given. This wholeness should then also be reflected in a Christian's theorizing and should lie at the basis of his antireductionist ontology, and give rise to it. As a result, such biological concepts as behavior, purpose,[23] or animal color[24] can be discussed in terms of their total biological complexity. We should recognize at the same time the value and importance of the discoveries that molecular biology has made, for the processes that it describes are indispensible and basic to the function of biological structures.

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Footnotes

1. J.D. Watson and F.H.C. Crick, "A Structure for Deoxyribose Nucleic Acid," *Nature 171*, (1953), 737-738.

2. F.H.C. Crick, "Nucleic Acids," *Scientific American 197* (1957), 188-200.

3. E. Nordenskiöld, *The History of Biology* (New York: Knopf, 1928), p. 238.

4. R. Munson (ed.), *Man and Nature. Philosophical Issues in Biology* (New York: Dell Publishing, 1971). Introduction by R. Munson, pp. 4-5.

5. F. Griffith, "Significance of Pneumococcal Types," *Journal of Hygiene 27* (1928), 113-159.

6. O.T. Avery, C.M. MacLeod, and M. McCarty, "Studies on the Chemical Nature of the Substance Inducing Transformation of Pneumococcal Types," *Journal of Experimental Medicine 79* (1944), 137-158.

7. A.D. Hershey and M.C. Chase, "Independent Functions of Viral Proteins and Nucleic Acid in Growth of Bacteriophage," *Journal of General Physiology 36* (1952), 39-56.

8. For a personal account of the discovery see J.D. Watson, *The Double Helix* (New York: Athenium, 1968). For further biographical details see R. Olby, "Francis Crick, DNA, and the Central Dogma," *Daedalus 99* (1970), 939-987.

9. J.D. Watson and F.H.C. Crick, "Genetical Implications of the Structure of Deoxyribonucleic Acid," *Nature 171* (1953), 964-967.

10. D. Baltimore, "RNA-dependent DNA in Virions of RNA Tumour Viruses," *Nature 226* (1970), 1209-1211; H.M. Temin and S. Muzitani, "RNA-dependent DNA Polymerase in the Virions of Rous Sarcoma Virus," *Nature 226* (1970), 1211-1213. For a review, see also H.M. Temin, "RNA Directed DNA Synthesis," *Scientific American 226* (1972), 24-33.

11. S.L. Wolfe, *Biology of the Cell* (Belmont, Cal.: Wadsworth Publishing, 1972), Chapter 11; H.A. Harper, V.W. Rodwell, and P.A. Mayes, *Review of Physiological Chemistry*, 16th edition (Los Altos, Cal.: Lange Medical Publications, 1977); or another cell physiology or genetics book.

12. An important area of cell physiology is the one that deals with energy metabolism. For one review, see H.A. Krebs, "The History of the Tricarboxylic Acid Cycle," *Perspectives in Biology and Medicine 14* (1970), 154-170.

13. One area that has proved resistant to the formulation of molecular or physical theories, however, is the functioning of the brain. The comments of Gunther Stent are of interest. G.S. Stent, "That Was the Molecular Biology That Was," *Science 160* (1968), 390-395. For a reductionist view of the brain and its functions see D.E. Wooldridge, *Mechanical Man. The Physical Basis of Intelligent Life* (New York: McGraw-Hill, 1968).

14. K.F. Schaffner, Theories and Explanations in Biology," *Journal of the History of Biology 2* (1969), 19-33. In R. Munson (ed.) *Man and Nature. Philosophical Issues in Biology* (New York: Dell Publishing, 1971) see the contributions of R. Munson, pp. 3-16, and E. Nagel, pp. 19-32.

15. Most of the authors cited in footnote 14 make this point also. In addition see K.F. Schaffner, in R. Munson, op. cit., pp. 44-54.

16. F.J. Ayala, "Introduction," in F.J. Ayala and T. Dobzhansky (eds.), *Studies in the Philosophy of Biology. Reduction and Related Problems* (Berkeley: University of California Press, 1974), p. viii.

17. June Goodfield, "Changing Strategies; a Comparison of Reductionist Attitudes in Biological and Medical Research in the Nineteenth and Twentieth Centuries." In: F.J. Ayala and T. Dobzhansky, op. cit., pp. 65-86.

18. M. Polanyi, "Life Transcending Physics and Chemistry," *Chemical and Engineering News 21* (1967), p. 61.

19. M. Polanyi, op. cit., pp. 64-65.

20. M. Polanyi, op. cit., p. 62.

21. M. Polanyi, op. cit., p. 64.

22. This is probably also the reason that it is difficult to say whether "reductionism" as it is used in this paper is the same as "modal absolutization" as it is used by H. Dooyeweerd, *A New Critique of Theoretical Thought* (Philadelphia: Presbyterian and Reformed, 1957) I, p. 46. It seems to me, also for the reasons given in this paragraph, that when we are dealing with molecules that have a biological "information content," then this information is a biological phenomenon.

23. The subject of "purpose" or "teleology" in biology has been a topic of much discussion in biology. See, e.g., M. Beckner, "Function and Teleology," *Journal of the History of Biology 2* (1969), 151-164; F.J. Ayala, "Teleological Explanations in Biology," *Philosophy of Science 37* (1970), 1-15. See also the books edited by R. Munson (footnote 15) and by F.J. Ayala and T. Dobzhansky footnote 17).

24. See the chapter on Adolf Portmann in M. Grene, *Approaches to a Philosophical Biology* (New York: Basic Books, 1965), pp. 3-54.